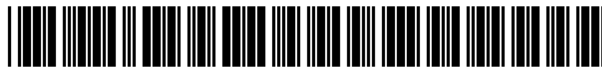
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Thothadri et al.

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(45) **Date of Patent: Jun. 11, 2019**

(54) **MASKLESS PARALLEL PICK-AND-PLACE TRANSFER OF MICRO-DEVICES**

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(73) Assignee: **Applied Materials, Inc.**, Santa Clara, CA (US)

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H01L 33/00	(2010.01)

(Continued)

(52) **U.S. Cl.**

CPC ***H01L 27/156*** (2013.01); ***H01L 21/67144*** (2013.01); ***H01L 21/6835*** (2013.01);

(Continued)

(58) **Field of Classification Search**

None

See application file for complete search history.

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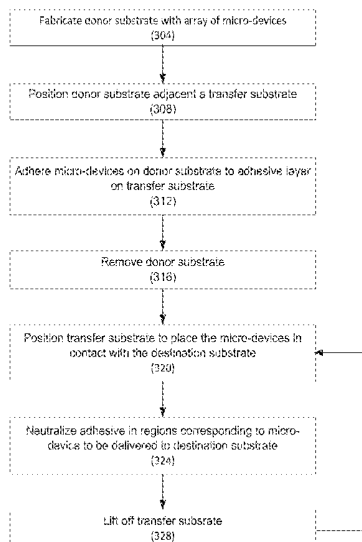
Primary Examiner — Jack S Chen
(74) *Attorney, Agent, or Firm* — Fish & Richardson P.C.

(57) **ABSTRACT**

A method of surface mounting micro-devices includes adhering a first plurality of micro-devices on a donor substrate to a transfer surface with an adhesive layer, removing the first plurality of micro-devices from donor substrate while the first plurality of micro-devices remain adhered to the transfer surface, positioning the transfer surface relative to a destination substrate so that a subset of the plurality of micro-devices on the transfer surface abut a plurality of receiving positions on the destination substrate, the subset including one or more micro-devices but less than all of micro-devices of the plurality of micro-devices, selectively neutralizing one or more of regions of the adhesive layer on the transfer surface corresponding to the subset of micro-device to light to detach the subset of micro-devices from the adhesive layer, and separating the transfer surface from the destination substrate such that the subset of micro-devices remain on the destination substrate.

15 Claims, 8 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/348,691, filed on Jun. 10, 2016.

(51) **Int. Cl.**

H01L 25/075	(2006.01)
H01L 33/60	(2010.01)
H01L 21/683	(2006.01)
H01L 21/67	(2006.01)
H05K 13/04	(2006.01)
H05K 3/00	(2006.01)
H05K 3/30	(2006.01)
H05K 13/00	(2006.01)
H01L 33/20	(2010.01)
H01L 33/48	(2010.01)

(52) **U.S. Cl.**

CPC ***H01L 25/0753*** (2013.01); ***H01L 33/0095*** (2013.01); ***H01L 33/60*** (2013.01); ***H05K 3/0026*** (2013.01); ***H05K 3/305*** (2013.01); ***H05K 13/0015*** (2013.01); ***H05K 13/0069*** (2013.01); ***H05K 13/0469*** (2013.01); *H01L 33/20* (2013.01); *H01L 33/48* (2013.01); *H01L 2221/68322* (2013.01); *H01L 2221/68368* (2013.01); *H01L 2221/68381* (2013.01); *H01L 2933/0033* (2013.01)

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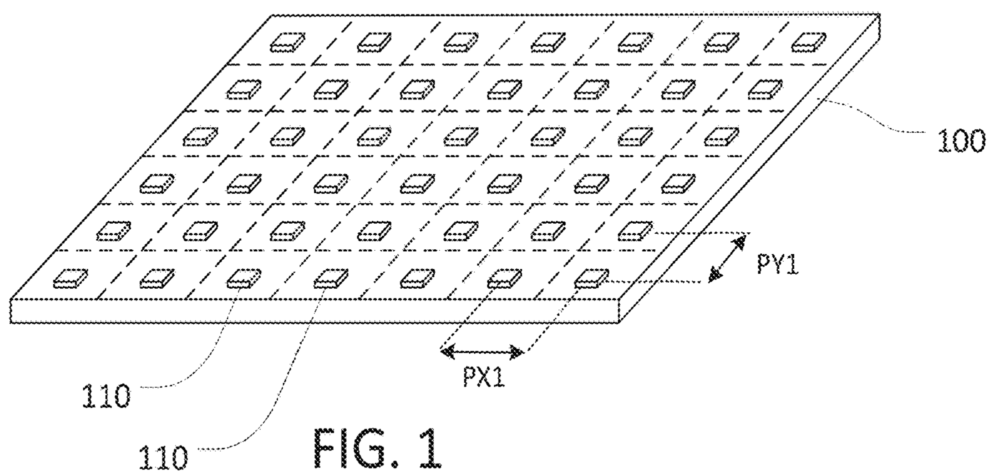


