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(54) ILLUMINATION APPARATUS AND SYSTEM FOR PRODUCTION AND INTEGRATION OF COMPACT ILLUMINATION SCHEMES

BELEUCHRUNGSVORRICHTUNG UND -SYSTEM ZUR HERSTELLUNG UND INTEGRATION KOMPAKTER BELEUCHTUNGSSCHEMATA

APPAREIL D’ILLUMINATION ET SYSTÈME D’ILLUMINATION POUR LA PRODUCTION ET L’INTÉGRATION DE SCHÉMAS D’ILLUMINATION COMPACTS

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Description

BACKGROUND:

1. Technical Field:

[0001] The present disclosure is generally directed towards the field of photoacoustic (PA) imaging. More particularly, exemplary embodiments of the present disclosure are directed towards illumination apparatus and systems for the production of highly compact illumination schemes whereby PA waves are induced. Exemplary embodiments of the present disclosure are also directed towards illumination apparatus and systems for the production of a compact and portable, integrated transducer-illumination array (TIA).

2. Background Art:

[0002] US 2003/025842 A1 discloses an optical projection system that distributes light from an illumination source via fiber optic cables to non-imaging morphing collimating optical elements and beam splitting elements.

[0003] US 2004/174591 A1 discloses a lighting device for a microscope comprising at least one observation beam path, in particular a surgical microscope, with an illumination system and a deflection device for deflecting light emitted from the illumination system onto an object to be observed, in particular an eye to be operated on, the deflection device providing an illumination of the object under various illumination angles with regard to the at least one observation beam path, wherein the deflection device comprises two deflection at least partly provided as physical beam splitters.

[0004] Photoacoustic (PA) imaging is a non-invasive medical imaging technique that may be used for detecting vascular and dermatological diseases, e.g., skin and breast cancers. The PA effect (as first reported in 1880 by A.G. Bell) arises wherein a target sample becomes heated due to absorption of light, producing an increase in pressure and/or volume of the material and its surroundings. By modulating the intensity of the light, the resulting periodic variation in pressure and/or volume can be detected as ultrasonic (US) waves. The US waves can ultimately be converted to near-real time two or three-dimensional images of the target sample using various mathematical equations. Thus, PA imaging provides relatively inexpensive and effective near real-time high-contrast imaging with relatively little danger to the target sample.

[0005] Prior apparatus, systems, and methods for PA imaging generally employ a single low-energy near-infrared laser to illuminate the target sample using a single US transducer. *See,* for example, "Optoacoustic Tomography," Oraevsky and Karabutov, Biomedical Photonics Handbook, P 34-1, 2003, CRC Press LLC, "Ultrasound-mediated biophotonic imaging: A review of acousto-optical tomography and photo-acoustic tomography," Disease Makers 19, P. 123-138 (2003-2004); U.S. Patent Number 4,255,971 to Rosencwaig, "Thermoacoustic Microscopy;" U.S. Patent Number 5,070,733 to Nagata and Koda, "Photoacoustic Imaging Method;" U.S. Patent Number 5,840,023 to Oraevsky et al., "Optoacoustic Imaging for Medical Diagnosis;" U.S. Patent Number 6,212,421 to Vo-Dinh et al., "Method and Apparatus of Spectro-Acoustically Enhanced Ultrasonic Detection for Diagnostics;" U.S. Patent Number 5,977,538 to Unger and Wu, "Optoacoustic Imaging System;" U.S. Patent Number 6,979,292 to Kanayama et al., "Method and Apparatus for Forming an Image that shows information about a subject;" U.S. Patent Number 6,833,540 to MacKenzie et al., "System for measuring a biological parameter by means of photoacoustic interaction;" and U.S. Patent Number 6,846,288 to Nagar et al., "Photoacoustic Assay and Imaging System."

[0006] Of note, prior art teachings do not provide adequate means for selectively illuminating a target sample under a US transducer array. For example, Niederhauser et. al. disclose a glass prism illumination scheme for a US transducer array that is not sufficiently compact and/or portable and therefore not very practical for in-field PA imaging applications. [*See,* Niederhauser et. al., IEEE Transactions on Medical Imaging, Vol. 24, No. 4, Page 436, Apr. 2005.] Additionally, existing illumination schemes do not enable control of illuminated patterns or geometries and/or to match the disparate illumination patterns and geometries with various transducers/transducer arrays on the market. U.S. Patent Number 4,576,436 to Daniel discloses a light distribution assembly, comprising beam splitting mirrors, which operates effectively to distribute light that originates as a substantially parallel beam into a uniform pattern. Generally illumination apparatus and systems are needed that produce/provide compact illumination schemes. Furthermore, illumination apparatus and systems are needed that produce/provide compact illumination schemes of controllable patterns and/or geometries. Indeed, production of dynamically controllable illumination schemes would be particularly advantageous. Additionally, there is a need for illumination apparatus and systems that compactly integrate such illumination schemes with one or more ultrasonic transducers/ultrasonic transducer arrays.

[0007] These and other needs are satisfied by the disclosed illumination apparatus and systems described herein.

SUMMARY OF THE DISCLOSURE:

[0008] According to a first aspect of the present invention there is provided an illumination apparatus for production of compact lightning shemes, in particular for photoacoustic imaging, as claimed in claim 1. According to another aspect of the present invention there is provided a system for compactly integrating one or more illumination apparatus, as claimed in claims 1 to 8, with an ultrasound transducer assembly as claimed in claim 9. Preferred embodiments are defined in the dependent claims.

[0009] Advantageous illumination apparatus and systems for the production and integration of compact illumination schemes are provided according to the present disclosure. Exemplary embodiments of the disclosed illumination apparatus and systems provide simple, effective and compact means for controllably illuminating a target sample for photoacoustic (PA) imaging purposes. However, while exemplary embodiments and implementations of the present disclosure generally relate to PA imaging, it is specifically contemplated that the disclosed illumination apparatus and systems apply to any field where compact illumination schemes may be used.

[0010] Exemplary embodiments of the presently disclosed apparatus/system generally include at least one lighting source and a beam splitting assembly. The at least one lighting source may include a laser optically configured to produce a concentrated beam of electromagnetic waves (e.g., visible or infrared light) of a desired intensity and wavelength. For PA imaging purposes, a wavelength in the near-infrared range is often desirable. The near-infrared wavelengths suffer less absorption and increased penetration deeper into a target sample, resulting in a larger radiated area and, ultimatly, greater depths. The intensity of the laser beam is kept well within the required limits set by the official standards (ANSI limits). With reference to the polarizing beamsplitter that may be associated with the disclosed apparatus/system, the degree of polarization of the source beam (e.g., homogenized and depolarized light) may have a significant impact on operation thereof. In exemplary embodiments of the present disclosure, the beamsplitting assembly generally includes a sequence of one or more beamsplitters, e.g., beamsplitter cubes, dicroic mirrored prisms, half silvered mirrors, dielectric optical coated mirrors and/or polarizers, such as Wollaston prisms. The sequence of one or more beamsplitters is configured such that the source beam for a subsequent beamsplitter is one of the resulting beams from a preceding beamsplitter.

[0011] The sequence of one or more beamsplitters is typically unbranched with each intermediate beamsplitter producing (i) a source beam for the subsequent beamsplitter, and (ii) an illumination beam. It is, however, specifically contemplated that branched configurations may likewise be employed, i.e., wherein a beamsplitter produces source beams for more than one subsequent beamsplitter. Therefore, in general, each disclosed beamsplitter produces at least two resultant beams including any combination of (i) one or more source beams for subsequent beamsplitters and/or (ii) one or more illumination beams.

