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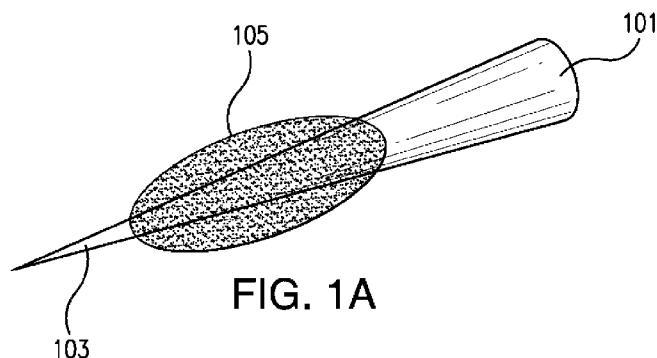
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(54) Title: MICRO-DEVICE TRANSFER FOR HYBRID PHOTONIC AND ELECTRONIC INTEGRATION USING POLYDI-METHYLSILOXANE PROBES



(57) Abstract: Techniques for positioning at least one device on a target using a probe having a tip, the tip being at least partially covered by an elastomer coating having a first shape, are disclosed. An exemplary method includes contacting the elastomer coating to a device to partially deform the elastomer coating and attach the device thereon by surface forces; lifting the probe while the elastomer coating is still deformed and attached to the device; and positioning the device on the target.

# MICRO-DEVICE TRANSFER FOR HYBRID PHOTONIC AND ELECTRONIC INTEGRATION USING POLYDIMETHYLSILOXANE PROBES

# PATENT APPLICATION SPECIFICATION

### STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

This invention was made with government support under Grant No. W911NF-10-1-0416, awarded by the Army Research office/DARPA. The government has certain rights in the invention.

### CROSS REFERENCE TO RELATED APPLICATION

This application claims priority from U.S. Provisional Application Serial No. 61/705,896, filed September 26, 2012, the disclosure of which is incorporated by reference herein.

## BACKGROUND

The disclosed subject matter relates to systems and methods for Micro-device transfer for hybrid photonic and electronic integration using polydimethylsiloxane (PDMS) probes.

Photonic and electronic devices can be made of different materials that are at least partially incompatible to each other. For example, light-emitting devices can be made of compound semiconductors whereas transistors can be made of silicon. Achieving epitaxial growth of compound semiconductors on silicon can be challenging. In the quantum regime, even more materials can be used for different devices with different functionalities. For example, infrared single-photon detectors can be made of superconducting materials; single-photon emitters can be based on nano-diamond crystals.

Integration of these devices made of different materials on a single chip can allow for advanced functionalities in computation and communication, including in both the classical and quantum regimes. Transfer devices to silicon substrates, for example on which silicon waveguides or metal interconnects serve as the bus can allow for hybrid integration without the need for hybrid metal growth.

### SUMMARY

Systems and methods for Micro-device transfer for hybrid photonic and electronic integration using polydimethylsiloxane probes are disclosed herein.

5           In one aspect of the disclosed subject matter, techniques for positioning at least one device on a target using a probe is disclosed. Such probes can include a tip, the tip being at least partially covered by an elastomer coating having a first shape. An exemplary method can include contacting the elastomer coating to the device to partially deform the elastomer coating and attach the device by surface  
10   forces, lifting the probe while the elastomer coating is still deformed and attached to the device, and positioning the device on the target.

          In some embodiments, the method can include lifting the probe within a predetermined amount of time while the elastomer coating is still deformed and attached to the device.

15           In some embodiments, the method can include lifting the probe while the at least one device rests on the target to substantially return the elastomer coating to its initial shape and detach the device from the elastomer coating.

          In some embodiments, the method can include lifting the probe within a predetermined amount of time while the device rests on the target to substantially  
20   return the elastomer coating to its initial shape and detach the at least one device from the elastomer coating.

          In some embodiments, the method can include moving the probe tangentially to device while the at least one device rests on the target to substantially return the elastomer coating to the first shape and detach the device from the  
25   elastomer coating.

          In some embodiments, the method can include rotating and/or flipping the device.

          In some embodiments, the target can include a further probe having a further tip at least partially covered by a further elastomer coating having a second  
30   shape, the method can further include moving the probe tangentially to the at least one device while the at least one device rests on the further probe to return the elastomer coating to the first shape and detach the at least one device from the elastomer coating, and positioning the at least one device on a further target.

In some embodiments, the target can further include one of a substrate, a waveguide, a fiber facet, or electrical contact pads on a substrate.

In another aspect of the disclosed subject matter, an exemplarily apparatus for positioning a device can include a probe including a tip, and an elastomer coating at least partially covering the tip and having a first shape, the elastomer coating adapted to deform when pressure is applied thereto and to return to the first shape when the pressure is removed.

In some embodiments, the probe can include a metal, for example, tungsten. The tip can include a diameter substantially in a range of 300 nm to ten micron.

In some embodiments, the elastomer coating can be polydimethylsiloxanepolydime (PDMS) coating or an platinum catalyzed silicone coating.

In another aspect of the disclosed subject matter, methods for positioning a device are disclosed. A method for positioning a device can include providing a probe including a tip, and at least partially covering the tip with an elastomer coating, the elastomer coating adapted to deform when pressure is applied thereto and to return to the first shape when the pressure is removed.

In some embodiments, the at least partially covering can include submerging the tip in an elastomer mixture and removing the tip from the mixture while a portion of the elastomer adheres to the tip thereby forming the elastomer coating.

The accompanying drawings, which are incorporated and constitute part of this disclosure, illustrate embodiments of the disclosed subject matter and serve to explain its principles.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A and FIG. 1B depict an exemplary and non-limiting apparatus for positioning a device in accordance with some embodiments of the disclosed subject matter.

FIG. 2A is a flow chart that illustrates an exemplary method of making a probe in accordance with some embodiments of the disclosed subject matter.

FIG. 2B is a flow chart that illustrates an exemplary method of preparing a solution in accordance with the disclosed subject matter.

FIG. 3A and FIG. 3B depict an exemplary and non-limiting embodiment that illustrates an exemplary method on how to retrieve an object using a probe in accordance with some embodiments of the disclosed subject matter.

FIG. 4 is a flow chart that illustrates an exemplary method on how to  
5 retrieve an object using a probe in accordance with some embodiments of the disclosed subject matter.

FIG. 5 is a flow chart that illustrates an exemplary method on how to roll print an object using probe in accordance with some embodiments of the disclosed subject matter.

10 FIG. 6A, FIG. 6B, and FIG. 6C are an exemplary and non-limiting illustration of an embodiment according to the disclosed subject matter in connection with the transfer of superconducting-nanowire single-photon detectors, in accordance with some embodiments of the disclosed subject matter.

FIG. 7A and FIG. 7B are an exemplary and non-limiting illustration of  
15 an embodiment according to the disclosed subject matter in connection with the transfer of a photonic crystal membrane, in accordance with some embodiments of the disclosed subject matter.

FIG. 8A, FIG. 8B, FIG. 8C, FIG. 8D, FIG. 8E, and FIG. 8F are an  
exemplary and non-limiting illustration of an embodiment according to the disclosed  
20 subject matter in connection with the transfer of nano-diamond crystals, in accordance with some embodiments of the disclosed subject matter.

FIG. 9A, FIG. 9B, FIG. 9C, FIG. 9D, and FIG. 9E illustrate high  
alignment accuracy that can be achieved in accordance with some embodiments of the  
disclosed subject matter.

25 FIG. 10A, FIG. 10B, FIG. 10C, and FIG. 10D illustrate an example application of illustrated exemplary systems and methods of using silicon membranes as robust etch mask that can be achieved in accordance with some embodiments of the disclosed subject matter.

FIG. 11A, FIG. 11B, and FIG. 11C illustrate an application of the  
30 exemplary systems and methods transferrable on unconventional targets in accordance with some embodiments of the disclosed subject matter.

FIG. 12A and FIG. 12B illustrate an example application where sub-10  
nm resolution was achieved in accordance with some embodiments of the disclosed  
subject matter.

### DETAILED DESCRIPTION

Techniques for providing low-cost transfer of devices onto a target are presented. An exemplary technique includes contacting solution on a probe to a device to partially deform the solution and attach the device thereon by surface forces. The exemplary technique further includes lifting the probe while the solution is still deformed and attached to the device and positioning the device on the target. Another exemplary technique includes lifting the probe while the device rests on the target to return the solution to the first shape and detach the device from the solution.

FIG. 1A and FIG. 1B illustrate an exemplary probe in accordance with the disclosed subject matter, for example, a tungsten-PDMS probe. With reference to FIG. 1A, a probe 101 can include a tip 103. The tip 103 of the probe can be used to prepare the probe to transfer objects and also used to retrieve or deposit the object at a location. A suitable material can be used as a probe 101, for example, glass, metal, or the like. Additionally, the tip of the probe can be any suitable size. For example, the size of the tip can be from 300 nm to ten microns. A preferred size can include, but is not limited to, up to tens of microns. The size can also be smaller than 300 nm, depending on application. In an example, in order to prepare the probe 101 to transfer objects, the probe 101 can be dipped in a solution that will assist the probe 101 to retrieve or deposit objects in a location. The residue of the solution 105 can stick to the surface of the probe as shown in FIG. 1A and FIG. 1B.

FIG 1B illustrates an exemplary tungsten-PDMS probe 101. With reference to FIG. 1B, the probe 101 can be made out of Tungsten. Additionally, probe 101 can be dipped into a PDMS solution 105 in order to prepare the probe 101 to retrieve, transfer or deposit objects at a location.

A probe 101 can be mounted on a manual stage that moves in one or more dimensions, such as, for example, a XYZ manual stage with about 50-nm or lower spatial resolution (for example, using a piezo actuation). An XYZ stage is an exemplary manual stage that moves in three dimensions. The whole transferring process can be operated under an optical microscope. Other example of stages that can be used include, but are not limited to, any suitable manual stage, any suitable motorized stage, a stage that moves in all three directions, can change pitch, and/or yaw, or the like.

FIG. 2 is a flow chart that illustrates an exemplary method of making or preparing a probe. With reference to FIG. 2, a probe 101 can be made or prepared by dipping the probe 101 into a solution. (201). Examples of materials a probe 101 can be made out of material, for example, any suitable metal, including Tungsten, any  
5 suitable glass, or the like. Examples of materials of a solution the probe 101 can be dipped into include, but are not limited to, elastomer solutions, or the like. For Elastomer materials, any suitable rubber can also be used. Examples of elastomer solutions include, but are not limited to, polydimethylsiloxane (PDMS), platinum catalyzed silicones, or the like. PDMS is a non-Newtonian fluid as its viscosity can  
10 be dependent on shear rate. Thus, the PDMS sphere can be pressed against the sample slowly, in which case it can spread out and achieve a large contact area with it. Then, the probe can be rapidly lifted up while retaining this large contact area, enabling it to pick up an object effectively. In this case, the adhesion can be high. After some time, for example about milliseconds to about seconds, the PDMS can relax back into the  
15 spherical shape, in which it has low contact area with the object. Then, it can be possible to position and drop off the object on another substrate. The probe 101 can then removed from the solution. (203).

Since some solution can stick to the probe 101, a process can be used to move, dry, or remove the solution sticking to the probe 101. (205). Examples  
20 include, but are not limited to, blow drying with air or heated air, using centripetal force (for example by a centrifuge), or enabling the surface chemistry of the probe to change in order to repel the solution from the probe. These methods can push the solution to the tip 103 of the probe 101. This can be required because some solutions, such as a PDMS solution, can have a tendency to stick to more than just the tip of the  
25 probe due to surface tension. Additionally, heat can be provided to the probe 101. (207).

In another example, the PDMS ball size can be controlled by (1) adjusting the depth of the tip dipping into PDMS mixture, (2) adjusting the angle of dipping, or (3) spinning the probe in a centrifuge, or the like. Examples of a probe  
30 101 that can be used include a tungsten probe. The tungsten tip 103 of the probe can be dipped into an elastomer solution, such as PDMS. Since an elastomer such as PDMS has a tendency to stick to more than just the tip of the probe, probe can then be blow-dried using a hot gun.

