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

(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.

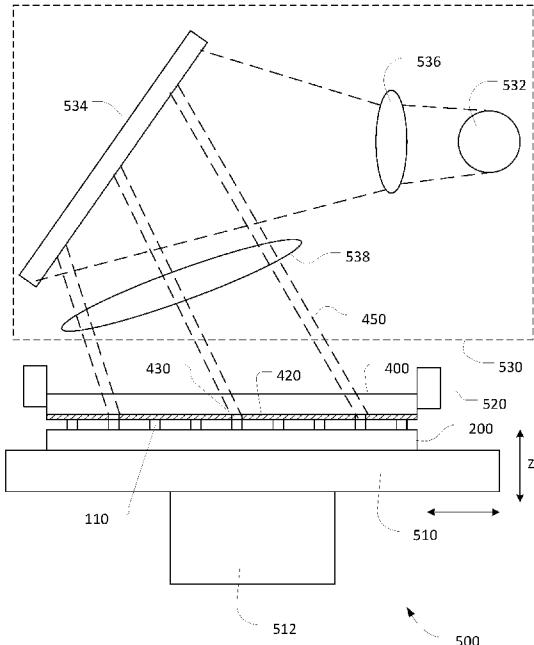


FIG. 11B

MASKLESS PARALLEL PICK-AND-PLACE TRANSFER OF MICRO-DEVICES**TECHNICAL FIELD**

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

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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 10 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 15 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 20 (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 25 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 30 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 5 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 10 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 15 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 20 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.

25 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 30 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

5 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 body from the destination substrate such that the subset of micro-devices

10 remain on the destination substrate.

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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.

20 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

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30 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 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.

20 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.

25 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 5 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 10 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 15 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 20 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 25 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 30 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 5 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 10 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 15 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 20 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 25 transferring multiple micro-devices from the donor substrate to the destination substrate.

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

FIG. 11B is a schematic cross-sectional side view of a system for illuminating 30 the adhesive layer on a transfer substrate.

FIG. 11C 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.

5 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.

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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.

15 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 20 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.

25 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 5 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, 10 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 15 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 20 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 25 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 30 array with pitch PX1 and PY1 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 5 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 10 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 PX2 and PY2 in the two perpendicular directions parallel to the face of the destination 15 substrate 200. Thus, the pitch PX2 can be greater than the pitch PX1 and the pitch PY2 can be greater than the pitch PY1. 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 20 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 25 can include one or more bond pads which will electrically connect to one or more bond pads on the micro-device 110.

FIG. 11A is a schematic cross-sectional side view of a system for transferring micro-devices from a donor substrate to a destination substrate. FIG. 11A illustrates a system 600 for transferring the micro-devices from the donor substrate 100 to the 30 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 5 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 10 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 15 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 20 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 25 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 30 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 5 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 10 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).

15 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 20 420 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 25 110. 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 30 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 5 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).

10 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 15 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, 20 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 25 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 30 layer 420, and the exposed portion is removed with a developer.

FIG. 11B 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 5 200, 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.

10 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.

15 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.

20 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.

25 Referring to FIG. 11C, 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 550a, 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

30 second position, e.g., shown by mirror 550b, 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
5 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
10 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
15 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.

20 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,
25 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
30 a 2-axis mirror gimbal 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 110a in place on the destination substrate 200 (step 328). The remaining micro-devices 110b 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 PX2 is an integer multiple of the pitch PX1 and the pitch PY1 is an integer multiple of the pitch PX2, 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 have cells 440 that are missing micro-devices 110b. 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 $(PX2*PY2)/(PX1*PY1)$ times.

As shown in FIG. 14, some products may need multiple micro-devices 110i, 110j, 110k 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
5 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
10 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
15 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
20 screen. Alternatively or in addition, the destination substrate 200 can be 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
25 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
30 the destination spots in a single release operation. For example, the pitch PX2 might not be an integer multiple of the pitch PX1 and/or the pitch PY1 might not be an integer multiple of the pitch PX2.

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 5 the original spacing of the micro-devices on the donor substrate.

Initially, the micro-devices 110 are transferred from a donor substrate to a a first surface of a first transfer device, e.g., a first transfer substrate 400a. The micro-devices 110 are arranged on the first transfer substrate 110 at a pitch PX1 along the X-axis and a pitch PY1 along the Y-axis. The first transfer substrate 400a is then 10 positioned adjacent a second surface of a second transfer device, e.g., a second transfer substrate 400b. 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 15 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 20 of cells to receive micro-devices 110. The first transfer substrate 400a is be positioned adjacent the second substrate 400b, 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 400b. Then the first transfer substrate 400a is shifted relative to the second transfer substrate 400b along the X-axis, and 25 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 400b. The amount of the shift of the first transfer substrate 400a relative 30 to the second transfer substrate 400b is such that the pitch of the micro-devices along the X-axis on the second transfer substrate 400b matches the desired pitch PX2 for the destination substrate. The pitch of the micro-devices along the Y-axis can be PY1, or an integer multiple of PY1.

Once the array of M columns with N rows of micro-devices are transferred to the second transfer substrate 400b, the micro-devices 110 can be transferred to the destination substrate 200. The second transfer substrate 400b is positioned adjacent the second substrate 400b, and the illumination system is controlled to

5 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 400b is shifted relative to the destination substrate 400b along the Y-axis, and the illumination system is controlled to illuminate regions corresponding to another M micro-devices 100 within another

10 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 400b 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

15 desired pitch PY2 for the destination substrate 200. As a result, the pitch of the micro-devices on the destination substrate is now PX2 along X-axis and PY2 along Y-axis, with any arbitrary relationship between PX1 and PX2, and between PY1 and PY2.

