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(54) **SYSTEMS, METHODS, AND DEVICES USING STRETCHABLE OR FLEXIBLE ELECTRONICS FOR MEDICAL APPLICATIONS**

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(58) **Field of Classification Search**

None

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,949,410	A	4/1976	Bassous
4,058,418	A	11/1977	Lindmayer

(Continued)

FOREIGN PATENT DOCUMENTS

CN	1222758	7/1999
CN	1454045	11/2003

(Continued)

OTHER PUBLICATIONS

Abbaschian et al. (Dec. 2005) "High Pressure-High Temperature Growth of Diamond Crystals Using Split Sphere Apparatus," *Diamond Relat. Mater.* 14(11-12):1916-1919.

(Continued)

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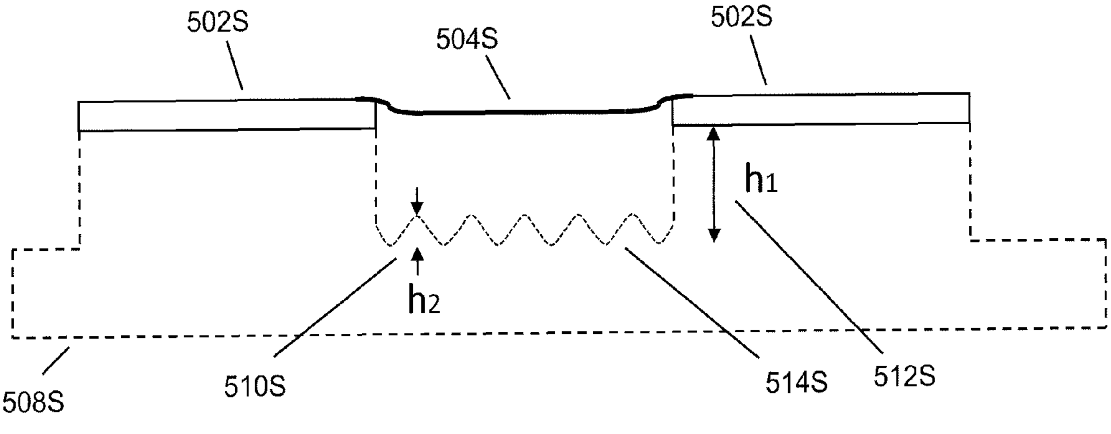
(57) **ABSTRACT**

System, devices and methods are presented that integrate stretchable or flexible circuitry, including arrays of active devices for enhanced sensing, diagnostic, and therapeutic capabilities. The invention enables conformal sensing contact with tissues of interest, such as the inner wall of a lumen, a nerve bundle, or the surface of the heart. Such direct, conformal contact increases accuracy of measurement and delivery of therapy.

24 Claims, 22 Drawing Sheets



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(56) **References Cited**

U.S. PATENT DOCUMENTS

4,392,451	A	7/1983	Mickelsen et al.	
4,416,288	A *	11/1983	Freeman	600/544
4,471,003	A	9/1984	Cann	
4,487,162	A	12/1984	Cann	
4,658,153	A	4/1987	Brosh et al.	
4,663,828	A	5/1987	Hanak	
4,761,335	A	8/1988	Aurichio et al.	
4,763,275	A	8/1988	Carlin	
4,766,670	A	8/1988	Gazdik et al.	
4,784,720	A	11/1988	Douglas	
4,855,017	A	8/1989	Douglas	
5,041,973	A	8/1991	Lebron et al.	
5,086,785	A	2/1992	Gentile et al.	
5,108,819	A	4/1992	Heller et al.	
5,118,400	A	6/1992	Wollam	
5,147,519	A	9/1992	Legge	
5,178,957	A	1/1993	Kolpe et al.	
5,204,144	A	4/1993	Cann et al.	
5,306,917	A	4/1994	Black et al.	
5,313,094	A	5/1994	Beyer et al.	
5,331,966	A *	7/1994	Bennett et al.	600/508
5,360,987	A	11/1994	Shibib	
5,403,700	A	4/1995	Heller et al.	
5,427,096	A	6/1995	Bogusiewicz et al.	
5,434,751	A	7/1995	Cole, Jr. et al.	
5,439,575	A	8/1995	Thornton et al.	
5,455,178	A	10/1995	Fattinger	
5,455,430	A	10/1995	Noguchi et al.	
5,469,845	A	11/1995	DeLonzor et al.	
5,477,088	A	12/1995	Rockett et al.	
5,501,893	A	3/1996	Laermer et al.	
5,525,815	A	6/1996	Einset	
5,539,935	A	7/1996	Rush, III	
5,545,291	A	8/1996	Smith et al.	
5,549,108	A	8/1996	Edwards et al.	
5,560,974	A	10/1996	Langley	
5,567,975	A	10/1996	Walsh et al.	
5,625,471	A	4/1997	Smith	
5,648,148	A	7/1997	Simpson	
5,687,737	A	11/1997	Branham et al.	
5,691,245	A	11/1997	Bakhit et al.	
5,746,207	A	5/1998	McLaughlin	
5,753,529	A	5/1998	Chang et al.	
5,757,081	A	5/1998	Chang et al.	
5,767,578	A	6/1998	Chang et al.	
5,772,905	A	6/1998	Chou	
5,783,856	A	7/1998	Smith et al.	
5,790,151	A	8/1998	Mills	
5,811,790	A	9/1998	Endo et al.	
5,817,242	A	10/1998	Biebuyck et al.	
5,824,186	A	10/1998	Smith et al.	
5,837,546	A	11/1998	Allen	
5,860,974	A	1/1999	Abele	
5,871,443	A	2/1999	Edwards et al.	
5,904,545	A	5/1999	Smith et al.	
5,907,189	A	5/1999	Mertol	
5,915,180	A	6/1999	Hara et al.	
5,917,534	A	6/1999	Rajeswaran	
5,928,001	A	7/1999	Gillette et al.	
5,955,781	A	9/1999	Joshi et al.	
5,968,839	A	10/1999	Blatt	
5,976,683	A	11/1999	Liehr et al.	
5,978,972	A	11/1999	Stewart	
5,998,291	A	12/1999	Bakhit et al.	
6,009,632	A	1/2000	Douglas	
6,024,702	A	2/2000	Iverson	
6,057,212	A	5/2000	Cha et al.	
6,080,608	A	6/2000	Nowak	
6,097,984	A	8/2000	Douglas	
6,121,110	A	9/2000	Hong	
6,148,127	A	11/2000	Adams et al.	
6,150,602	A	11/2000	Campbell	
6,165,391	A	12/2000	Vedamuttu	
6,165,885	A	12/2000	Gaynes et al.	
6,171,730	B1	1/2001	Kuroda et al.	
6,225,149	B1	5/2001	Gan et al.	
6,236,883	B1	5/2001	Ciaccio et al.	
6,265,326	B1	7/2001	Ueno	
6,274,508	B1	8/2001	Jacobsen et al.	
6,276,775	B1	8/2001	Schulte	
6,277,712	B1	8/2001	Kang et al.	
6,281,038	B1	8/2001	Jacobsen et al.	
6,282,960	B1	9/2001	Samuels et al.	
6,284,418	B1	9/2001	Trantolo	
6,291,896	B1	9/2001	Smith	
6,301,500	B1	10/2001	Van Herk et al.	
6,309,351	B1	10/2001	Kurnik	
6,316,278	B1	11/2001	Jacobsen et al.	
6,316,283	B1	11/2001	Saurer	
6,317,175	B1	11/2001	Salerno et al.	
6,322,895	B1	11/2001	Canham	
6,322,963	B1	11/2001	Bauer	
6,334,960	B1	1/2002	Willson et al.	
6,344,616	B1	2/2002	Yokokawa	
6,360,615	B1	3/2002	Smela	
6,380,729	B1	4/2002	Smith	
6,403,397	B1	6/2002	Katz	
6,403,944	B1	6/2002	MacKenzie	
6,413,790	B1	7/2002	Duthaler et al.	
6,414,783	B2	7/2002	Zavracky et al.	
6,417,025	B1	7/2002	Gengel	
6,420,266	B1	7/2002	Smith et al.	
6,433,401	B1	8/2002	Clark et al.	
6,451,191	B1	9/2002	Bentsen et al.	
6,459,418	B1	10/2002	Comiskey et al.	
6,468,638	B2	10/2002	Jacobsen et al.	
6,479,395	B1	11/2002	Smith et al.	
6,504,105	B1	1/2003	Acocella et al.	
6,517,995	B1	2/2003	Jacobson et al.	
6,518,168	B1	2/2003	Clem et al.	
6,527,964	B1	3/2003	Smith et al.	
6,555,408	B1	4/2003	Jacobsen et al.	
6,566,744	B2	5/2003	Gengel	
6,567,158	B1	5/2003	Falciai et al.	
6,580,151	B2	6/2003	Vandeputte et al.	
6,586,338	B2	7/2003	Smith et al.	
6,590,346	B1	7/2003	Hadley et al.	
6,606,079	B1	8/2003	Smith	
6,606,247	B2	8/2003	Credelle et al.	
6,608,370	B1	8/2003	Chen et al.	
6,613,979	B1	9/2003	Miller et al.	
6,623,579	B1	9/2003	Smith et al.	
6,639,578	B1	10/2003	Comiskev et al.	
6,655,286	B2	12/2003	Rogers	
6,657,289	B1	12/2003	Craig et al.	
6,661,037	B2	12/2003	Pan et al.	
6,665,044	B1	12/2003	Jacobsen et al.	
6,666,821	B2	12/2003	Keimel	
6,667,548	B2	12/2003	O'Connor et al.	
6,683,663	B1	1/2004	Hadley et al.	
6,693,384	B1	2/2004	Vicentini et al.	
6,706,402	B2	3/2004	Rueckes et al.	
6,720,469	B1	4/2004	Curtis et al.	
6,723,576	B2	4/2004	Nozawa et al.	

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,730,990	B2	5/2004	Kondo et al.	
6,731,353	B1	5/2004	Credelle et al.	
6,743,982	B2	6/2004	Biegelsen et al.	
6,762,510	B2	7/2004	Fock et al.	
6,780,696	B1	8/2004	Schatz	
6,784,450	B2	8/2004	Pan et al.	
6,787,052	B1	9/2004	Vaganov	
6,805,809	B2	10/2004	Nuzzo et al.	
6,814,898	B1	11/2004	Deeman et al.	
6,816,380	B2	11/2004	Credelle et al.	
6,826,509	B2	11/2004	Crisco, III et al.	
6,836,744	B1	12/2004	Asphahani et al.	
6,844,673	B1	1/2005	Bernkopf	
6,848,162	B2	2/2005	Arneson et al.	
6,850,312	B2	2/2005	Jacobsen et al.	
6,856,830	B2	2/2005	He	
6,863,219	B1	3/2005	Jacobsen et al.	
6,864,435	B2	3/2005	Hermanns et al.	
6,864,570	B2	3/2005	Smith	
6,872,645	B2	3/2005	Duan et al.	
6,878,871	B2	4/2005	Scher et al.	
6,881,979	B2	4/2005	Starikov et al.	
6,885,030	B2	4/2005	Onozuka et al.	
6,887,450	B2	5/2005	Chen et al.	
6,900,094	B2	5/2005	Hammond et al.	
6,917,061	B2	7/2005	Pan et al.	
6,936,181	B2	8/2005	Bulthaup et al.	
6,949,199	B1	9/2005	Gauzner et al.	
6,949,206	B2	9/2005	Whiteford et al.	
6,950,220	B2	9/2005	Abramson et al.	
6,984,934	B2	1/2006	Moller et al.	
6,989,285	B2	1/2006	Ball	
7,029,951	B2	4/2006	Chen et al.	
7,033,961	B1	4/2006	Smart et al.	
7,054,784	B2	5/2006	Flentov et al.	
7,067,903	B2	6/2006	Tachibana et al.	
7,081,642	B2	7/2006	Onozuka et al.	
7,116,318	B2	10/2006	Amundson et al.	
7,132,313	B2	11/2006	O'Connor et al.	
7,148,512	B2	12/2006	Leu et al.	
7,158,277	B2	1/2007	Berggren et al.	
7,169,546	B2	1/2007	Suzuki et al.	
7,169,669	B2	1/2007	Blakers et al.	
7,170,164	B2	1/2007	Chen et al.	
7,186,624	B2	3/2007	Welser et al.	
7,190,051	B2	3/2007	Mech et al.	
7,195,733	B2	3/2007	Rogers et al.	
7,223,609	B2	5/2007	Anvar et al.	
7,223,632	B2	5/2007	Onozuka et al.	
7,252,664	B2	8/2007	Nasab et al.	
7,253,442	B2	8/2007	Huanq et al.	
7,255,919	B2	8/2007	Sakata et al.	
7,265,298	B2	9/2007	Maghribi et al.	
7,291,146	B2	11/2007	Steinke et al.	
7,291,540	B2	11/2007	Mech et al.	
7,293,353	B2	11/2007	Matsuda	
7,337,012	B2	2/2008	Maghribi et al.	
7,374,968	B2	5/2008	Kornilovich et al.	
7,425,523	B2	9/2008	Ikemizu et al.	
7,487,587	B2	2/2009	Vanfleteren et al.	
7,491,892	B2	2/2009	Wagner et al.	
7,509,835	B2	3/2009	Beck	
7,521,292	B2	4/2009	Rogers et al.	
7,525,304	B1	4/2009	Feng et al.	
7,526,389	B2	4/2009	Greenwald et al.	
7,552,031	B2	6/2009	Vock et al.	
7,557,367	B2	7/2009	Rogers et al.	
7,593,086	B2	9/2009	Jeong et al.	
7,622,367	B1	11/2009	Nuzzo et al.	
7,629,691	B2	12/2009	Roush et al.	
7,633,761	B2	12/2009	Kim	
7,635,755	B2	12/2009	Kaplan et al.	
7,674,882	B2	3/2010	Kaplan et al.	
7,700,402	B2	4/2010	Wild et al.	
7,704,684	B2	4/2010	Rogers et al.	
7,705,280	B2	4/2010	Nuzzo et al.	
7,709,961	B2	5/2010	Greenberg et al.	
7,727,199	B2	6/2010	Fernandes et al.	
7,727,575	B2	6/2010	Kaplan et al.	
7,732,012	B2	6/2010	Hongu et al.	
7,742,795	B2	6/2010	Stone et al.	
7,759,167	B2	7/2010	Vanfleteren et al.	
7,769,472	B2	8/2010	Gerber	
7,799,699	B2	9/2010	Nuzzo et al.	
7,838,964	B2	11/2010	Carobolante et al.	
7,842,780	B2	11/2010	Kaplan et al.	
7,857,781	B2	12/2010	Noda et al.	
7,871,661	B2	1/2011	Maghribi et al.	
7,884,540	B2	2/2011	Sung et al.	
7,909,971	B2	3/2011	Nuzzo et al.	
7,932,123	B2	4/2011	Rogers et al.	
7,935,056	B2	5/2011	Zdeblick	
7,943,491	B2	5/2011	Nuzzo et al.	
7,960,246	B2	6/2011	Flamand et al.	
7,972,875	B2	7/2011	Rogers et al.	
7,982,296	B2	7/2011	Nuzzo et al.	
8,008,575	B2	8/2011	De Ceuster et al.	
8,039,847	B2	10/2011	Nuzzo et al.	
8,107,248	B2	1/2012	Shin et al.	
8,198,621	B2	6/2012	Rogers et al.	
8,207,473	B2	6/2012	Axisa et al.	
8,252,191	B2	8/2012	Heejoon et al.	
8,367,035	B2	2/2013	Rogers et al.	
8,394,706	B2	3/2013	Nuzzo et al.	
8,440,546	B2	5/2013	Nuzzo	
2001/0003043	A1	6/2001	Metspalu et al.	
2001/0012918	A1*	8/2001	Swanson	600/510
2001/0021867	A1*	9/2001	Kordis et al.	607/112
2002/0021445	A1	2/2002	Bozhevolnyi et al.	
2002/0026127	A1	2/2002	Balbierz et al.	
2002/0082515	A1	6/2002	Campbell et al.	
2002/0094701	A1	7/2002	Biegelsen et al.	
2002/0095087	A1	7/2002	Mourad et al.	
2002/0110766	A1	8/2002	Tsai et al.	
2002/0128700	A1*	9/2002	Cross, Jr.	607/117
2002/0151934	A1*	10/2002	Levine	607/9
2003/0006527	A1	1/2003	Rabolt et al.	
2003/0017848	A1	1/2003	Engstrom et al.	
2003/0032892	A1	2/2003	Erlach et al.	
2003/0082889	A1	5/2003	Maruyama et al.	
2003/0087476	A1	5/2003	Oohata et al.	
2003/0097165	A1*	5/2003	Krulevitch et al.	607/115
2003/0120271	A1	6/2003	Burnside et al.	
2003/0138704	A1	7/2003	Mei et al.	
2003/0149456	A1	8/2003	Rottenberg et al.	
2003/0171691	A1	9/2003	Casscells et al.	
2003/0178316	A1	9/2003	Jacobs et al.	
2003/0222282	A1	12/2003	Fjelstad et al.	
2003/0227116	A1	12/2003	Halik et al.	
2003/0236455	A1*	12/2003	Swanson et al.	600/374
2004/0005723	A1	1/2004	Empedocles et al.	
2004/0006264	A1*	1/2004	Mojarradi et al.	600/378
2004/0026684	A1	2/2004	Empedocles et al.	
2004/0061543	A1	4/2004	Nam et al.	
2004/0079464	A1	4/2004	Kumakura	
2004/0081384	A1	4/2004	Datesman et al.	
2004/0085469	A1	5/2004	Johnson	
2004/0092806	A1*	5/2004	Sagon et al.	600/374
2004/0095658	A1	5/2004	Buretea et al.	
2004/0106334	A1	6/2004	Suzuki et al.	
2004/0112964	A1	6/2004	Empedocles et al.	
2004/0135094	A1	7/2004	Niigaki et al.	
2004/0136866	A1	7/2004	Pontis et al.	
2004/0138558	A1	7/2004	Dunki-Jacobs et al.	
2004/0146560	A1	7/2004	Whiteford et al.	
2004/0149921	A1	8/2004	Smyk	
2004/0155290	A1	8/2004	Mech et al.	
2004/0171969	A1	9/2004	Socci	
2004/0178390	A1	9/2004	Whiteford	
2004/0178466	A1	9/2004	Merrill et al.	
2004/0192062	A1	9/2004	Mikelson	
2004/0192082	A1	9/2004	Wagner et al.	
2004/0200734	A1	10/2004	Co	
2004/0206448	A1	10/2004	Dubrow	

(56) **References Cited**

U.S. PATENT DOCUMENTS

2004/0211458	A1	10/2004	Gui et al.	
2004/0211459	A1	10/2004	Suenaga et al.	
2004/0229830	A1	11/2004	Tachibana et al.	
2004/0243204	A1*	12/2004	Maghribi et al.	607/115
2004/0250950	A1	12/2004	Dubrow	
2004/0252559	A1	12/2004	Gupta	
2005/0020094	A1	1/2005	Forbes et al.	
2005/0021103	A1*	1/2005	DiLorenzo	607/45
2005/0037511	A1	2/2005	Sharrock	
2005/0038498	A1	2/2005	Dubrow et al.	
2005/0054939	A1	3/2005	Ben-Ari et al.	
2005/0082526	A1	4/2005	Bedell et al.	
2005/0107716	A1	5/2005	Eaton et al.	
2005/0113744	A1*	5/2005	Donoghue et al.	604/66
2005/0115308	A1	6/2005	Koram et al.	
2005/0124712	A1	6/2005	Anderson et al.	
2005/0133954	A1	6/2005	Homola	
2005/0136501	A1	6/2005	Kuriger	
2005/0171524	A1	8/2005	Stern et al.	
2005/0177335	A1	8/2005	Crisco	
2005/0203366	A1*	9/2005	Donoghue et al.	600/378
2005/0214962	A1	9/2005	Daniels et al.	
2005/0227389	A1	10/2005	Bhattacharya et al.	
2005/0233546	A1	10/2005	Oohata et al.	
2005/0238967	A1	10/2005	Rogers et al.	
2005/0255686	A1	11/2005	Yamano et al.	
2005/0260706	A1	11/2005	Kaplan et al.	
2005/0261561	A1	11/2005	Jones et al.	
2006/0038182	A1	2/2006	Rogers et al.	
2006/0049485	A1	3/2006	Pan et al.	
2006/0056161	A1	3/2006	Shin et al.	
2006/0068576	A1	3/2006	Burdick, Jr. et al.	
2006/0076561	A1	4/2006	Hioki et al.	
2006/0084012	A1	4/2006	Nuzzo et al.	
2006/0084394	A1	4/2006	Engstrom et al.	
2006/0085976	A1	4/2006	Eldridge et al.	
2006/0102525	A1	5/2006	Volkel et al.	
2006/0106321	A1	5/2006	Lewinsky et al.	
2006/0119853	A1	6/2006	Baumberg et al.	
2006/0127817	A1	6/2006	Ramanujan et al.	
2006/0129056	A1	6/2006	Leuthardt et al.	
2006/0132025	A1	6/2006	Gao et al.	
2006/0134893	A1	6/2006	Savage et al.	
2006/0154398	A1	7/2006	Qing et al.	
2006/0159837	A1	7/2006	Kaplan et al.	
2006/0169989	A1	8/2006	Bhattacharya et al.	
2006/0173364	A1	8/2006	Clancy et al.	
2006/0177479	A1	8/2006	Giachelli et al.	
2006/0178655	A1	8/2006	Santini et al.	
2006/0244105	A1	11/2006	Forbes et al.	
2006/0255341	A1	11/2006	Pinnington et al.	
2006/0273279	A1	12/2006	Kaplan et al.	
2006/0279191	A1	12/2006	Geohegan et al.	
2006/0286488	A1	12/2006	Rogers et al.	
2006/0286785	A1	12/2006	Rogers et al.	
2007/0009968	A1	1/2007	Cunningham et al.	
2007/0027514	A1*	2/2007	Gerber	607/116
2007/0031607	A1	2/2007	Dubson et al.	
2007/0032089	A1	2/2007	Nuzzo et al.	
2007/0043416	A1	2/2007	Callas et al.	
2007/0058254	A1	3/2007	Kim	
2007/0073130	A1	3/2007	Finch et al.	
2007/0104944	A1	5/2007	Laude et al.	
2007/0108389	A1	5/2007	Makela et al.	
2007/0122819	A1	5/2007	Wu	
2007/0187862	A1	8/2007	Kaplan et al.	
2007/0212730	A1	9/2007	Vepari et al.	
2007/0213616	A1	9/2007	Anderson et al.	
2007/0227586	A1	10/2007	Zapalac	
2007/0233208	A1	10/2007	Kurtz et al.	
2007/0254468	A1	11/2007	Burdick, Jr. et al.	
2008/0000871	A1	1/2008	Suh et al.	
2008/0008626	A1	1/2008	Lin et al.	
2008/0038236	A1	2/2008	Gimble et al.	
2008/0041617	A1	2/2008	Chen et al.	
2008/0046080	A1	2/2008	Bulcke et al.	
2008/0054875	A1	3/2008	Saito	
2008/0055581	A1	3/2008	Rogers et al.	
2008/0077225	A1	3/2008	Carlin et al.	
2008/0085272	A1	4/2008	Kaplan et al.	
2008/0090322	A1	4/2008	Mech et al.	
2008/0102096	A1	5/2008	Molin et al.	
2008/0108171	A1	5/2008	Rogers et al.	
2008/0108942	A1	5/2008	Brister et al.	
2008/0140152	A1	6/2008	Imran	
2008/0152281	A1	6/2008	Lundquist et al.	
2008/0157234	A1	7/2008	Hong	
2008/0157235	A1	7/2008	Rogers et al.	
2008/0183076	A1	7/2008	Witte et al.	
2008/0188912	A1	8/2008	Stone et al.	
2008/0193749	A1	8/2008	Thompson et al.	
2008/0203268	A1	8/2008	Hobbs et al.	
2008/0203431	A1	8/2008	Garcia et al.	
2008/0208268	A1	8/2008	Bartic et al.	
2008/0212102	A1	9/2008	Nuzzo et al.	
2008/0239755	A1	10/2008	Parker et al.	
2008/0257586	A1	10/2008	Chen et al.	
2008/0280360	A1	11/2008	Kaplan et al.	
2008/0287167	A1	11/2008	Caine	
2008/0288037	A1	11/2008	Neysmith et al.	
2008/0293919	A1	11/2008	Kaplan et al.	
2008/0313552	A1	12/2008	Buehler et al.	
2009/0001550	A1	1/2009	Li et al.	
2009/0004737	A1	1/2009	Borenstein et al.	
2009/0015560	A1	1/2009	Robinson et al.	
2009/0028910	A1	1/2009	Desimone et al.	
2009/0054742	A1	2/2009	Kaminska et al.	
2009/0088750	A1	4/2009	Hushka et al.	
2009/0105605	A1	4/2009	Abreu	
2009/0107704	A1	4/2009	Vanfleteren et al.	
2009/0149930	A1	6/2009	Schecnk	
2009/0183986	A1	7/2009	Johnson et al.	
2009/0184254	A1	7/2009	Miura	
2009/0198293	A1	8/2009	Cauller et al.	
2009/0199960	A1	8/2009	Nuzzo et al.	
2009/0202614	A1	8/2009	Kaplan et al.	
2009/0204168	A1	8/2009	Kallmyer et al.	
2009/0208555	A1	8/2009	Kuttler et al.	
2009/0215385	A1	8/2009	Waters et al.	
2009/0221896	A1	9/2009	Rickert et al.	
2009/0232963	A1	9/2009	Kaplan et al.	
2009/0234026	A1	9/2009	Kaplan et al.	
2009/0247909	A1	10/2009	Mukumoto	
2009/0273909	A1	11/2009	Shin et al.	
2009/0289246	A1	11/2009	Schneider et al.	
2009/0294803	A1	12/2009	Nuzzo et al.	
2009/0308455	A1	12/2009	Kirscht et al.	
2009/0317639	A1	12/2009	Axisa et al.	
2010/0002402	A1	1/2010	Rogers et al.	
2010/0028451	A1	2/2010	Kaplan et al.	
2010/0046902	A1	2/2010	Kaplan et al.	
2010/0052112	A1	3/2010	Rogers et al.	
2010/0055438	A1	3/2010	Kaplan et al.	
2010/0059863	A1	3/2010	Rogers et al.	
2010/0063404	A1	3/2010	Kaplan et al.	
2010/0065784	A1	3/2010	Kaplan et al.	
2010/0068740	A1	3/2010	Kaplan et al.	
2010/0070068	A1	3/2010	Kaplan et al.	
2010/0072577	A1	3/2010	Nuzzo et al.	
2010/0073669	A1	3/2010	Colvin, Jr. et al.	
2010/0087782	A1	4/2010	Ghaffari	
2010/0096763	A1	4/2010	Kaplan et al.	
2010/0116526	A1	5/2010	Arora	
2010/0117660	A1	5/2010	Douglas et al.	
2010/0120116	A1	5/2010	Kaplan et al.	
2010/0121420	A1	5/2010	Fiset et al.	
2010/0152619	A1	6/2010	Kalpaxis et al.	
2010/0176705	A1	7/2010	Van Herpen et al.	
2010/0178304	A1	7/2010	Wang et al.	
2010/0178722	A1	7/2010	de Graff	
2010/0188799	A1	7/2010	Galvagni et al.	
2010/0191328	A1	7/2010	Kaplan et al.	
2010/0196447	A1	8/2010	Kaplan et al.	
2010/0200752	A1	8/2010	Lee et al.	

(56) References Cited

U.S. PATENT DOCUMENTS

2010/0203226	A1	8/2010	Kaplan et al.
2010/0252840	A1	10/2010	Ibbetson et al.
2010/0271191	A1	10/2010	de Graff
2010/0279112	A1	11/2010	Kaplan et al.
2010/0283069	A1	11/2010	Rogers et al.
2010/0289124	A1	11/2010	Nuzzo et al.
2010/0298895	A1	11/2010	Ghaffari
2010/0317132	A1	12/2010	Rogers et al.
2010/0324455	A1	12/2010	Rangel et al.
2010/0327387	A1	12/2010	Kasai et al.
2011/0011179	A1	1/2011	Gustafsson et al.
2011/0018838	A1	1/2011	Lee et al.
2011/0034912	A1	2/2011	de Graff
2011/0054583	A1	3/2011	Litt et al.
2011/0068672	A1	3/2011	Hasnain
2011/0114894	A1	5/2011	Choi et al.
2011/0147715	A1	6/2011	Rogers et al.
2011/0170225	A1	7/2011	Rogers et al.
2011/0171813	A1	7/2011	Rogers et al.
2011/0177332	A1	7/2011	Park et al.
2011/0187798	A1	8/2011	Rogers et al.
2011/0215931	A1	9/2011	Callsen
2011/0218756	A1	9/2011	Callsen
2011/0218757	A1	9/2011	Callsen
2011/0220890	A1	9/2011	Nuzzo et al.
2011/0230747	A1	9/2011	Rogers et al.
2011/0266561	A1	11/2011	Rogers et al.
2011/0272181	A1	11/2011	Koo et al.
2011/0277813	A1	11/2011	Rogers et al.
2011/0316120	A1	12/2011	Rogers et al.
2012/0051005	A1	3/2012	Vanfleteren et al.
2012/0052268	A1	3/2012	Axisa et al.
2012/0065937	A1	3/2012	de Graff
2012/0083099	A1	4/2012	Nuzzo et al.
2012/0092178	A1	4/2012	Callsen
2012/0105528	A1	5/2012	Alleyne
2012/0157804	A1	6/2012	Rogers et al.
2012/0157986	A1	6/2012	Stone et al.
2012/0157987	A1	6/2012	Steinke et al.
2012/0157988	A1	6/2012	Stone et al.
2012/0157989	A1	6/2012	Stone et al.
2012/0158101	A1	6/2012	Stone et al.
2012/0165759	A1	6/2012	Rogers et al.
2012/0251824	A1	10/2012	Hur et al.
2012/0256308	A1	10/2012	Helin
2012/0261551	A1	10/2012	Rogers
2012/0279762	A1	11/2012	Hur et al.
2012/0320581	A1	12/2012	Rogers et al.
2012/0327608	A1	12/2012	Rogers et al.
2013/0036928	A1	2/2013	Rogers et al.
2013/0041235	A1	2/2013	Rogers et al.
2013/0100618	A1	4/2013	Rogers et al.

FOREIGN PATENT DOCUMENTS

CN	1864095		11/2006
CN	101772348	A	7/2010
DE	4241045	C1	5/1994
DE	19748173		5/1999
EP	0929097		7/1999
EP	1357773		10/2003
EP	1 467 224		10/2004
EP	1 477 230		11/2004
EP	1 498 456		1/2005
EP	1 511 096		3/2005
EP	1 558 444		8/2005
EP	1 613 796		1/2006
EP	1746869		1/2007
EP	1 773 240		4/2007
EP	1 915 436		4/2008
EP	1 726 329		8/2009
EP	2 086 749		8/2009
EP	2 101 975		9/2009
EP	2 107 964		10/2009
EP	2 109 634		10/2009
EP	2 129 772		12/2009
EP	2 206 017		7/2010
EP	2 211 876		8/2010
EP	2 249 886		11/2010
JP	01-223064		9/1989
JP	2006118441		4/1994
JP	2006-163365		6/1994
JP	2011-026344		1/1999
JP	2001332383		11/2001
JP	2002092984		3/2002
JP	2003182475		7/2003
JP	2003289136		10/2003
JP	2003297974		10/2003
JP	2005059800		3/2005
JP	2006-504450		2/2006
JP	2006044383		2/2006
JP	2006-186294		7/2006
JP	2007-515391		6/2007
JP	2008-502739		1/2008
JP	2008-531137		8/2008
JP	2010-508852		3/2010
JP	2010-509593		3/2010
JP	2010-509644		3/2010
JP	2010-509645		3/2010
JP	2010-522583		7/2010
JP	2010-529230		8/2010
KR	10-2007-0100617		10/2007
KR	10-2008-0069553		7/2008
MY	P-020607		8/2012
TW	367570		8/1999
TW	494257		7/2002
TW	200836353		9/2008
WO	WO 96/21245		7/1996
WO	WO 98/49936		11/1998
WO	WO 99/45860		9/1999
WO	WO 00/46854		8/2000
WO	WO 00/49421		8/2000
WO	WO 00/49658		8/2000
WO	WO 00/55915		9/2000
WO	WO 00/55916		9/2000
WO	WO 01/31082		5/2001
WO	WO 01/33621		5/2001
WO	WO 01/66833		9/2001
WO	WO 01/98838		12/2001
WO	WO 02/27701		4/2002
WO	WO 02/43032		5/2002
WO	WO 02/45160		6/2002
WO	WO 02/071137		9/2002
WO	WO 02/073699		9/2002
WO	WO 02/092778		11/2002
WO	WO 02/097708		12/2002
WO	WO 02/097724		12/2002
WO	WO 03/021679		3/2003
WO	WO 03/030194		4/2003
WO	WO 03/032240		4/2003
WO	WO 03/049201		6/2003
WO	WO 03/063211		7/2003
WO	WO 03/085700		10/2003
WO	WO 03/085701		10/2003
WO	WO 03/092073		11/2003
WO	WO 04/000915		12/2003
WO	WO 04/001103		12/2003
WO	WO 2004/003535		1/2004
WO	WO 2004/016485		2/2004
WO	WO 2004/022637		3/2004
WO	WO 2004/022714		3/2004
WO	WO 2004/023527		3/2004
WO	WO 2004/024407		3/2004
WO	WO 2004/027822		4/2004
WO	WO 2004/032190		4/2004
WO	WO 2004/032191		4/2004
WO	WO 2004/032193		4/2004
WO	WO 2004/034025		4/2004
WO	WO 2004/062697		7/2004
WO	WO 2004/086289		10/2004
WO	WO 2004/094303		11/2004
WO	WO 2004/099536		11/2004
WO	WO 2004/100252		11/2004

(56) References Cited

FOREIGN PATENT DOCUMENTS

WO	WO 2004/099068	12/2004
WO	WO 2004/105456	12/2004
WO	WO 2004/107973	12/2004
WO	WO 2005/000483	1/2005
WO	WO 2005/005679	1/2005
WO	WO 2005/012606	2/2005
WO	WO 2005/015480	2/2005
WO	WO 2005/017962	2/2005
WO	WO 2005/022120	3/2005
WO	WO 2005/029578	3/2005
WO	WO 2005/033786	4/2005
WO	WO 2005/033787	4/2005
WO	WO 2005/054119	6/2005
WO	WO 2005/099310	10/2005
WO	WO 2005/104756	11/2005
WO	WO 2005/106934	11/2005
WO	WO 2005/122285	12/2005
WO	WO 2005/123114	12/2005
WO	WO 2006/028996	3/2006
WO	WO 2006/042287	4/2006
WO	WO 2006/069323	6/2006
WO	WO 2006/076711	7/2006
WO	WO 2006/104069	10/2006
WO	WO 2006/130558	12/2006
WO	WO 2006/130721	12/2006
WO	WO 2007/000037	1/2007
WO	WO 2007/016524	2/2007
WO	WO 2007/028003	3/2007
WO	WO 2007/056183	5/2007
WO	WO 2007/126412	11/2007
WO	WO 2008/030666	3/2008
WO	WO 2008/030960	3/2008
WO	WO 2008/036837	3/2008
WO	WO 2008/055054	5/2008
WO	WO 2008/085904	7/2008
WO	WO 2008/103464	8/2008
WO	WO 2008/106485	9/2008
WO	WO 2008/108838	9/2008
WO	WO 2008/118133	10/2008
WO	WO 2008/118211	10/2008
WO	WO 2008/127401	10/2008
WO	WO 2008/127402	10/2008
WO	WO 2008/127403	10/2008
WO	WO 2008/127404	10/2008
WO	WO 2008/127405	10/2008
WO	WO 2008/140562	11/2008
WO	WO 2008/143635	11/2008
WO	WO 2008/150861	12/2008
WO	WO 2009/011709	1/2009
WO	WO 2009/023615	2/2009
WO	WO 2009/061823	5/2009
WO	WO 2009/075625	6/2009
WO	WO 2009/076088	6/2009
WO	WO 2009/090398	7/2009
WO	WO 2009/100280	8/2009
WO	WO 2009/111641	9/2009
WO	WO 2009/114115	9/2009
WO	WO 2009/114689	9/2009
WO	WO 2009/118678	10/2009
WO	WO 2009/126689	10/2009
WO	WO 2009/140588	11/2009
WO	WO 2009/155397	12/2009
WO	WO 2010/005707	1/2010
WO	2010/046883	4/2010
WO	WO 2010/036807	4/2010
WO	WO 2010/036992	4/2010
WO	WO 2010/040528	4/2010
WO	WO 2010/042798	4/2010
WO	WO 2010/049881	5/2010
WO	WO 2010/057142	5/2010
WO	WO 2010/065957	6/2010
WO	WO 2010/126640	11/2010
WO	WO 2010/132552	11/2010
WO	WO 2010/141133	12/2010
WO	WO 2011/002931	1/2011
WO	WO 2011/005381	1/2011
WO	WO 2011/006133	1/2011
WO	WO 2011/008842	1/2011
WO	WO 2011/011347	1/2011
WO	WO 2011/026101	3/2011
WO	WO 2011/038401	3/2011
WO	2011/041507	4/2011
WO	WO 2011/041395	4/2011
WO	WO 2011/046652	4/2011
WO	WO 2011/084450	7/2011
WO	WO 2011/112931	9/2011
WO	WO 2011/115643	9/2011
WO	WO 2012/097163	7/2012
WO	WO 2012/158709	11/2012
WO	WO 2012/167096	12/2012
WO	WO 2013/010113	1/2013

OTHER PUBLICATIONS

Adachi et al (1982) "Chemical Etching of InGaAsP/inP DH Wafer," *J. Electrochem. Soc.* 129:1053-1062.

Adachi et al. (1983) "Chemical Etching Characteristics of (001) GaAs," *J. Electrochem. Soc.* 130:2427-2435.

Adrega et al. (2010) "Stretchable Gold Conductors Embedded in PDMS and Patterned by Photolithography: Fabrication and Electromechanical Characterization," J. Micromech. Microeng. 20:055025.

Ago et al. (2005) "Aligned Growth of Isolated Single-Walled Carbon Nanotubes Programmed vby Atomic Arrangement of Substrate Surface," Chem. Phys. Lett. 408:433-438.

Ago et al. (2006) "Synthesis of Horizontally-Aligned Single-Walled Carbon Nanotubes with Controllable Density on Sapphire Surface and Polarized Raman Spectroscopy," Chem. Phys. Lett. 421:399-403.

Ahmed et al. (Web Release Oct. 11, 2005) "Extending the 3w-Method to the MHz Range for Thermal Conductivity Measurements of Diamond Thin Films," *Diamond Relat. Mater. 15*(2-3):389-393.

Ahn et al. (2007) "Bendable Integrated Circuits on Plastic Substrates by Use of Printed Ribbons of Single-Crystalline Silicon," *Appl. Phys. Lett. 90*:213501.

Ahn et al. (Dec. 15, 2006) "Heterogeneous Three-Dimensional Electronics by Use of Printed Semiconductor Nanomaterials," *Science 314*:1754-1757.

Ahn et al. (Jun. 2006) "High-Speed Mechanically Flexible Single-Crystal Silicon Thin-Film Transistors on Plastic Substrates," *IEEE Electron Dev. Lett. 27*(6):460-462.

Ai-Sarawi et al. (Feb. 1998) "A Review of 3-D Packaging Technology," *IEEE Trans. Compo Packag. Manufac. Technol.* B 21(1):2-14.

Al-Halhouli et al. (2008) "Nanoindentation Testing of SU-8 Photoresist Mechanical Properties," Microelectronic Eng. 85:942-944.

Aliot, E. M. et al. (2009) "EHRA/HRS Expert Consensus on Catheter Ablation of Ventricular Arrhythmias: Developed in a partnership with the European Heart Rhythm Association (EHRA), a Registered Branch of the European Society of Cardiology (ESC), and the Heart Rhythm Society (HRS); in collaboration with the American College of Cardiology (ACC) and the American Heart Association (AHA)," Europace 11:771-817.

Alivisatos et al. (1996) "Semiconductor Clusters, Nanocrystals, and Quantum Dots," *Science* 271 :933-937.

Alivisatos et al. (1998) "From Molecules to Materials: Current Trends and Future Directions," *Adv. Mater. 10*:1297-1336.

Allen et al. (Feb. 20, 2006) "Nanomaterial Transfer Using Hot Embossing for Flexible Electronic Devices," *Appl. Phys. Lett. 88*:083112.

Altman et al., "Silk-Based Biomaterials," Biomaterials 2003; 24 (3): 24:401-416.

Amano et al. (Feb. 3, 1986) "Metalorganic Vapor Phase Epitaxial Growth of a High Quality GaN Film Using an Ain Buffer Layer," *Appl. Phys. Lett. 48*(5):353-355.

Ambrosy et al. (1996) "Silicon Motherboards for Multichannel Optical Modules," *IEEE Trans Compon. Pack. A 19*:34-40.

Amir et al. (2000) "The Influence of Helium-Neon Irradiation on the Viability of Skin Flaps in the Rat," Br. J. Plast. Surg. 53:58-62.

(56) **References Cited**

OTHER PUBLICATIONS

Amsden et al. (Nov. 9, 2009) "Spectral Analysis of Induced Color Change on Periodically Nanopatterned Silk Films," Opt. Express 17(23):21271-21279.

Andersen et al. (2004) "Selecting the Signals for a Brain-Machine Interface," Curr. Opin. Neurobiol. 14:720-726.

Andersson et al. (Oct. 16, 2002) "Active Matrix Displays Based on All-Organic Electrochemical Smart Pixels Printed on Paper," *Adv. Mater. 14*:1460-1464.

Ando et al. (2004) "Self-Aligned Self-Assembly Process for Fabricating Organic Thin-Film Transistors," *Appl. Phys. Lett. 85*:1849-1851.

Angadi et al. (Web Release Jun. 1, 2006) "Thermal Transport and Grain Boundary Conductance in.Ultrananocrystalline Diamond Thin Films," *J. Appl. Phys. 99*:114301.

Aoki et al. (2003) "Microassembly of Semiconductor Three Dimensional Photonic Crystals," *Nat. Mater. 2*:117-121.

Arnold et al. (Web Release Dec. 28, 2002) "Field-Effect Transistors Based on Single Semiconducting Oxide Nanobelts," *J. Phys. Chem.* B 107(3):659-663.

Ayon et al. (Jan. 1999) "Characterization of a Time Multiplexed Inductively Coupled Plasma Etcher," *J. Electrochem. Soc.* 146(1):339-349.

Baca et al. (2008) "Semiconductor Wires and Ribbons for High-Performance Flexible Electronics," *Angew. Chern. Int. Ed. 47*:5524-5542.

Bachtold et al. (Nov. 9, 2001) "Logic Circuits with Carbon Nanotube Transistors," *Science 294*:1317-1320.

Bae et al. (Jul. 1, 2002) "Single-Crystalline Gallium Nitride Nanobelts," *Appl. Phys. Lett*. 81: 126-128.

Ball et al. (2004) "Towards an Implantable Brain-Machine Interface Based on Epicortical Field Potentials," Biomed. Tech. 49:756-759.

Balmer et al. (2005) "Diffusion of Alkanethiols in PDMS and Its Implications on Microcontact Printing (IJCP)," *Langmuir* 21 (2):622-632.

Banerjee et al. (May 2001) "3-D ICs: A Novel Chip Design for Improving DeepSubmicrometerinterconnect Performance and Systems-on-Chip Integration," *Proc. IEEE 89*(5):602-633.

Bao et al. (1997) "High-Performance Plastic Transistors Fabricated by Printing Techniques," *Chem. Mater. 9*:1299-1301.

Bao et al. (1999) "Printable Organic and Polymeric Semiconducting Materials and Devices," *J. Mater. Chern. 9*:1895-1904.

Barquins, M. (1992) "Adherence, Friction and Wear of Rubber-Like Materials," *Wear* 158:87-117.

Bates, F.S. (1991) "Polymer-Polymer Phase Behavior," *Science* 251 :898-905.

Battaglia et al. (2003) "Colloidal Two-Dimensional Systems: CdSe Quantum Shells and Wells," Angew. Chem. Int. Ed. 442:5035-5039.

Bauer et al. (2004) "Biological Applications of High Aspect Ratio Nanoparticles," *J. Mater. Chem. 14*:517-526.

Berg et al. (2003) "Tailored Micropatterns Through Weak Polyelectrolyte Stamping," Langmuir 19:2231-2237.

Bernard et al. (1998) "Printing Patterns of Proteins," *Langmuir 14*(9):2225-2229.

Bett et al. (Aug. 1999) "III-V Compounds for Solar Cell Applications," Appl. Phys. A. Mater. Sci. 69(2):119-129.

Bhunia et al. (2004) "Free-Standing and Vertically Aligned InP Nanowires Grown by Metalorganic.Vapor Phase Epitaxy," *Physica E* 21 :583-587.

Bhushan et al. (2004) "Multiwalled Carbon Nanotube AFM Probes for Surface Characterization of Micro/Nanostructures," *Microsyst. Technol*. 10:633-639.

Bioflex—Biocompatible Flexible Electronic Circuits. Available at http:/tfcg.elis. Ugent.be/projects. Accessed Feb. 8, 2012.

Bietsch et al. (2000) "Conformational Contact and Pattern Stability of Stamps Used for Soft Lithography," *J. Appl. Phys. 88*:4310-4318.

Bishay et al. (2000) "Temperature Coefficient of the Surface Resistivity of Two-Dimensional Island Gold Films," *J. Phys. D. Appl. Phys. 33*(18):2218-2222.

Blanchet et al. (2003) "Large Area, High Resolution, Dry Printing of Conducting Polymers for Organic Electronics," *Appl. Phys. Lett. 82*:463-465.

Blanchet et al. (2003) "Printing Techniques for Plastic Electronics," *J. Imag. Sci. Tech*. 47(4):296-303.

Blazdell et al. (Nov. 1999) "Preparation of Ceramic Inks for Solid Freeforming Using a Continuous Jet Printer," *J. Mat. Syn. Process. 7*(6):349-356.

Boltau et al. (1998) "Surface-Induced Structure Formation of Polymer Blends on Patterned Substrates," *Nature* 391:877-879.

Boncheva et al. (Mar. 15, 2005) "Magnetic Self-Assembly of Three-Dimensional Surfaces from Planar Sheets," *Proc. Natl. Acad. Sci. USA* 102(11):3924-3929.

Boncheva et al. (Mar. 18, 2005) "Templated Self-Assembly: Formation of Folded Structures by Relaxation of Pre-Stressed, Planar Tapes. The Path to Ubiquitous and Low-cost Organic Electronic Appliances on Plastic," *Ad. Mater*. 17(5): 553-557.

Bourzac, K. (May/Jun. 2010) "TR10: Implantable Electronics," Technology Review, Published by MIT, http://www.technologyreview.com/biomedicine/25086/?a=f.

Bowden et al. (1997) "Self Assembly of Mesoscale Objects into Ordered Two-Dimensional Arrays," Science 276:233-235.

Bowden et al. (1998) "Spontaneous Formation of Ordered Structures in Thin Films of Metals Supported on an Elastomeric Polymer," Nature 393:146-149.

Bowden et al. (2001) "Molecule-Mimetic Chemistry and Mesoscale Self-Assembly," Ace. Chem. Res. 34:231-238.

Bracher et al. (2009) "Shaped Films of lonotropic Hydrogels Fabricated Using Templates of Patterns Paper," Adv. Mater. 21 :445-450.

Bradley et al. (2003) "Flexible Nanotube Electronics," Nano Lett., vol. 3, No. 10, pp. 1353-1355.

Braun et al. (1999) "Electrochemically Grown Photonic Crystals," *Nature 402*:603-604.

Britton et al. (Web Release Oct. 25, 2005) "Microstructural Defect Characterization of a Si:H Deposited by Low Temperature HW-CVD on Paper Substrates," Thin Solid Films 501(1-2):79-83.

Brown et al. (2005) "Evaluation of Polydimethylsiloxane Scaffolds with Physiologically-Relevant Elastic Moduli: Interplay of Substrate Mechanics and Surface Chemistry Effects on Vascular Smooth Muscle Cell Response," Biomaterials 26:3123-3129.

Brown et al. (Dec. 19, 2001) "Heterogeneous Materials Integration: Compliant Substrates to Active Device and Materials Packaging," Mater. Sci. Eng. B 87(3):317-322.

Brown, H.R. (1991) "The Adhesion Between Polymers," *Ann. Rev. Mater. Sci*. 21:463-489.

Bruschi et al. (2001) "Micromachined Silicon Suspended Wires With Submicrometric Dimensions," Microelectron. Eng. 57-58:959-965.

Buma et al. (2001) "High-Frequency Ultrasound Array Element Using Thermoelastic Expansion in an Elastomeric Film," Appl. Phvs. Lett. 79:548-550.