FIG. 1

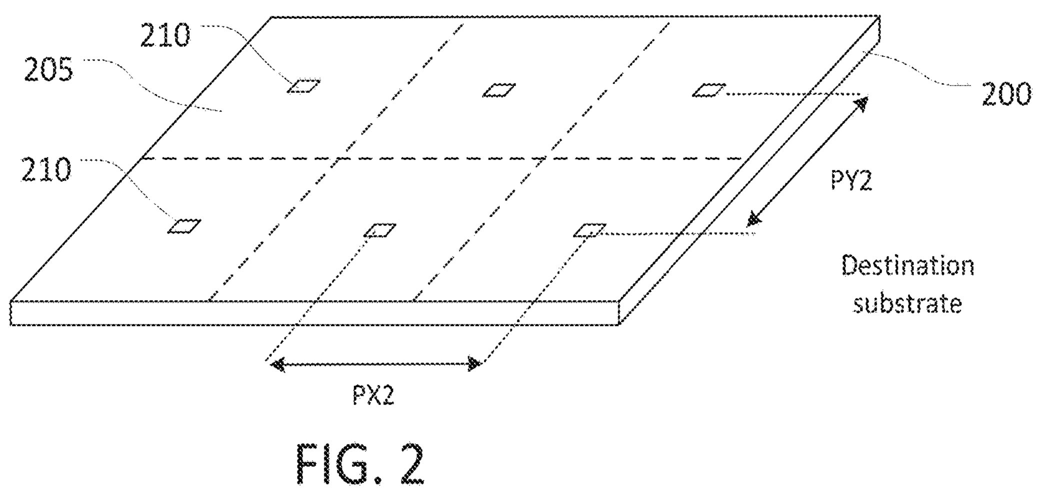


FIG. 2

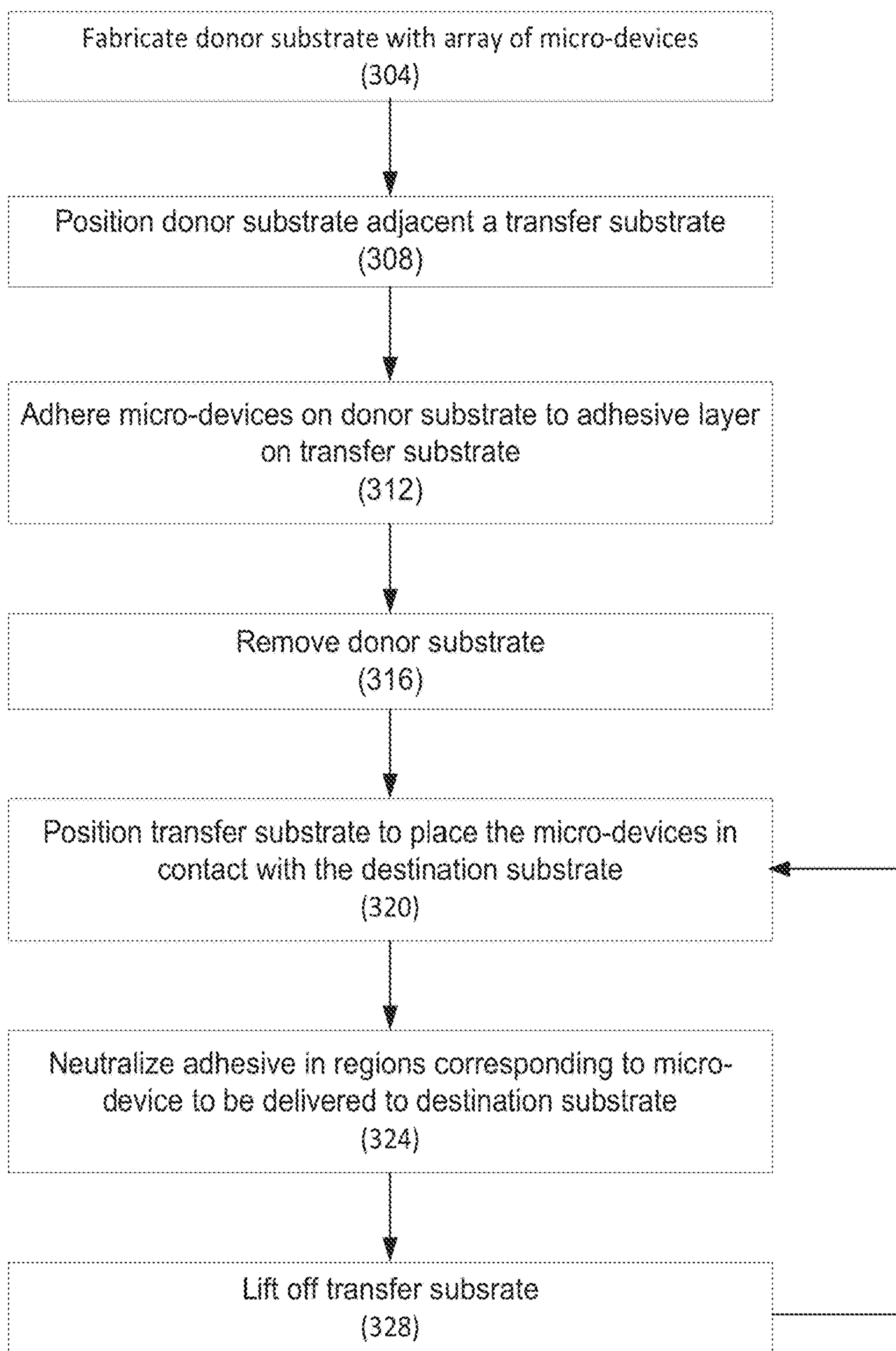


FIG. 3

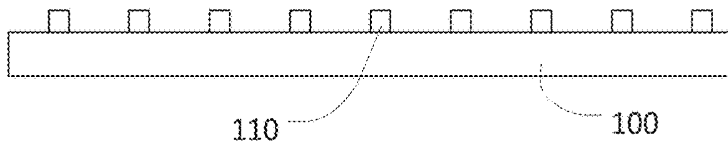


FIG. 4

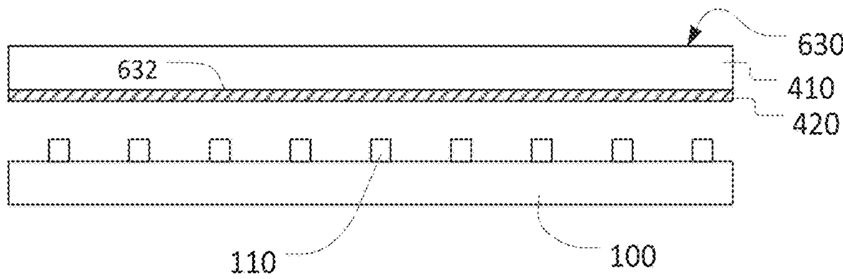


FIG. 5

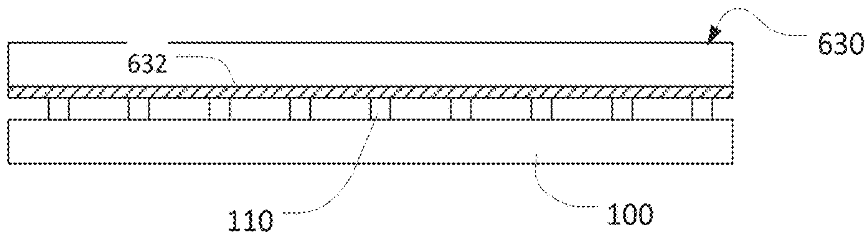


FIG. 6

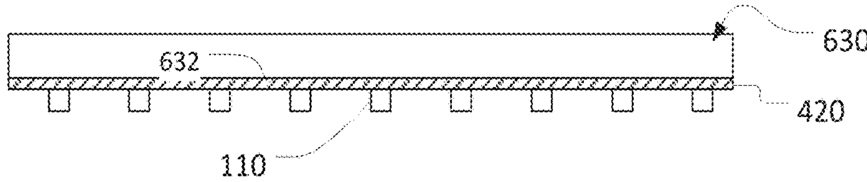


FIG. 7

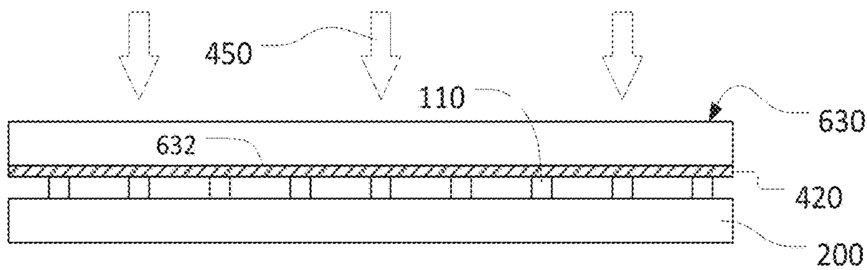


FIG. 8

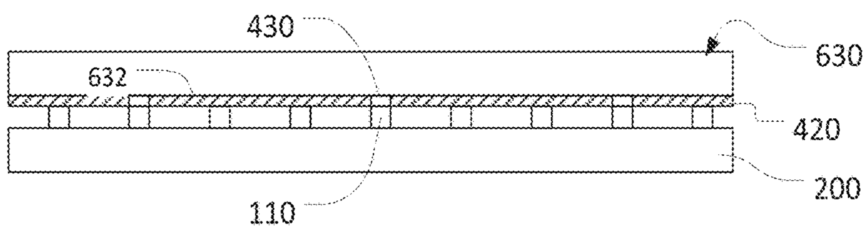


FIG. 9

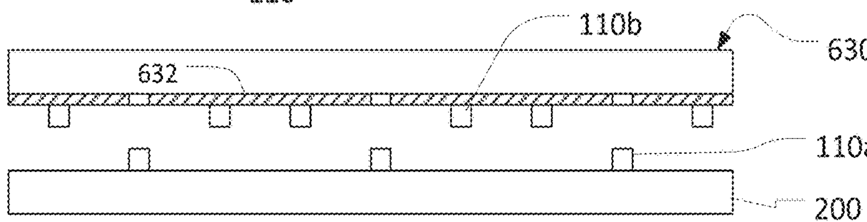


FIG. 10

FIG. 11A

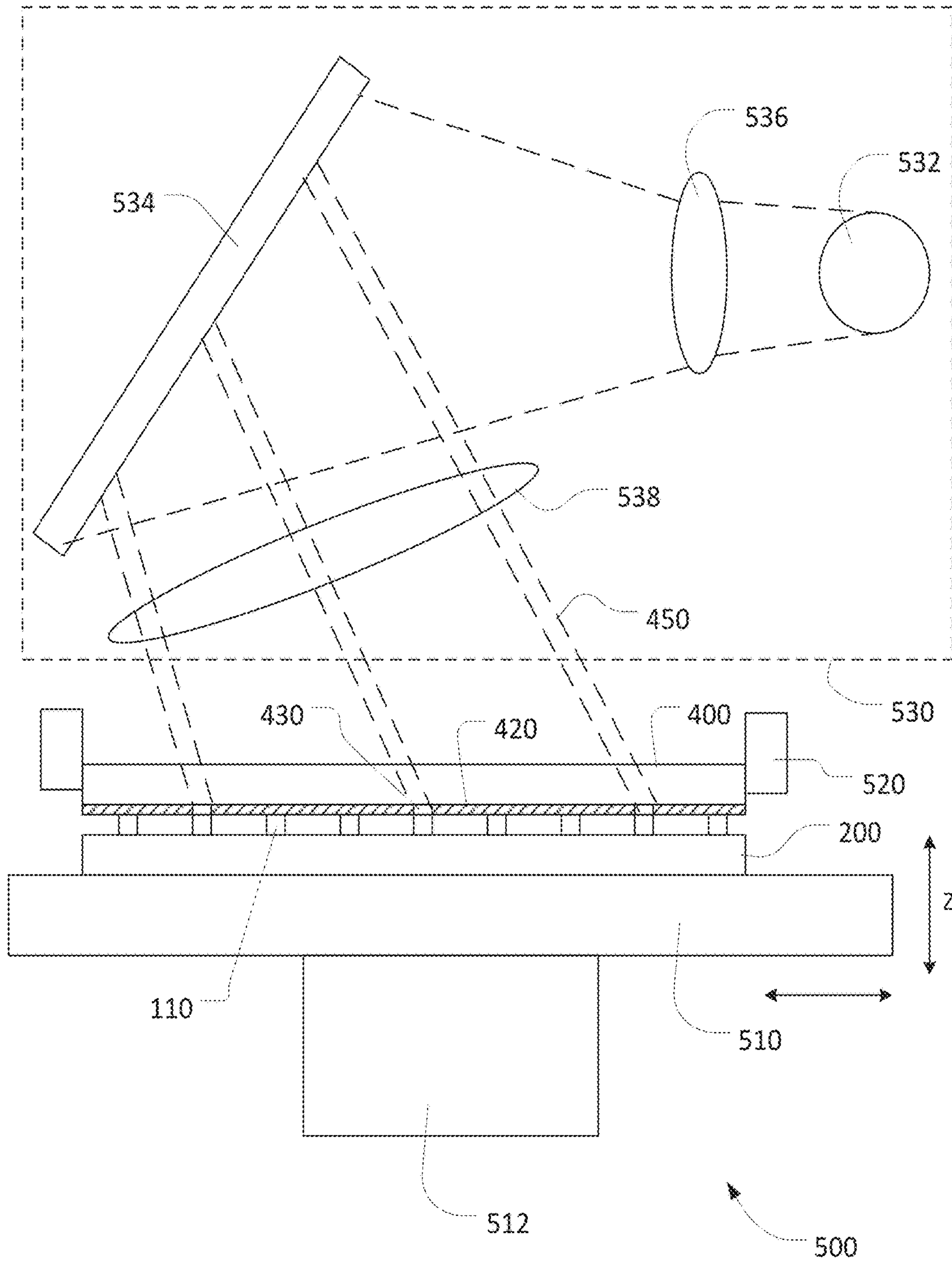


FIG. 11B

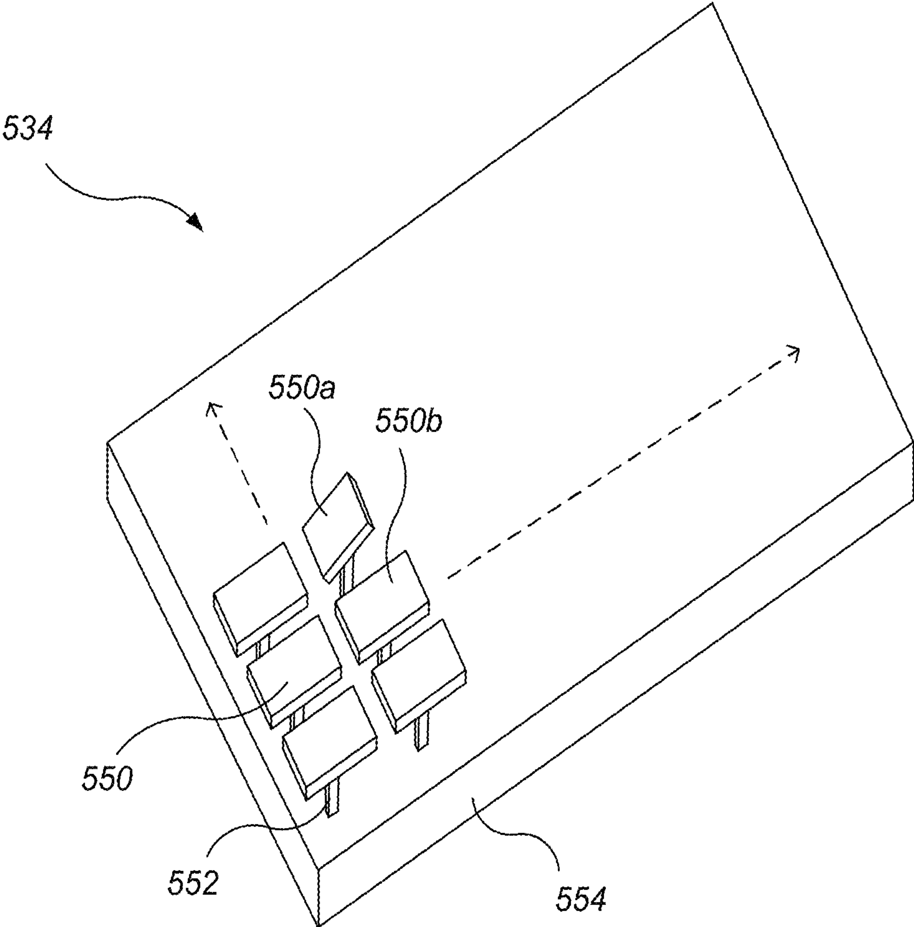


FIG. 11C

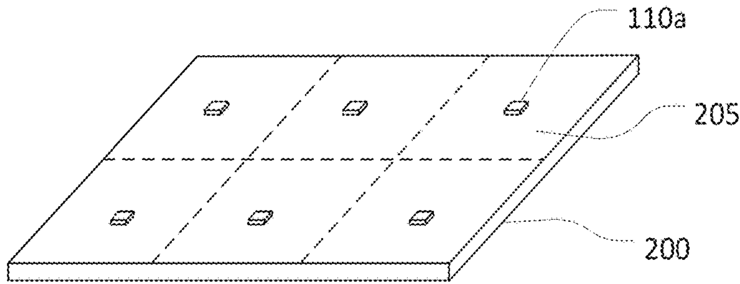


FIG. 12

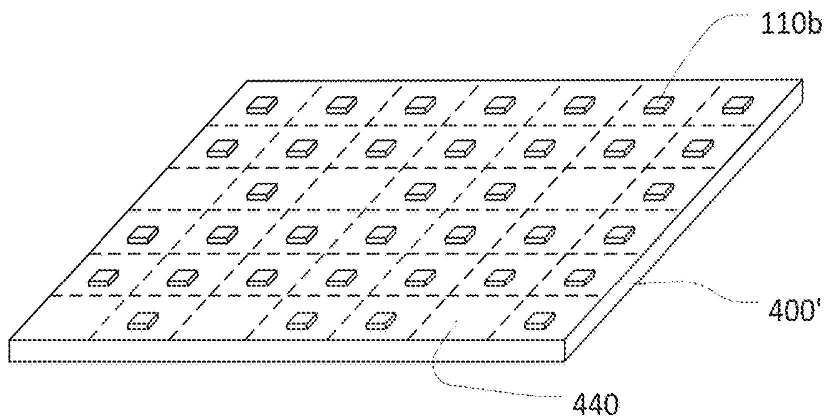


FIG. 13

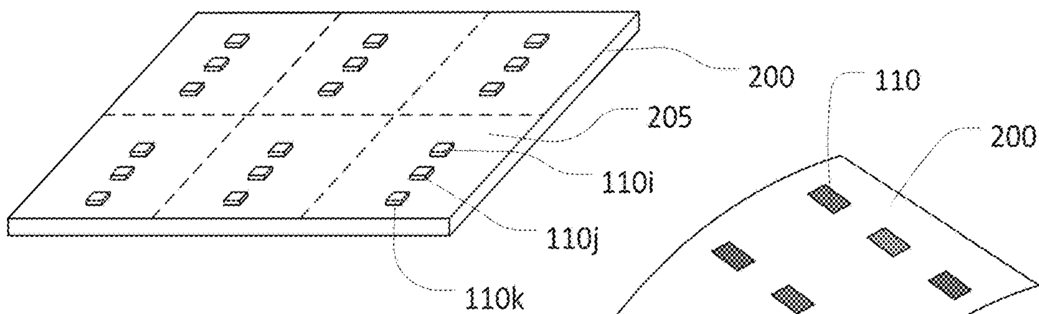


FIG. 14

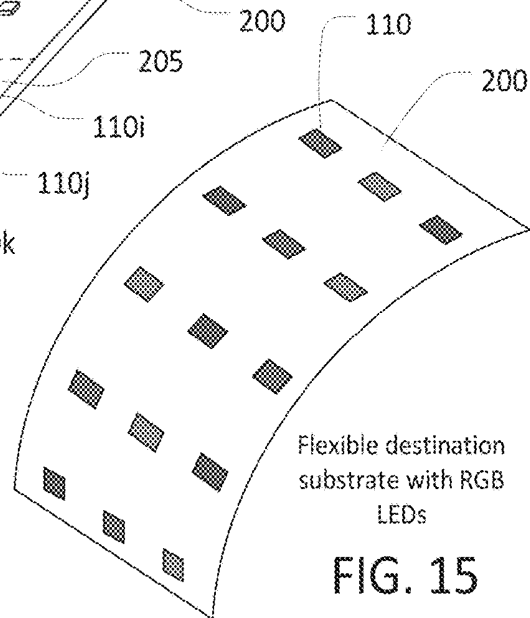
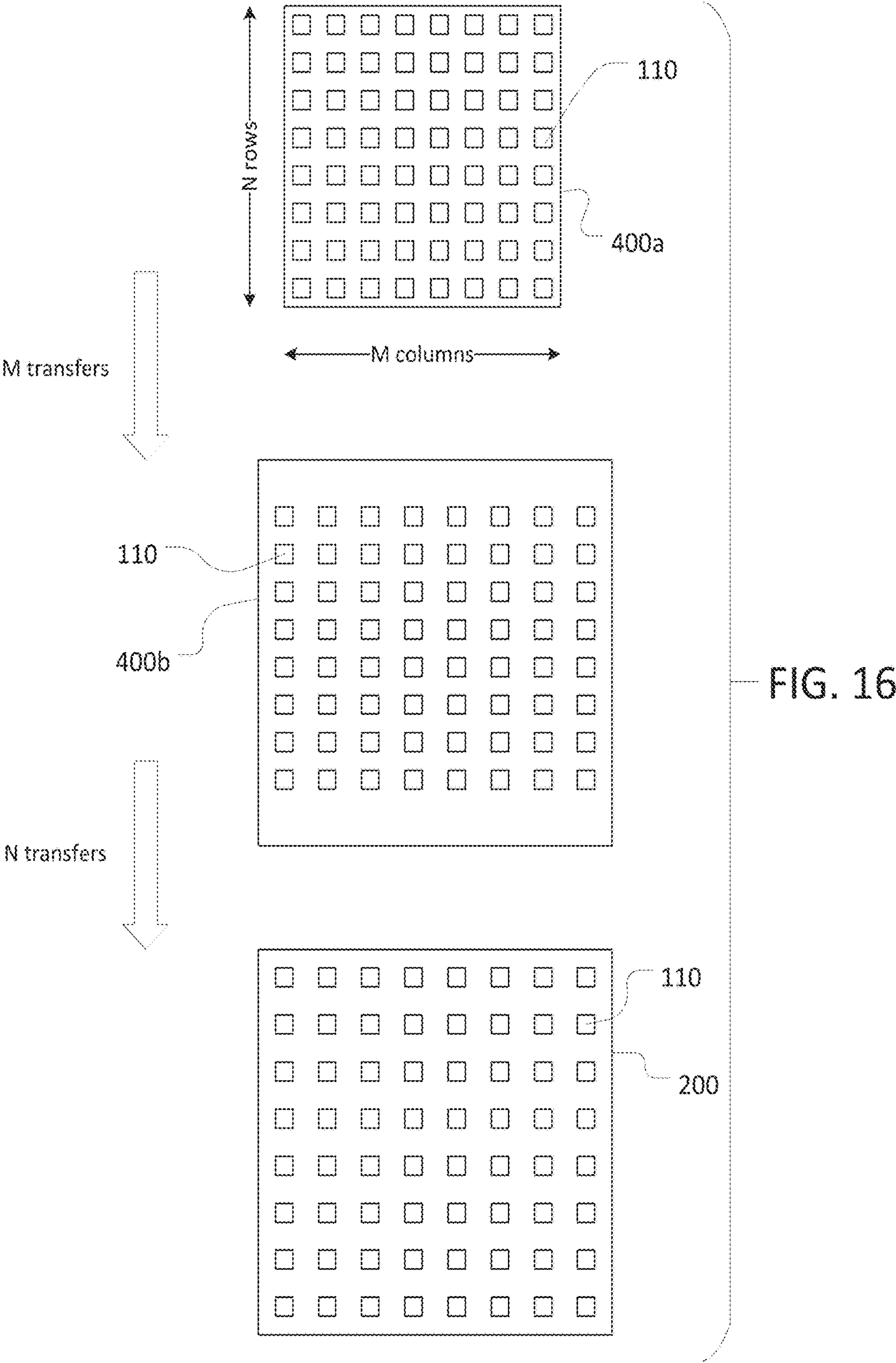


FIG. 15


N rows
110
400a
M columns
M transfers
110
400b
N transfers
110
200
FIG. 16

MASKLESS PARALLEL PICK-AND-PLACE TRANSFER OF MICRO-DEVICES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a divisional of U.S. patent application Ser. No. 15/619,173, filed on Jun. 9, 2017, which claims priority to U.S. Provisional Application Ser. No. 62/348,691, filed on Jun. 10, 2016, the disclosures of which are incorporated by reference.

TECHNICAL FIELD

This disclosure generally relates to the transfer of micro-devices from a donor substrate to a destination substrate.

BACKGROUND

A wide variety of products include an array of individual devices on a substrate, with the devices addressable or controllable by circuitry on the substrate. Where the individual devices are on the micron scale, e.g., less than 100 microns across, the devices can be considered micro-devices. In general, micro-devices can be fabricated using a sequence of microfabrication techniques, such as deposition, lithography and etching, to deposit and pattern a sequence of layers.

One approach for fabricating a device that includes an array of individual micro-devices is to directly fabricate the individual micro-devices on the substrate which will form part of the product. This technique has been used, e.g., to fabricate the TFT panel and color filter panels of an active matrix liquid crystal display (LCD).

One proposed display panel technology uses an array of LEDs, with individual LEDs providing the individually controllable pixel elements. Such an LED panel can be used for a computer, touch panel device, personal digital assistant (PDA), cell phone, television monitor, and the like.

Although organic light-emitting diode (OLED) panels are in use, an LED panel that uses micron-scale LEDs based on III-V semiconductor technology (also called microLEDs) faces additional problems. In particular, depositing and growing III-V semiconductor microLEDs directly on a final display substrate poses technical and manufacturing hurdles. Moreover, microLED panels are difficult to manufacture in curved or bendable display.