FIG. 2B is a flow chart that illustrates an exemplary method of preparing a solution in accordance with the disclosed subject matter. With reference to FIG. 2B, the first ingredient of a predetermined amount (211) can be combined with a second ingredient of a predetermined amount. (213, 215). It should be understood by those skilled in the art that one or more additional ingredients can be used as well. For making an elastomer solution, such as a PDMS, for example, the first ingredient can be a base and the second ingredient can be a curing agent. In an example, a separate curing agent is optional for making PDMS. For example, ultraviolet light can be used for curing some adhesives. For example, curing agent can comprise dimethyl or methylhydrogen siloxane. The curing agent may be available commercially, for example, under the name of Sylgard 184 silicone elastomer curing agent by Dow Corning. The degree of stickiness that the solution can depend on the ratio of the first ingredient to the second ingredient. For example, by having a ratio of base to curing agent as 5:1, the PDMS solution can result in a harder or a thicker solution. For example, a mixture 3g of Curing Agent and 30g of Base can result in a thick PDMS solution. In another example, by having a ratio of base to curing agent as 10:1, the PDMS solution can result in a softer or thinner solution. For example, a mixture of 1.5g Curing Agent and 15g of Base can result in a thin PDMS solution. The ratio of the base to the curing agent can be substantially in the range of 5:1 to 20:1. The default ratio of base to the curing agent that can be used is 10:1. The resulting mixture or solution from 215 can be cured by, for example heating the solution to a temperature for a period of time. (217). The temperature to heat the solution and the period of time can be predetermined. Example of heat sources for curing include, but are not limited to, a hot plate, an oven, or other suitable heat source. For example, the PDMS solution can be cured by heating it to a temperature of, for example, 100 degree Celsius for an extended length of time, such as two hours. After curing the solution, the solution can be cleaned. (219). For example, cleaning the PDMS can involve immersing the PDMS into solvents. Examples of solvents include, but are not limited to, acetone, water, or a combination of acetone and water, or the like.

In another example, the procedure to make a PDMS can be: 1) Label a Petri Dish. 2) Weigh a plastic cup and zero the weighing scale. 3) Pipe Curing Agent into the plastic cup using Pipette 1. Weigh and zero the weighing scale. 4) Pour, then spoon, then drip, base into the cup using Pipette 2. Weigh and zero the weighing



scale. 5) Stir the Curing Agent and the Base, for example, vigorously, for a period of time, for example 5 minutes, using Pipette 3. 6) Pour the curing Agent and Base mixture into the Petri Dish. 7) Set the Petri Dish into a vacuum chamber, not a desiccator. Wait for a period of time, for example, overnight. 8) Set the Petri Dish  
5 into an oven at a temperature, for example, 100 degree Celsius, for a period of time, for example 45 minutes.

An exemplary tungsten-PDMS apparatus can be prepared as follows. PDMS (or, in certain embodiments, other suitable lassoers, such as platinum catalyzed silicone, or the like) can be mixed with a curing agent at a certain pre-determined  
10 ratio. A tungsten probe with a tip diameter of, for example, 300 nm can be dipped into the PDMS. After the tungsten probe is lifted up, some PDMS can stay adhered to the tungsten tip. A heat gun can then be used to blow dry the probe for a predetermined amount of time, for example, 1 minute. The PDMS can form a hemispherical shape and cover the tip of the tungsten probe.

15 FIG. 3A illustrates exemplary method to attach, transfer, or deposit objects 107 using a device, such as a probe. As FIG. 3A illustrates a device, such as the probe illustrated above, can be used to attach, transfer, or deposit an object 107 onto a target 109. In one example, this exemplary method of attaching, transferring, or depositing objects can be used by controlling the adhesion force between the object  
20 107 and the probe 101 or the object 107 and the solution 105 sticking to the probe 101. In an example, the adhesion force can be controlled by controlling the time it takes to retrieve the probe 101 from the surface or the speed of retrieving the probe 101. In an example, faster retrieving, for example, can give rise to a stronger force between the solution or probe and the object, as further described below.

25 FIG. 3B illustrates an exemplary tungsten-PDMS probe that can be used to retrieve an object. As illustrated by FIG. 3B, if a tungsten-PDMS probe 101 is being used to retrieve a membrane 107, faster retrieving of the tungsten-PDMS probe can give a stronger force between the PDMS 105 and the membrane 107. In another example, this exemplary method of attaching, transferring, or depositing  
30 objects can be used by controlling the composition of the solution 105. For example, the adhesion force can be controlled by controlling the ratio of the PDMS and the curing agent used in the PDMS solution. Use of less curing agent can yield a stronger force between the PDMS and the membrane 107, as discussed above. For example, the normal fraction of curing agent is about 10% by weight.

As depicted in FIG. 3A and FIG. 3B, the exemplary method to attach, transfer, or deposit an object can include using different adhesion forces on the two surfaces. For example, picking up or dropping off a micro-device can be achieved by different adhesive forces on its two surfaces. Therefore, the adhesive force between PDMS and the micro-device can be controlled in order to attach, transfer, or deposit an object 107. This force can be dependent on the speed of retrieving the solution, such as PDMS, and how the solution, such as PDMS, is prepared (for example, the ratio between the base of the PDMS and the curing agent as well as the heating time).

FIG. 4 is a flow chart that illustrates an exemplary method on how to retrieve, transfer, or deposit an object using a probe 101. After the probe 101 is prepared by dipping it into a solution 105, the probe 101 can be used to retrieve an object 107. With reference to FIG. 4, the probe 101 can be used to press against an object 107 in order to attach the object 107 to the probe 101. (401). This process can deform the solution 105, such as the PDMS sphere and create a large surface of contact or high surface force. The object 107 can then be picked up at a predetermined speed or within a predetermined time from the surface. (403).

For example, in order to retrieve or pick up the object 107, the probe 101 can be picked up rapidly, which maintains the large surface area during the pick-up. For example, rapidly picking up the probe 101 to pick up the object 107 can include picking up the probe 101 to pick up the object 107 from the surface within a time of a range of less than 10ms. More specifically, the probe 101 can be picked up from the surface within a time of range of 1ms to 10ms. Thereafter (for example, a fraction of a second later), however, the sphere of solution 105 can relax to a shape such as an oblong shape, with a smaller contact area. The object 107 can then be transferred using the probe 101. (405). This can be done by moving the probe to a desired location with the object 107 still in contact with the probe 101.

FIG. 4 further illustrates an exemplary method to deposit an object using a probe 101. Thus, when the object 107 is then pressed against a target 109 (407) to detach the object 107 from the probe 101, the probe 101 can be removed at a predetermined speed or within a predetermined period of time from the surface, such as slowly (409), which can cause a smaller contact area than the original large surface area during the pick-up and hence cause a small force. For example, the smaller contact area can be about 10% to about 1% of the cross section of the sphere. For example, the probe 101 can be picked from the surface within a time that will allow

the solution 105 to return to substantially its original shape. It should be understood that returning to substantially its original shape implies returning approximately to its original shape. In some embodiments, returning to substantially its original shape can include returning perfectly to its original shape. In an example, the contact area can be  
5 decreased by more than about one hundred times compared to the contact area in the distorted shape immediately after pick-up. This predetermined amount of time, can be for example, in the range greater than 1 millisecond. The object 107 then can be thus detached from the probe 101 and can reliably stay on the target 109.

The exemplary systems and methods disclosed herein can be used for  
10 example, to transfer individual devices, and to assemble hybrid photonic and electronic integrated systems, or the like. Additionally, individual desired devices can be selected for transfer. These systems and methods disclosed herein can be used to transfer any object 107. Additionally, the object 107 can have arbitrary-shaped surface such as a curved surfaces. For arbitrary-shaped surface such as a curved  
15 surfaces, a flexible membrane or object 107 can conform to the new surface and the probe 101 can be used to transfer the object 107. After the object 107 is either retrieved, transferred, or deposited, a residue of the solution 105 can be left on the object 107. This residue can be avoidable by, for example, cleaning the solution 105 of solution 105 thoroughly before use. (411). Exemplary cleaning procedures can  
20 include the following process: first baking the probe 101 or the tips 103 of the probe with solution, for example, micro-PDMS balls on hotplate for a predetermined amount of time, for example, overnight, and then sonicating them in solution such as, acetone and ethanol for predetermined amount of time, for example several times.

## 25           **Examples**

For purpose of illustration and not limitation, exemplary embodiments of the disclosed subject matter will now be described. While the disclosed techniques can be versatile, description will now be made for purposes of illustration in  
30 connection with the transfer of (1) superconducting-nanowire single-photon detectors (made of niobium nitride) on SiN membranes (with reference to FIG. 6A, FIG. 6B, and FIG. 6C); (2) nano-diamond crystals (made of carbon) (with reference to FIG. 7A and FIG. 7B); (3) photonic crystal membranes (made of GaAs) (with reference to FIG. 8A, FIG. 8B, FIG. 8C, FIG. 8D, and FIG. 8E). Moreover, the techniques

disclosed herein can enable the flipping of the membrane devices 107, the placing of the devices on another target 109 or a fiber facet, and the accurate positioning of the membrane devices relative to an existing pattern, while obtaining electrical contact between the transferred device 107 and the contact pads on the target 109.

5                   FIG. 6A, FIG. 6B, and FIG. 6C are exemplary and non-limiting illustrations of an embodiment according to the disclosed subject matter in connection with the transfer of superconducting-nanowire single-photon detectors. FIG. 6A, FIG. 6B, and FIG. 6C illustrate transfer of superconducting-nanowire single-photon detectors. FIG. 6A illustrates an exemplary embodiment of a superconducting-  
10   nanowire single photon detector in SiN membrane with undercut and supporting bridges. FIG. 6B illustrates an exemplary embodiment of the receiving target substrate 109 with contact pads. FIG. 6C illustrates the resulting device after transfer. In this example, the pads of the membrane and on the substrates 109 can intimately contact with no additional electrical resistance.

15                   FIG. 6A illustrates an exemplary embodiment of using SNSPDs on SiN membrane with undercut and four bridges as mechanical support. FIG. 6B illustrates that the SNSPDs on SiN membrane can be picked up, flipped, and placed face-down, such that close contact with the pads on a second substrate is achieved so as to enable electrical contact. In this exemplary embodiment, two tungsten-PDMS  
20   probes 601 with different PDMS - curing agent ratios can be used. For example, the ratio of 5:1 can be suitable for picking up the device and the ratio of 10:1 can be suitable for accepting the membranes to achieve flipping and then placing it down. To pick up the membrane 607, an XYZ stage can be used to move the first probe 601 and let it approach the membrane 607 vertically from the top (move in Z-direction).  
25   After the PDMS hemisphere initially contacts the membrane 607, the Z-knob of the stage can be used to push the PDMS down further until it begins to move laterally across the surface, indicating that it is in contact. The membrane 607 can then be picked up by retrieving the probe 601 from the surface (move the probe in Z-direction). The device 607 can be attached to the first tungsten-PDMS probe 601.

30                   To flip the chip, the membrane 607 on the first tungsten-PDMS probe 601 can be “roll printed” to the second probe 601. For example, the first tungsten-PDMS probe 601 can approach the second probe 601 vertically from the top. After the probes 601 approach each other, the first tungsten-PDMS probe 601 can be moved

horizontally back and forth in X-direction or Y-direction, where the X-direction is perpendicular to Y-direction and Y-direction is perpendicular to the X-direction and the Z-direction. The first probe 601 can then be retrieved. The membrane 607 can be adhered to the second probe 601. The second tungsten-PDMS probe 601 can be  
5 rotated 180 degrees so that the device is facing down. The tungsten-PDMS probe 601 can then be moved down and approach the receiving target substrates 609. The membrane 607 can be "roll printed" onto the receiving target substrate 609 so that the contact pads on the membrane 607 and on the target substrate 609 intimately contact each other. The resulting device structure is shown in FIG. 6C. No additional  
10 electrical resistance needs to be added during this process.

FIG. 7A and FIG. 7B illustrate an exemplary and non-limiting illustration of the transfer photonic crystal membrane, in accordance with some embodiments of the disclosed subject matter. FIG. 7A illustrates an exemplary method that aligns the photonic crystal with the silicon waveguide using a tungsten tip  
15 without PDMS covering. FIG. 7B illustrates an exemplary method of scanning-electron-beam image of the resulting structure. In an exemplary embodiment, the microcavity is right at the central line of the waveguide.