Burdinski et al. (2005) "Single Etch Patterning of Stacked Silver and Molybdenum Alloy Layers on Glass Using Microcontat Wave Printing," J. Am. Chem. Soc. 127(31):10786-1 0787.

Burdinski, D. (non-dated) "Soft Lithography and Microcontact Wave Printing," htt,Q:/iINWW.research.Q,hili,Qs.comitechnologies/light deY microsys/softlitho/index.html, Downloaded May 23, 2007.

Burge et al. (Jun. 25, 1997) "X-Ray Holography for VLSI Using Synthetic Bilevel Holograms," Proc. Int. Soc. Opt. Eng. 3183:2-13.

Burgin et al. (2000) "Large Area Submicrometer Contact Printing Using a Contact Aligner," Langmuir 16:5371-5375.

Burns et al. (2003) "Printing of Polymer Thin-Film Transistors for Active-Matrix-Display Applications," J. Soc. Int. Display 11 :599-604.

Campbell et al. (2000) "Fabrication of Photonic Crystals for the Visible Spectrum by Holographic Lithography," *Nature 404*:53-56.

Cao et al. (2006) "Highly Bendable,Transparent Thin-Film Transistors That Use Carbon-Nanotube-Based Conductors and Semiconductors with Elastomeric Delectrics," Adv. Mater. 18(3):304-309.

Cao et al. (2006) "Bilayer Organic-Inorganic Gate Dielectrics for High-Performance, Low-Voltage, Single-Walled Carbon Nanotube Thin-Film Transistors, Complementary Logic Gates, and p-n Diodes on Plastic Substrates," Adv. Funct. Mater. 16:2355-2362.

(56) **References Cited**

OTHER PUBLICATIONS

Cao et al. (2006) "Transparent flexible organic thin-film transistors that use printed single-walled carbon nanotube electrodes," Applied Physics Letters 88:113511.
Cao et al. (Jan. 5, 2009) "Ultrathin Films of Single-Walled Carbon Nanotubes for Electronics and Sensors: A Review of Fundamental and Applied Aspects," Adv. Mater. 21(1):29-53.
Cao et al. (Jul. 24, 2008) "Medium-Scale Carbon Nanotube Thin-Film Integrated Circuits on Flexible Plastic Substrates," Nature 454:495-500.
Carr et al. (1998) "Measurement of Nanomechanical Resonant Structures in Single-Crystal Silicon," J. Vac. Sci. Technol. B 16:3821-3824.
Chadhury et al. (1991) "Direct Measurement of Interfacial Interactions Between Semispherical Lenses and Flat Sheets of Poly(dimethylsiloxane) and their Chemical Derivatives," Langmuir 7: 1013-1025.
Chang et al. (1994) "Process Techniques, Lithography and Device-Related Physics and Principles," In; GaAs High-Speed Devices: Physics, Technology and Circuit Application, John Wiley and Sons, New York, pp. 115-278.
Chen et al. (2003) "Characterization of Pd-GaAs Schottly Diodes Prepared by the Electrodes Plating Technique," Semiconductor. Sci. Technol. 18:620-626.
Chen et al. (2003) "Electronic Paper: Flexible Active-Matrix Electronics Ink Display," Nature 423: 136.
Chen et al. (2004) "Herringbone Buckling Patterns of Compresses Thin Films on Comlliant Substrates," J. Appl. Mech. 71 :597.
Chen et al. (2005) "InGaN Nanorings and Nanodots by Selective Area Epitaxy," Appl. Phys. Lett. 87:143111.
Chen et al. (2005) "The Role of Metal-Nanotube Caontact in the Performance of Carbon Nanotube Field-Effect Transistors," Nano Lett. 5(7):1497-1502.
Chen et al. (Feb. 27, 2006) "Complementary Carbon Nanotube-Gated Carbon Nanotube Thin-Fim Transistor," Appl. Phys. Lett. 88:093502.
Chen et al. (Jun. 2002) Effect of Process Parameters on the Surface Morphology and Mechanical Performance of Silicon Structures After Deep Reactive Ion Etching (DRIE) J. Microelectromech. Syst. 11 (3):264-2775.
Chen et al. (Mar. 2004) "A Family of Herringbone Patterns in Thin Films," Scr. Mater. 50(6):797-801.
Chen et al. (Mar. 24, 2006) "An Integrated Logic Circuit Assembled on a Single Carbon Nanotube," Science 311:1735.
Chen et al. (Sep. 2004) "Herringbone Buckling Patterns of Compressed Thin Films on Compliant Substrates," J. Appl. Mech. 71:597-603.
Cheng et al. (2005) "Ink-Jet Printing, Self-Assembled Polyelectrolytes, and Electroless Plating: Low Cost Fabrication of Circuits on a Flexible Substrate at Room Temperature," Macromol. Rapid Commun. 26:247-264.
Childs et al. (2002) "Decal Transfer Microlithography: A New Soft-Lithographic Patterning Method," J. Am. Chern. Soc. 124:13583-13596.
Childs et al. (2005) "Masterless Soft-Lithography: Patterning UV/Ozone-Induced Adhesion on Poly(dimethylsiloxane) Surfaces," Langmuir 21:10096-10105.
Childs et al. (Aug. 14, 2004) "Patterning of Thin-Film Microstructures on Non-Planar Substrate Surfaces Using Decal Transfer lithography," Adv. Mater. 16(15):1323-1327.
Choi et al. (2007) "Biaxially Stretchable 'Wavy' Silicon Nanomembranes," Nano Lett. 7(6): 1655-1663.
Choi et al. (Web Release Jan. 25, 2005) "Simple Detachment Patterning of Organic Layers and.Its Applications to Organic light-Emitting Diodes," Adv. Mater. 17(2):166-171.
Chou et al. (2004) "An Orientation-Controlled Pentacene Film Aligned by Photoaligned Polyimide for Organic Thin-Film Transistor Applications," Adv. Func. Mater. 14:811-815.
Chou et al. (Jun. 8, 1999) "Micromachining on (111)-Oriented Silicon," Sens. Actuators A 75(3):271-277.
Chu et al. (2005) "High-Performance Organic Thin-Film Transistors with Metal Oxide/Metal Bilayer Electrode," Appl. Phys. Lett. 87: 193508.
Chung et al. (2000) "Silicon Nanowire Devices," Appl. Phys. Lett. 76(15):2068-2070 Chung et al. (Jul. 1, 2003) "A Study on Formation of Al and Al2O3 on the Porous Paper by Dc Magnetron Sputtering," Surf. Coat. Technol. 171(1-3):65-70.
Chung et al. (Jul. 1, 2003) "A Study on Formation of Al and Al2O3 on the Porous Paper by DC Magnetron Sputtering," Surf. Coat. Technol. 171(1-3):65-70.
Ciesinski, Michael, "Flexible Electronics: Why the Interest? Where are the Markets? What's Next?" *Flextech Alliance* Apr. 14, 2010, [retrieved online Apr. 28, 2011] http://www.avsusergroups.org/tfug_pdfs/tfug2010_4ciensinski.pdf.
Clerc, L. (1976) "Directional Differences of Impulse Spread in Trabecular Muscle from Mammalian Heart," J. Physiol. 255:335-346.
Cohen-Karni et al. (2009) "Flexible Electrical Recording from Cells Using Nanowire Transistor Arrays," Proc. Natl. Acad. Sci. USA 106:7309-7313.
Cole et al. (2008) "Patterned Growth and Transfer of ZnO Micro- and Nanocrystals with Size and Location Control," Adv. Mater. 20:1474-1478.
Collins et al. (Apr. 27, 2001) "Engineering Carbon Nanotubes and Nanotube Circuits Using Electrical Breakdown," Science 292:706-709.
Corazza et al. (2007) "Photobiomodulation on the Angiogenesis of Skin Wounds in Rats Using Different Light Sources," Photomedicine Laser Surg. 25:102-106.
Cox, H. L. (1952) "The Elasticity and Strength of Paper and Other Fibrous Materials," Br. J. Appl. Phys. 3:72-79.
Creagh et al. (2003) "Design and Performance of Inkjet Print Heads for Non-Graphic-Arts Applications," MRS Bull. 28:807-811.
Crone et al. (Feb. 3, 2000) "Large-Scale Complementary Integrated Circuits Based on Organic Transistors," Nature 403:521-523.
Crowder et al. (1998) "Low-Temperature Single-Crystal Si TFTs Fabricated on Si Films Processed via Sequential Lateral Solidification," IEEE Electron. Dev. Lett. 19:306-308.
Cui et al. (2001) "Nanowire Nanosensors for Highly Sensitive and Selective Detection of Biological and Chemical Species," Science 293:1289-1292.
Dai et al. (2002) "Gallium Oxide Nanoribbons and Nanosheets," J. Phys. Chem. B.106(5):902-904.
Dai et al. (2003) "Novel Nanostructures of Functional Oxides Synthesized by Thermal Evaporation," Adv. Funct. Mater. 13:9-24.
Dai et al. (Web Release Jan. 15, 2002) "Gallium Oxide Nanoribbons and Nanosheets," J. Phys. Chem. B 106(5):902-904.
Davidson et al. (2004) "Supercritical Fluid-liquid-Solid Synthesis of Gallium Arsenide Nanowires Seeded by Alkanethiol-Stabilized Gold Nanocrystals," Adv. Mater. 16:646-649.
de Gans (2004) "Inkjet Printing of Polymers: State of the Art and Future Developments," Adv. Mater. 16(3):203-213.
De Sio et al. (Web Release May 18, 2005) "Electro-Optical Response of a Single-Crystal Diamond Ultraviolet Photoconductor in Transverse Configuration," Appl. Phys. Lett. 86:213504.
DeBoer et al. (2004) "Organic Single-Crystal Field-Effect Transistors," *Phys. Stat. Sol. 201* :1302-1331.
Deen et al. (2004) "Electrical Characterization of Polymer-Based FETs Fabricated by Spin-Coating Poly(3-alkylthiophene)s," IEEE Trans. Electron Devices 51: 1892-1901.
Delmerche et al. (1997) "Stability of Molded Polydimethylsiloxane Microstructures," Adv. Mat. 9:741-746.
Deruelle et al. (1995) "Adhesion at the Solid-Elastomer Interface: Influence of Interfacial Chains," Macromol. 28:7419-7428.
Derycke et al. (Sep. 2001) "Carbon Nanotube Inter- and Intramolecular Logic Gates," Nano Lett. 1(9):453-456.
Desai et al. (Feb. 1999) "Nanopore Technology for Biomedical Applications," *Biomed. Microdevices 2* (1):11-40.
Dick et al. (2004) "Synthesis of Branched 'Nanotrees' by Controlled Seeding of Multiples Branching Events," Nat. Mater. 3:380-38.
Dimroth et al. (Mar. 2007) "High-Efficiency Multijunction Solar Cells," *MRS Bull. 32*:230-235.

(56) References Cited

OTHER PUBLICATIONS

Ding et al. (Oct. 4, 2004) "Self Catalysis and Phase Transformation in the Formation of CdSe Nanosaws," Adv. Mater. 16(19):1740-1743.

Dinsmore et al. (2002) "Colloidosomes: Selectively Permeable Capsules Composed of Colloidal Particles," Science 298:1006-1009.

Dinyari et al., (2008) "Curving Monolithic Silicon for Nonplanar Focal Plane Aarray Applications," Appl Phys Lett, 92:091114.

Divliansky et al. (2003) "Fabrication of Three-Dimensional Polymer Photonic Crystal Structures Using Single Diffraction Element Interference Lithography," Appl. Phys. Lett. 82(11):1667-1669.

Dodabalapur A. (Apr. 2006) "Organic and Polymer Transistors for Electronics," *Mater Today 9*(4):24-30.

Dodabalapur et al. (1995) "Organic Transistors: Two-Dimensional Transport and mproved Electrical Characteristics," Science 268:270-27.

Duan et al. (2000) "General Synthesis of Compound Semiconductor Nanowires," *Adv. Mater. 12*:298-302.

Duan et al. (2003) "High-performance Thin-Film Transistors Using Semiconductor Nanowires and Nanoribbons," Nature 425:274-278.

Duan X, (2003) "Semiconductor Nanowires: From Nanoelectronics to Macroelectronics," Abstract from a presentation given at the 11th Foresight Conference on Molecular Nanotechnology, Oct. 10-20, Burlingame, CA.

Duboz et al. (1998) "Transistors and Detectors Based on GaN-Related Materials," In; Group III Nitride Semiconductor Compounds, Gill, B. ed., Clarendon, Oxford, pp. 343-387.

Duesberg et al. (2000) "Polarized Raman Spectroscopy on Isolated Single-Wall Carbon Nanotubes," Phys. Rev. Lett., vol. 85, No. 25, pp. 5436-5439.

Duffy et al. (1998) "Rapid Prototyping of Microfluidic Systems in Poly(dimethylsiloxane)," Anal Chern. 70(23):4974-4984.

Dupuis et al. (2008) "History, Development, and Applications of High-Brightness Visible Light-Emitting Diodes," IEEE J. Lightwave Tech. 26:1154-1171.

Durkop et al. (2004) "Extraordinary Mobility in Semiconducting Carbon Nanotube," *Nano Lett.* 4(1):35-39.

Eder et al. (Apr. 5, 2004) "Organic Electronics on Paper," *Appl. Phys. Lett. 84*(14):2673-2675.

Edrington et al. (2001)"Polymer-Based Photonic Crystals," *Adv. Mater. 13*:421-425.

Efimenko et al. (Oct. 15, 2002) "Surface Modification of Sylgard-184 Poly(dimethyl Siloxane) Networks by Ultraviolet and UltravioleUOzone Treatment," J. Colloid Interface Sci. 254(2):306-315.

Eftekhari, G. (1993) "Variation in the Effective Richardson Constant of Metal-GaAs and Metal-InP Contacta Due to the Effect of Processing Parameters," Phys. Status Solid A—Appl. Res. 140:189-194.

Ensell, G. (1995) "Free Standing Single-Crystal Silicon Microstructures," *J.Micromech. Microeng. 5*: 1-4.

European Extended Search Report dated Feb. 9, 2012 in Application No. 09826745.3.

Examination Report, Clear Report, Corresponding to Malaysian Patent Application No. PI 20062672, issued May 13, 2011.

Examination Report, Corresponding to European Application No. EP 05 756 327.2, Dated Jan. 20, 2010.

Examination Report, Corresponding to Malaysian Patent Application No. PI20052553, Issued Feb. 27, 2009.

Examination Report, Corresponding to Malaysian Patent Application No. PI20092343, Issued May 26, 2012.

Examination Report, Corresponding to Malaysian Patent Application No. PI 20062672, Mailed Aug. 28, 2009.

Examination Report, Corresponding to Malaysian Patent Application No. PI20092343, Mailed Jun. 15, 2010.

Examination Report, Corresponding to Malaysian Patent Publication No. PI20052553, Mailed Mar. 13, 2009.

Examination Report, Corresponding to Singapore Patent Application No. 200608359-6, Completed on Aug. 27, 2008.

Faez et al. (1999) "An Elastomeric Conductor Based on Polyaniline Prepared by Mechanical Mixing," Polymer 40:5497-5503.

Feigner et al. (1996) "Flexural Rigidity of Microtubules Measured with the Use of Optical Tweezers," J. Cell Sci. 109:509-516.

Final Office Action, Corresponding to U.S. Appl. No. 12,575,008, mailed Oct. 17, 2011.

Final Office Action, Corresponding to U.S. Appl. No. 11/851,182, Mailed Oct. 29, 2010.

Fink et al. (1999) "Block Copolymers as Photonic Bandgap Materials," *J. Lightwave Tech. 17*:1963-1969.

Flewitt et al. (2005) "Low-Temperature Deposition of Hydrogenated Amorphous Silicon in an Electron Cyclotron Resonance Reactor for Flexible Displays," Proc. IEEE 93: 1364-1373.

Folch et al. (1999) "Wafer-Level In-Registry Microstamping," *J. Microelectromech. Syst. 8*:85-89.

Forment et al. (2004) "Influence of Hydrogen Treatment and Annealing Processes Upon the Schottky Barrier Height of Au/n-GaAs and Ti/n-GaAs Diodes," Semicond. Sci. Technol. 19:1391-1396.

Forrest et al. (2004) "The Path to Ubiquitous and Low-Cost Organic Electronic Appliances on Plastic," Nature 428:911-918.

Fortunato et al. (2005) "Flexible a-Si: H Position-Sensitive Detectors," *Proc. IEEE 93*:1281-1286.

Fortunato et al. (Sep. 2008) "High-Performance Flexible Hybrid Field-Effect Transistors Based on Cellulose Fiber Paper," IEEE Electron. Dev. Lett. 29(9):988-990.

Freeman et al. (2000) "Spatial Spectral Analysis of Human Electrocardiograms Including the Alpha and Gamma Bands," J. Neurosci. Methods 95:111-121.

Freire et al. (1999) "Thermal Stability of Polyethylene Terephthalate (PET): Oligomer Distribution and Formation of Volatiles," Packag. Technol. Sci. 12:29-36.

Freund, L.B. (2000) "The Mechanics of Electronic Materials," *Int. J. Solids Struct. 37*:185-196.

Friedman et al. (2005) "Nanotechnology: High-Speed Integrated Nanowire Circuits," Nature 434: 1085.

Fu et al. (Jan. 10, 2003) "Patterning of Diamond Microstructures on Si Substrate by Bulk and Surface Micromachining," J. Mater. Process. Technol. 132(1-3):73-81.

Furneaux et al. (1989) "The Formation of Controlled-Porosity Membranes from Anodically Oxidized Aluminum," Nature 337:147-149.

Gan et al. (2002) "Preparation of Thin-Film Transistors with Chemical Bath Deposited CdSe and CdS Thin Films," IEEE Trans. Electron. Dev. 49:15-18.

Gao et al. (Sep. 9, 2005) "Conversion of Zinc Oxide Nanobelts into Superlattice-Structures Nanohelices," Science 309: 1700-1704.

Garcia et al. (Oct. 2004) "Etchant Anisotropy Controls the Step Bunching Instability in KOH Etching of Silicon," Phys. Rev. Lett. 93(16):166102.

Gardner et al. (1965) "Physical Aspects of the Internal Water Relations of Plant Leaves," Plant Physiol. 40:705-710.

Garnier et al. (1994) "All-Polymer Field-Effect Transistor Realized by Printing Techniques," Science 265:1684-1686.

Geim et al. (Mar. 2007) "The Rise of Graphene," *Nature Mater. 6*:183-191.

Geissler et al. (2003) "Fabrication of Metal Nanowires Using Microcontact Printing," Langmuir 19(15):6301-6311.

Geissler et al. (Jun. 2003) "Selective Wet-Etching of Microcontact-Printed Cu Substrates with.Control Over the Etch Profile," Microelec. Eng. 67-68:326-332.

Gelinck et al. (2000) "High-Performance All-Polymer Integrated Circuits," *Appl. Phys. Lett. 77*:1487-1489.

Gelinck et al. (2004) "Flexible Active-Matrix Displays and Shift Registers Based on Solution-Processed Organic Transistors," Nat. Mater. 3: 106-110.

Georgakilas et al. (2002) "Wafer-Scale Integration of GaAs Optoelectronic Devices with Standard Si Integrated Circuits Using a Low-Temperature Bonding Procedure," Appl. Phys. Lett. 81:5099-5101.

Givargizov, E.I. (1991) "Applications," In; *Oriented Crystallization on Amorphous Substrates*, Plenum Press, New York, pp. 341-363.

Goetting et al. (1999) "Microcontact Printing of Alkanephosphonic Acids on Aluminum: Pattern Transfer by Wet Chemical Etching," *Langmuir 15*:1182-1191.

(56) References Cited

OTHER PUBLICATIONS

Goldman et al. (1996) "Correlation of Buffer Strain Relaxation Modes with Transport Properties of Two-Dimensional Electron Gases," *J. Apple. Phys. 80*:6849-6854.

Goldmann et al. (2004) "Hole Mobility in Organic Single Crystals Measured by a "Flip Crystal" Field-Effect Technique," *J. Appl. Phys. 96*:2080-2086.

Goldsmith, T.H. (Sep. 1990) "Optimization, Constraint, and History in the Evolution of Eyes," *Quart. Rev. Biol. 65*(3):281-322.

Gratz et al. (1991) "Atomic Force Microscopy of Atomic-Scale Ledges and Etch Pits Formed During Dissolution of Quartz," Science, 251:1343-1346.

Gray et al. (2004) "High-Conductivity Elastomeric Electronics," *Adv. Mater. 16*:393 397.

Gray et al. (Dec. 2001) "Screen Printed Organic Thin Film Transistors (OTFTs) on a Flexible Substrate," *Proc. SPIE 4466*:89-94.

Grayson, T. (2002) "Curved Focal Plane Wide Field of View Telescope Design," *Proc. SPIE 4849*:269-274.

Gruen et al. (Mar. 21, 1994) "Fullerenes as Precursors for Diamond Film Growth Without Hydrogen or Oxygen Additions," *Appl. Phys. Lett. 65*(12):1502-1504.

Gudiksen et al. (Web Release Apr. 18, 2001) "Synthetic Control of the Diameter and Length of Single Crystal Semiconductor Nanowires," *J. Phys. Chem.* B 105:4062-4064.

Guo et al. (Aug. 19, 2002) "Metal-Insulator-Semiconductor Electrostatics of Carbon Nanotubes," *Appl. Phys. Lett. 81*(8):1486-1488.

Gur et al. (2005) "Air-Stable All-Inorganic Nanocrystal Solar Cells Processed from Solution," *Science 310*:462-465.

Gurbuz et al. (Jul. 2005) "Diamond Semiconductor Technology for RF Device Applications." *Solid State Electron*. 49(7): 1055-1070.

Haisma et al. (2002) "Contact Bonding, Including Direct-Binding in a Historical and Recent Context of Materials Science and Technology, Physics and Chemistry—Historical Review in a Broader Scope and Comparative Outlook," *Mater. Sci. Eng.* R 37:1-60.

Halik et al. (2004) "Low-Voltage Organic Transistors with an Amorphous Molecular Gate Dielectric," *Nature* 431 :963-966.

Hamedi et al. (May 2007) "Towards Woven Logic from Organic Electronic Fibres," *Nat. Mater. 6*:357-362.

Hamilton et al. (2004) "Field-Effect Mobility of Organic Polymer Thin-Film Transistors," *Chem. Mater*. 16:4699-4704.

Han et al. (2005) "Template-Free Directional Growth of Single-Walled Carbon Nanotues on a- and r-Plane Sapphire," *J. Am. Chem. Soc. 127*:5294-5295.

Harada et al. (2001) "Catalytic Amplification of the Soft Lithographic Patterning of Si. Nonelectrochemical Orthogonal Fabrication of Photoluminescent Porous Si Pixel Arrays," *J. Am. Chem. Soc. 123*:8709-8717.

Harkonen et al. (Jun. 8, 2006) "4 W Single-Transverse Mode VECSEL Utilizing Intra-Cavity Diamond Heat Spreader," *Electron Lett. 42*(12):693-694.

Hayase et al. (2001) "Photoangioplasty with Local Motexafin Lutetium Delivery Reduces Macrophages in a Rabbit Post-Balloon Injury Model," Cardiovascular Res. 49:449-455.

He et al. (2005) "Si Nanowire Bridges in Microtrenches: Integration of Growth into Device Fabrication," *Adv. Mater. 17*:2098-2102.

Heffelfinger et al. (1997) "Steps and the structure of the (0001) α-alumina surface," Surf. Sci., 370:L168-L172.

Hillbrog et al. (Web Release Dec. 30, 2003) "Nanoscale Hydrophobic Recovery: Chemical Force Microscopy Study of UV/Ozone-Treated Cross-Linker Poly(dimethylsiloxane)," *Langmuir 20*(3):785-794.

Hines et al. (2005) "Nanotransfer Printing of Organic and Carbon Nanotube Thin-Film Transistors on Plastic Substrates," *Appl. Phys. Lett. 86*:163101.

Hollenberg et al. (2006) "A MEMS Fabricated Flexible Electrode Array for Recording Surface Field Potentials," J. Neurosci. Methods 153:147-153.

Holmes et al. (Feb. 25, 2000) "Control of Thickness and Orientation of Solution-Grown Silicon Nanowires," *Science 287*:1471-1473.

Horan et al. (Jun. 2005) "In Vitro Degradation of Silk Fibroin," Biomaterials 26(17):3385-3393.

Horn et al. (1992) "Contact Electrification and Adhesion Between Dissimilar Materials," *Science 256*:362-364.

Hoyer, P. (1996) "Semiconductor Nanotube Formation by a Two-Step Template Process," *Adv. Mater. 8*:857-859.

Hsia et al. (2005) "Collapse of Stamps for Soft Lithography Due to Interfacial Adhesion," *Appl. Phys. Lett. 86*:154106.

Hsu et al. (2002) "Amorphous Si TFTs on Plastically Deformed Spherical Domes," *J. Non-Crystalline Solids* 299-302: 1355-1359.

Hsu et al. (2003) "Nature of Electrical Contacts in a Metal-Molecule-Semiconductor System," *J. Vac. Sci. Technol.* B 21(4):1928-1935.

Hsu et al. (2004) "Effects of Mechanical Strain on TFTs on Spherical Domes," *IEEE Trans. Electron. Dev*. 51 :371-377.

Hsu et al. (Jan. 15, 2004) "Spherical Deformation of Compliant Substrates with Semiconductor Device Islands," *J. Appl. Phys. 95*(2):705-712.

Hsu et al. (Mar. 2004) "Effects of Mechanical Strain on TFT's on Spherical Domes," IEEE Trans. Electron Dev. 51(3):371-377.

Hu et al. (1997) "Using Soft Lithography to Fabricate GaAs/AlGaAs Heterostructure Field Effect Transistors," *Appl. Phys. Lett.* 71 :2020-2022.

Hu et al. (1999) Chemistry and Physics in One Dimension: Synthesis and Properties of Nanowires and Nanotubes, *Ace. Chem. Res. 32*:435-445.

Hu et al. (2004) "Percolation in Transparent and Conducting Carbon Nanotube Networks," Nano Lett., vol. 4, No. 12, pp. 2513-2517.

Hu et al. (2009) "Highly Conductive Paper for Energy-Storage Devices," Proc. Natl. Acad. Sci. USA 106:21490-21494.

Hu et al. (2010) "Stretchable, Porous, and Conductive Energy Textiles," Nano Lett. 10:708-714.

Huang et al. (2001) "Directed Assembly of One-Dimensional Nanostructures into Functional Networks," *Science* 291 :630-633.

Huang et al. (2001) "Room-Temperature Ultraviolet Nanowire Nanolasers," Science 292:1897-1899.

Huang et al. (2003) "Growth of Millimeter-Long and Horizontally Aligned Single-Walled Carbon Nanotubes on Flat Substrates," J. Am. Chem. Soc., 125:5636-5637.

Huang et al. (2004) "Long and Oriented Single-Walled Carbon Nanotubes Grown by Ethanol Chemical Vapor Deposition," J. Phys. Chem. B. 108:16451-16456.

Huang et al. (2004) "Self-Organizing High-Density Single-Walled Carbon Nanotube Arrays from Surfactant Suspensions," Nanotechnol. 15:1450-1454.

Huang et al. (2005) "Nanomechanical Architecture of Strained Bilayer Thin Films: From Design Principles to Experimental Fabrication," *Adv. Mater. 17*(23):2860-2864.

Huang et al. (2005) "Nanowires for Integrated Multicolor Nanophotonics," *Small* 1(1):142-147.

Huang et al. (2005) "Nonlinear Analyses of Wrinkles in a Film Bonded to a Compliant Substrate," *J. Mech. Phys. Solids 53*:2101-2118.

Huang et al. (2005) "Stamp Collapse in Soft Lithography," *Langmuir* 21 :8058-8068.

Huang et al. (Jan. 16, 2001) "Catalytic Growth of Zinc Oxide Nanowires by Vapor Transport," *Adv. Mater. 13*(2):113-116.

Huck et al. (2000) "Ordering of Spontaneously Formed Buckles on Planar Surfaces," *Langmuir 16*:3497-3501.

Huie, J.C. (2003) "Guided Molecular Self-Assembly: A Review of Recent Efforts," *Smart Mater. Struct. 12*:264-271.

Huitema et al. (2001) "Plastic Transistors in Active-Matrix Displays," *Nature 414*:599.

Hur et al. (2005) "Organic Nanodelectrics for Low Voltage Carbon Nanotube Thin Film Transistors and Complementary Logc Gates," *J. Am. Chem. Soc. 127*:13808-13809.

Hur et al. (2005) "Printed thin-film transistors and complementary logic gates that use polymer-coated single-walled carbon nanotube networks," J. Appl. Phys., 98, 114302.

Hur et al. (Dec. 2004) "Nanotransfer Printing by Use of Noncovalent Surface Forces: Applications to Thin-Film Transistors that Use Single-Walled Carbon Nanotube Networks and Semiconducting Polymers," *Appl. Phys. Lett. 85*(23):5730-5732.

(56) **References Cited**

OTHER PUBLICATIONS

Hur et al. (Jun. 13, 2005) "Extreme Bendability of Single Walled Carbon Nanotube Networks Transferred From High-Temperature Growth Substrates to Plastic and Their Use in Thin-Film Transistors," *Appl. Phys. Lett. 243502*.

Hutchinson et al. (1992) "Mixed Mode Cracking in Layered Materials," *Adv. Appl. Mech. 29*:63-191.

Imparato et al. (2005) "Excimer Laser Induced Crystallization of Amorphous Silicon on Flexible Polymer Substrates," *Thin Solid Films 487*:58-62.

International Preliminary Report on Patentability for PCT Application PCT/US2009/067670, mailed Jun. 14, 2011.

International Preliminary Report on Patentability for PCT Application PCT/US2010/051196, mailed Apr. 12, 2012.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/2005/014449, Mailed Jul. 3, 2008.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US 07/77759, Mailed Apr. 11, 2008.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US10/50468, Mailed Jan. 6, 2011.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US10/60425, Mailed May 25, 2011.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US07/74293, Mailed Jul. 24, 2008.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US07/77217, Mailed Jun. 3, 2008.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US07/82633, Mailed May 16, 2008.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US09/47442, Mailed Sep. 21, 2009.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US2006/032125, Mailed Mar. 21, 2008.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US2009/036192, Mailed Jul. 6, 2009.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US2009/058231, Mailed Nov. 17, 2009.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US2010/027209, Mailed Nov. 11, 2010.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US2010/034520, Mailed Sep. 24, 2010.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US2010/042585, Mailed May 25, 2011.

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US2011/028094, Mailed Jul. 14, 2011.

International Search Report and Written Opinion, Corresponding to International PCT Application No. PCT/US2006/021161, Mailed Feb. 28, 2008.

International Search Report and Written Opinion, Corresponding to International PCT Application No. PCT/US2007/077759, Mailed Apr. 11, 2008.

International Search Report and Written Opinion, Corresponding to International PCT Application No. PCT/US2007/079070, Mailed Apr. 23, 2008.

International Search Report and Written Opinion, Corresponding to International PCT US2010/061151.

International Search Report and Written Opinion, Corresponding to International PCT Application No. PCT/US05/19354 Mailed Apr. 18, 2007.

International Search Report Corresponding to International Application No. PCT/US2009/036956, mailed Jun. 29, 2009.

International Search Report, Corresponding to International Application No. PCT/US2009/059892, mailed Jan. 7, 2010.

International Search Report, Corresponding to International Application No. PCT/US2009/064199, mailed May 20, 2011.

International Search Report, Corresponding to International Application No. PCT/US2009/065806, mailed Jun. 1, 2010.

International Search Report, Corresponding to International Application No. PCT/US2009/067670, mailed Aug. 4, 2010.

International Search Report, Corresponding to International Application No. PCT/US2010/020742, mailed Sep. 14, 2010.

International Search Report, Corresponding to International Application No. PCT/US2010/051196, mailed Dec. 1, 2010.

International Search Report Corresponding to International Application No. PCT/US2011/031648, mailed Dec. 15, 2011.

Isberg et al. (Sep. 6, 2002) "High Carrier Mobility in Single-Crystal Plasma-Deposited Diamond," *Science 297*:1670-1672.

Islam et al. (Jan. 16, 2003) "High Weight Fraction Surfactant Solubilization of Single-Wall Carbon Nanotubes in Water," *Nano Lett. 3*(2):269-273.

Ismach et al. (2004) "Atomic-Step-Templated Formation or a Single Wall Carbon Nanotube Patterns," *Angew. Chem. Int. Ed. 43*:6140-6143.

Itoh et al. (1991) "Cathodoluminescence Properties of Undoped and Zn-Doped Al$_x$Ga$_{1-x}$N Grown by Metaloganic Vapor Phase Epitaxy," *Jap. J. Appl. Phys*. 30: 1604-1608.

Jabbour et al. (2001) "Screen Printing for the Fabrication of Organic Light-Emitting Devices," *IEEE J. Select. Top. Quantum. Electron. 7*(5):769-773.

Jackman et al. (Aug. 4, 1995) "Fabrication of Submicrometer Features on Curved Substrates by Microcontact Printing," *Science 269*:664-666.

Jacobs et al. (2001) "Submicrometer Patterning of Charge in Thin-Film Electrets," Science 291:1763-1766.

Jacobs et al. (2002) "Fabrication of a Cylindrical Display by Patterned Assembly," *Science 296*:323-325.

Jain et al. (2000) "III-Nitrides: Growth, Characterization, and Properties," *J. Appl. Phys.87*:965-1006.

Jain et al. (2005) "Flexible Electronics and Displays: High-Resolution, Roll-to-Roll, Projection Lithography and Photoblation processing Technologies for Hiogh- Throughput Production," *Proc. IEEE 93*:1500-1510.

James et al. (1998) "Patterned Protein Layers on Solid Substrates by This Stamp Microcontact Printing," *Langmuir 14*:742-744.

Jang et al. (2003) "Lateral Growth of Aligned Multiwalled Carbon Nanotubes Under Electric Fiels," Solid State Commun. 126:305-308.

Jang et al. (2006) "Low-Voltage and High-Field-Effect Mobility Organic Transistors with a Polymer Insulator," *Appl. Phys. Lett. 88*:072101.

Javey et al. (2002) "High-K Dielectrics for Advanced Carbon-Nanotube Transistors and Logic Gates," *Nature Mater*. 1:241-246.

Javey et al. (2005) "High Performance n-Type Carbon Nanotube Field-Effect Transistors with Chemically Doped Contacts," Nano Lett., vol. 5, No. 2, pp. 345-348.

Javey et al. (Aug. 7, 2003) "Ballistic Carbon Nanotube Field-Effect Transistors," *Nature 424*:654-657.

Jenkins et al. (1994) "Gallium Arsenide Transistors: Realization Through a Molecularly Designed Insulator," *Science 263*:1751-1753.

Jeon et al. (1995) "Patterning of Dielectric Oxide Thin Layers by Microcontact Printing of Self-Assembled Monolayers," *J. Mater. Res. 10*:2996-2999.

Jeon et al. (2003) "Structural and Mechanical Properties of Woven Fabrics Employing Peirce's Model," Textile Res. J. 73:929-933.

Jeon et al. (2004) "Fabricating Complex Three-Dimensional Nanostructures with High Resolution Conformable Phase Masks," *Proc. Natl. Acad. Sci. USA 101*:12428-12433.

Jeon et al. (2004) "Three Dimensional Nanofabrication with Arubber Stamps and Conformable Photomasks," Adv. Mater. 16:593-600.

(56) **References Cited**

OTHER PUBLICATIONS

Jeon et al. (Aug. 4, 2004) "Three Dimensional Nanofabrication with Rubber Stamps and Conformable Photomasks," *Adv. Mater. 16*(15):1369-1373.

Jiang et a. (Oct. 2, 2007) "Finite Deformation Mechanics in Buckled Thin Films on Compliant.Supports," *Proc. Natl. Acad. Sci. USA 104*(40):15607-15612.

Jiang et al. (1999) "Preparation of Macroporous Metal Films from Colloidal Crystals," *J. Am. Chem. Soc.* 121 :7957-7958.

Jiang et al. (2002) "Polymer-on-Polymer Stamping: Universal Approaches to Chemically Patterned Surfaces," *Langmuir 18*:2607-2615.

Jiang et al. (2007) "Mechanical Properties of Robust Ultrathin Silk Fibroin Films," Adv. Funct. Mater. 17:2229-2237.

Jin et al. (2004) "Scalable Interconnection and Integration of Nanowire Devices Without Registration," *Nano Lett. 4*:915-919.

Jin et al. (2004) "Soft Lithographic Fabrication of an Image Senbsor Array on a Curved Substrate," *J. Vac. Sci. Technol.* B 22:2548-2551.

Jin et al. (Aug. 2005) "Water-Stable Silk Films with Reduced β-Sheet Content," Adv. Funct. Mater. 15(8):1241-1247.

Jin et al. (Web Release Jan. 23, 2004) "Biomaterial Films of Bombyx mori Silk Fibroin with Poly(ethylene oxide)," Biomacromolecules 5(3):711-717.

Jiyun, C.H. (2003) "Guided Molecular Self-Assembly: A Review of Recent Efforts," Smart Mater. Struct. 12:264-271.

Joachim et al. (Nov. 30, 2000) "Electronics Using Hybrid-Molecular and Mono-Molecular Devices," *Nature 408*:541-548.

Johnson et al. (1999) "Ordered Mesoporous Polymers of Tunable Pore Size from Colloidal Silica Templates," *Science 283*:963-965.

Jones et al. (Jul./Aug. 2004) "Stretchable Wavy Metal Interconnects," *J. Vac. Sci. Technol. A 22*(4):1723-1725.

Joo et al. (2006) "Low-Temperature Solution-Phase Synthesis of Quantum Well Structures CdSe Nanoribbons," *J. Am. Chem. Soc. 128*(17):5632-5633.

Jortner et al. (2002) "Nanostructured Advanced Materials Perspectives and Directions," *Pure Appl. Chem. 74*(9):1491-1506.

Joselevich (2002) "Vectorial Growth of Metallic and Semiconducting Single-Wall Carbon Nanotubes," Nano Lett., vol. 2, No. 10, pp. 1137-1141.

Kadish et al. (1988) "Interaction of Fiber Orientation and Direction of Impulse Propagation with Anatomic Barriers in Anisotropic Canine Myocardium," Circulation. 78:1478-1494.

Kagan (1999) "Organic-Inorganic Hybrid Materials as Semiconducting Channels in Thin-Film Field-Effect Transistors," *Science 286*:945-947.

Kagan et al. (2001) "Patterning Organic-Inorganic Thin-Film Transistors Using Microcontact Printed Templates," *Appl. Phvs Lett. 79*(21):3536-3538.

Kagan et al. (2003) "Thin Film Transistors—A Historical Perspective," In; *Thin Film Transistors*, Dekker, New York, pp. 1-34.

Kane et al. (2000) "Analog and Digital Circuits Using Organic Thin-Film Transistors on Polyester Substrates," *IEEE Electron. Dev. Lett.* 21 :534-536.

Kang et al. (2007) "High-Performance Electronics Using Dense, Perfectly Aligned Arrays of Single-Walled Carbon Nanotubes," *Nat. Nanotechnol. 2*:230-236.

Kang et al. (2007) "Printed Multilayer Superstructures of Aligned Single-Walled Carbon Nanotubes for Electronic Applications," Nano Lett. 7(11):3343-3348.

Kar et al. (Web Release Feb. 18, 2006) "Shape Selective Growth of CdS One-Dimensional.Nanostructures by a Thermal Evaporation Process," *J. Phys. Chem.* B. 110(10):4542-4547.

Kar et al. (Web Release Feb. 8, 2005) "Controlled Synthesis and Photoluminescence Properties of ZnS Nanowires and Nanoribbons," *J. Phys. Chem.* B 109(8):3298-3302.

Kar et al. (Web Release Sep. 28, 2005) "Synthesis and Optical Properties ofCdS Nanoribbons," *J. Phys. Chem* B. 109(41):19134-19138.

Karnik et al. (2003) "Lateral Polysilicon p$^+$-p-n$^+$ and p$^+$-n-n$^+$ Diodes," *Solid-State Electronics 47*:653-659.

Karnik et al. (2003) "Multiple Lateral Polysilicon Diodes as Temperature Sensors for Chemical Microreaction Systems," *Jpn. J. Appl. Phys. 42*:1200-1205.

Kato et al. (2004) The Characteristic Improvement of Si(111) Metal-Oxide-Semiconductor Field-Effect Transistor by Long-Time Hydrogen Annealing, *Jpn. J. Appl. Phys*. 43(10):6848-6853.

Katz et al. (2001) "Synthetic Chemistry for Ultrapure, Processable, and High-Mobility Organic.Transistor Semiconductors," *Ace. Chem. Res. 34*:359-369.

Katz, H.E. (2004) "Recent Advances in Semiconductor Performance and Printing Processes for Organic Transistor-Based Electronics," *Chem. Mater. 16*:4748-4756.

Kawata et al. (2001) "Finer Features for Functional Microdevices," *Nature 412*:697- 698.

Kellis et al. (2009) "Human Neocortical Electrical Activity Recorded on Nonpenetrating Microwire Arrays: Applicability for Neuroprostheses," Neurosurg. Focus 27(1):E9.

Kendall, D.L. (1979) "Vertical Etching of Silicon at Very High Apect Ratios," *Ann. Rev. Mater. Sci. 9*:373-403.

Khakani et al. (2006) "Lateral Growth of Single Wall Carbon Nanotubes on Various Substrates by Means of an 'All-Laser' Synthesis Approach," Diamond Relat. Mater. 15:1064-1069.

Khan et al. (1993) "High Electron Mobility Transistor Based on a GaN—Al$_x$Ga$_{1-x}$N Heterojunction," *Appl. Phys. Lett. 63*:1214-1215.

Khang et al. (2006) "A Stretchable Form of Single-Crystal Silicon for High-Performance Electronics on Rubber Substraights," *Science* 311 :208-212.

Kilby, J.S. (1976) "Invention of the Integrated Circuit," *IEEE Trans. Electron. Dev* 23:648-654.

Kim et al. (2000) "Field Emission from Carbon Nanotubes for Displays," *Diamond and Related Mater*. 9(3-6): 1184-1189.

Kim et al. (2002) "Nanolithography Based on Patterned Metal Transfer and its Application to Organic Electronic Devices," *Appl. Phys. Lett. 80*:4051-4053.

Kim et al. (2003) "Epitaxial self-assembly of block copolymers on lithographically defined nanopatterned substrates," *Nature 424*:411-414.

Kim et al. (2008) "Materials and Noncoplanar Mesh Designs for Integrated Circuits with Linear Elastic Responses to Extreme Mechanical Deformations," *Proc. Natl. Acad. Sci. USA 105*(48):18675-18680.

Kim et al. (2008) "Stretchable and Foldable Silicon Integrated Circuits," *Science 320*:507-511.

Kim et al. (2008) "Stretchable Electronics: Materials Strategies and Devices," Adv. Mater. 20:4887-4892.

Kim et al. (2009) "Integrated Wireless Neural Interface Based on the Utah Electrode array," Biomed. Microdevices 11:453-466.

Kim et al. (2009) "Optimized Structural Designs for Stretchable Silicon Integrated Circuits," Small 5(24):2841-2847.

Kim et al. (Dec. 2, 2008) "Materials and Noncoplanar Mesh Designs for Integrated Circuits with Linear Elastic Responses to Extreme Mechanical Deformations," Proc. Natl. Acad. Sci. USA 105(48):18675-18680.

Kim et al. (Jan. 2008) "Complementary Logic Gates and Ring Oscillators Plastic Substrates by Use of Printed Ribbons Single-Crystalline Silicon," *IEEE Electron. Dev. Lett. 29*(1):73-76.

Kim et al. (Nov. 15, 1999) "Direct Observation of Electron Emission Site on Boron- Doped Polycrystalline Diamond Thin Films Using an Ultra-High-Vacuum Scanning Tunneling Microscope," *Appl. Phys. Lett. 75*(20):3219-3221.

Kim et al. (Oct. 17, 2010) "Waterproof AlInGaP optoelectronics on stretchable substrates with applications in biomedicine and robotics," Nature Materials 9:929-937.

Kim et al. (Oct. 2004) "Organic TFT Array on a Paper Substrate," *IEEE Electron. Dev.Lett. 25*(10):702-704.

Kim et al. (Web Release Apr. 18, 2010) "Dissolvable Films of Silk Fibroin for Ultrathin Conformal Bio-Integrated Electronics," Nature Materials 9:511-517.

Kim et al. (Web Release Feb. 29, 2008) "Highly Emissive Self-Assembled Organic Nanoparticles Having Dual Color Capacity for Targeted Immunofluorescence Labeling," *Adv. Mater. 20*(6):1117-1121.

(56) **References Cited**

OTHER PUBLICATIONS

Kim et al. (Web Release Jul. 31, 2008) "Complementary Metal Oxide Silicon Integrated Circuits Incorporating Monolithically Integrated Stretchable Wavy Interconnects," Appl. Phys. Lett. 93(4):044102.

Kim et al. (Web Release Jul. 6, 2009) "Ultrathin Silicon Circuits with Strain-Isolation Layers and Mesh Layouts for High-Performance Electronics on Fabric, Vinyl, Leather and Paper," *Adv. Mater.* 21 (36):3703-3707.

Kim et al. (Web Release Sep. 29, 2009) "Silicon Electronics on Silk as a Path to Bioresorbable, Implantable Devices," Appl. Phys. Lett. 95:133701-133703.

Kim et al., (2008) "Complimentary Metal Oxide Silicon Integrated Circuits Incorporating Monolithically Integrated Stretchable Wavy Interconnects," Appl Phys Lett, 93:044102.

Kim, Y.S. (Web Release Aug. 9, 2005) "Microheater-Integrated Single Gas Sensor Array Chip Fabricated on Flexible Polyimide Substrate," *Sens. Actuators* B 114(1):410-417.

Klauk et al. (2002) "High-Mobility Polymer Gate Dielectric Pentacene Thin Film Transistors," *J. Appl. Phys. 92*:5259-5263.

Klein-Wiele et al. (2003) "Fabrication of Periodic Nanostructures by Phase-Controlled Multiple-Beam Interference," *Appl. Phys. Lett. 83*(23):4707-4709.

Knipp et al. (2003) "Pentacine Thin Film Transistors on Inorganic Dielectrics: Morphology, Structural Properties, and Electronic Transport," *J Appl. Phys. 93*:347-355.

Ko et al. (2006) "Bulk Quantities of Single-Crystal Silicon Micro-/ Nanoribbons Generated from Bulk Wafers," *Nano Lett. 6*(10):2318-2324.

Ko et al. (2008) "A Hemispherical Electronic Eye Camera Based on Compressible Silicon Optoelectronics," *Nature 454*:748-753.

Ko et al. (2010) "Flexible Carbon Nanofiber Connectors with Anisotropic Adhesion Properties," Small 6:22-26.

Ko et al. (Web Release Oct. 28, 2009) "Curvilinear Electronics Formed Using Silicon Membrane Circuits and Elastomeric Transfer Elements," *Small* 5(23):2703-2709.

Kocabas et al. (2004) "Aligned Arrays of Single-Walled Carbon Nanotubes Generated from Random Networks by Orientationally Selective Laser Ablation," Nano Lett., vol. 4, No. 12, pp. 2421-2426.

Kocabas et al. (2005) "Guided Growth of Large-Scale, Horizontally Aligned Arrays of Single-Walled Carbon Nanotubes and Their Use in Thin-Film Transstors," *Small* 1(11): 111 0-1116.

Kocabas et al. (2006) "Spatially Selective Guided Growth of High-Coverage Arrays and Random Networks of Single-Walled Carbon Nanotbes and Thir Integration into Electronic Devices," *J. Am. Chem. Soc. 128*:4540-4541.

Kocabas et al. (2006) "Large Area Aligned Arrays of SWNTs for High Performance Thin Film Transistors," American Physical Society, APS March Meeting, Mar. 13-17, Abstract # W31.004.

Kocabas et al. (2007) "Experimental and Theoretical Studies of Transport Through Large Scale, Partially Aligned Arrays of Single-Walled Carbon Nanotubes ni Thin Film Type Transistors," Nano Lett. 7(5):1195-1202.

Kocabas et al. (Feb. 5, 2008) "Radio Frequency Analog Electronics Based on Carbon Nanotube Transistors," *Proc. Natl. Acad. Sci. USA 105*(5):1405-1409.

Kodambaka et al. (2006) "Control of Si Nanowire Growth by Oxygen," *Nano Lett.* 6(6):1292-1296.

Koide et al. (2000) "Patterned Luminescence of Organic Light-Emitting Diodes by Hot Microcontact Printing (H1JCP) of Self-Assembled Monolayers," *J. Am. Chem. Soc.* 122:11266-11267.

Konagai et al. (1978) "High Efficiency GaAs Thin Film Solar Cells by Peeled Film Technology," *J. Cryst. Growth 45*:277-280.

Kong et al. (2004) "Single-Crystal Nanorings Formed by Epitaxial Self-Coiling of Polar Nanobelts," *Science* 303: 1348-1351.

Kong et al. (Jan. 28, 2000) "Nanotube Molecular Wires as Chemical Sensors," *Science 287*:622-625.

