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(54) **Title**: ARRANGEMENT OF OPTICAL FIBERS, AND A METHOD OF FORMING SUCH ARRANGEMENT

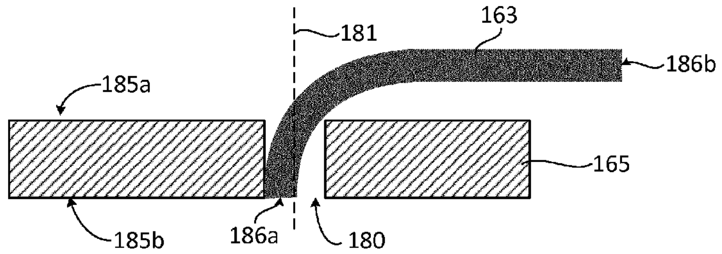

Fig. 11

(57) **Abstract**: The invention relates to a method of forming an optical fiber array. The method comprises providing a substrate having a first surface and an opposing second surface. The substrate is provided with a plurality of apertures extending through the substrate from the first surface to the second surface. Additionally, a plurality of fibers is provided. The fibers have fiber ends with a diameter smaller than the smallest diameter of the apertures. For each fiber, from the first surface side of the substrate, the fiber is inserted in a corresponding aperture such that the fiber end is positioned in close proximity of the second surface. Then the fiber is bent in a predetermined direction such that the fiber abuts a side wall of the aperture at a predetermined position. Finally, the bent fibers are bonded together using an adhesive material.

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Arrangement of optical fibers, and a method of forming such arrangement

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The invention relates to an arrangement of optical fibers. The invention further relates to a method of forming an optical fiber array. Finally, the invention relates to a modulation device and a lithographic apparatus comprising such arrangement.

2. Description of the Related Art

[0002] Charged particle multi-beamlet systems are known in the art, for example from US-patent 6,958,804 and/or from WO2009/127659, both in the name of the applicant, the latter one, being specifically adapted for very high volume throughput operation. Such lithography system uses a plurality of charged particle beamlets to transfer a pattern to a target surface. The system may operate with a continuous radiation source or with a source operating at constant frequency. Pattern data are sent by means of pattern data carrying light beams to a modulation device. The modulation device may then include light sensitive elements capable of converting received light signals into corresponding electric signals. The electric signals are then used to modulate the beamlets by electrostatic deflection. Finally, the modulated beamlets are transferred to the target surface.

[0003] Modulated light beams may be transferred using optical fibers. However, in order to obtain accurate data transfer, such optical fibers need to be aligned very accurately with respect to the light sensitive elements to allow accurate and reliable data transfer. In multi-beam charged particle lithography systems as described above the number of optical fibers is extremely high, and may easily be in the order of 10,000. Consequently, positioning of the fibers needs to be done very accurately. Such accurate placement is not straightforward. Furthermore, the volume being occupied by such large amount of optical fibers is preferably as small as possible, to enable the apparatus to be of limited size. Therefore, it is an object of the invention to provide an optical fiber arrangement or fiber array with very accurate positioning of the fibers, while occupying limited space.

BRIEF SUMMARY OF THE INVENTION

[0004] The invention provides in one aspect a method of forming an optical fiber array, the method comprising: providing a substrate having a first surface and an opposing second surface, the substrate being provided with a plurality of apertures extending through the substrate from the first surface to the second surface; providing a plurality of fibers, the fibers having fiber ends with a diameter smaller than the smallest diameter of the apertures; for each fiber, inserting, from the first surface side of the substrate, the fiber in a corresponding aperture such that the fiber end is positioned in close proximity of the second surface and bending the fiber in a predetermined direction such that the fiber abuts a side wall of the aperture at a predetermined position; and bonding the bent fibers together using an adhesive material.

[0005] The apertures in the substrate may be arranged in an array at positions corresponding to an array of light sensitive elements such as photo diodes. The substrate may be used to position the fiber ends at positions corresponding to an array of light sensitive elements such as photo diodes, the second surface of the substrate facing the light sensitive elements and the first surface facing away from them. The fiber ends may be positioned so that light emitted from the fiber ends is directed onto the light sensitive elements.

[0006] The fibers may have an outer jacket or coating which is stripped from the portion of the fibers inserted into the apertures, or the fibers may be inserted into the apertures without stripping. The fiber ends have a diameter smaller than the smallest diameter of the apertures, so that stripping the outer jacket or coating will reduce the required diameter of the apertures.

[0007] The fibers are inserted from the first surface side of the substrate sufficiently far into the apertures so that the fiber ends are flush with the second surface, or are inside the aperture but close to the second surface, or extend slightly outside the aperture. Alternatively, the fibers may be inserted all the way through the apertures and the protruding portions of the fibers may be cut off to result in the fiber ends being positioned in close proximity of the second surface.