[0012] In exemplary embodiments of the present disclosure, transmit-reflect ratios (T/R) are assigned to each beam splitter. Transmit-reflect ratios are relative measures of intensity and are defined, for purposes of the present disclosure, as the intensity of the light transmitted divided by the intensity of the light reflected (i.e., the intensity of a resulting source beam divided by the intensity of a resulting illumination beam). For beamsplitters that produce/yield more than two resultant beams, the transmit-reflect ratio is calculated for each resultant beam as the intensity of a particular resultant beam divided by the summed intensities of the remaining resultant beams. In general, transmit-reflect ratios can be used according to the present disclosure to calculate the relative intensities for each illumination beam in an entire sequence of one or more beamsplitters.

[0013] In exemplary embodiments of the present disclosure, the beamsplitting assembly may include at least one polarizing beamsplitter. The at least one polarizing beamsplitter (e.g., Wollaston prism) is generally effective to reflect waves of a particular polarization while transmiting waves of opposed polarizations. Thus, the intensity and polarization of resultant beams can be predictably controlled by properly configuring the polarizing beamsplitter. It is noted that, for a polarizing beamsplitter, the degree of polarization of the source beam is an essential element in determining the relative intensities of the resultant beams. For example, if an unpolarized light source is passed through a particular polarizing beamsplitter, the resultant S and P polarized beams may be of equal intensity if the T/R ratio is unity. By contrast, an S dominated polarized light source will produce a resultant S beam of greater intensity than the resultant P beam. In exemplary embodiments of the present disclosure, the beamsplitting assembly may include at least one polarizing beamsplitter that includes a dynamically switchable polarization material that supports and/or facilitates dynamic control of the resultant beam intensities and/or polarizations.

[0014] In exemplary embodiments of the present disclosure, the transmit-reflect ratios and/or sequence configurations of the one or more beamsplitters are selected and/or designed such that the resulting illumination beams are of desired intensities and/or are arranged in desired patterns/geometries, e.g., four illumination beams of increasing intensity arranged in line. In polarizing beamsplitting embodiments/implementations, the polarization of particular illumination beams can be similarly controlled. Moreover, where the at least one polarizing beamsplitter is dynamically controllable, the resultant beam intensities, geometrical arrangement and/or degrees of polarization can likewise be dynamically controlled.

[0015] As a result, the illumination apparatus and systems of the present disclosure advantageously provide adaptable imaging system that can be configured in near-real time for particular image requirements, e.g., scanning depth, sample material, etc. Direction-altering mirror assemblies may also be utilized prior to, during or after the beamsplitting process to alter the path of a beam and thus affect a particular pattern/geometry and/or assist in compacting the overall apparatus/system.

[0016] Advantageous systems for the production and/or integration of compact illumination schemes are also provided according to the present disclosure. Exemplary embodiments generally include: (1) one or more illumination apparatus for production of compact lighting schemes (i.e., illumination component(s)), (2) an ultrasonic (US) transducer assembly, and (3) means for coupling the illumination component(s) and US transducer assembly with a target sample. Coupling means/techniques may include, but are not limited to, use of (i) a US gel pad, e.g., a transparent ultrasound coupling pad, (ii) a container encasing the transducer assembly and illumination component(s) in coupling fluid, and/or (iii) US coupling gel.

[0017] In general, the disclosed illumination apparatus may act to illuminate specific regions of the target sample probing a desired region of interest for the PA effect. The resulting US waves emanating from the target sample are then detected using the disclosed transducer assembly. In exemplary embodiments, the disclosed apparatus/system may be integrated into a larger system, e.g., whereby data from the transducer assembly may be used to create two or three-dimensional images of the target sample. Of note, an additional feedback loop may be added using the image data to optimize the lighting, e.g., in embodiments/implementations where dynamic control is provided and/or facilitated.

[0018] In alternative exemplary embodiments and for compacting purposes, the at least one lighting source disclosed herein need not be part of an actual transducer assembly/illumination apparatus complex. Rather, the at least one lighting source, e.g., a laser, can be housed elsewhere, i.e., remote from the transducer/illumination complex, with the source beam introduced into the illumination apparatus via fiberoptics or other electromagnetic wave conduction mechanisms. The waveguide fiber may be advantageously tapered into the beam splitting assembly and encased therewith or otherwise bonded with respect thereto.

[0019] The disclosed illumination apparatus may be positioned relative to the transducer assembly such that the area and/or the target sample positioned directly under the transducer assembly is illuminated. A light reflecting layer, e.g., a mirror or foil, may be positioned between the transducer assembly and the target sample. In such embodiments/implementations, the reflective layer generally acts to minimize electromagnetic wave dissipation from the sample and illuminating the transducer. Additionally, the reflective layer may be coupled with one or more direction-altering mirror assemblies in order to minimize the distance between the transducer assembly and the target sample and/or to compact the system. For example, illumination beams emanating from the illumination apparatus could be reflected off of a mirror positioned directly below the illumination apparatus, e.g., wherein the mirror is angled such that the illumination beams are then reflected off of a second mirror and/or reflective layer toward the area of the target sample directly under the transducer assembly.

[0020] Additional advantageous features, functions and benefits associated with the disclosed illumination apparatus and systems will be apparent from the description which follows, particularly when read in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS:

[0021] To assist those of ordinary skill in the relevant art in making and using the subject matter hereof, reference is made to the appended drawings, wherein:

Figure 1 depicts exemplary beamsplitting apparatus including four (4) non-polarizing beamsplitters with varying transmission-reflection coefficients.

Figure 2 depicts the exemplary beamsplitting apparatus of Figure 1, which does not fall within the scope of appended claim 1, wherein the transmission-reflection coefficients of the non-polarizing beamsplitters are configured such that a constant intensity lighting scheme is obtained.

Figure 3 depicts the exemplary beamsplitting apparatus of Figure 1, wherein the transmission-reflection coefficients of the non-polarizing beamsplitters are configured such that a center-concentrated lighting scheme is obtained.

Figure 4 depicts the exemplary beamsplitting apparatus of Figure 1, wherein the transmission-reflection coefficients of the non-polarizing beamsplitters are configured such that a graduated intensity lighting scheme is obtained.

Figure 5 depicts exemplary beamsplitting apparatus that includes a dynamic polarizing beamsplitter with varying polarization coefficients

Figure 6 depicts the exemplary beamsplitting apparatus of Figure 5, which does not fall within the scope of appended claim 1, wherein the dynamic polarizing beamsplitter is a two-stage polarizing beamsplitters, whereby homogenized and depolarized electro magnetic radiation (i.e., light) is split into S and P polarization beams of equal intensity.

Figure 7 depicts an exemplary integrated illumination-transducer system that includes a US gel pad and reflective foil.

Figure 8 depicts an exemplary integrated illumination-transducer system wherein beamsplitting apparatus are encased together with a transducer/transducer array in a container.

Figure 9 depicts an exemplary integrated illumination-transducer system wherein a compact housing scheme is used to minimize the separation between a transducer/transducer array and a target sample.

DESCRIPTION OF EXEMPLARY EMBODIMENTS:

[0022] The disclosed illumination apparatus and systems provide means for producing and/or integrating compact lighting schemes. Indeed, exemplary embodiments of the present disclosure produce compact illumination schemes of dynamically controllable intensity, polarization, patterns and/or geometries and integrate such illumination schemes with one or more ultrasonic (US) transducers/ultrasonic transducer arrays.