Kong et al. (Oct. 2003) "Structure of Indium Oxide Nanobelts," *Solid State Commun.* 128(1): 1-4.

Kong et al. (Oct. 29, 1998) "Synthesis of Individual Single-Walled Carbon Nanotubes on Patterned Silicon Wafers," *Nature 395*:878-881.

Kudo et al. (Web Release Jun. 13, 2006) "A Flexible and Wearable Glucose Sensor Based on Functional Polymers with Soft-MEMS Techniques," *Biosens. Bioelectron.* 22:558-562.

Kulkarni et al. (2002) "Mesoscale Organization of Metal Nanocrystals," *Pure Appl. Chem 74*(9):1581-1591.

Kumar et al. (1993) "Features of Gold Having Micrometer to Centimeter Dimensions can be Formed Through a Combination of Stamping with an Elastomeric Stamp and an Alkanethiol "Ink" Followed by Chemical Etching," *Appl. Phys. Lett. 63*(14):2002-2004.

Kumar et al. (1994) "Patterninq Self-Assembled Monolavers: Applications in Material Science," *Langmuir 10*:1498-1511.

Kumar et al. (2002) "Thermally-Stable Low-Resistance Ti/Al/Mo/Au Multilayer Ohmic Contacts on n-GaN," *J. Appl. Phys. 92*:1712-1714.

Kumar et al. (2005) "Percolating in Finite Nanotube Networks," Phys. Rev. Lett., 95, 066802.

Kuo et al. (1985) "Effect of Mismatch Strain on Band Gap in III-V Semiconductors," *J. Appl. Phys. 57*:5428-5432.

Kuykendall et al. (Aug. 2004) "Crystallographic Alignment of High Density Gallium Nitride Nanowire Arrays," *Nat. Mater. 3*:524-528.

Lacour et al. (2003) "Stretchable Gold Conductors on Elastomeric Substrates," *Appl. Phys. Lett. 82*(15):2404-2406.

Lacour et al. (2005) "Stretchable Interconnects for Elastic Electronic Surfaces," *Proc.IEEE 93*(8):1459-1467.

Lacour et al. (2010) "Flexible and Stretchable Micro-Electrodes for in Vitro and n Vivo Neural Interfaces," Med. Biol. Eng. Comput. 48:945-954.

Lacour et al. (Apr. 2004) "Design and Performance of Thin Metal Film Interconnects for Skin-Like Electronic Circuits," *IEEE Electron. Dev. Lett. 25*(4):179-181.

Lacour et al. (Dec. 2004) "An Elastically Stretchable TFT Circuit," *IEEE Electron Dev. Lett. 25*(12):792-794.

Lacour et al. (Web Release Jul. 14, 2006) "Stiff Subcircuit Islands of Diamondlike Carbon for Stretchable Electronics," *J. Appl. Phys. 100*:014913.

Lacour et al. (Web Release May 16, 2006) "Mechanisms of Reversible Stretchability of Thin Metal Films on Elastomeric Substrates," *Appl. Phys. Lett.* 88:204103.

Laimer et al. (Mar. 1997) "Diamond Growth in a Direct-Current Low-Pressure Supersonic Plasmajet," *Diamond Relat. Mater.* 6:406-410.

Lambacher et al. (2004) "Electrical Imaging of Neuronal Activity by Multi-Transistor-Array (MTA) Recording at 7.8 μm Resolution," *Appl. Phys. A 79*:1607-1611.

Landes et al. (2002) "Some Properties of Spherical and Rod-Shaped Semiconductorand Metal Nanocrystals," *Pure Appl. Chem. 74*(9):1675-1692.

Law et al. (2004) "Semiconductor Nanowires and Nanotubes," *Ann. Rev. Mater. Res.*34:83-122.

Law et al. (Aug. 27, 2004) "Nanoribbon Waveguides for Subwavelength PhotonicsIntegration," *Science 305*:1269-1273.

Lawrence et al. (2008) "Bioactive Silk Protein Biomaterial Systems for Optical Devices," Biomacromolecules 9:1214-1220.

Lay et al. (2004) "Simple Route to Large-Scale Ordered Arrays of Liquid-Deposited Carbon Nanotubes," Nano Lett., vol. 4, No. 4, pp. 603-606.

Leclercq et al. (1998) "II I-V Micromachined Devices for Microsystems," *Microelectronics J. 29*:613-619.

Lecomte et al. (Apr. 2006) "Degradation Mechanism of Diethylene Glycol Units in aTerephthalate Polymer," *Polym. Degrade. Stab. 91*(4):681-689.

Lee et al. (2000) "Thin Film Transistors for Displays on Plastic Substrates," *Solid State Electron. 44*:1431-1434.

Lee et al. (2003) "High-Performance Poly-Si TFTs on Plastic Substrates Using a Nano-Structured Separation Layer Approach," *IEEE Elec. Dev. Lett. 24*: 19-21.

Lee et al. (2004)"Organic Light-Emitting Diodes Formed by Soft Contact Lamination," *Proc. Natl. Acad .Sci. USA 101*(2):429-433.

Lee et al. (2005) "A Printable Form of Single-Crystalline Gallium Nitride for Flexable Optoelectronic Systems," *Small* 1:1164-1168.

(56) References Cited

OTHER PUBLICATIONS

Lee et al. (2005) "Large-Area, Selective Transfer of Microstructured Silicon (ps-Si): A Printing-Based Approach to High-Performance Thin-Film Transistors Supported on Flexible Substraights," *Adv. Mater. 17*:2332-2336.

Lee et al. (2006) "Micron and Submicron Patterning of Polydimethylsiloxane Resists on Electronic Materials by Decal Transfer Lithography and Reactive Ion-Beam Etching: Application to the Fabrication of High-Mobility, Thin-Film Transistors," Journal of Applied Physics 100. 0894907 (2006).

Lee et al. (Apr. 2005) "Fabrication of Stable Metallic Patterns Embedded in Poly(dimethylsiloxane) and Model Applications in Non-Planar Electronic and Lab-on a-Chip Device Patterning," *Adv. Funct. Mater. 15*(4):557-566.

Lee et al. (Dec. 1999) "The Surface/Bulk Micromachining (SBM) Process: A New Method for Fabricating Released Mems in Single Crystal Silicon," *J. Microelectromech. Syst.* 8(4):409-416.

Lee et al. (Feb. 2001) "Application of Carbon Nanotubes to Field Emission Displays," *Diamond and Related Mater*. 10(2):265-270.

Lee et al. (Feb. 2005) "Weave Patterned Organic Transistors on Fiber for E-Textiles," *IEEE Trans. Electron. Dev. 52*(2):269-275.

Leong et al. (2009) "Tetherless Thermobiochemicall Actuated Microgrippers," Proc. Natl. Acad. Sci. USA 106:703-709.

Letant et al. (Jun. 2003) "Functionalized Silicon Membranes for Selective Bio-Organisms Capture," Nat. Mater. 2:391-395.

Li et al. (2002) "High-Resolution Contact Printing with Dendrimers," *Nano Lett.* 2(4):347-349.

Li et al. (2003) "Ultrathin Single-Crystalline-Silicon Cantilever Resonators: Fabrication Technology and Significant Specimen Size Effect on Young's Modulus," *Appl. Phys. Lett. 83*:3081-3083.

Li et al. (2004) "Electrospinning of Nanofibers: Reinventing the Wheel," *Adv. Mater.*16(14):1151-1170.

Li et al. (2006) "Catalyst-Assisted Formation of Nanocantilever Arrays on ZnS Nanoribbons by Post-Annealing Treatment," J. Phys. Chem. B 110(13):6759-6762.

Li et al. (Dec. 2005) "Compliant Thin Film Patterns of Stiff Materials as Platforms for Stretchable Electronics," *J. Mater. Res. 20*(12):3274-3277.

Li et al. (Jul. 1, 2002) "ZnO Nanobelts Grown on Si Substrate," *Appl. Phys. Lett.* 81 (1): 144-146.

Li et al. (Web Release Mar. 16, 2006) "Catalyst-Assisted Formation of Nanocantilever Arrays on ZnS Nanoribbons by Post-Annealing Treatment," *J. Phys. Chem. 8* 110(13):6759-6762.

Lieber, C. (2001) "The Incredible Shrinking Circuit," *Sci. Am. 285*(3):58-64.

Lieber, C.M. (2003) "Nanoscale Science and Technology: Building a Bog Future from Small Things," *MRS. 8ull. 28*:486-491.

Lim et al. (2005) "Flexible Membrance Pressure Sensor," *Sens. Act. A 119*:332-335.

Lima et al. (2007) "Creating Micro- and Nanostructures on Tubular and Spherical Surfaces,"J. *Vac. Sci. Technol. 825*(6):2412-2418.

Lin et al. (2005) "High-Performance Carbon Nanotube Field-Effect Transistor with Tunable Polarities," *IEEE Trans. Nano 4*(5):481-489.

Linder et al. (1994) "Fabrication Technology for Wafer Through-Hole Interconnections and Three-Dimensional Stacks of Chips and Wafers," *Proc. IEEE Micro. Electro Mech. Syst. 349-354*.

Ling et al. (2004) "Thin Film Deposition, Patterning, and Printing in Organic Thin Film Transistors," *Chem. Mater. 16*:4824-4840.

Liu et al. (1999) "Controlled deposition of individual single-walled carbon nanotubes on chemically functionalized templates," Chem. Phys. Lett., 303:125-129.

Long et al. (1990) "Heterostructure FETs and Bipolar Transistors," In; *Gallium Arsenide Digital Integrated Circuit Design*, McGraw-Hill, New York, pp. 58-69.

Loo et al. (2002) "Additive, Nanoscale Patterning of Metal Films with a Stamp and a Surface Chemistry Mediated Transfer Process: Applications in Plastic Electronics," *Appl. Physics Lett.* 81 :562-564.

Loo et al. (2002) "High-Resolution Transfer Printing on GaAs Surfaces Using Alkane Dithiol Monolavers," *J. Vac. Sci. Technol.* B 20(6):2853-2856.

Loo et al. (2002) "Interfacial Chemistries for Nanoscale Transfer Printing," *J. Am. Chem. Soc. 124*:7654-7655.

Loo et al. (2002) "Soft, Conformable Electrical Contacts for Organic Semiconductors: High-Resolution Plastic Circuits by Lamination," *Proc. Natl. Acad. Sci. USA* 99(16): 10252-1 0256.

Loo et al. (2003) "Electrical Contacts to Molecular Layers by Nanotransfer Printing," *Nano Lett. 3*(7):913-917.

Lopes et al. (Sep. 2004) "Thermal Conductivity of PET/(LDPE/AI) Composites Determined by MDSC," *Polym. Test.23*(6):637-643.

Lu et al. (Apr. 2010) "Water-Insoluble Silk Films with Silk I Structure," Acta Biomater. 6(4):1380-1387.

Lu et al. (Dec. 2006) "Electronic Materials-Buckling Down for Flexible Electronics," *Nat. Nanotechnol.* 1: 163-164.

Lu et al. (Jul. 19, 2005) "One Dimensional Hole Gas in Germanium/ Silicon Nanowire Heterostructures," *Proc. Nat. Acad. Sci. USA 102*(29):10046-10051.

Lu et al. (Nov. 2008) "Nanowire Transistor Performance Limits and Applications," *IEEE Trans Electron Dev*. 55(11):2859-2876.

Luan et al. (1992) "An Experimental Study of the Source/Drain Parasitic Resistance Effects in Amorphous Silicon Thin Film Transistors," *J. Appl. Phys. 72*:766-772.

Ma et al. (2004) "Single-Crystal CdSe Nanosaws," *J. Am. Chem. Soc. 126*(3):708-709.

Mack et al. (2006) "Mechanically Flexible Thin-Film Transistors that Use Ultrathin Ribbons of Silicon Derived from Bulk Wafers," *Appl. Phvs. Lett. 88*:213101.

Madou, M. (1997) "Etch-Stop Techniques," In; *Fundamentals of Microfabrication*, CRC Press, New York, pp. 193-199.

Maikap et al. (2004) "Mechanically Strained-Si NMOSFETs," *IEEE Electron. Dev. Lett*. 25:40-42.

Maldovan et al. (2004) "Diamond-Structured Photonic Crystals," *Nature Materials* 3:593-600.

Mandlik et al. (Aug. 2006) "Fully Elastic Interconnects on Nanopatterned Elastomeric Substrates," *IEEE Electron Dev. Lett. 27*(8):650-652.

Manna et al. (Web Release May 25, 2003) "Controlled Growth of Tetrapod-Branched Inorganic Nanocrystals," *Nat. Mater. 2*:382-385.

Markovich et al. (1999) "Architectonic Quantum Dot Solids," *Ace. Chem. Res. 32*:415-423.

Marquette et al. (2004) "Conducting Elastomer Surface Texturing: A Path to Electrode Spotting Application to the Biochip Production," *Biosens. Bioelectron. 20*:197-203.

Martensson et al. (2004) "Nanowire Arrays Defined by Nanoimprint Lithography," *Nano Lett. 4*:699-702.

Martin, C.R. (1995) "Template Synthesis of Electronically Conductive Polymer Nanostructures," *Ace. Chem. Res. 28*:61-68.

Mas-Torrent et al. (2006) "Large Photoresponsivity in High-Mobility Single-Crystal Organic Field-Effect Phototransistors," *ChemPhysChem 7*:86-88.

Masuda et al. (2000) "Fabrication of Ordered Diamonds/Metal Nanocomposite Structures," *Chem. Lett. 10*:1112-1113.

Matsunaga et al. (2003) "An Improved GaAs Device Model for the Simulation of Analog Integrated Circuit," *IEEE Trans. Elect. Dev. 50*:1194-1199.

McAlpine et al. (2003) "High-Performance Nanowire Electronics and Photonics on Glass and Plastic Substrates," *Nano Lett. 3*:1531-1535.

McAlpine et al. (2005) "High-Performance Nanowire Electronics and Photonics and Nanoscale Patterning on Flexible Plastic Substrates," *Proc. IEEE 93*:1357-1363.

McCaldin et al. (1971) "Diffusivity and Solubility of Si in the Al Metallization of Integrated Circuits," *Appl. Phys. Lett. 19*:524-527.

Mehring C. et al. (2003) Inference of hand movements from local field potentials in monkey motor cortex. Nature Neurosci. 6, 1253-1254.

Meisel et al. (2004) "Three-Dimensional Photonic Crystals by Holographic Lithography Using the Umbrella Configuration: Symmetries and Complete Photonic Band Gaps," *Phys. Rev*. B. 70:165101:1-10.

Meitl et al. (2004) "Solution Casting and Transfer Printing Single-Walled Carbon Nanotube Films," *Nano Lett. 4*(9):1643-1947.

Meitl et al. (2006) "Transfer Printing by Kinetic Control of Adhesion to an Elastomeric Stamp," *Nat. Mater. 5*:33-38.

(56) **References Cited**

OTHER PUBLICATIONS

Meitl et al. (Web Release Feb. 22, 2007) "Stress Focusing for Controlled Fracture in Microelectromechanical Systems," Appl. Phys. Lett. 90:083110.

Melosh et al. (2003) "Ultrahigh-Density Nanowire Lattices and Circuits," *Science 300*:112-115.

Menard et al. (2004) "A Printable Form of Silicon for High Performance Thin Film Transistors on Plastic Substrates," Appl. Phys. Lett. 84:5398-5400.

Menard et al. (2004) "High-Performance n- and p-Type Single-Crystal Organic Transistors with Free-Space Gate Dielectrics," Adv. Mat. 16:2097-2101.

Menard et al. (2004) "Improved Surface Chemistries, Thin Film Deposition Techniques, and Stamp Designs for Nanotransfer Printing," Langmuir 20:6871-6878.

Menard et al. (2005) Bendable Single Crystal Silicon Thin Film Transistors Formed by Printing on Plastic Substrates Appl. Phys. Lett. 86:093507.

Menard et al. (2007) Micro- and Nanopatterning Techniques for Organic Electronic and Optoelectronic Systems, Chem. Rev. 107:1117-1160.

Miao et al. (2003) "Micromachining of Three-Dimensional GaAs Membrane Structures Using High-Energy Nitrogen Implantation," J. Micromech. Microenq. 13:35-39.

Michalske et al. (1985) "Closure and Repropagation of Healed Cracks in Silicate Glass," J. Am. Ceram. Soc. 68:586-590.

Michel et al. (2001) Printing Meets Lithography: Soft Approaches to High-Resolution Patterning, IBM J. Res. Dev. 45(5):697-719.

Miller et al. (2002) "Direct Printing of Polymer Microstructures on Flat and Spherical Surfaces Using a Letterpress Technique," J. Vac. Sci. Technol. B 20(6):2320-2327.

Milliron et al. (2004) "Colloidal Nanocrystal Heterostructures with Linear and Branched Topoloqy," Nature 430:190-195.

Min, G. (Apr. 4, 2003) "Plastic Electronics and Their Packaging Technologies," *Syn. Metals. 135*:141-143.

Minev et al. (2010) "Impedance Spectroscopy on Stretchable Microelectrode Arrays," Appl. Phys. Lett. 97:043707.

Mirkin et al. (Jul. 2001) "Emerging Methods for Micro- and Nanofabrication," *MRS Bull. 26*(7):506-507.

Misewich et al. (May 2, 2003) "Electronically Induced Optical Emission from a Carbon Nanotube FET," Science 300:783-786.

Mishra et al. (2002) "AlGaN/GaN HEMTs—an Overview of Device Operation and Applications," Proc. IEEE 90:1022-1031.

Mitzi et al. (2004) "High-Mobility Ullthin Semiconducting Films Prepared by Spin Coating," Nature 428:299-303.

Moon et al. (2002) "Ink-Jet Printing of Binders for Ceramic Compinents," *J. Am. Ceram. Soc. 85*(4):755-762.

Moore et al. (Sep. 9, 2003) "Individually Suspended Single-Walled Carbon Nanotubes in Various Surfactants," Nano Lett. 3(10):1379-1382.

Morales et al. (Jan. 9, 1998) "A Laser Ablation Method for the Synthesis of Crystalline Semiconductor Nanowires," Science 279:208-211.

Morent et al. (2007) "Adhesion Enhancement by a Dielectric Barrier Discharge of PDMS used for Flexible and Stretchable Electronics," J. Phys. D. Appl. Phys. 40:7392-7401.

Mori et al. (1978) "A New Etching Solution System, H3PO4—H202—H20, for GaAs and Its Kinetics," J. Electrochem. Soc. 125:1510-1514.

Morkoc et al. (1995) "High-Luminosity Blue and Blue-Green Gallium Nitride Light-Emitting Diodes," Science 267:51-55.

Morkved et al. (1994) "Mesoscopic Self-Assembly of Gold Islands on Diblock-Copolymer Films," Appl. Phys. Lett. 64:422-424.

Morra et al. (1990) "On the Aging of Oxygen Plasma-Treated Polydimethylsiloxane Surfaces," J. Colloid Interface Sci. 137:11-24.

Murakami et al. (2005) "Polarization Dependence of the Optical Absorption of Single-Walled.Carbon Nanotubes," Phys. Rev. Lett., 94, 087402.

Murphy et al. (2008) "Modification of Silk Fibroin Using Diazonium Coupling Chemistry and the Effects on hMSC Proliferation and Differentiation," Biomaterials 29:2829-2838.

Namazu et al. (2000) "Evaluation of Size Effect on Mechanical Properties of Single Crystal Silicon by Nanoscale Bending Test Using AFM," J. MEMS 9:450-459.

Nanotube Films, *Nano Lett. 4*(9):1643-1947.

Nath et al. (2002) "Nanotubes of the Disulfides of Groups 4 and 5 Metals," *Pure Appl. Chem. 74*(9):1545-1552.

Nathan et al. (2000) "Amorphous Silicon Detector and Thin Film Transistor Technology for Large-Area Imaging of X-Rays,." Microelectron J. 31 :883-891.

Nathan et al. (2002) "Amorphous Silicon Technology for Large Area Digital X-Ray and Optical Imaging," Microelectronics Reliability 42:735-746.

Newman et al. (2004) "Introduction to Organic Thin Film Transistors and Design of n-Channel Organic Semiconductors," Chem. Mater. 16:4436-4451.

Nirmal et al. (1999) "Luminescence Photophysics in Semiconductor Nanocrystals," Ace. Chem. Res. 32:407-414.

Noda et al. (1996) "New Realization Method for Three-Dimensional Photonic Crystal in Optical Wavelength Region," Jpn. J. Appl. Phys. 35:L909-L912.

Nomura et al. (2004) "Room-Temperature Fabrication of Transparent Flexible Thin-Film Transistors Using Oxide Semiconductors," Nature 432:488-492.

Notice of Allowance, Corresponding to U.S. Appl. No. 11/423,287, Mailed Jan. 12, 2009.

Notice of Allowance, Corresponding to U.S. Appl. No. 12/723,475, mailed on Oct. 14, 2011.

Notice of Allowance, U.S. Appl. No. 11/851,182, mailed Feb. 16, 2012.

Notice of Allowance, U.S. Appl. No. 12/405,475, mailed Mar. 1, 2012.

Notification Concerning Transmittal of International Preliminary Report on Patentability, Corresponding to International Application No. PCT/US2009/059892, mailed Jan. 7, 2011.

Notification Concerning Transmittal of International Preliminary Report on Patentability, Corresponding to International Application No. PCT/US2009/064199, mailed May 17, 2011.

Novoselov et al. (Oct. 22, 2004) "Electric Field Effect in Atomically Thin Carbon Films," Science 306:666-669.

O'Riordan et al. (2004) "Field Configured Assembly: Programmed Manipulation and Self-Assembly at the Mesoscale," Nano Lett. 4:761-765.

O'Connell et al. (Jul. 26, 2002) "Band Gap Fluorescence from Individual Single-Walled Caarbon Nanotubes," Science 297:593-596.

Odom et al. (2002) "Improved Pattern Transfer in Soft Lithography Using Compasite Stamps," Langmuir 18:5314-5320.

Office Action and Response, Corresponding to Malaysian Patent Publication No. PI 20052553, Mailed Mar. 13, 2009 and Dec. 8, 2009.

Office Action and Response, Corresponding to U.S. Appl. No. 11/423,287, Mailed Feb. 13, 2008.

Office Action and Response, Corresponding to U.S. Appl. No. 11/421,654, Mailed Sep. 29, 2009.

Office Action and Response, Corresponding to U.S. Appl. No. 11/858,788, Mailed Beginning Jan. 28, 2011.

Office Action Corresponding to Chinese Patent Application No. 200780041127.6, issued Apr. 8, 2011.

Office Action Corresponding to Chinese Patent Application No. 200780049982.1, Issued May 12, 2010.

Office Action Corresponding to European Patent Application No. 05755193.9, issued Jul. 12, 2011.

Office Action, Corresponding to Chinese Paten Application No. 200580013574.1, Issued May 11, 2010.

Office Action, Corresponding to Taiwan Patent Application No. 095121212, Issued May 7, 2010.

Office Action, Corresponding to U.S. Appl. No. 11/423,287, Mailed Feb. 13, 2008.

Office Action, Corresponding to U.S. Appl. No. 12,686,076.

Office Action, Corresponding to U.S. Appl. No. 11/851,182, Mailed Apr. 1, 2010.

(56) **References Cited**

OTHER PUBLICATIONS

Office Action, Corresponding to U.S. Appl. No. 11/851,182, Mailed Jun. 7, 2011.

Office Action, Corresponding to U.S. Appl. No. 11/421,654, Mailed Sep. 23, 2010.

Office Action, Corresponding to U.S. Appl. No. 11/981,380, Mailed Sep. 23, 2010.

Office Actions, Corresponding to Chinese Patent Application No. 200580018159.5, Issued Jan. 23, 2009 and Feb. 12, 2010.

Office Actions, Corresponding to U.S. Appl. No. 11/145,542, Mailed between Apr. 5, 2007 and Dec. 23, 2008.

Office Action, Corresponding to U.S. Appl. No. 12/616,922, mailed Apr. 9, 2012.

Office Action, Corresponding to U.S. Appl. No. 12/636,071, mailed Jun. 6, 2012.

Ohzono et al. (Web Release Jul. 7,2005) "Geometry-Dependent Stripe Rearrangement Processes Induced by Strain on Preordered Microwrinkle Patterns," Langmuir 21(16):7230-7237.

Omenetto et al. (2008) "A New Route for Silk," Nature Photon. 2:641-643.

Ong et al. (2004) "High-Performance Semiconducting Poolythiophenes for Organic Thin-Film Transistors," J. Am. Chem. Soc. 126:3378-3379.

Ong et al. (2005) "Design of High-Performance Regioreular Polythiophenes for Organic Thin-Film Transistors," Proc. IEEE 93:1412-1419.

Origin Energy (May 2004) "Fact Sheet—Sliver Cells," www.oriqinenergY.com.au/sliver Ouyang et al. (2002) "High-Performance, Flexible Polymer Light-Emitting Diodes Fabricated by a Continuous Polymer Coating Process," Adv. Mat. 14:915-918.

Ouyang et al. (2002) "High-Performance, Flexible Polymer Light-Emitting Diodes Fabricated by a Continuous Polymer Coating Process," Adv. Mat. 14:915-918.

Ouyang et al. (2008) "High Frequency Properties of Electro-Textiles for Wearable Antenna Applications," IEEE Trans. Antennas Propaq. 56(2):381-389.

Ouyang et al. (Web Release Mar. 20, 2000) "Conversion of Some Siloxane Polymers to Silicon Oxide by UV/Ozone Photochemical Processes," Chem. Mater. 12(6): 1591-1596.

Overholt et al. (2005) "Photodynamic Therapy for Esophageal Cancer using a 180° Windowed Esophageal Balloon," Lasers in Surg. Med. 14:27-33.

Pan et al. (2001) "Nanobelts of Semiconducting Oxides," *Science* 291: 1947-1949.

Panev et al. (2003) "Sharp Exciton Emission from Single InAs Quantum Dots in GaAs Nanowires," Appl. Phys. Lett. 83:2238-2240.

Pardo et al. (2000) "Application of Screen Printing in the Fabrication of Organic Ligh-Emitting Devices," Adv. Mater. 12(17):1249-1252.

Park et al. (1997) "Block Copolymer Lithography: Periodic Arrays of -10 Holes in 1 Square Centimeter," Science 276:1401-1404.

Park et al. (1998) "Fabrication of Three-Dimensional Macroporous Membranes with Assemblies of Microspheres as Templates," Chem. Mater. 10:1745-1747.

Park et al. (Aug. 2009) "Printed Assemblies of Inorganic Light-Emitting Diodes for Deformable and Semitransparent Displays," Science 325:977-981.

Park et al. (Web Release Feb. 22, 2009) "Biodegradable Luminescent Porous Silicon Nanoparticles for in Vivo Applications," Nature Mater. 8:331-336.

Parker et al. (2009) "Biocompatible Silk Printed Optical Waveguides," Adv. Mater. 21:2411-2415.

Patolsky et al. (2006) "Detection, Stimulation, and Inhibition of Neuronal Signals with High-Density Nanowire Transistor Arrays," Science 313:1100-1104.

Patton et al. (Mar. 1998) "Effect of Diamond like Carbon Coating and Surface Topography on the Performance of Metal Evaporated Magnetic Tapes," IEEE Trans Magn. 34(2):575-587.

Paul et al. (Apr. 2003) "Patterning Spherical Surfaces at the Two Hundred Nanometer Scale Using Soft Lithography," Adv. Func. Mater. 13(4):259-263.

Pearton et al. (1999) "GaN: Processing, Defects, and Devices," *J. Appl. Phys. 86*:1-78.

Peng et al. (Mar. 2, 2000) "Shape Control of CdSe Nanocrystals," *Nature 404*:59-61.

Perry et al. (2008) "Nano- and Micropatterning of Optically Transparent, Mechanically Robust, Biocompatible Silk Fibroin Films," Adv. Mater. 20:3070-3072.

Piazza et al. (2005) "Protective Diamond-Like Carbon Coatings for Future Optical Storage Disks," Diamond Relat. Mater. 14:994-999.

Pimparkar et al. (Feb. 2007) "Current-Voltage Characteristics of Long-Channel Nanobundle.Thin-Film Transistors: A 'Bottom-Up' Perspective," IEEE Electron Dev. Lett. 28(2):157-160.

Podzorov et al. (2005) "Hall Effect in the Accumulation Layers on the Surface of Orgaic Semiconductors," Phys. Rev. lett. 95:226601.

Pushpa et al. (2002) "Stars and Stripes. Nanoscale Misfit Dislocation Patterns on Surfaces," Pure Appl. Chem. 74(9):1663-1671.

Qian et al. (2006) "Scaling Effects of Wet Adhesion in Biological Attachment Systems," Acta Biomaterialia 2:51-58.

Quake et al (2000) "From Micro- to Nanofabrication with Soft Materials," *Science 290*: 1536-1540.

Radtke et al. (Feb. 5, 2007) "Laser-Lithography on Non-Planar Surfaces," *Opt. Exp. 15*(3):1167-1174.

Raman et al. (1989) "Study of Mesa Undercuts Produced in GaAs with H_3PO_4-Based Etchants," J. Electrochem. Soc. 136:2405-2410.

Randall et al. (2005) "Permeation-driven flow in poly(dimethylsiloxane) microfluidic devices," Proc. Nat. Acad. Sci. USA 102(31):10813-10818.

Rao et al. (2003) "Large-scale assembly of carbon nanotubes," Nature, 425:36-37.

Razavi et al. (2009) "Three Dimensional Nanopillar Array Photovoltaics on Low Cost and Flexible Substrates," Nature Materials 8:648-653.

Razeghi et al. (1994) "High-Power Laser Diodes Based on InGaAsP Alloys," *Nature 369*:631-633.

Razouk et al. (Sep. 1979) "Dependence of Interface State Density on Silicon Thermal Oxidation Process Variables," J. Electrochern. Soc. 126(9):1573-1581.

Reuss et al. (2005) "Microelectronics: Perspectives on Technology and Applications," Proc. IEEE 93:1239-1256.

Reuss et al. (Jun. 2006) "Microelectronics," *MRS Bull.* 31 :447-454.

Ribas et al. (1998) "Bulk Micromachining Characterization of 0.2 µm HEMT MMIC Technology for GaAs Mems Design," Mater. Sci. Eng. B 51 :267-273.

Ridley et al. (1999) "All-Inorganic Field Effect Transistors Fabricated by Printing," Science 286:746-749.

Roberts et al. (1979) "Looking at Rubber Adhesion," *Rubber Chem. Technol. 52*:23-42.

Roberts et al. (May 2006) "Elastically Relaxed Free-Standing Strained-Silicon Nanomembranes," Nat. Mater. 5:388-393.

Robinson et al. (1983) "GaAs Readied for High-Speed Microcircuits," *Science 219*:275-277.

Roelkens et al. (Dec. 2005) "Integration of InP/InGaAsP Photodetectors onto Siliconon-Insulator Waveguide Circuits," Optics Express 13(25):10102-10108.

Rogers et al. (1997) "Using an Elastomeric Phase Mask for Sub-100 nm Photolithography in the Optical Near Field," Appl. Phys. Lett. 70:2658-2660.

Rogers et al. (1998) "Generating ~90 Nanometer Features Using Near Field Contact Mode Photolithography with an Elastomeric Phase Mask," J. Vac. Sci. Technol. 16(1):59-68.

Rogers et al. (1998) "Quantifying Distortions in Soft Lithography," *J. Vac. Sci. Technol. 16*:88-97.

Rogers et al. (1998) "Using Printing and Molding Techniques to Produce Distributed Feedback and Bragg Reflector Resonators for Plastic Lasers," Appl. Phys. Lett. 73: 1766-1768.

Rogers et al. (1999) Printing Process Suitable for Reel-to-Reel Production of High-Performance Organic Transistors and Circuits, Adv. Mater. 11 (9):741-745.

Rogers et al. (2000) "Organic Smart Pixels and Complementart Inverter Circuits Formed on Plastic Substrates by Casting and Rubber Stamping," IEEE Electron Dev. Lett. 21 (3): 100-103.

(56) References Cited

OTHER PUBLICATIONS

Rogers et al. (2001) "Paper-Like Electronic Displays: Large-Area Rubber-Stamped Plastic Sheets of Electronics and Microencapsulated Electrophoretic Inks," Proc. Nat/Acad. Sci. USA 98:4835-4840.

Rogers et al. (2002) "Printed Plastic Electronics and Paperlike Displays," *J. Polym. Sci. Part A. Polym. Chem. 40*:3327-3334.

Rogers, J. (Jul. 9, 2010) "Farewell to Flatland," Science 329:138139.

Rogers, JA (2001) "Rubber Stamping for Plastic Electronics and Fiber Optics," *MRS Bulletin 26*(7):530-534.

Rogers, JA (2001) "Toward Paperlike Displays," *Science* 291: 1502-1503.

Rosenblatt et al. (2002) "High Performance Electrolyte Gated Carbon Nanotube Transistors," Nano Lett. 2(8):869-872.

Rotkin et al. (2003) "Universal Description of Channel Conductivity for Nanotube and Nanowire Transistors," Appl. Phys. Lett. 83:1623-1625.

Roundy et al. (2003) "Photonic Crystal Structure with Square Symetry within EachLayer and a Three-Dimensional Band Gap," Appl. Phys Lett. 82:3835-3837.

Rubehn et al. (2009) "A MEMS based Flexible Multichannel ECoG-Electrode Array," J. Neural Eng. 6:036003.

Ruchehoeft et al. (2000) "Optimal Strategy for Controlling Linewidth on Spherical Focal Surface Arrays," J. Vac. Sci. Technol. B 18(6):3185-3189.

Ryu et al. (2009) "Human Cortical Prostheses: Lost in Translation?" Neurosurg Focus 27(1):E5.

Samuelson et al. (2004) "Semiconductor Nanowires for Novel One-Dimensional Devices," Physica E 21 :560-567.

Sangwal et al. (1997) "Nature of multilayer steps on the {100} cleavage planes of MgO single crystals," Surf. Sci., 383:78-87.

Santin et al. (1999) "In vitro Evaluation of the Inflammatory Potential of the Silk Fibroin," J. Biomed. Mater. Res. 46:382-389.

Sanyal et al. (2002) "Morphology of Nanostructures Materials," *Pure Appl. Chem. 74*(9): 1553-1570.

Sazonov et al. (2005) "Low-Temperature Materials and Thin-Film Transistors for Flexible Electronics," Proc. IEEE 93:1420-1428.

Scherlag et al. (1969) "Catheter Technique for Recording His Bundle Activity in Man," Circulation 39:13-18.

Schermer et al. (2005) "Thin-Film GaAs Epitaxial Lift-Off Solar Cells for Space Applications," Prog. Photovolt. Res. Appl. 13:587-596.

Schermer et al. (2006) "Photon Confinement in High-Efficiency, Thin Film II I-V Solar Cells Obtained by Epitaxial Lift-Off," Thin Solid Films 211-512:645-653.

Schindl et al. (2003) "Direct Stimulatory Effect of Low-Intensity 670-nm Laser Irradiation on Human Endothelial Cell Proliferation," Br. J. Dermatol. 148:334-336.

Schlegel et al. (2002) "Structures of quartz (1010)- and (1011)-water interfaces determined by X-ray reflectivity and atomic force microscopy of natural growth surfaces," Geochim. Cosmochim. Acta, vol. 66, No. 17, pp. 3037-3054.

Schmid et al. (2003) "Preparation of Metallic Films on Elastomeric Stamps and Their Application for Contact Processing and Contact Printing," Adv. Funct. Mater. 13:145-153.

Schmid et al. (Mar. 25, 2000) "Siloxane Polymers for High-Resolution, High-Accuracy Soft Lithography," Macromolecules 33(8):3042-3049.

Schmid et al. (May 11, 1998) "Light-Coupling Masks for Lensless, Sub-wavelength Optical Lithography," Appl. Phys. Lett. 72(19):2379-2381.

Schmidt et al. (Mar. 8, 2001) "Thin Solid Films Roll up into Nanotubes," *Nature 410*:168.

Schnable et al. (1969) "Aluminum Metallization; Advantages and Limitations for Integrated Circuit Applications," IEEE 57: 1570-1580.

Schneider et al. (2008) "Mechanical Properties of Silicones for MEMS," *J. Micromech. Microeng. 18*:065008.

Schon et al. (1995) "Ambipolar Pentacene Field-Effect Transistors and Inverters,"Science 287: 1022-1 023.

Schrieber et al. (1998) "The Effectiveness of Silane Adhesion Promotors in the Performance of Polyurethane Adhesives," J. Adhesion 68:31-44.

Scorzoni et al. (Oct. 4, 2004) "On the Relationship Between the Temperature coefficient of Resistance and the Thermal Conductance of Integrated Metal Resistors," Sens Actuators A 116(1): 137-144.

Search and Examination Report, Corresponding to Singapore Patent Application No. 200607372-0, Mailed Oct. 17, 2007.

Search Report and Examination Report Corresponding to Singapore Patent Application No. 200901178-4, completed Mar. 13, 2010.

Search Report Corresponding to Singapore Patent Application No. SG 200607372-0, Mailer Oct. 17, 2007.

Search Report Corresponding to Taiwanese Application No. 095121212, completed Oct. 8, 2010.

Search Report, Corresponding to Republic of China (Taiwan) Patent Application No. 094118507, Dated Feb. 24, 2007.

Seidel et al. (2004) "High-Current Nanotube Transistors," Nano Lett., vol. 4, No. 5, pp. 831-834.

Sekitani et al. (2005) "Bending Experimant on Pentacene Field-Effect Transistors on Plastic Films," Appl. Phys. Lett. 86:073511.

Sekitani et al. (2009) "Stretchable Active-Matrix Organic Light-Emitting Diode Display Using Printable Elastic Conductors," Nature Mater. 8:494-499.

Sekitani et al. (Sep. 12,2008) "A Rubberlike Stretchable Active Matrix Using Elastic Conductors," Science 321 :1468-1472.

Sen et al. (2002) "Nonequilibrium Processes for Generating Silicon Nanostructures in Single-Crystalline Silicon," Pure Appl. Chem. 74(9):1631-1641.

Serikawa et al. (May 1, 2000) "High-Mobility Poly-Si Thin Film Transistors Fabricated on Stainless-Steel Foils by Low-Temperature Processes Using Sputter-Depositions," Jpn. J. Appl. Phys. 39:L393-L395.

Servanti et al. (2005) "Functional Pixel Circuits for Elastic AMOLED displays," *Prac. IEEE 93*:1257-1264.

Service, R.F. (Aug. 15,2003) "Electronic Textiles Charge Ahead," *Science* 301 :909-911.

Shan et al. (2004) "From Si Source Gas Directly to Positioned, Electrically Contacted Si Nanowires: the Self-Assembling 'Grow-in-Place' Approach," Nano Lett. 4(11):2085-2089.

Sharp et al. (2003) "Holographic Photonic Crystals with Diamond Symmetry," *Phys. Rev. B 68*:205102/1-205102/6.

Sheraw et al. (2002) "Organic Thin-Film Transistor-Driven Polymer-Dispersed Liquid Crystal Displays on Flexible Polymeric Substrates," Appl. Phys. Lett. 80: 1088-1 090.

Shetty et al. (2005) "Formation and Characterization of Silicon Films on Flexible Polymer Substrates," Mater. Lett. 59:872-875.

Shi et al. (2001) "Free-Standing Single Crystal Silicon Nanoribbons," J. Am. Chem. Soc. 123(44):11095-11096.

Shi et al. (Sep. 2000) "Synthesis of Large Areas of Highly Oriented, Very Long Silicon Nanowires," Adv. Mater. 12(18):1343-1345.

Shi et al. (Web Release Oct. 11, 2001) "Free-Standing Single Crystal Silicon Nanoribbons," J. Am. Chem. Soc. 123(44):11095-11096.

Shin et al. (2003) "PDMS-Based Micro PCR Chip with Parylene Coating," J. Micromech. Microeng. 13:768-774.

Shtein et al. (Oct. 15, 2004) "Direct Mask-Free Patterning of Molecular Organic Semiconductors Using Organic Vapor Jet Printing," J. Appl. Phys. 96(8):4500-4507.

Shull et al. (1998) "Axisymmetric Adhesion Tests of Soft Materials," *Macramol. Chem. Phys.199*:489-511.

Siegel et al. (2009) "Thin, lightweight, Foldable Thermochromic Displays on Paper," Lab Chip 9:2775-2781.

Siegel et al. (2010) "Foldable Printed Circuit Boards on Paper Substrates," Adv. Funct. Mater. 20:28-35.

Siegel et al. (Web Release Feb. 7, 2007) "Microsolidics: Fabrication of Three-Dimensional Metallic Microstructures in Poly(dimethylsiloxane)," Adv. Mater. 19(5):727-733.

Sim et al. (1993) "An Analytical Back-Gate Bias Effect Model for Ultrathin SOI CMOS Devices," IEEE Trans. Elec. Dev. 40:755-765.

Sirringhaus et al. (2003) "Inkjet Printing of Functional Materials," *MRS Bull. 28*:802-806.

Sirringhaus et al. (Dec. 15, 2000) "High-Resolution Inkjet Printing of All-Polymer Transistor Circuits," Science 290:2123-2126.

(56) References Cited

OTHER PUBLICATIONS

Sirringhaus, H. (2005) "Device Physics of Solution-Processed Organic Field-Effect Transistors," Adv. Mater. 17:2411-2425.

Smay et al. (2002) "Colloidal Inks for Directed Assembly of 3-D Periodic Structures," Langmuir 18:5429-5437.

Smith et al. (2000) "Electric-Field Assisted Assembly and Alignment of Metallic Nanowires," Appl. Phys. Lett. 77(9):1399-1401.

Snow et al. (2003) "Random networks of carbon nanotubes as an electronic material," Appl. Phys. Lett., vol. 82, No. 13, pp. 2145-2147.

Snow et al. (2005) "High-mobility carbon-nanotube transistors on a polymeric substrate," Appl. Phys. Lett., 86, 033105.

So et al. (2008) Organic Light-Emitting Devices for Solid-State Lighting, MRS Bull. 33:663-669.

Sofia et al. (2001) "Functionalized Silk-Based Biomaterials for Bone Formation," J. Biomed. Mater. Res. 54:139-148.

Someya et al. (2005) "Conformable, Flexible, Large-Area Networks of Pressure and Thermal Sensors with Organic Transistor Active Matrixes," Proc. Nat. Acad. Sci. USA 102:12321-12325.

Someya et al. (2005) "Integration of Organic FETs with Organic Photodiodes for a Large Area, Flexible, and Lightweight Sheet Image Scanners," IEEE Trans. Electron Devices 52:2502-2511.

Someya et al. (Jul. 6,2004) "A Large-Area, Flexible Pressure Sensor Matrix With Organic Field-Effect Transistors for Artificial Skin Applications," Proc. Nat. Acad. Sci. USA 101 (27):9966-9970.

Someya, T. (Aug. 7, 2008) "Electronic Eyeballs," Nature 454:703-704.

Soole et al. (Mar. 1991) "InGaAs Metal-Semiconductor-Metal Photodetectors for Long Wavelength Optical Communications," IEEE J. Quantum Electron. 27(3):737-752.

Soong et al. (1984) "Adverse Reactions to Virgin Silk Sutures in Cataract Surgery," Ophthalmology 91:479-483.

Srinivasan et al. (Web Release Mar. 26, 2007) "Piezoelectric/Ultrananocrystalline Diamond Heterostructures for High-Performance Multifunctional Micro/Nanoelectromechanical Systems," Appl. Phys. Lett. 90: 1341 01.

Stafford et al. (2004) "A Buckling-Based Metrology for Measuring the Elastic Moduli of Polymeris Thin Films," Nature Mater. 3:545-550.

Star et al. (2004) "Nanotube Optoelectric Memory Devices," Nano Lett., vol. 4, No. 9, pp. 1587-1591.

Stella Newsletter IV, Stretchable Electronics for Large Area Applications [online: Apr. 29, 2011] http://www.stella-project.de/Portals/0/Stella_Newsletter_6.pdf.

Storm et al. (Web Release Jul. 13, 2003) "Fabrication of Solid-State Nanopores with Single-Nanometre Precision," Nat. Mater. 2:537-540.

Streetman et al. (2000) "Intrinsic Material," In; Solid State Electronic Devices, 5th Ed., Prentice Hall; Upper Saddle River, NJ; pp. 74-75.

Strukov et al. (2005) "CMOL FPGA: A Reconfigurable Architecture for Hybrid Digital Circuits with Two-Terminal Nanodevices," Nanotechnology 16:888-900.

Su et al. (2000) "Lattice-Oriented Growth of Single-Walled Carbon Nanotubes," J. Phys. Chem. B 104(28):6505-6508.

Sum et al. (2009) "Near-Infrared Spectroscopy for the Detection of Lipid Core Coronary Plaques," Curr. Cardiovasc. Imag. Rep. 2:307-315.

Sumant et al. (Apr. 2005) "Toward the Ultimate Tribological Interface: Surface Chemistry and Nanotribology of Ultrananocrystalline Diamond," Adv. Mater 17(8):1039-1045.

Sun et al. (2004) "Fabricating Semiconductor Nano/Microwires and Transfer Printing Ordered Arrays of them onto Plastic Substrates," *Nano Lett.* 4: 1953-1959.

Sun et al. (2005) "Advances in Organic Field-Effect Transistors," *J. Mater. Chem. 15*:53-65.

Sun et al. (2005) "Bendable GaAs Metal-Semiconductor Field-Effect Transistors Formed with a Printed GaAs Wire Arrays on Plastic Substrates," Appl. Phys. Lett. 87:083501.

Sun et al. (2005) "Photolithographic Route to the Fabrication of Micro/Nanowires of II I-V Semiconductors," Adv. Funct. Mater. 15:30-40.

Sun et al. (2007) "Inorganic Semiconductors for Flexible Electronics," *Adv. Mater. 19*:1897-1916.

Sun et al. (2007) "Structural Forms of Single Crystal Semiconductor Nanoribbons for High-Performance Stretchable Electronics," J. Mater Chem. 17:832-840.

Sun et al. (2007) "Controlled Buckling of Semiconductor Nanoribbons for Stretchable Electronics," Nat. Nanotechnol. 1:201-207.

Sun et al. (Nov. 2006) "Buckled and Wavy Ribbons of GaAs for High-Performance Electronics on Elastomeric Substrates," Adv. Mater. 18(21):2857-2862.

Sun et al. (Web Release Dec. 5, 2006) "Controlled Buckling of Semiconductor Nanoribbons for Stretchable Electronics," Nature Nanotech. 1:201-207.

Sundar et al. (2004) "Elastomeric Transistor Stamps: Reversible Probing of Charge Transport in Organic Crystals," Science 303: 1644-1646.

Suo et al. (Feb. 22, 1999) "Mechanics of Rollable and Foldable Film-on-Foil Electronics," Appl. Phys. Lett. 74(8):11771179.

Supplemental European Search Report for European Application 07 84 1968, completed Mar. 31, 2011.

Supplementary European Search Report, Corresponding to European Application No. 04 81 2651, Completed Oct. 19, 2010.

Supplementary European Search Report, Corresponding to European Application No. EP 05 75 6327, Completed Sep. 25, 2009.

Swain et al. (2004) "Curved CCD Detector Devices and Arrays for Multi-Spectral Astrophysical Application and Terrestrial Stereo Panoramic Cameras," Proc. SPIE 5499:281-301.

Sweet: Stretchable and Washable Electronics for Embedding Textiles. Available at http://tfcg.elis.ugent.be/projects/sweet. Access Feb. 8, 2012.

Sze et al. (1985) *Semiconductor Devices, Physics and Technology*, 2^{nd} ed., Wiley, New York, pp. 190-192.

Sze, S. (1985) "Lithography and Etching," In; *Semiconductor Devices: Physics and Technology*, New York: Wiley, pp. 428-467.

Sze, S. (1985) Semiconductor Devices: Physics and Technology, New York: Wiley, pp. 428-467.

Sze, S. (1988) VLSI Technology, Chapter 8, ION Implantation, Mcgraw-Hill, 327-374, 566-611.

Sze, S. (1994) "Semiconductor Sensor Technologies," In; *Semiconductor Sensors*,John Wiley and Sons: New York pp. 17-95.

Takamoto et al. (Jan 20, 1997) "Over 30% Efficient InGaP/GaAs Tandem Solar Cells," Appl. Phys. Lett. 70(3):381-383.

Talapin et al. (Oct. 7, 2005) "PbSe Nanocrystal Solids for n- and p-Channel Thin Film Field-Effect Transistors," Science 310:86-89.

Tan et al. (Apr. 12, 2004) "Performance Enhancement of InGaN Light Emitting Diodes by Laser-Lift-off and Transfer from Sapphire to Copper Substrate," Appl. Phys. Lett. 84(15):2757-2759.

Tanase et al. (2002) "Magnetic Trapping and Self-Assembly of Multicomponent Nanowires," J. Appl. Phys. 91 :8549-8551.

Tang et al. (2005) "One-Dimensional Assemblies of Nanoparticles: Preparation,Properties, and Promise," Adv. Mater. 17:951-962.