[0008] Each fiber is inserted into a corresponding aperture from the first surface side of the substrate, leaving a length of fiber extending out from the aperture at the first surface side, and the extending length of fiber is bent in a predetermined direction. All of the fibers may be bent in the same direction. The amount of bending of each fiber is sufficient to cause at least a portion of the fiber positioned in the corresponding aperture to be pushed into abutment with a side wall of the aperture at a predetermined position. The bending of each fiber may be performed by a predetermined amount and at a predetermined position sufficiently close to the corresponding aperture so that at least a portion of the fiber positioned in the corresponding aperture is pushed into abutment with a side wall of the aperture at a predetermined position. The fibers may each have a length of fiber extending out from the aperture at the first surface side of the substrate, and at least a portion of the extending fiber lengths may be bent in a predetermined direction. The apertures in the substrate may be arranged in a two-dimensional array having rows, the fibers each having a length of fiber extending out from the apertures at the first surface side of the substrate, and the bending of the fibers may be performed by bending the fibers inserted into a first row of the apertures at a first radius of curvature, and bending the fibers inserted into a next adjacent row of the apertures at a second greater radius of curvature.

[0009] The bent fibers may be stacked in a predefined spatial arrangement, and may be stacked in a rectangular arrangement. The fibers may each have a length of fiber extending out from the aperture at the first surface side of the substrate. At least a portion of the extending fiber lengths may be arranged to run substantially parallel to the first surface. At least a portion of the extending fiber lengths may be arranged to run substantially parallel to each other in the same direction in a predetermined spatial arrangement. The predetermined spatial arrangement may comprise equidistant spacing of the extending fiber lengths in an array formation, and spacing elements may be located between the extending fiber lengths to position the extending fiber lengths with respect to each other.

[0010] At least a portion of the extending fiber lengths may be bonded together using an adhesive material. The portions of the extending fiber lengths which are bonded together may include the bent portions or unbent portions or both bent and unbent portions. The adhesive material may comprise a glue, an epoxy, or an epoxy encapsulant. The bonding may comprise curing the adhesive applied to the fibers. The curing may comprise exposing the adhesive to UV light, and/or may comprise applying heat to the adhesive.

[0011] The fiber ends may be secured within the apertures. Securing the fiber ends in the apertures may be executed after insertion of all of the fibers in corresponding apertures. The fiber ends may be secured in the apertures using an adhesive. Prior to inserting the fibers in the apertures, an adhesive may be applied onto the fiber ends, and securing the fiber ends may comprise curing the adhesive applied on the fiber ends. The curing may comprise exposing the adhesive to UV light, and/or may comprise applying heat to the adhesive. Alternatively, the fiber ends may be secured by clamping.

[0012] The method may further comprise polishing the second surface of the substrate. The polishing may include polishing the fiber ends and the second surface at the same time.

[0013] The apertures may have a cross-sectional shape consisting of a circular portion and an additional portion in the form of a groove, and the fibers may be bent in such direction that the predetermined position at which the fibers abut the side wall of the apertures is within the additional portion. The groove may form a wedge shape, the fibers abutting two opposing portions of the wedge shape. The amount of bending of each fiber may be sufficient to cause at least a portion of the fiber positioned in the corresponding aperture to be pushed into the groove. The apertures in the substrate may be arranged in an array at positions corresponding to an array of light sensitive elements such as photo diodes, and the groove in each aperture may be located so that the fiber ends are positioned at a desired location with respect to the light sensitive elements.

[0014] The fibers may be bent on top of a bending structure. The bending structure may form an integral part of the substrate at the first surface side of the substrate, or the bending structure may be a temporary removable structure. The bending of the fibers may be performed by bending a portion of the fibers over a curved section of the bending structure so that the curvature of the bent part of the portion of fibers follows the curvature of the bending structure. The apertures in the substrate may be arranged in a two-dimensional array having rows, the fibers each having a length of fiber extending out from the apertures at the first surface side of the substrate, and the bending of the fibers may be performed by bending the fibers inserted into a first row of the apertures over a curved section of the bending structure so that the curvature of the bent part of the fibers in the first row of the apertures follows the curvature of the bending structure. The bending of fibers inserted into a next adjacent row of the apertures may be performed by bending the fibers inserted into the next adjacent row of apertures over the curved section of the fibers inserted into the first row of apertures. The bending of fibers inserted into a each row of the apertures may be performed by bending the fibers over the curved section of the fibers inserted into the preceding row of apertures.