SUMMARY

The present disclosure generally relates to systems and methods for surface mounting micro-devices over a large area.

In one aspect, an apparatus for positioning micro-devices on a destination substrate includes a first support to hold a destination substrate, a second support to provide or hold a transfer body having a surface to receive an adhesive layer, one or more actuators configured to provide relative motion between the first support and the second support, an illumination system configured to selectively and masklessly expose regions of the adhesive layer on the transfer body, and a controller. The controller is configured to cause the one or more actuators to create relative motion such that a plurality of micro-devices attached to the adhesive layer contact the destination substrate, cause the illumination system to selectively expose one or more portions of the adhesive layer to create one or more neutralized portions, and cause the one or more actuators to create relative motion such that the surface and the destination substrate are moved away from each other and one or more micro-devices corresponding to the one or more neutralized portions of the adhesive layer remain on the destination substrate.

Implementations may include one or more of the following features.

A third support may hold a donor substrate. The one or more actuators may be configured to provide relative motion between the first support and the third support. The controller may be configured to cause the one or more actuators to create relative motion between the donor substrate and the transfer body such that the adhesive layer on the surface of the transfer substrate contacts the plurality of micro-devices when the plurality of micro-devices are on the donor substrate so that the plurality of micro-devices adhere to the adhesive layer on the transfer body. The second support may include a robotic arm to hold the transfer body. The robotic arm may be operable to move the transfer body between the third support and the first support. The robotic arm may be operable to move the transfer body vertically relative to the first support and the third support.

The transfer body may be a transfer substrate that is removable from the second support. The second support may include a robotic arm having an end effector to releasably hold the transfer substrate.