An advantage of this multi-step transfer process is that the total number of

20 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.

5 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 10 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 15 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 20 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 25 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, 30 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

5 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. An apparatus for positioning micro-devices on a destination substrate, the apparatus comprising:
 - 5 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;
- 10 an illumination system configured to selectively and masklessly expose regions of the adhesive layer on the transfer body; and
- 15 a controller 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
- 20 more micro-devices corresponding to the one or more neutralized portions of the adhesive layer remain on the destination substrate.
2. The apparatus of claim 1, further comprising a third support to hold a donor substrate, wherein the one or more actuators are configured to provide relative motion between the first support and the third support, and wherein the controller is 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
- 30 adhere to the adhesive layer on the transfer body.

3. The apparatus of claim 2, wherein the second support comprises a robotic arm to hold the transfer body, wherein the robotic arm is operable to move the transfer body between the third support and the first support.

5 4. The apparatus of claim 1, wherein the transfer body comprises a transfer substrate that is removable from the second support.

5. The apparatus of claim 1, wherein the illumination system comprises a digital mirror device having an array of individually actuatable mirrors.

10

6. The apparatus of claim 5, wherein the digital mirror device comprises a two-dimensional array of mirrors.

15

7. The apparatus of claim 6, wherein a field of view of the illumination system spans only a portion of the transfer body, and an actuator to cause relative motion between the two-dimensional array and the one or more supports.

20

8. The apparatus of claim 5, wherein the digital mirror device comprises a linear array of mirrors and an actuator to cause relative motion between the linear array and the one or more supports.

9. 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;

25

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;

30

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.

5 10. The method of claim 9, wherein the plurality of micro devices comprise all of the micro-devices on the donor substrate.

11. The method of claim 9, wherein the plurality of micro-devices are disposed in a first array on the transfer surface, and the plurality of receiving positions are

10 disposed in a second array on the destination substrate.

12. The method of claim 11, wherein a spatial density of the first array is greater than a spatial density of the second array.

15 13. The method of claim 9, wherein the micro-devices comprise micro-LEDs.

14. The method of claim 9, 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.

20

15. An apparatus for positioning micro-devices on a destination substrate, the apparatus comprising:

a first support to hold a destination substrate;

a second support to provide or hold a transfer body having a surface to

25 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 light beam on the adhesive layer

30 on the transfer body; and

a controller 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

5 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.

10 16. The apparatus of claim 15, wherein the light source comprises a laser and the light beam comprises a laser beam.