[0015] Bonding the bent fibers together may comprise: forming a mold around the plurality of bent fibers; filling the mold with an adhesive material; and curing the adhesive material. The resulting bonded structure increases the stiffness and structural integrity of the bent fibers.

[0016] In another aspect the invention provides an arrangement of optical fibers comprising: a substrate having a first surface and an opposing second surface, the substrate being provided with a plurality of apertures extending through the substrate from the first surface to the second surface; a plurality of fibers, each fiber having a fiber end with a diameter smaller than the smallest diameter of a corresponding aperture in the substrate. Each fiber is inserted from the first surface side of the substrate into the corresponding aperture so that the fiber end is positioned in close proximity of the second surface, the fiber having a length extending from the aperture out from the first surface. The extending length of each fiber is bent in a predetermined direction so that the fiber abuts a side wall of the corresponding aperture at a predetermined position, and the extending lengths of the fibers are bonded together using an adhesive.

[0017] The apertures in the substrate may be arranged in an array at positions corresponding to an array of light sensitive elements, so that the fiber ends are positioned so that light emitted from the fiber ends is directed onto the light sensitive elements.

[0018] The extending lengths of the fibers may be all bent in the same direction. The apertures in the substrate may be arranged in a two-dimensional array having rows, the fibers inserted into a first row of the apertures having a portion of their extending lengths bent at a first radius of curvature, and the fibers inserted into a next adjacent row of the apertures having a portion of their extending lengths bent at a second greater radius of curvature. Alternatively, the apertures in the substrate may be arranged in a two-dimensional array having rows, and all of the fibers inserted into each row of the apertures may have a portion of their extending lengths bent at a same radius of curvature, and the radius of curvature of the fibers of each row may also be the same.

[0019] At least a portion of the extending lengths of the fibers may be stacked in a predefined spatial arrangement, and may be stacked in a rectangular arrangement. At least a portion of the extending fiber lengths may be arranged to run substantially parallel to the first surface. At least a portion of the extending fiber lengths may be arranged to run substantially parallel to each other in the same direction in a predetermined spatial arrangement. The predetermined spatial arrangement may comprise equidistant spacing of the extending fiber lengths in an array formation, and spacing elements may be located between the extending fiber lengths to position the extending fiber lengths with respect to each other.

[0020] At least a portion of the extending lengths of the fibers may be bonded together using an adhesive. The fiber ends may be secured within the apertures, and an adhesive may be used to secure the fiber ends. The adhesive for bonding the extending lengths and/or the fiber ends may comprise a glue, an epoxy, or an epoxy encapsulant.

[0021] At least a portion of the extending lengths of the fibers may be bent as described herein, stacked in a spatial arrangement as described herein, and bonded together as described herein to form a unitary structure. This unitary structure may be substantially rigid, and may be enclosed in an enclosing structure.

[0022] The apertures may have a cross-sectional shape consisting of a circular portion and an additional portion in the form of a groove, and the fibers may be bent in such a direction that the predetermined position at which the fibers abut the side wall of the apertures is within the additional portion.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] Various aspects of the invention will be further explained with reference to embodiments shown in the drawings wherein:

[0024] FIG. 1 schematically shows a maskless lithography system that may be used in embodiments of the inventions;

[0025] FIG. 2 schematically shows the operation of an embodiment of the beamlet blanker array in the lithography system of FIG. 1;

[0026] FIG. 3 shows a simplified block diagram of a modular lithography system;

[0027] FIG. 4 schematically shows a cross-sectional view of a portion of a beamlet blanker array that may be used in the lithography system of FIG. 1;

[0028] FIG. 5 schematically shows a top view of a lay-out of a beamlet blanker array that may be used in embodiments of the invention;

[0029] FIG. 6 schematically shows a top view of a more detailed lay-out of a beamlet blanker array that may be used in embodiments of the invention;

[0030] FIG. 7A schematically shows an optical fiber arrangement on top of the beamlet blanker array of FIG. 5;

[0031] FIG. 7B schematically shows a cross-sectional view of the arrangement shown in FIG. 7A along the line VIIB-VIIB';

[0032] FIG. 8 schematically shows a more detailed view of the alignment between optical fibers and corresponding light sensitive elements;

[0033] FIGS. 9A, 9B schematically show two different ways of connecting a fiber array substrate to a blanker array;

[0034] FIG. 10 schematically shows yet another way of aligning a fiber array substrate to a blanker array;

[0035] FIG. 11 schematically shows a cross-sectional view of a portion of a fiber array substrate;

[0036] FIGS. 12A, 12B schematically show a top view of an aperture in a fiber array substrate;

[0037] FIG. 13 schematically shows a gripping device that may be used to form an arrangement of optical fibers;

[0038] FIGS. 14A-14E depict different stages in a method of forming an arrangement of optical fibers according to an embodiment of the invention;

[0039] FIG. 15 depicts a cross-sectional view of a spatial arrangement of fibers being prepared using the method shown in FIGS. 14A-14E;

[0040] FIG. 16 schematically shows another embodiment of the optical fiber arrangement; and

[0041]

DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0042] The following is a description of various embodiments of the invention, given by way of example only and with reference to the figures. The figures are not drawn to scale and merely intended for illustrative purposes.