Tao et al. (2003) "Langmuir-Blodgett Silver Nanowire Monolayers for Molecular Sensing Using Surface-Enhanced Raman Spectroscopy," Nano Lett. 3:1229-1233.

Tate et al. (2000) "Anodization and Microcontact Printing on Elotroless Silver: Solution-Based Fabrication Procedures for Low-Voltage Electronic Systems with Organic Active Components," Langmuir 16:6054-6060.

Teshima et al. (2001) "Room-Temperature Deposition of High-Purity Silicon Oxide Films by RF Plasma-Enhanced CVD," Surf. Coat. Technol. 146-147:451-456.

Theiss et al. (1998) "PolySilicon Thin Film Transistors Fabricated at 100° C. on a Flexible Plastic Substrate," IEDM 98:257-260.

Thornwood et al. (Oct. 1, 1990) "Utilizing Olptical Lithography in the Sub-Micron Dimensional Regime," IBM Tech. Disc. Bull. 33(5):187-188.

Timko et al. (2009) "Electrical Recording from Hearts with Flexible Nanowire Device Arrays," Nano Lett. 9:914-918.

Toader et al. (2004) "Photonic Band Gap Architectures for Holographic lithography," Phy. Rev. Lett. 043905/1-043905/4.

(56) **References Cited**

OTHER PUBLICATIONS

Toader et al. (2004) "Photonic Band Gaps Based on Tetragonal Lattices of Slanted Pores," Phys. Rev. Lett. 90:233901/1-233901/4.

Tong (1999) "Stresses in Bonded Wafers," In; *Semiconductor Wafer Bonding: Science and Technology*, John Wiley; New York, pp. 187-221.

Tong (1999) Semiconductor Wafer Bonding: Science and Technology, John Wiley; New York, pp. 187-221.

Trau et al. (1997) "Microscopic Patterning of Orientated Mesoscopic Silica Through Guided Growth," Nature 390:674-676.

Trentler et al. (1995) "Solution-liquid-Solid Growth of Crytalline III-V Semiconductors: An Analogy to Vapor-liquid-Solid Growth," Science 270:1791-1794.

Tseng et al. (Web Release Dec. 19, 2003) "Monolithic Integration of Carbon Nanotube Devices with Silicon MOS Technology" Nano Lett. 4(1):123-127.

Ucjikoga, S. (2002) "Low-Temperature Polycrystalline Silicon Thin-Film Transistor Technologies of System-on-Glass Displays," MRS Bull. 27:881-886.

Upon the Schottky Barrier Height of Au/n-GaAs and Ti/n-GaAs Diodes, *Semicond. Sci. Technol.* 19:1391-1396.

Urruchi et al. (2000) "Etching of DLC Films Using a Low Intensity Oxygen Plasma Jet," Diamond Relat. Mater. 9:685-688.

U.S. Appl. No. 11/423,287, filed Jun. 9, 2006.

U.S. Appl. No. 11/851,182, filed Sep. 6, 2006.

U.S. Appl. No. 12/398,811, filed Mar. 5, 2009.

U.S. Appl. No. 12/723,475, filed Mar. 12, 2010.

U.S. Appl. No. 12/575,008, filed Oct. 7, 2008.

U.S. Appl. No. 12/616,922, filed Nov. 12, 2009.

U.S. Appl. No. 12/625,444, filed Nov. 24, 2009.

U.S. Appl. No. 12/636,071, filed Dec. 11, 2009.

U.S. Appl. No. 12/686,076, filed Jan. 12, 2010.

U.S. Appl. No. 12/972,073, filed Dec. 17, 2010.

U.S. Appl. No. 12/976,607, filed Dec. 22, 2010.

U.S. Appl. No. 12/976,814, filed Dec. 22, 2010.

U.S. Appl. No. 12/976,833, filed Dec. 22, 2010.

U.S. Appl. No. 13/082,388, filed Apr. 7, 2010.

US Office Action for U.S. Appl. No. 12/575,008 mailed Feb. 17, 2011.

Vanhollenbeke et al. (2000) "Compliant Substrate Technology: Integration of Mismatched Materials for Opto-Electronic Applications," Prog. Cryst. Growth Charact. Mater. 41(1-4):1-55.

Velev et al. (1997) "Porous silica via colloidal crystallization," *Nature 389*:447-448.

Vepari et al. (Aug. Sep. 2007) "Silk as a Biomaterial," Prog. Polym. Sci. 32(8-9):991-1007.

Vilan et al. (2000) "Molecular Control Over Au/GaAs Diodes," *Nature 404*:166-168.

Vinck et al. (2003) "Increased Fibroblast Proliferation Induced by Light Emitting Diode and Low Power Laser Irradiation," Lasers Med. Sci. 18:95-99.

Viventi et al. (Mar. 2010) "A Conformal, Bio-Interfaced Class of Silicon Electronics for Mapping Cardiac Electrophysiology," Sci. Trans. Med. 2(24):24ra22.

Vlasov et al. (2001) "On-Chip Natural Assembly of Silicon Photonic Bandgap Crystals," Nature 414:289-293.

Voss, D. (2000) "Cheap and Cheerful Circuits," *Nature 407*:442-444.

Wagner et al. (2003) "Silicon for Thin-Film Transistors," *Thin Solid Films* 430: 15-19.

Wagner et al. (2005) "Electronic Skin: Architecture and Components," *Physica E* 25:326-334.

Wagner et al. (Mar. 1, 1964) "Vapor-liquid-Solid Mechanism of Single Crystal Growth," Appl. Phys. Lett. 4(5):89-90.

Waksman et al.(2008) "Photopoint Photodynamic Therapy Promotes Stabilization of Atherosclerotic Plaques and Inhibits Plaque Progression," J. Am. Coll. Cardiol. 52:1024-1032.

Wang et al. (2003) "A Solution-Phase, Precursor Route to Polycrystalline SnO_2 Nanowores That Can Be Used for Gas Sensing under Ambient Conditions," J. Am. Chem. Soc. 125:16176-16177.

Wang et al. (2005) "Oxidation Resistant Germanium Nanowires: Bulk Synthesis, Long Chain Alkanethiol Functionalization, and Langmuir-Blodgett Assembly," J. Am. Chern. Soc. 127(33):11871-11875.

Wang et al. (2005) "Electronically Selective Chemical Functionalization of Carbon Nanotubes: Correlation between Raman Spectral and Electrical Responses," J. Am. Chem. Soc., 127:11460-11468.

Wang et al. (2006) "Direct Synthesis and Characterization of CdS Nanobelts," *Appl. Phys. Lett. 89*:033102.

Wang et al. (Aug-Sep. 2008) "In Vivo Degradation of Three-Dimensional Silk Fibroin Scaffolds," Biomaterials 29(24-25):3415-3428.

Waxman et al. (2009) "In vivo Validation of a Catheter-Based Near-Infrared Spectroscopy System for Detection of Lipid Core Coronary Plaques: Initial Results of the Spectacl Study," J. Am. Coll. Cardiol. Img. 2:858-868.

Waxman, S. (2008) "Near-Infrared Spectroscopy for Plaque Characterization," J. Interv. Cardiol. 21:452-458.

Weber et al. (Jan. 2004) "A Novel Low-Cost, High Efficiency Micromachined Silicon Solar Cell," IEEE Electron Device Lett. 25(1):37-39.

Wen et al. (Web Release Dec. 4, 2004) "Controlled Growth of Large-Area, Uniform, Vertically Aligned Arrays of a-Fe202 Nanobelts and Nanowires," J. Phys. Chem. B 109(1):215-220.

Whang et al. (2003) "Large-Scale Hierarchical Organization of Nanowire Arrays for Integrated Nanosystems," Nano Lett. 3(9): 1255-1259.

Williams et al. (Oct. 2006) "Growth and Properties of Nanocrystalline Diamond Films," Phys. Stat. Sol. A 203(13):3375-3386.

Williams et al. (Web Release Jan. 23, 2006) "Comparison of the Growth and Properties of Ultranocrystalline Diamond and Nanocrystalline Diamond," Diamond Relat. Mater. 15:654-658.

Willner et al. (2002) "Functional Nanoparticle Architectures for Senoric, Optoelectronic, and Bioelectronic Applications," Pure Appl. Chem. 74(9): 1773-1783.

Wilson et al. (2006) "ECoG Factors Underlying Multimodal Control of a Brain—Computer Interface," IEEE Trans. Neural Syst. Rehabil. Eng. 14:246-250.

Wind et al. (May 20, 2002) "Vertical Scaling of Carbon Nanotube-Field-Effect Transitors Using Top Gate Electrodes," Appl. Phys. Lett. 80(20):3871-3819.

Wise et al. (Jul. 2008) "Microelectrodes, Microelectronics, and Implantable Neural Microsystems," Proc. IEEE 96(7):1184-1202.

Won et al. (2004) "Effect of Mechanical and Electrical Stresses on the Performance of an a-Si:H TFT on Plastic Substrate," J. Electrochem. Soc. 151:G167-G170.

Wong-Riley et al. (2005) "Photobiomodulation Directly Benefits Primary Neurons Functionally Inactivated by Toxins," J. Biol. Chem. 280:4761-4771.

Woodburn et al. (1996) "Phototherapy of Cancer and Atheromatous Plaque with Texaphyrins," J. Clin. Laser Med. Surg. 14:343-348.

Written Opinion of the International Search Authority Corresponding to International patent Application No. PCT/US05/19354 Issued Apr. 18, 2007.

Wu et al. (2001) "Amorphous Silicon Crystallization and Polysilicon Thin Film Transistors on SiO2 Passivated Steel Foil Substrates," Apple. Surf. Sci 175-176:753-758.

Wu et al. (2001) "Thermal Oxide of Polycrystalline Silicon on Steel Foil as a Thin-Film Transitor Gate Dielectric," Appl. Phys. Lett. 78:3729-3731.

Wu et al. (2001) "Direct Observation of Vapor-Liquid-Solid Nanowire Growth," J. Am. Chem. Soc. 123(13):3165-3166.

Wu et al. (2002) "Growth of Au-Catalyzed Ordered GaAs Nanowire Arrays by Molecular-Beam Epitaxy," Appl. Phys. Lett. 81 :5177-5179.

Wu et al. (2002) "Inorganic Semiconductor Nanowires: Rational Growth, Assembly, and Novel Properties," Chem. Eur. J. 8(6):1261-1268.

Wu et al. (2002) "Block-by-Block Growth of Single-Crystalline Si/SiGe Superlattice Nanowires," Nano Lett. 2(2):83-86.

Wu et al. (2002) "Growth of Au-Catalyzed Ordered GaAs Nanowire Arrays by Molecular-Beam Epitaxy," Appl. Phys. Lett. 81:5177-5179.

(56) **References Cited**

OTHER PUBLICATIONS

Wu et al. (2003) "Growth, Branching, and Kinking of Molecular-Beam Epitaxial (110) GaAs Nanowires," Appl. Phys. Lett. 83:3368-3370.

Wu et al. (Jul. 1, 2004) "Single-Crystal Metallic Nanowires and Metal/Semiconductor Nanowire Heterostructures," Nature 430:61-65.

Wu et al. (Nov. 2002) "Complementary Metal-Oxide-Semiconductor Thin-Film Transistor Circuits from a High-Temperature Polycrystalline Silicon Process on Steel Foil Substrates," IEEE Trans. Electr. Dev. 49(11): 1993-2000.

Wu et al. (Web Release Jan. 19, 2002) "Block-by-Block Growth of Single-Crystalline Si/SiGe Superlattice Nanowires," Nano Lett. 2(2):83-86 Si/SiGe Superlattice Nanowires, Nano Lett. 2(2):83-86.

Wu et al. (Web Release Mar. 13, 2001) "Direct Observation of Vapor-Liquid-Solid Nanowire Growth," J. Am. Chern. Soc. 123(13):3165-3166.

Xia (1998) "Soft Lithography" *Angew. Chern. Int. Ed.* 37:551-575.

Xia et al. (1996) "Shadowed Sputtering of Gold on V-Shaped Microtrenches Etched in Silicon and Applications in Microfabrication," Adv. Mater. 8(9):765-768.

Xia et al. (1998) "Soft Lithography," *Annu. Rev. Mater. Sci.* 28:153-184.

Xia et al. (1999) "Unconventional Methods for Fabricating and Patterning Nanostructures," Chem. Rev. 99: 1823-1848.

Xia et al. (2003) "One-Dimensional Nanostructures: Synthesis, Characterization and Applications," Adv. Mater. 15:353-389.

Xia et al. (Jul. 19, 1996) "Complex Optical Surfaces Formed by Replica Molding Against Elastomeric Masters," Science 273:347-349.

Xiang et al. (Mar. 25, 2006) "Ge/Si Nanowire Heterostructures as High-Performance Field-Effect Transistors," Nature 441 :489-493.

Xiao et al. (2003) "High-mobility thin-film transistors based on aligned carbon nanotubes," Appl. Phys. Lett., vol. 83, No. 1, pp. 150-152.

Xie et al. (May 2003) "Polymer-Controlled Growth of Sb_2Se_3 Nanoribbons Via a Hydrothermal Process," J. Cryst. Growth 252(4):570-574.

Xin et al. (Jun. 2005) "Evaluation of Polydimethylsiloxane Scaffolds with Physiologically-Relevant Elastic Moduli: Interplay of Substrate Mechanics and Surface Chemistry Effects on Vascular Smooth Muscle Cell Response," Biornaterials 26(16):3123-3129.

Yang et al. (1997) "Mesoporous Silica with Micrometer-Scale Desgns," *Adv. Mater. 9*:811-814.

Yang et al. (2000) "Stability of Low-Temperature Amorphous Silicon Thin Film Transistors Formed on Glass and Transparent Plastic Substrates," J. Vac. Sci. Technol. B 18:683-689.

Yang et al. (2002) "Creating Periodic Three-Dimensional Structures by Multibeam Interface of Visible Laser," Chem. Mater. 14:2831-2833.

Yang et al. (Dec. 2007) "RFID Tag and RF Structures on a Paper Substrate Using Inkjet-Printing Technology," IEEE Trans. Microw. Theory Tech. 55(12):2894-2901.

Yang, P. (2005) "The Chemistry and Physics of Semiconductor Nanowires," *MRS Bull. 30*:85-91.

Yanina et al. (2002) "Terraces and ledges on (001) spinel surfaces," Surf. Sci., 513:L402-L412.

Yao et al. (2008) "Seeing Molecules by Eye: Surface Plasmon Resonance Imaging at Visible Wavelengths with High Spatial Resolution and Submonolayer Sensitivity," Angew. Chem.47:5013-5017.

Yao et al. (2010) "Functional Nanostructured Plasmonic Materials," Adv. Mater. 22:1102-1110.

Yao et al. (Mar. 2000) "High-Field Effect Electrical Transport in Single-Walled Carbon Nanotubes," Phys. Rev. Lett. 84(13):2941-2944.

Yeager et al. (Aug. 30, 2008) "Characterization of Flexible ECoG Electrode Arrays for Chronic Recording in Awake Rats," J. Neurosci. Methods 173(2):279-285.

Yeh et al. (1994) "Fluidic Self-Assembly for the Integration of GaAs light-Emitting Diodes on Si Substrates," IEEE Photon. Technol. Lett. 6:706-708.

Yin et al. (2000) "A Soft lithography Approach to the Fabrication of Nanostructures of Single Crystalline Silicon with Well-Defined Dimensions and Shapes," Adv. Mater. 12:1426-1430.

Yin et al. (2005) "Colloidal Nanocrystal Synthesis and the Organic-Inorganic Interface," Nature 437:664-670.

Yoon et al. (2005) "Low-Voltage Organic Field-Effect Transistors and Inverters Enabled by Ultrathin Cross-linked Polymers as Gate Dielectrics," J. Am. Chern. Soc. 127: 10388-10395.

Yu et al. (2000) "Silicon Nanowires: preparation, Device Fabrication, and Transport Properties," J. Phys. Chem. B 104(50):11864-11870.

Yu et al. (2003) "Solution-liquid-Solid Growth of Soluble GaAs Nanowires," *Adv. Mater. 15*:416-419.

Yu et al. (2003) "Two- Versus Three-Dimensional Quantum Confinement in Indium Phosphide Wires and Dots," Nat. Mater. 2:517-520.

Yu et al. (2004) "The Yield Strength of Thin Copper Films on Kapton," J. Appl. Phys. 95:2991-2997.

Yuan et al. (2006) "High-Speed Strained-Single-Crystal-Silicon Thin-Film Transistors on Flexible Polymers," J. Appl. Phys. 100:013708.

Yurelki et al. (Jul. 24, 2004) "Small-Angle Neutron Scattering from Surfactant-Assisted Aqueous Dispersions of Carbon Nanotubes," J. Am. Chem. Soc. 126(32):9902-9903.

Zakhidov et al. (1998) "Carbon Structure with Three-Dimensional Periodicity at Optical Wavelengths," Science 282:897-901.

Zaumseil et al. (2003) "Nanoscale Organic Transistors that use Source/Drain Electrodes Supported by High Resolution Rubber Stamps," Appl. Phys. Lett. 82(5):793-795.

Zaumseil et al. (2003) "Three-Dimensional and Multilayer Nanostructures Formed by Nanotransfer Printing," Nano Lett. 3(9):1223-1227.

Zhang et al. (2001) "Electric-field-directed growth of aligned single-walled carbon nanotubes," Appl. Phys. Lett., vol. 79, No. 19. pp. 3155-3157.

Zhang et al. (2005) "Low-Temperature Growth and Photoluminescence Property of ZnS Nanoribbons," J. Phys. Chem. B 109(39):18352-18355.

Zhang et al. (2006) "Anomalous Coiling of SiGe/Si and SiGe/Si/Cr Helical Nanobelts," Nano Lett. 6(7):1311-1317.

Zhang et al. (Apr. 2003) "Oxide-Assisted Growth of Semiconducting Nanowires," *Adv. Mater.* 15(7-8):635-640.

Zhang et al. (Apr. 5, 2004) "Structure and Photoiluminescence of ZnSe Nanoribbons Grown by Metal Organic Chemical Vapor Deposition," Appl. Phys. Lett. 84(14):2641-2643.

Zhang et al. (Feb. 9, 2006) "Electronic Transport in Nanometre-Scale Silicon-on-Insulator Membranes," Nature 439:703-706.

Zhang et al. (Jun. 6, 2006) "Anomalous Coiling of SiGe/Si and SiGe/Si/Cr Helical Nanobelts," Nano Lett. 6(7):1311-1317.

Zhao et al. (Mar. 2007) "Improved Field Emission Properties from Metal-Coated Diamond Films," Diamond Relat Mater. 16(3):650-653.

Zheng et al. (1998) "Sudden Cardiac Death in the United States, 1989 to 1998," Circulation 104, 2158-2163.

Zheng et al. (2004) "Shape-and Solder-Directed Self-Assembly to Package Semiconductor Device Segments," Appl. Phys. Lett. 85:3635-3637.

Zheng et al. (Aug. 31,2004) "Sequential Shape-and-Solder-Directed Self Assembly of Functional Microsystems," Proc. Natl. Acad. Sci. USA 101(35):12814-12817.

Zhou et al. (2002) "An Efficient Two-Photon-Generated Photoacid Applied to Positive-Tone 3D Microfabrication," Science 296:1106-1109.

Zhou et al. (2004) "p-Channel, n-Channel Thin Film Transistors and p-n Diodes Based on Single Wall Carbon Nanotube Networks," Nano Lett. 4:2031-2035.

Zhou et al. (2005) "Band Structure, Phonon Scattering, and the Performance Limit of Single-Walled Carbon Nanotube Transistors," Phys. Rev. Lett. 95:146805.

Zhou et al. (2005) "Mechanism for Stamp Collapse in Soft Lithography," *Appl. Phys.Lett. 87*:251925.

(56) References Cited

OTHER PUBLICATIONS

Zhu et al. (2005) "Spin on Dopants for High-Performance Single Crystal Silicon Transistors on Flexible Plastic Substrates," Applied Physics Letters 86, 133507 (2005).

Zipes et al. (2006) "ACC/AHA/ESC 2006 Guidelines for Management of Patients With Ventricular Arrhythmias and the Prevention of Sudden Cardiac Death: A Report of the American College of Cardiology/American Heart Association Task Force and the European Society of Cardiology Committee for Practice Guidelines (Writing Committee to Develop Guidelines for Management of Patients With Ventricular Arrhythmias and the Prevention of.Sudden Cardiac Death," Circulation 114:385-484.

Examination Report, Corresponding to European Application No. 07 841 968.6.

International Preliminary Report on Patentabiltiy for PCT Application No. PCT/US2010/060425, mailed Jun. 28, 2012.

International Search Report Corresponding to International Application No. PCT/US2012/028590, mailed Jun. 13, 2012.

International Search Report and Written Opinion dated Jul. 30, 2012, corresponding to International Patent Application No. PCT/US12/37973.

Notice of Reasons for Rejection corresponding to Japanese Patent Application No. P2006-165159, Dispatched Apr. 24, 2012—includes English translation.

Notice of Reasons for Rejection corresponding to Japanese Patent Application No. P2009-546361, Dispatched Jul. 3, 2012—includes English translation.

Supplementary European Search Report dated Jun. 15, 2012, corresponding to European Patent Application No. 09 71 6695.

Ahn, H. et al., "Additive Soft Lithographic Patterning of Submicron and Nanometer-Scale Large Area Resists on Electronic Materials," *Nano Letters*, 5, 2533-2537 (2005).

Baca, A.J. et al., "Compact monocrystalline silicon solar modules with high voltage outputs and mechanically flexible designs," *Energy Environ. Sci*., 2010, 3, 208-211.

Baca, A.J. et al., "Printable single-crystal silicon micro/nanoscale ribbons, platelets and bars generated from bulk wafers," *Adv. Func. Mater*. 17, 3051-3062 (2007).

Bagnall, D.M. et al. "Photovoltaic Technologies," *Energy Policy*, 2008, 36, 4390.

Bergmann, R.B. "Crystalline Si thin-film solar cells: a review," *Appl. Phys*. A 69, 187-194 (1999).

Biancardo, M. et al., "Characterization of microspherical semi-transparent solar cells and modules," *Sol. Energy* 81, 711-716 (2007).

Bossert, R.H. et al., "Thin Film Solar Cells: Technology Evaluation and Perspectives," *ECN*, May 2000.

Brendel, R. "Review of layer transfer processes for crystalline thin-film silicon solar cells," *Jpn. J. Appl. Phys*. 40, 4431-4439 (2001).

Brendel, R. et al., "Ultrathin crystalline silicon solar cells on glass substrates," *Appl. Phys. Lett*. 70, 390-392 (1997).

Burgelman, M. et al. "Modeling Thin-Film PV Devices," *Progress in Photovoltaics* 12, 143-153 (2004).

Cahill, D.G. et al., "Thermal conductivity of epitaxial layers of dilute SiGe alloys," *Phys. Rev. B*, 71:23, 235202-1-4 (2005).

Campbell, P. et al., "Light Trapping Properties of Pyramidally Textured Surfaces," *J. Appl. Phys*. 62, 243-249 (1987).

Clugston, D.A. et al., "Modelling Free-Carrier Absorption in Solar Cells," *Progress in Phoovoltaics* 5, 229-236 (1997).

Clugston, D.A. et al., "PC1D version 5: 32-bit solar cell modeling on personal computers," *Photovoltaic Specialist Conference*, 1997, Conference Record of the Twenty-Sixth IEEE, 207-210.

Ebong, A. et al., "Rapid Thermal Processing of High Efficiency N-Type Silicon Solar Cells With Al back Junction," 14th World Conference on Photovoltaic Energy Conversion, Hawaii, USA; May 7-12, 2006.

Feng, N.-N. et al., "Design of Highly Efficient Light-Trapping Structures for Thin-Film Crystalline Silocon Solar Cells," *IEEE Trans. Elect. Dev*. 54, 1926-1933 (2007).

First Office Action dated Mar. 5, 2013 from Chinese Patent Application No. 200980116128.1—includes English translation.

Green, M.A. "Crystalline and thin-film silicon solar cells: state of the art and future potential," *Sol. Energy* 74, 181-192 (2003).

Heine, C. et al., "Submicrometer Gratings for Solar-Energy Applications," *Appl. Opt*. 34, 2476-2482 (1995).

International Search Report and Written Opinion, Corresponding to International Application No. PCT/US12/59131, mailed Apr. 8, 2013.

J. Wang et al., "Binding and Diffusion of a Si Adatom Around the Type-A Step on Si(01) c4x2," *Appl. Phys. Lett*., 66:15, 1954 (1995).

J. Yoon et al., "Arrays of Monocrystalline Silicon Solar Micro-cells for Modules with Ultra-thin, Mechanically Flexible, Semi-transparent and Micro-optic Concentrator Designs," Materials Research Society (MRS) Symposium P: Photovoltaic Materials and Manufacturing Issues, Fall Meeting, Dec. 3, 2008—Abstract provided.

J. Yoon et al., "Ultrathin silicon solar microcells for semitransparent, mechanically flexible and microconcentrator module designs," *Nat. Mater*., 2008, 7, 907.

Jeon, S. et al., "Fabricating three dimensional nanostructures using two photon lithography in a single exposure step," *Optics Express*, 14:6, 2300-23208 (2006).

Jeon, S. et al., "Optically fabricated three dimensional nanofluidic mixers for microfluidic systems," *Nano Letters*, 5:7, 1351-1356 (2005).

K. J. Weber et al., "A Novel Silicon Texturization Method Based on Etching Through a Silicon Nitride Mask," *Progress in Photovoltaics: Research and Applications* 13, 691-695 (2005).

Kazmerski, L.L. et al., "Solar photovoltaics R&D at the tipping point: A 2005 technology overview." *J. Elect. Spec. Rel. Phenom*. 150, 105-135 (2006).

Kerschaver, E. V. et al., "Back-contact Solar Cells: A Review," *Prog. Photovolt*. 14, 107-123 (2006).

Kunnavakkam, M.V. et al., "Low-cost, low-loss microlens arrays fabricated by soft-lithography replication process," *Appl. Phys. Lett*. 82, 1152-1154 (2003).

Lee, H.H. et al., "Fabrication of Large Area Stamps, Moulds, and Conformable Photomasks for Soft Lithography," *Journal of Nanoengineering and Nanosystems* 218, 105 (2005).

Lee, K.J. et al., "Bendable GaN High Electron Mobility Transistors on Plastic Substrates," *Journal of Applied Physics* 100, 124507 (2006).

Lei, C. et al., "Grain Boundary Compositions in Cu(InGa)Se$_2$," *J. Appl. Phys*., 101:2, 24909-1-7 (2007).

Lei, C. et al., "Void formation and surface energies in Cu(InGa)Se$_2$," *J. Appl. Phys*. 100:7, 073518 (2006).

Liao, D. et al., "Cu depletion at the CuInSe$_2$ Surface," *Appl. Phys. Lett*., 82:17, 2829-2831 (2003).

Liu, Z.X. et al., "A concentrator module of spherical Si solar cell," *Sol. Energy Mater. Sol. Cells* 91, 1805-1810 (2007).

Love, J.C. et al., "Self-Assembled Monolayers of Thiolates on metals as a Form of Nanotechnology," *Chem. Rev*., 105, 1103-1169 (2005).

M.E. Stewart et al., "Quantitative Multispectral Miosensing and 1-D Imaging Using Quasi-3D Plasmonic Crystals," *Proc. Nat. Acad. Sci*., 103, 17143-17148 (2006).

Mack, S. et al., "Mechanically flexible thin-film transistors that use ultrathin ribbons of silicon derived from bulk wafers," *Appl. Phys. Lett*., 88, 213101 (2006).

Malyarchuk, V. et al., "High performance plasmonic crystal sensor formed by soft nanoimprint lithography," *Optics Express*, 13:15, 5669-5675 (2005).

Mercaldo, L.V. et al., Thin film silicon photovoltaics: Architectural perspectives and technological issues, *App. Energy*, 2009, 86, 1836.

Minemoto, T. et al., "Fabrication of spherical silicon crystals by dropping method and their application to solar cells," *Jpn. J. Appl. Phys*. 46, 4016-4020 (2007).

Nelson, B. et al., "Amorphous and Thin-Film Silicon," *NCPV and Solar Program Review*, NREL/CD-520-33586, 583-585, 2003.

Nelson, B. et al., "Project Summary of the NREL Amorphous Silicon Team," NCPV and Solar Program Review, NREL/CD-520-33586, 825-828, 2003.

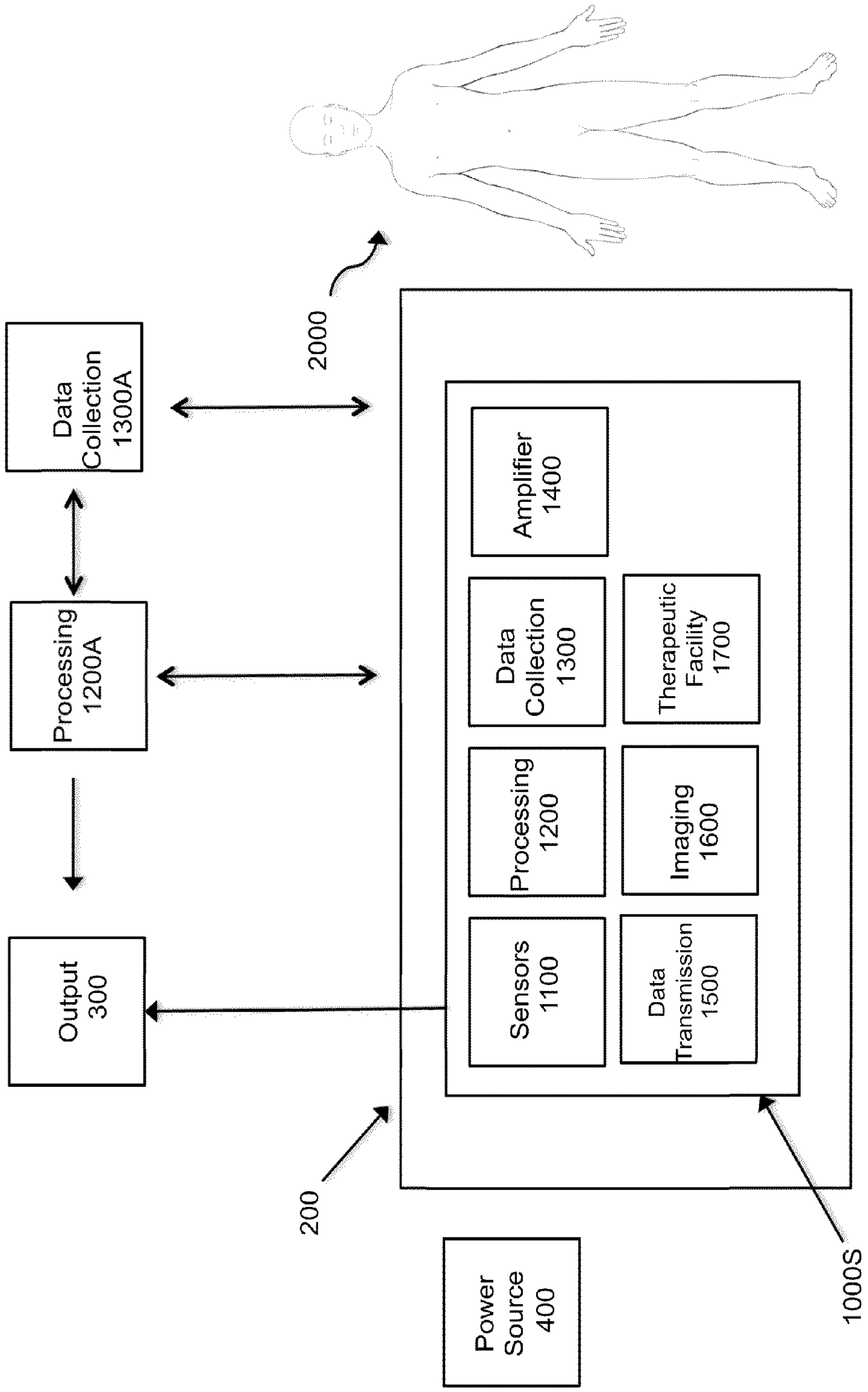
Niggemann, M. et al., Realization of Ultrahigh Photovoltaics with Organic Photovoltaic Nanomodules, *Adv. Mater*. 2008, 20, 4055.

(56) References Cited

OTHER PUBLICATIONS

Notice of Allowance corresponding to Korean Patent Application No. 10-20102-7010094, dated Feb. 25, 2013—includes English translation.
Notice of Allowance, U.S. Appl. No. 12/398,811 mailed May 24, 2013.
Notice of Final Rejection for Japanese Patent Application No. 2006-16159, dated Apr. 16, 2013.
Notice of Preliminary Rejection corresponding to Korean Patent Application No. 10-2007-7000216, dated Feb. 21, 2013—includes English translation.
Notice of Preliminary Rejection corresponding to Korean Patent Application No. 10-2012-7030789, dated Feb. 25, 2013—includes English translation.
Office Action, Corresponding to Chinese Patent Application No. 2009801161280.1, mailed Mar. 5, 2013.
Office Action, Corresponding to U.S. Appl. No. 13/441,618, mailed May 23, 2013.
Office Action, Corresponding to U.S. Patent Appl. No. 13/120,486, mailed Apr. 12, 2013.
Orega, P. et al., "High Voltage Photovoltaic Mini-modules," *Progr. Photovolt.: Res. Appl.*, 2008, 16, 369.
Pizzini, S., "Bulk solar grade silicon: how chemistry and physics play to get a benevolent microstructured material," *Appl. Phys. A: Mater. Sci. Process.*, 2009, 96, 171.
R. Rockett et al., "Prediction of dopant ionization energies in silicon: The importance of strain," *Physical Review B*, 6823:23, 3208 (2003).
Rockett, A. "The effect of Na in polycrystalline and single crystal CuIn$_{1-x}$Ga$_x$Se$_2$ " *Thin Solid Films*, 480-1, 2-7 (2005).
Rockett, A. et al., "A Monte Carlo simulation of the growth of Si(001)2x1: adatom/SA step interactions and growth mechanisms," *Surf. Sci.*, 312, 201-212 (1994).
Rockett, A. et al., "Near-surface Defect Distributions in Cu(In,Ga)Se$_2$" *Thin Solid Films*, 431-2, 301-306 (2003).
Roedern, B. "Status of Amorphous and Crystalline Thin-Film Silicon Solar Cell Activities," NCPV and Solar Program Review, NREL/CD-520-33586, 552-555, 2003.
Ruby, D.S. et al., "Rie-texturing of multicrystalline silicon solar cells," *Solar Energy Materials & Solar Cells* 74, 133-137 (2002).
Sha, A. et al., "Recent progress on microcrystalline solar cells.," *Photovoltaic Specialists Conference, Conference Record of the Twenty-Sixth IEEE*, 569-574 1997).
Sinton, R.A. et al., "27.5-Percent Silicon Concentrator Solar-Cells," *IEEE Elect. Dev. Lett.* 7, 567-569 (1986).
Sobajima et al., "Microstructures of high-growth-rate (up to 8.3 nm/s) microcrystalline silicon photovoltaic layers and their influence on the photovoltaic performance of thin-film solar cells," *J. Non-Cryst. Solids*, 2008, 354, 2407.
Sun, Y. et al., "Gigahertz Operation in Mechanically Flexible Transistors on Plastic Substrates," *Applied Physics Letters* 88, 183509 (2006).
Sun, Y. et al., "Printed Arrays of Aligned GaAs Wires for Flexible Transistors, Diodes and Circuits on Plastic Substrates," *Small* 2(11), 1330-1334 (2006).
Sun, Y. et al., "Top Down Fabrication of Semiconductor Nanowires With Alternating Structures Along Their Transverse and Longitudinal Axes," *Small* 1(11), 1052-1057 (2005).
Taguchi, M. et al., "HIT™ cells—High efficiency crystalline Si cells with novel structure," *Prog. Photovolt.* 8, 503-513 (2000).
Verlinden, P.J. et al., "Silver (R) solar cells: a new thin-crystalline silicon photovoltaic technology," *Sol. Energy Mater. Sol. Cells* 90, 3422-3430 (2006).
Weber, K.J. et al. "A Novel-Low Cost, High Efficiency Micromachined Silicon Solar Cell," *IEEE Electron Device Letters*, vol. 25, No. 1, 37-39 (2004).
Wenham, S.R. et al., "Buried contact silicon solar cells," *Solar Energy Materials and Solar Cells*, 34, 101-110 (1994).
Yamamoto, K. et al., "Thin-film poly-Si solar cells on glass substrate fabricated at low temperature," *Applied Physics A: Materials Science & Processing* 69, 179-185 (1999).
Zhao et al., "24.5% efficiency silicon PERT cells on MCZ substrates and 24.7% efficiency PREL cells on FZ substrates," *Prog. Photovolt.* 7, 471-474 (1999).
International Search Report and Written Opinion, Corresponding to International Application No. PCT/US2012/039779, mailed Feb. 1, 2013.
International Search Report and Written Opinion corresponding to International Application No. PCT/US2012/058114 mailed Feb. 1, 2013.
Notice of Reasons of Rejection corresponding to Japanese Patent Application No. 2009-527564, mailed Jan. 29, 2013.
Notification of Grant of Patent Right and Notice of Registration corresponding to Chinese Patent App. No. 200780041127.6 issued Dec. 26, 2012.
Office Action for U.S. Appl. No. 13/441,598 mailed Jan. 14, 2013.
Office Action, Corresponding to U.S. Appl. No. 12/778,588 mailed Jan. 8, 2013.
Examination and Search Report, Corresponding to Malaysian Patent Application No. PI 20090622, Mailed Sep. 28, 2012.
Final Office Action mailed Nov. 21, 2012 corresponding to U.S. Appl. No. 12/921,808.
International Search Report and Written Opinion, Corresponding to International Application No. PCT/US12/46930 mailed Dec. 10, 2012.
International Search Report and Written Opinion Corresponding to International Application No. PCT/US2012/053701 mailed Jan. 15, 2013.
Notice of Final Rejection for Japanese Patent Application No. 2007-515549, dated Sep. 19, 2012.
Office Action, Corresponding to U.S. Appl. No. 12/398,811 mailed Nov. 26, 2012.
Second Substantive Office Action corresponding to Chinese Patent Application No. 20100519400.5 issued on Oct. 30, 2012.

* cited by examiner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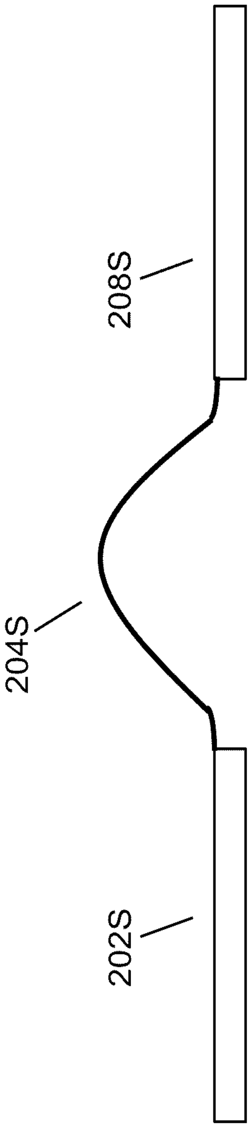

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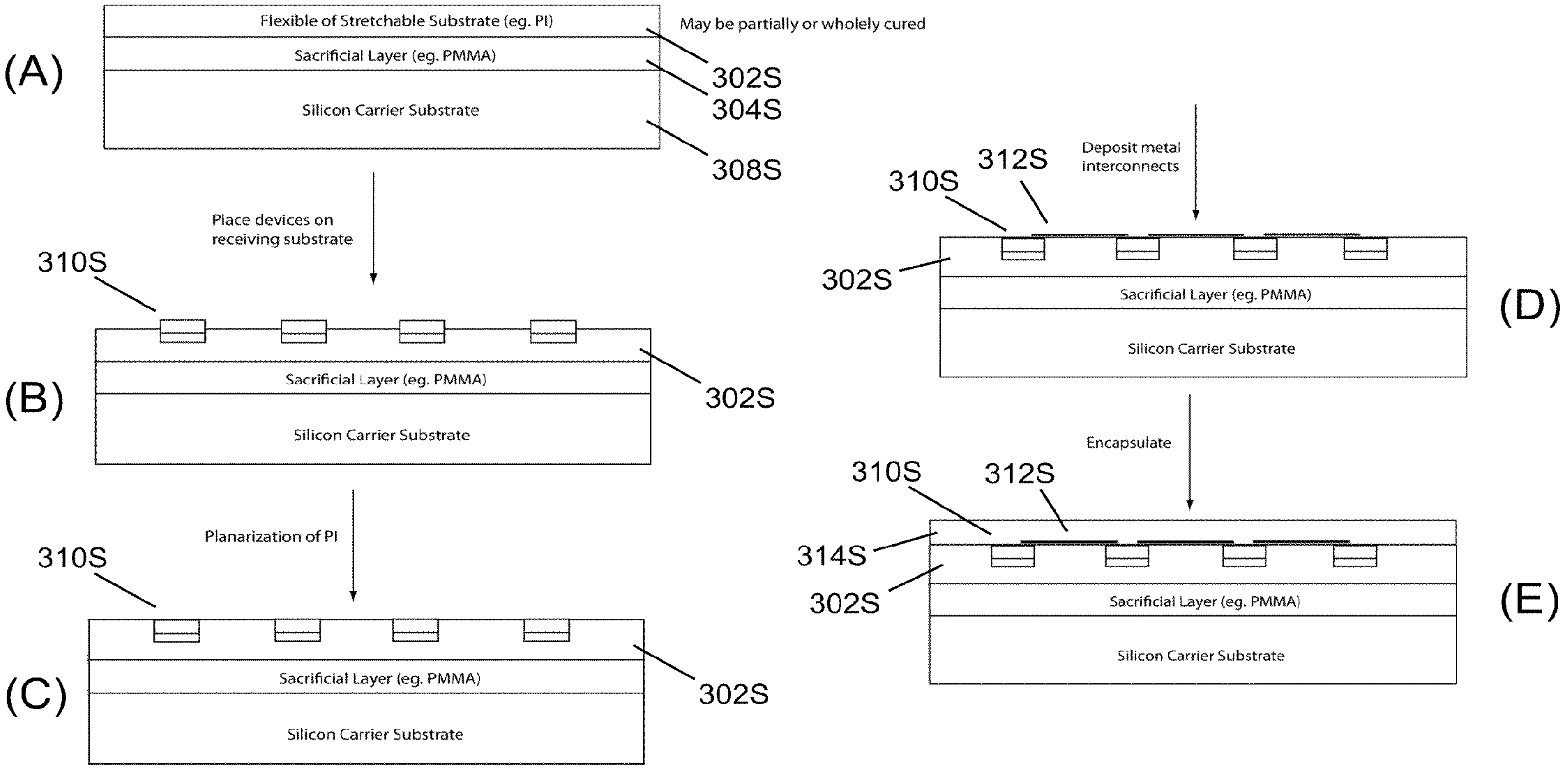
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Flexible of Stretchable Substrate (eg. PI)
Sacrificial Layer (eg. PMMA)
Silicon Carrier Substrate
May be partially or wholely cured
302S
304S
308S
Place devices on receiving substrate
310S
(B)
Sacrificial Layer (eg. PMMA)
Silicon Carrier Substrate
302S
Planarization of PI
310S
(C)
Sacrificial Layer (eg. PMMA)
Silicon Carrier Substrate
302S
310S
312S
Deposit metal interconnects
302S
Sacrificial Layer (eg. PMMA)
Silicon Carrier Substrate
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Encapsulate
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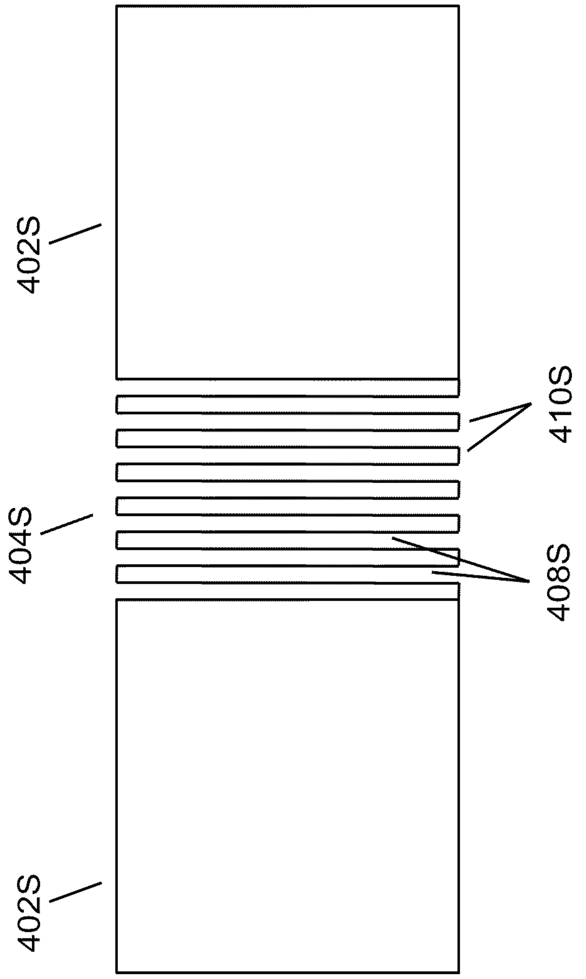
Silicon Carrier Substrate
(E)

Figure 3



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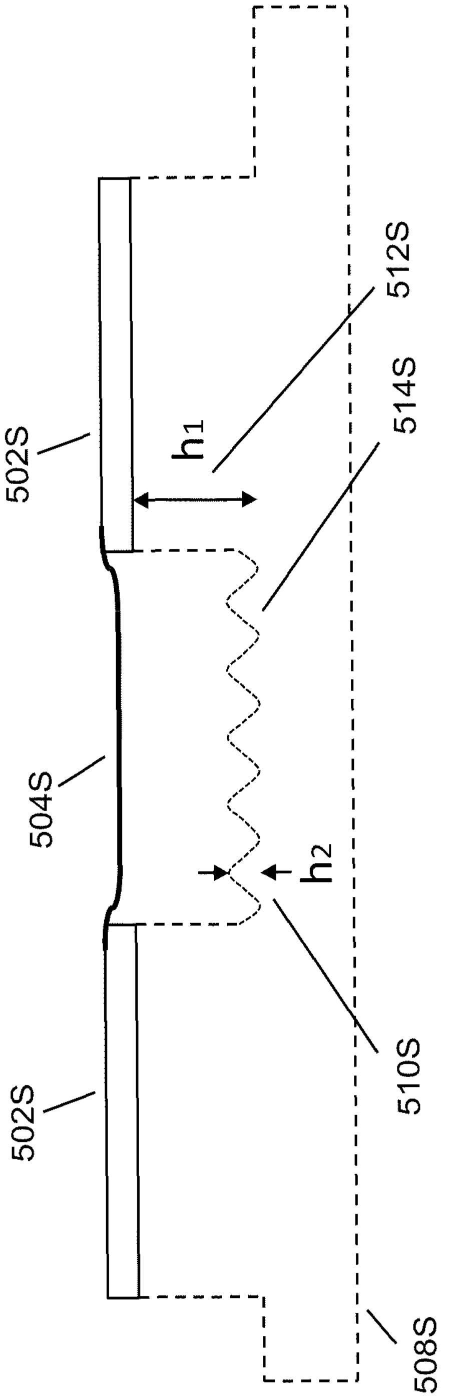