The illumination system may include a digital mirror device having an array of individually actuatable mirrors. The digital mirror device may include a two-dimensional array of mirrors. A field of view of the illumination system may span only a portion of the transfer body, and an actuator may cause relative motion between the two-dimensional array linear array and the one or more supports. The digital mirror device may be a linear array of mirrors, and an actuator may cause relative motion between the linear array and the one or more supports.

In another aspect, a method of surface mounting micro-devices includes adhering a plurality of micro-devices on a donor substrate to a transfer surface with an adhesive layer, removing the plurality of micro-devices from the donor substrate while the plurality of micro-devices remain adhered to the transfer surface, positioning the transfer surface relative to a destination substrate so that at least some of the plurality of micro-devices on the transfer surface abut at least some of a plurality of receiving positions on the destination substrate selectively and masklessly exposing a plurality of regions of the adhesive layer on the transfer surface corresponding to a subset of micro-device to light to detach the subset of micro-devices from the adhesive layer, the subset including multiple micro-devices but less than all of micro-devices of the plurality of micro-devices, and separating the transfer surface from the destination substrate such that the subset of micro-devices remain on the destination substrate.

Implementations may include one or more of the following features.

The plurality of micro devices may include all of the micro-devices on the donor substrate. The donor substrate may be a donor substrate on which the plurality of micro-devices were fabricated.

The plurality of micro-devices may be disposed in a first array on the transfer surface, and the plurality of receiving positions may be disposed in a second array on the destination substrate. A spatial density of the first array may be greater than a spatial density of the second array. The first array may be first rectangular array with cells for the plurality of micro-devices disposed at a first pitch PX1 along

a first axis and a second pitch PY1 along a second axis perpendicular to the first axis, and the second array may be a second rectangular array with the receiving positions disposed at a third pitch PX2 along the first axis and a fourth pitch PY2 along the second axis perpendicular to the first axis. The third pitch PX2 may be an integer multiple of the first pitch PX1 and the fourth pitch PY2 is an integer multiple of the second pitch PY1.

The micro-devices may include micro-LEDs. A passivating layer may be disposed over the subset of micro-devices on the destination substrate.

Selectively exposing the plurality of regions may include directing light to a digital mirror device and actuating selected mirrors of the digital mirror device to reflect light to the plurality of regions.