[0043] FIG. 1 shows a simplified schematic drawing of an embodiment of a charged particle multi-beamlet lithography system **1**. The lithography system **1** suitably comprises a beamlet generator generating a plurality of beamlets, a beamlet modulator patterning the beamlets to form modulated beamlets, and a beamlet projector for projecting the modulated beamlets onto a surface of a target.

[0044] The beamlet generator typically comprises a source and at least one beam splitter. The source in FIG. 1 is an electron source **3** arranged to produce a substantially homogeneous, expanding electron beam **4**. The beam energy of the electron beam **4** is preferably maintained relatively low in the range of about 1 to 10 keV. To achieve this, the acceleration voltage is preferably low, and the electron source **3** may be kept at a voltage between about -1 to -10 kV with respect to the target at ground potential, although other settings may also be used.

[0045] In FIG. 1 the electron beam **4** from the electron source **3** passes a collimator lens **5** for collimating the electron beam **4**. The collimator lens **5** may be any type of collimating optical system. Before collimation, the electron beam **4** may pass a double octopole (not shown). Subsequently, the electron beam **4** impinges on a beam splitter, in the embodiment of FIG. 1 an aperture array **6**. The aperture array **6** preferably comprises a plate having through-holes. The aperture array **6** is arranged to block part of the beam **4**. Additionally, the array **6** allows a plurality of beamlets **7** to pass through so as to produce a plurality of parallel electron beamlets **7**.

[0046] The lithography system **1** of FIG. 1 generates a large number of beamlets **7**, preferably about 10,000 to 1,000,000 beamlets, although it is of course possible that more or less beamlets are generated. Note that other known methods may also be used to generate collimated beamlets. A second aperture array may be added in the system, so as to create subbeams from the electron beam **4** and to create electron beamlets **7** from the subbeam. This allows for manipulation of the subbeams further downstream, which turns out beneficial for the system operation, particularly when the number of beamlets in the system is 5,000 or more.

[0047] The beamlet modulator, denoted in FIG. 1 as modulation system **8**, typically comprises a beamlet blanker array **9** comprising an arrangement of a plurality of blankers, and a beamlet stop array **10**. The blankers are capable of deflecting one or more of the electron beamlets **7**. In embodiments of the invention, the blankers are more specifically electrostatic deflectors provided with a first electrode, a second electrode and an aperture. The electrodes are then located on opposing sides of the aperture for generating an electric field across the aperture. Generally, the second electrode is a ground electrode, i.e. an electrode connected to ground potential.

[0048] To focus the electron beamlets **7** within the plane of the blanker array **9** the lithography system may further comprise a condenser lens array (not shown).

[0049] In the embodiment of FIG. 1, the beamlet stop array **10** comprises an array of apertures for allowing beamlets to pass through. The beamlet stop array **10**, in its basic form, comprises a substrate provided with through-holes, typically round holes although other shapes may also be used. In some embodiments, the substrate of the beamlet stop array **10** is formed from a silicon wafer with a regularly spaced array of through-holes, and may be coated with a surface layer of a metal to prevent surface charging. In some further embodiments, the metal is of a type that does not form a native-oxide skin, such as CrMo.

[0050] The beamlet blanker array **9** and the beamlet stop array **10** operate together to block or let pass the beamlets **7**. In some embodiments, the apertures of the beamlet stop array **10** are aligned with the apertures of the electrostatic deflectors in the beamlet blanker array **9**. If beamlet blanker array **9** deflects a beamlet, it will not pass through the corresponding aperture in the beamlet stop array **10**. Instead the beamlet will be blocked by the substrate of beamlet block array **10**. If beamlet blanker array **9** does not deflect a beamlet, the beamlet will pass through the corresponding aperture in the beamlet stop array **10**. In some alternative embodiments, cooperation between the beamlet blanker array **9** and the beamlet stop array **10** is such that deflection of a beamlet by a deflector in the blanker array **9** results in passage of the beamlet through the corresponding aperture in the beamlet stop array **10**, while non-deflection results in blockage by the substrate of the beamlet stop array **10**.