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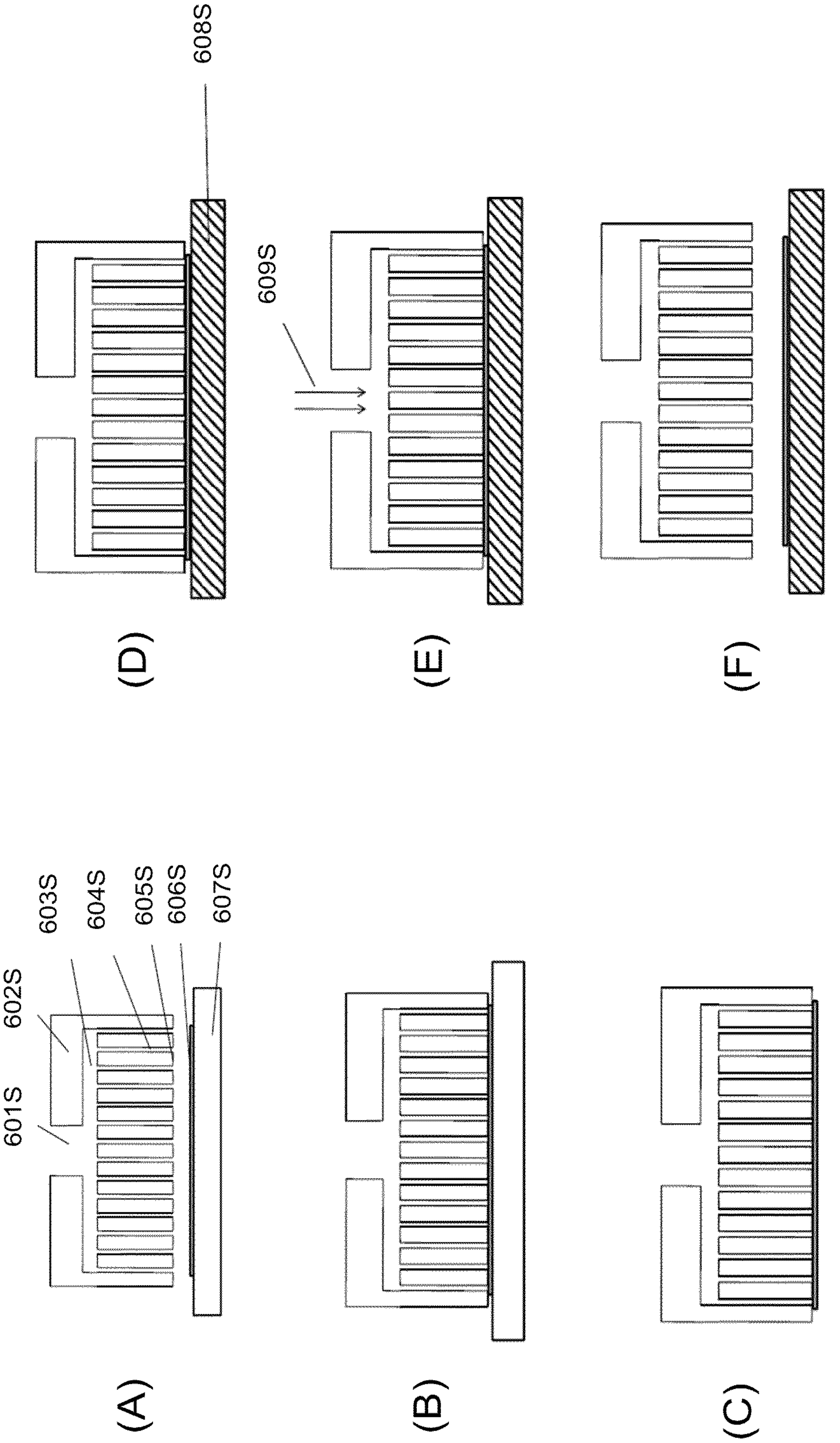

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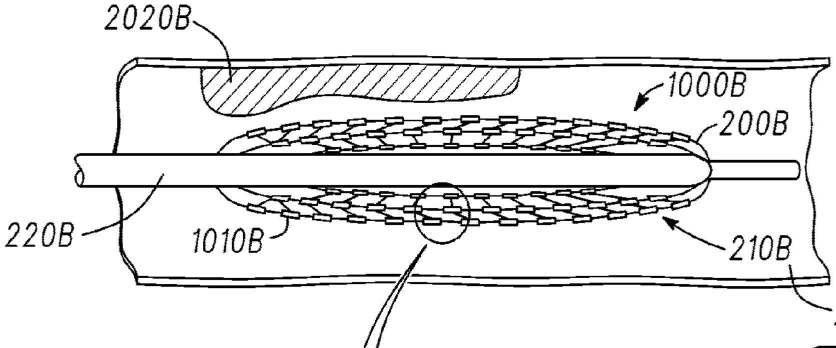

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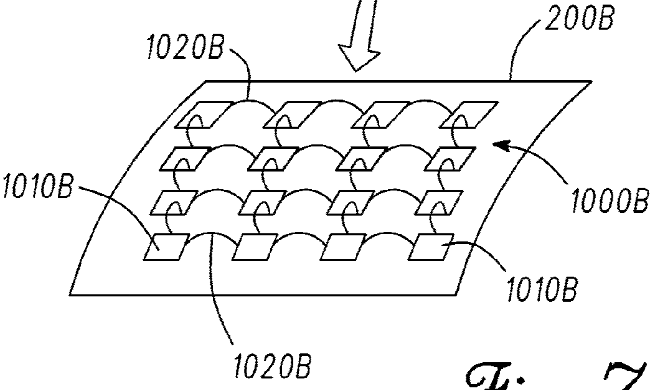

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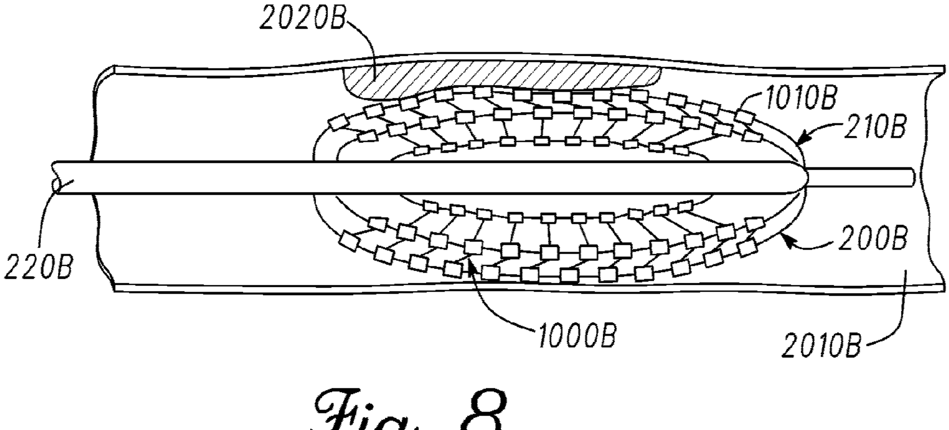

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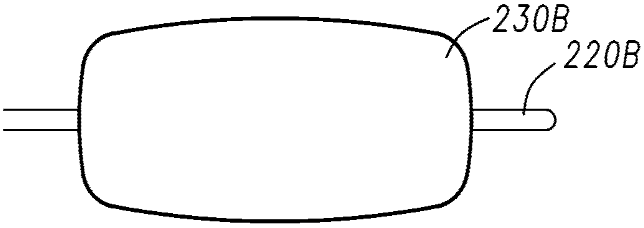

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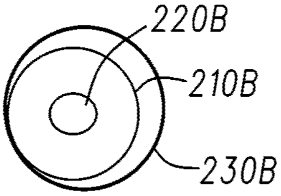

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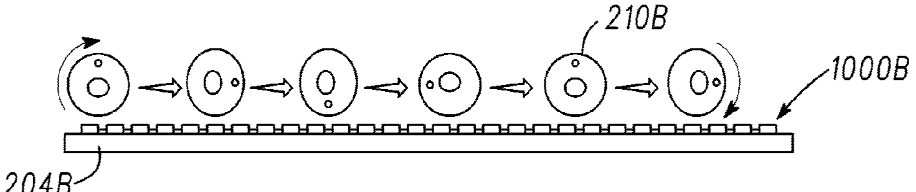

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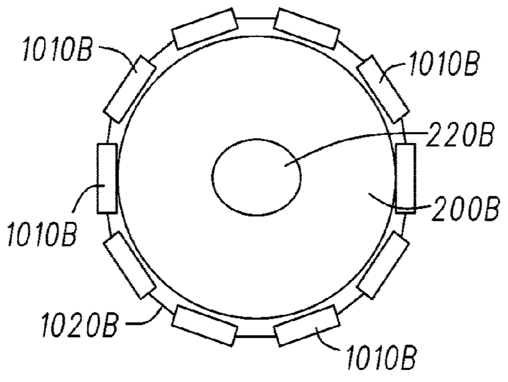

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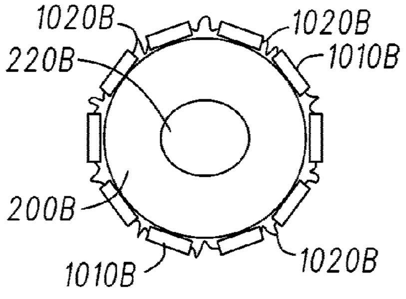

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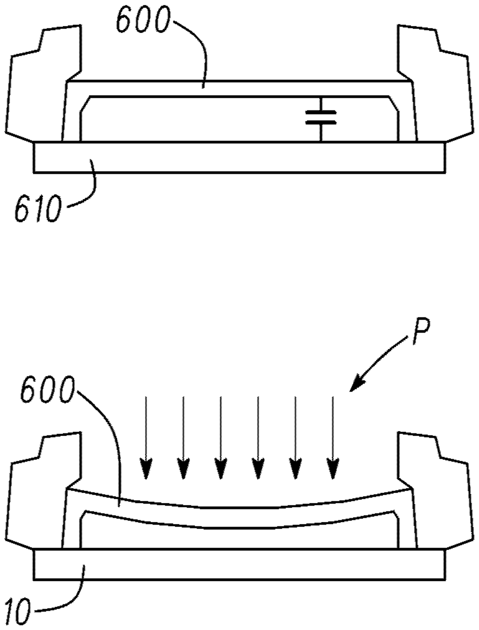

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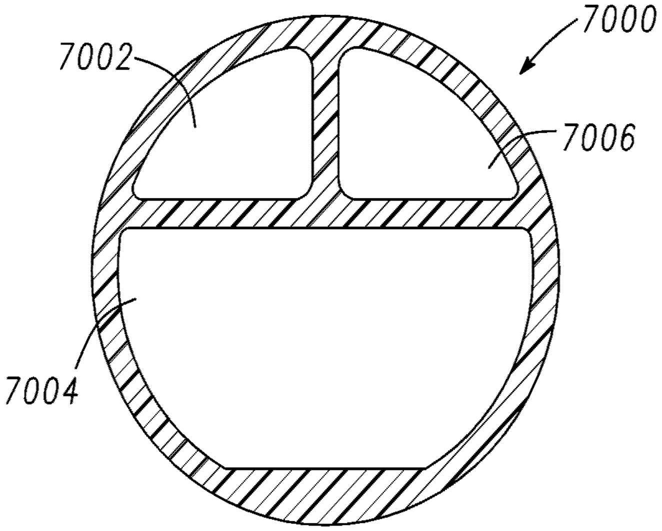

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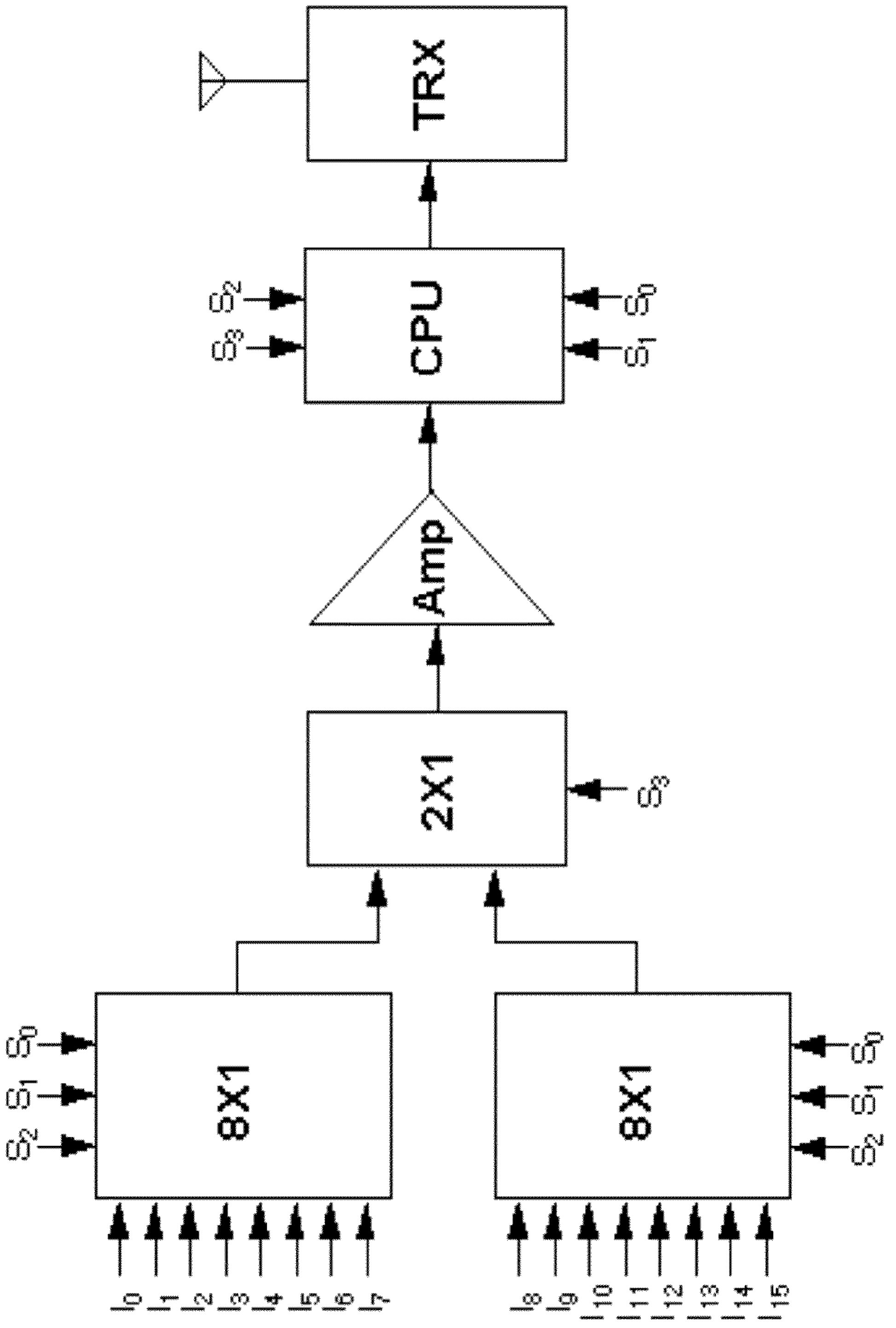
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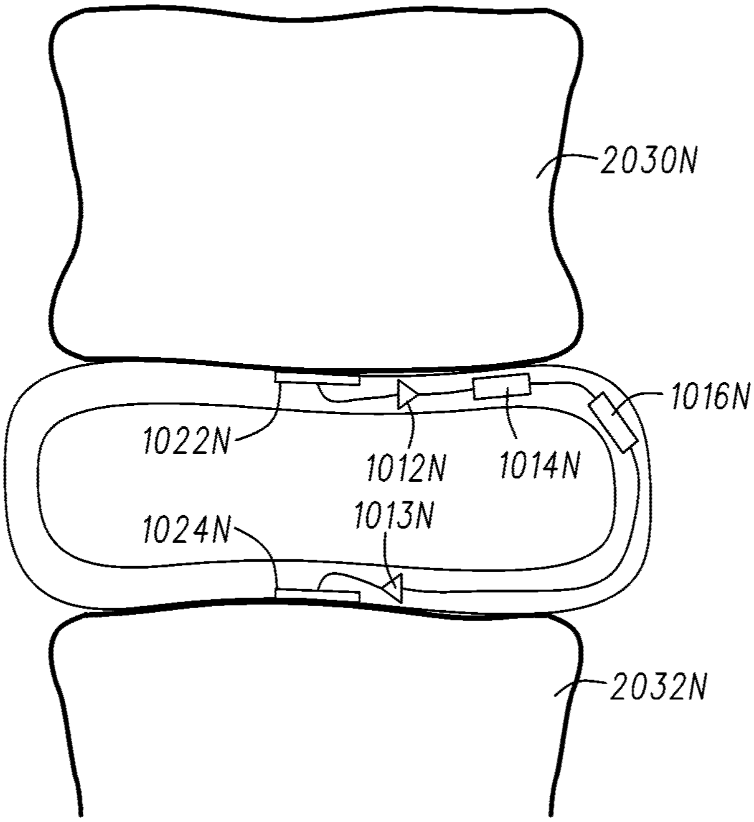
Figure 10F



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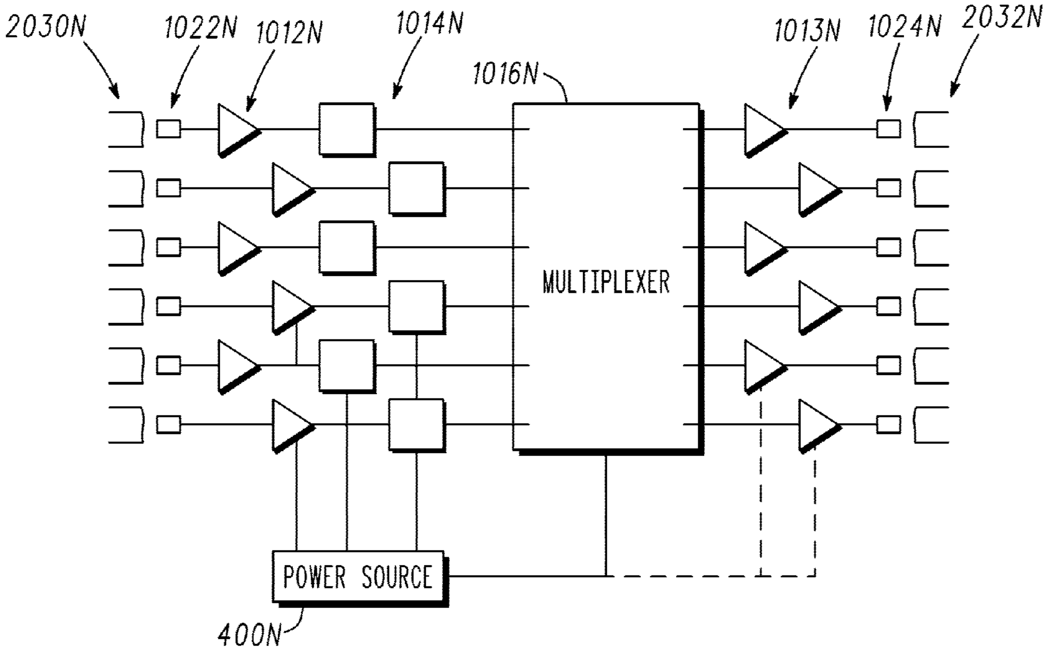
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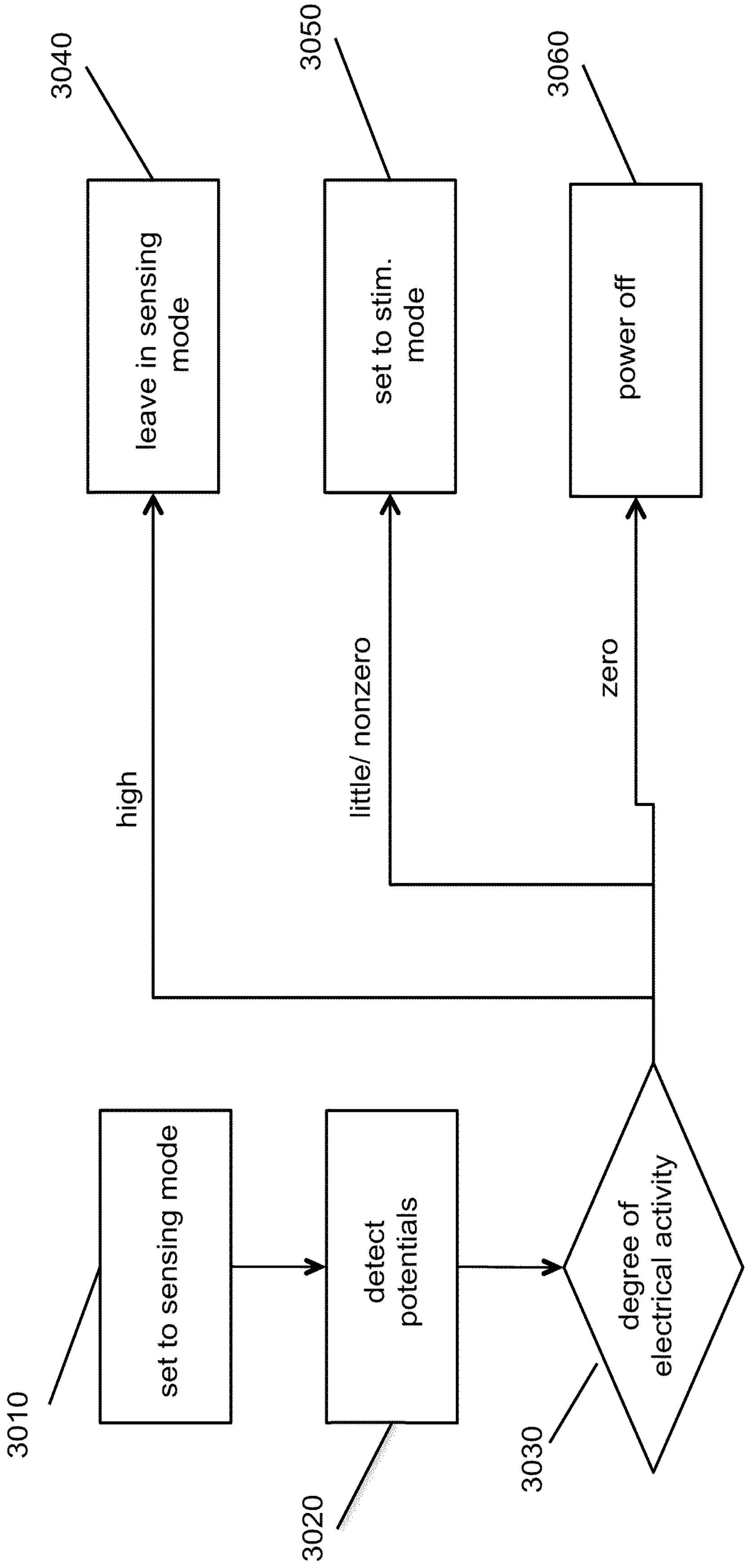
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Figure 13

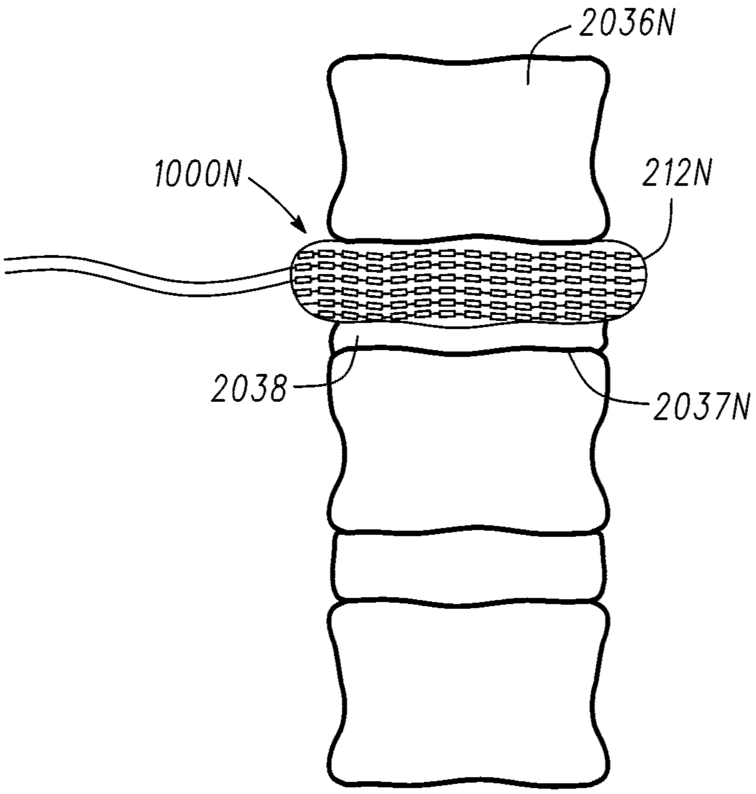


Fig. 14

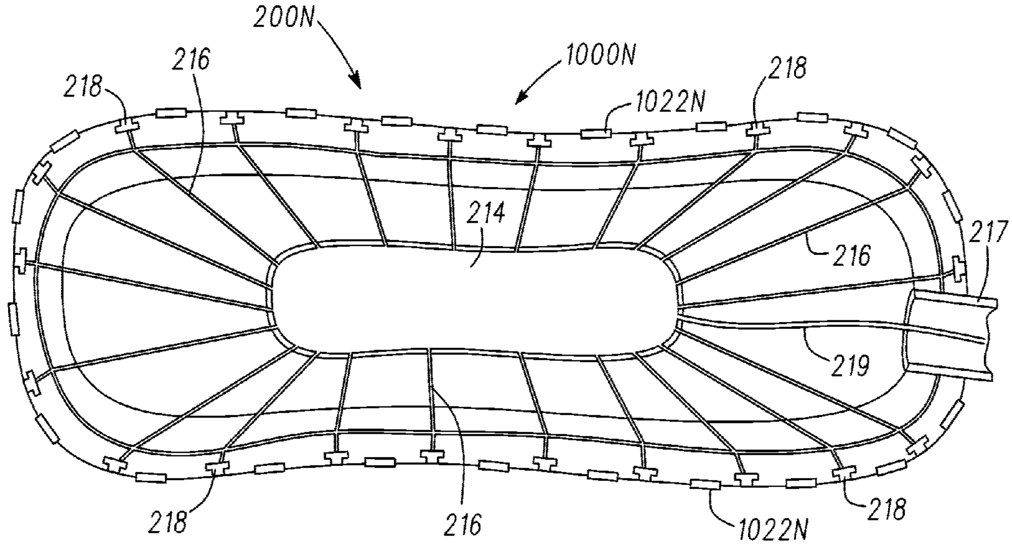
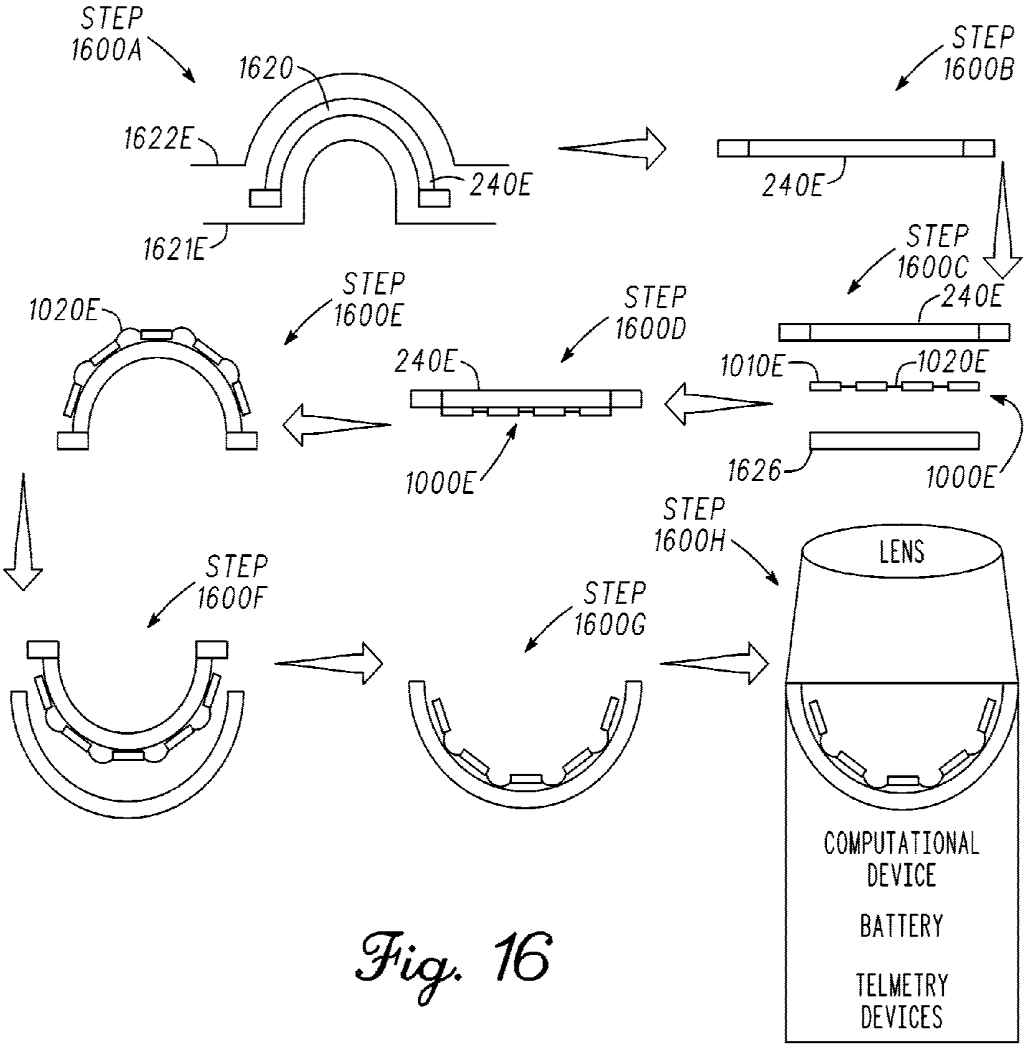


Fig. 15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1620
1622E
240E
1621E
STEP 1600B
240E
STEP 1600C
240E
1010E
1020E
1626
1000E
STEP 1600D
240E
1000E
STEP 1600E
1020E
STEP 1600F
STEP 1600G
STEP 1600H
LENS
COMPUTATIONAL DEVICE
BATTERY
TELMETRY DEVICES

Fig. 16

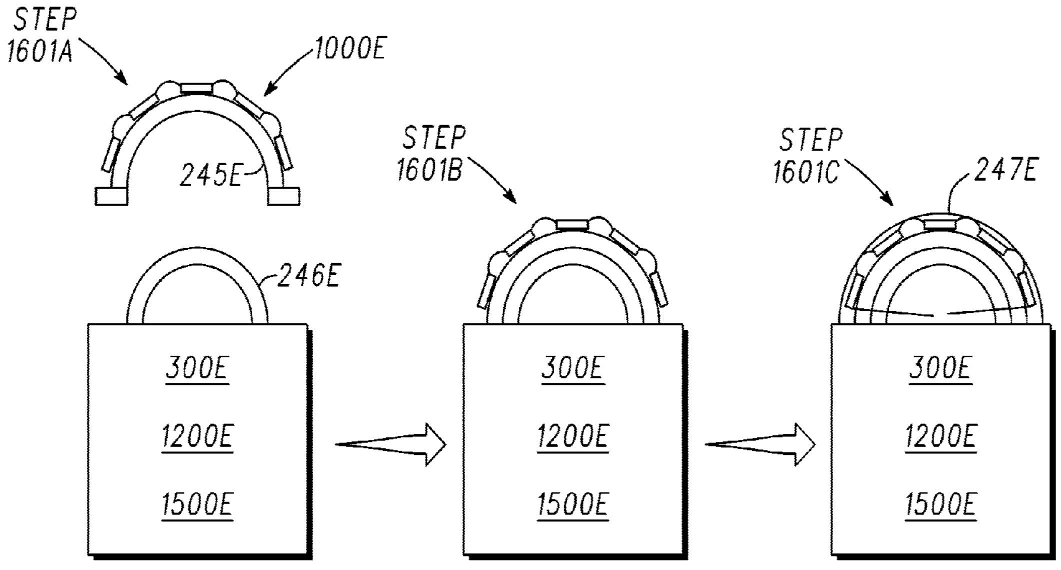
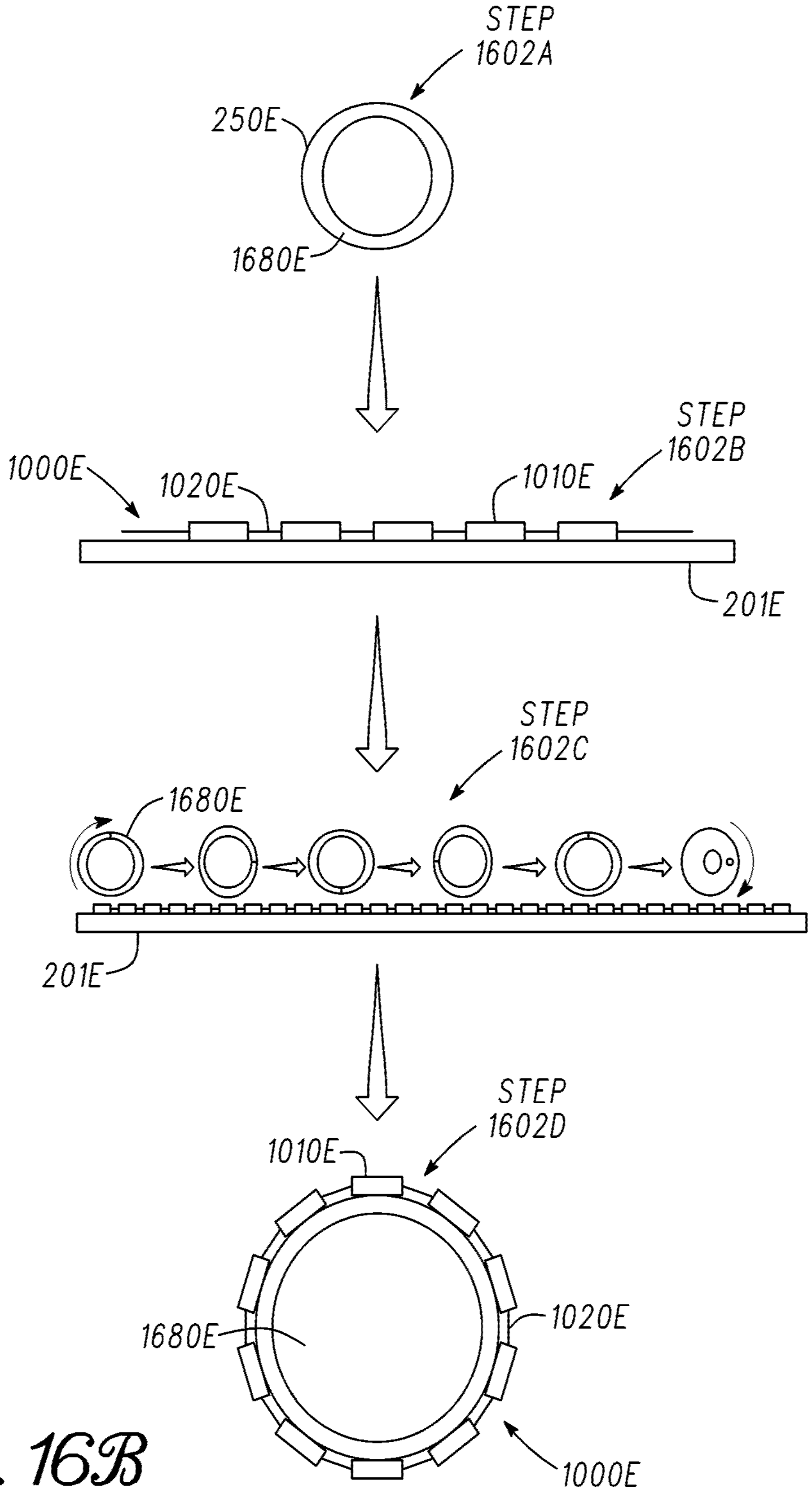

STEP 1601A
1000E
245E
246E
300E
1200E
1500E
STEP 1601B
300E
1200E
1500E
STEP 1601C
247E
300E
1200E
1500E
1680E

Fig. 16A


STEP
1602A
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1680E
STEP
1602B
1000E
1020E
1010E
201E
STEP
1602C
1680E
201E
STEP
1602D
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1020E
1680E
1000E

Fig. 16B

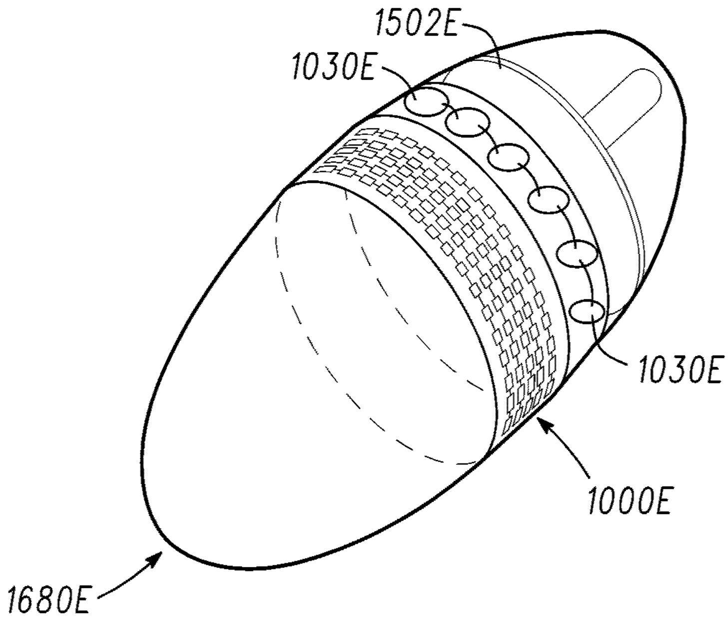

Fig. 17

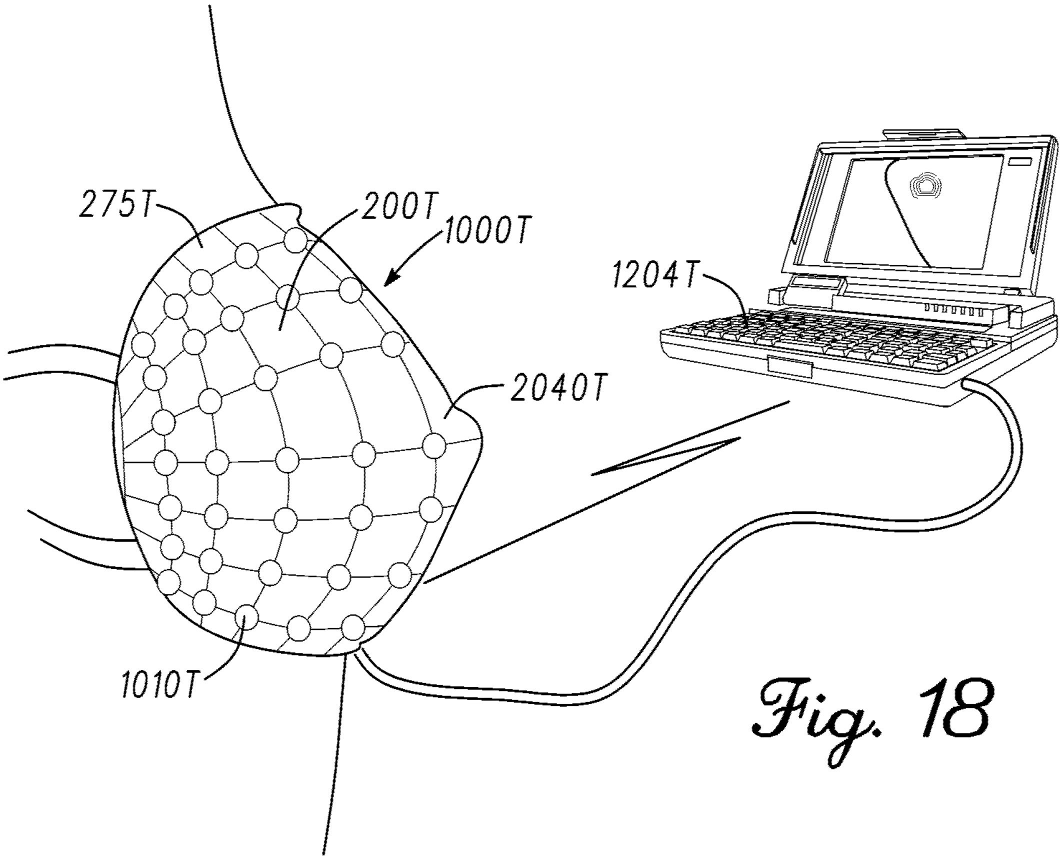

Fig. 18

SYSTEMS, METHODS, AND DEVICES USING STRETCHABLE OR FLEXIBLE ELECTRONICS FOR MEDICAL APPLICATIONS

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of the following U.S. Provisional Applications: Ser. No. 61/121,568 entitled "Endoscopy Device" filed Dec. 11, 2008; Ser. No. 61/121,541 entitled "Nerve Bundle Prosthesis" filed Dec. 11, 2008; and Ser. No. 61/140,169 entitled "Body Tissue Screener" filed Dec. 23, 2008, the entirety of each of which is incorporated herein by reference. Further, this application is a continuation-in-part of and claims the benefit of copending U.S. Nonprovisional patent application Ser. No. 12/616,922 entitled "Extremely Stretchable Electronics" filed Nov. 12, 2009, the entirety of which is incorporated herein by reference. Nonprovisional patent application Ser. No. 12/616,922 claims the benefit of U.S. Provisional Application No. 61/113,622 entitled "Extremely Stretchable Interconnects" filed on Nov. 12, 2008, the entirety of which is incorporated herein by reference. Also, Nonprovisional patent application Ser. No. 12/616,922 is a continuation-in-part of, and claims the benefit of copending U.S. Non-Provisional Application Ser. No. 12/575,008, entitled "Catheter Balloon Having Stretchable Integrated Circuitry and Sensor Array" filed on Oct. 7, 2009, the entirety of which is incorporated herein by reference. Nonprovisional Application Ser. No. 12/575,008 claims priority to U.S. Provisional Application No. 61/103,361 entitled "Catheter Balloon Sensor and Imaging Arrays", filed Oct. 7, 2008, the entirety of which is incorporated herein by reference; and U.S. Provisional Application No. 61/113,007 entitled "Catheter Balloon with Sensor and Imaging Array", filed Nov. 10, 2008 the entirety of which is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention relates to systems, apparatuses, and methods utilizing expandable or stretchable integrated circuitry and sensor arrays on expandable, flexible or stretchable substrates in or on medical devices.

BACKGROUND OF THE INVENTION

High quality medical sensing and imaging data has become important in the diagnoses and treatment of a variety of medical conditions include those related to conditions associated with the digestive system, conditions related to the cardiocirculatory system, injuries to the nervous system, cancer, and the like. Current sensing and therapeutic devices suffer from various disadvantages due to a lack of sophistication related to the sensing, imaging, and therapeutic functions. One of these disadvantages is that such devices are unable to achieve direct or conformal contact with the part of the body being measured or treated. The inability to achieve direct or conformal contact of such devices is partially attributable to the rigid nature of the devices and accompanying circuitry. This rigidity prevents devices from coming into confirming and/or direct contact with human tissue, which as readily apparent may change shape and size, and may be soft, pliable, curved, and/or irregularly shaped. Such rigidity thus compromises accuracy of measurements and effectiveness of treatment. Thus, devices, systems and methods, which employ flexible and/or stretchable systems would be desirable.

Examples of areas that are amenable to such flexible and/or stretchable approaches include, endoscopy, vascular examination and treatment, neurological treatment and examination, and tissue screening.

As an example, endoscopic imaging of the gastrointestinal (GI) tract is essential for effective diagnosis and treatment of a variety of GI disorders, including inflammations, ulcers, abscesses, and cancer detection. By way of elaboration, endoscopic imaging capsules may offer certain advantages over traditional endoscopes for a variety reasons: they involve minimal patient discomfort and can image regions along the GI tract that are inaccessible with traditional endoscopes. All components are encapsulated within an ellipsoid body whose volume must be small enough to be swallowed and ingested. Consequently, there is an added benefit to minimizing the volume of these ingestible capsules. There also are a variety of features, including power storage and imaging quality that can be significantly improved if the spatial layout of the components within the capsule could be optimized. Additionally, optical imagers in current endoscopic capsules generally have a planar geometry, with the imager aligned with the optical center of the lens. This geometry is subject to intrinsic limitations such as aberrations, peripheral distortion and illumination inhomogeneity. Stretchable and/or flexible circuitry could mitigate some of the disadvantages described above with respect to capsule endoscopy, as well as traditional endoscopic devices.

Spinal cord and other complex brain or nerve injury is a major cause of disability, death and suffering, and to date there are few effective treatments. As an example, the complexity of the spinal cord, consisting of thousands of nerve fibers and both dark and gray matter, makes surgical repair extremely difficult, with a high degree of additional irreversible injury. Therefore, much attention has been focused on reducing scarring and stimulating regeneration with pharmaceuticals or stem cells. Bionic solutions have also gained some interest. Experiments have been conducted on electrical sensing and stimulation of ascending and descending bundles, demonstrating that electrical impulses can be used to provide some level of function. Separately, there are devices in clinical use which perform electrical stimulation of nerves in and near the spine to treat chronic pain, but these are not intended to restore nerve function. Combining the benefits of these existing devices may not go far enough toward dramatically improving spinal cord therapies due to some of the limitation mentioned above. Accordingly, there is a need for dynamically configurable and conformable devices, systems, and methods that minimize the risk of further injury while providing increased function to the damaged nerves.

Another example where the benefits of flexible/and or stretchable devices are needed involves tissue screening. While tissue screening procedures are of paramount important for early detection, evaluation, and subsequent treatment of cancer, clinical diagnostic methods, such as mammography and ultrasound imaging are expensive and require trained personnel. Thus, almost two-thirds of cancers are initially detected by palpatory (i.e. tactile sense of touch) self-examination. Palpatory examination is a qualitative technique taught to women, for example, as a preclinical test for breast cancer to be conducted at the home. It is well known that cancerous tissue undergoes significant changes in mechanical properties with respect to healthy tissue. Local lesions in breast cancer tissue are stiffer by up to 2-fold. Although self-examinations of breast tissue have facilitated early detection of hardened legions, indicative of tumor growth, the qualitative nature of these tests makes it difficult to ascertain any quantitative data important to clinicians or to analyze trends over time. Because the self-examination approach generally involves manually detecting the location, size, shape, and density of lesions by conforming fingertips around the lesion, a device capable of achieving conformal contact with the tissue of interest that can quantify and record the intrinsic mechanical properties of tissue can have a significant impact on the way breast cancer screening is currently performed at the home and in the clinical setting as a supplement to mammography and ultrasound.

Finally, detection and treatment of conditions in the cardiovascular system would greatly benefit from approaches that increase the quality of data generated by sensing devices, techniques, and methods. Currently, such sensing techniques devices and methods are greatly limited by their inability to achieve close, direct, and or conformal contact with the area of interest. Therefore, gathering data relating to the electrical, chemical, and other physical activity or condition of the tissue is compromised.

Stretchable and/or flexible electronics can mitigate or resolve many of the shortcomings described above. Such techniques can be applied to the areas above, or to any area of physiological sensing, medical detection, or medical diagnostics that would be improved by enhanced contact with sensing or therapeutic devices.

SUMMARY OF THE INVENTION

Methods, systems, and devices are disclosed herein which employ stretchable/and or flexible circuitry for physiological sensing, detection of health-related parameters, and delivery of therapeutic measures. In embodiments, the circuitry is disposed on a stretchable, flexible, expandable, and/or inflatable substrate. In embodiments, circuitry comprises electronic devices, which may be active devices, in electronic communication with one another and programmed or configured to generate output and cause an output facility to display such output, deliver therapeutic measures, generate data regarding physiological parameters and/or make determinations of a health-related condition. Embodiments of the invention may include a storage facility in communication with the processing facility. The processing facility may cause at least one of data generated by the active devices and the output data to be stored in the storage facility and may generate output data related to the stored data. The processing facility may cause at least one of data generated by the active devices and the output data to be aggregated and may generate output data related to the aggregated data.

In embodiments, the methods and systems herein may comprise a neural prosthesis device. Thus, in an aspect of the invention, methods, devices and systems include an apparatus that may include a substrate on which is disposed circuitry that may include an array of recording electrodes for receiving signals from a plurality of nerve sources when a portion of the electrodes is in electrical contact with the plurality of nerve sources and an array of stimulating electrodes; and a processing facility in electronic communication with the arrays of electrodes, and being configured to receive signals from the recording electrodes and determine a pattern of stimulation signals to be effected by the stimulating electrodes.

In the aspect mentioned above and in other embodiments, the electrical contact may comprise physical contact. Further in embodiments, the apparatus may include a multiplexer configured to match the signals from the nerve sources and cause the stimulating electrodes to dispatch a corresponding signal to a second plurality of nerves. The apparatus may include a user interface to adjust the pattern of stimulation signals, which may be dynamically configurable.

In embodiments, the substrate is an inflatable body which may be a disk or a balloon.

In the aspect mentioned above, the processing facility is further configured to generate data related to the electrical conductivity of the nerve sources. The processing facility may be in electronic communication with an output facility and may cause the output facility to generate a map based on the data related to the electrical conductivity of the nerve sources.

In the aspect mentioned above and in other embodiments, the circuitry may be encapsulated with a thin polymer layer. The circuitry may be stretchable up to 300%. The electrodes may located discretely from one another. The circuitry may comprise stretchable electrical interconnects which may electrically connect the electrodes.

In embodiments, the circuitry may include sensors that may include any of temperature sensors, contact sensors, light or photo detectors, ultra sound emitters and transceivers, pressure sensors, or the like.

In this aspect mentioned in conjunction with the neural prosthesis and with respect to other embodiments disclosed herein, the substrate may include a reservoir in communication with the surface of the substrate, and the circuitry may be configured to open valves operable to release a drug contained within the reservoir where the circuitry may cause the valves to release the drug in a controlled manner.

In other embodiments, the methods and systems herein may comprise an inflatable device for sensing tissues.

Thus, in another aspect of the invention, methods and systems include an apparatus that may include an inflatable substrate on which may be disposed circuitry that remains functional upon inflation of the substrate and may include an array of active devices that may include sensing devices for detecting data indicative of a parameter associated with a tissue; and a processing facility in electronic communication with the circuitry, receiving data indicative of a parameter associated with the tissue; and an output facility in electronic communication with the processing facility, where the processing facility may be configured to generate output data associated with the tissue and to cause the output facility to generate output data.