As further illustrated in FIG. 7A and FIG. 7B, a photonic crystal membrane fabricated in a similar structure as the SNSPD can be transferred. The photonic crystal can have a microcavity at its center. The photonic crystal can be  
20 picked up, placed on a silicon waveguide, and the microcavity can be accurately aligned with the silicon waveguide. The setup and operating procedure can similar to the techniques described above. Because in this embodiment the membrane does not need to be flipped, only one tungsten-PDMS probe 701 (for example, a ratio of PDMS  
25 to curing agent is 5:1) can be needed. After "roll printing" the photonic crystal membrane on the silicon waveguide, another tungsten probe 701 not covered by PDMS can be used to finely adjust the location and orientation of the membrane 707 by, for example, pushing the edges and corners of the membrane 707 using the probe's tip 703, as shown in FIG. 7A. The resulting structure is shown in FIG. 7B.

30 FIG. 8A, FIG. 8B, FIG. 8C, FIG. 8D, FIG. 8E, and FIG. 8F illustrate an exemplary and non-limiting illustration of transfer nano-diamond crystals, in accordance with some embodiments of the disclosed subject matter. FIG. 8A illustrates an exemplary 2D imaging of the nano-diamond crystals. FIG. 8B illustrates exemplary nano-diamond crystals that were picked up by the tungsten-PDMS probe.

FIG. 8C illustrates an exemplary 2D imaging of the second substrate (glass slides) before placing the nano-diamond crystals. FIG. 8D illustrates an exemplary 2D imaging of the second substrate (glass slides) before placing the nano-diamond crystals. FIG. 8E illustrates an exemplary correlation measurement at location 1.

5 FIG. 8F illustrates an exemplary correlation measurement at location 2.

As depicted in FIG. 8A, FIG. 8B, FIG. 8C, FIG. 8D, FIG. 8E, and FIG. 8F, nano-diamond crystals can be transferred from one substrate to another. In an example, the nano-diamond crystals can have, for example, diameters of ~100 nm, and can be spread on a material, for example, a glass slide, or the like. A confocal  
10 microscope can be used to find the bright nano-diamond crystals (for example, with a single nitrogen-vacancy (NV) center in each) to be transferred. With reference to FIG. 8A, this pre-selection process can include two-dimensional (2D) imaging using, for example, a silicon SPAD and correlation,  $g(2)$ , measurement on individual crystals using two SPADs, or the like. The transferring process can similar to the techniques  
15 described elsewhere herein. With reference to FIG. 8B, a second 2D imaging can confirm that the crystals have been picked up. With reference to FIG. 8C, before placing down the crystals on a new substrate, a third 2D image can be acquired on the receiving location to confirm that there were no nano-diamond crystals. With reference to FIG. 8D, The crystals can be placed on the receiving substrate and a  
20 fourth 2D image can be performed to confirm the successful transfer. With reference to FIG. 8E and FIG. 8F, the  $g(2)$  can be measured for a second time to confirm that these bright spots are nano-diamond crystals.

The exemplary systems and methods disclosed herein can provide benefits, such as, low-cost, easy to operate, good alignment accuracy, and single-  
25 device manipulation, or the like. The exemplary systems and methods disclosed herein can be automated with automated piezo, or motorized stages, or the like. The exemplary systems and methods disclosed herein can also allow for integration of different devices made of different materials on one chip to achieve hybrid integration. For example, the exemplary systems and methods disclosed herein can be  
30 used to place on-chip amplifier onto a target substrate 109. The on-chip amplifier can be a photonic crystal device that has optical gain and can be used to amplify and optical signal. In another example, the techniques disclosed herein can be used to place on-chip light source onto a target substrate 109. The on-chip amplifier can be a photonic crystal laser device that acts as an on-chip light source. Additionally, other

example s where these exemplary systems and methods can also be used include, but are not limited to, transferring masks for reactive ion etching, moving a photodetector, moving a light source such as a photonic crystal laser, or the like. Transfer of silicon mask onto targets 109, such as artificial eyes, pollen, lab glove, lab swipe, and bottle cap, or the like, and use of a lift-off procedure for patterning on the targets 109, can also be achieved using this illustrated exemplary systems and methods.

As described above in connection with certain embodiments, a computer processor can be provided to perform the exemplary methods described herein and can be used to generate integration of devices and accuracy of alignment. In these embodiments, the computer processor can play a significant role in permitting the exemplary methods described herein to provide transfer of objects 107, such as devices or the like, onto targets 109, such as silicon substrates or the like. For example, a processor can be used to control the probe 101 to perform attach, transfer, or deposit objects 107 onto a target 109, as further illustrated in FIG. 4. Additionally, a processor can be used to perform the exemplary method of “roll printing” an object 107 onto a target 109, as further illustrated in FIG. 5, as well as to prepare the exemplary system with reference to FIG. 2A and FIG. 2B.

Example applications of the illustrated exemplary systems and methods were analyzed. These exemplary systems and methods can be referred to as an exemplary contact mask lithographic systems and methods. As described herein, these applications can result in a sub-10-nanometer resolution and sub-1 $\mu$ m alignment accuracy. These example applications used micro-PDMS ball 105 attached on a tungsten tip 103 or bulk PDMS to transfer an object 107 such as a silicon membrane onto desired target 109, such as diamond, gallium phosphide and silicon carbide, followed by anisotropic dry etching to transfer the pattern into the target. The target 109 can be of an arbitrary shape, and these example applications described herein illustrate that transfer can be made onto the fiber ferrule and TEM grid. These example applications also show that inverse pattern transfer can be achieved using the exemplary systems and methods with the addition of metal deposition and mask removal steps between mask transfer and dry etching.

There is now described an example application using the illustrated exemplary systems and methods to fabricate hard mask membranes using EBL on silicon, and transferring the silicon hard mask onto desired target substrate 109 resulting in sub-1 $\mu$ m alignment accuracy. This exemplary application can provide a

solution for fabricating nano- and micron-scale devices on materials such as conventional materials, such as III/V compound semiconductors, or emerging unconventional substrates, or the like. These conventional materials can not be easy to deal with using methods such as traditional lithography methods, for example diamond, LiNbO<sub>3</sub>, or SiC, or the like. In an example application, diamond and transferrable silicon membrane as etch mask are used to etch diamond with oxygen plasma. In the example application, Inverse pattern transfer is also demonstrated with the addition of metal deposition and mask removal steps, between mask transfer and dry etching. The inverses metal pattern can also be a very good etch mask.

10                   Using the illustrated exemplary systems and methods, silicon mask can be transferrable onto unconventional substrates, such as fiber facet for fiber integration and PDMS for stretchable photonic devices. By using atomic layer deposition (ALD) of alumina to conformally shrink the pattern size, the resolution limit of 100 kV electron beam lithography tool can be bypassed, and sub-10 nm  
15                   resolution can be achieved, as observed in the example application. The pattern transfer into metal layer as narrow as 12 nm can be achieved. The silicon mask membrane can be so robust that it can be re-used, for example, 12 times for oxygen plasma etching into diamond. For other applications, one can deposit materials such as, for example, some Cr or ALD some alumina, or the like, to make silicon mask  
20                   tougher. Additionally, a technique using silicon mask multiple times for ion implantation can be performed. In another example, wafer-scale silicon hard mask can also be transferrable with materials such as bulk PDMS, or a pair of tweezers, or the like. The properties of certain exemplary systems and methods are further explained below.

25                   FIG. 9A, FIG. 9B, FIG. 9C, FIG. 9D, and FIG. 9E illustrate high alignment accuracy that can be achieved using the illustrated exemplary systems and methods. FIG. 9A illustrates an exemplary embodiment including a tungsten tip 903 with a micro-PDMS ball 905 for contact mask accurate transfer. FIG. 9B illustrates an exemplary embodiment where a silicon mask 907 is attached to the micro-PDMS  
30                   ball 905 on tungsten tip 903. FIG. 9C illustrates statistical data of position-misalignment. FIG. 9D illustrates statistical data of angular misalignment. As illustrated, less than 1  $\mu\text{m}$  was achieved in the example application. FIG. 9E illustrates stacked silicon membranes that demonstrate the good positional and angular alignments achieved by the illustrated exemplary systems and methods



described herein. The alignment accuracy observed due to the illustrated exemplary systems and methods described herein can be comparable to that of techniques such as optical lithography. In an example, an optical microscope and a manual stage controller can be used to ensure the accuracy.

5                   FIG. 9A illustrates an exemplary embodiment of a material such as tungsten tips 903 attached with micro PDMS balls 905 that can be used during the illustrated exemplary methods described herein. The key to successful implementation of high alignment accuracy can be in the preparation of materials such as tungsten tips 903 attached with micro PDMS balls 905. In this example  
10 application, tungsten tips 903 with the tip radii of 0.5  $\mu\text{m}$  was purchased from Ted Pella, and a tungsten tip 903 was dipped in uncured PDMS mixture. After pulling out of the tip 903, a droplet of PDMS 905 attached near the sharpest point of the tip 903 was observed. In this example application, a heat gun was used to blow dry the PDMS droplet on the tip 903 and PDMS droplet 905 formed a hemisphere ball after  
15 the blow dry process.

                  In another example, the PDMS ball size can be controlled by adjusting (1) the depth of the tip dipping into PDMS mixture, or (2) the angle of dipping, or the like. In this example application, silicon photonic crystal (PC) masks were produced out of SOI wafers using the standard semiconductor fabrication techniques. As  
20 further illustrated in FIG. 9B, the tungsten tip 903 with a micro-PDMS ball 905 can be able to pick up a silicon PC mask 907 that is loosely attached on the SOI substrate. The tungsten tip 903 with a micro-PDMS ball 905 can also be used to transfer the silicon mask 907 onto a desired target substrate 909. In this example application, when the transferred silicon mask 907 was imaged with scanning electron microscope  
25 (SEM), it was observed that there was visible residue inside the PC holes, which can eventually prevent further pattern transfer using dry etching. The residue left on silicon mask 907 can be avoidable by, for example, cleaning the micro-PDMS ball 905 thoroughly before use.

                  Exemplary cleaning procedures can include baking tungsten tips 903  
30 with micro-PDMS balls 905 on hotplate overnight, and then sonicating them in acetone and ethanol for several times. FIG. 9C illustrates that the position-misalignment of the exemplary silicon mask method with micro-PDMS ball was measured to be less than 1  $\mu\text{m}$  in the example application. FIG. 9D further illustrates that angular misalignment of less than 1  $\mu\text{m}$  was achieved. FIG. 9E further illustrates

the high alignment accuracy of the silicon mask. As further illustrated in FIG. 9E, several silicon membranes 907 were stacked together and were closely put together.

FIG. 10A, FIG. 10B, FIG. 10C, and FIG. 10D illustrate another example application of the exemplary systems and methods of using silicon membranes as robust etch mask after the transfer. FIG. 10A illustrates fabrication schematics of silicon membrane directly used as etch mask. FIG. 10B illustrates the resultant diamond L5 PC cavity of oxygen etching. FIG. 10C illustrates fabrication schematics of inverse pattern transfer with the addition of metal deposition and mask removal steps between silicon mask transfer and dry etching. FIG. 10D illustrates the resultant diamond nano-wire arrays obtained from the exemplary inverse pattern transfer.

In this example application, silicon membranes as a robust etch mask are achieved after using the illustrated the exemplary systems and methods described herein to transfer with high alignment accuracy. Using silicon membranes as etch mask can be straight-forward for II/V materials, such as gallium phosphide, orgallium arsenide, or the like. To illustrate the capability of the illustrated exemplary systems and methods described herein, the pattern transfer over materials with immature thin film technologies in arbitrary shape is demonstrated. In this example application, diamond was used to show that the illustrated exemplary systems and methods can be used as robust etch mask because diamond has a very good thermal, mechanical and optical properties. Nitrogen vacancy centers in diamond can have characteristics for sensing and quantum information technologies. The exemplary systems and methods can also be referred to as exemplary contact mask lithography systems and methods. The exemplary systems and methods described herein can offer benefits including, but are not limited to, diamond patterning that is not constrained by a small sample size, charging, adhesion, and resist uniformity. The mask can be created on silicon. This can allow for obtaining nano-meter resolution that can be required by optical designs which can be hard to achieve in direct diamond writing. The illustrated exemplary systems and methods have demonstrated the ability to transfer objects 107 on both diamond membrane and bulk diamond.