[0051] The modulation system **8** is arranged to add a pattern to the beamlets **7** on the basis of input provided by a control unit **20**. The control unit **20** may comprise a data storage unit **21**, a read out unit **22** and data converter **23**. The control unit **20** may be located remote from the rest of the system, for instance outside the inner part of a clean room. The control system may further be connected to an actuator system **16**. The actuator system is arranged for executing a relative movement of the electron-optical column represented by the dashed line in FIG. 1 and a target positioning system **14**.

[0052] Modulated light beams **24** holding pattern data are transmitted to the beamlet blanker array **9** using optical fibers. More particularly, the modulated light beams **24** from optical fiber ends are projected on corresponding light sensitive elements located on the beamlet blanker array **9**. The light sensitive elements may be arranged to convert the light signal into a different type of signal, for example an electric signal. A modulated light beam **24** carries a portion of the pattern data for controlling one or more blankers that are coupled to a corresponding light sensitive element. In some embodiments, the light beams may, at least partially, be transferred towards the light sensitive elements by means of an optical waveguide.

[0053] The modulated beamlets coming out of the beamlet modulator are projected as a spot onto a target surface of a target **13** by the beamlet projector. The beamlet projector typically comprises a scanning deflector for scanning the modulated beamlets over the target surface and a projection lens system for focusing the modulated beamlets onto the target surface. These components may be present within a single end module.

[0054] Such end module is preferably constructed as an insertable, replaceable unit. The end module may thus comprise a deflector array **11**, and a projection lens arrangement **12**. The insertable, replaceable unit may also include the beamlet stop array **10** as discussed above with reference to the beamlet modulator. After leaving the end module, the beamlets **7** impinge on a target surface positioned at a target plane. For lithography applications, the target **13** usually comprises a wafer provided with a charged-particle sensitive layer or resist layer.

[0055] The deflector array **11** may take the form of a scanning deflector array arranged to deflect each beamlet **7** that passed the beamlet stop array **10**. The deflector array **11** may comprise a plurality of electrostatic deflectors enabling the application of relatively small driving voltages. Although the deflector array **11** is drawn upstream of the projection lens arrangement **12**, the deflector array **11** may also be positioned between the projection lens arrangement **12** and the target surface.

[0056] The projection lens arrangement **12** is arranged to focus the beamlets **7**, before or after deflection by the deflector array **11**. Preferably, the focusing results a geometric spot size of about 10 to 30 nanometers in diameter. In such preferred embodiment, the projection lens arrangement **12** is preferably arranged to provide a demagnification of about 100 to 500 times, most preferably as large as possible, e.g.

in the range 300 to 500 times. In this preferred embodiment, the projection lens arrangement **12** may be advantageously located close to the target surface.

[0057] In some embodiments, a beam protector (not shown) may be located between the target surface and the projection lens arrangement **12**. The beam protector may be a foil or a plate provided with a plurality of suitably positioned apertures. The beam protector is arranged to absorb the released resist particles before they can reach any of the sensitive elements in the lithography system **1**.

[0058] The projection lens arrangement **12** may thus ensure that the spot size of a single pixel on the target surface is correct, while the deflector array **11** may ensure by appropriate scanning operations that the position of a pixel on the target surface is correct on a microscale. Particularly, the operation of the deflector array **11** is such that a pixel fits into a grid of pixels which ultimately constitutes the pattern on the target surface. It will be understood that the macroscale positioning of the pixel on the target surface is suitably enabled by a target positioning system **14**.

[0059] Commonly, the target surface comprises a resist film on top of a substrate. Portions of the resist film will be chemically modified by application of the beamlets of charged particles, i.e. electrons. As a result thereof, the irradiated portion of the film will be more or less soluble in a developer, resulting in a resist pattern on a wafer. The resist pattern on the wafer can subsequently be transferred to an underlying layer, i.e. by implementation, etching and/or deposition steps as known in the art of semiconductor manufacturing. Evidently, if the irradiation is not uniform, the resist may not be developed in a uniform manner, leading to mistakes in the pattern. High-quality projection is therefore relevant to obtain a lithography system that provides a reproducible result. No difference in irradiation ought to result from deflection steps.

[0060] FIG. 2 schematically shows the operation of an embodiment of the beamlet blanker array **9** in the lithography system of FIG. 1. In particular, FIG. 2 schematically shows a cross-sectional view of a portion of a beamlet modulator comprising a beamlet blanker array **9** and beamlet stop array **10**. The beamlet blanker array **9** is provided with a plurality of apertures. For sake of reference the target **13** has also been indicated. The figure is not drawn to scale.

[0061] The shown portion of the beamlet modulator is arranged to modulate three beamlets **7a**, **7b**, and **7c**. The beamlets **7a**, **7b**, **7c** may form part of a single group of beamlets that may be generated from a beam originating from a single source or from a single subbeam. The beamlet modulator of FIG. 2 is arranged for converging groups of beamlets towards a common point of convergence P for each group. This common point of convergence P is preferably located on an optical axis O for the group of beamlets.