In another aspect, an apparatus for positioning micro-devices on a destination substrate includes a first support to hold a destination substrate, a second support to provide or hold a transfer body having a surface to receive an adhesive layer, one or more actuators configured to provide relative motion between the transfer body and the first support, a light source to generate a light beam, a mirror configured to adjustably position the collimated light beam on the adhesive layer on the transfer body, and a controller. The controller is configured to cause the one or more actuators to create relative motion such that a plurality of micro-devices attached to the adhesive layer on the transfer body contact the destination substrate, cause the light source to generate the light beam and adjust the mirror to position the light beam on the adhesive layer so as to selectively expose one or more portions of the adhesive layer to create one or more neutralized portions, and cause the one or more actuators to create relative motion such that the transfer body and the destination substrate are moved away from each other and one or more micro-devices corresponding to the one or more neutralized portions of the adhesive layer remain on the destination substrate.

Implementations may include one or more of the following features.

The transfer body may be a removable transfer substrate. The second support may include robotic arm to hold the transfer body. The robotic arm may be operable to move the body at least laterally between a third support to hold a donor substrate and the first support to hold the destination substrate.

The mirror may be a mirror in a galvo mirror scanner. The light source may be a laser and the light beam may be a laser beam.

In another aspect, a method of surface mounting micro-devices includes transferring a first plurality of micro-devices from a donor substrate to a first transfer surface, wherein transferring includes adhering the first plurality of micro-devices to a first adhesive layer on the first transfer surface, transferring the first plurality of micro-devices from the first transfer surface to a second transfer surface, wherein transferring includes adhering the first plurality of micro-devices to a second adhesive layer on the second transfer surface, releasing the plurality of micro-devices a column at a time from the first transfer surface by selectively neutralizing regions of the first adhesive layer to detach the column of micro-devices from the first adhesive layer, and moving the first transfer surface relative to the second transfer surface between transferring each column so as to establish the columns at a first pitch, transferring the first plurality of micro-devices from the second transfer surface to a destination substrate, wherein transferring includes releasing the plurality of micro-devices a row at a time from the second transfer surface by selectively neutralizing regions of the second adhesive layer to detach the row of micro-devices from the first adhesive layer, and moving the second transfer surface relative to the destination substrate between transferring each row so as to establish the rows at a second pitch.

Implementations can include one or more of the following features.

Transferring the first plurality of micro-devices from the donor substrate to the first transfer surface may include transferring all of the micro-devices on the donor substrate to the first transfer surface. The first plurality of micro-devices may be less than all of the micro-devices on the donor substrate. Transferring the first plurality of micro-devices from the first transfer surface to the second transfer surface may include transferring only the first plurality of micro-devices.

The plurality of micro-devices may be disposed in a first array on the first transfer surface, and the plurality of receiving positions may be disposed in a second array on the destination substrate. A spatial density of the first array may be greater than a spatial density of the second array.

The donor substrate may be a donor substrate on which the plurality of micro-devices were fabricated. The micro-devices may be micro-LEDs. A passivating layer may be disposed over the subset of micro-devices on the destination substrate.

Selectively neutralizing the regions may include selectively exposing the regions to light. Selectively exposing the plurality of regions may include directing light to a digital mirror device and actuating selected mirrors of the digital mirror device to reflect light to the plurality of regions.

Implementations can optionally provide (and are not limited to) one or more of the following advantages. The micro-devices on the donor substrate can be built at a higher spatial density than desired for the destination substrate, thereby increasing throughput and saving wafer space when building the micro-devices. A large number of micro-devices can be transferred in parallel from the donor substrate to the destination substrate. The transfer can be performed with high precision. Thus, yield can be increased and manufacturing time and cost can be reduced. Defective micro-devices on the donor substrate can be identified and excluded from the transfer. If micro-devices are arranged on the destination substrate at a different pitch than the donor substrate, then the number of transfer steps can be reduced relative to prior techniques.

If the micro-devices are micro-LEDs, then the technique can be used to manufacture multi-color displays, such as displays with three or more color subpixels. Flexible and/or stretchable displays can be fabricated more easily.

Other aspects, features, and advantages will be apparent from the description and drawings, and from the claims.

A variety of implementations are described below. It is contemplated that elements and features of one implementation may be beneficially incorporated in other implementations without further recitation.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic perspective view of a donor substrate with an array of micro-devices.

FIG. **2** is a schematic perspective view of a destination substrate.

FIG. **3** is a flow diagram of a method for transferring multiple micro-devices from the donor substrate to the destination substrate.

FIGS. **4-10** are schematic cross-sectional side views illustrating a method of transferring multiple micro-devices from the donor substrate to the destination substrate.

FIG. **11**A is a schematic cross-sectional side view of a system for transferring micro-devices from a donor substrate to a destination substrate.

FIG. **11**B is a schematic cross-sectional side view of a system for illuminating the adhesive layer on a transfer substrate.

FIG. **11**C is a schematic perspective view of a digital micro-mirror device.

FIG. **12** is a schematic perspective view of a destination substrate having an array of micro-devices mounted thereon.

FIG. **13** is a schematic perspective view of a transfer device after some of the micro-devices have been transferred.

FIG. **14** is a schematic perspective view of a destination substrate having multiple micro-devices per cell.

FIG. **15** is a schematic perspective view of a flexible substrate on which micro-LEDs have been mounted.

FIG. **16** is a schematic top view illustrating a multi-step transfer process.

Like reference symbols in the various drawings indicate like elements.

DETAILED DESCRIPTION

In order to manufacture some devices, new techniques are needed to precisely and cost-effectively provide micro-devices on substrates, such as large area substrates or flexible substrates. For example, it would be desirable to provide an LED panel based on III-V semiconductor technology, since microLEDs have significant brightness, lifetime and efficiency advantages over organic light-emitting diode (OLED) devices.

An approach for fabricating a device that includes an array of individual micro-devices is to fabricate the micro-devices en masse on an initial substrate, and then transfer the micro-devices to the receiving or destination substrate which will form part of the product. One reason to build the micro-devices on an initial substrate is that the destination substrate may be a material that is not compatible with the fabrication processes, e.g., etching and deposition, needed to form the micro-devices. For example, in the case of LEDs, deposition of the LED is an epitaxial growth process in which single crystalline gallium nitride (GaN) films are grown on sapphire wafers (sapphire wafers are used primarily due to the small lattice mismatch for GaN growth compared to other wafer materials). Another reason to build the micro-devices on initial substrate is that the micro-devices can be fabricated at higher spatial density than needed for the destination substrate, thereby increasing throughput and saving wafer real estate when building the micro-devices and consequently lowering cost.

One technique to transfer the micro-devices from the initial substrate to the destination substrate is a pick-and-place machine, e.g., a robot that transfers one micro-device at a time. However, this approach is not production worthy since it suffers from low throughput, particularly in view of the large number of micro-devices that would need to be transferred.

As the foregoing illustrates, there is a need for an improved method for manufacturing micro devices. As described below, a method for surface mounting micro-devices over a large area is disclosed. The method includes placing transfer substrate with an adhesive layer over the micro-devices on a donor substrate, adhering the adhesive layer to the micro-devices, removing the micro-devices from the donor substrate while they are adhered to the adhesive layer, aligning the micro-devices to a target locations on a destination substrate, placing the micro-devices, exposing the transfer substrate to a light source to separate the micro-devices from the transfer substrate, and moving the transfer substrate away from the micro-devices while the micro-devices remain on the transfer substrate. Micro-devices utilizing this method may be transferred to a polymer photo layer, and then transferred to the destination substrate using maskless lithography in a multitude of patterns and may be transferred to a wide variety of substrates.

Moreover, the micro-devices can be selectively released from the adhesive layer using a maskless lithography techniques. In contrast to a masked projection of light onto the adhesive layer, a maskless technique is adaptable to different release patterns, has a lower cost because it is not necessary to make a new mask for each release strategy, and is faster because time to fabricate the mask is not required.

FIG. **1** illustrates a donor substrate **100** with an array of micro-devices **110**. The micro-devices **110** are small electronic elements, e.g., light-emitting diodes (LEDs), and integrated circuit chips such as logic ICs, processors, memory, controllers, etc. The micro-devices **110** are micron-scale devices, e.g., with a maximum lateral dimension of about 1 to 100 microns. For example, the devices can have a lateral dimension of about 1-50 microns, e.g., 5-50 microns, e.g., 10-30 microns. The micro-devices **110** can be identical, i.e., same dimensions, circuit pattern and layer structure.

Although FIG. **1** illustrates the micro-devices **110** in a regular rectangular array with pitch PX**1** and PY**1** in the two perpendicular directions parallel to the face of the donor substrate, other array configurations are possible, e.g., staggered rows.

The micro-devices **110** can be fabricated directly on the donor substrate **100**, or the micro-devices **110** could have been fabricated on another substrate, e.g., a device substrate and then transferred to the donor substrate **100** without changing their pitch. For example, the micro-devices can be fabricated at relatively high density on the device substrate, and the donor substrate **100** can be an adhesive tape that is placed in contact with the devices. Then the device substrate can be removed or singulated so that each micro-device **110** is individually attached to the donor substrate, e.g., the tape.