FIG. 10A illustrates the exemplary fabrication procedure to fabricate photonic devices with diamond membrane. In this example fabrication procedure, a diamond membrane 1005 with the thickness of about 200 nm can be thinned down from a thicker single-crystal diamond membrane with chlorine dry etching. For

example, the thicker single-crystal diamond membrane can be a commercially available single-crystal diamond membrane, such as a 5- $\mu\text{m}$  single-crystal diamond membrane available commercially, for example from Element Six. 200-nm diamond thin-membranes can be easy to break. Therefore, in this example application, to save materials, the 200-nm diamond thin-membranes can be broken into tens of pieces and used separately. Then silicon PC masks 1003 were transferred onto a small piece of diamond membrane 1005, for example, a piece, that is 50  $\mu\text{m}$  x 50  $\mu\text{m}$  in area, and oxygen plasma 1007 can be used to drill PC holes into diamond membrane 1005. After etching there can be little erosion on silicon PC masks 1003, and the PC patterns can be well transferred into the diamond membrane 1005 underneath. Another tungsten tip can be used to sweep across silicon masks and mechanically remove them from the diamond membrane 1005. A SF<sub>6</sub> isotropic dry etching was used to remove the silicon underneath and suspend the diamond membrane 1005 at the device locations.

FIG. 10B illustrates an example application where a L5 photonic crystal cavity can be fabricated in diamond membrane using the exemplary fabrication procedure. For example, a lattice of holes can be formed in the polymer film. As used herein, a lattice can be any regular geometrical arrangement of holes. A photonic crystal cavity can be formed by a defect in the lattice. By way of example and not limitation, the photonic crystal cavity can be an L5 cavity. As used herein, an L5 cavity refers to a cavity defined by a defect that is the size of five linearly aligned missing holes in the lattice. This example application with bulk diamond can be similar to the exemplary fabrication procedure of diamond membrane. FIG. 10C further illustrates this example application, where silicon PC masks 1013 can be transferred onto a diamond membrane 1011. In this example application, inverse pattern transfer from holes to pillars 1017 can be achieved by adding metal deposition 1015 and mask removal steps between mask transfer and dry etching. As further illustrated in FIG. 10C, after oxygen dry etching, patterns can be transferred into bulk diamond 1011, which can form a lot of diamond nano-wire single photon sources. FIG. 10D illustrates the resultant diamond nano-wire arrays obtained from the exemplary inverse pattern transfer. This inverse pattern transfer can also be used to fabricate densely arranged vertical diamond membranes for quantum information processing and transmission electron microscopy sample preparation. Therefore, both

positive and negative etch mask can be achievable with the exemplary systems and methods described herein.

FIG. 11A, FIG. 11B, and FIG. 11C illustrate another application of the illustrated exemplary systems and methods to transfer objects on to unconventional targets 109. FIG. 11A illustrates a silicon membrane with PC cavity array transferred on fiber ferrule, FIG. 11B illustrates dot arrays can be inversely transferred on fiber ferrule, and FIG. 11C illustrates a silicon membrane with air holes transferred on TEM grid.

As described elsewhere herein, robust etch mask can be achieved using the illustrated exemplary systems and methods. Additionally, the illustrated exemplary systems and methods can also enable one to assemble membrane optoelectronic devices into various systems and enable the nanostructure fabrication on targets 109 with arbitrary shapes. In one example application, devices can be directly assembled on facets of standard optical fiber to functionalize optical fiber.

With reference to FIG. 11A, these devices can include nano-wire photon detectors and photonic-crystal micro-cavity lasers, or the like. Functionalization on fiber has been attracting a lot of attention in recent years since fiber based devices can be small, lightweight and portable, which can be important in in-situ sensing, imaging, and optical trapping applications, or the like. An important consideration for optical fiber based devices can be the transportation of the guided light from the end face of the fibers to designated target. In this example application using the illustrated exemplary systems and methods, after the transfer, a layer of 70 nm gold can be deposited and silicon mask can be removed. As further illustrated in FIG. 11B, photonic crystal dot arrays can be patterned on a fiber facet, which can enable the functionalization of Surface Enhanced Raman Scattering patterns with fiber. FIG. 11C further illustrates another example application of the transfer of silicon membrane onto TEM grid.

FIG. 12A and FIG. 12B illustrate an example application where sub-10 nm resolution was achieved through the illustrated exemplary systems and methods. FIG. 12A further illustrates the air lines in silicon membrane with reduced width after alumina ALD deposition. FIG. 12B further illustrates the metal lines were observed to be as narrow as 12 nm after patterns were inversely transferred onto other target substrate 109.

In this example application, by using atomic layer deposition (ALD) of alumina to conformally shrink the pattern size, the resolution limit of 100 kV electron beam lithography tool can be bypassed to achieve sub-10 nm resolution. FIG. 12A further illustrates that, in this example application, sub-10 nm line patterns can be used to serve as nitrogen ion implantation mask in our lab. FIG. 12A further illustrates the air lines in silicon membrane with reduced width after alumina ALD deposition. In this example application, it was observed that the air line width was 40 nm before ALD. In this example application, after a metal deposition step, patterns were inversely transferred onto other target substrate 109. As further illustrated in FIG. 12B, the lines as narrow as 12 nm can be achieved using the illustrated exemplary systems and methods.

The illustrated exemplary systems and methods described herein can also be re-used for chip-scale industrial applications. In diamond etching, for example, the etch rate can be 1.8  $\mu\text{m}/\text{h}$  for oxygen etching of diamond. 220-nm silicon mask can be able to withstand 1 hours' etching before eroding too much. Diamond membrane can be 150 nm in thickness, which means that the silicon mask can be re-used up to, for example, twelve times. One can deposit materials, such as Cr, or ALD some alumina, or the like to make silicon mask tougher. Using silicon mask has been demonstrated multiple times for ion implantation in our lab. Chip-scale production can be implemented with improved transfer efficiency of bulk PDMS, or even a pair of tweezers, or the like.

Silicon contact masks, with nanometer-scale alignment accuracy, can be re-used as robust etch mask on unconventional substrate with sub-10 nm resolution. The illustrated exemplary systems and methods described herein can avoid direct electron beam writing, which can be a solution, for example, for samples that are electron sensitive or can be easily damaged by electron irradiation.

The foregoing merely illustrates the principles of the disclosed subject matter. Various modifications and alterations to the described embodiments will be apparent to those skilled in the art in view of the teachings herein. It will thus be appreciated that those skilled in the art will be able to devise numerous techniques which, although not explicitly described herein, embody the principles of the disclosed subject matter and are thus within its spirit and scope.

CLAIMS

WE CLAIM:

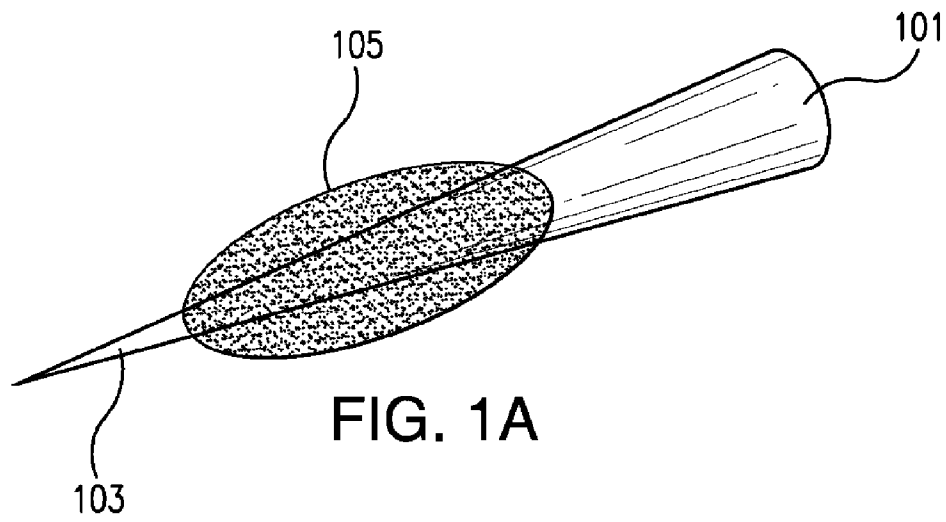
1. A method for positioning at least one device on a target using a probe having a tip, the tip being at least partially covered by an elastomer coating having a first  
5 shape, comprising:
  - contacting the elastomer coating to the at least one device to partially deform the elastomer coating and attach the at least one device to the elastomer coating by surface forces;
  - lifting the probe while the elastomer coating is still deformed and  
10 attached to the device; and
  - positioning the at least one device on the target.
2. The method of claim 1, the lifting comprising lifting the probe within a predetermined amount of time while the elastomer coating is still deformed and attached to the device.
- 15 3. The method of claim 1, further comprising lifting the probe while the at least one device rests on the target to return the elastomer coating to the first shape and detach the at least one device from the elastomer coating.
4. The method of claim 3, the lifting the probe while the at least one device rests on the target comprising lifting the probe within a predetermined amount of time  
20 while the at least one device rests on the target to return the elastomer coating to the first shape and detach the at least one device from the elastomer coating.
5. The method of claim 1, further comprising moving the probe tangentially to the at least one device while the at least one device rests on the target to return the elastomer coating to the first shape and detach the at least one device from the  
25 elastomer coating.
6. The method of claim 5, the moving comprising moving the probe within a predetermined amount of time tangentially to the at least one device while the at least one device rests on the target to return the elastomer coating to the first shape and detach the at least one device from the elastomer coating.

7. The method of claim 1, further comprising at least one of rotating the at least one device or flipping the at least one device.
8. The method of claim 1, wherein the target comprises a further probe comprising a further tip, the further tip at least partially covered by a further elastomer coating having a second shape, the method further comprising:
- 5 moving the probe tangentially to the at least one device while the at least one device rests on the further probe to return the elastomer coating to the first shape and detach the at least one device from the elastomer coating; and
- 10 positioning the at least one device on a further target.
9. The method of claim 8, the moving comprising moving the probe within a predetermined amount of time tangentially to the at least one device while the at least one device rests on the further probe to return the elastomer coating to the first shape and detach the at least one device from the elastomer coating.
- 15 10. The method of claim 1, further comprising pushing the at least one device.
11. The method of claim 10, the pushing comprising pushing the at least one device with a further probe.
12. The method of claim 1, the target comprising one of a substrate, a waveguide, a fiber facet, or electrical contact pads on a substrate.
- 20 13. An apparatus for positioning a device, comprising:
- a probe having a tip; and
- an elastomer coating at least partially covering the tip and having a first shape, the elastomer coating adapted to deform when pressure is applied thereto and to return to the first shape when the pressure is
- 25 removed.
14. The apparatus of claim 13, wherein the probe comprises tungsten.
15. The apparatus of claim 13, wherein the tip comprises a tip having a diameter substantially in a range of 300 nm to ten micron.

16. The apparatus of claim 13, the elastomer coating comprising one of a polydimethylsiloxanepolydime (PDMS) coating or an platinum catalyzed silicone coating.
17. The apparatus of claim 13, further comprising a manual stage, the probe  
5 mounted on the manual stage.
18. A method of making a positioning a device, comprising:  
providing a probe having a tip; and  
at least partially covering the tip with an elastomer coating, the  
elastomer coating adapted to deform when pressure is applied thereto  
10 and to substantially return to the first shape when the pressure is removed.
19. The method of claim 18, the at least partially covering comprising:  
submerging the tip in a mixture comprising a base and a curing agent;  
and  
15 removing the tip from the mixture while a portion of the elastomer adheres to the tip thereby forming the elastomer coating.
20. The method of claim 19, wherein the curing agent comprises at least one of Dimethyl and methylhydrogen siloxane.
21. The method of claim 19, wherein a ratio of the base to the curing agent is  
20 substantially in the range of 5:1 to 20:1.
22. The method of claim 19, further comprising heating the elastomer coating.
23. The method of claim 22, the heating comprising heating the curing agent with a heat gun.