[0023] With initial reference to **Figure 1,** an exemplary apparatus for the production of compact lighting schemes (illumination apparatus) 10 is depicted that includes a single light source 20 and a beamsplitting assembly 30 of four non-polarizing beamsplitters 32a, 32b, 32c, and 32d with varying transmission-reflection(T/R) coefficients. The light source 20 is directed into the beamsplitting assembly 30 using a direction-altering mirror assembly 24 that includes a single angled mirror 22. The intensity of the resultant illumination beams 34a, 34b, 34c, and 34d is determined by the T/R coefficients.

[0024] **Figures 2-4** depict exemplary intensity configurations of the illumination beams 34a, 34b, 34c, and 34d for the exemplary apparatus 10 depicted in **Figure 1.** More specifically, **Figure 2** depicts a uniform intensity scheme, which does not fall within the scope of appended claim 1, **Figure 3** depicts a center focused intensity scheme, and **Figure 4** depicts a graduated intensity scheme. Each scheme is produced by using the correct T/R ratio for each beamsplitter 32a, 32b, 32c, and 32d. For example, the uniform intensity scheme depicted in **Figure 2** is produced using the following T/R ratios (assuming a source beam 20 intensity of 100): T/R for beamsplitter 32a = 75/25, T/R for beamsplitter 32b = 50/25, T/R for beamsplitter 32c = 25/25, and T/R for beamsplitter 32d = 0/25). The physical effect of these coefficients is that, for example, beamsplitter 32a produces a resultant illumination beam with an intensity of 25 and a resultant source beam for beamsplitter 32b with an intensity of 75. Similarly T/R ratios for the illumination schemes depicted in **Figure 3** and **Figure 4** can be calculated (once again assuming a source beam 20 intensity of 100) as follows: for the center focused intensity scheme (90/10, 50/40, 10/40, 0/10) and for the graduated intensity scheme (90/10, 70/20, 40/30, 0/40) (where the ratios are presented as T/R for beamsplitter 32a, T/R for beamsplitter 32b, T/R for beamsplitter 32c, T/R for beamsplitter 32d, respectively). Of note, since the final beamsplitter 32d effectively acts as a perfect mirror reflecting all the remaining light, such beamsplitter 32d may be replaced with a mirror assembly according to the exemplary implementation depicted therein.

[0025] With reference now to **Figure 5,** an exemplary illumination apparatus 15 is depicted that includes a single light source 20 and a beamsplitting assembly 30 that includes two polarizing beamsplitters 40a and 40b with varying polarization effects. In exemplary embodiments of the present disclosure, the light source 20 is a homogonous non-polarized laser; however, alternative sources/polarizations may be utilized. As discussed previously, for apparatus/systems disclosed herein that include at least one polarizing beamsplitter, the polarization of the source light 20 is an essential element in determining the intensity and/or polarization of the resultant illumination beams 42a and 42b. Alternatively, the polarization of the source light 20 may be altered to dynamically and controllably effect a change in the resultant lighting scheme.

[0026] In the exemplary embodiment depicted in **Figure 5,** the second polarizing beamsplitter 40b effectively acts as a perfect mirror reflecting all the remaining light and may accordingly be replaced with a mirror assembly. **Figure 6** depicts an exemplary embodiment of the illumination apparatus 15 depicted in **Figure 5,** which does not fall within the scope of appended claim 1, wherein an unpolarized light source 20 is passed through the polarizing beamsplitters 40a and 40b in order to produce resultant S and P polarized illumination beams of equal intensity.

[0027] **Figures 7-9** depict various embodiments of systems for integrating compact lighting schemes of the present disclosure with a transducer/transducer array. Of note, the disclosed systems include (1) one or more illumination apparatus for the production of compact lighting schemes (i.e., illumination component(s)/apparatus) 56, (2) an ultrasonic (US) transducer assembly 50, and (3) means for coupling the one or more illumination component(s) 56 and US transducer assembly 50 with a target sample 70. In the exemplary embodiments depicted herein, the target sample 70 is a dermis layer of live patient wherein subsurface blood vessels 72 are being investigated for vascular disease. The source beams for the illumination apparatus, as depicted in the exemplary embodiments depicted in **Figures 7-9,** are introduced into the system via fiberoptic lines 52. The waveguide fiber 52 is tapered into the illumination apparatus 56 and encased therewith. Also, in the exemplary embodiments depicted in **Figures 7-9,** the disclosed systems 2, 4 and 6, respectively, are integrated into a larger system whereby data from the transducer assembly 50 is transmitted to a processing device 54, e.g., a computer, and used to create two or three-dimensional images of the target sample 70.

[0028] In exemplary embodiments of the present disclosure, the disclosed means for coupling illumination component(s) and US transducer assembly may include, but is not limited to, use of a US gel pad, use of a container encasing the transducer assembly and illumination apparatus in coupling fluid, and/or US coupling gel. **Figure 7** depicts the use of a transparent ultrasound gel coupling pad 60 as the means for coupling the illumination apparatus 56 and the transducer assembly 50 with the target sample 70. Alternatively, **Figure 8** and **Figure 9** depict the combined use of a container 62 of coupling fluid and a layer of US coupling gel 64 as means for coupling the exemplary system 4 with the target sample 70. It is noted that, in the particular embodiments depicted in **Figure 8** and **Figure 9,** the illumination apparatus 56 and part of the transducer assembly 50 are encased in the container 62.

[0029] For the particular embodiments presented in **Figures 7-9,** the illumination apparatus 56 is positioned relative to the transducer assembly 50 such that the area and/or the target sample 70 positioned directly under the transducer assembly 50 is illuminated. For the particular embodiment depicted in **Figure 9,** a reflective layer 68 is coupled with direction-altering mirrors 66 in order to minimize the distance between the transducer assembly 50 and the target sample 70, thus compacting the system 6. The illumination beams emanating from the illumination apparatus 56 are first reflected off the mirrors 66 and then reflected off the reflective layer 68 toward the area of the target sample 70 directly under the transducer assembly 50. A reflective layer may also be used as depicted in **Figure 7** to counteract the dissipation of electromagnetic waves from the sample. In exemplary system 2, the illumination beams emanating from the illumination apparatus 56 are further concentrated on the target sample 70 by means of the reflective layer 58 positioned under and adjacent to the transducer assembly 50.

[0030] Although the present disclosure is described with reference to exemplary embodiments and implementations thereof, the present disclosure is not to be limited by or to such exemplary embodiments and/or implementations. Rather, the illumination apparatus and systems of the present disclosure are susceptible to various modifications, variations and/or enhancements within the scope of the appended claims.

Claims

1. Illumination apparatus (10,15) for production of compact lighting schemes, comprising:

> at least one lighting source (20) configured to provide an illumination beam, and
> a beamsplitting assembly (30) that includes a sequence of beamsplitters (32,34) of varying transmit-reflect ratios, a transmit-reflect ratio being the intensity of the light transmitted divided by the intensity of the light reflected, wherein the sequence of beamsplitters is configured such that a source beam for a subsequent beamsplitter of the sequence is one of the resulting beams from a preceding beamsplitter of the sequence; and
> wherein the illumination beam of the at least one light source is arranged to pass through the beamsplitting assembly and wherein the beamsplitting assembly is configured to divide the illumination beam of the at least one light source into beams (34a,34b,34c,34d; 42a,42b) of desired intensity to provide an illumination scheme selected from the group consisting of a center focused intensity scheme and a graduated intensity scheme.

2. The illumination apparatus according to claim 1, wherein the illumination beam of the at least one light source (20) is arranged to pass through one or more direction-altering mirror assemblies (22,66) prior to, during or after the beamsplitting process.