In the aspect mentioned above for sensing tissues and in other embodiments, the processing facility may receive data generated by the sensing devices and produce an image of the tissue. In embodiments, the sensing devices are configured to be in an active matrix which may be operated by circuitry which may include at least one of an amplifier and a logic circuit. Further, the apparatus may include a multiplexer which may be located at the base of a catheter guide wire coupled to the substrate which may be a balloon.

In embodiments, the processing facility may be within the circuitry. In other embodiments, the processing facility may be separate from the circuitry.

In this aspect mentioned above with respect to sensing tissue parameters, the output data related to the tissue may be a map which may include a map of electrical activity of the tissue. The output data may comprise data related to temperature heterogeneity present in arterial plaque. Further, the output data may comprise an indication of plaque type.

In aspects mentioned above and in other embodiments, the circuitry may comprise a therapeutic facility which may be configured to ablate the tissue. The circuitry may comprise light emitting electronics. The circuitry may comprise an array of photodetectors in communication with the processing facility where the processing facility may be configured to generate image of the tissue and to cause the output facility to output an image which may be high resolution. Where the circuitry is delivered via a catheter having a guide wire, the guide wire may include a light source, which may be an optical fiber, to provide light to the photodetectors.

In embodiments, the tissue of interest may include any of a pulmonary vein, a septal wall of a heart, an atrial surface of a heart, and a ventricular surface of a heart.

In another aspect of the invention, methods and systems include a method of detecting parameters associated with a lumen in the body of an individual. The method may include inserting an un-inflated balloon catheter into the lumen, the balloon catheter having a stretchable balloon having stretchable circuitry applied thereto, the stretchable circuitry comprising sensing devices; directing the sensing devices to be in an area of interest within the lumen; and inflating the balloon and causing the sensing devices to come into conformal contact with surface of the area of interest within the lumen.

With respect to embodiments mentioned above and others disclosed herein, the invention may comprise sensing devices to generate data indicative of a parameter of the area of interest when the sensing devices are in conformal contact with the area of interest. Like other embodiments, the generated data may be used to produce any of an image of the area of interest and a map of the area of interest where the map may include data indicative of the electrical activity of the area of interest.

In another aspect of the invention, methods and systems include a method of detecting parameters associated with a lumen in the body of an individual. The method may include inserting an un-inflated balloon catheter into the lumen, the balloon catheter having a stretchable balloon having stretchable circuitry applied thereto, the stretchable circuitry comprising sensing devices; directing the sensing devices to be in an area of interest within the lumen; and inflating the balloon and causing the sensing devices to come into partial sensing contact with surface of the area of interest within the lumen.

In yet an aspect of the invention, methods and systems include a method of detecting a parameter of a tissue. The method may include placing an array of active sensing devices in conformal contact with the tissue, the array comprising stretchable circuitry; generating data with the sensing devices; and determining the parameter from the generated data.

The methods and systems herein may comprise a tissue screening device.

Thus, in still yet another aspect of the invention, methods and systems include a tissue screening device, including a stretchable substrate conformable to the contour of an area of interest on a body on which may be affixed stretchable circuitry which may include an array of active devices; a processing facility in electronic communication with the array of active devices; and an output facility in electronic communication with the processing facility, wherein the processing facility may be programmed to generate output data based on data generated by the array of active devices and to cause the output facility to display the output data.

In this aspect, as with others the substrate may be inflatable. The substrate may be affixed to a bra.

In embodiments, the sensor devices include pressure sensors, which may include an on-off switch coupled to the pressure sensor to indicate whether the pressure sensor has been activated.

In the tissue screening embodiments and in others mentioned above, the processing facility may receive data generated by the ultrasound emitters and receivers and may produce an image of the tissue.

In embodiments of the invention, the output data comprises a contour map of the area of interest.

In an aspect of the invention, methods and systems include a method of examination for cancerous or suspicious tissue which may include providing a subject with a wearable device conforming to an area of interest on subject's body, the wearable device comprising a stretchable array of pressure sensors; exerting a manual force on the wearable device sufficient to activate the array of pressure sensors; receiving data from the pressure sensors; and characterizing the tissue in the area of interest based on the received data. Further in this aspect, instructing the subject to exert the manual force. In this aspect, the wearable device may be inflatable. In this aspect, the wearable device may be affixed to a bra. In embodiments, the wearable device may be a sheet.

The methods and systems herein may comprise an endoscopy device.

Thus, in another aspect of the invention, methods and systems include an endoscopic device, including a housing to and within which may be mounted curvilinear circuitry which may include a focal plane array generating visual data; a transmission facility in electronic communication with the circuitry configured to wirelessly transmit the visual data; and an output facility receiving and displaying the visual data.

In this aspect, the housing may be a capsule. The circuitry, transmission facility, and the output facility may be mounted within the capsule. In this aspect, the housing may be located at a tip of the endoscopic device. In this aspect, the circuitry further comprises light emitting electronics. In this aspect, the circuitry may be configured to illuminate select portions of the light emitting electronics. the circuitry may be affixed to an exterior surface of the housing, or the circuitry may be affixed to an interior surface of the housing.

Further in embodiments related to endoscopy and with respect to other embodiments herein, the circuitry may include sensing devices which may be capable of generating any of data related to enzymatic activity and data related to chemical activity.

In this embodiment and others herein, the circuitry comprises sensing devices and a processing facility receiving data from the sensing devices, the processing facility in electronic communication with the output facility. The processing facility may cause the output facility to display information related to data generated by the sensing devices.

Further in this aspect and others, including a processing facility within the circuitry. Further in this aspect, including a processing facility separate from the circuitry.

In this aspect, the visual data is an image. In this aspect, the visual data may be a map.

The methods and systems herein may comprise a dynamically configurable sheet of electronic devices.

Thus, in another aspect of the invention, methods and systems include a configurable sheet of electronic devices, a substantially flat substrate on which may be disposed stretchable circuitry containing an array of electronic devices in electronic communication with one another; and a processing facility capable of polling the array of electronic devices to determine a first set of information related to the identity and location of each electronic device in the array, the processing facility configured to adjust the operation of the array based upon information related to a second set of information related to the identity and location of each electronic device in the array. In this aspect, the second set of information is received after the circuitry is reshaped, where the reshaping may be caused by cutting the circuitry.

In embodiments, circuitry may include an array of electronic devices may include sensor devices which may generate data of a tissue of interest when the sheet is at least one of partial electrical contact and partial conformal contact with the tissue of interest.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more fully apparent from the following description and appended claims, taken in conjunction with the accompanying figures. Understanding that these figures merely depict exemplary embodiments of the present invention they are, therefore, not to be considered limiting of its scope. It will be readily appreciated that the components of the present invention, as generally described and illustrated in the figures herein, could be arranged and designed in a wide variety of different configurations. Nonetheless, the invention will be described and explained with additional specificity and detail through the use of the accompanying figures in which:

FIG. **1** is a schematic depiction of embodiments of the invention;

FIG. **2** depicts a buckled interconnection;

FIG. **3** depicts a stretchable electronics configuration with semiconductor; islands mounted on an elastomeric substrate with stretchable interconnects;

FIG. **4** depicts an extremely stretchable interconnect;

FIG. **5** depicts a raised stretchable interconnect with expandable elastomeric substrate;

FIG. **6** depicts a method for controlled adhesion on an elastomeric stamp;

FIG. **7** depicts an embodiment of the invention wherein stretchable circuitry is applied to a balloon catheter, in which the balloon catheter is deflated;

FIG. **7**A is a expanded view of the circuitry shown in FIG. **7**;

FIG. **8** depicts an embodiment of the invention wherein stretchable circuitry is applied to a balloon catheter, in which the balloon catheter is inflated;

FIG. **9**A shows a side view of a balloon with a PDMS layer wrapped around the surface of the balloon;

FIG. **9**B is a cross-sectional view which shows the catheter, the surface of the balloon, and the thin PDMS layer applied to the balloon;

FIGS. **10**A, B, and C depict a process for applying stretchable circuitry to the surface of a catheter balloon;

FIG. **10**D is an embodiment of a pressure sensor utilized with embodiments of the invention;

FIG. **10**E is a cross-sectional view of a tri-lumen catheter according to embodiments of the invention;

FIG. **10**F schematically depicts a multiplexor according to an embodiment of the present invention;

FIG. **11** is a schematic depiction of an embodiment of the invention involving a neural prosthesis;

FIG. **12** is a circuit diagram for an embodiment of the invention;

FIG. **13** depicts a process for operating an array of electronic devices according to an embodiment of the present invention;

FIG. **14** depicts an embodiment of the invention involving a neural prosthesis;

FIG. **15** depicts an embodiment of the invention having a reservoir for holding and delivering a therapeutic agent, along with valves controlled by the circuitry to deliver said therapeutic agent;

FIG. **16** depicts a process for assembling curvilinear circuitry according to an embodiment of the invention;

FIGS. **16**A and B depicts the process for applying a curvilinear array of circuitry to an endoscopic device according to an embodiment of the invention;

FIG. **17** depicts an embodiment of an endoscopic device according to the present invention; and

FIG. **18** depicts a tissue screening device according to an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Detailed embodiments of the present invention are disclosed herein; however, it is to be understood that the disclosed embodiments are merely exemplary of the invention, which can be embodied in various forms. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting but merely as a basis for the claims and as a representative basis for teaching one skilled in the art to variously employ the present invention in virtually any appropriately detailed structure. Further, the terms and phrases used herein are not intended to be limiting but rather to provide an understandable description of the invention.

The terms “a” or “an,” as used herein, are defined as one or more than one. The term “another,” as used herein, is defined as at least a second or more. The terms “including” and/or “having” as used herein, are defined as comprising (i.e., open transition). The term “coupled” or “operatively coupled,” as used herein, is defined as connected, although not necessarily directly and not necessarily mechanically or physically. “Electronic communication” is the state of being able to convey or otherwise transmit data either through a physical connection, wireless connection, or combinations thereof.

As described herein, the present invention comprises devices, systems, and methods utilizing flexible and/or stretchable electronic circuits on flexible, expandable, or inflatable surfaces. With reference to the present invention, the term “stretchable”, and roots and derivations thereof, when used to modify circuitry or components thereof describes circuitry and/or components thereof having soft or elastic properties capable of being made longer or wider without tearing or breaking, and it is also meant to encompass circuitry having components (whether or not the components themselves are individually stretchable as stated above) that are configured in such a way so as to accommodate a stretchable, inflatable, or expandable surface and remain functional when applied to a stretchable, inflatable, or otherwise expandable surface that is stretched, inflated, or otherwise expanded respectively. The term “expandable”, and roots and derivations thereof, when used to modify circuitry or components thereof is also meant to have the meaning ascribed above. Thus, “stretch” and “expand”, and all derivations thereof, may be used interchangeably when referring to the present invention. The term “flexible”, and roots and derivations thereof, when used to modify circuitry or components thereof describes circuitry and/or components thereof capable of bending without breaking, and it is also meant to encompass circuitry having components (whether or not the components themselves are individually flexible as stated above) that are configured in such a way so as to accommodate a flexible surface and remain functional when applied to a flexible surface that is flexed or otherwise bent. In embodiments, at the low end of ‘stretchable’, this may translate into material stains greater than 0.5% without fracturing, and at the high end to structures that may stretch 100,000% without a degradation of electrical performance. “Bendable” and roots and derivations thereof, when used to modify circuitry or components thereof describes circuitry and/or components thereof able to be shaped (at least in part) into a curve or angle, and may sometimes be used synonymously herein with "flexible".

FIG. **1** is a schematic depiction of embodiments of the invention. Further description of each of the components of FIG. **1** will be included throughout the specification. Circuitry **1000S** is applied, secured, or otherwise affixed to substrate **200**. In embodiments, substrate **200** is stretchable and or expandable as described herein. As such the substrate **200** can be made of a plastic material or can be made of an elastomeric material, or combinations thereof. Note that the term "plastic" may refer to any synthetic or naturally occurring material or combination of materials that can be molded or shaped, generally when heated, and hardened into a desired shape. The term "elastomer" may refer a naturally occurring material or a synthetic material, and also to a polymeric material which can be stretched or deformed and return to its original shape without substantial permanent deformation. Such elastomers may withstand substantial elastic deformations. Examples of elastomers used in substrate material include polymeric organosilicon compounds (commonly referred to as "silicones") including Polydimethylsiloxane (PDMS).

Other materials suitable for the substrate include polyimide; photopatternable silicone; SU8 polymer; PDS polydustrene; parylene and its derivatives and copolymers (parylene-N); ultrahigh molecular weight polyethylene; poly ether ether ketones (PEEK); polyurethanes (PTG Elasthane®, Dow Pellethane®); polylactic acid; polyglycolic acid; polymer composites (PTG Purisil Al®, PTG Bionate®, PTG Carbosil); silicones/siloxanes (RTV 615®, Sylgard 184®); polytetrafluoroethylene (PTFE, Teflon®); polyamic acid; polymethyl acrylate; stainless steel; titanium and its alloys; platinum and its alloys; and gold. In embodiments, the substrate is made of a stretchable or flexible biocompatible material having properties which may allow for certain devices to be left in the body **2000** for a period of time without having to be retrieved.

Some of the materials mentioned above, specifically parylene and its derivatives and copolymers (parylene-N); ultrahigh molecular weight polyethylene; poly ether ether ketones (PEEK); polyurethanes (PTG Elasthane®, Dow Pellethane®); polylactic acid; polyglycolic acid; polymer composites (PTG Purisil Al®, PTG Bionate®, PTG Carbosil); silicones/siloxanes (RTV 615®, Sylgard 184®); polytetrafluoroethylene (PTFE, Teflon®); polyamic acid; polymethyl acrylate; stainless steel; titanium and its alloys; platinum and its alloys; and gold, are biocompatible. Coatings for the substrate to increase its biocompatibility may include, PTFE, polylactic acid, polyglycolic acid, and poly(lactic-co-glycolic acid).

The materials disclosed for substrate **200** herein may be understood to apply to any of the embodiments disclosed herein that require substrate. It should also be noted that materials can be chosen based on their properties which include degree of stiffness, degree of flexibility, degree of elasticity, or such properties related to the material's elastic moduli including Young's modulus, tensile modulus, bulk modulus, shear modulus, etc., and or their biodegradability.

The substrate **200** can be one of any possible number of shapes or configurations. In embodiments, the substrate **200** is substantially flat and in some embodiments configured to be a sheet or strip. Yet it should be noted that such flat configurations of substrate **200** can be any number of geometric shapes. Other embodiments of flat substrates will be described below including substrates having a tape-like or sheet configuration. Flexible and/or stretchable substrate **200** having a sheet or otherwise substantially flat configuration may be configured such that substrate **200** can be folded, furled, bunched, wrapped or otherwise contained. In embodiments, a substrate **200** configured as such can be folded, furled, bunched, collapsed (such as in an umbrella-like configuration), wrapped, or otherwise contained during delivery through narrow passageways in the subject's body **2000** and then deployed into an unfolded, unfurled, etc. state once in position for deployment. As a non-limiting example, a furled substrate **200** carrying circuitry **100S** comprising sensing device **1100** could be delivered via a catheter, then unfurled at such point when it is desired for the sensing device to contact the tissue of interest, such as the surface of the heart, or the inner surface of a lumen such as the pulmonary vein. In embodiments, substrates **200** may also be formed into concave and convex shapes, such as lenses. Such convex and concave substrates can be made of material suitable for contact with the eye, such as a contact lens or implantation into the eye, such a retinal or corneal implant.

Substrate **200** may also be three-dimensional. The three-dimensional substrate **200** can be any number of shapes. Such three-dimensional substrates may be a solid or substantially solid. In embodiments, the three-dimensional substrate may be pliable, flexible and stretchable while still comprising homogeneous or substantially homogenous material throughout its form, such as a foam or a flexible/stretchable polymeric sphere, ovoid, cylinder, disc, or other three-dimensional object. In embodiments, the three-dimensional substrate **200** may be made from several materials. In the presently preferred embodiment for the three-dimensional substrate **200**, the substrate is an inflatable body (also referred to herein as an elastomeric vessel). Inflatable bodies of this type may be stretchable, such as a balloon or the like; however, in other embodiments, the inflatable body inflates without stretching. In embodiments, inflation can be achieved via a gas or liquid. In certain embodiments, inflation with a viscous fluid is preferable, but it should be clear that a variety of gases, fluids or gels may be employed for such inflation. Embodiments comprising balloon-like and disc-like inflatable substrates will be discussed in further detail below. The systems to achieve inflation discussed in connection with those embodiments apply to all inflatable embodiments of substrate herein.

In embodiments where the substrate **200** is stretchable, circuitry **1000S** is configured in the applicable manners described herein to be stretchable and/or to accommodate such stretching of the substrate **200**. Similarly, in embodiments where the substrate **200** is flexible, but not necessarily stretchable, circuitry **1000S** is configured in the applicable manners described herein to be flexible and/or accommodate such flexing of the substrate **200**. Circuitry **1000S** can be applied and/or configured using applicable techniques described below, including those described in connection with exemplary embodiments.

As mentioned above, the present invention may employ one or more of a plurality of flexible and/or stretchable electronics technologies in the implementation thereof. Traditionally, electronics have been fabricated on rigid structures, such as on integrated circuits, hybrid integrated circuits, flexible printed circuit boards, and on printed circuit boards. Integrated circuits, also referred to as ICs, microcircuits, microchips, silicon chips, or simple chips, have been traditionally fabricated on a thin substrate of semiconductor material, and have been constrained to rigid substrates mainly due to the high temperatures required in the step of inorganic semiconductor deposition. Hybrid integrated circuits and printed circuit boards have been the main method for integrating multiple ICs together, such as through mounting the ICs onto a ceramic, epoxy resin, or other rigid non-conducting surface. These interconnecting surfaces have traditionally been rigid in order to ensure that the electrical interconnection methods, such as solder joints to the board and metal traces across the boards, do not break or fracture when flexed. In addition, the ICs themselves may fracture if flexed. Thus, the field of electronics has been largely constrained to rigid electronics structures, which then tend to constrain electronics applications that may require flexibility and or stretchability necessary for the embodiments disclosed herein. For example, high-quality sensing can be achieved by enabling the electronic devices, such as sensor device, into intimate or direct contact with tissues of interest. The rigidity of devices described above has prevented such direct contact. Embodiments described below achieve such direct contact (in some cases described as "conformal contact").

Advancements in flexible and bendable electronics technologies have emerged that enable flexible electronics applications, such as with organic and inorganic semiconductors on flexible plastic substrates, and other technologies described herein. Further, stretchable electronics technologies have emerged that enable applications that require the electronics to be stretchable, such as through the use of mounting ICs on flexible substrates and interconnected through some method of stretchable electrical interconnect, and other technologies as described herein. The present invention may utilize one or more of these flexible, bendable, stretchable, and like technologies, in applications that require the electronics to operate in configurations that may not be, or remain, rigid and planar, such as applications that require electronics to flex, bend, expand, stretch and the like.

In embodiments, the circuitry of the invention may be made in part or in full by utilizing the techniques and processes described below. Note that the below description of the various ways to achieve stretchable and/or flexible electronics is not meant to be limiting, and encompasses suitable variants and or modifications within the ambit of one skilled in the art. As such, this application will refer to the following United States patents and patent applications, each of which is incorporated by reference herein in its entirety: U.S. Pat. No. 7,557,367 entitled "Stretchable Semiconductor Elements and Stretchable Electrical Circuits", issued Jul. 7, 2009 (the "'367 patent"); U.S. Pat. No. 7,521,292 entitled "Stretchable Form of Single Crystal Silicon for High Performance Electronics on Rubber Substrates", issued Apr. 29, 2009 (the "'292 patent"); United States Published Patent Application No. 20080157235 entitled "Controlled Buckling Structures in Semiconductor Interconnects and Nan membranes for Stretchable Electronics", filed Sep. 6, 2007 (the "'235 application"); U.S. patent application having Ser. No. 12/398,811 entitled "Stretchable and Foldable Electronics", filed Mar. 5, 2009 (the "'811 application"); United States Published Patent Application No. 20040192082 entitled "Stretchable and Elastic Interconnects" filed Mar. 28, 2003(the "'082 application"); United States Published Patent Application No. 20070134849 entitled "Method For Embedding Dies", filed Nov. 21, 2006 (the "'849 application"); United States Published Patent Application No. 20080064125 entitled "Extendable Connector and Network, filed Sep. 12, 2007 (the "'125 application"); United States Provisional Patent Application having Ser. No. 61/240,262 (the "'262 application") "Stretchable Electronics", filed Sep. 7, 2009; U.S. patent application having Ser. No. 12/616,922 entitled "Extremely Stretchable Electronics", filed Nov. 12, 2009 (the "'922 application"); United States Provisional Patent Application having Ser. No. 61/120,904 entitled "Transfer Printing", filed Dec. 9, 2008 (the "'904 application"); United States Published Patent Application No. 20060286488 entitled "Methods and Devices for Fabricating Three-Dimensional Nanoscale Structures", filed Dec. 1, 2004; U.S. Pat. No. 7,195,733 entitled "Composite Patterning Devices for Soft Lithography" issued Mar. 27, 2007; United States Published Patent Application No. 20090199960 entitled "Pattern Transfer Printing by Kinetic Control of Adhesion to an Elastomeric Stamp" filed Jun. 9, 2006; United States Published Patent Application. No. 20070032089 entitled "Printable Semiconductor Structures and Related Methods of Making and Assembling" filed Jun. 1, 2006; United States Published Patent Application No. 20080108171 entitled "Release Strategies for Making Transferable Semiconductor Structures, Devices and Device Components" filed Sep. 20, 2007; and United States Published Patent Application No. 20080055581 entitled "Devices and Methods for Pattern Generation by Ink Lithography", filed Feb. 16, 2007.

"Electronic device" is used broadly herein to encompass an integrated circuit(s) having a wide range of functionality. In embodiments, the electronic devices may be devices laid out in a device island arrangement, as described herein including in connection to exemplary embodiments. The devices can be, or their functionality can include, integrated circuits, processors, controllers, microprocessors, diodes, capacitors, power storage elements, antennae, ASICs, sensors, amplifiers, A/D and D/A converters, associated differential amplifiers, buffers, microprocessors, optical collectors, transducer including electro-mechanical transducers, piezo-electric actuators, light emitting electronics which include LEDs, logic, memory, clock, and transistors including active matrix switching transistors, and combinations thereof. The purpose and advantage of using standard ICs (in embodiments, CMOS, on single crystal silicon) is to have and use high quality, high performance, and high functioning circuit components that are also already commonly mass-produced with well known processes, and which provide a range of functionality and generation of data far superior to that produced by a passive means. Components within electronic devices or devices are described herein, and include those components described above. A component can be one or more of any of the electronic devices described above and/or may include a photodiode, LED, TUFT, electrode, semiconductor, other light-collecting/detecting components, transistor, contact pad capable of contacting a device component, thin-film devices, circuit elements, control elements, microprocessors, interconnects, contact pads, capacitors, resistors, inductors, memory element, power storage element, antenna, logic element, buffer and/or other passive or active components. A device component may be connected to one or more contact pads as known in the art, such as metal evaporation, wire bonding, application of solids or conductive pastes, and the like.

Components incapable of controlling current by means of another electrical signal are called passive devices. Resistors, capacitors, inductors, transformers, and diodes are all considered passive devices

For purposes of the invention, an active device is any type of circuit component with the ability to electrically control electron flow. Active devices include, but are not limited to, vacuum tubes, transistors, amplifiers, logic gates, integrated circuits, silicon-controlled rectifiers (SCRs), and triode for alternating current (TRIACs).

"Ultrathin" refers to devices of thin geometries that exhibit flexibility.

"Functional layer" refers to a device layer that imparts some functionality to the device. For example, the functional layer may be a thin film, such as a semiconductor layer. Alternatively, the functional layer may comprise multiple layers, such as multiple semiconductor layers separated by support layers. The functional layer may comprise a plurality of patterned elements, such as interconnects running between device-receiving pads.

Semiconductor materials which may be used to make circuits may include amorphous silicon, polycrystalline silicon, single crystal silicon, conductive oxides, carbon annotates and organic materials.

In some embodiments of the invention, semiconductors are printed onto flexible plastic substrates, creating bendable macro-electronic, micro-electronic, and/or nano-electronic devices. Such bendable thin film electronics devices on plastic may exhibit field effect performance similar to or exceeding that of thin film electronics devices fabricated by conventional high temperature processing methods. In addition, these flexible semiconductor on plastic structures may provide bendable electronic devices compatible with efficient high throughput processing on large areas of flexible substrates at lower temperatures, such as room temperature processing on plastic substrates. This technology may provide dry transfer contact printing techniques that are capable of assembling bendable thin film electronics devices by depositing a range of high quality semiconductors, including single crystal Si ribbons, GaAs, INP wires, and carbon nano-tubes onto plastic substrates. This high performance printed circuitry on flexible substrates enables an electronics structure that has wide ranging applications. The '367 patent and associated disclosure illustrates an example set of steps for fabricating a bendable thin film electronics device in this manner. (See FIG. 26A of the '367 patent for Example).

In addition to being able to fabricate semiconductor structures on plastic, it has been demonstrated that metal-semiconductor electronics devices may be formed with printable wire arrays, such as GaAs micro-wires, on the plastic substrate. Similarly, other high quality semiconductor materials have been shown to transfer onto plastic substrates, including Si nano-wires, micro-ribbons, platelets, and the like. In addition, transfer printing techniques using elastomeric stamps may be employed. The '367 patent provides an example illustration of the major steps for fabricating, on flexible plastic substrates, electronics devices that use arrays of single wires (in this instance GaAs wires) with epitaxial channel layers, and integrated holmic contacts. (See FIG. 41 of the '367 patent). In an example, a semi-insulating GaAs wafer may provide the source material for generating the micro-wires. Each wire may have multiple ohmic stripes separated by a gap that defines the channel length of the resultant electronic device. Contacting a flat, elastomeric stamp of PDMS to the wires forms a van der Waals bond. This interaction enables removal of all the wires from the wafer to the surface of the PDMS when the stamp is peeled back. The PDMS stamp with the wires is then placed against an uncured plastic sheet. After curing, peeling off the PDMS stamp leaves the wires with exposed ohmic stripes embedded on the surface of the plastic substrate. Further processing on the plastic substrate may define electrodes that connect the ohmic stripes to form the source, drain, and gate electrodes of the electronics devices. The resultant arrays are mechanically flexible due to the bendability of the plastic substrate and the wires.

In embodiments, and in general, stretchable electronics may incorporate electrodes, such as connected to a multiplexing chip and data acquisition system. For example, such an electrode system may be integrated into a medical application, such as in a catheter for neurological or cardiac monitoring and stimulation. In an example, an electrode may be fabricated, designed, transferred, and encapsulated. In an embodiment, the fabrication may utilize and/or include an SI wafer; spin coating an adhesion layer (e.g. an HMDS adhesion layer); spin coating (e.g. PMMA) patterned by shadow mask, such as in oxygen RIE; spin coating Polyimide; depositing PECVD SiO2; spin 1813 Resist, photolithography patterning; metal evaporation (e.g. Ti, Pt, Au, and the like, or combination of the aforementioned); gold etchant, liftoff in hot acetone; spin Polyimide; PECVD SiO2; spin 1813 Resist, photolithography patterning; RIE etch, and the like. In this embodiment, the fabrication step may be complete with the electrodes on the Si wafer. In embodiments, the Si wafer may then be bathed in a hot acetone bath, such as at 100° C. for approximately one hour to release adhesion layer while PI posts keep electrode adhered to the surface of the Si wafer. In embodiments, electrodes may be designed in a plurality of shapes and distributed in a plurality of distribution patterns. Electrodes may be interconnected to electronics, multiplexing electronics, interface electronics, a communications facility, interface connections, and the like including any of the facilities/elements described on connection with FIG. **1** and/or the exemplary embodiments herein. In embodiments, the electrodes may be transferred from the Si wafer to a transfer stamp, such as a PDMS stamp, where the material of the transfer stamp may be fully cured, partially cured, and the like. For example, a partially cured PDMS sheet may be ~350 nm, where the PDMS was spun on at 300 rpm for 60 s, cured 65 C for 25 min, and used to lift electrodes off of the PDMS sheet. In addition, the electrodes may be encapsulated, such as wherein the electrodes are sandwiched between a supporting PDMS layer and second PDMS layer while at least one of the PDMS layers is partially cured.

In embodiments, stretchable electronics configurations may incorporate flex PCB design elements, such as flex print, chip flip configurations (such as bonded onto the PCB), and the like, for connections to electrodes and/or devices, and for connections to interface electronics, such as to a data acquisition system (DAQ). For example, a flex PCB may be joined to electrodes by an anisotropic conductive film (ACF) connection, solder joints may connect flex PCB to the data acquisition system via conductive wires, and the like. In embodiments, the electrodes may be connected onto a surface by employing a partially-cured elastomer (e.g. PDMS) as an adhesive.

In embodiments, stretchable electronics may be formed into sheets of stretchable electronics, such as to monitor neural signal activity via stretchable electrode systems as described below. In embodiments, stretchable sheets may be thin, such as approximately 100 μm. Optionally, amplification and multiplexing may be implemented without substantially heating the contact area, such as with micro-fluidic cooling.

In embodiments, a sheet having arrays of electronic devices comprising electrodes may be cut into different shapes and remain functional, such as through communicating electrode islands which determine the shape of the electrode sheet. Electrodes are laid out in a device island arrangement (as described herein) and may contain active circuitry designed to communicate with each other via inter-island stretchable interconnects so that processing facility (described herein) in the circuitry can determine in real-time the identity and location of other such islands. In this way, if one island becomes defective, the islands can still send out coordinated, multiplexed data from the remaining array. Such functionality allows for such arrays to be cut and shaped based on the size constraints of the application. A sheet, and thus circuitry, may be cut to side and the circuitry will poll remaining electrodes and/or devices to determine which are left and will modify the calibration accordingly. An example of a stretchable electronics sheet containing this functionality, may include electrode geometry, such as a 20×20 array of platinum electrodes on 1 mm pitch for a total area of 20×20 mm^2; an electrode impedance, such as 5 kohm at 1 khz (adjustable); a configuration in a flexible sheet, such as with a 50 μm total thickness, and polyimide encapsulated; a sampling rate, such as 2 kHz per channel; a voltage dynamic range, such as +/−6 mV; a dc voltage offset range, such as −2.5 to 5 V, with dc rejection; a voltage noise, such as 0.002 mV, a maximum signal-to-noise ratio, such as 3000; a leakage current, such as 0.3 to typical, 10 μA to maximum, as meets IEC standards, and the like; an operating voltage of 5 V; an operating power per channel, such as less than 2 mW (adjustable); a number of interface wires, such as for power, ground, low impedance ground, data lines, and the like; a voltage gain, such as 150; a mechanical bend radius, such as 1 mm; a local heating capability, such as heating local tissue by up to 1° C.; biocompatibility duration, such as 2 weeks; active electronics, such as a differential amplifier, a multiplexer (e.g. 1000 transistors per channel); a data acquisition system, such as with a 16 bit A/D converter with a 500 kHz sampling rate, less than 2 μV noise, data login and real-time screen display; safety compliance, such as to IEC10601; and the like.

In embodiments of the invention, mechanical flexibility may represent an important characteristic of devices, such as on plastic substrates, for many applications. Micro/nanowires with integrated ohmic contacts provide a unique type of material for high performance devices that can be built directly on a wide range of device substrates. Alternatively, other materials may be used to connect electrical components together, such as connecting electrically and/or mechanically by thin polymer bridges with or without metal interconnects lines.

In embodiments, an encapsulation layer may be utilized. An encapsulating layer may refer to coating of the device, or a portion of the device. In embodiments, the encapsulation layer may have a modulus that is inhomogeneous and/or that spatially varies. Encapsulation layers may provide mechanical protection, device isolation, and the like. These layers may have a significant benefit to stretchable electronics. For example, low modulus PDMS structures may increase the range of stretchability significantly (described at length in the '811 application). The encapsulation layer may also be used as a passivation later on top of devices for the protection or electrical isolation. In embodiments, the use of low modulus strain isolation layers may allow integration of high performance electronics. The devices may have an encapsulation layer to provide mechanical protection and protection against the environment. The use of encapsulation layers may have a significant impact at high strain. Encapsulants with low moduli may provide the greatest flexibility and therefore the greatest levels of stretchability. As referred to in the '811 application, low modulus formulations of PDMS may increase the range of stretchability at least from 60%. Encapsulation layers may also relieve strains and stresses on the electronic device, such as on a functional layer of the device that is vulnerable to strain induced failure. In embodiments, a layering of materials with different moduli may be used. In embodiments, these layers may be a polymer, an elastomer, and the like. In embodiments, an encapsulation may serve to create a biocompatible interface between an implanted stretchable electronic system, such as Silk encapsulation of electronic devices in contact with tissue.

Returning to flexible and stretchable electronics technologies that may be utilized in the present invention, it has been shown that buckled and wavy ribbons of semiconductor, such as GaAs or Silicon, may be fabricated as part of electronics on elastomeric substrates. Semiconductor ribbons, such as with thicknesses in the submicron range and well-defined, 'wavy' and/or 'buckled' geometries have been demonstrated. The resulting structures, on the surface of, or embedded in, the elastomeric substrate, have been shown to exhibit reversible stretchability and compressibility to strains greater than 10%. By integrating ohmic contacts on these structured GaAs ribbons, high-performance stretchable electronic devices may be achieved. The '292 patent illustrates steps for fabricating stretchable GaAs ribbons on an elastomeric substrate made of PDMS, where the ribbons are generated from a high-quality bulk wafer of GaAs with multiple epitaxial layers (See FIG. **22**). The wafer with released GaAs ribbons is contacted to the surface of a pre-stretched PDMS, with the ribbons aligned along the direction of stretching. Peeling the PDMS from the mother wafer transfers all the ribbons to the surface of the PDMS. Relaxing the prestrain in the PDMS leads to the formation of large scale buckles/wavy structures along the ribbons. The geometry of the ribbons may depend on the prestrain applied to the stamp, the interaction between the PDMS and ribbons, and the flexural rigidity of the ribbons, and the like. In embodiments, buckles and waves may be included in a single ribbon along its length, due for example, to thickness variations associated with device structures. In practical applications, it might be useful to encapsulate the ribbons and devices in a way that maintains their stretchability. The semiconductor ribbons on an elastomeric substrate may be used to fabricate high-performance electronic devices, buckled and wavy ribbons of semiconductor multilayer stacks and devices exhibiting significant compressibility/stretchability. In embodiments, the present invention may utilize a fabrication process for producing an array of devices utilizing semiconductor ribbons, such as an array of CMOS inverters with stretchable, wavy interconnects. Also, a strategy of top layer encapsulation may be used to isolate circuitry from strain, thereby avoiding cracking.

In embodiments, a neutral mechanical plane (NMP) in a multilayer stack may define the position where the strains are zero. For instance, the different layers may include a support layer, a functional layer, a neutral mechanical surface adjusting layer, an encapsulation layer with a resultant neutral mechanical surface such as coincident with the functional layer, and the like. In embodiments, the functional layer may include flexible or elastic device regions and rigid island regions. In embodiments, an NMP may be realized in any application of the stretchable electronics as utilized in the present invention.

In embodiments, semiconductor ribbons (also, micro-ribbons, nano-ribbons, and the like) may be used to implement integrated circuitry, electrical interconnectivity between electrical/electronic components, and even for mechanical support as a part of an electrical/electronic system. As such, semiconductor ribbons may be utilized in a great variety of ways in the configuration/fabrication of flexible and stretchable electronics, such as being used for the electronics or interconnection portion of an assembly leading to a flexible and/or stretchable electronics, as an interconnected array of ribbons forming a flexible and/or stretchable electronics on a flexible substrate, and the like. For example, nano-ribbons may be used to form a flexible array of electronics on a plastic substrate. The array may represent an array of electrode-electronics cells, where the nano-ribbons are pre-fabricated, and then laid down and interconnected through metallization and encapsulation layers. Note that the final structure of this configuration may be similar to electronic device arrays as fabricated directly on the plastic, as described herein, but with the higher electronics integration density enabled with the semiconductor ribbons. In addition, this configuration may include encapsulation layers and fabrication steps which may isolate the structure from a wet environment. This example is not meant to limit the use of semiconductor ribbons in any way, as they may be used in a great variety of applications associated with flexibility and stretchability. For example, the cells of this array may be instead connected by wires, bent interconnections, be mounted on an elastomeric substrate, and the like, in order to improve the flexibility and/or stretchability of the circuitry.

Wavy semiconductor interconnects is only one form of a broader class of flexible and stretchable interconnects that may (in some cases) be referred to as 'bent' interconnects, where the material may be semiconductor, metal, or other conductive material, formed in ribbons, bands, wire, traces, and the like. A bent configuration may refer to a structure having a curved shape resulting from the application of a force, such as having one or more folded regions. These bent interconnections may be formed in a variety of ways, and in embodiments, where the interconnect material is placed on an elastomeric substrate that has been pre-strained, and the bend form created when the strain is released. In embodiments, the pre-strain may be pre-stretched or pre-compressed, provided in one, two, or three axes, provided homogeneously or heterogeneously, and the like. The wavy patterns may be formed along pre-strained wavy patterns, may form as 'pop-up' bridges, may be used with other electrical components mounted on the elastomer, or transfer printed to another structure. Alternately, instead of generating a 'pop-up' or buckled components via force or strain application to an elastomeric substrate, a stretchable and bendable interconnect may be made by application of a component material to a receiving surface. Bent configurations may be constructed from microwires, such as transferred onto a substrate, or by fabricating wavy interconnect patterns either in conjunction with electronics components, such as on an elastomeric substrate.

Semiconductor nanoribbons, as described herein, may utilize the method of forming wavy 'bent' interconnections through the use of forming the bent interconnection on a pre-strained elastomeric substrate, and this technique may be applied to a plurality of different materials. Another general class of wavy interconnects may utilize controlled buckling of the interconnection material. In this case, a bonding material may be applied in a selected pattern so that there are bonded regions that will remain in physical contact with the substrate (after deformation) and other regions that will not. The pre-strained substrate is removed from the wafer substrate, and upon relaxation of the substrate, the unbounded interconnects buckle ('pop-up') in the unbonded (or weakly bonded) regions. Accordingly, buckled interconnects impart stretchability to the structure without breaking electrical contact between components, thereby providing flexibility and/or stretchability. FIG. **2** shows a simplified diagram showing a buckled interconnection **204**S between two components **202**S and **208**S.

In embodiments, any, all, or combinations of each of the interconnection schemes described herein may be applied to make an electronics support structure more flexible or bendable, such as applying bent interconnects to a flexible substrate, such as plastic or elastomeric substrates. However, these bent interconnect structures may provide for a substantially more expandable or stretchable configuration in another general class of stretchable electronic structures, where rigid semiconductor islands are mounted on an elastomeric substrate and interconnected with one of the plurality of bent interconnect technologies. This technology is presented here, and also in the '262 application, which has been incorporated by reference in its entirety. This configuration also uses the neutral mechanical plane designs, as described herein, to reduce the strain on rigid components encapsulated within the system. These component devices may be thinned to the thickness corresponding to the desired application or they may be incorporated exactly as they are obtained. Devices may then be interconnected electronically and encapsulated to protect them from the environment and enhance flexibility and stretchability.

In an embodiment, the first step in a process to create stretchable and flexible electronics as described herein involves obtaining required electronic devices and components and conductive materials for the functional layer. The electronics are then thinned (if necessary) by using a back grinding process. Many processes are available that can reliably take wafers down to 50 microns. Dicing chips via plasma etching before the grinding process allows further reduction in thickness and can deliver chips down to 20 microns in thickness. For thinning, typically a specialized tape is placed over the processed part of the chip. The bottom of the chip is then thinned using both mechanical and/or chemical means. After thinning, the chips may be transferred to a receiving substrate, wherein the receiving substrate may be a flat surface on which stretchable interconnects can be fabricated. FIG. **3** illustrates an example process, which begins by creating a flexible substrate **302**S on the carrier **308**S coated with a sacrificial layer **304**S (FIG. **3**A), placing devices **310**S on the flexible substrate (FIG. **3**B), and performing a planarization step in order to make the top surface of the receiving substrate the same height as that of the die surface (FIG. **3**C). The interconnect fabrication process follows. The devices **310**S deposited on the receiving substrate are interconnected **312**S which join bond pads from one device to another (FIG. **3**D). In embodiments, these interconnects **312**S may vary from 10 microns to 10 centimeters. A polymeric encapsulating layer **314**S may then be used to coat the entire array of interconnected electronic devices and components (FIG. **2**E). The interconnected electronic devices are then released from the substrate by etching away sacrificial materials with a solvent. The devices are then ready to undergo stretch processing. They are transferred from the rigid carrier substrate to an elastomeric substrate such as PDMS. Just before the transfer to the new substrate, the arrays are pre-treated such that the device/component islands preferentially adhere to the surface leaving the encapsulated interconnects free to be displaced perpendicular to the receiving substrate.

In embodiments, the interconnect system is a straight metal line connecting two or more bond pads. In this case the electronic array is transferred to a pre-strained elastomeric substrate. Upon relaxation of this substrate the interconnects will be displaced perpendicular to the substrate, thus producing outward buckling. This buckling enables stretching of the system.

In another embodiment, the interconnects are a serpentine pattern of conductive metal. These types of interconnected arrays need not be deposited on a pre-strained elastomeric substrate. The stretchability of the system is enabled by the winding shape of the interconnects.

Stretchable/flexible circuits may be formed on paper, plastic, elastomeric, or other materials with the aid of techniques including but not limited to conventional photolithographic techniques, sputtering, chemical vapor deposition, ink jet printing, or organic material deposition combined with patterning techniques. Semiconductor materials which may be used to make circuits may include amorphous silicon, polycrystalline silicon, single-crystal silicon, conductive oxides, carbon nanotubes and organic materials. In embodiments, the interconnects may be formed of electrically conducting film, stripe, pattern, and the like, such as on an elastomer or plastic material, where the film may be made to buckle, deform, stretch, and the like, as described herein. In embodiments, the interconnect may be made of a plurality of films, such as on or embedded in the flexible and/or a stretchable substrate or plastic.

In embodiments, the interconnection of device islands **402**S may utilize an extremely stretchable interconnect **404**S, such as shown in FIG. **4**, and such as the various configurations disclosed in the '922 application. The geometry and the dimension of the interconnects **404**S is what makes them extremely compliant. Each interconnect **404**S is patterned and etched so that its structural form has width and thickness dimensions that may be of comparable size (such as their ratio or inverse ratio not exceeding about a factor of 10); and may be preferably equal in size. In embodiments, the interconnect may be formed in a boustrophedonic style such that it effectively comprises long bars **408**S and short bars **410**S. This unique geometry minimizes the stresses that are produced in the interconnect when subsequently stretched because it has the effective form of a wire, and behaves very differently than interconnect form factors having one dimension greatly exceeding the other two (for example plates). Plate type structures primarily relieve stress only about a single axis via buckling, and withstand only a slight amount of shear stress before cracking. This invention may relieve stress about all three axes, including shears and any other stress. In addition, because the interconnect may be formed out of rigid materials, after being stretched it may have a restorative force which helps prevent its wire-like form from getting tangled or knotted when re-compressing to the unstretched state. Another advantage of the boustrophedonic geometry is that it minimizes the initial separation distance between the islands. In embodiments, the interconnects may be formed either monolithically (i.e., out of the same semiconductor material as the device islands) or may be formed out of another material.

In another embodiment the elastomeric substrate may comprise two layers separated by a height **512**S, such as shown in FIG. **5**. The top "contact" layer contacts the device island **502**S, where the device islands **502**S are interconnected **504**S with one of the interconnection schemes described herein. In addition, the bottom layer may be a "wavy" layer containing ripples **514**S or square waves molded into the substrate **508**S during elastomer fabrication. These waves enable additional stretching, whose extent may depend on the amplitude **510**S and wavelength of the waves pattern-molded in the elastomer.

In embodiments, the device island may be any prefabricated integrated circuit (IC), where the IC may be mounted on, inside, between, and the like, a flexible and/or stretchable substrate. For example, an additional elastomeric layer may be added above the structure as shown in FIG. **5**, such as to encapsulate the structure for protection, increased strength, increase flexibility, and the like. Electrical contacts to embedded electrical components may be provided across the embedded layer, through the elastomeric layer(s) from a second electrical interconnection layer, and the like. For example, an IC may be encapsulated in a flexible material where the interconnects are made accessible as described in the '849 application. (See FIG. 1 of the '849 application for example). In this example the embedded IC is fabricated by first placing the IC onto a carrier, such as a rigid carrier, and where the IC may be a thinned IC (either thinned before the mounting on the carrier, or thinned while on the carrier). A second step may involve a coating of the IC with some adhesive, elastomer, or other insulating material that can be flowed onto the IC. A third step may be to gain access to the electrical contacts of the IC, such as by laser drilling or other method known to the art. A fourth step may be to flow electrical conductor into the openings, thus establishing a electrical access to the electrical connections of the IC. Finally, the IC thus encased may be freed from the carrier. Now the structure may be more easily embedded into a flexible substrate while maintaining electrical connectivity. In embodiments, this structure may be a flexible structure, due to the thinness of the IC, the elastic character of the surrounding structure, the elastic configuration of the extended electrical contacts, and the like.

It should be noted that many of the stretchable electronics techniques utilize the process of transfer printing, for example, with a PDMS stamp. In embodiments, the present invention may include a method of dynamically controlling the surface adhesion of a transfer printing stamp, such as described here, and disclosed in the '904 application. Transfer printing stamps have many uses, one of which is to pick up thin films of materials ("targets") from one surface ("initial surface") and deposit them onto another surface ("final surface"). The pickup may be achieved by pressing the transfer printing stamp into contact with the targets, applying some pressure to create Van der Waals bonds between the stamp and the targets, peeling off the stamp with the targets, and then placing the stamp with targets into contact with another surface, applying pressure, and peeling off the stamp without the targets so they remain on the final surface. If the final surface has a higher bonding strength with the targets than the transfer stamp, they will remain on the final surface when the transfer stamp is peeled off. Alternately, the rate of peeling the transfer stamp can be adjusted to vary the target to stamp and target to final surface bonding force ratio. The present invention describes a novel method of depositing the targets, by changing the surface adhesion of the transfer stamp after the targets have been picked up. This may be done while the stamp with targets is in contact with the final surface. In embodiments, the adhesion control can be done by introducing micro-fluidic channels into the transfer stamp, so that water or other fluid can be pumped to the surface of the stamp from within it, thereby changing the surface adhesion from sticky to non-sticky.

In embodiments, the present invention may accomplish transfer printing by using a transfer printing stamp that has been formed with micro-fluidic channels such that a fluid (liquid or gas) can be pumped to the surface of the stamp to wet or chemically functionalize the surface and therefore change the surface adhesion of the stamp surface. The transfer printing stamp may be made out of any material, including but not limited to poly-dimethyl-siloxane (PDMS) and derivatives thereof. In one non-limiting embodiment, the stamp is a piece of PDMS formed into a cuboid, which may have dimensions ranging from about 1 micrometer to 1 meter. For this example, the cuboid is 1 cm×1 cm×0.5 cm (length, width, thickness). One 1 cm×1 cm surface of the cuboid is designated as the stamping face. By using a photolithography mask, or a stencil mask, a pattern of vertical holes (channels) is etched from the stamping face through to the opposing face of the stamp. This may be done with an oxygen reactive ion etch. These holes are the micro-fluidic channels, and may be about 0.1-10 micrometers in diameter. They may be spaced apart by about 1-50 micrometers. Another piece of PDMS may be formed into a reservoir shape (eg. a 1 cm×1 cm×0.5

cm cuboid with a smaller cuboid (about 0.8 cm×0.8 cm×0.3 cm) cut out from one surface). This shape may be formed by pouring the PDMS into a mold, curing it, and removing it from the mold. This additional piece of PDMS may then be placed into contact with the first piece of PDMS and bonded (this may be done via ultraviolet ozone exposure or oxygen plasma exposure of the PDMS prior to contacting the two pieces) such that the two pieces form the shape shown in FIG. **6**, step A. Then, one or more holes may be punctured into the top of the reservoir so that a fluidic pipe can be fitted for pumping water into the stamp. In another non-limiting embodiment, the stamp is constructed as described above, except that the first piece of PDMS is formed to have micro-fluidic channels by means of molding. PDMS molding is a well known art. First, a mold is created that is the inverse of the desired shape. In this case, that is an array of vertical posts on a base with four walls. This mold is then filled with PDMS by pouring in the PDMS, allowing it to cure (which may be at elevated temperature), and then removing the PDMS. In another non-limiting embodiment, the stamping surface is also patterned with an array of shallow-etched surface channels. In embodiments, these channels may be about 100-10000 nm wide, and 100-10000 nm etched-into the PDMS. They may form a linear array or a checkerboard grid. The purpose of the channels is to help distribute a liquid from the vertical micro-fluidic channels around the surface of the stamp. In addition, these channels serve to allow an exit for the air that must be displaced to push the liquid to the surface of the stamp. An example of a liquid that may be used includes, but is not limited to, water (which will wet the surface of the stamp and decrease its adhesivity). In the case of a gas fluid, these surface channels may not be necessary. Examples of gasses that can lower the surface adhesion of PDMS are dimethyldichlorosilane (DDMS), perfluorooctyltrichlorosilane (FOTS), perfluorodecyltris(dimethylamino) silane (PF10TAS), and perfluorodecanoic acid (PFDA), and the like.