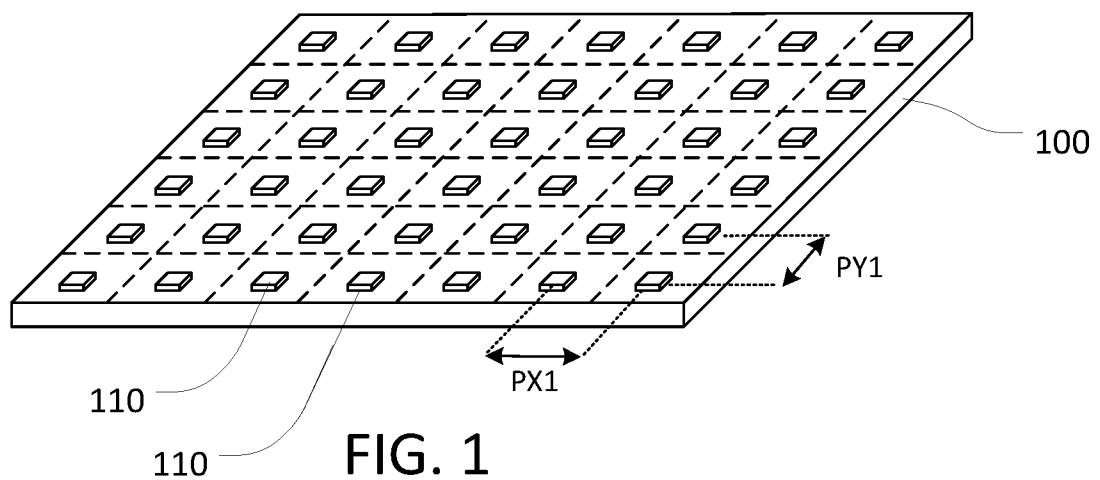


FIG. 1

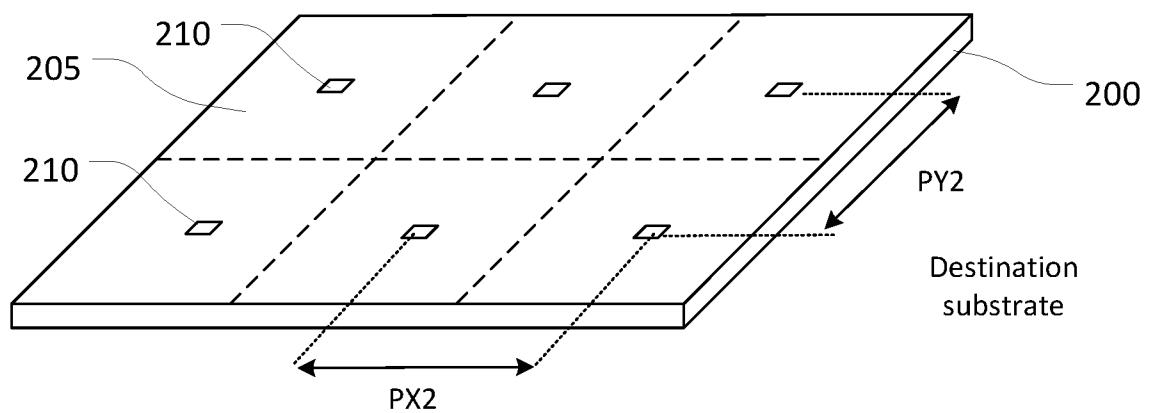


FIG. 2

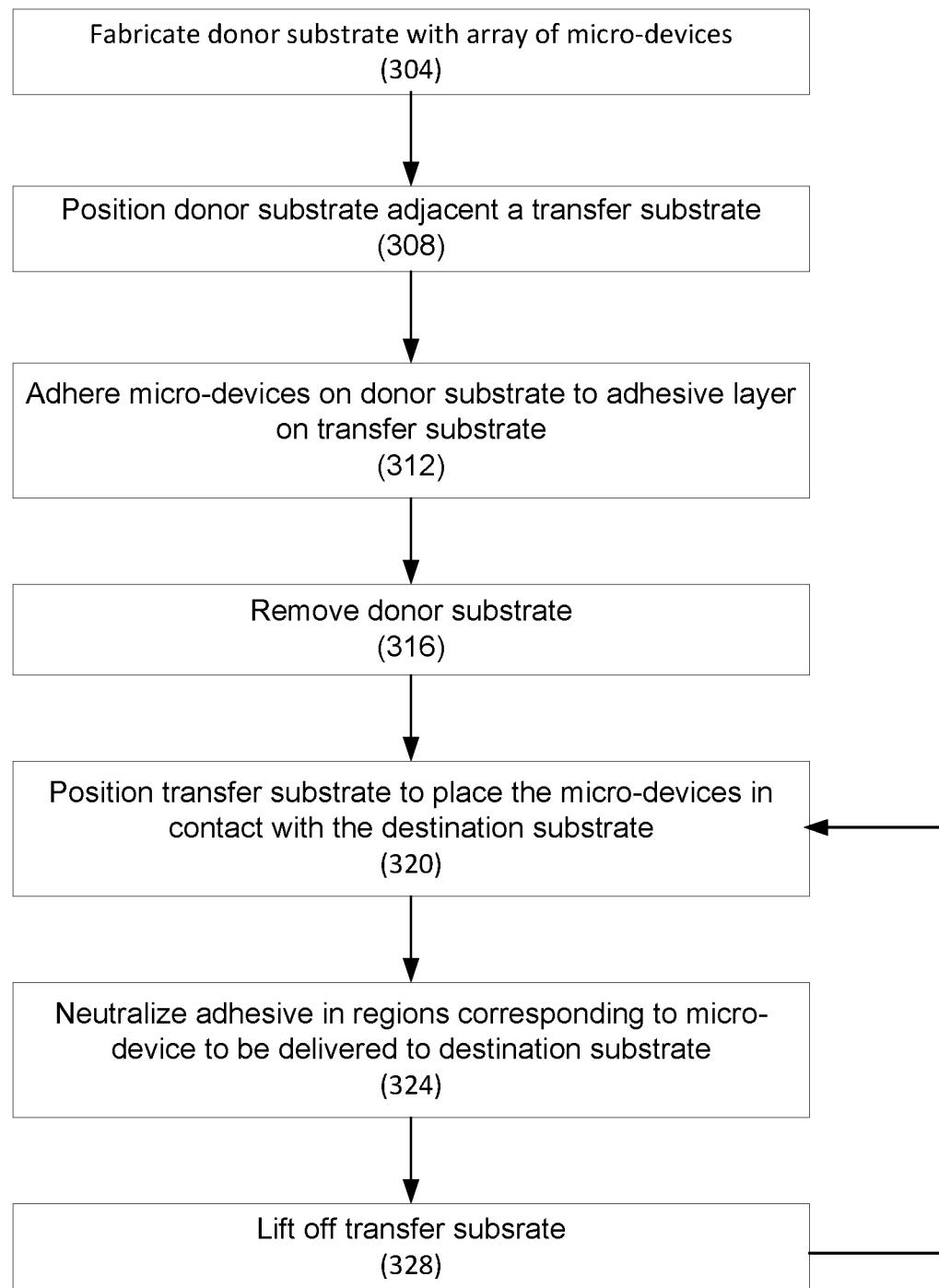
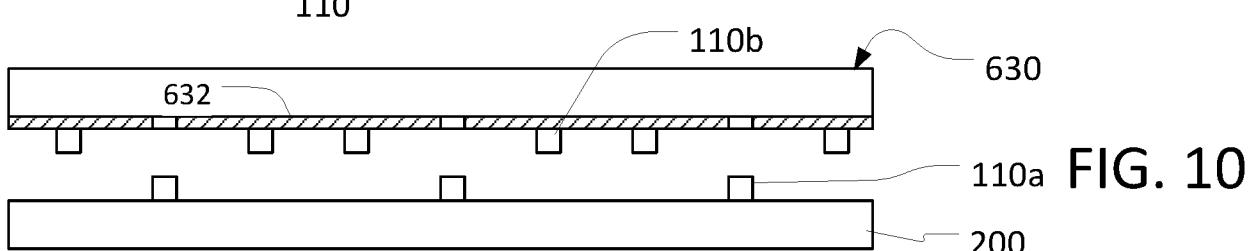
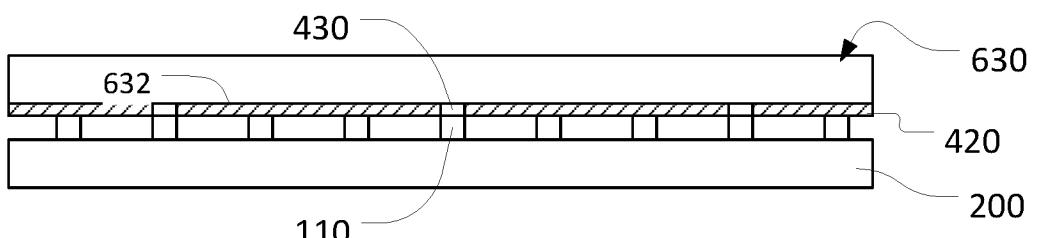