3. The illumination apparatus according to claim 1, wherein the sequence of beamsplitters (32,40) includes at least one polarizing beamsplitter (40a,40b).

4. The illumination apparatus according to claim 3, wherein the at least one polarizing beamsplitter (40a,40b) is a polarizing beamsplitter arranged to divide the illumination beam of the at least one lighting source into S and P polarized beams.

5. The illumination apparatus according to claim 3, wherein the at least one polarizing beamsplitter (40a,40b) includes dynamically switchable polarization material such that resulting beam intensities and/or polarizations of the beams are dynamically controllable.

6. The illumination apparatus according to claim 1, wherein the beams of the illumination scheme are configured for photoacoustic imaging.

7. The illumination appartus of claim 1, wherein the at least one lightning source includes a laser optically configured to produce a concentrated beam of electromagnetic waves of a desired intensity and desired wavelength.

8. The illumination apparatus of claim 7, wherein the desired wavelength is in the near-infrared range.

9. A system (6) for compactly integrating one or more illumination apparatus (10,15,56) with an ultrasonic transducer assembly (50), the system comprising:

> one or more illumination apparatus (10,15,56) according to one of claims 1 to 8;
> an ultrasonic transducer assembly (50) including at least one ultrasonic transducer; wherein said ultrasonic transducer assembly is arranged to detect ultrasonic waves emanating relative to the target sample; and
> means (60,62,64) for coupling the one or more illumination apparatus and the ultrasonic transducer assembly (50) with a target sample (70).

10. The system according to claim 9, wherein the means for coupling the one or more illumination apparatus (10,15,56) and the ultrasonic transducer assembly (50) with a target sample (70) comprises an ultrasonic gel pad (60), or a container with coupling fluid (62) and a layer of ultrasonic gel (64), or a compact housing (62) and a layer of ultrasonic gel (64).

11. The system according to claim 9, wherein the ultrasonic transducer assembly comprises a transducer array.

12. The system of claim 9, further wherein, when the illumination scheme comprises a center focused intensity scheme, the one or more illumination apparatus comprising two illumination apparatus, wherein the beamsplitting assembly of each illumination apparatus comprises a sequence of four beamsplitters, and wherein the center focused intensity scheme includes intensities of 10, 40, 40, and 10 out of 100 percent intensity for respective beamsplitters of the beamsplitting assembly.

13. The system of claim 9, further wherein, when the illumination scheme comprises a graduated intensity scheme, the one or more illumination apparatus comprising two illumination apparatus, wherein the beamsplitting assembly of each illumination apparatus comprises a sequence of four beamsplitters, and wherein the graduated intensity scheme includes intensities of 10, 20, 30, and 40 out of 100 percent intensity for respective beamsplitters of the beamsplitting assembly.

14. The system of claim 9, wherein the one or more illumination apparatus is arranged to dynamically control the beams of desired intensity to produce an illumination scheme configured to match with the at least one ultrasonic transducer of the ultrasonic transducer assembly (50).

15. The system of claim 9, further comprising one or more direction-altering mirror assemblies (66) and a reflective layer (68) coupled with the one or more direction-altering mirror assemblies (66), wherein the reflective layer is positioned directly below the ultrasonic transducer assembly (50), wherein the one or more direction-altering mirror assemblies (66) are positioned (i) directly below a respective beamsplitting assembly of the one or more illumination apparatus (10,15,56) and (ii) below the ultrasonic transducer assembly (50), and wherein the one or more direction-altering mirror assemblies (66) are angled such that the beams of desired intensity eminating from the respective one or more illumination apparatus (10,15,56) are then reflected off of the reflective layer (68) toward the area of the target sample (70) directly under the transducer assembly (50).

Patentansprüche

1. Beleuchtungsvorrichtung (10, 15) zur Herstellung kompakter Beleuchtungsschemata, umfassend:

mindestens eine Lichtquelle (20), die konfiguriert ist, um einen Beleuchtungsstrahl bereitzustellen, und

eine Strahlenteilerbaugruppe (30), die eine Sequenz von Strahlenteilern (32, 34) von unterschiedlichen Durchlass-Reflektions-Verhältnissen umfasst, wobei ein Durchlass-Reflektions-Verhältnis die Intensität des durchgelassenen Lichts dividiert durch die Intensität des reflektierten Lichts ist, wobei die Sequenz von Strahlenteilern derartig konfiguriert ist, dass ein Quellenstrahl für einen nachfolgenden Strahlenteiler der Sequenz einer der resultierenden Strahlen aus einem vorhergehenden Strahlenteiler der Sequenz ist; und

wobei der Beleuchtungsstrahl von der mindestens einen Lichtquelle vorgesehen ist, um die Strahlenteilerbaugruppe zu durchqueren, und wobei die Strahlenteilerbaugruppe konfiguriert ist, um den Beleuchtungsstrahl der mindestens einen Lichtquelle in Strahlen (34a, 34b, 34c, 34d; 42a, 42b) von gewünschter Intensität aufzuteilen, um ein Beleuchtungsschema ausgewählt aus der Gruppe bestehend aus einem zentrumfokussierten Intensitätsschema und einem abgestuften Intensitätsschema bereitzustellen.

2. Beleuchtungsvorrichtung nach Anspruch 1, wobei der Beleuchtungsstrahl der mindestens einen Lichtquelle (20) vorgesehen ist, um vor, während oder nach dem Strahlenteilungsprozess eine oder mehrere richtungsändernde Spiegelbaugruppen (22, 66) zu durchqueren.

3. Beleuchtungsvorrichtung nach Anspruch 1, wobei die Sequenz von Strahlenteilern (32, 40) mindestens einen polarisierenden Strahlenteiler (40a, 40b) umfasst.

4. Beleuchtungsvorrichtung nach Anspruch 3, wobei der mindestens eine polarisierende Strahlenteiler (40a, 40b) ein polarisierender Strahlenteiler ist, der vorgesehen ist, um den Beleuchtungsstrahl der mindestens einen Lichtquelle in S- und P-polarisierte Strahlen aufzuteilen.

5. Beleuchtungsvorrichtung nach Anspruch 3, wobei der mindestens eine polarisierende Strahlenteiler (40a, 40b) dynamisch umschaltbares Polarisationsmaterial umfasst, so dass resultierende Strahlintensitäten und/oder Polarisierungen der Strahlen dynamisch steuerbar sind.

6. Beleuchtungsvorrichtung nach Anspruch 1, wobei die Strahlen des Beleuchtungsschemas für photoakustische Bildgebung konfiguriert sind.

7. Beleuchtungsvorrichtung nach Anspruch 1, wobei die mindestens eine Lichtquelle einen Laser umfasst, der optisch konfiguriert ist, um einen konzentrierten Strahl von elektromagnetischen Wellen einer gewünschten Intensität und einer gewünschten Wellenlänge zu erzeugen.

8. Beleuchtungsvorrichtung nach Anspruch 7, wobei die gewünschte Wellenlänge im nahen Infrarotbereich liegt.

9. System (6) zum kompakten Integrieren einer oder mehrerer Beleuchtungsvorrichtungen (10, 15, 56) mit einer Ultraschallwandlerbaugruppe (50), wobei das System Folgendes umfasst:

eine oder mehrere Beleuchtungsvorrichtungen (10, 15, 56) nach einem der Ansprüche 1 bis 8;
eine Ultraschallwandlerbaugruppe (50) umfassend mindestens einen Ultraschallwandler; wobei die genannte Ultraschallwandlerbaugruppe vorgesehen ist, um in Bezug auf die Zielprobe austretende Ultraschallwellen zu detektieren; und
Mittel (60, 62, 64) zum Koppeln der einen oder mehreren Beleuchtungsvorrichtungen und der Ultraschallwandlerbaugruppe (50) mit einer Zielprobe (70).