FIG. **2** illustrates a destination substrate **200** with an array of cells **205**, each of which has a spot **210** to receive a micro-device **110**. Thus, the spots **210** are also arranged in an array. However, the spacing of the array of spots **210** on the destination substrate **200** can differ from the spacing of the micro-devices **110** on the donor substrate **100**. Typically, the spacing between the spots **210** is larger than the spacing between the micro-devices **110** on the donor substrate **100**. For example, FIG. **2** illustrates the spots **210** in a rectangular array with pitch PX**2** and PY**2** in the two perpendicular directions parallel to the face of the destination substrate **200**. Thus, the pitch PX**2** can be greater than the pitch PX**1** and the pitch PY**2** can be greater than the pitch PY**1**. As noted above, other array configurations are possible, e.g., staggered rows. Since the spacing between the spots **210** differs from the spacing between the micro-devices **110**, the donor substrate **100** cannot simply be placed abutting the destination substrate **200** to transfer the micro-devices en masse.

Although not illustrated in FIG. **2**, the destination substrate **100**, particularly if it is the substrate that will form part of the product, can include circuitry and other components

for delivering power to and/or addressing and/or controlling the micro-devices **110** when correctly secured in the spot **210**. For example, each spot **210** can include one or more bond pads which will electrically connect to one or more bond pads on the micro-device **110**.

FIG. **11**A is a schematic cross-sectional side view of a system for transferring micro-devices from a donor substrate to a destination substrate. FIG. **11**A illustrates a system **600** for transferring the micro-devices from the donor substrate **100** to the destination substrate **200**. For the purpose of discussion, the Z-axis is direction perpendicular to the plane of the substrates **100**, **200**, and the X-axis and Y-axis are the two perpendicular directions that are parallel to the plane of the substrates **400**. Typically the Z-axis will be a vertical axis, i.e., aligned with gravity, but this is not necessary.

The apparatus **600** includes a stage **610** to support the donor substrate **100**, a stage **510** to support the destination substrate **200**, and transfer device **630**. The transfer device **630** includes a surface **632** on which an adhesive layer **420** can be placed. The transfer device **630** can include a replaceable transfer substrate **420** on which the adhesive layer **420** is formed. Alternatively, the surface **632** can be an integral part of the transfer device **630**.

The surface **632** can be planar, e.g., the bottom of a flat sheet, and can be parallel to the top surfaces of the stages **610**, **510**. Alternatively, the surface **632** can be cylindrical, e.g., the outer surface of a rotatable drum.

One or more actuators provide relative motion between the transfer device **630** and the stages **610** and **620**. For example, the transfer device **630** can include a three-axis robotic arm **512** that can move the surface **632** along the X-axis, Y-axis and Z-axis. However, many other arrangements are possible. For example, the stages **610**, **620** could be vertically movable while the arm **512** provides only Y-axis and Y-axis movement, or the stages could move along the Y-axis, etc. Assuming, the transfer device **630** includes a replaceable transfer substrate **410**, the robotic arm **512** can include an end effector to hold the substrate. The end effector can be a vacuum chuck or an edge grip actuator.

The apparatus **600** also include a system to selectively "neutralize" portions of the adhesive layer **420** on the surface **632**. In this context, "neutralize" includes either removing the adhesive layer entirely, e.g., by dissolving or melting, or modifying the physical property of the material so that it is no longer adhesive (also termed "denaturing"). The system can be an illumination system **530** to selectively direct light from the light source onto the back side of the body that provides the surface **632**. Alternatively, the system can include individually controllable heaters embedded in the body that provides the surface **632**.

A controller **650**, such as a programmable computer, coordinates operation of the various components of the apparatus, e.g., the actuators and illumination system. In operation, the adhesive layer **420** on the surface **632** is lowered into contact with micro-devices **110** on the donor substrate **100**, and lifted away with the micro-devices. The micro-devices **110** on the adhesive layer **420** are moved laterally over to the destination substrate **200**, and lowered onto the destination substrate **200**. Then the adhesive layer is neutralized in selected regions, and the surface **632** with the remaining adhesive layer **420** is lifted away from the destination substrate **200**, leaving micro-devices remaining on the destination substrate at spots corresponding to regions where the adhesive layer was neutralized. Although the description above is phrased as the surface **632** providing the relative motion, it will be understood that motion of the stages **610**, **620** could provide some or all of the necessary relative motion.

FIG. **3** is a flow diagram of a method **300** for transferring multiple micro-devices from the donor substrate to the destination substrate. FIGS. **4-10** are schematic cross-sectional side views illustrating a method of transferring multiple micro-devices from the donor substrate to the destination substrate.

As shown in FIG. **4**, the donor substrate **100** with the array of micro-devices **110** is fabricated or received from a fabrication plant (step **304**).

As shown in FIG. **5**, the donor substrate **100** is positioned adjacent a surface **632** of a transfer device **630** (step **308**). The donor substrate is oriented so that the micro-devices **110** are on the side of the donor substrate **100** facing the transfer device **630**. The transfer device includes an adhesive layer **420**. The adhesive layer **420** can be part of a removable transfer substrate **400**. The adhesive layer **420** can be adhesive polymer, e.g., an uncured or partially cured positive photoresist.

The adhesive layer **420** extends across at least portions of the surface **632** corresponding to the array of micro-devices **110**. In some implementations, the adhesive layer **420** is a continuous unitary layer spanning all of the micro-devices **110**. The advantage of such a layer is that the transfer device **630** does not need to be precisely laterally positioned relative to the donor substrate **100**. In some implementations, the adhesive layer **632** is segmented into a plurality of separate islands, each island corresponding to one of the micro-devices **110**. However, in such implementations, the transfer device **630** will need to be laterally positioned so that the islands contact the micro-devices **110** on the donor substrate **100**.

The adhesive layer **420** can be applied to the surface **632** of the transfer device **630** by spin-coating or by droplet printing. The body that provides the surface **632**, e.g., the backing substrate **410**, is a material, e.g., glass or quartz, that is substantially transparent to a wavelength of light that will be used to cure or dissolve the adhesive layer **420**.

Although FIG. **5** illustrates the adhesive layer **420** as a continuous layer, this is not required. For example, the adhesive layer **420** could be applied in individual spots corresponding to the locations of the micro-devices **110** on the donor substrate **110**, or in stripes or other patterns.

As shown in FIG. **6**, the transfer device **630** is then placed adjacent the donor substrate **100** so that the micro-devices **110** adhere to the adhesive layer **420** (step **312**).

As an alternative to the method shown in FIGS. **5-6**, the adhesive layer **420** could be deposited directly onto the donor substrate **100** so that the adhesive material at least covers the micro-devices **110**. For example, a blanket continuous layer **420** of adhesive material can be deposited across at least the array of micro-devices **110**. Then the surface **632** of the transfer device **630** can be lowered into contact with the adhesive layer **420**.

As shown in FIG. **7**, the donor substrate **100** can now be removed (step **316**), leaving the micro-devices **110** attached to the adhesive layer **420** on the transfer device **630**. For example, an infra-red heat source, e.g., a laser, can be used to melt a region where each micro-device **110** is attached to the donor substrate **100**, thus detaching the donor substrate **100** from the micro-devices **110**.

Referring to FIG. **8**, the transfer device **630** can be positioned to place the micro-devices **110** in contact with the destination substrate **200** (step **320**).

Referring to FIGS. **8** and **9**, selected regions **430** of the adhesive layer **420** that correspond to micro-devices **110** desired to be delivered to the destination substrate **200** are neutralized, e.g., removed or denatured (step **324**). For example, light **450** can be selectively directed through the body that provides the surface **632**, e.g., the backing substrate **410**, to the regions **430**. The light can melt or dissolve the regions **430** of the adhesive layer **420**, or cure the regions **430** into a non-adhesive composition. In some implementations, the light exposes the adhesive layer **420**, and the exposed portion is removed with a developer.

FIG. **11**B illustrates an apparatus **500** for transferring the micro-devices from the transfer substrate **400** to the destination substrate **200**. For the purpose of discussion, the Z-axis is direction perpendicular to the plane of the transfer substrate **400**, and the X-axis and Y-axis are the two perpendicular directions that are parallel to the plane of the transfer substrate **400**. Typically the Z-axis will be a vertical axis, i.e., aligned with gravity, but this is not necessary.

The apparatus **500** includes a stage **510** to support the destination substrate **200**, and holder **520**, e.g., an edge grip actuator, to hold the transfer substrate **400**. An actuator **512**, such as a linear actuator, can provide relative motion along the Z-axis between the stage **510** and the holder **520**. As illustrated, the actuator **512** can be coupled to and configured to move the stage **510** along the Z-axis while the holder **520** remains stationary, or vice-versa.

In some implementations, one or more additional actuators provide relative motion along the X-axis and Y-axis between the stage **510** and the holder **520**. Again, the actuator can be coupled to and configured to move the stage **510** in the X-Y plane while the holder **520** remains stationary, or vice-versa. For example, the holder **520** can be positioned on a robot arm that provides motion in the X-Y plane.