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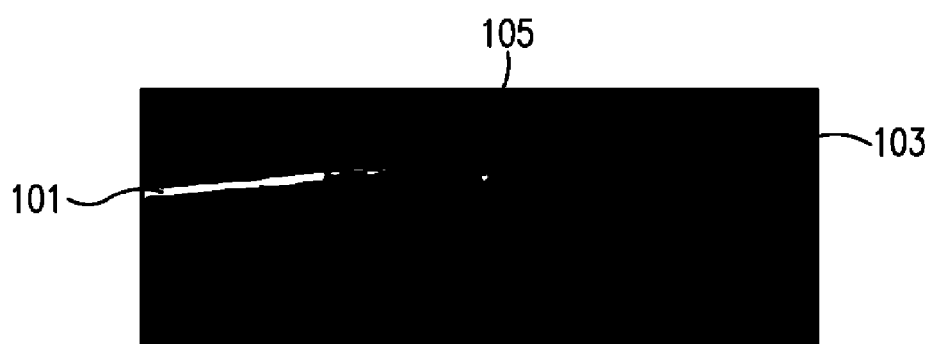


FIG. 1B

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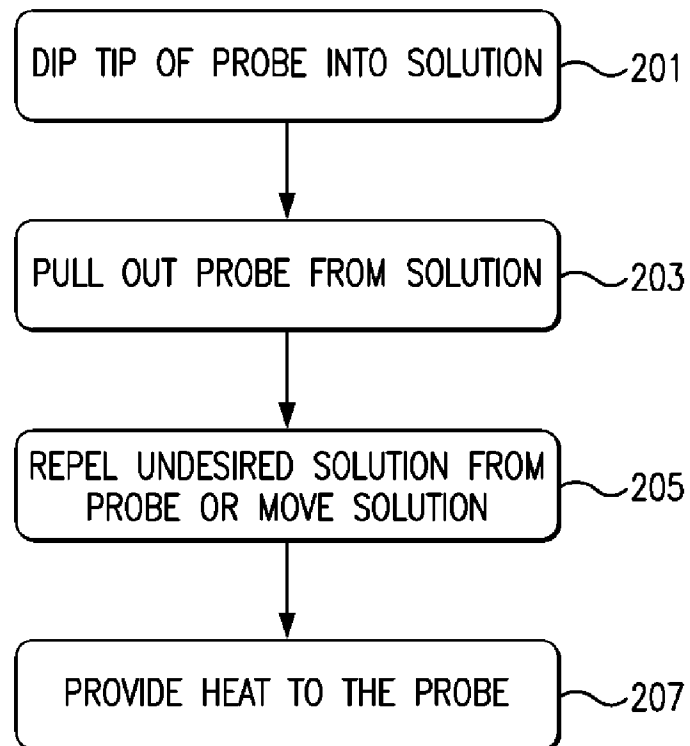


FIG. 2A

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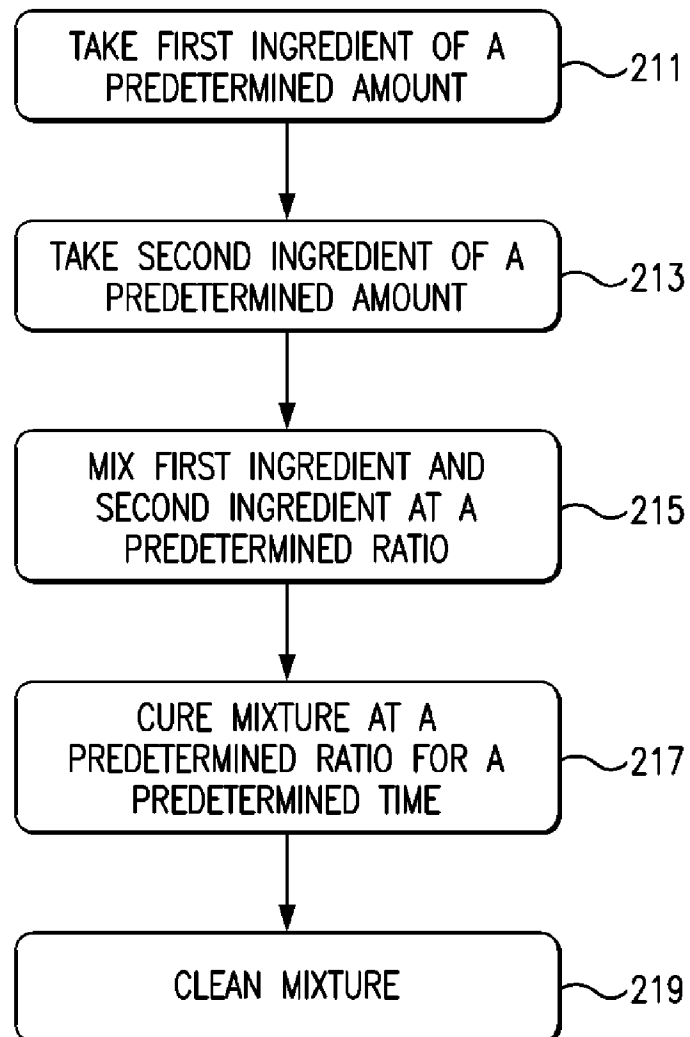
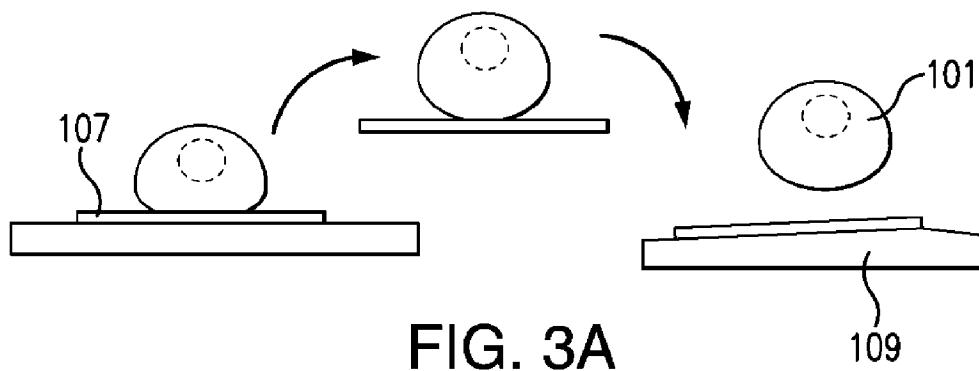


FIG. 2B

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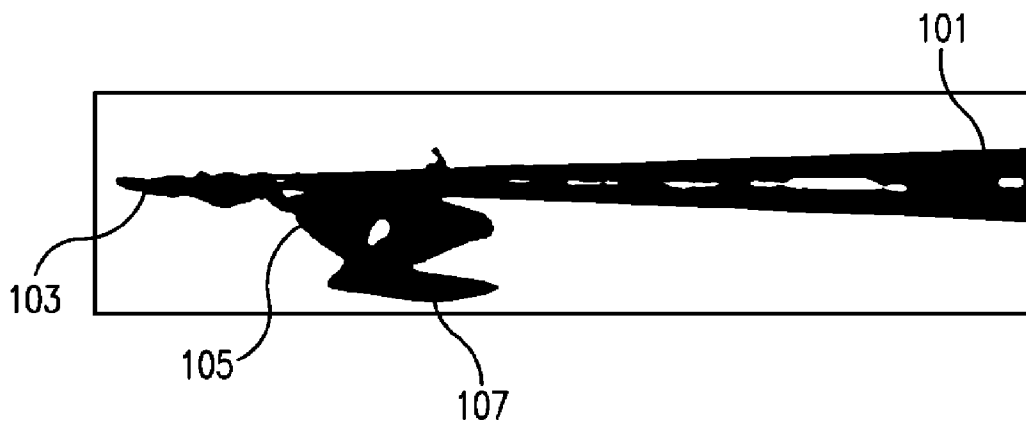


FIG. 3B

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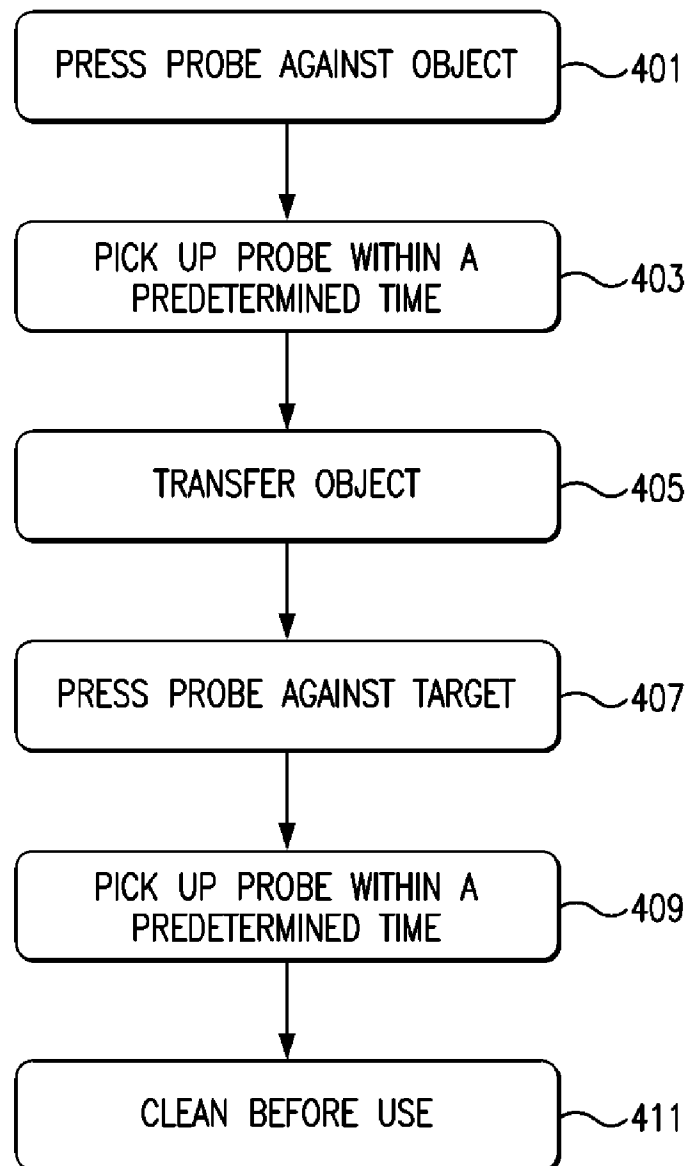


FIG. 4

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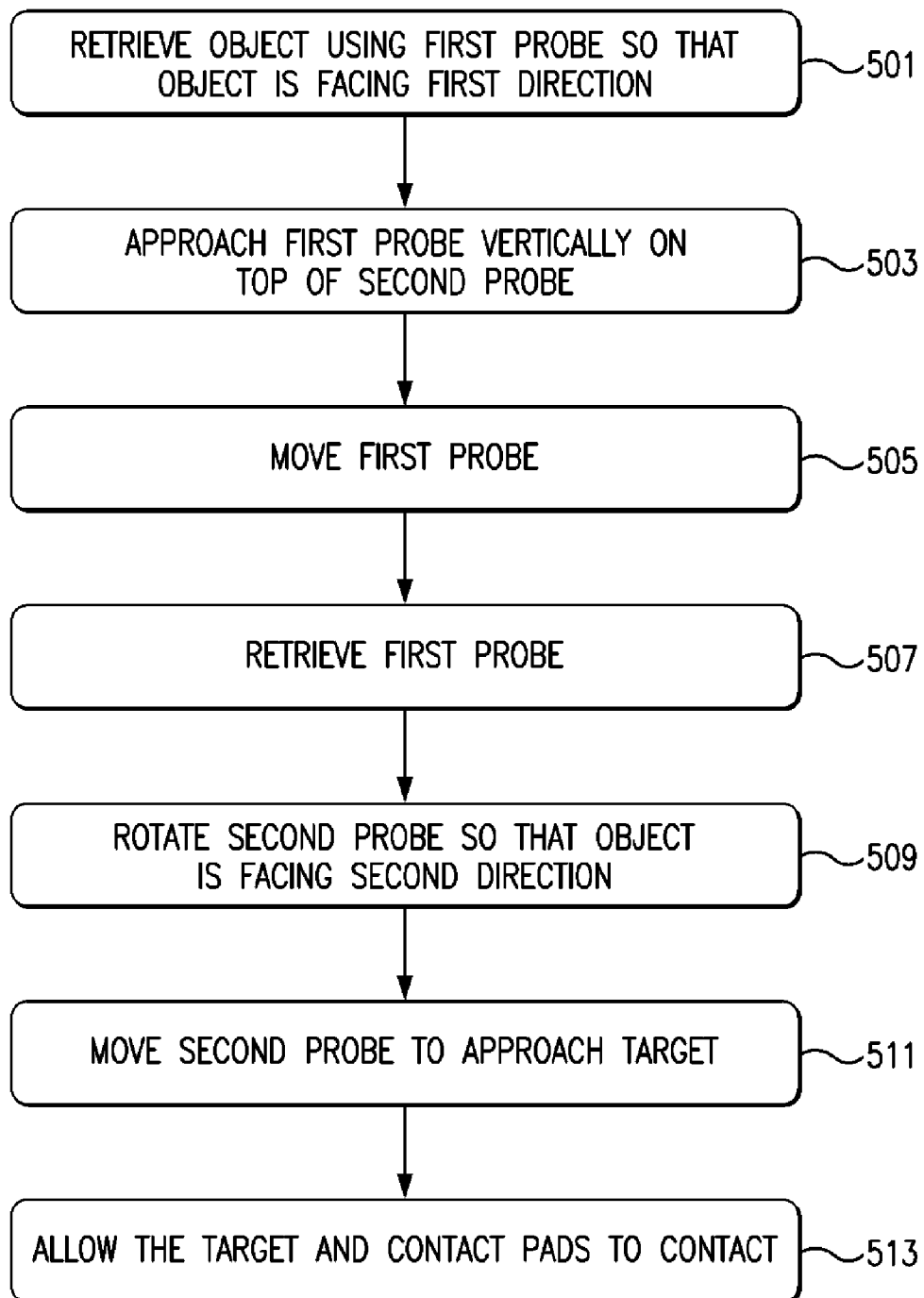