10. System nach Anspruch 9, wobei das Mittel zum Koppeln der einen oder mehreren Beleuchtungsvorrichtungen (10, 15, 56) und der Ultraschallwandlerbaugruppe (50) mit der Zielprobe (70) ein Ultraschall-Gelkissen (60), oder einen Behälter mit Kopplungsfluid (62) und einer Schicht aus Ultraschallgel (64), oder ein kompaktes Gehäuse (62) und eine Schicht aus Ultraschallgel (64) umfasst.

11. System nach Anspruch 9, wobei die Ultraschallwandlerbaugruppe ein Wandlerarray umfasst.

12. System nach Anspruch 9, wobei weiterhin, wenn das Beleuchtungsschema ein zentrumfokussiertes Intensitätsschema umfasst, die eine oder mehrere Beleuchtungsvorrichtungen zwei Beleuchtungsvorrichtungen umfassen, wobei die Strahlenteilerbaugruppe jeder Beleuchtungsvorrichtung eine Sequenz von vier Strahlenteilern umfasst, und wobei das zentrumfokussierte Intensitätsschema Intensitäten von 10, 40, 40 und 10 von 100 Prozent Intensität für jeweilige Strahlenteiler der Strahlenteilerbaugruppe umfasst.

13. System nach Anspruch 9, wobei weiterhin, wenn das Beleuchtungsschema ein abgestuftes Intensitätsschema umfasst, die eine oder mehrere Beleuchtungsvorrichtungen zwei Beleuchtungsvorrichtungen umfassen, wobei die Strahlenteilerbaugruppe jeder Beleuchtungsvorrichtung eine Sequenz von vier Strahlenteilern umfasst, und wobei das abgestufte Intensitätsschema Intensitäten von 10, 20, 30 und 40 von 100 Prozent Intensität für jeweilige Strahlenteiler der Strahlenteilerbaugruppe umfasst.

14. System nach Anspruch 9, wobei die eine oder mehrere Beleuchtungsvorrichtungen vorgesehen sind, um die Strahlen von gewünschter Intensität dynamisch zu steuern, um ein Beleuchtungsschema zu erzeugen, das konfiguriert ist, um mit dem mindestens einen Ultraschallwandler der Ultraschallwandlerbaugruppe (50) übereinzustimmen.

15. System nach Anspruch 9, weiterhin umfassend eine oder mehrere richtungsändernde Spiegelbaugruppen (66) und eine mit der einen oder mehreren richtungsändernden Spiegelbaugruppen (66) gekoppelte reflektierende Schicht (68), wobei die reflektierende Schicht direkt unter der Ultraschallwandlerbaugruppe (50) positioniert ist, wobei die eine oder mehrere richtungsändernde Spiegelbaugruppen (66) (i) direkt unter einer jeweiligen Strahlenteilerbaugruppe der einen oder mehreren Beleuchtungsvorrichtungen (10, 15, 56) und (ii) unter der Ultraschallwandlerbaugruppe (50) positioniert sind, und wobei die eine oder mehrere richtungsändernde Spiegelbaugruppen (66) derartig gewinkelt sind, dass die Strahlen von gewünschter Intensität, die aus der jeweiligen einen oder mehreren Beleuchtungsvorrichtungen (10, 15, 56) austreten, dann von der reflektierenden Schicht (68) zur Fläche der Zielprobe (70) direkt unter der Wandlerbaugruppe (50) reflektiert werden.

Revendications

1. Appareil d'illumination (10, 15) pour la production de plans d'éclairage compacts, comprenant :

au moins une source de lumière (20) configurée pour fournir un faisceau d'illumination, et
un ensemble de séparation de faisceau (30) qui comporte une séquence de séparateurs de faisceau (32, 34) de rapports de transmission-réflexion variables, un rapport de transmission-réflexion étant l'intensité de la lumière transmise divisée par l'intensité de la lumière réfléchie, dans lequel la séquence de séparateurs de faisceau est configurée de sorte qu'un faisceau source pour un séparateur de faisceau suivant de la séquence soit l'un des faisceaux résultants d'un séparateur de faisceau précédent de la séquence ; et
dans lequel le faisceau d'illumination de l'au moins une source de lumière est agencé pour traverser l'ensemble de séparation de faisceau et dans lequel l'ensemble de séparation de fais-

ceau est configuré pour diviser le faisceau d'illumination de l'au moins une source de lumière en faisceaux (34a, 34b, 34c, 34d ; 42a, 42b) d'intensité souhaitée pour fournir un plan d'illumination choisi dans le groupe constitué d'un plan à intensité focalisée au centre et d'un plan à intensité graduée.

2. Appareil d'illumination selon la revendication 1, dans lequel le faisceau d'illumination de l'au moins une source de lumière (20) est agencé pour traverser un ou plusieurs ensembles de miroirs modifiant la direction (22, 66) avant, pendant ou après le processus de séparation de faisceau.

3. Appareil d'illumination selon la revendication 1, dans lequel la séquence de séparateurs de faisceau (32, 40) comporte au moins un séparateur de faisceau polarisant (40a, 40b).

4. Appareil d'illumination selon la revendication 3, dans lequel l'au moins un séparateur de faisceau polarisant (40a, 40b) est un séparateur de faisceau polarisant agencé pour diviser le faisceau d'illumination de l'au moins une source d'éclairage en faisceaux polarisés S et P.

5. Appareil d'illumination selon la revendication 3, dans lequel l'au moins un séparateur de faisceau polarisant (40a, 40b) comporte un matériau de polarisation commutable dynamiquement de sorte que des intensités et/ou des polarisations de faisceau résultantes des faisceaux soient commandables dynamiquement.

6. Appareil d'illumination selon la revendication 1, dans lequel les faisceaux du plan d'illumination sont configurés pour une imagerie photoacoustique.

7. Appareil d'illumination selon la revendication 1, dans lequel l'au moins une source d'éclairage comporte un laser configuré optiquement pour produire un faisceau concentré d'ondes électromagnétiques d'une intensité souhaitée et d'une longueur d'onde souhaitée.

8. Appareil d'illumination selon la revendication 7, dans lequel la longueur d'onde souhaitée est dans la plage du proche infrarouge.

9. Système (6) pour intégrer de façon compacte un ou plusieurs appareils d'illumination (10, 15, 56) avec un ensemble de transducteurs ultrasonores (50), le système comprenant :

un ou plusieurs appareils d'illumination (10, 15, 56) selon l'une des revendications 1 à 8 ;
un ensemble de transducteurs ultrasonores (50) comportant au moins un transducteur ultrasonore ; dans lequel ledit ensemble de transducteurs ultrasonores est agencé pour détecter des ondes ultrasonores émanant par rapport à l'échantillon cible ; et
un moyen (60, 62, 64) pour coupler les un ou plusieurs appareils d'illumination et l'ensemble de transducteurs ultrasonores (50) à un échantillon cible (70).

10. Système selon la revendication 9, dans lequel le moyen pour coupler les un ou plusieurs appareils d'illumination (10, 15, 56) et l'ensemble de transducteurs ultrasonores (50) à un échantillon cible (70) comprend un tampon de gel ultrasonore (60), ou un contenant avec un fluide de couplage (62) et une couche de gel ultrasonore (64), ou un boîtier compact (62) et une couche de gel ultrasonore (64).