The apparatus **500** also includes an illumination system **530**. The illumination system **530** includes a light source **532** and a mechanism to selectively direct light from the light source onto the back side of the transfer substrate **400**. In one implementation, the illumination system **530** includes a two-dimensional array of independently controllable mirrors, e.g., a digital micro-mirror device (DMD) **534**. The illumination system **530** can also include illumination optics **536** to direct light from the light source **532** to the DMD **534**, and/or projection optics **538** to direct light reflected by activated mirrors of the DMD **534** onto the adhesive layer **420**. By controlling which mirrors of the DMD **534** are activated, light **450** can be selectively directed to the desired regions **430**.

Referring to FIG. **11**C, a DMD **534** can include a plurality of independently mirrors **550**. Each mirror **550** can be independently tilted between a first position, e.g., shown by mirror **550***a*, in which incident light from the light source **532** is reflected and passed to the projection optics **538** and illuminates a particular pixel in an imaging plane (e.g., the adhesive layer on the transfer substrate **400**), and a second position, e.g., shown by mirror **550***b*, in which incident light from the light source **532** is reflected along a path such that the reflected light does not reach the imaging area (e.g., the adhesive layer on the transfer substrate **400**). The mirrors **550** can be supported on posts **552** above a substrate **554** on which circuitry is formed to control the individual mirrors **550**; many other forms of DMDs are possible.

The light source **532** can be an arc lamp, e.g., a mercury arc lamp, or a laser, e.g., a solid state laser diode. One end of a bundled group of optical fibers can be coupled to one or more laser diodes; light from the other end of the optical fibers can be directed to the illumination optics **536** or sent directly to the DMD **534**.

Further discussion of an illumination system that includes a DMD can be found in U.S. Patent Publication Nos. 2016/0282728, 2016,0219684 and 2016/0124316. In particular, U.S. Patent Publication No. 2016/0124316 discusses an optical system that includes an illumination-projection beam separator that could be used to direct light from the light source **532** onto DMD **534** and separate the reflected light **450**.

In some implementations, the field of view of the projection optics **538** spans the entire transfer substrate **400**. In this case, it is not necessary to have lateral motion between the light **450** and the transfer substrate **400**. However, in some implementations, the field of view of the projection optics **538** spans only a portion of the transfer substrate **400**. In this case, an actuator could provide relative motion in the X-Y plane between the illumination system **530** and the transfer substrate **400** between exposures of the transfer substrate **400**.

Rather than a two-dimensional array of mirrors, the illumination system **530** could include a linear array of mirrors, and an actuator could provide relative motion in the X-Y plane between the illumination system **530** and the transfer substrate **400** to scan the linear array of mirrors across the transfer substrate **400**. Alternatively, the illumination system **530** could include a linear array of mirrors, and an actuator, e.g., a galvo, could rotate the linear DMD array **534** to scan the resulting reflected light across the transfer substrate **400**.

As another implementation, a light beam, e.g., from a laser, could be raster scanned across the transfer substrate **400**, and modulated as it scans to provide the same function as the DMD. For example, the illumination system **430** could include a 2-axis mirror gimbal that that can rotate a single mirror about two perpendicular axes and thus scan the light beam along two perpendicular axes on the transfer substrate. As another example, the illumination system **430** could include two galvo mirror scanners in series (along the path of the light beam), that permit the light beam to be scanned along two perpendicular axes on the transfer substrate.

As shown in FIGS. **10** and **12-13**, once the selected regions **430** have been illuminated, the transfer device **630** can be lifted off, leaving the selected micro-devices **110***a* in place on the destination substrate **200** (step **328**). The remaining micro-devices **110***b* where the adhesive layer **430** was not exposed remain on the transfer substrate **400**.

Referring to FIGS. **1-2** and **12-13**, the initial spatial density of micro-devices on the donor substrate **100**, and thus on the transfer device **630**, is greater than the spatial density of the spots **210** on the destination substrate **200**. However, assuming that the spots **210** align with particular micro-devices **110** on the transfer substrate, just those micro-devices **110** that correspond to the spots **210** can be transferred. For example, if the pitch PX**2** is an integer multiple of the pitch PX**1** and the pitch PY**1** is an integer multiple of the pitch PX**2**, then one of every (PX2*PY2)/(PX1*PY1) micro-devices **110** will be transferred. For a rectangular array, the transferred micro-devices **110** can be positioned every PX2/PX1 columns and every PY2/PY1 rows.

As shown in FIG. **13**, the resulting transfer device **630'** will be have cells **440** that are missing micro-devices **110***b*. However, the transfer device **630'** can be reused for additional destination substrates **200**. In brief, steps **320**, **324**,

328 can be repeated, but with a different destination substrate and using a different set of micro-devices from the transfer device **630**. That is, the transfer device **630'** can be positioned adjacent the new destination substrate, but with a different set of micro-devices aligned with the spots **120**. For example, the transfer device **630'** can be shifted by one cell for each cycle. Ideally, for a rectangular array, this would permit the transfer device **630** to be used a total of (PX**2***PY**2**)/(PX**1***PY**1**) times.

As shown in FIG. **14**, some products may need multiple micro-devices **110***i*, **110***j*, **110***k* of different types in each cell **205**. For example, for a color LED display may need three micro-LEDs, one for each of red, blue and green. Each micro-LED can provide a sub-pixel. A variety of patterns are possible for the sub-pixels. For example, the different colored sub-pixels can simply be arranged in a single row or column. Alternatively, for example, the sub-pixels within a cell can be arranged in a quincunx pattern with two sub-pixels each of two colors, e.g., red and green, and a single sub-pixel of the third color, e.g., blue (this pattern is also known as a PenTile matrix). The transfer techniques can be used to form displays with more than three color sub-pixels, e.g., a display with red, green, blue and yellow micro-LEDs.

The different color LEDs can be LEDs with phosphor layers that emit differently colored light, or they can be LEDs with different colored filter layers, or they can be LEDs that emit white light but also include an overlaying phosphor material that absorbs the white light and re-emits differently colored light (this material can be quantum dots).

The different micro-devices, e.g., the different color micro-LEDs, can be fabricated on different donor substrates at higher spatial density than needed for the destination substrate. The transfer process can then be performed for each donor substrate. That is, the micro-devices from each particular donor substrate can be transferred to its own transfer substrate. For example, there can be a transfer substrate with blue micro-LEDs, a transfer substrate with red micro-LEDs, and a transfer substrate with green micro-LEDs. For each transfer substrate, a micro-device can be transferred for each cell to the destination substrate.

As shown in FIG. **15**, in some implementations, the destination substrate **200** is a flexible substrate. For example, the destination substrate **200** can be a flexible circuit and micro-devices **110** can be micro-LEDs, thus providing a flexible display screen. Alternatively or in addition, the destination substrate **200** can a stretchable substrate.

The discussion above has assumed that the donor substrate (and thus the target substrate) has a micro-device that aligns properly with the destination spot for each cell on the destination substrate. This permits all the micro-devices to be transferred from the transfer substrate to the destination substrate in a single release operation (i.e., exposing all the corresponding regions of the adhesive layer simultaneously).

However, it may be the case that the spacing between the micro-devices on the donor substrate is such that it is not possible to transfer all the micro-devices to the destination spots in a single release operation. For example, the pitch PX**2** might not be an integer multiple of the pitch PX**1** and/or the pitch PY**1** might not be an integer multiple of the pitch PX**2**.

Never-the-less, it is still possible to achieve significant increase in manufacturing throughput, at least as compared to having to pick-and-place individual micro-devices. Referring to FIG. **16**, a modified process permits micro-devices to be placed in a rectangular array that has an arbitrary spacing relative to the original spacing of the micro-devices on the donor substrate.

Initially, the micro-devices **110** are transferred from a donor substrate to a first surface of a first transfer device, e.g., a first transfer substrate **400***a*. The micro-devices **110** are arranged on the first transfer substrate **110** at a pitch PX**1** along the X-axis and a pitch PY**1** along the Y-axis. The first transfer substrate **400***a* is then positioned adjacent a second surface of a second transfer device, e.g., a second transfer substrate **400***b*. Rather than transferring all of the micro-devices at once to the second transfer substrate, a single column at a time is transferred, with the first transfer substrate undergoing lateral re-positioning between each transfer to provide the appropriate spacing in one of the directions. Then the micro-devices are transferred from the second transfer substrate to the destination substrate one row at a time, with the first transfer substrate undergoing lateral re-positioning between each transfer to provide the appropriate spacing in the other direction.