[0062] Considering the shown beamlets **7a**, **7b**, **7c** in FIG. 2, beamlets 7a, 7c have an incident angle extending between the beamlet and the optical axis O. The orientation of beamlet 7b is substantially parallel to the optical axis. The direction of beamlet deflection to establish blocking of deflected beamlets by the substrate of the beamlet stop array **10** may be different for each beamlet. Beamlet 7a is blocked by deflection towards the left, i.e. towards the "-"-direction in FIG. 2, indicated by dashed line 7a-. Beamlets 7b, 7c on the other hand are to be deflected towards the right, i.e. towards the "+"-direction, to established blocking of the respective beamlets. These blocking directions are indicated by dashed lines 7b+ and 7c+ respectively. Note that the choice of deflection direction may not be arbitrary. For example, for beamlet 7a, dashed line 7a+ shows that deflection of beamlet 7a towards the right would result in passage through the beamlet stop array **10**. Therefore, deflection of beamlet 7a along line 7a+ would be inappropriate. On the other hand, deflection of beamlet 7b towards the left, indicated by dashed line 7b-, would be an option.

[0063] FIG. 3 shows a simplified block diagram of a modular lithography system **50**. The lithography system is preferably designed in a modular fashion to permit ease of maintenance. Major subsystems are preferably constructed in self-contained and removable modules, so that they can be removed from the lithography machine with as little disturbance to other subsystems as possible. This is particularly advantageous for a lithography machine enclosed in a vacuum chamber, where access to the machine is limited. Thus, a faulty subsystem can be removed and replaced quickly, without unnecessarily disconnecting or disturbing other systems.

[0064] In the embodiment shown in FIG. 3 these modular subsystems include an illumination optics module **81** including a charged particle beam source **71** and a beam collimating system **72**, an aperture array and condenser lens module **82** including an aperture array **73** and a condenser lens array **74**, a beam switching module **83** including a beamlet blanker array **75**, and a projection optics module **84** including a beam stop array **76**, a beam deflector array **77**, and projection lens arrays

78. The modules may be designed to slide in and out from an alignment frame. In the embodiment shown in FIG. 3, the alignment frame comprises an alignment inner sub-frame **85** and an alignment outer sub-frame **86**. The projection optics module **84** may be connected to at least one of the alignment inner sub-frame **85** and the alignment outer sub-frame **86** by means of one or more flexures.

Abovementioned components in the illumination optics module **81**, the aperture array and condenser lens module **82**, the beam switching module **83** and the projection optics module **84** may be arranged to operate in correspondence to the functionality of similar components in the lithography system **1** of FIG. 1.

In the embodiment of FIG. 3, a frame **88** supports the alignment sub-frames **85** and **86** via vibration damping mounts **87**. In this embodiment, a wafer **55** rests on a wafer table **89**, which is in turn mounted on further supporting structure **90**. The combination of wafer table **89** and further supporting structure **90** may hereafter also be referred to as chuck **90**. The chuck **90** sits on the stage short stroke **91** and long stroke **92**. The lithography machine is enclosed in vacuum chamber **60**, which preferably includes a mu metal shielding layer or layers **65**. The machine rests on a base plate **95** supported by frame members **96**.

Each module may require a large number of electrical signals and/or optical signals, and electrical power for its operation. The modules inside the vacuum chamber receive these signals from one or more control systems **99**, which are typically located outside of the chamber. The vacuum chamber **60** includes openings, referred to as ports, for admitting cables carrying the signals from the control systems into the vacuum housing while maintaining a vacuum seal around the cables. Each module preferably has its collection of electrical, optical, and/or power cabling connections routed through one or more ports dedicated to that module. This enables the cables for a particular module to be disconnected, removed, and replaced without disturbing cables for any of the other modules. In some embodiments, a patch panel may be provided within the vacuum chamber **60**. The patch panel comprises one or more connectors for removably connecting one or more connections of the modules. One or more ports may be used for admitting the one or more connections of the removable modules into the vacuum chamber.

[0065] FIG. 4 schematically shows a cross-sectional view of a portion of a beamlet blanker array **9** that may be used in the lithography system of FIG. 1. The beamlet blanker array **9** comprises a plurality of modulators **101**. A modulator comprises a first electrode **103a**, a second electrode **103b**, and an aperture **105**. The electrodes **103a**, **103b** are located on opposing sides of the aperture **105** for generating an electric field across the aperture.