11. Système selon la revendication 9, dans lequel l'ensemble de transducteurs ultrasonores comprend un réseau de transducteurs.

12. Système selon la revendication 9, dans lequel en outre, lorsque le plan d'illumination comprend un plan à intensité focalisée au centre, les un ou plusieurs appareils d'illumination comprenant deux appareils d'illumination, dans lequel l'ensemble de séparation de faisceau de chaque appareil d'illumination comprend une séquence de quatre séparateurs de faisceau, et dans lequel le schéma à intensité focalisée au centre comporte des intensités de 10, 40, 40, et 10 pour 100 pourcent d'intensité pour des séparateurs de faisceau respectifs de l'ensemble de séparation de faisceau.

13. Système selon la revendication 9, dans lequel en outre, lorsque le plan d'illumination comprend un plan à intensité graduée, les un ou plusieurs appareils d'illumination comprenant deux appareils d'illumination, dans lequel l'ensemble de séparation de faisceau de chaque appareil d'illumination comprend une séquence de quatre séparateurs de faisceau, et dans lequel le plan à intensité graduée comporte des intensités de 10, 20, 30, et 40 pour 100 pourcent d'intensité pour des séparateurs de faisceau respectifs de l'ensemble de séparation de faisceau.

14. Système selon la revendication 9, dans lequel les un ou plusieurs appareils d'illumination sont agencés pour commander dynamiquement les faisceaux d'intensité souhaitée pour produire un plan d'illumination configuré pour concorder avec l'au moins un transducteur ultrasonore de l'ensemble de transducteurs ultrasonores (50).

15. Système selon la revendication 9, comprenant en outre un ou plusieurs ensembles de miroirs modifiant la direction (66) et une couche réfléchissante (68) couplée aux uns ou plusieurs ensembles de miroirs modifiant la direction (66), dans lequel la couche réfléchissante est positionnée directement en dessous de l'ensemble de transducteurs ultrasonores (50), dans lequel les un ou plusieurs ensembles de miroirs modifiant la direction (66) sont positionnés (i) directement en dessous d'un ensemble de séparation de faisceau respectif des un ou plusieurs appareils d'illumination (10, 15, 56) et (ii) en dessous de l'ensemble de transducteurs ultrasonores (50), et dans lequel les un ou plusieurs ensembles de miroirs modifiant la direction (66) sont orientés de sorte que les faisceaux d'intensité souhaitée émanant des un ou plusieurs appareils d'illumination (10, 15, 56) respectifs soient alors réfléchis par la couche réfléchissante (68) vers la zone de l'échantillon cible (70) directement sous l'ensemble de transducteurs (50).

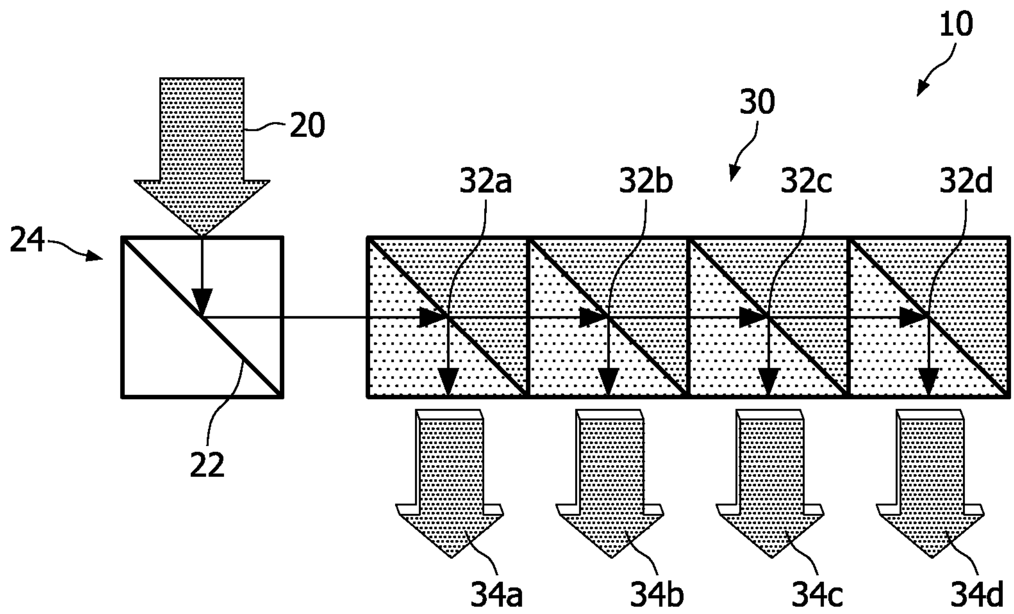

10
30
20
32a
32b
32c
32d
24
22
34a
34b
34c
34d

FIG. 1

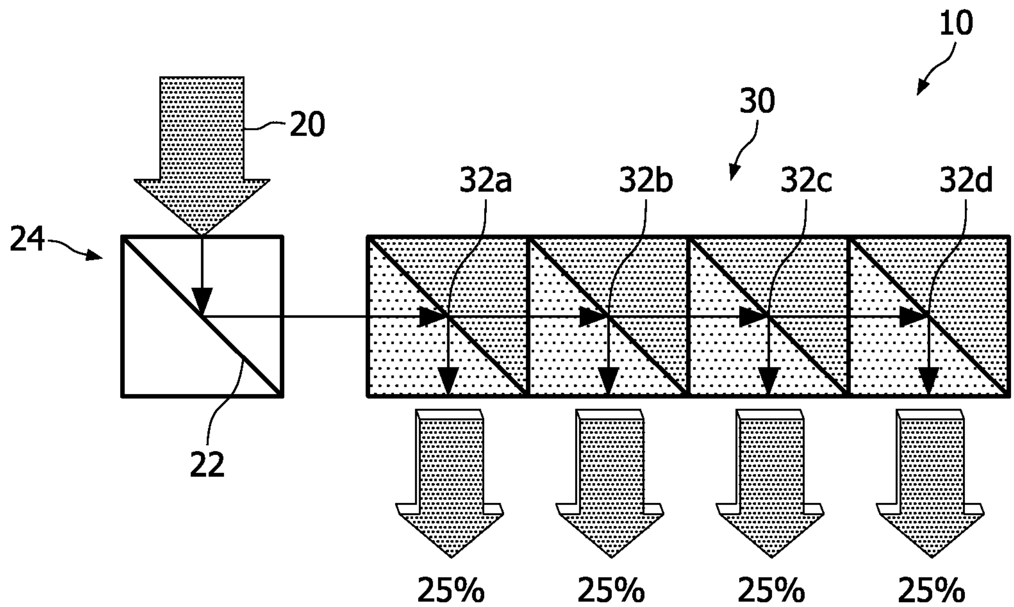
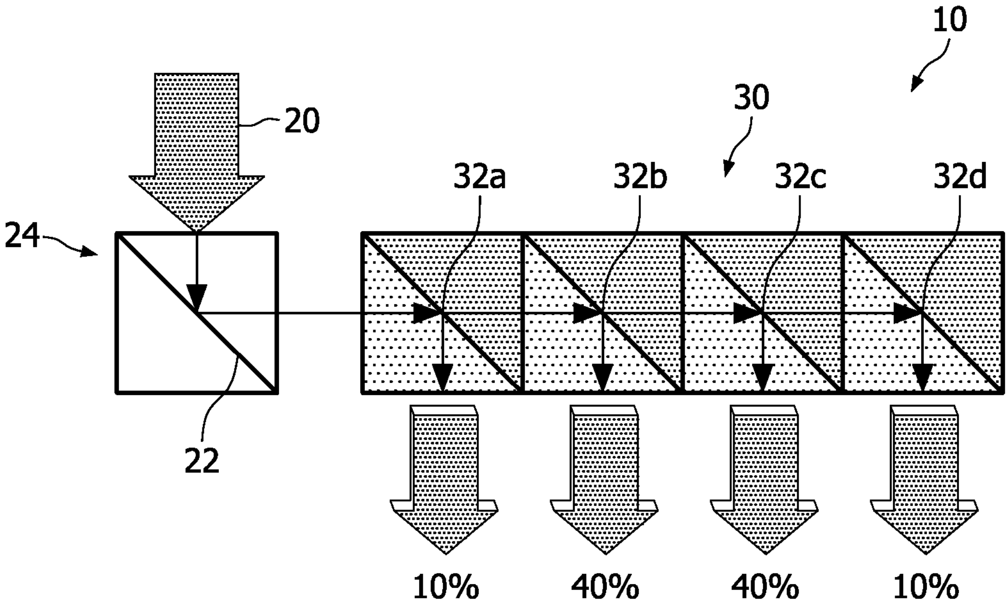