In embodiments, the stamp may be operated as shown in FIG. **6**. First, it is pressed into contact with a substrate that has the target material or devices to be picked up. (FIG. **6**A). The target material is picked up by Van der Waal's forces between itself and the stamp as is well known (FIGS. **6**B,C). Target material is placed in contact with the final substrate, and pressed into contact (FIG. **6**D). The fluid (for example, water) is pumped to the stamp surface, to reduce adhesion (FIG. **6**E). The stamp may be left in this state (of contact with water) for as long as necessary for the water to fully wet the stamp surface. Finally, the stamp is removed, leaving the target material behind on the final substrate (FIG. **6**F). In FIGS. **6**A-F, the following labels are made for clarity: fluid inlet **601**S; PDMS stamp **602**S; fluid distribution reservoir **603**S; micro-fluidic channels to stamp surface **604**S; adhesive stamp surface **605**S; devices to be picked up and transfer printed **6**; initial substrate **607**S; final substrate **608**S; pump in water **609**S so it reaches the end of the micro-fluidic channels to alter the surface adhesion of the transfer stamp and release the devices. Note that any surface channels on the stamp surface are not shown in the Figure, and the Figure is not drawn to scale.

Another example of configurations to enable stretchable circuitry are as described in the '125 application in connection with an extendable interconnect. (See FIG. 3 of the '125 application). The electrical component may be considered as one of a plurality of interconnected nodes, whose interconnections expand/extend as the underlying flexible substrate expands. In embodiments, flexible and stretchable electronics may be implemented in a great variety of ways, including configurations involving the substrate, the electrical components, the electrical interconnects, and the like, and involve electrical, mechanical, and chemical processes in their development and implementation.

As amply discussed herein, CMOS devices offer a variety sophisticated functionality including sensing, imaging, processing, logic, amplifiers, buffers, A/D converters, memory, clock and active matrix switching transistors. The electronic devices or the "device islands" of the stretchable/flexible circuitry of the present invention may be devices and are themselves capable of performing the functionality described herein, or portions thereof.

In embodiments, devices and device islands, devices are to be understood as "active" as described above.

In embodiments, the electronic devices are optionally laid out in a device island arrangement, as described herein. The functionality described herein with respect to circuitry **1000S** and thus electronic devices may thus be present in an electronic device itself, spread across arrays of electronic devices and/or device components, or achieved via electronic communication and cooperation with other electronic devices and/or device components each electronic device (or electronic device and device component combination) having separate or additive, but complementary functions that will become apparent from this disclosure. In embodiments, such electronic communication could be wireless. Therefore, said devices may comprise a transducer, transmitter, or receiver capable of such wireless transmission.

Returning to FIG. **1**, this figure schematically depicts the functionality of the circuitry **1000S** (and thus the electronic devices, device components, or combinations thereof). Elements **1100-1700** and their sub elements and components including electronic devices, device components, or combinations thereof may be present in the circuitry **1000S** individually or in any combination as applicable. Certain combinations will be discussed below; however, the below discussions merely depict exemplary embodiments of the present invention and thus they are therefore not to be considered limiting of its scope. It will be readily appreciated that the elements of circuitry **1000S**, as generally described herein, could be arranged and designed in a wide variety of different configurations. Nonetheless, the invention will be described and explained with additional specificity and detail.

Circuitry **1000S** comprises sensors (alternatively termed "sensor devices") **1100** to detect various parameters of the subject's body including, thermal parameters such as temperature, and infrared; optical parameters; electrochemical and biochemical parameters such as, pH, enzymatic activity, blood components including blood gas and blood glucose, ion concentrations, protein concentrations; electrical parameters such as resistance, conductivity, impedance, EKG, EEG, and EMG; sound, and pressure, tactile, surface characteristics, or other topographic features of the body. Thus, to achieve the detection of the above-mentioned parameters, sensors may include thermistors, thermocouples, silicon band gap temperature sensors, thin-film resistance temperature devices, LED emitters, optical sensors including photodetectors, electrodes, piezoelectric sensors, ultrasonic including ultrasound emitters and receivers; ion sensitive field effect transistors, and microneedles. Exemplary embodiments using one or more of the above sensors, or detecting and/or measuring one or more of the above parameters will be discussed below.

The separation distance between sensors (e.g., sensor device islands) can be any that is manufacturable, a useful range may be, but is not limited to, 10 μm-10000 μm. In embodiments, sensors **1100** can be characterized as sensor circuits. Individual sensors may be coupled to a differential amplifier, and/or a buffer and/or an analog to digital converter. The resulting sensor circuits may be formed on the same, or different, devices than the sensors themselves. The circuits may be laid out in an active matrix fashion such that the readings from multiple sensors **1100** can be switched into and processed by one or a few amplifier/logic circuits. Signals from the array of sensors **1100** can be processed using multiplexing techniques, including those described in published international patent application WO2009/114689 filed Mar. 12, 2009 the entirety of which is hereby incorporated herein by reference. Multiplexor component circuitry may be located on or within the circuitry **1000S** on the substrate **200**, or at a location that avoids interference with the operation of the device such as for example at the base of a catheter guide wire (which is relevant in embodiments where the substrate is a catheter balloon; although other areas that avoid interference with operation will be apparent.)

Circuitry **1000S** comprises processing facility **1200** (alternatively referred to herein as "processor", "processing", and the terms mentioned immediately below) which may include a signal processor, digital processor, embedded processor, microcontroller, microprocessor, ASIC, or the like that may directly or indirectly facilitate execution of program code or program instructions stored thereon or accessible thereto. In addition, the processing facility **1200** may enable execution of multiple programs, threads, and codes. The threads may be executed simultaneously to enhance the performance of the processing facility **1200** and to facilitate simultaneous operations of the application. By way of implementation, methods, program codes, program instructions and the like described herein may be implemented in one or more thread. The thread may spawn other threads that may have assigned priorities associated with them; the processing facility **1200** may execute these threads based on priority or any other order based on instructions provided in the program code. The processing facility **1200** (and/or the circuitry **1000S** in general) may include or be in electronic communication memory that stores methods, codes, instructions and programs as described herein and elsewhere. The processing facility **1200** may access a storage medium through an interface that may store methods, codes, and instructions to perform the methods and functionality described herein and elsewhere. Processing facility **1200** comprised in or is in electronic communication with the other elements of the circuitry **1000S** including the electronic devices and/or device components. Off-board processing facility **1200A** comprises all the functionality described above; however, is physically separate from circuitry **1000S** yet in electronic communication thereto.

Data collection facility **1300** (and off-board data collection facility **1300A**) are configured to each independently or both collect and store data generated by the circuitry **1000S** and the elements thereof including imaging facility **1600** (discussed below), and therapeutic facility **1700** (discussed below). Data transmission facility **1500** includes a means of transmitting (RF and/or wired) the sensor information to processing facility **1200** or off-board processing facility **1200A**. Each of the elements **1100-1700** are also configured to be in electronic communication with one another and need not necessarily communicate through the data transmission facility **1500**. In embodiments, circuitry **1000S** and/or data transmission facility **1500** is in electronic communication with output facility **300** which, in embodiments, can be in electronic communication with processing facility **1200A** or a separate processing facility. The various outputs described herein, such as visual maps based on sensed parameters, should be understood to emanate from the output facility **300**.

Circuitry **1000S** may be connected or otherwise in electronic communication with external/separate devices and systems by physical connection, including the methods described above and by providing conductive pads on the circuitry **1000S** in an accessible location or location that avoids interference with the operation of the device and interfacing anisotropic conductive film (ACF) connectors to the conductive pads. Also, the circuitry **1000S** and/or associated devices **10105** may comprise a transducer, transmitter, transceiver, or receiver capable of wireless transmission and thus wireless communication with external/separate devices and systems. In addition, circuitry **1000S** islands may be made to perform optical data communication down a waveguide, such as the one described below.

Power source **400** can supply power to circuitry **1000S** in any number of ways, including externally optically, with a waveguide and having PV cells made in a stretchable/flexible format in addition to the rest of the circuitry. Alternately, thin film batteries may be used to power the circuitry **1000S**, which could enable an apparatus to be left in the body and communicate with the operator. Alternately, RF communication circuits on the apparatus may not only be used to facilitate wirelessly communication between devices within the circuitry and/or to external/separate systems, but they may also receive RF power to power the circuits. Using such approaches, the need for external electrical interfaces may be eliminated.

Circuitry **1000S** includes therapeutic facility **1700** in embodiments of the invention, include various elements to effect a desired therapy. In embodiments, circuitry can comprise heat or light activated drug-delivery polymers that when activated could release chemical agents, such as anti-inflammatory drugs, to local sites in the body. Therefore, in embodiments, light emitting electronics (such as LED) could be utilized to activate a drug delivery polymer. Other therapies can be administered/effected by circuitry **1000S** such as circuitry configured to deliver ablative therapy to cardiac tissue during deployment. Other exemplary embodiments of therapeutic facility **1700** will be described herein. Those, exemplary configurations and methods for the therapeutic facility are not to be considered limiting of scope as such should not be considered as uniquely and exclusively applying to the particular exemplary embodiments being described but rather to all embodiments utilizing a therapeutic facility **1700**.

In embodiments of the invention, circuitry **1000S** comprises imaging circuitry **1600**. Imaging circuitry **1600** in embodiments comprises a packed array of active pixel sensors. Each pixel in the array may contain a photodetector, a pn junction blocking diode, an active amplifier, and an analog to digital converter, formed in a single piece of single crystalline silicon (50×50 μm2; 1.2 μm thick). In embodiments, Imaging circuitry **16000** may be encapsulated with a polymer layer such as PDMS to prevent contact stress induced damage. Imaging circuitry **1600** can comprise an array of photodetectors on the substrate **200** positioned in close proximity to the site of interest within the subject's body **2000** can provide high spatial resolution imaging without the need for a lens-based focusing due to the proximity of the photodetectors to the tissue. Imaging circuitry **1600** comprise a light source comprising or connected to an optical fiber or an LED to provide illumination to the photodetectors for imaging the tissue of interest.

Thus, the above configuration, designs, and techniques enables the circuitry to be in direct contact with and in some cases conform to the tissues in the body. Such conformal contact with tissues enhances the capabilities of the medical devices, methods, and systems disclosed herein.

Exemplary configurations for the circuitry **1000**S including sensor **1100**, processing **1200** and **1200**A, output **300**, and therapeutic facility **1700** methods, configurations as well as fabrication techniques will be described below and referred to in the following discussion with reference **1000**B (and subsequently **1000**N, **1000**T, and **1000**E). However, it should be understood that any embodiment of circuitry (and therefore its electronic devices, components, and other functional elements) described herein in shall apply to any of the exemplary embodiments. The exemplary configurations and techniques are not to be considered limiting of scope. It will be readily appreciated that the circuitry elements, configurations, and fabrication techniques of the present invention, as generally described herein, could be utilized, arranged or otherwise implemented in a wide variety of different ways. Also, and by way of clarification, the circuitry configurations and functional elements as well as the fabrication techniques described for this (and all exemplary embodiments) described herein shall be considered to apply to each or any of the embodiments disclosed herein and as such should not be considered as uniquely and exclusively applying to the particular exemplary embodiments being described.

FIG. **7** shows an embodiment of the invention wherein circuitry **1000**B is stretchable and on an expandable/stretchable substrate **200**B which in this embodiment is an inflatable body. In some embodiments (such as the one shown in FIG. **7**) the inflatable body is a balloon on a catheter **220**B. The skilled artisan will appreciate that the balloon and catheter together are referred to as a "balloon catheter" **210**B, which is a type of catheter with an inflatable balloon at its tip and which is used during a catheterization procedure for various medical procedures such as to enlarge a narrow opening or passage within the body. The deflated balloon catheter **210**B is positioned, then inflated to perform the necessary procedure, and deflated again in order to be removed.

FIG. **7** shows the balloon catheter **210**B in a relaxed or deflated state, which is inserted into a lumen **2010**B, which in this embodiment is an artery. FIG. **7** also shows arterial plaque **2020**B formed on the inner wall of the artery **2010**B. The stretchable electronic circuitry **1000**B is configured in the manner described above with reference to the various embodiments of stretchable circuitry **1000**B and is thus applied to the surface of the substrate, i.e., inflatable body **200**B according to the applicable techniques described above. In embodiments, the circuitry **1000**B utilizes complementary metal-oxide semiconductor (CMOS) technology.

FIG. **7**A shows a detailed view the circuitry **1000**B while the device is in a deflated or unexpanded state. As mentioned above, the circuitry **1000**B of the invention comprises at least one device, which is depicted in FIGS. **7** and **7**A as discrete device **1010**B. As described above, in embodiments the electronic device is in electronic communication with at least one other device **1010**B. In embodiments, the devices are arranged in a "device island" arrangement as described herein and are themselves capable of performing the functionality of the circuitry described herein including the that which has been described for elements **1100-1700** in FIG. **1**, the exemplary embodiments below, or portions thereof. Thus, in embodiments, such functionality of the devices **1010**B (or any such electronic device herein) can include integrated circuits, physical sensors (e.g. temperature, pH, light, radiation etc), biological and/or chemical sensors, amplifiers, A/D and D/A converters, optical collectors, electro-mechanical transducers, piezo-electric actuators, light emitting electronics which include LEDs, and combinations thereof.

In embodiments, in order to accommodate the devices **1010**B, which may be rigid, to the demands of an expandable and stretchable substrate **200**B such as a catheter balloon **210**B, the devices **1010**B are fabricated such that they are located in discrete and isolated "device islands" and are electrically interconnected with stretchable interconnects **1020**B, or interconnects configured to accommodate an expandable or stretchable surface. As with all elements of the circuitry **1000**B, the interconnects **1020**B can be fabricated according to techniques described herein and thus may be configured differently than what is depicted and described with reference to this exemplary embodiment.

In this exemplary embodiment, it can be seen that the interconnects **1020**B are flexible and thus able to accommodate the stretching caused by the inflation of the balloon **210**B (shown in FIG. **8**). Thus, the entirety of the circuitry **1000**B is expandable or stretchable. In the embodiment shown in FIG. **7**A, the interconnects **1020**B are buckled or non-coplanar when the substrate **200**B is in a deflated state. When inflated (as shown in FIG. **8**), the interconnects **1020**B become either coplanar or non-buckled so as to accommodate the increased distance between the devices **1010**B upon inflation. Such buckling, non-coplanar interconnects, as well as circuitry having similar properties, are described elsewhere herein and apply.

As mentioned above, in embodiments, the electronic communication between the devices and/or between said devices and separate (external, for example) devices could be wireless. Therefore, said circuitry **1000**B and/or associated devices **1010**B may comprise a transducer, transmitter, or receiver capable of such wireless transmission.

The specific fabrication method for such circuitry may depend on the specific circuit classes desired to incorporate into the device, and the specific characteristics of the circuitry, including those of the devices, the interconnects, etc., and include, but is not limited to, those disclosed with respect to this exemplary embodiment. A non-limiting example of the complete fabrication steps of an exemplary embodiment of the invention, i.e., a catheter balloon instrumented with temperature sensors, is described in the following paragraphs. It should be noted that while the embodiment described below refers to an inflatable system (specifically a catheter balloon), the skilled artisan will appreciate that such principals of operation will apply to situations where the substrate on which the circuitry is applied is otherwise stretchable or expandable but not inflatable, or where the substrate is inflatable but not necessary stretchable as described above with reference the FIG. **1** and the discussion of substrates.

In embodiments herein including but not limited to those described herein for balloon catheters, a neural bundle prosthesis, endoscopy, and tissue screening, the arrays of devices, which may include temperature sensors and associated differential amplifiers, buffers, A/D converters, logic, memory, clock and active matrix switching transistors are laid out in a "device island" arrangement. The device islands can be 50 μm×50 μm squares, most of which accommodate a single conventional sensor circuit, e.g., one a temperature sensor, connected to a buffer, that itself connected to an amplifier. The temperature sensor, which may be resistive, diode-based, etc., as described in greater detail below, supplies a signal that reflects temperature (or a temperature change), and the remaining sensor circuitry conditions the signal for subsequent processing.

In embodiments herein including but not limited to those described herein for balloon catheters, a neural bundle prosthesis, endoscopy, and tissue screening, devices accommodate active matrix switches and A/D converters for transforming an analog temperature signal into digital form, and some devices accommodate logic circuitry capable of reading in digital signals and processing them (e.g., to assign a value to the sensed temperature or temperature change). These circuits may output the temperature reading to another module or, and are capable of outputting data or storing it in on-board memory cells.

In embodiments herein including but not limited to those described herein for a balloon catheter, a neural bundle prosthesis, endoscopy, and tissue screening, the circuitry is arranged and designed such that preferably only about one, but not more than about 100 electrical interconnections are required between any two device islands. In embodiments, the circuitry is then fabricated on an SOI wafer (although it should be understood that standard wafers could be used) (1.2 μm thick top Si, 1 μm thick buried oxide) using standard CMOS fabrication technology, and the silicon space in between each island is etched away to isolate each island. The circuits are protected by a polyimide passivation layer, then a short HF etch step is applied to partially undercut the islands. The passivation layer is removed, and then a thin film of SiO_2 is deposited and patterned (100 nm thick) by PECVD or other deposition technique combined with a liftoff procedure, such that the oxide layer covers most of the space between devices (a/k/a device islands) except for a region around each device island that is about 5 μm wide. Another polyimide layer is spun on and patterned into the shape of the interconnects. Typically one interconnect may extend from the center of one device to the center of another device. Alternately, two interconnects may extend from each corner of the device to two different device corners. Alternatively, one interconnect may extend from the center of one island edge to the center of another island edge. The interconnect bridges may be about 25 μm wide and may accommodate multiple electrical lines. The polyimide partially fills where the device island is undercut; this serves to stabilize the island later in the release process and to prevent its migration. VIAs are etched into the PI layer to allow metal wires, patterned in the next step, to contact the circuits and connect one island to another. (This step can be repeated to form additional sets of wires located above the first set). Another PI layer is spun on (covering the wires and everything else). The PI (both layers) is then isolated by etching with a deposited SiO2 hard mask, in O2 RIE. PI located outside the devices and bridges is etched, as well as PI covering areas that are meant to be externally electrically interfaced, and small areas leading to the underlying oxide. Etch holes may be formed if necessary and then transferred through the silicon or metal layers by wet and/or dry etching. The underlying buried oxide is etched away using HF etchant to free the devices, which remains attached to the handle substrate due to the first polyimide passivation layer which contacts the handle wafer near the border around the devices.

If the HF etch is not controllable enough and seeps under the PI isolation layer and thereby attack the CMOS devices, then prior to the first PI passivation of brief Argon sputtering can be done to remove any native oxide followed by amorphous silicon sputtering followed by the PI passivation and the rest of the processing. After rinsing, the devices are left to air dry.

In connection with some embodiments, after drying, they are picked up with a PDMS stamp, and transfer printed onto either the surface of the substrate, which in this particular exemplary embodiment is an inflatable body such as a catheter balloon **210**B, or a surface of the inflatable body coated with a thin PDMS layer, or a separate thin PDMS layer (that may later be wrapped around the inflatable body). FIG. **9**A shows a side view of a balloon with the PDMS layer **230**B wrapped around the surface of the balloon. FIG. **9**B is a cross-sectional view which shows the catheter **220**B, the surface of the balloon **210**B, and the thin PDMS layer **230**B applied to the balloon.

It is also possible for a thin PDMS mold to be made of half the (inflated) balloon shape (in embodiments involving an inflatable body), such that it can be stretched flat, and have circuits transferred onto it in the flat state, and then released to pop back into the half-balloon shape; this half-balloon can then be easily attached to the real balloon, and may even be glued. It is noted that in some cases where the circuits are on the outside of the balloon, the bridges (also referred to as interconnects and physical electrical connections herein) pop or buckle outward when the devices are compressed or the expendable/inflatable body is otherwise in a relaxed or deflated state. In the inflated state, the bridges **1020**B should be fairly non-buckled and/or coplanar with the surface of the substrate **200**B so that in the deflated state they can buckle to accommodate the significant compressive stress.

Alternately, this process can be repeated with a mold made in the deflated state of the balloon, and stretched beyond flat so that it is significantly expanded, such that after the circuits are transferred and the mold is released, they compress significantly. In this case, they should be compressed enough so that after transfer to the actual balloon, when it is fully expanded, the bridges are nearly flat or fully extended and almost non-buckled.

In embodiments where the circuitry **1000**B is directly transferred to the balloon, the PDMS stamp should be made thin (~100-500 μm in thickness) and thereby compliant enough to conform to the shape of the balloon.

In embodiments where the circuitry **1000**B is first transferred to a separate thin PDMS layer, the PDMS layer may be on a rigid substrate so that the transferring can be done easily. Then the PDMS layer can be peeled off the substrate and wrapped around the balloon **210**B either in the inflated or deflated state, depending on whether the circuitry **1000**B was transferred with any prestrain or not. It may be desirable to make the circuitry in a 1D array rather than a 2D array. In this way, the thin PDMS layer is a long, narrow ribbon that can be easily wrapped around the balloon **210**B so as to cover the entire balloon **210**B surface.

In embodiments, to apply the circuitry, the balloon **210**B can be directly rolled along a planar array of circuitry **1000**B on PDMS carrier substrate **204**B as shown in FIG. **10**A. The balloon can be subsequently deflated and/or re-inflated. Deflation can cause the interconnects in the circuitry to buckle and take on compression forces imposed by deflation as shown in FIG. **10**C, while inflation causes the interconnects to be substantially coplanar with the substrate (as shown in FIG. **10**B). This principle applied to inflatable, stretchable, and flexible embodiments herein. Further, it should be understood that the described stamping methodologies applied to the balloon catheter can be applied to stamp the electronic circuitry in all of the embodiments described herein.

In embodiments circuitry may be encapsulated (in embodiments, while in its compressed state) with another layer of PDMS, or a liquid layer of PDMS followed by an upper layer of solid PDMS to make a fluid encapsulation.

In embodiments where the circuitry is facing outwards on the balloon, it may be electrically externally interfaced at conductive pads that should be designed to be located at the base of the balloon. Anisotropic conductive film (ACF) connectors can be used to interface to these conductive pads, by pressing and heating the film onto the pads. The film can then run down the length of the catheter since it is so thin and flexible.

In embodiments where the circuitry is encapsulated or facing inwards, they may be electrically externally interfaced by first removing part of the encapsulating polymer over the conductive pads through wet or dry chemical etching, or physical mechanical removal of material, including but not limited to drilling. At this point, the ACF may be incorporated. Alternatively, the stretchable circuitry may be electrically interfaced to an ACF prior to the transfer or encapsulation process.

As described above, in embodiments the circuitry is powered externally optically, using the catheter tube as a waveguide and having PV cells made in a stretchable format in addition to the rest of the circuitry. In addition, LED islands may be made to perform optical data communication down the catheter waveguide. Alternately, thin film batteries may be used to power the circuitry. Alternately, RF communication circuits on the device may be used to wirelessly communicate outside of the body, and may also receive RF power to power the circuits.

In embodiments, the substrate is polymeric, e.g., polyimide or polydimethylsiloxane (PDMS). The single-crystal semiconductor devices themselves may be created on a silicon-on-insulator (SOI) carrier wafer in accordance with a circuit design implementing the desired functionality. Interconnect systems (as described herein) may also be created during this step to join smaller device islands. The processed single-crystal devices are removed from the SOI wafer (e.g., by etching) and are then placed in contact with an elastomeric stamp for transfer printing (via methods described herein) onto the desired flexible polymer substrate. In embodiments, the circuitry **1000**B is transferred onto the stretchable substrate, which may be pre-stretched prior to transfer. In embodiments, the stretchable substrate serves as the catheter balloon **210**B, and can be conformed to the shape of an inflated balloon by a mold. The balloon polymer can be stretched over large strains (greater than 300%) of its relaxed or native state without causing damage to the circuitry **1000**B. As described herein, the circuitry can be encapsulated including with additional thin polymer layers to provide further protection from cracks or local contact stresses.

In an apparatus of the present invention involving but not limited to the exemplary embodiment of the balloon catheter presently being described, the substrate (in this embodiment, a catheter balloon **210**B) is covered with stretchable circuitry **1000**B having an array of devices **210**B and may be inserted in a lumen **2010**B of the subject's body. The devices may include temperature sensors. The temperature sensors may be, for example, silicon band gap temperature sensor, consisting of silicon diodes. The forward voltage of these silicon diodes are sensitive to changes in temperature. Alternatively, platinum thin-film resistance temperature devices (RTD), which measure temperature based on temperature-induced changes in electrical resistance or thermocouple circuits that sense temperature changes between different thermoelectric materials can be utilized. For thermal resistors, the normalized changes in resistance (R), temperature coefficients of resistors (α), are related to the change in temperature (T) by

$$\Delta R/R = \alpha T.$$

Platinum (500 Å) and an adhesion layer of chromium (150 Å) can be patterned and deposited on SOI wafers using thermal evaporation via e-beam to define individual RTD sensors. The RTD sensors can be integrated with CMOS based amplifiers, transducers, computation logic elements, and A/D circuitry on the same device islands as previously described.

Once the circuitry **1000**B is transferred onto the inflatable body in this embodiment, a balloon catheter **210**B, stretching and fatigue tests can be performed with a mechanical bending stage, capable of applying uneasily tensile or compressive strains in multiple directions or by repetitive inflation and deflation loading cycles. The mechanical bending stages can work in parallel with electrical probing stations (Agilent, 5155C) that are coupled to the circuit semi-conductors. In embodiments, to evaluate the performance of the circuitry, multiple cycling of heating and cooling tests can be performed. The circuits can be heated to 160° C. for 5 min. and subsequently cooled down before and after each electrical measurement.

In this exemplary embodiment and in others where it is desirable to protect the circuitry from external damage, an encapsulating thin layer of polymer can be applied to the circuitry, including on the surface of the inflatable body after the circuitry is applied thereto according to the description below and other applicable encapsulation methods described herein. This encapsulating polymer layer may be extremely thin (<100 um) and photocurable in order to allow selective curing in regions where direct contact with sensors is not required. Thus, areas of the device that do require direct or conformal contact with the tissue of interest may be exposed. Such selective encapsulation is described below, but any technique for selective encapsulation described herein may apply. It should be noted all methods of selective encapsulation apply to any embodiment disclosed herein.

In embodiments, the RTD temperature sensors may be preferentially exposed for direct contact during photocuring. There are several polymers that may be used for preferential photocuring of the encapsulating layer, including but not limited to polyethylene glycol (PEG) with 2-hydroxy-2-methylpropiophenone photoinitiator. The photocurable PEG encapsulation cures once it is exposed to ultraviolet light. Photomasks designed using AUTOCAD can be printed to allow preferential curing of the surface of the inflatable body. These masks can be inserted as a filter into a UV light source stage coupled with a wide excitation UV filter. Exposure with an aligned mask enables polymerization in strategic regions of the inflatable body. Visual alignment during polymerization can be achieved with a CCD camera.

In embodiments, the substrate (in embodiments an inflatable body such as a catheter balloon **210**B) is instrumented with an array of devices **1010**B comprising sensors such as temperature sensors can be deployed such that the temperature sensors are positioned in direct contact and or conformal with the surface of plaque in the lumen upon inflation of the inflatable body.

An important advantage realized in this embodiment, and in other embodiments having the flexible and/or stretchable circuitry described herein is that the circuitry (and thus its devices such as sensors) can not only come into direct contact with the surface or tissue of interest (in this case, the plaque and inner surface of the lumen), but also achieve conformal contact with the contours and/or surface features of the surface or tissue so as to achieve greatly improved performance.

In embodiments, the separation distance between sensors can be any that is manufacturable, a useful range may be, but is not limited to, 10 μm-10000 μm. Individual sensors may be coupled to a differential amplifier, and/or a buffer and/or an analog to digital converter. These circuits may be formed on the same, or different, devices than the temperature sensors. The circuits may be laid out in an active matrix fashion such that the readings from multiple temperature sensors can be switched into and processed by one or a few amplifier/logic circuits. These sensor arrays record input signals that can then be channeled from the surface of the balloon to guide wires and a processor using metal electrodes deposited near the junction between the balloon surface and the catheter tubing. Alternatively, gold metal wires may be used to attach the balloon circuitry to the surface of the catheter guide wire using a wire bonder. Signals from the array of sensors can be processed using multiplexing techniques, including those described in published international patent application WO2009/114689 filed Mar. 12, 2009 the entirety of which is hereby incorporated herein by reference. Multiplexor component circuitry located in the base of the catheter guide wire can facilitate this type of data analysis/processing.

Such multiplexing techniques disclosed herein allow for the circuitry (or an operator) to select which active devices should be utilized, or what pattern of active devices should be functioning. Processing facility is configured to generate a user interface on output facility such that the operator may make said selections or adjustments. In some cases the identity or pattern of active devices being utilized is based upon whether (or the degree to which) the devices are in electrical or conformal contact with the tissue of interest. Thus, all embodiments herein are able to generate useful amounts of data even when all electronic devices are not in complete contact with the area of interest on the tissue, but may only be in partial contact.

The device operator may use optical guidance during an x-ray angiography to deploy the balloon catheter once the guide wire reaches the region of the plaque location. The deformable and stretchable nature of the catheter balloon allows temperature measurements at multiple contact points on non-uniform surface contours such as that of arterial lumen and deposited plaque (shown as **2020**B in FIGS. **7** and **7**A). (The conformal capabilities of the circuitry enable such abilities). Once deployed, the processing facilities described herein process the transmitted signals and produce a spatial temperature map of the plaque in the lumen. This data can be used by the device operator to detect temperature heterogeneity presence along the plaque and determine plaque type. Once plaque type is determined and surface contours are characterized, the balloon catheter can be deflated and removed.

In another embodiment of the invention, the stretchable circuitry **1000**B comprises pressure sensor arrays. Such sensor arrays may be silicon-based and utilize piezo-resistive or capacitive sensing, or may be polymer based or optically based. In embodiments, a pressure sensor has a working range and size suitable to the application, and should be amenable to application as described herein and tolerant to the stretching forces it will experience.

FIG. **10**D shows one exemplary pressure/contact sensor which may be utilized with any embodiment described herein requiring a pressure sensor or contact sensor. The pressure sensor comprises a flexible and suspended diaphragm **600** of a flexible material such as thin single-crystal silicon, polysilicon, and/or silicon nitride thin film. The diaphragm **600** can be suspended directly above a base layer of doped silicon consisting of a metal electrode layer extracted from an SOI wafer. The polysilicon diaphragm layer may be formed as a suspended layer by first depositing an SiO2 layer on the silicon electrode **610**. The polysilicon may then be deposited on the SiO2 layer, which in turn can be selectively etched. This etching step allows for the formation of a suspended and flexible polysilicon structure. In order to produce diaphragms with a controlled thickness, precise etch rates using HF must be used. This diaphragm with known thickness (2-10 μm thick), material modulus, and surface area and the underlying silicon electrode collectively form a parallel-plate capacitor. The sensor capacitance is a function of distance between the top polysilicon layer and the underlying silicon electrode. The capacitance recordings relate diaphragm deflection (caused by force P) to changes in capacitance.

In embodiments of the invention, the stretchable circuitry comprises an array of contact sensors. The contact sensors are designed to provide an on/off electrical resistance change in response to a pressure, such that when the applied pressure exceeds a predetermined threshold, the sensor provides an electrical signal indicating that it is in contact with, e.g., the arterial wall. One example of how to form a contact sensor is to make a simple mechanical-electrical switch, in which one conductor is mechanically pressed onto another conductor. The lower conductor, located on the surface balloon, consists of a metal wire that is non-continuous in one or more places to form an open circuit. Encapsulated around this open circuit is a diaphragm formed out of PDMS. The PDMS may be molded or etched into a diaphragm shape. The upper wall of the diaphragm is coated with a metal conductor, by standard means of photolithography patterning, electrochemical etching, etching, shadow evaporation, etc. The diaphragm is aligned and bonded to the surface of the balloon. The diaphragm is designed so that when a certain pressure is applied, it bends down to allow the upper conductor to contact and short-circuit the lower non-continuous conductor. This is done by control of the geometry (height and width) and materials of the diaphragm. In yet another non-limiting example, the diaphragm may be made with MEMS techniques, such as sacrificial silicon dioxide layers with a polysilicon bridge on top.

In embodiments of the invention, to measure relative pressure, each pressure sensor can be coupled with reference sensor unit, which has identical electrical characteristics except for a significantly lower pressure sensitivity. Difference in pressure measurements between the sensor and the reference unit enable compensation for many parasitic effects. The reference units may be created by leaving a passivation layer on the top surface of the polysilicon electrode. Having a reference unit along with a pressure sensor unit allows for differential pressure recordings. Once deployed, such sensor arrays can generate data that can be used by circuitry to determine, among other things, the presence and mechanical properties of the tissue such as the presence and properties of an arterial lumen and plaque therein. In embodiments where the substrate is a balloon, such data may also be used to estimate the diameter of the balloon and the lumen and provide feedback to the device operator to end balloon inflation at this point. This type of sensing can be combined with temperature sensor arrays to provide a thorough assessment of tissue mechanical and thermal properties during a single deployment attempt.

In embodiments, data generated by such pressure sensing also allows for creation of a tactile image map of the surface contours of materials such as arterial plaque. Further, this type of mechanical imaging in balloon catheter embodiments can indicate whether a stent has been successfully deployed when the balloon is inflated.

In embodiments of the invention including a therapeutic facility **1700**, plaque type is initially determined with data generated by temperature sensors and immediately afterwards, drug-delivery polymers and circuitry embedded in the balloon polymer are activated to cause local cooling and/or release of chemical agents, such as anti-inflammatory drugs, to local sites on the plaque where inflammation is present. In embodiments, therapeutic facility **1700** comprises light emitting electronics (such as LED) could be utilized to activate a drug delivery polymer.

In embodiments of the invention, circuitry comprises imaging circuitry (referred to in connection with FIG. **1** as

1600). Imaging circuitry comprises packed array of active pixel sensors. Each pixel in the array may contain a photodetector, a pn junction blocking diode, an active amplifier, and an analog to digital converter, formed in a single piece of single crystalline silicon (50×50 μm2; 1.2 μm thick). In embodiments on an inflatable body such as a catheter balloon, all of the circuitry may be encapsulated with a polymer layer such as PDMS to prevent contact stress induced damage of circuitry on the inflatable body, since there is no requirement for direct contact of the lumen with photosensor arrays. An array of photodetectors on the inflatable body positioned in close proximity to the plaque site within a the arterial lumen can provide data used by processing facilities to create high spatial resolution images without the need for a lens-based focusing due to the proximity of the photodetectors to the lumen. The catheter guide wire may comprise a light source, such as an optical fiber or an LED to provide illumination to the photodetectors for imaging the plaque and lumen surface.

In embodiments of the invention, the substrate is covered with ultrasound emitters and receivers to generate data used to produce a lateral deep-tissue image of the plaque and arterial lumen.

In embodiments of the invention, substrate is covered with stimulating and recording electrodes used for measuring plaque conductivity. Since vulnerable plaque is significantly less conductive than stable plaque and arterial tissue, this form of sensor array can help determine the plaque type based on measured conductivity of the plaque. Once the inflatable body is deployed, the electrodes are positioned in direct contact and/or conformal with the plaque deposits and electrical conductivity is measured. Again, this device can be combined with other sensor array types embedded in the stretchable inflatable body to provide multiple sensing and therapeutic functionalities in parallel.

Data collected by sensors at the site of the plaque can be interpreted against a baseline established by deploying the same inflatable body (or a second inflatable body on the same catheter) at a different location, which is free of plaque, in the lumen.

In embodiments of the invention, the array of devices includes temperature detectors, pressure sensors, and photodetectors collectively fabricated in a flexible and stretchable polymer-based balloon catheter substrate. These active device components can be designed using 0.6 μm design feature resolution or smaller. They may be integrated on the devices that are pieces of single crystalline silicon (50×50 μm2; 1.2 μm thick). Once the balloon is inserted in the arterial lumen, the device operator navigates the guide wire leading the balloon to the plaque location. The deployment of the balloon can stop blood flow intermittently. The guide wire is preferably fitted with an optical fiber or LED; the close contact of the imaging arrays to the lumen avoids the need for optical lens arrays, since light from the optical source may pass through the interconnect gap regions between the arrays, scatter through the lumen/plaque, and reach the photodetectors directly.

In this embodiment, the pressure sensor array detects when the inflatable body initially contacts the plaque and generates data used to spatially map the entire region of contact to ensure successful deployment. Circuitry continuously record data generated by the sensors and spatially maps temperature as a way to detect where in the arterial plaque there may be inflammation and macrophage deposits. The device operator may examine the data and decide whether to take immediate action through drug-delivery measures, stent deployment, or further tests on the plaque. The device operator may also utilize light imaging to visualize the plaque. Having integrated pressure sensors and imaging sensor arrays on the balloon, in addition to temperature sensors, allows for creation of a detailed tactile, thermal and visual map of the regions where the balloon contacts the plaque. This type of distributed mechanical sensing and imaging with an array of pressure sensors and photodetectors ensures that the stent and/or balloon contact the entire surface of the plaque.

In embodiments, the lumen may be a pulmonary vein. In such embodiments, the circuitry **1000**B comprises devices having sensors that generate data related to the electrical activity of the pulmonary vein which in turn can be used processing facility to generate maps of the circumferential electrical activity of the pulmonary veins. In other embodiments, the sensor may include active electrodes. Such embodiments may generate data for mapping electrical activity of the pulmonary vein. Further, embodiments may also include a pressure sensor and temperature sensor for heterogeneous sensing on a balloon to be deployed in the pulmonary vein for mapping electrical activity. Such embodiments described for the pulmonary vein may apply to any lumen. While in other embodiments, the sensor may include active electrodes for generating data used for mapping electrical activity of the septal wall, atrial wall or surfaces, and/or ventricular surfaces.

Other embodiments may include active electrodes configured to generate data to map electrical activity while the inflatable body is inflated allowing concurrent mapping and ablation. In embodiments, ablation may be effected cryogenically, via laser or via RF energy.

In other embodiments, a contact pressure sensor device generates data used by processing device maps force per unit area applied to the ostium of the pulmonary vein which can be used for occlusion of the inflatable body, i.e., balloon, during mapping and ablation.

The inflatable body herein may be inflated with fluid of specified temperature. Data related to the temperature of the fluid may be generated by circuitry and thus used to tune the heat output of the electronics, or to calibrate the sensors.

Embodiments, of the balloon catheter can be deployed with a stent that may be fitted around the active sensing and imaging regions of the balloon.

Embodiments utilizing a catheter may utilize the inventive catheter described herein. FIG. **10**E shows a catheter **7000** comprising three lumens: guide wire lumen **7002** (houses the guide wire); fluid injection lumen **7006** (channel for fluid which will be used to inflate balloon and or control temperature of the electrodes or active devices on the balloon surface); and the circuitry lumen **7004** (houses the flexible PCB and wiring which will be connected to the DAQ). In the assembly of the catheter system, the flexible PCB is wired for connection to the DAQ and also electrically connected to the stretchable electrode array. This unit is then threaded into the circuitry lumen, of the tri-lumen extrusion as illustrated in with the DAQ-bound wires entering first and exiting through the proximal end of the catheter for connection to the DAQ.

An embodiment of the multiplexer is described in connection with the balloon catheter exemplary embodiment; although it should be understood to apply to other embodiments. FIG. **10**F shows a Wireless catheter statistical multiplexer that concentrates **16** (but could be other numbers) asynchronous channels over a single radio link. In FIG. **10**E, **I0**-**I15** are the balloon catheter electrodes. 3 cross point switches are used for multiplexing. After the mux, an X time's amp is employed. This is feed into the A/D of the CPU and then transmitted wirelessly. Two wires are needed for power and ground (3-5V @ 5-7.5 mA).

The asynchronous ports can be individually set for speeds to 57.6 Kbps. Hardware (CTS/Busy high or low) or software (Xon/Xoff even, odd, mark, space or transparent) flow control is also set on a port by port basis.

The Wireless catheter statistical multiplexer composite is a wireless link that runs at 57.6 Kbps. It transmits on the license-free ISM or MedRadio band. The link radio modules are easily configured using a terminal or PC connected to the network management port or port one. The range is 4-6 feet or up to 1000 feet with optional external repeater, not shown.

The network management port includes local and remote configuration commands. The Show Configuration Commands allow the system manager to view the configuration settings of both the local and remote multiplexers. Network management features include port and composite loopbacks, capture of a remote or local port, send a test message to an individual local or remote port, set multiplexer ID for node identification and a built-in "data line monitor" which allows the monitoring of the transmit or receive lines at the local multiplexer. A unique feature of the multiplexer is the Copy Command. This command allows a trainer at the host site to "copy" any local or remote port to view exactly what the user is entering.

Such multiplexing techniques allow for the circuitry (or an operator) to select which active devices should be utilized, or what pattern of active devices should be functioning. In some cases the identity or pattern of active devices being utilized is based upon whether (or the degree to which) the devices are in electrical or conformal contact with the tissue of interest. Thus, all embodiments herein are able to generate useful amounts of data even when all electronic devices are not in complete contact with the area of interest on the tissue, but may only be in partial contact.

Referring back to FIG. **1**, another embodiment of the present invention involves a substrate **200** (denoted as **200**N with reference to certain embodiments below) which is, or which comprises, a prosthetic device which can be inserted by means of a small opening, between severed ends of a nerve bundle. The external surface of the prosthetic device is provided with circuitry according to the disclosure herein wherein the circuitry comprises microelectrodes coupled with amplification and stimulating circuitry.

The prosthetic device can be stretched, inflated or otherwise expanded to conform to the shape of the nerve bundles. This expansion may facilitate the orientation of microelectrodes, strategically positioned on the device, in such a manner as to bridge gaps in nerve bundles. Moreover, circuitry (and in embodiments therapeutic facility **1700**) may selectively create connections between a plurality of nerves with the help of onboard logic components or by manual input from an operator utilizing an external device interfaced to the circuitry in the manners herein described. The execution of these actions may occur without movement of electrodes or further physical intervention.

The benefits of this particular embodiment include the ability to electrically reconnect many individual nerves without the need to manipulate them directly, reduce risk of aggravation to nerve damage by using a minimally invasive procedure and its ability subsequently "rewire" the connections one or more times without further surgical procedure. Additionally, this embodiment has the advantage of employing signal amplification and conditioning to adapt the input and output of each "reconnection" to the characteristics and function of a specific nerve fiber.

In this embodiment, circuitry is fabricated according to the methods described above. It should be noted that like other embodiments described herein, devices can be laid out in a device "island" arrangement. The devices are ~50 μm×50 μm2 squares, most of which accommodate one or more components connected to a buffer and also to an amplifier. Some devices accommodate active matrix switches and A/D converters, and some islands accommodate logic circuitry capable of reading in digital signals and processing them, and are capable of outputting data or storing data in memory cells. Circuitry may also contain device components which comprise metal contact pads. The circuits on devices are configured and designed such that preferably only about one, but not more than about 100 electrical interconnections are required between any two device islands or devices.

In embodiments, substrate comprises an elastomeric vessel (which is also referred to herein as an "inflatable body"). In certain embodiments such substrate is in the shape of a disk, said vessel covered with flexible and/or stretchable circuits described herein and having a multitude of electrodes. The disk can be deformed to enable its passage through a small opening in a "deflated" configuration and subsequent deployment in the gap between severed or damaged nerve bundles. Inflation with a viscous fluid is preferable, but it should be clear that a variety of gases, fluids or gels may be employed. According to the methods described herein, the flexible and/or stretchable circuitry is sealed with the miniature electrodes exposed so as to enable them to interact with the surrounding tissue. Each electrode can serve as either a sensing electrode or a stimulating electrode, and is connected to either a sensing or stimulation amplifier depending on device configuration. Signals are routed from sensing electrodes through signal processing circuitry to stimulation electrodes. In this embodiment, any electrode can act as a stimulating or a sensing electrode, depending on the dynamic configuration in effect at the time. Such electrodes may generate data while in electrical contact and/or direct physical contact. "Electrical contact" in meant to encompass situations where the electrodes are generating data regarding a tissue of interest while not necessarily being in direct physical contact. It should be noted that, "functional contact" or "sensing contact" is similarly meant to encompass situations where the sensing devices are generating data regarding a tissue of interest while not necessarily being in direct physical contact.

FIG. **11** shows the path of a single nerve pulse in an exemplary embodiment of the invention. Electrode **1022**N is in contact with nerve ending **2030**N at a given location on the surface of the device. Electrical activity affects the current or potential at the electrode and is amplified by the sensing amplifier **1012**N and then optionally undergoes further signal conditioning by block **1014**N. From there, the electrical signal flows to the multiplexer **1016**N which is configured to match nerve-signal sources and destinations in a way most beneficial to clinically desirable outcomes. The multiplexer **1016**N dispatches the signal to the appropriate location on the other side of the device, where it is again amplified by the stimulation amplifier **1013**N and finally effects nerve activity of nerve ending **2032** through electrode **1024**N. FIG. **12** shows a circuit diagram showing multiple channels for the embodiment just described,

Preferred embodiments contain thousands of such paths, enabling the interconnection of many nerves across a nerve gap in a flexible/configurable manner. Notably, the connection between two ends is not determined by the position of the device or at the time of implantation, it can be altered during the procedure or at any time thereafter by altering the dimensions of the invention. Among the reasons for altering the routing of the nerve signals would be observations about mappings of the various nerves, progress of the patient's recovery or effects of neuro-plasticity, or shifts in the relative positions of electrode and tissue in the course of motion or physiological processes. One automated means of configuring the apparatus is as follows.

As shown in FIG. **13**, on initial deployment, all electrodes and associated amplifiers are set to be in sensing mode **3010**. Electrodes then detect data of the potentials **3020**. Electrodes are individually and collectivity affected by the activity of the nerves next to them. These are then amplified and processed (by any applicable processing facility described herein) to determine the presence or degree of electrical activity **3030**, which is then used to configure the channels in the following manner: as shown in step, **3040** electrodes those regions with high electrical activity are left in sensing mode. Step **3050** shows that electrodes in regions with less, but non-zero, activity are switched to stimulation mode. In step **3060**, electrodes in regions with no activity are turned off to conserve power and avoid interference. The full nature of the electrical signals, including their amplitude and frequency, are optionally utilized by this embodiment to deduce the original anatomical function of the nerve tissue it is contacting.

In embodiments, circuitry makes measurements of conductivity between electrodes. These measurements correlate with the electrical activity of physiological structures and hence can be used by circuitry or external processing facility **1200**A to create a contour map of conductivity. In embodiments, such map can be used to enhance the configurations of the electrodes and multiplexing strategy.

As mentioned elsewhere herein, sensors can also include temperature or pH sensors or orientation sensors, and the measurements obtained from them used to improve the connections.

In other embodiments, the device does not simply provide one-to-one correspondence of electrodes. Stimulation of a given output electrode can be based on signals from more than one sensor and/or more than one input (sensing) electrode, or the stimulation of many electrodes based in signal from just one input electrode.

After initial configuration, the disclosed invention can be reconfigured one or more times thereafter, by establishing a wireless control link to the device from outside of the body (in the manners described herein) and using additional information to make decisions about the best configuration. For example, the clinician can communicate with the patient, asking him or her to attempt to move certain muscles, or to report absence or presence of certain sensations. Since as mentioned above, the substrate is biocompatible, the reconfigurations can be done after a surgical incision has successfully healed and without anesthesia or further trauma to the patient, enabling the connections between nerves to be slowly optimized for maximum benefit over a period of time. The benefit of the present invention is that these adjustments do not require any physical or surgical manipulation, thus avoiding further risks and suffering to the patient. Furthermore, subsequent configurations can be integrated into a comprehensive rehabilitation program.

The circuitry is distributed throughout substrate, which provides a high density of electrodes while allowing the invention to be realized in a variety of sizes and shapes most advantageous to a specific anatomical location. The flexible/stretchable nature of the circuitry enables it to achieve—and maintain—close contact with irregular surfaces of transected nerve fibers, providing a significant advantage over electrode systems that have to be individually positioned or require nerves to be flat planar surfaces that are not usually found in nature. In addition to making initial contact possible without either explicit surgical placement (which would be impractical for thousands of individual nerves) or perfectly flat surfaces, the present invention has the benefit of maintaining contact (electrical or physical) with a large number of nerves despite physical movement, physiological processes (such as inflammation or scarring), or the passage of time, since a near-uniform pressure is applied to all of the electrodes by the fluid filling the apparatus.

FIG. **14** shows the device implanted in the spine of a subject having neural damage. **2036**N and **2037**N are vertebrate of a spine. Cartilaginous disc **2038**N disc is also shown. Inflatable disk **212**N having circuitry **1000**N is shown being inserted into the area of damage. Once in place, disk **212**N is inflated thus contacting the nerves as described above.