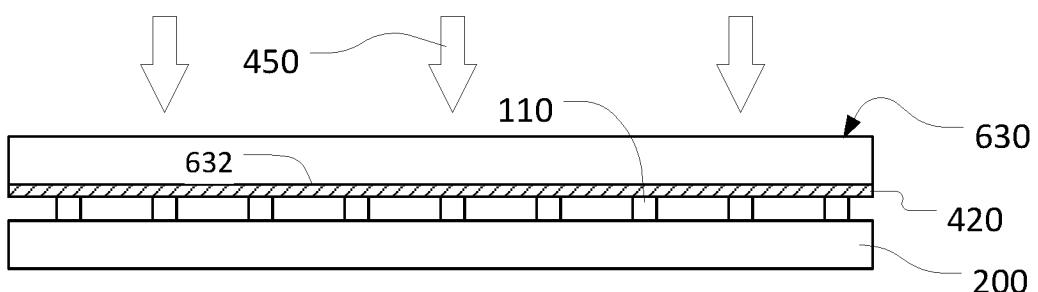
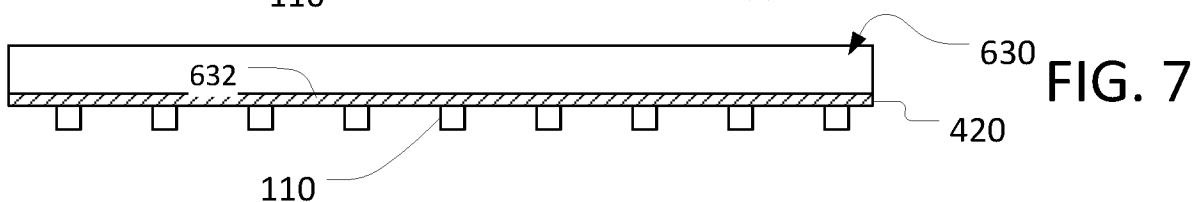
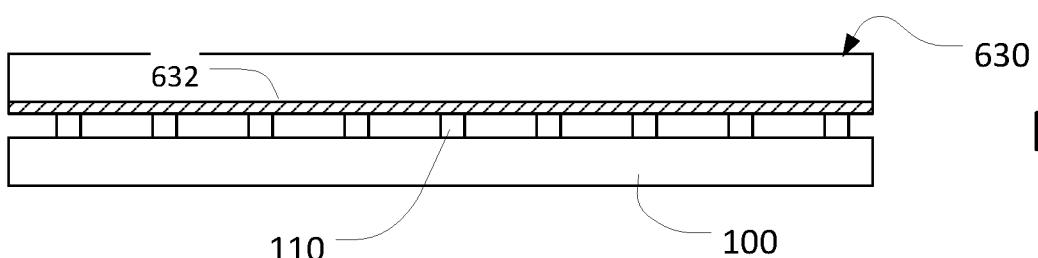
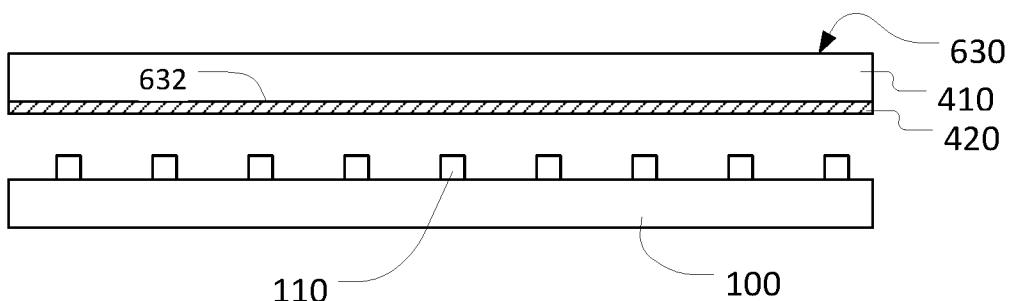
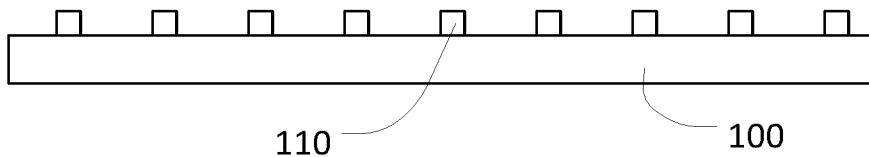