FIG. 5



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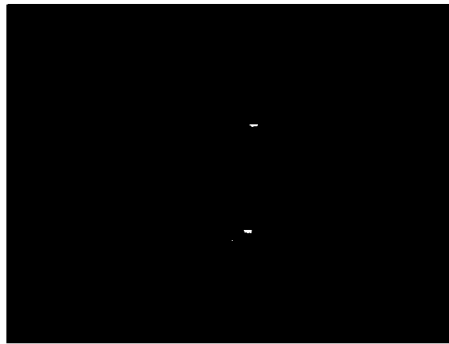


FIG. 6A

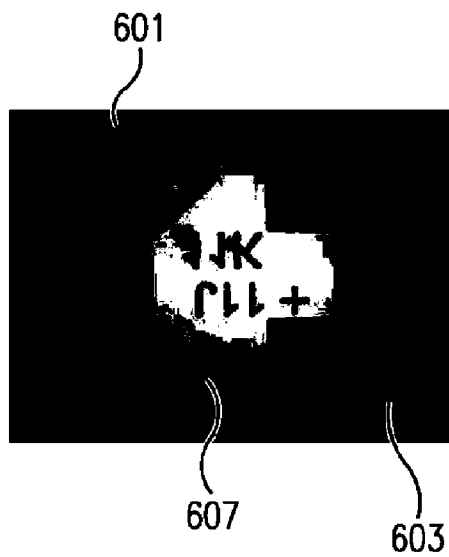


FIG. 6B



FIG. 6C

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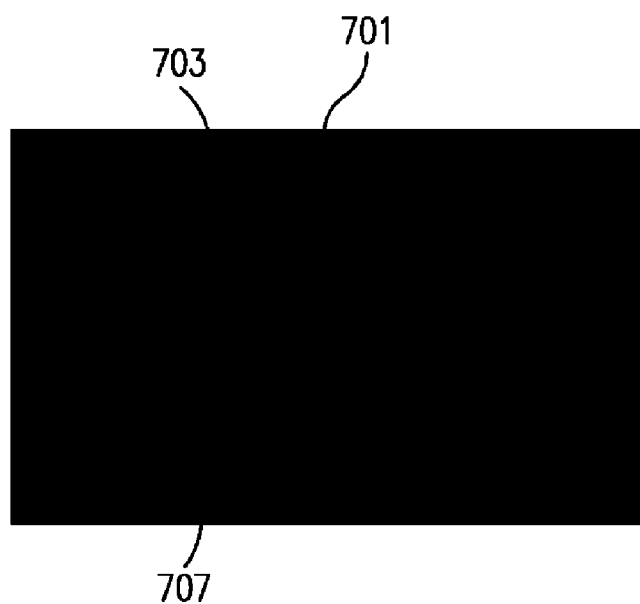


FIG. 7A

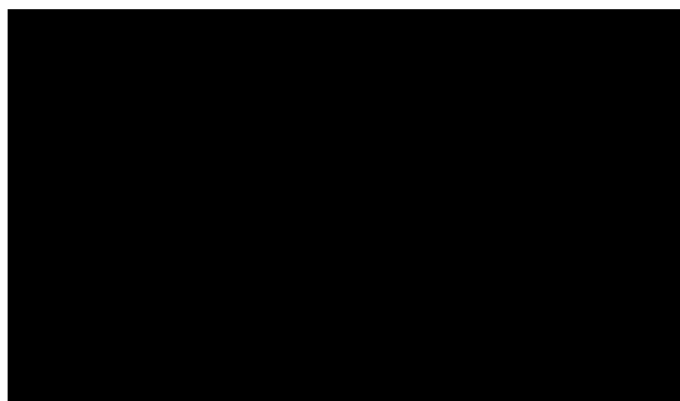


FIG. 7B

11/25

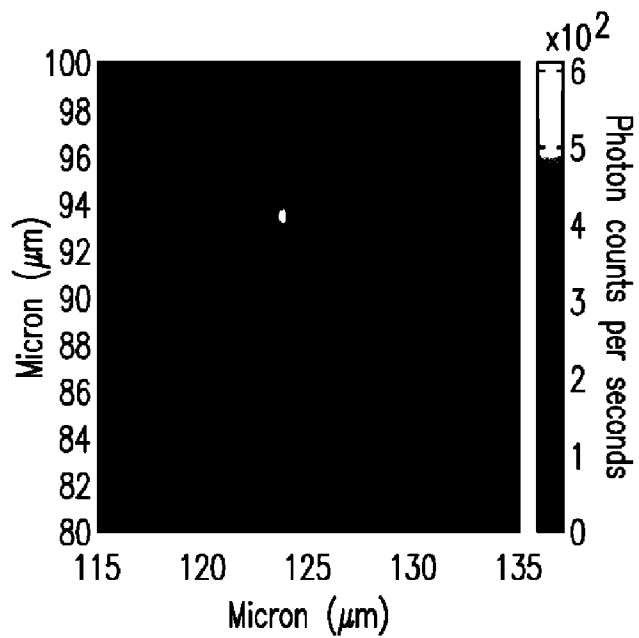


FIG. 8A

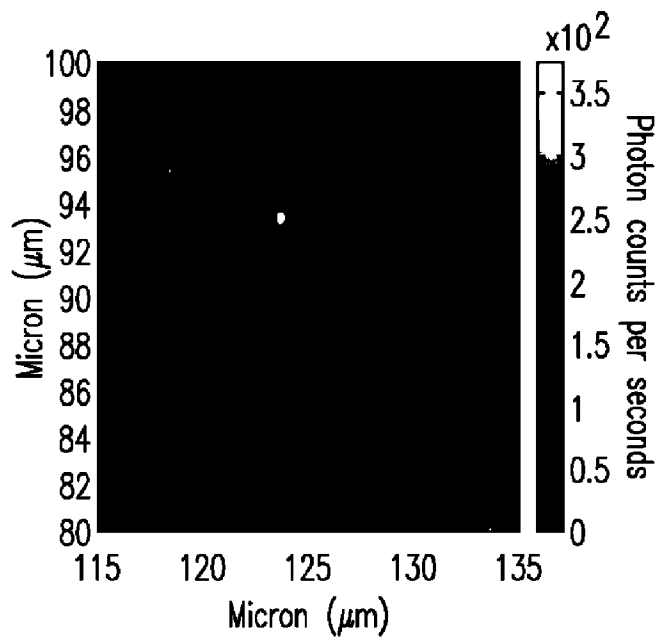


FIG. 8B

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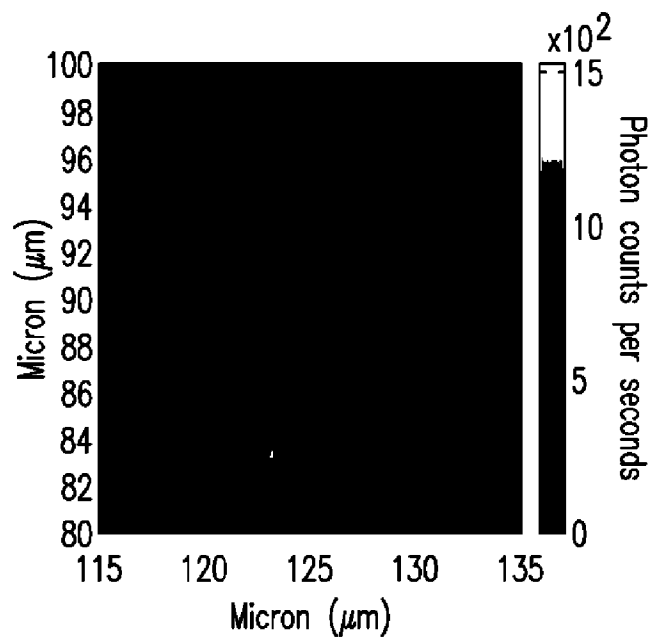


FIG. 8C

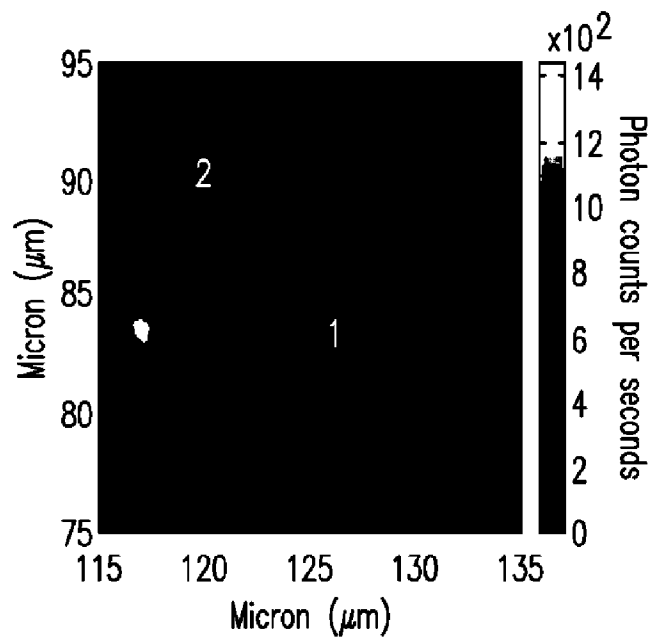


FIG. 8D

13/25

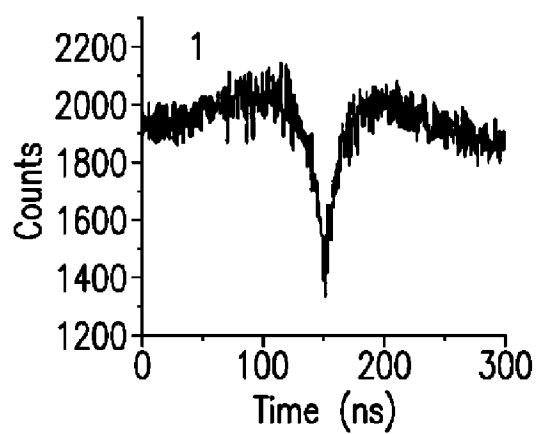


FIG. 8E

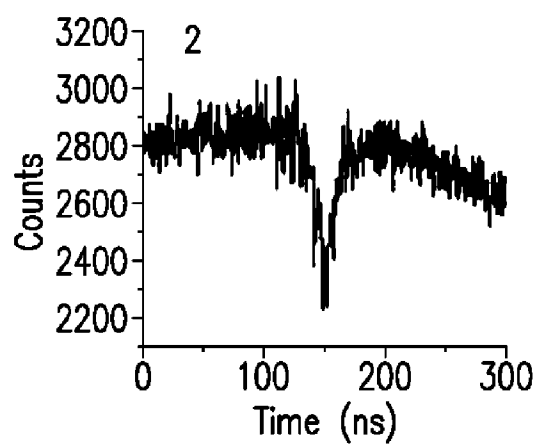


FIG. 8F

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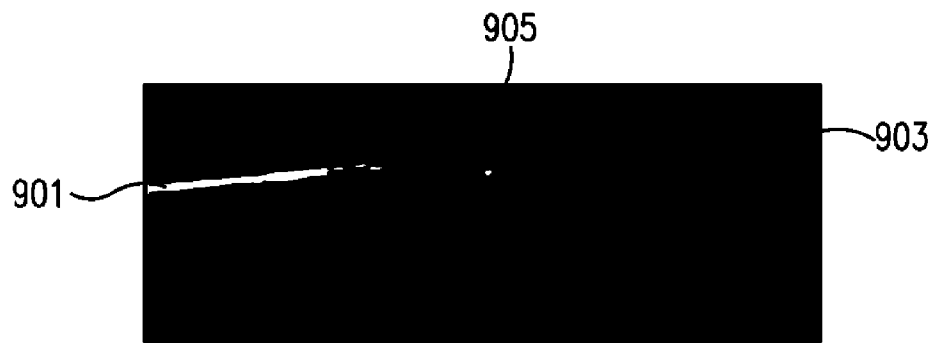