Other embodiments could include a therapeutic facility (such as **1700** described in FIG. **1**) invention would also incorporate drug delivery capabilities alongside electrode arrays. FIG. **15** shows such an embodiment. Circuitry **1000**N comprising electrodes **1022**N, for example, is provided on the outside surface of disk **200**N, which may or may not be inflatable. A drug reservoir **214**N is provided, which communicates with the surface of the disc **200**N by way of channels **216**N. At the end of the channels **216**N are valves **218**N which in embodiments are MEMS valves, which are connected to and controlled by circuitry **1000**N which comprises the therapeutic facility **1700**. Refill line **219**N is connected to the reservoir which allows for the reservoir **214**N to be refilled in embodiments. One benefit of such a capability is to deliver drugs to reduce rejection or scar formation at the interface between the tissue and the apparatus. The release of a drug can be controlled by means of the MEMS valve **218**N and delivered only in areas where processing facility **1300** has determined, by being so configured, that previous measurements (such as temperature or conductivity) have indicated that it may be of greatest benefit. Other embodiments include individual cavities containing the drug, which when consumed necessitate the replacement of the device if further drug therapy is desired.

In another embodiment of the invention, electrodes on substantially flat substrates, in embodiments, sheets that comprise stretchable and/or flexible electronics may deliver stimulation to the brain, patch of exterior skin, neural bundles, internal organs, and the like. Higher density electrodes (such as <1 cm spacing) may be enabled by reducing wiring complexity, including communications facilities with each electrode or to groups of electrodes, by including amplification and multiplexing capabilities within array of electrodes, and the like.

Other embodiments of the invention, involve endoscopic imaging devices having improved design efficiencies in terms of power and volume. Embodiments of the present invention incorporate conformal, curvilinear electronic components for the purpose of volume reduction, imaging enhancement, and increased functionality.

It will be appreciated that the approach of the embodiment described below may be applied to conventional tubular endoscopy devices and capsule endoscopy devices, as well as any device utilizing the herein described curved focal plane arrays of photodetectors that are comprised in a CMOS imager. It should be noted that such curved focal plane arrays can be utilized in conjunction with any embodiment described herein and that all other embodiments described herein including those related to the circuitry including and the elements thereof are intended to be utilized as applicable in the endoscopy embodiment described below. Curved silicon optical sensor arrays have significant advantages over conventional planar arrays. These advantages include a reduced number of optical elements, reduced aberrations including astigmatism and coma, and increased off-axis brightness and sharpness.

In embodiments of the invention, an endoscopy device is fitted with a curvilinear array of sensors and/or transducers, e.g., on the exterior surface thereof, thereby reducing the required volume of the device. This approach is particularly advantageous in reducing the overall size of an endoscopy device, allowing integration of additional diagnostic and therapeutic and/or sensing functionality including any described herein an the following examples, ultrasound, pressure sensing, temperature sensing, pH, chemical sensing, targeted drug delivery, electrocautery, biopsy, laser, and heating), and increasing the allowable battery size. Increasing the power storage of a capsule endoscopy device can lead to improvements in image quality, image compression, transmission rate, number of images captured, and the intensity of illumination produced by the LEDs.

In embodiments of the invention, a capsule endoscopy device and its internal circuitry are both made flexible and/or stretchable from any of the materials described for substrates including other biocompatible materials apparent to those skilled in the art. Such a flexible/stretchable endoscopy device may have increased ease of motion along the GI tract and also increased viable volume. In other embodiments, the device may have a rigid capsule-like structure with electronics conformally fitted in the inner and/or outer shell of the capsule. The exposed surface—either a rigid ellipsoid shell or a flexible or stretchable layer—is fabricated from a material resistant to the harsh digestive environment that the endoscopy device will encounter, but which is also is biocompatible and harmless to the patient's internal anatomy. Other properties of biocompatibility of the outer surface are described herein.

The stretchable electronic components of the endoscopy device have been described herein in connection with the discussion of circuitry in all embodiments. In embodiments, circuitry comprises sensing and imaging arrays for monitoring features that are inside of bodily cavities and lumen such as the GI tract. As described above, the functionality may reside in circuitry comprising devices which may comprise device islands or vice verse. The islands house required circuitry and are interconnected mechanically and electronically via interconnects such as those described herein. The interconnects, in turn, preferentially absorb strain and thus channel destructive forces away from the device islands. They provide a mechanism by which the integrated circuits can stretch and flex when a force is applied. The device islands and interconnects may be integrated into the casing or encapsulating shell of the endoscopy device by transfer printing, as described below. Encapsulation of electronic devices and system/device interconnect integration can be performed at any of a number of stages in this process.

As with other embodiments described herein, the circuitry used in the electronic devices may comprise standard IC sensors, transducers, interconnects and computation/logic elements. In embodiments, electronic devices are typically made on a silicon-on-insulator (SOI) wafer in accordance with a circuit design implementing the desired functionality. Semiconductor devices may be processed on suitable carrier wafers which provide a top layer of ultrathin semiconductor supported by an easily removed layer (eg. PMMA). These wafers are used to fabricate flex/stretch ICs by standard processes, with particular island and interconnect placement being tailored to the requirements of a particular application.

"Ultrathin" refers to devices of thin geometries that exhibit extreme levels of bendability. They are typically less than 10 μm in thickness.

The above discussions of fabrication of circuitry applies to endoscopy embodiments. However, the following discussion will describe a transfer step for embodiments related to endoscopy (but not necessarily limited thereto). In such embodiments, the circuitry is primarily used to enhance the imaging system of the device.

Imaging with a curved optical sensor array (instead of a planar array) is used in conjunction with a lens, illuminating LEDs, battery, computing unit, antenna and a radio transmitter. Wired telemetry is used for conventional tube endoscopy. A passive or active matrix focal plane array is fabricated using one of the stretchable processing techniques described above. The array includes single-crystal silicon photo-detectors and current-blocking p-n junction diodes. Images captured using the array are minimally processed by onboard computing and transmitted (wired or wireless) to an external receiver for further processing.

The focal plane array described below could be considered part of any imaging facility described above. The individual photo detectors may be networked via interconnect systems in accordance with the present invention. These devices are found on islands and are connected by interconnects such as those interconnects described herein. In embodiment, films of polyimide support certain regions and encapsulate the entire system. Such a focal plane array can thus be incorporated into the endoscopy device.

FIG. **16** illustrates the process of making a such focal plane array. The first step is fabricating the necessary circuitry **1000**E, which in this embodiment is a focal plane array, is the creation of a suitable geometric transfer stamp to facilitate this process. In this embodiment, the circuitry is represented herein as **1000**E (although it should be understood that is contemplated that this circuitry **1000**E relates to and may be used with other circuitry embodiments described herein).

At Step **1600**A, an appropriate stamp (also referred to as transfer element) **240**E is created by casting and curing poly (dimethylsiloxane) (PDMS) in the gap between opposing convex and concave lenses with matching radii of curvature (**1621**E and **1622**E respectively). The radius of curvature should reflect the optimal parabolic curvature useful for a non-coplanar imager. At step **1600**B, the cured curved transfer element **240**E (the removal of which from lenses stamping mechanism not shown) can be stretched using a specially designed mechanism which provides outward radial forces (in embodiments equal outward forces) along the rim of the stamp to create the planar pre-strained geometric transfer element. The transfer element should return to its initial size when relaxed. Transfer element **240**E should also be large enough in its planar configuration to contact the entire area of electronic device islands on the donor substrate.

A component of the circuitry **1000**E in this embodiment is the processed electronic devices joined by interconnects **1020**E. At step **1600**C, the circuitry **1000**E is brought into contact with the planar transfer element **240**E, which adheres to the former via sufficiently strong van der Waals interactions. The transfer element **240**E is peeled back, thereby removing the focal plane array, i.e., circuitry **1000**E, from its handle wafer **1626**, shown at **1600**D. After the focal plane array **1000**E is removed from the handle wafer, the tension in the stamp is released and the contacting layers, i.e., the focal plane array and the stamp, both take initial geometric form of the stamp (shown at **1600**E). The focal plane array **1000**E compresses and the networked interconnects **1020**E of the array buckle to accommodate the strain. The buckled focal plane array **1000**E is then transferred to its final substrate (shown in steps **1600**F-H) which has a matching radius of curvature and is also in communication with the battery, antenna and a radio transmitter via electrical contacts. This transfer occurs by contacting both surfaces and is aided by the use of a photocurable adhesive. The adhesive provides sufficient attraction such that when the PDMS stamp is removed, it releases the curvilinear array of photodetectors onto the imaging system port. The curved focal plane array is then connected to the rest of the imaging electronic components via electrode contact pads on the outer perimeter of the array.

In another embodiment shown in FIG. **16**A, and endoscopy device **1680**E comprising power **300**E in the form of a battery, processing facility **1200**E, and data transmission facility **1500**E is shown. Step **1601**A shows convex focal plane array **1000**E that is adhered to the outer shell of the endoscopy device **1680**E by, for example, a geometric transfer stamp **245**E. After lifting the focal plane array off the handle wafer with the planar pre-strained PDMS (as described in connection with previous FIG. **16**), it can be relaxed and directly deposited onto the distal end of the endoscopy device **1680**E, which is provided with a receiving substrate **246**E having, for example, a photocurable adhesive. After deposition onto the endoscopy device **1680**E (status shown as **1601**B), electrical contacts are made from the array **1000**E to the internal circuitry of the endoscopy device **1680**E. At **1601**C, all of the exposed circuitry can be sealed with a suitable polymer and/or metal layer (eg. parylene, polyurethane, platinum, gold) **247**E.

Micro-lens arrays may be required for such optical array systems. However, with proper illumination and negligible distance between the optical array and the surface being imaged (e.g. near field imaging), this requirement may be nullified.

In yet another embodiment, a focal plane array, also referred to as circuitry **1000**E (as described above) is conformally wrapped around an endoscopy device such that it points in an outward radial direction from the long axis of the device. This is achieved by completing the same planar stretchable processing steps mentioned above and transferring the circuit with a different specialized polymeric stamp. The transfer stamp may take the form of a planar rectangular strip. Each polymeric strip is pre-strained by thermal expansion (heat to around 160° C.) or by applying uniform radial strain. This pre-strained polymer is then positioned in direct contact with the processed focal array. The elastomer is subsequently peeled back to release the array from its handle wafer. The stamp is then relaxed via cooling to room temperature or gradual release of the mechanically induced strain. Release of this strain causes the elastomer to return to its initial shape, which in turn forces the device islands of the array to draw closer. In embodiments, the interconnects are forced to buckle, enabling stretching and bending characteristics. In embodiments, the area upon which the array is meant to adhere is pre-treated with a photo-curable adhesive. Alternatively, a layer of PDMS may be used to enhance adhesion.

FIG. **16**B details an embodiment of the process for transferring circuitry to the endoscopy device. The transfer is achieved by stamping the planar array of device islands and interconnects onto a curvilinear surface such as an endoscopic device **1680**E. **1602**A shows the endoscopy device having a thin PDMS shell or adhesive outer layer **250**E. **1602**B shows the circuitry **1000**E on a carrier substrate **201**E. **1602**C shows the step of rotating the endoscopic device **1680**E around a single revolution over the substrate **201**E containing planar array of device islands, the array of photodetectors and interconnects will preferentially adhere to the surface of the endoscopy device **1680**E in a curvilinear manner as shown in Step **1602**D.

In another embodiment, micro-lens arrays may be required for optimal focusing and image quality. However, with proper illumination and negligible distance between the optical array and the surface being imaged, this requirement may be nullified. In the case where micro-lens arrays are required, they may be created directly as the encapsulating layer of the photodetector arrays during stretchable processing. They may also be stamped on after the endoscopic devices are made. This optical array is then encapsulated and electronically integrated with the rest of the endoscopic device in the following manner: electronic devices which have been processed for stretching, can be picked up with a planar pre-strained PDMS stamp. The pre-strained PDMS stamp is then relaxed and brought into contact with the acceptor substrate for transfer printing. This acceptor surface may be the surface of the endoscopy device, said surface coated with a thin PDMS layer, or a separate thin appropriately shaped PDMS layer that may later be wrapped around the endoscope. In the case where the devices are facing outwards on the endoscopy device substrate, they may be encapsulated (while in their compressed state) with another layer of PDMS, or a liquid layer of PDMS followed by an upper layer of solid PDMS to make a fluid encapsulation. Other materials/methods may also be applied. In the case where the devices are facing outwards on the endoscopy device substrate, they may be electrically externally interfaced at conductive pads that should be designed to be located at a convenient location. Anisotropic conductive film (ACF) connectors can be used to interface to these conductive pads, by pressing and heating the film onto the pads.

In the case where the devices are fully encapsulated or facing inwards, they may be electrically externally interfaced by first removing part of the encapsulating polymer over the conductive pads through wet or dry chemical etching, or physical mechanical removal of material, including but not limited to drilling. At this point, the ACF may be incorporated. Alternatively, the stretchable electronics may be electrically interfaced to an ACF prior to the transfer or encapsulation process.

In embodiments, circuitry **1000**E may include a flexible LED array on the outer surface of the endoscopy device **1680**E, as shown in FIG. **17**. Such an array provides illumination required for optical image capture. A representative process for creating a flexible LED system is as follows:

LEDs are made from quantum well (QW) structures on a GaAs substrate. In between the GaAs substrate and the QW structure is an AlAs sacrificial layer. The QW structure is etched with reactive ion etching (RIE) to down to the sacrificial layer to form isolated square islands which may be in the range of, for example, 10-1000 μm on an edge. A partial release/undercut of the islands with HF etching is performed. Photoresist is spun onto the substrate and patterned to form squares around the corners of the islands, to serve as anchors. A full HF release etch is performed to free the islands from the GaAs bulk substrate; the photoresist anchors prevent the islands from floating away during etch, rinse and dry steps. An elastomeric stamp (for example PDMS) is used to pick up the islands and transfer them to another substrate. The transfer may be done in multiple steps, picking up a fraction of the GaAs islands at a time, to rearrange them geometrically. The substrate onto which the islands are transferred for further processing may be a layer of PET (polyethylene plastic) on a glass substrate that can be later peeled off, or a layer of polyimide on top of a PMMA (polymethylmethacrylate) sacrificial layer, or a layer of PDMS etc. Parts of the LED islands are then patterned and wet etched so that the bottom n-type contact is exposed; this may be done with, for example, a $H3PO4+H2O2$ combination. Parts of the islands are unetched so that the upper p-type material can be contacted electrically as well. Next, a planarization layer of polyimide is spun on, patterned so that vias extend down to the p and n type contact regions of the device. Thin film wires are deposited and patterned such that the wires to the p-type regions run in one direction, and the wires to the n-type regions run in an orthogonal direction. One of the other wires should have a gap so as not to cross-circuit. This gap is bridged by spinning another planarization layer thereover and patterning it with vias to each side of the gap, and metal is patterned over the planarization layer to make the connection. Another passivation layer is spun on top, and the entire stack is etched so that the bridges and islands remain encapsulated with polymer but the intervening areas are completely etched away. This allows the bridges to be flexible. The PMMA sacrificial layer is undercut, or the PET layer is peeled off, and the entire sheet with circuits may be picked up again by PDMS stamp, and flipped over. The backside of the lower polyimide, or bottom of the circuits, is coated with Cr/SiO2; coating of the bridges is avoided by using a shadow mask evaporation procedure. The samples are subjected to a UV ozone treatment to impart dangling bonds to the SiO2, facilitating formation of covalent bonds with the next substrate to which the circuits are transferred. This final substrate may be thermally or mechanically pre-strained PDMS, such that after transfer, the strain is relaxed and the devices move closer together and the bridges pop up and buckle to accommodate the strain.

The stretchable LED array is transferred to the endoscopy device in a manner similar to that of the cylindrical optical sensor array. It is then encapsulated and integrated at the device level according to the methods described herein in connection with the micro-lens array. FIG. **17** shows an endoscopy device **1680**E wherein circuitry **1000**E comprises and array of photodetector and array of LED's (individually shown as **1030**E. The LED array may utilize processing **1200**E in the form of a logic device so that it only illuminates areas of interest during the operation and can be turned off when not in use as a power-saving mechanism. Device also includes a data transmission facility which includes RF antenna **1502** to wireless communicate with external devices.

In another embodiment of the present invention, the endoscopy device is equipped with an array of sensors which can be selected from those herein including those in connection with the discussion of **1100**. Said sensors working in conjunction with circuitry **1000**E to monitor pH, the presence of chemicals, and/or enzyme activity. IN embodiments, the data collected by this sensor array is processed by local computing devices and transmitted via RF antenna or wired telemetry to an external receiver for further analysis.

At least some of the sensors in the array may comprise an ion-sensitive field effect transistor (ISLET), which generate data relating to changes in ion concentration. The output signals are typically a voltage and/or current difference, the magnitude of which varies with the change of sensed ion (eg. hydronium) and/or enzyme. Other types of chemical sensors may be also or alternatively be utilized.

Another embodiment of the present invention relates to a capsule endoscopy device with a plurality of electronic components conformally fitted to the inside and/or outside walls of the capsule shell in order to conserve space. Conformal components are created by first performing stretchable processing on suitable materials as described herein. The basic components of such an endoscopy device include a passive or active matrix focal plane array, lens, illuminating LEDs, battery and telemetry devices (antenna and a radio transmitter). Optional components may include sensors described herein including ultrasound transducers, pressure sensors (eg. silicon-based devices utilizing piezo-resistive or capacitive sensing mechanism, polymer-based sensors, and/or optically based sensors that measure physical deflections), temperature sensors (eg. silicon band-gap temperature sensors, Pt resistance temperature devices), Ph/enzymatic/chemical sensors (eg. Islets, as discussed above), targeted drug delivery components, electrocautery devices, biopsy devices, lasers, and heating devices. Components that benefit from contact with the GI wall and fluids (eg. chemical sensors, LED, optical arrays) are situated in such a manner as to communicate fluidly or optically with the outer environment. This may be accomplished, for example, by placing the devices conformally on the outer surface of the capsule or through the use of electrodes which relay information from the outer region to the inside of the capsule. The remaining components (eg. battery, telemetry devices) are preferably located on the inside of the capsule.

Methods for creating stretchable focal plane arrays and incorporating them into a desired substrate are described above. The same methods used to process and transfer focal plane arrays (stretchable processing) may be employed for various single-crystal silicon based electronic devices (eg. antenna, RF transmitter, ISFET), with circuits being laid out (eg. using CAD tools) in a manner that accommodates mechanical deformation and stretching.

In embodiments where it is desired to incorporate heterogeneous integrated circuits (non-silicon based devices), a slightly different approach may be employed. When creating a device that requires heterogeneous integration (eg. LEDs), circuits are typically created on different substrates. After stretchable processing, the electronic devices are combined onto the same substrate using stamping methods previously described. This substrate may be the final destination of the devices (product integration) or may instead be intermediate (i.e. A rigid, flexible or stretchable material which will be incorporated into the product at a later time). At this point interconnects may be required to keep all of the heterogeneous components in electrical communication. These may be provided using soft lithography or another low-impact, low-temperature-processing (<400° C.) method with accurate alignment (<5 μm). The integrated circuit is then appropriately encapsulated and system/device interconnect integration can be executed as described above in connection with the micro-lens array.

As mentioned above, materials for the substrate used in the embodiments herein may be biocompatible. Such is the case with substrates including outer coatings of endoscopy device. In addition to biocompatibility, any part of the device housing that comes between the imager array and the object being monitored is preferably transparent. Further, the material in the outer shell of the endoscopy device facilitates easy travel through the GI tract. Examples of suitable biocompatible materials are given above.

It is to be understood that the housing of the device described above may also be the substrate and vice verse. Therefore, the skilled artisan will appreciate that certain discussions related to the substrate's material may—in certain embodiments—be understood as to apply to said housing.

It has been described herein in connection with embodiments of the invention that substrate can be fitted with circuitry comprising an array sensors and that said sensors could comprise pressure sensors. Circuitry can also comprise processing **1200** and **1200**A, data collection **1300**, amplifiers

1400, and data transmission 1500, among other capabilities. Therefore, another embodiment will be described that facilitates a quantitative examination of tissue based on palpation. In embodiments, the device is configured for self examination. The device is particularly suited for breast self-examinations; however, it will be appreciated that notwithstanding the following disclosure of an exemplary embodiment, the device and methods disclosed in connection with this exemplary embodiment apply to examinations of a variety of tissues and areas of the body, and such examination need not only be based on palpation.

Such an apparatus comprises a conformable and stretchable polymer fitted with an array of pressure transducers which remain operative notwithstanding stretching and bending of the body. The polymer substrate may cover a portion or the entire surface of the tissue and is used to measure the mechanical stiffness of the tissue at multiple discrete points. Pressure transducers coupled with processing facility can measure the mechanical stiffness of the tissue in response to known strains exerted on the surface of the tissue during palpation. As with other embodiment of the invention, the electronic devices of the circuitry may apparatus may comprise multiplexors, data acquisition and microprocessor circuits, which are connected via electronics wiring to the sensory circuitry covering the polymer substrate. Detection of abnormally hard regions of the tissue begins by first pressing the array of pressure transducers to the surface of the body part, for example, a breast. In embodiments, the device is fitted over the entire surface area of the body part (for example the breast) and as such a profile of the body-part stiffness can be mapped with high spatial resolution.

Embodiments of the present invention determine the presence and spatial extent of abnormally stiff legions of biological tissue, discriminate between relative stiffness of healthy and cancerous tissue, and facilitate immediate and localized therapeutic measures if appropriate. Because the mechanical properties of breast tissue are intrinsically heterogeneous, the present invention may be used regularly over time to precisely map the healthy state of the examined tissue thereby enabling the detection of structural abnormalities and/or deviations over time.

Embodiments of the present invention involve an instrumented polymer membrane fitted with flexible and stretchable electronic sensor and imaging arrays for measuring the material, mechanical, and/or optical properties of biological tissue. The invention utilizes flexible and stretchable circuitry suited for measuring parameters such as temperature, pressure and electrical conductivity of biological tissues. More specifically, the breast region is one area of interest for such tissue interrogation. The electronic components may be arranged in islands, which house required circuitry and are interconnected mechanically and electronically via interconnects. The interconnects, in turn, preferentially absorb strain and therefore enable the sensor arrays to withstand extreme stretching and conform to non-uniform shapes of biological tissues. The device islands and interconnects may be integrated into the device by transfer printing, as described below. Encapsulation of electronic devices and system/device interconnect integration can be performed at a number of stages in this process.

As decried amply herein, the arrays of devices, which may include one or more electronic devices and/or device components described herein (eg. pressure, light and radiation sensors, biological and/or chemical sensors, amplifiers, A/D and D/A converters, optical collectors, electro-mechanical transducers, piezo-electric actuators), connected to a buffer and also to an amplifier are laid out in a device "island" arrangement. The device islands are ~50 μm×50 μm2 squares, most of which. Some islands accommodate active matrix switches and A/D converters, and some islands accommodate logic circuitry capable of reading in digital signals and processing them, and are capable of outputting data or storing data in memory cells. The circuits on these islands are configured and designed such that preferably only about one, but not more than about 100 electrical interconnections are required between any two device islands. Circuitry is made and applied according the methods described above, including in the manner described for a device island arrangement of devices.

FIG. **18** shows an embodiment of the invention adapted for the human breast. In embodiments of the invention, a conformable polymeric membrane **200**T in the shape of a single human breast **2040**T. Applied to the membrane **200**T is circuitry **1000**T comprising sensor and/or imaging arrays based on, for example, complementary metal-oxide semiconductor (CMOS) technology. In embodiments, the array(s) **1000**T are physically integrated into the surface of the polymeric breast-shaped membrane **200**T such as (poly)dimethylsiloxane (PDMS). This stamping procedure may be done by a transfer printing process defined herein. As described herein, arrays **1000**T can be made of CMOS devices, which offer a variety of sophisticated sensing, imaging, and therapeutic functions, including (but not limited to) pressure sensing, light imaging, and trans-dermal drug delivery. The device arrays **1000**T are designed to withstand stretching and bending by the use of effective circuit layout and interconnect designs as described herein.

In embodiments, the tissue screener may be created in the form of a bra **275**T or integrated into a bra.

Embodiments may include circuitry/array **1000**T that comprises arrayed pressure sensors. As such electronic devices **1010**T can include pressure sensor. Each pressure sensor island comprises a flexible diaphragm membrane, which can record changes in capacitance in response to deflection. The pressure sensors can be made of a series of piezoresistive strain gauges, and/or conductive polymers. Each electronic device may contain an amplifier and A/D transistors to provide local signal processing on each island. The sensor islands are encapsulated with a thin layer of polymer (~100 μm thick) to protect the interconnects and the circuitry. The surface containing the thin layer is positioned in direct contact with the breast tissue during the procedure. The surface opposite the sensors can be fitted with an additional polymer layer (300-500 μm thick) that forms as an enclosure with an air-filled gap. Inflating this air-filled space by a known amount (with a peristaltic pump) facilitates the application of known strains to the breast tissue. Therefore, breast tissue can be depressed by a fixed amount over its entire surface by inflating the air-filled space, and the pressure at each location is recorded with pressure sensors.

In another embodiment, each device **1010**T includes on-off switch transistors that are coupled to said pressure sensors and activated once pressure is applied. Using this on-off mechanism, the device can determine which sensors have been pressed during sensing and communicate such to the user, via for example, a graphical user interface on an external device, or visual means such as lighted areas were sensors have been either activated or not activated, or tactile indicators of actuation. One key advantage of using a sensor array with on-off feedback is that it alerts the user if any part of the sensor array has not been depressed in the case of manual force exertion onto the breast. Therefore, it eliminates the possibility of overlooking regions of the breast during a manual examination. Thus in embodiments, each electronic device can provide feedback if the pressure sensing mechanism was not properly activated during breast examination.

In another embodiment of the invention, the devices are anchored to the breasts with straps similar to those of a **275**T. Thus in use, the user can wear the apparatus like a bra. In embodiments, the device has a port (not shown) for connecting to an external processing facility **1200**A, which in FIG. **18** is depicted as residing in a laptop computer **1204**T. Wireless communication is also possible and depicted in the figure. The external device can provide power and also receives data during screening. In embodiments, processing facility **1204**T, is in electronic communication with the circuitry and is configured to detect that the bra is worn and prompts the user to start the breast exam. The outer surface of the device on the side opposite to the breast can be covered with a thin encapsulating layer of polymer as described in previous embodiments. The space between this outer surface and the surface of the apparatus can be air-sealed and filled with air using a peristaltic air pump. Filling this space with air enables uniform pressure to be applied along the entire surface of the breast, which in turn provides control over how much strain is applied to the breast.

In another embodiment of the invention, the stretchable material **200**T comprises circuitry **1000**T having an array of ultrasound transducers (eg. piezoelectric crystals). Each device **1010**T comprises a receiver that senses acoustic reflections generated by a source emitter that sends acoustic waves through the tissue at megahertz frequencies. This embodiment can be combined with other sensors mentioned herein, including, pressure sensors to further locate and image abnormal regions of breast tissue. As with all embodiments herein, the sensors can be in electronic communication with the other facilities, electronic devices, components, and elements of the circuitry or external devices including processing facilities that receive the data from said sensors and process it according to the methods described herein, and further cause output devices to generate the output as described herein.

Circuitry **1000**T could also comprise an array of infrared emitters and detectors (eg. bolometer). The infrared wavelength is chosen to minimize the ratio of healthy tissue absorption to cancerous tissue absorption. The emitters illuminate the breast and the detectors image the radiation. This embodiment can be combined and integrated with any of the aforementioned sensing concepts for increased accuracy.

Circuitry **1000**T could also comprise an array of stimulating and recording electrodes to produce a spatial map of electrical impedance of the tissue. The electrical conductivity and dielectric properties of cancerous tissue may differ from those of healthy tissue. To detect changes in electrical impedance induced by the presence of local cancer tissue, a known AC current can be injected at a known location, and voltage is recorded at a number of points defined by the array of recording electrodes. In this embodiment, the encapsulating layer of polymer covers everything except the contact regions of the electrodes. A photo-patternable polymer can be used to achieve this step.

Electrical impedance scanning provides data to enable a 3-D spatial map of complex impedance and permittivity over a range of frequencies, which can be used as a sensing tool to predict the presence of abnormal cancerous cells deep within breast tissue. This embodiment can be combined and integrated with any of the aforementioned methods and concepts for increased accuracy.

The data collected by the array of sensors can be stored for retrieval and/or transmitted to an external system for time-based tracking of tissue health.

In embodiments, the sensor data from the array **1000**T of pressure transducers can amplified and converted to digital form at the level of each sensor and then transmitted to a multiplexor. Alternatively, the analog circuitry can be included at the level of each device **1010**T and the digital processing circuits can be housed off of the polymer. Once the data is collected from each point and transmitted to a computer terminal, the user may prompted that the examination is complete. The user may examine the data herself and/or send it to her doctor for further review (as an example).

Thus, in embodiments it will be apparent that the circuitry of the device is in electronic communication with a processing facility configured to accept data from the device and cause output facility (previously discussed in connection with FIG. **1** as **300**) to generate a graphical or otherwise visual presentation of data related to the examination. For example, tissue maps as described herein may be created from all sensor data disclosed herein and presented on output facility (as shown on **1204**T). Textual and graphical data relating to the data generated by the circuitry may be presented to the user. The processing facility may be configured to cause historical data generated by the circuitry to be stored, aggregated, and presented in a variety of ways including daily, weekly, monthly, or any other useful interval readings, charts, reports, and the like.

Returning to the physical characteristics of the device itself, the device may be opaque such that the woman's breasts are not visible. This feature can be achieved by adding opaque (e.g., black) dye to the elastomer prior to curing. In this embodiment, the array of sensors remains in close contact with the breast without having to expose her bare breasts. Because of the biocompatibility of polymers like PDMS, this type of device can be fitted within a normal bra for convenience.

In one embodiment of the invention the electronics are integrated into an elastomeric material which contours a breast. This shape is reproducible in different sizes depending on the breast size of the intended user. The process of creating the breast shaped device begins with the creation of a first breast shaped mold. A second negatively shaped mold is then made to match the curvature of the first. An elastomeric material such as PDMS is poured between the two moulds to create a thin film (less than 2 mm). This layer is cured to create a solid breast shaped film of elastomeric material upon which the electronics will be stamped by the transfer printing process described above. In order to accomplish this printing step, the elastomeric material is stretched into a flat plane and placed in contact with the already "stretch processed" electronics. The electronics preferentially adhere to the surface of the elastomer either by Van der Waal forces or by chemical aided means. Subsequently, the elastomer with embedded electronics is relaxed and buckling occurs within the interconnects of the electronics array, enabling stretchability.

Further encapsulation and device integration may be required. This may be done by connecting (manually or by electronic automation) anisotropic conductive films (ACF) to bond pads which are designed to be in an easily accessible area on the stretchable electronic array (for example on its outer perimeter). This ACF connects the electronics embedded elastomer to a device which is responsible for supplying power, relaying information of other tasks that require electrical contact.

In accordance with one or more embodiments, the stretchable electronics are integrated directly onto a bra-like substrate. This may be achieved by coating a bra-like article with an elastomeric substrate (eg. PDMS) and adhering the above described stretchable electronic array to the newly coated bra-like article.

Certain of the methods and systems described in connection with the invention described (hereinafter referred to as the "Subject Methods and Systems") may be deployed in part or in whole through a machine that executes computer software, program codes, and/or instructions on a processor integrated with or separate from the electronic circuitry described herein. Said certain methods and systems will be apparent to those skilled in the art, and nothing below is meant to limit that which has already been disclosed but rather to supplement it.

The active stretchable or flexible circuitry described herein may be considered the machine necessary to deploy the Subject Methods and System in full or in part, or a separately located machine may deploy the Subject Methods and Systems in whole or in part. Thus, "machine" as referred to herein may be applied to the circuitry described above, a separate processor, separate interface electronics or combinations thereof.

The Subject Methods and Systems invention may be implemented as a method on the machine, as a system or apparatus as part of or in relation to the machine, or as a computer program product embodied in a computer readable medium executing on one or more of the machines. In embodiments, the processor may be part of a server, client, network infrastructure, mobile computing platform, stationary computing platform, or other computing platform. A processor may be any kind of computational or processing device capable of executing program instructions, codes, binary instructions and the like. The processor may be or include a signal processor, digital processor, embedded processor, microprocessor or any variant such as a co-processor (math co-processor, graphic co-processor, communication co-processor and the like) and the like that may directly or indirectly facilitate execution of program code or program instructions stored thereon. In addition, the processor may enable execution of multiple programs, threads, and codes. The threads may be executed simultaneously to enhance the performance of the processor and to facilitate simultaneous operations of the application. By way of implementation, methods, program codes, program instructions and the like described herein may be implemented in one or more thread. The thread may spawn other threads that may have assigned priorities associated with them; the processor may execute these threads based on priority or any other order based on instructions provided in the program code. The processor, or any machine utilizing one, may include memory that stores methods, codes, instructions and programs as described herein and elsewhere. The processor may access a storage medium through an interface that may store methods, codes, and instructions as described herein and elsewhere. The storage medium associated with the processor for storing methods, programs, codes, program instructions or other type of instructions capable of being executed by the computing or processing device may include but may not be limited to one or more of a CD-ROM, DVD, memory, hard disk, flash drive, RAM, ROM, cache and the like. Nothing in this paragraph or the paragraphs below is meant to limit or contradict the description of the processing facility described herein and throughout.

A processor may include one or more cores that may enhance speed and performance of a multiprocessor. In embodiments, the process may be a dual core processor, quad core processors, other chip-level multiprocessor and the like that combine two or more independent cores (called a die).

The Subject Methods and Systems described herein may be deployed in part or in whole through a machine that executes computer software on a server, client, firewall, gateway, hub, router, or other such computer and/or networking hardware. The software program may be associated with a server that may include a file server, print server, domain server, internet server, intranet server and other variants such as secondary server, host server, distributed server and the like. The server may include one or more of memories, processors, computer readable media, storage media, ports (physical and virtual), communication devices, and interfaces capable of accessing other servers, clients, machines, and devices through a wired or a wireless medium, and the like. The methods, programs or codes as described herein and elsewhere may be executed by the server. In addition, other devices required for execution of methods as described in this application may be considered as a part of the infrastructure associated with the server.

The server may provide an interface to other devices including, without limitation, clients, other servers, printers, database servers, print servers, file servers, communication servers, distributed servers and the like. Additionally, this coupling and/or connection may facilitate remote execution of program across the network. The networking of some or all of these devices may facilitate parallel processing of a program or method at one or more location without deviating from the scope of the invention. In addition, any of the devices attached to the server through an interface may include at least one storage medium capable of storing methods, programs, code and/or instructions. A central repository may provide program instructions to be executed on different devices. In this implementation, the remote repository may act as a storage medium for program code, instructions, and programs.

If the Subject Methods and Systems are embodied in a software program, the software program may be associated with a client that may include a file client, print client, domain client, internet client, intranet client and other variants such as secondary client, host client, distributed client and the like. The client may include one or more of memories, processors, computer readable media, storage media, ports (physical and virtual), communication devices, and interfaces capable of accessing other clients, servers, machines, and devices through a wired or a wireless medium, and the like. The methods, programs or codes as described herein and elsewhere may be executed by the client. In addition, other devices required for execution of methods as described in this application may be considered as a part of the infrastructure associated with the client.

The client may provide an interface to other devices including, without limitation, servers, other clients, printers, database servers, print servers, file servers, communication servers, distributed servers and the like. Additionally, this coupling and/or connection may facilitate remote execution of program across the network. The networking of some or all of these devices may facilitate parallel processing of a program or method at one or more location without deviating from the scope of the invention. In addition, any of the devices attached to the client through an interface may include at least one storage medium capable of storing methods, programs, applications, code and/or instructions. A central repository may provide program instructions to be executed on different devices. In this implementation, the remote repository may act as a storage medium for program code, instructions, and programs.

The Subject Methods and Systems described herein may be deployed in part or in whole through network infrastructures. The network infrastructure may include elements such as computing devices, servers, routers, hubs, firewalls, clients, personal computers, communication devices, routing devices and other active and passive devices, modules and/or components as known in the art. The computing and/or non-computing device(s) associated with the network infrastructure may include, apart from other components, a storage medium such as flash memory, buffer, stack, RAM, ROM and the like. The processes, methods, program codes, instructions described herein and elsewhere may be executed by one or more of the network infrastructural elements.

The methods, program codes, and instructions pertaining to the Subject Methods and Systems described herein and elsewhere may be implemented on a cellular network having multiple cells. The cellular network may either be frequency division multiple access (FDMA) network or code division multiple access (CDMA) network. The cellular network may include mobile devices, cell sites, base stations, repeaters, antennas, towers, and the like. The cell network may be a GSM, GPRS, 3G, EVDO, mesh, or other networks types.

The methods, program codes, and instructions pertaining to the Subject Methods and Systems described herein and elsewhere may be implemented on or through mobile devices. The mobile devices may include navigation devices, cell phones, mobile phones, mobile personal digital assistants, laptops, palmtops, netbooks, pagers, electronic books readers, music players and the like. These devices may include, apart from other components, a storage medium such as a flash memory, buffer, RAM, ROM and one or more computing devices. The computing devices associated with mobile devices may be enabled to execute program codes, methods, and instructions stored thereon. Alternatively, the mobile devices may be configured to execute instructions in collaboration with other devices. The mobile devices may communicate with base stations interfaced with servers and configured to execute program codes. The mobile devices may communicate on a peer to peer network, mesh network, or other communications network. The program code may be stored on the storage medium associated with the server and executed by a computing device embedded within the server. The base station may include a computing device and a storage medium. The storage device may store program codes and instructions executed by the computing devices associated with the base station.

The computer software, program codes, and/or instructions pertaining to the Subject Methods and Systems may be stored and/or accessed on machine readable media that may include: computer components, devices, and recording media that retain digital data used for computing for some interval of time; semiconductor storage known as random access memory (RAM); mass storage typically for more permanent storage, such as optical discs, forms of magnetic storage like hard disks, tapes, drums, cards and other types; processor registers, cache memory, volatile memory, non-volatile memory; optical storage such as CD, DVD; removable media such as flash memory (e.g. USB sticks or keys), floppy disks, magnetic tape, paper tape, punch cards, standalone RAM disks, Zip drives, removable mass storage, off-line, and the like; other computer memory such as dynamic memory, static memory, read/write storage, mutable storage, read only, random access, sequential access, location addressable, file addressable, content addressable, network attached storage, storage area network, bar codes, magnetic ink, and the like.

The Subject Methods and Systems described herein may transform physical and/or or intangible items from one state to another. The methods and systems described herein may also transform data representing physical and/or intangible items from one state to another.

The elements described and depicted herein and the functions thereof may be implemented on machines through computer executable media having a processor capable of executing program instructions stored thereon as a monolithic software structure, as standalone software modules, or as modules that employ external routines, code, services, and so forth, or any combination of these, and all such implementations may be within the scope of the present disclosure. Examples of such machines may include, but may not be limited to, personal digital assistants, laptops, personal computers, mobile phones, other handheld computing devices, medical equipment, wired or wireless communication devices, transducers, chips, calculators, satellites, tablet PCs, electronic books, gadgets, electronic devices, devices having artificial intelligence, computing devices, networking equipments, servers, routers and the like. Furthermore, the elements depicted in the flow chart and block diagrams or any other logical component may be implemented on a machine capable of executing program instructions. Thus, while the foregoing descriptions set forth functional aspects of the disclosed systems, no particular arrangement of software for implementing these functional aspects should be inferred from these descriptions unless explicitly stated or otherwise clear from the context. Similarly, it will be appreciated that the various steps identified and described above may be varied, and that the order of steps may be adapted to particular applications of the techniques disclosed herein. All such variations and modifications are intended to fall within the scope of this disclosure. As such, the depiction and/or description of an order for various steps should not be understood to require a particular order of execution for those steps, unless required by a particular application, or explicitly stated or otherwise clear from the context.

The Subject Methods and Systems, and steps associated therewith, may be realized in hardware, software or any combination of hardware and software suitable for a particular application. The hardware may include a general purpose computer and/or dedicated computing device or specific computing device or particular aspect or component of a specific computing device. The processes may be realized in one or more microprocessors, microcontrollers, embedded microcontrollers, programmable digital signal processors or other programmable device, along with internal and/or external memory. The processes may also, or instead, be embodied in an application specific integrated circuit, a programmable gate array, programmable array logic, or any other device or combination of devices that may be configured to process electronic signals. It will further be appreciated that one or more of the processes may be realized as a computer executable code capable of being executed on a machine readable medium.

The computer executable code may be created using a structured programming language such as C, an object oriented programming language such as C++, or any other high-level or low-level programming language (including assembly languages, hardware description languages, and database programming languages and technologies) that may be stored, compiled or interpreted to run on one of the above devices, as well as heterogeneous combinations of processors, processor architectures, or combinations of different hardware and software, or any other machine capable of executing program instructions.

Thus, in one aspect, methods described above in connection with the Subject Systems and Methods and combinations thereof may be embodied in computer executable code that, when executing on one or more computing devices, performs the steps thereof. In another aspect, the methods may be embodied in systems that perform the steps thereof, and may be distributed across devices in a number of ways, or all of the functionality may be integrated into a dedicated, standalone device or other hardware. In another aspect, the means for performing the steps associated with the processes described above may include any of the hardware and/or software described above. All such permutations and combinations are intended to fall within the scope of the present disclosure.

While the invention has been described in connection with certain preferred embodiments, other embodiments would be understood by one of ordinary skill in the art and are encompassed herein.

All documents referenced herein are hereby incorporated by reference.

What is claimed is:

1. An apparatus comprising:

a stretchable substrate;

a stretchable circuitry selectively attached to said stretchable substrate, said stretchable circuitry comprising:

an array of recording electrodes receiving signals from a plurality of nerve sources when at least a portion of said array of recording electrodes is in electrical contact with said plurality of nerve sources;

a plurality of amplifiers, each amplifier of said plurality of amplifiers being in electronic communication with a recording electrode of said array of recording electrodes;

at least one stretchable interconnect capable of being made longer or wider without tearing or breaking, said at least one stretchable interconnect disposed between, and in electrical communication with, at least one recording electrode of the array of recording electrodes and at least one amplifier of the plurality of amplifiers, said at least one recording electrode of the array of recording electrodes and said at least one amplifier of the plurality of amplifiers being selectively attached to said stretchable substrate, and at least a portion of said at least one stretchable interconnect being free of said stretchable substrate; and

an array of stimulating electrodes; and

a processing facility in electronic communication with said array of recording electrodes and said array of stimulating electrodes that receives said signals from a plurality of nerve sources from said recording electrodes and is configured to determine a pattern of stimulation signals to be effected by said array of stimulating electrodes.

2. The apparatus of claim **1**, wherein said electrical contact comprises physical contact.

3. The apparatus of claim **1**, further comprising a multiplexer configured to match said signals from said nerve sources and cause at least one of said plurality of stimulating electrodes to dispatch a corresponding signal to a second plurality of nerves.

4. The apparatus of claim **1**, further comprising a user interface to allow an operator to adjust said pattern of stimulation signals.

5. The apparatus of claim **1**, wherein said stretchable substrate is an inflatable body.

6. The apparatus of claim **5**, wherein said inflatable body is a disk.

7. The apparatus of claim **1**, wherein said pattern of stimulation signals is dynamically configurable.

8. The apparatus of claim **1**, wherein said processing facility is further configured to generate data related to the electrical conductivity of said nerve sources.

9. The apparatus of claim **8**, wherein said processing facility is in electronic communication with an output facility and causes said output facility to generate a map, said map being based on said data related to the electrical conductivity of said nerve sources.

10. The apparatus of claim **1**, wherein said stretchable circuitry is encapsulated with a thin polymer layer.

11. The apparatus of claim **1**, wherein said stretchable circuitry comprises at least one stretchable electrical interconnect, and wherein said stretchable circuitry is stretchable up to 300%.

12. The apparatus of claim **1**, wherein said electrodes are located discretely from one another.

13. The apparatus of claim **1**, wherein said at least one stretchable interconnect of said stretchable circuitry is a plurality of stretchable electrical interconnects.

14. The apparatus of claim **13**, wherein said plurality of stretchable electrical interconnects electrically connect said array of recording electrodes and said plurality of stimulating electrodes.

15. The apparatus of claim **1**, wherein said stretchable circuitry comprises temperature sensors.

16. The apparatus of claim **1**, wherein said stretchable circuitry comprises contact sensors.

17. The apparatus of claim **1**, wherein said stretchable circuitry comprises pressure sensors.

18. The apparatus of claim **1**, wherein said stretchable substrate comprises a reservoir in communication with a surface of said stretchable substrate.

19. The apparatus of claim **18**, wherein said stretchable circuitry is configured to open valves operable to release a drug contained within said reservoir.

20. The apparatus of claim **19**, wherein said stretchable circuitry causes the valves to release said drug in a controlled manner.

21. The apparatus of claim **1**, further comprising at least one stretchable interconnect disposed between, and in electrical communication with, at least one stimulating electrode of the array of stimulating electrodes and at least one amplifier of the plurality of amplifiers.

22. An apparatus comprising:

a stretchable substrate;

a stretchable circuitry selectively attached to said stretchable substrate, said stretchable circuitry comprising:

a plurality of dynamically configurable electrodes,

wherein a first set of the plurality of dynamically configurable electrodes is configured as recording electrodes to provide an array of recording electrodes, said recording electrodes receiving signals from a plurality of nerve sources when said array of recording electrodes is in electrical contact with said plurality of nerve sources;

wherein a second set of the plurality of dynamically configurable electrodes is configured as stimulating electrodes to provide an array of stimulating electrodes; and

wherein a dynamically configurable electrode of said plurality of dynamically configurable electrodes can be configured at different times as a recording electrode or as a stimulating electrode;

a plurality of amplifiers, each amplifier of said plurality of amplifiers being in electronic communication with a recording electrode or a sensing electrode; and

at least one stretchable interconnect capable of being made longer or wider without tearing or breaking, said at least one stretchable interconnect disposed between, and in electrical communication with, at least one dynamically configurable electrode of the plurality of dynamically configurable electrodes and at least one amplifier of the plurality of amplifiers, said at least one dynamically configurable electrode of the plurality of dynamically configurable electrodes and said at least one amplifier of the plurality of amplifiers being selectively attached to said stretchable substrate, and at least a portion of said at least one stretchable interconnect being free of said stretchable substrate; and

a processing facility in electronic communication with said plurality of dynamically configurable electrodes that receives said signals from a plurality of nerve sources from said recording electrodes and is configured to determine a pattern of stimulation signals to be effected by said stimulating electrodes.

23. The apparatus of claim **22**, wherein said plurality of amplifiers comprises sensing amplifiers and stimulation amplifiers, wherein a dynamically configurable electrode that is configured as a recording electrode is placed in electronic communication with a sensing amplifier of said plurality of amplifiers, and wherein a dynamically configurable electrode that is configured as a stimulating electrode is placed in electronic communication with a stimulation amplifier of said plurality of amplifiers.

24. An apparatus comprising:

a stretchable substrate, said stretchable substrate having a first layer and a second layer, said first layer and said second layer separated by a height;

a stretchable circuitry disposed on said stretchable substrate, said stretchable circuitry comprising:

an array of recording electrodes receiving signals from a plurality of nerve sources when at least a portion of said array of recording electrodes is in electrical contact with said plurality of nerve sources;

a plurality of amplifiers, each amplifier of said plurality of amplifiers being in electronic communication with a recording electrode of said array of recording electrodes;

at least one stretchable interconnect capable of being made longer or wider without tearing or breaking, said at least one stretchable interconnect disposed between, and in electrical communication with, at least one recording electrode of the array of recording electrodes and at least one amplifier of the plurality of amplifiers, said at least one recording electrode of said array of recording electrodes and said at least one amplifier of said plurality of amplifiers being coupled to said first layer, and said at least one stretchable interconnect free to be displaced perpendicular to said second layer; and

an array of stimulating electrodes; and

a processing facility in electronic communication with said array of recording electrodes and said array of stimulating electrodes that receives said signals from a plurality of nerve sources from said recording electrodes and is configured to determine a pattern of stimulation signals to be effected by said array of stimulating electrodes.

* * * * *

专利名称(译)	使用可伸缩或柔性电子设备用于医疗应用的系统，方法和设备		
公开(公告)号	US8886334	公开(公告)日	2014-11-11
申请号	US12/636071	申请日	2009-12-11
[标]申请(专利权)人(译)	Ghaffari Roozbeh DE GRAFF贝塞尔 卡尔森GILMAN ARORA WILLIAMĴ SCHLATKA BENJAMIN KUZNETABOV EUGENE		
申请(专利权)人(译)	Ghaffari Roozbeh DE GRAFF贝塞尔 卡尔森GILMAN ARORA WILLIAMĴ SCHLATKA BENJAMIN KUZNETSOV EUGENE		
当前申请(专利权)人(译)	MC10，INC.		
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摘要(译)

提出了集成可伸展或柔性电路的系统，设备和方法，包括用于增强感测，诊断和治疗能力的有源设备阵列。本发明使得保形感测能够与感兴趣的组织接触，例如内腔的内壁，神经束或心脏的表面。这种直接的保形接触提高了测量和治疗递送的准确性。