For example, supposing the destination substrate has N rows and M columns of cells to receive micro-devices **110**. The first transfer substrate **400***a* is be positioned adjacent the second substrate **400***b*, and the illumination system would be controlled to illuminate regions corresponding to N micro-devices **110** within a single column. So a single column containing N micro-devices **110** would be transferred to the second transfer substrate **400***b*. Then the first transfer substrate **400***a* is shifted relative to the second transfer substrate **400***b* along the X-axis, and the illumination system is controlled to illuminate regions corresponding to another N micro-devices **100** within another single column, thus placing another column of N micro-devices. This process of shifting and placing is repeated M−1 times, until M columns with N rows of micro-devices are transferred to the second transfer substrate **400***b*. The amount of the shift of the first transfer substrate **400***a* relative to the second transfer substrate **400***b* is such that the pitch of the micro-devices along the X-axis on the second transfer substrate **400***b* matches the desired pitch PX**2** for the destination substrate. The pitch of the micro-devices along the Y-axis can be PY**1**, or an integer multiple of PY**1**.

Once the array of M columns with N rows of micro-devices are transferred to the second transfer substrate **400***b*, the micro-devices **110** can be transferred to the destination substrate **200**. The second transfer substrate **400***b* is positioned adjacent the second substrate **400***b*, and the illumination system is controlled to illuminate regions corresponding to M micro-devices **110** within a single row. So a single row containing M micro-devices **110** would be transferred to the destination substrate **200**. Then the second transfer substrate **400***b* is shifted relative to the destination substrate **400***b* along the Y-axis, and the illumination system is controlled to illuminate regions corresponding to another M micro-devices **100** within another single row, thus placing another row of M micro-devices. This process of shifting and placing is repeated N−1 times, until N rows of M columns of micro-devices are transferred to the destination substrate **200**. The amount of the shift of the second transfer substrate **400***b* relative to the destination substrate **200** is such that the pitch of the micro-devices along the Y-axis on the destination substrate **200** matches the desired pitch PY**2** for the destination substrate **200**. As a result, the pitch of the micro-devices on the destination substrate is now PX**2** along X-axis and PY**2** along Y-axis, with any arbitrary relationship between PX**1** and PX**2**, and between PY**1** and PY**2**.

An advantage of this multi-step transfer process is that the total number of transfer steps is approximately M+N. While for a high resolution display this total M+N may still be a large number, it is much smaller than the number of transfer steps that would be required for individual pick-and-place, i.e., M*N.

In some implementations, the micro-devices are inspected or tested before being transferred to the destination substrate. Testing might occur while the micro-devices are still on the donor substrate, or inspection might occur while the micro-devices are on the transfer substrate. For each cell where inspection or testing indicates that the micro-device is defective, the illumination system of the transfer system is controlled to not illuminate the region of the transfer substrate corresponding to the defective micro-device. Thus, the identified defective micro-devices are not transferred to the destination substrate. Any cell on the destination substrate that thus lacks a micro-device can receive a functional micro-device in a later pick-and-place operation. This permits the destination substrate, and thus the product, to be fabricated with very high yield.

For some implementations, depending on which side of the micro-device is required to contact the destination substrate, it may be necessary to transfer the micro-devices to a third transfer substrate (which could be before the first transfer substrate, after the second transfer substrate, or between the first and second transfer substrates) in order to flip the micro-devices.

It should be understood that while the above method described a method of surface mounting a single micro device, the method can include more than one micro device.

The controller can be implemented in digital electronic circuitry, or in computer software, firmware, or hardware, or in combinations of them. The controller can include one or more computer program products, i.e., one or more computer programs tangibly embodied in an information carrier, e.g., in a non-transitory machine readable storage medium or in a propagated signal, for execution by, or to control the operation of, data processing apparatus, e.g., a programmable processor, a computer, or multiple processors or computers. A computer program (also known as a program, software, software application, or code) can be written in any form of programming language, including compiled or interpreted languages, and it can be deployed in any form, including as a standalone program or as a module, component, subroutine, or other unit suitable for use in a computing environment. A computer program can be deployed to be executed on one computer or on multiple computers at one site or distributed across multiple sites and interconnected by a communication network.

The processes and logic flows described in this specification can be performed by one or more programmable processors executing one or more computer programs to perform functions by operating on input data and generating output. The processes and logic flows can also be performed by, and apparatus can also be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit).

Terms of positioning, such as vertical and lateral, have been used. However, it should be understood that such terms refer to relative positioning, not absolute positioning with respect to gravity. For example, laterally is a direction parallel to a substrate surface, whereas vertically is a direction normal to the substrate surface.

It will be appreciated to those skilled in the art that the preceding examples are exemplary and not limiting. It is intended that all permutations, enhancements, equivalents, and improvements thereto that are apparent to those skilled in the art upon a reading of the specification and a study of the drawings are included within the true spirit and scope of the present disclosure. It is therefore intended that the following appended claims include all such modifications, permutations, and equivalents as fall within the true spirit and scope of these teachings.

What is claimed is:

1. A method of surface mounting micro-devices, comprising:

adhering a plurality of micro-devices on a donor substrate to a transfer surface with an adhesive layer;

removing the plurality of micro-devices from the donor substrate while the plurality of micro-devices remain adhered to the transfer surface;

positioning the transfer surface relative to a destination substrate so that at least some of the plurality of micro-devices on the transfer surface abut at least some of a plurality of receiving positions on the destination substrate;

selectively and masklessly exposing a plurality of regions of the adhesive layer on the transfer surface corresponding to a subset of micro-devices to light to detach the subset of micro-devices from the adhesive layer, the subset including multiple micro-devices but less than all of micro-devices of the plurality of micro-devices; and

separating the transfer surface from the destination substrate such that the subset of micro-devices remain on the destination substrate.

2. The method of claim **1**, wherein the plurality of micro devices comprise all of the micro-devices on the donor substrate.

3. The method of claim **1**, wherein the plurality of micro-devices are disposed in a first array on the transfer surface, and the plurality of receiving positions are disposed in a second array on the destination substrate.

4. The method of claim **3**, wherein a spatial density of the first array is greater than a spatial density of the second array.

5. The method of claim **4**, wherein the first array is first rectangular array with cells for the plurality of micro-devices disposed at a first pitch PX**1** along a first axis and a second pitch PY**1** along a second axis perpendicular to the first axis, and the second array is a second rectangular array with the receiving positions disposed at a third pitch PX**2** along the first axis and a fourth pitch PY**2** along the second axis perpendicular to the first axis.

6. The method of claim **5**, wherein the third pitch PX**2** is an integer multiple of the first pitch PX**1** and the fourth pitch PY**2** is an integer multiple of the second pitch PY**1**.

7. The method of claim **6**, wherein the donor substrate is a donor substrate on which the plurality of micro-devices were fabricated.

8. The method of claim **1**, wherein the micro-devices comprise micro-LEDs.

9. The method of claim **1**, wherein selectively exposing the plurality of regions comprises directing light to a digital mirror device and actuating selected mirrors of the digital mirror device to reflect light to the plurality of regions.

10. The method of claim **9**, comprising exposing a first portion of the plurality of regions, thereafter moving the digital mirror device relative to the adhesive layer, and thereafter exposing a second portion of the plurality regions.

11. The method of claim **10**, wherein digital mirror device comprises a linear array of mirrors.

12. The method of claim **10**, wherein digital mirror device comprises a two-dimensional array of mirrors.

13. The method of claim **1**, further comprising disposing a passivating layer over the subset of micro-devices on the destination substrate.

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14. The method of claim **1**, wherein positioning the transfer surface comprises moving a transfer body having the transfer surface relative to the destination substrate.

15. The method of claim **14**, comprising removably holding and moving the transfer body with a robotic arm.

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patsnap

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[标]申请(专利权)人(译)	应用材料股份有限公司		
申请(专利权)人(译)	APPLIED MATERIALS，INC.		
当前申请(专利权)人(译)	APPLIED MATERIALS，INC.		
[标]发明人	THOTHADRI MANIVANNAN VISSER ROBERT JAN		
发明人	THOTHADRI, MANIVANNAN VISSER, ROBERT JAN		
IPC分类号	H01L27/15 H01L33/60 H01L21/683 H01L21/67 H05K13/04 H05K3/30 H05K13/00 H01L25/075 H01L33/00 H05K3/00 H01L33/20 H01L33/48		
CPC分类号	H01L27/156 H01L21/6835 H01L25/0753 H01L33/0095 H01L33/60 H05K3/0026 H05K3/305 H05K13/0015 H05K13/0069 H05K13/0469 H01L21/67144 H01L2933/0033 H01L33/20 H01L33/48 H01L2221/68322 H01L2221/68368 H01L2221/68381 H01L21/67132 G03F7/70383 G03F7/70825		
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摘要(译)

一种表面安装微器件的方法，包括利用粘合剂层将供体基板上的第一多个微器件粘附到转移表面，从供体基板移除第一多个微器件，同时保留第一多个微器件粘附到转移表面，将转移表面相对于目标基板定位，使得转移表面上的多个微器件的子集邻接目标基板上的多个接收位置，该子集包括一个或多个微器件但是少于所有多个微器件中的微器件，选择性地中和对应于微器件子集的转移表面上的粘合剂层的一个或多个区域，以使微器件的子集从中分离出来。粘合剂层，并将转移表面与目标基板分离，使得微器件子集保留在目标基板上。