FIG. 9A

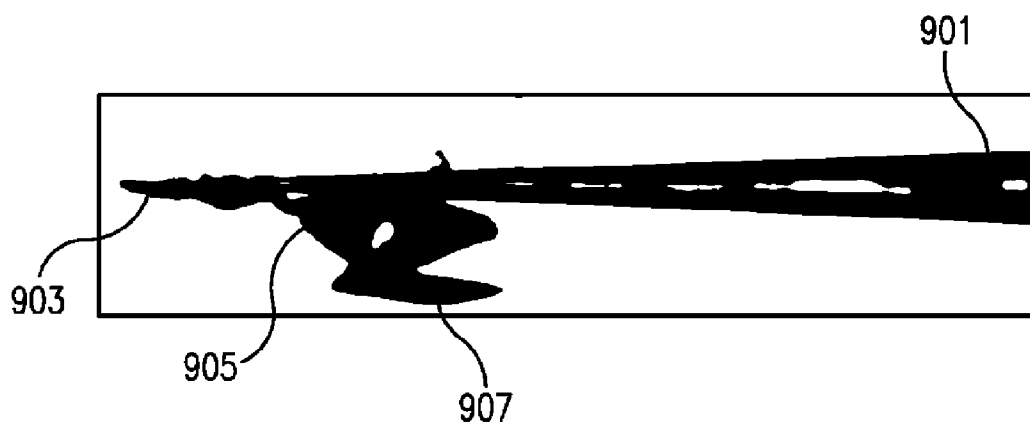


FIG. 9B

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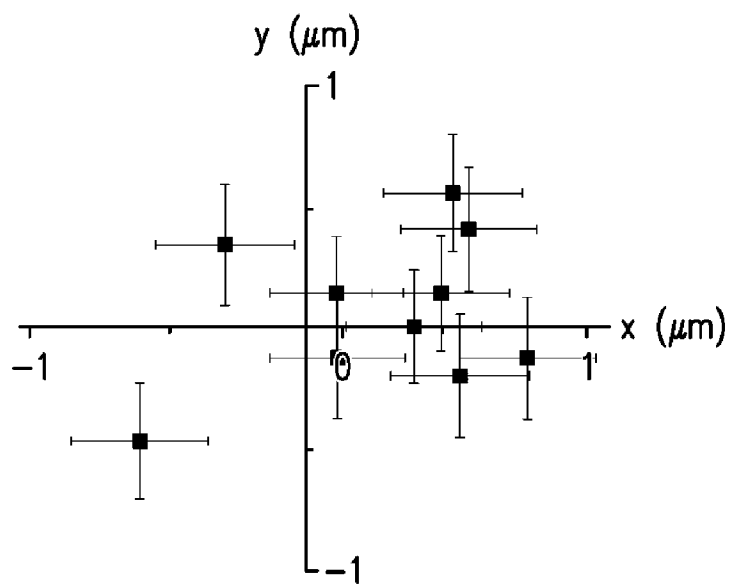


FIG. 9C

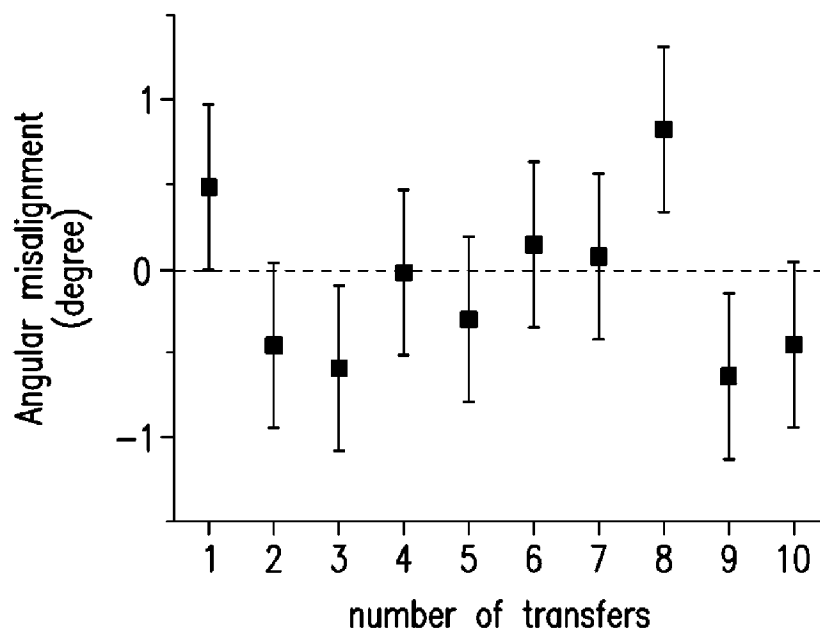


FIG. 9D

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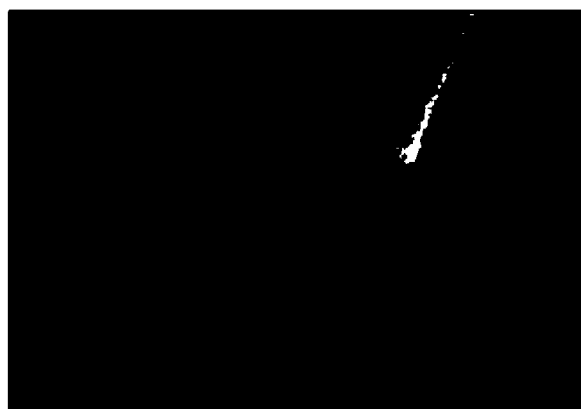


FIG. 9E



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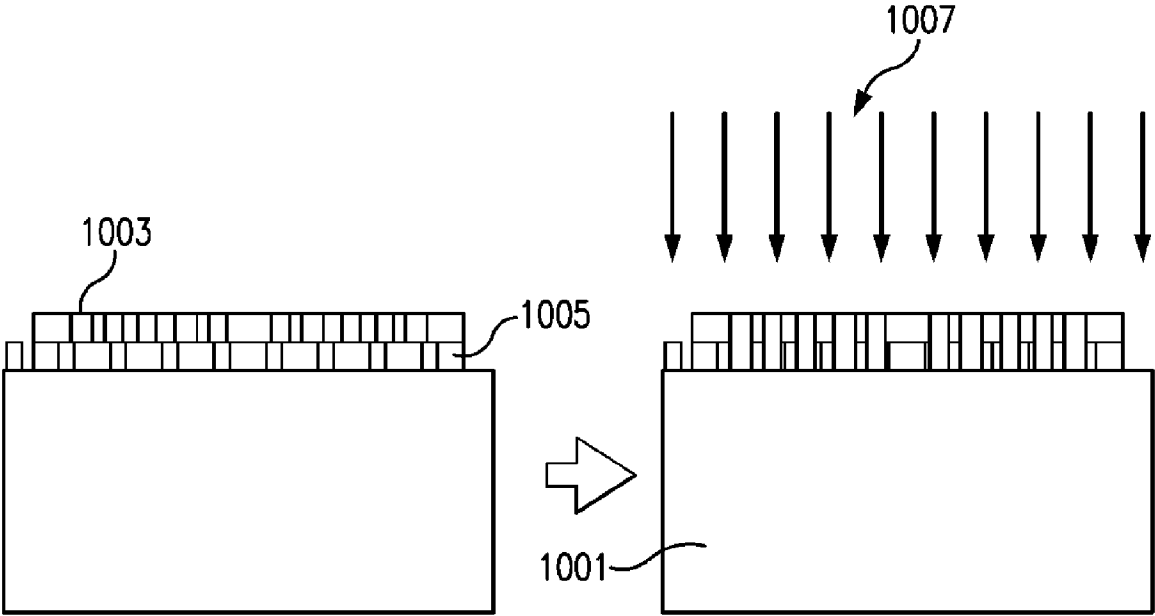


FIG. 10A

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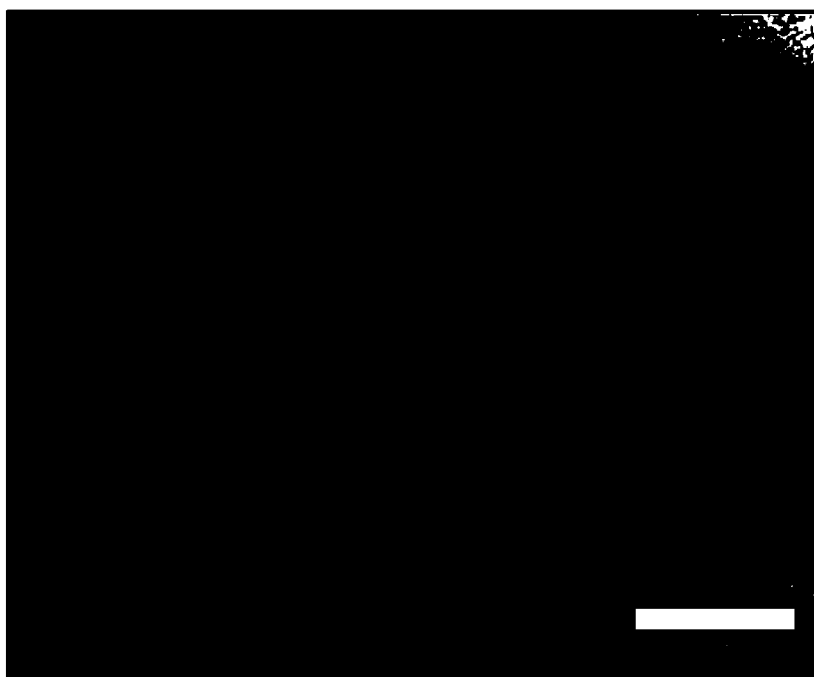
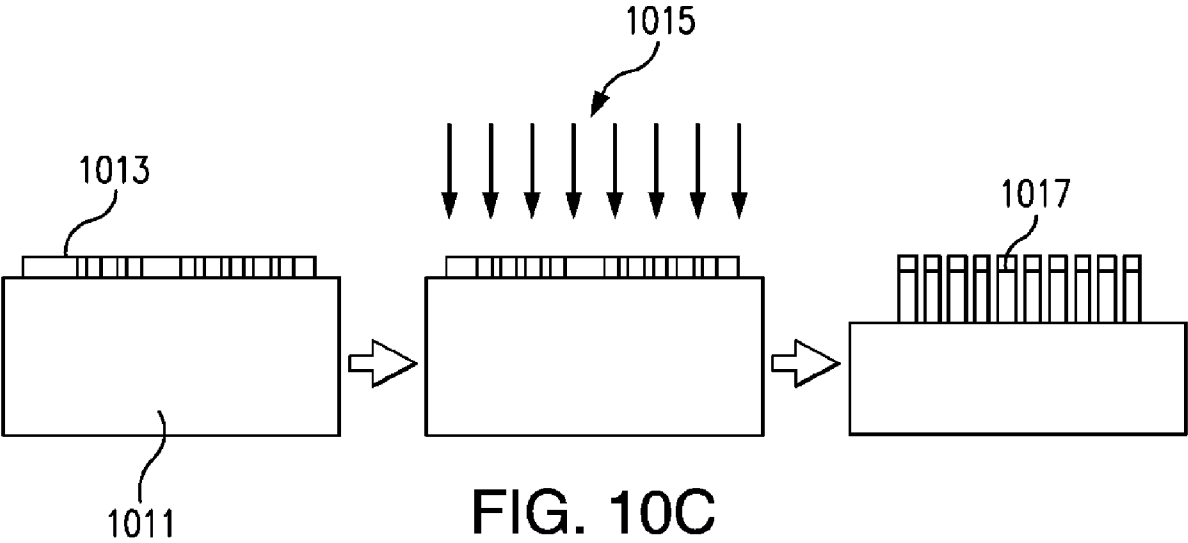