[0066] A light sensitive element **107** is arranged to receive pattern data carrying light beams (not shown). The light sensitive element **107** is electrically connected to one or more modulators **101** via an electrical connection **109**. The light sensitive element **107** receives pattern data via the light beams, converts the light signal into an electrical signal and then forwards the received and converted pattern data via the electrical connection **109** towards the one or more connected modulators **101**. The one or more modulators **101** then modulate passing charged particle beamlets, such as electron beamlets **7** in accordance with the received pattern data. The light sensitive element **107** may be provided with an anti-reflection coating **108** to reduce background radiation caused by reflected light, which may disturb a correct readout of the data carried by the light beam.

[0067] FIG. 5 schematically shows a top view of a lay-out of a beamlet blanker array **9** that may be used in embodiments of the invention. The beamlet blanker array **9** shown in FIG. 5 is divided into beam areas **121** and non-beam areas **122**. Although the width of the beam areas **121** and non-beam areas **122** are shown to be about the same, this is not essential. The dimensions of the areas may differ based on the layout used.

[0068] The beam areas **121** include one or more modulators for modulating beamlets. The non-beam areas **122** include one or more light sensitive elements. The use of beam areas **121** and non-beam areas **122** in an optical column in a maskless lithography system has the advantage that the density of modulators and light sensitive area can be increased.

[0069] Although the beam areas **121** and the non-beam areas **122** are shown in an arrangement forming a perfect rectangle, the areas may actually form a skew arrangement to allow for an optimal projection of beamlets onto the target surface, as will be understood by a person skilled in the art.

[0070] FIG. 6 schematically shows a top view of a more detailed lay-out of a portion of a beamlet blanker array **9** that may be used in embodiments of the invention. The blanker array portion includes a beam area **121** surrounded by an area reserved for a shielding structure **141**. The beamlet blanker array **9** further includes a non-beam area, which effectively is all the space that is not reserved for the beam area **121** and the shielding structure **141**. The shielding structure **141** is arranged to substantially shield electric fields that are externally generated, for example in the proximity of light sensitive elements, such as photodiodes, within the non-beam areas.

[0071] The shielding structure **141** can be described as comprising side walls forming an open-ended box-like structure. Note that the shielding structure **141** is not necessarily physically connected to the beamlet blanker array **9**. If located within sufficiently close distance of the beamlet blanker array **9** the shielding structure **141** can still sufficiently shield electric fields.

[0072] Materials suitable for the shielding structure **111** are materials with sufficiently high electric conductivity. Additionally, the material should have sufficient strength and workability. An exemplary suitable material for use as main component of the shielding structure is titanium (Ti). Other exemplary materials that may be used include molybdenum (Mo) and aluminum (Al). In an exemplary embodiment, the shielding structure is made using Ti-plates coated with Mo. In another exemplary embodiment the shielding structure includes a stack of Mo sheets with Al spacers.

[0073] The beamlet blanker array portion of FIG. 6 further includes an optical interface area **143** reserved for establishing an optical interface between optical fibers arranged for carrying light signals and light sensitive elements within the beamlet blanker array **9**. The light sensitive elements, such as photodiodes, are thus placed within the optical interface area **143**. The optical fibers may cover the entire optical interface area **143** or a portion thereof. The optical fibers are suitably arranged so that they do not physically block electron beamlets within the beam area **121** during use of the lithography system.

[0074] Additionally, the non-beam area of the beamlet blanker array **9** includes a power interface area **145**. The power interface area **145** is arranged to accommodate a power arrangement for suitably powering the light sensitive elements, and optionally other components, within the optical interface area **143**. The power arrangement **145** may extend in a direction substantially perpendicular to, and away from the blanker array **9**. Such arrangement **145** may enable the spread of the power lines over a large surface area, which improves the efficiency and reduces losses, e.g. due to a reduced thermal resistance caused by an increased radiation surface area.

[0075] The position of the power interface area **145** on the sides of the optical interface area **143** enables the use of relatively short power supply lines to the light sensitive elements. Consequently, the variation in voltage drop between different power lines, i.e. connections with nearby light sensitive elements versus connections with light sensitive elements further away, can be reduced.

[0076] The non-beam area may further include an additional interface area **147** to enable the accommodation of further circuitry, for example a clock and/or a control. The power arrangement within the power interface area **145** may also be arranged to provide sufficient power to the additional interface area **147**.

[0077] Although FIG. 6 schematically shows a very specific lay-out of the several areas, it will be understood that it is possible to have a different lay-out. Similarly, the size and shape of the different interface areas may vary in dependence of the specific application.