10
30
20
32a
32b
32c
32d
24
22
25%
25%
25%
25%

FIG. 2


10
30
20
32a
32b
32c
32d
24
22
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40%
40%
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FIG. 3

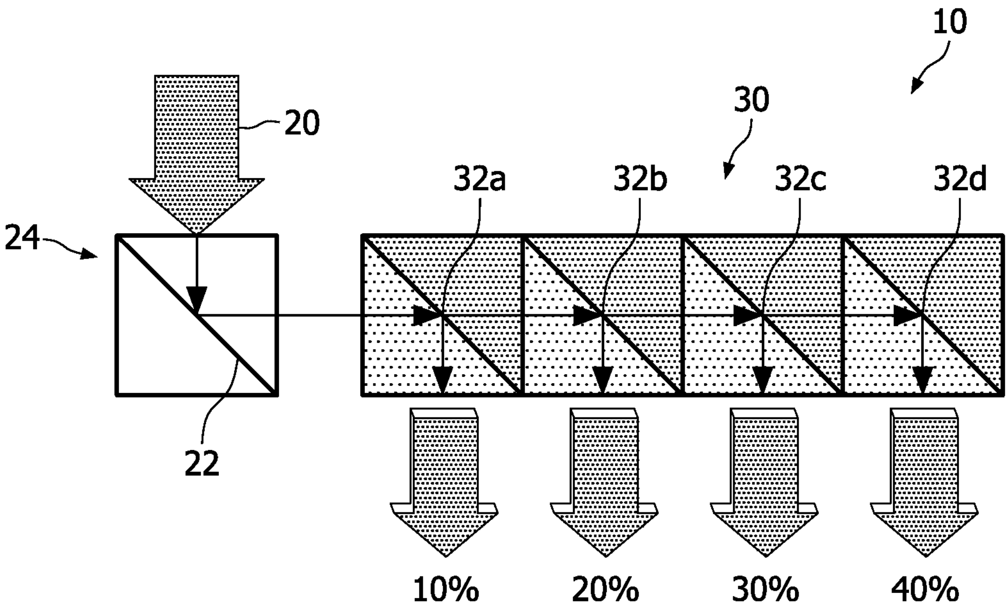
10
30
20
32a
32b
32c
32d
24
22
10%
20%
30%
40%