FIG. 3



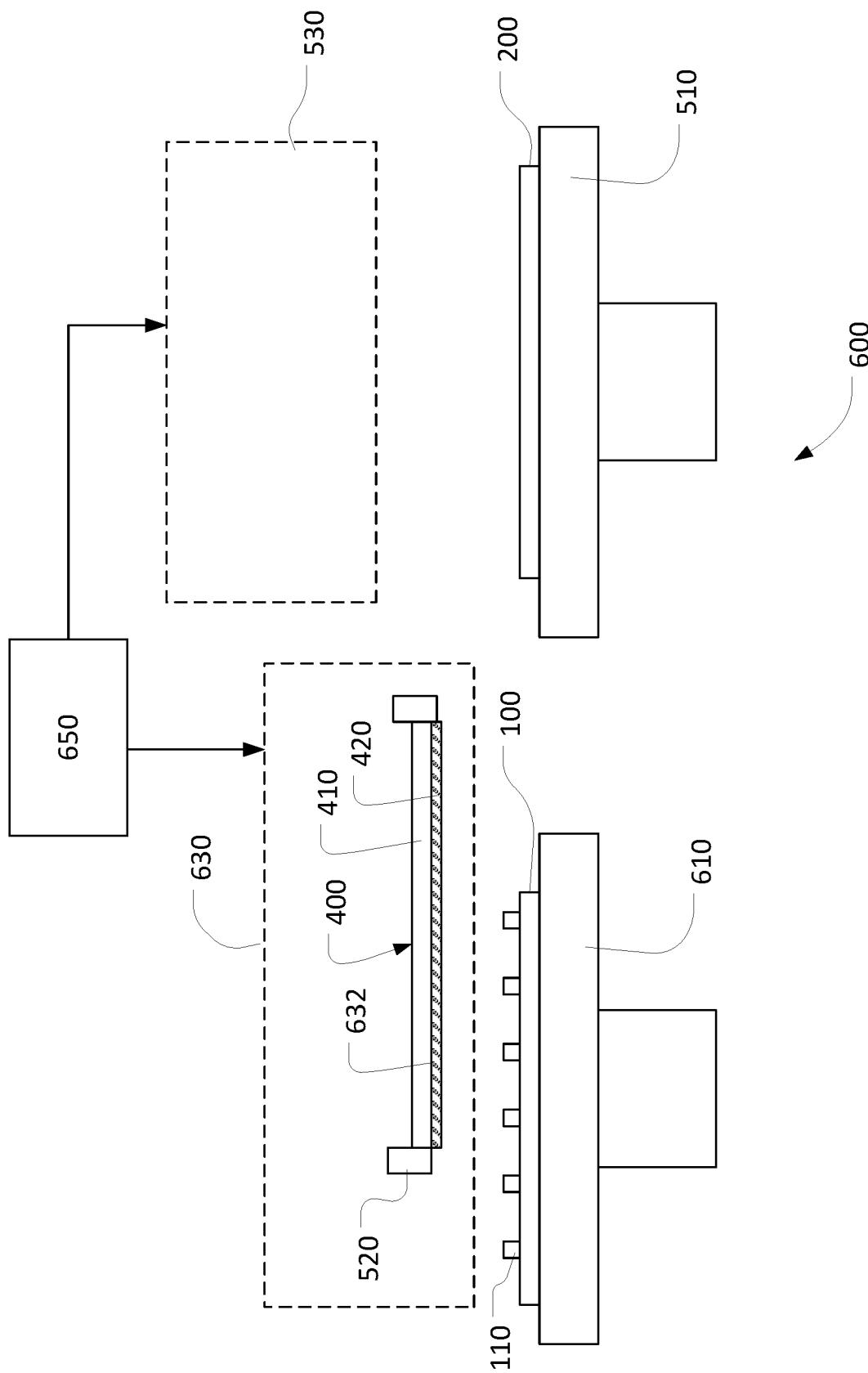


FIG. 11A

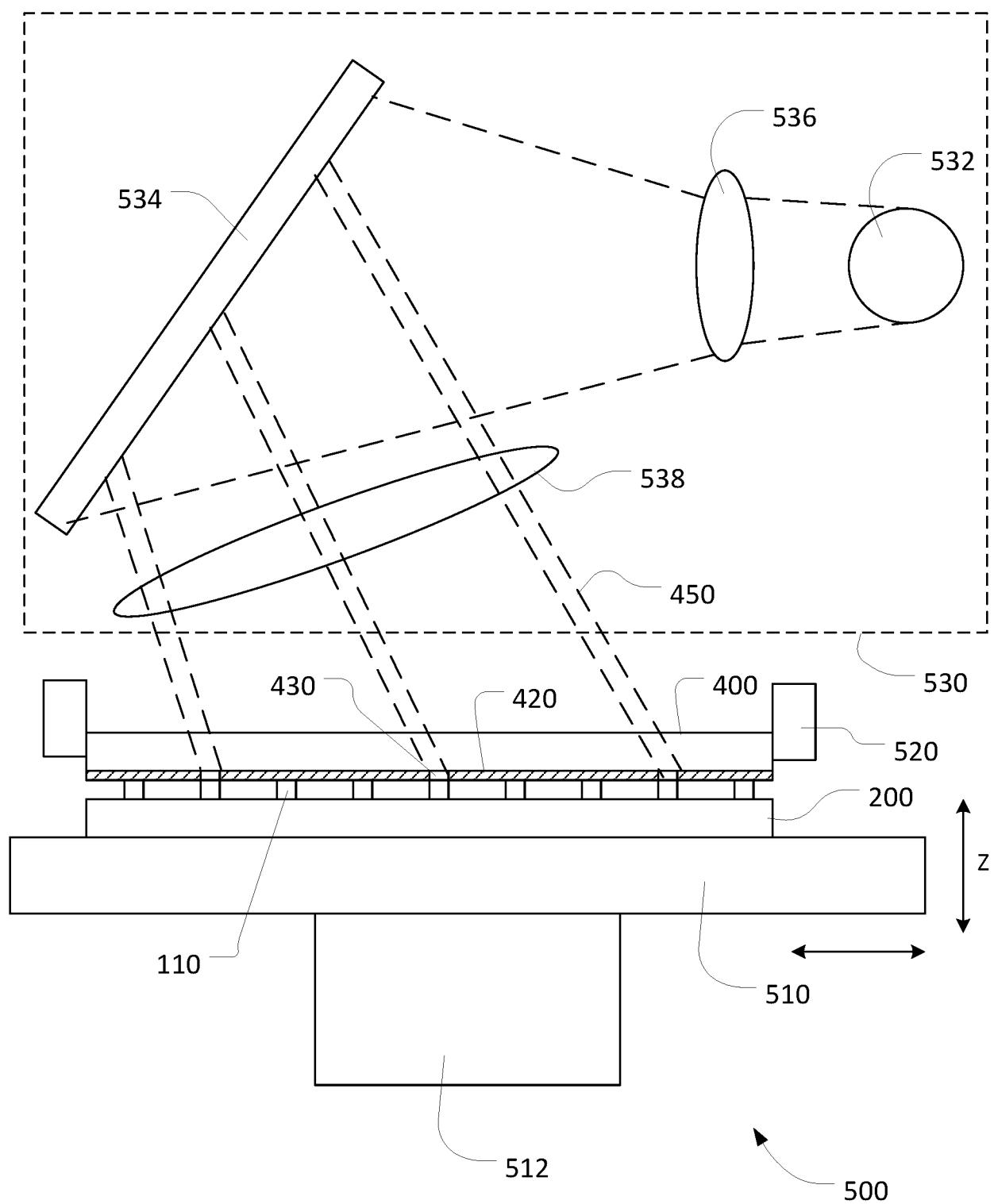