FIG. 10B



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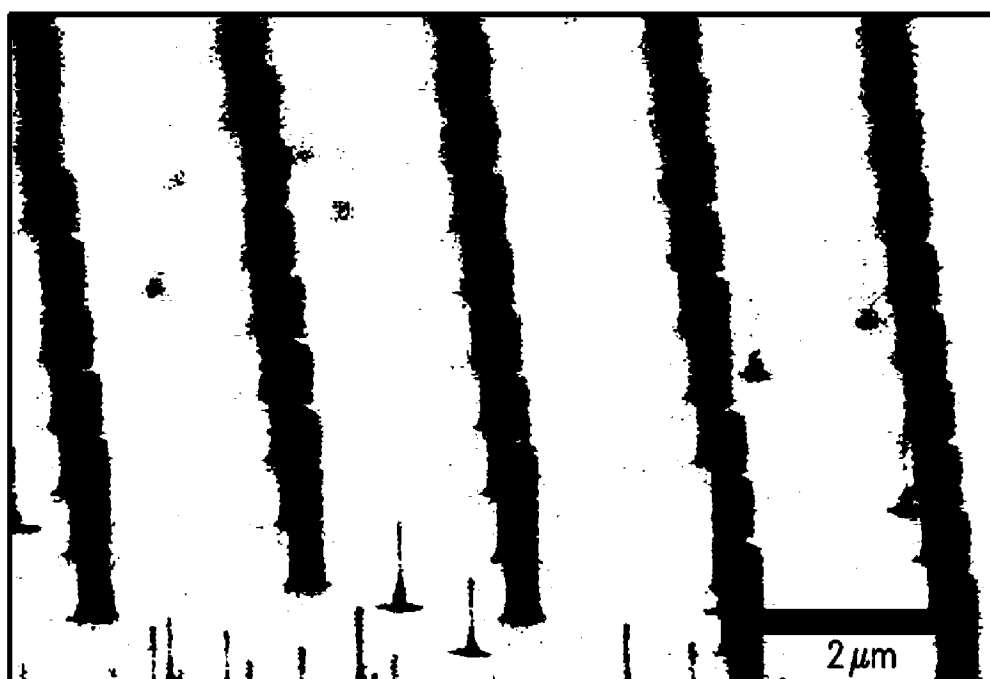


FIG. 10D

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FIG. 11A

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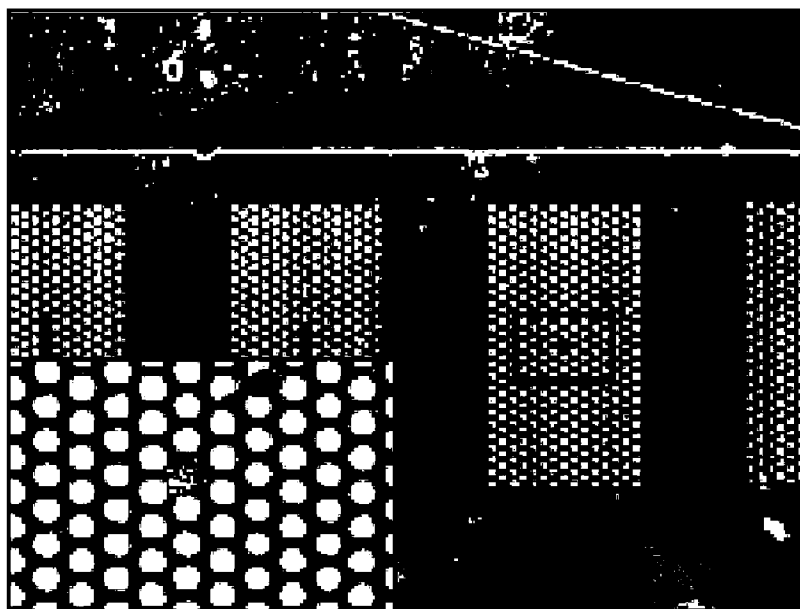


FIG. 11B

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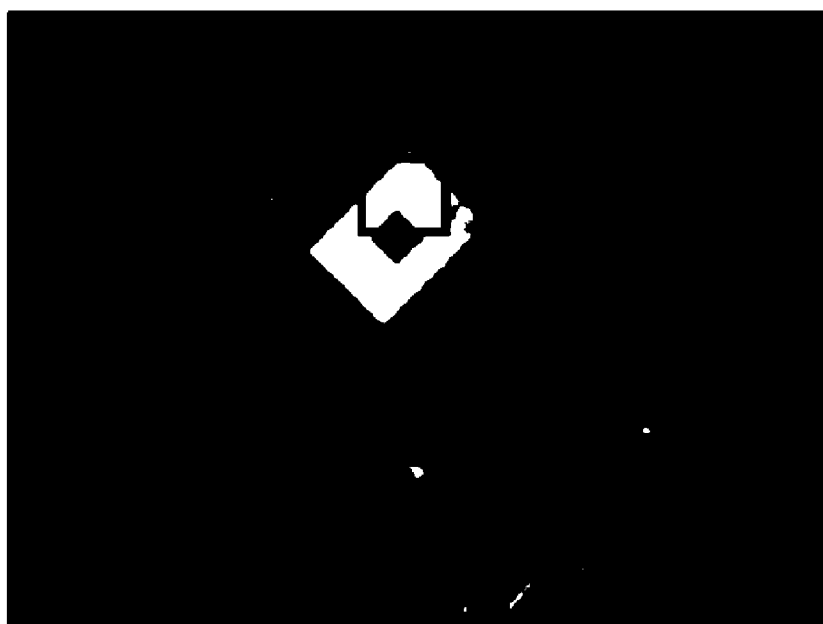


FIG. 11C

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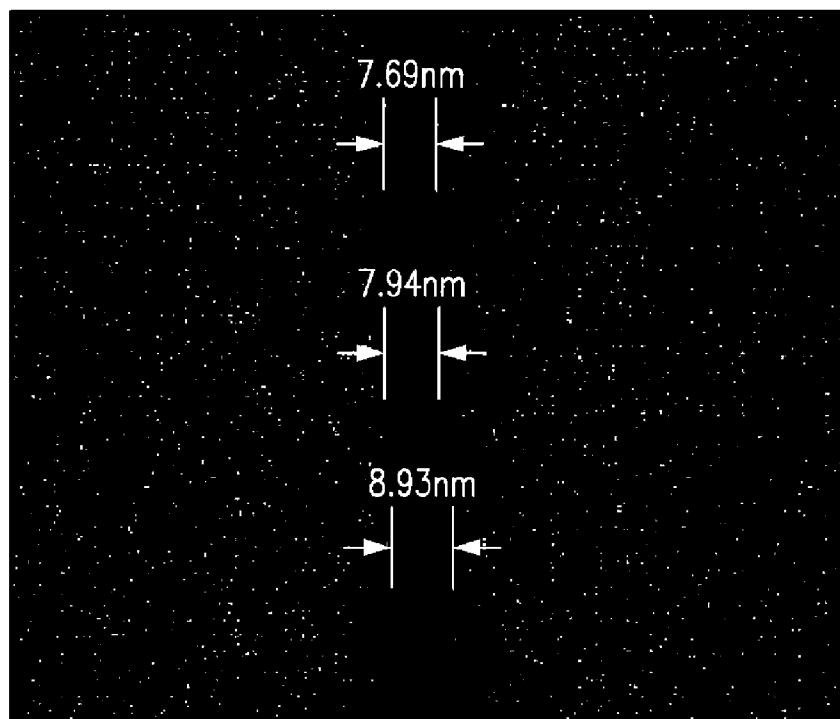


FIG. 12A



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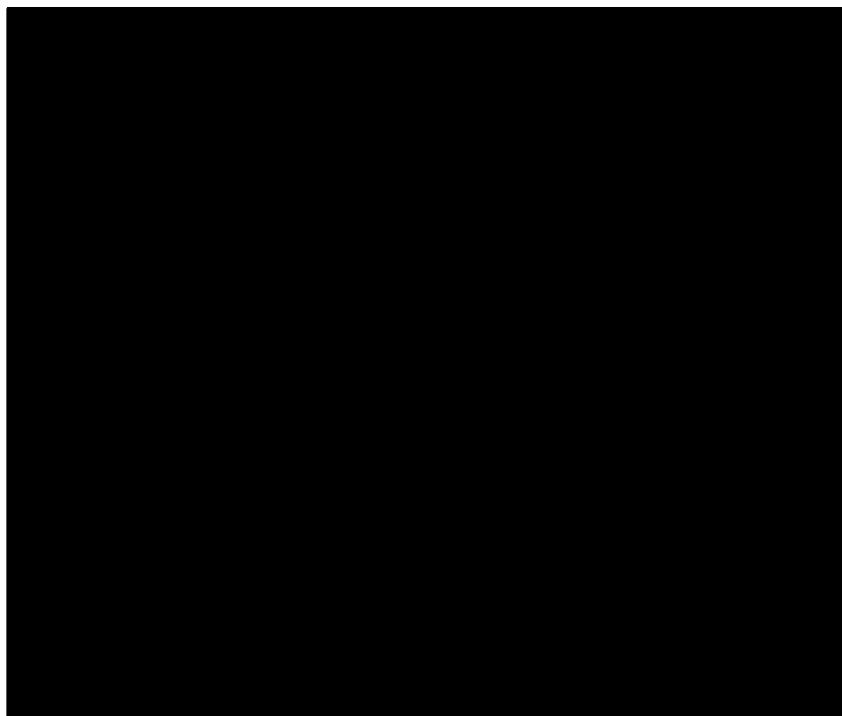


FIG. 12B

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(8) - A61B 18/18, B05D 1/26, B05D 3/12 (2014.01)

USPC - 73/866.5, 427/393.5, 427/397.7, 427/430.1, 427/444, 977/860

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)

IPC(8)- A61B 18/18, B05D 1/26, B05D 3/12 (2014.01);

USPC- 73/866.5, 427/393.5, 427/397.7, 427/430.1, 427/444, 977/860

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
Patents and NPL (classification, keyword; search terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Pub West (US EP JP WO), Pat Base (AU BE BR CA CH CN DE DK EP ES FI FR GB IN JP KR SE TH TW US WO), Google Patent, Google Scholar, Free Patents Online; search terms: tip, probe, coat, silicone, elastomer, PDMS, position, location, move, lift, deform

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,742,174 A (KISTER et al.) 21 April 1998 (21.04.1998), Figs. 1-4, 7-9; col 4, ln 13-44; col 5, ln 12-51; col 6, ln 3-54	13, 15, 17, 18
Y	US 2007/0003588 A1 (CHINN et al.) 04 January 2007 (04.01.2007), para [0011], [0014], [0041], [0047], [0125], [0174], [0182], [0191], [0192], [0202], [0234]-[0236], [0253], [0257], [0261]	1-12, 14, 16, 19-23
Y	US 2008/0157795 A1 (SMITH et al.) 03 July 2008 (03.07.2008), para [0004]-[0044]	1-12, 14, 16, 19-23
Y	US 2007/0208276 A1 (KORNKVEN VOLK et al.) 06 September 2007 (06.09.2007), para [0010]-[0126]	1-23
Y	US 2007/0073213 A1 (BROWN) 29 March 2007 (29.03.2007), para [0010]-[0030]	1-23
Y	US 6,846,735 B1 (LIN et al.) 25 January 2005 (25.01.2005), col 3, ln 16 to col 21, ln 28	1-23
Y	US 6,206,273 B1 (BEAMAN et al.) 27 March 2001 (27.03.2001), col 1, ln 65 to col 10, ln 54	1-23
Y	US 5,382,795 A (BAYER et al.) 17 January 1995 (17.01.1995), col 2, ln 45 to col 5, ln 52	1-23

☐ Further documents are listed in the continuation of Box C.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"&amp;" document member of the same patent family

Date of the actual completion of the international search

08 May 2014 (08.05.2014)

Date of mailing of the international search report

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Name and mailing address of the ISA/US

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