FIG. 4

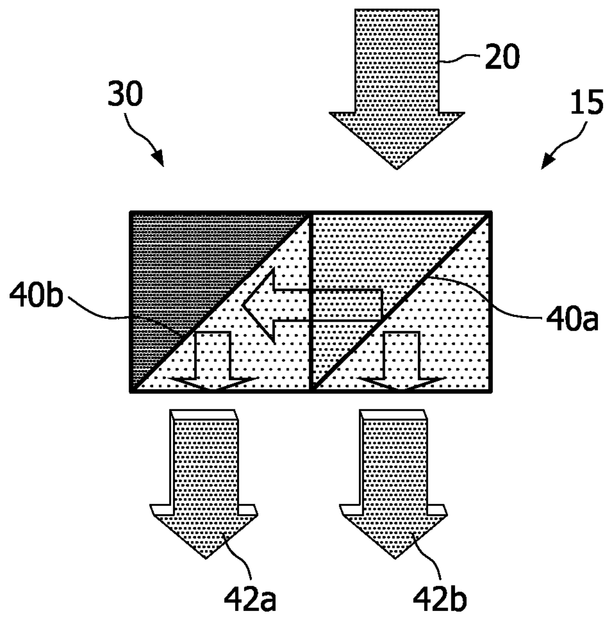

FIG. 5

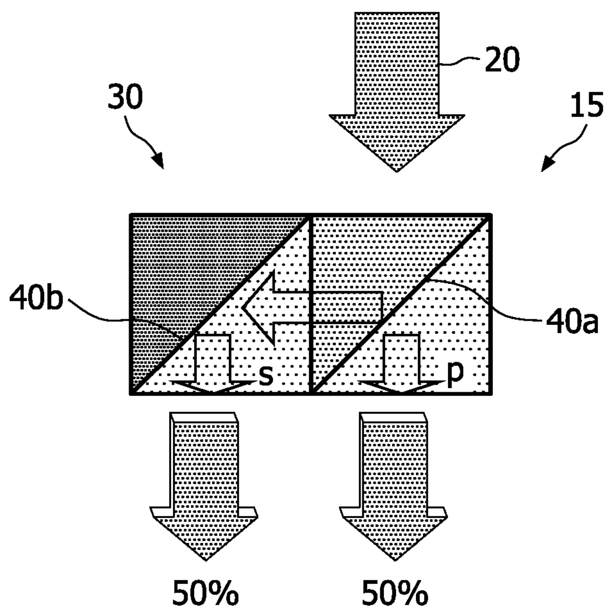

FIG. 6

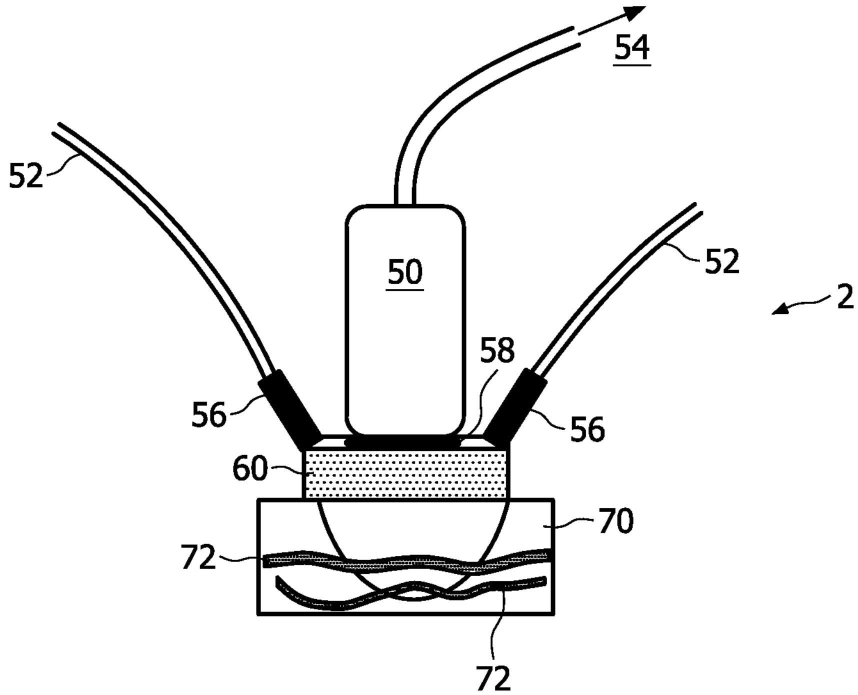

FIG. 7

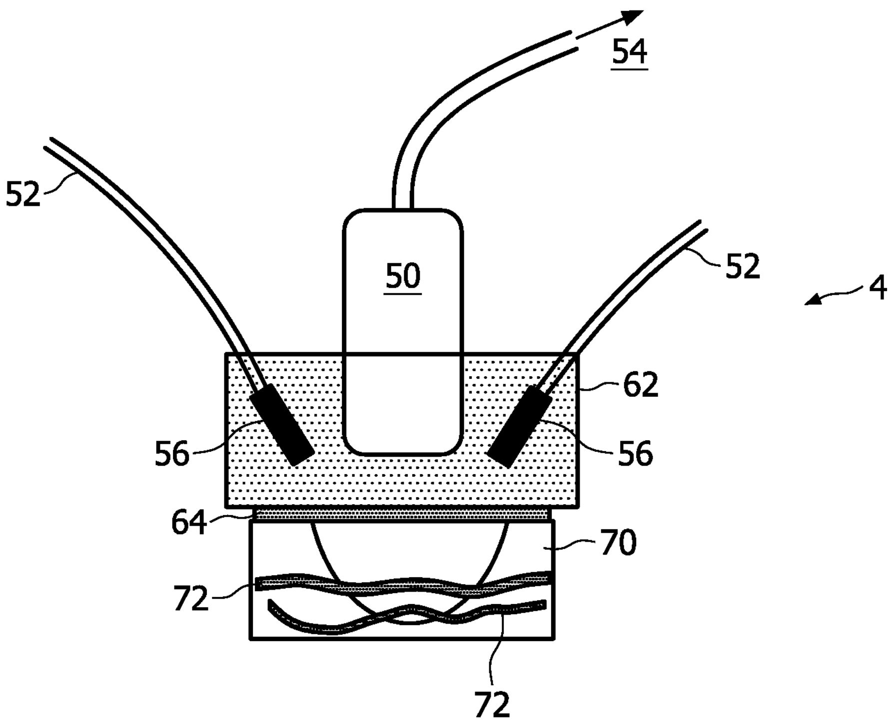

FIG. 8

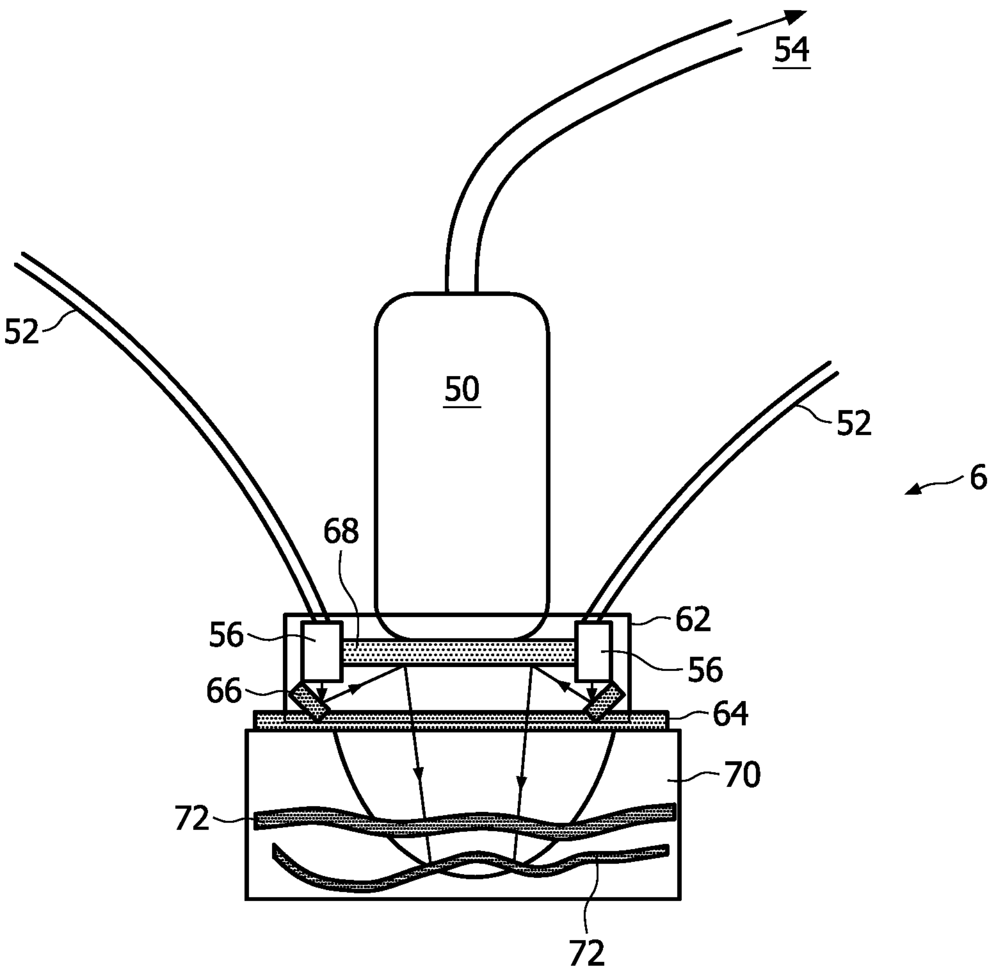

FIG. 9

REFERENCES CITED IN THE DESCRIPTION

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专利名称(译)	用于生产和集成紧凑照明方案的照明装置和系统

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申请号	EP2008807968	申请日	2008-10-13

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CPC分类号	A61B5/0059 A61B5/0095 A61B5/02007 A61B2562/146 G01N21/1702 G01N21/255 G01N2021/1782 G01N2021/1785 G01N2201/0221 G01N2201/0636 G01N2201/0666 G01N2291/02466 G01N2291/02475 G01N2291/106 G02B6/4203 G02B27/283
优先权	60/980207 2007-10-16 US
其他公开文献	EP2203734A1
外部链接	Espacenet

摘要(译)

提供了用于紧凑照明方案的生产和集成的装置，系统和方法。更具体地，所公开的实施例涉及用于产生高度紧凑的照明方案的设备/系统和方法，由此在目标样本中感应光声波。另外，所公开的装置/系统和方法对于生产紧凑和便携的集成换能器照明阵列是有效的。所公开的装置通常包括至少一个光源和分束组件。所公开的系统通常包括一个或多个用于制造紧凑照明方案的装置，超声换能器组件和用于将一个或多个装置和US换能器组件与目标样本耦合的装置。

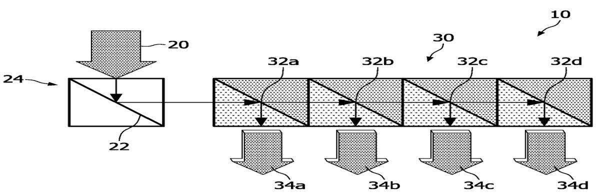

FIG. 1

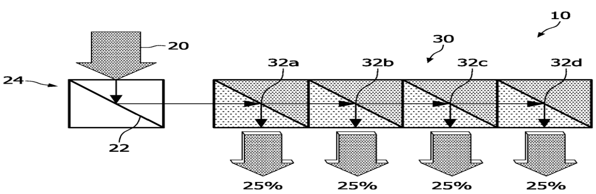

FIG. 2