FIG. 11B

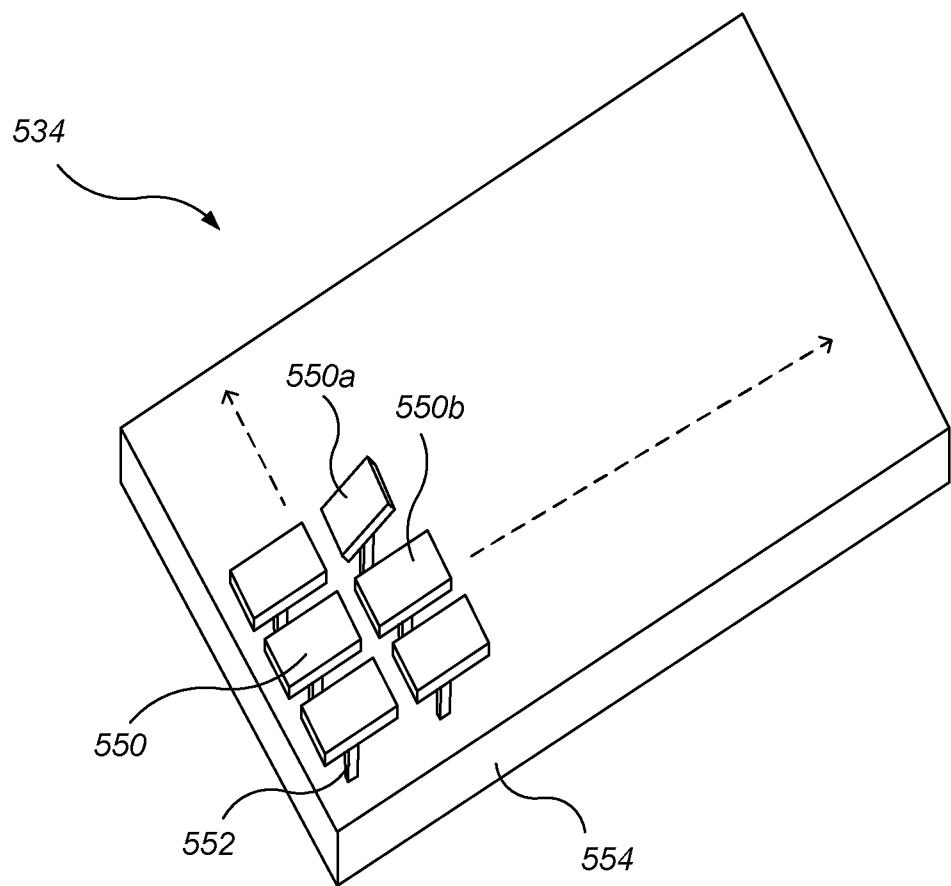
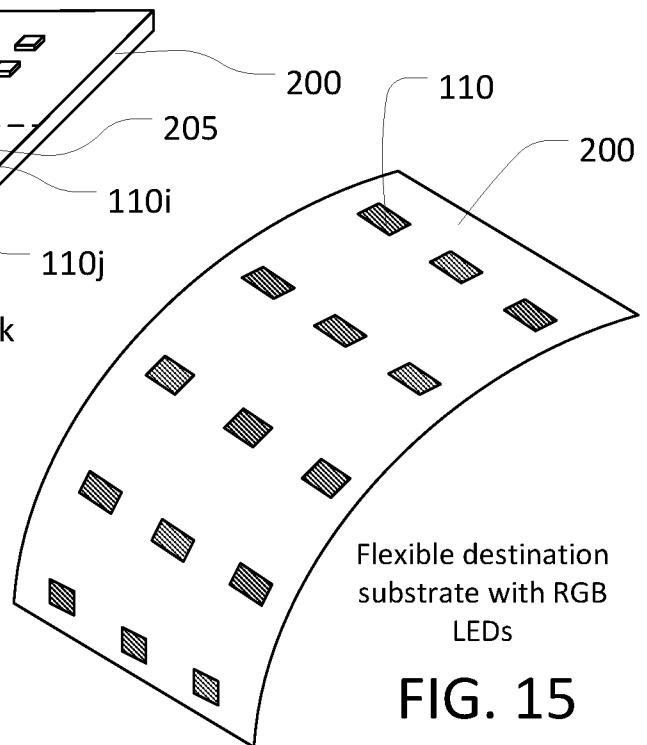
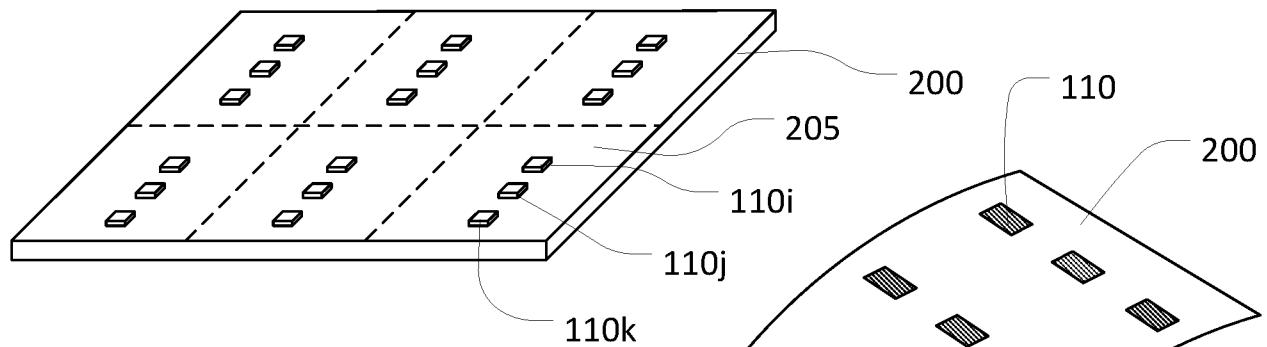
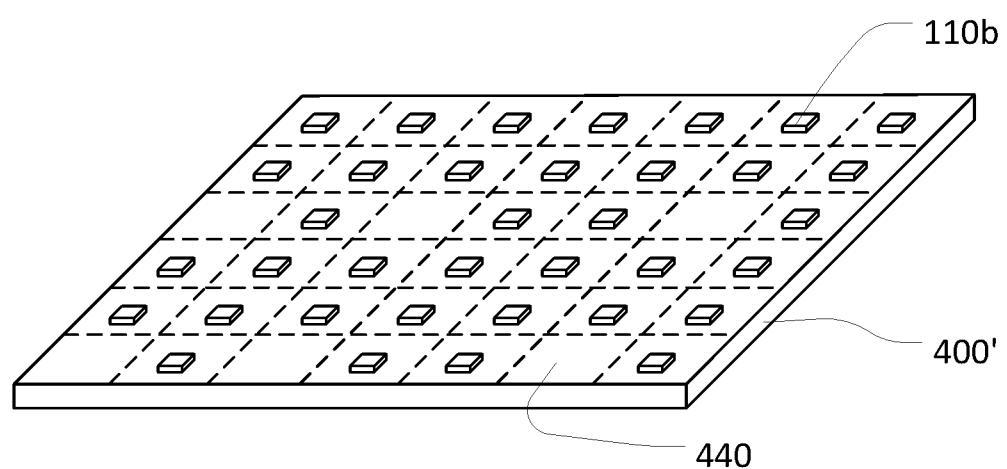
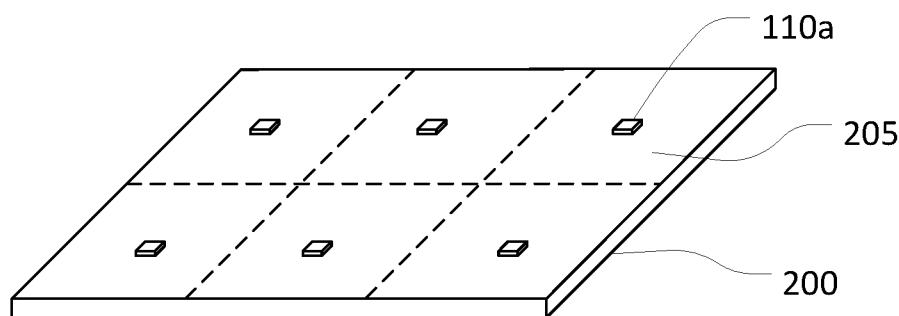


FIG. 11C



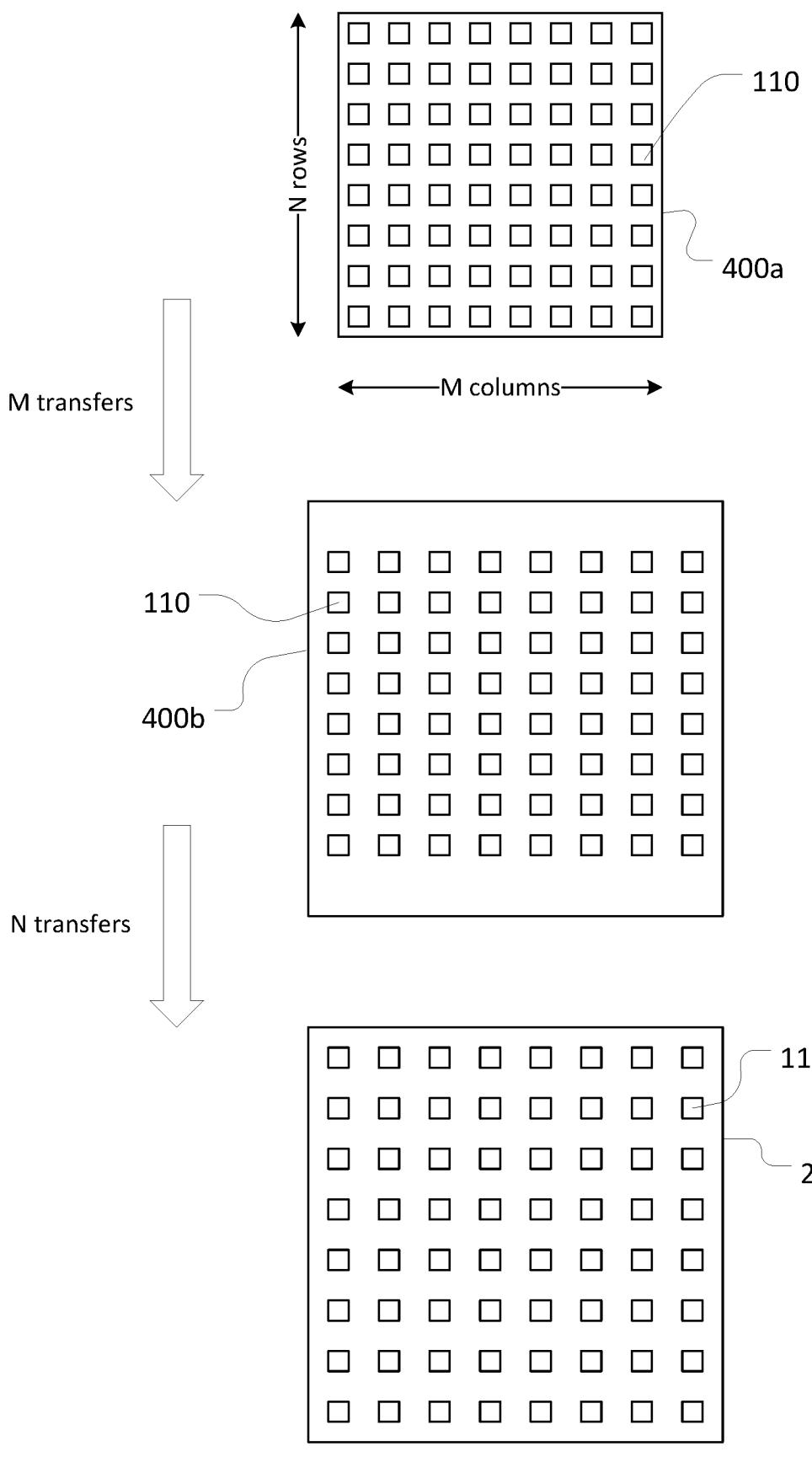


FIG. 16

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/036804

A. CLASSIFICATION OF SUBJECT MATTER

G03F 7/20(2006.01)i, H01L 21/683(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

G03F 7/20; B29C 59/00; B28B 11/08; H01L 51/52; B41J 29/38; H01L 51/56; B29C 35/08; H01L 21/683

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility modelsElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: apparatus, positioning, micro-devices, destination substrate, first support, second support, transfer body, an adhesive layer, actuators, illumination system, controller configured, neutralized portions, surface

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2013-010113 A1 (THE BOARD OF TRUSTEES OF THE UNIVERSITY OF ILLINOIS) 17 January 2013 See paragraphs [0032], [0036], [0070], [0125]; claims 1-4; and figures 1, 2.	1-4, 9-13
Y	WO 2014-074954 A2 (DAS, S.) 15 May 2014 See page 18, lines 18-20; page 103, lines 7-15; and figure 96.	5-8, 14-16
A	US 2010-0123268 A1 (MENARD, E.) 20 May 2010 See the entire document.	1-16
A	US 2012-0025182 A1 (UMEDA, T. et al.) 02 February 2012 See the entire document.	1-16
A	US 2016-0124316 A1 (APPLIED MATERIALS, INC.) 05 May 2016 See the entire document.	1-16

 Further documents are listed in the continuation of Box C. See patent family annex.

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 18 September 2017 (18.09.2017)	Date of mailing of the international search report 18 September 2017 (18.09.2017)
Name and mailing address of the ISA/KR International Application Division Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea Facsimile No. +82-42-481-8578	Authorized officer LEE, Ki Cheul Telephone No. +82-42-481-3353

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/036804

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