[0078] FIG. 7A schematically shows an exemplary embodiment of an optical fiber arrangement **161** selectively placed over the beamlet blanker array **9** of FIG. 5. The optical fiber arrangement **161** comprises a plurality of optical fibers **163** arranged to guide pattern data carrying light beams towards the light sensitive elements within the non-beam areas **122**. The fibers **163** are positioned such that they do not hinder a passage of charged particle beamlets arranged to pass through the apertures within the beam area **121** of the beamlet blanker array **9**.

[0079] The exemplary optical fiber arrangement **161** of FIG. 7A comprises two portions per non-beam area **122**. A first portion **161a** comprises a number of fibers **163** that enter a space above the non-beam area **122** from one side, while the second portion **161b** comprises a number of fibers **163** entering the space above the non-beam area **122** at an opposing side. The number of fibers **163** within each portion **161a**, **161b** may be equal to each other. The use of different portions allows for more space per fiber **163**, and reduces the risk of damaging the fibers **163**.

[0080] Alternatively, all fibers **163** may enter the space above the non-beam area **122** from one side. In such case, the other side may be used to accommodate power circuitry, for example to supply power to power lines within the power interface in the power interface area **145** in FIG. 6. Furthermore, the entry of fibers at one side may simplify maintenance operations. For example, in case of fiber replacement, only one side of the system needs to be dismantled.

[0081] FIG. 7B schematically shows a cross-sectional view of the arrangement shown in FIG. 7A along the line VIIB-VIIB'. The fibers **163** within the arrangement **161** terminate in a body **165** forming a fiber array. The body **165** typically takes the form of a substrate, and will hereafter be referred to as substrate **165**. The ends of the fibers within the substrate **165** are directed towards the light sensitive elements (not shown) within the non-beam area of the beamlet blanker array **9**. As will be discussed in more detail, the substrate **165** is placed in close proximity of, and secured, or fixated, to the surface of the beamlet blanker array **9**. Such position minimizes alignment errors due to poorly oriented fibers **163** within the substrate **165**.

[0082] FIG. 8 schematically shows a more detailed view of the alignment between optical fibers **163** within the substrate **165** and corresponding light sensitive elements **107** within the non-beam area of the blanker array **9**. The substrate **165** is placed in close proximity to the light sensitive elements **107**, preferably at a distance smaller than about 100 microns, more preferably at a distance smaller than about 50 microns. Due to the short distance between the light sensitive elements **107** and the fiber ends, optical communication using light beams **170** can be achieved with reduced light loss.

[0083] The alignment of the fibers **163** in the substrate **165** and the light sensitive elements **107** in the blanker array **9** is fixed. This can be done after an alignment procedure, which may include the use of markers, such as optical markers, on the blanker array **9**. Alternatively, both the substrate **165** and the array of light sensitive elements **107** on the blanker array **9** are manufactured with sufficient precision that alignment of the two structures with respect to each other leads to sufficient alignment between corresponding fibers **163** and light sensitive elements **107**. In case test results before actual operation of the lithography system show that a combination of a specific fiber **163** and a corresponding light sensitive element **107** does not perform according to the predetermined specifications, such combination may be excluded by the control unit during lithographic processing.

[0084] FIGS. 9A, 9B schematically show two different ways of connecting a substrate **165** to a blanker array **9**. In both FIGS. 9A, 9B, only a single combination of a fiber **163** and a light sensitive element **107** is shown.

[0085] In FIG. 9A the substrate **165** is connected to the blanker array **9** using an adhesive **175**. The adhesive **175** may be a suitable glue, for example an epoxy glue. The adhesive **175** contacts the blanker array **9** such that there is no contact between the adhesive and the light sensitive element **107**. This way of fixating allows for the use of small quantities of adhesive, and is easy to execute.

[0086] As also shown in FIG. 8, the light beams **170** exiting the fibers **163** diverge. As a result, the beam spot size on the surface of the blanker array **9** increases with an increase of the distance between the substrate **165** and the blanker array **9**. Furthermore, the light intensity of the beam spot per unit area decreases. Therefore, an increase in distance between the substrate **165** and the blanker array **9** may reduce the portion of the light beam **170** that can be captured by the light sensitive element **107**. In particular in case the light spot formed on the light sensitive element **107** is designed to entirely fall within the light sensitive surface of the light sensitive element **107**, alignment errors may have a more profound effect in case the distance between the substrate **165** and the blanker array **9** becomes too large.

[0087] In some cases, in particular when it is not desirable to reduce the distance between the fiber and the light sensitive element, fixating is preferably done using a suitable transparent adhesive layer **177**, sometimes referred to as underlay, as schematically shown in FIG. 9B. The transparent adhesive layer **177** is in contact with a large portion of both the blanker array **9** and the substrate **165**, and may act as a filler such as Silica which effectively fills the gap between the blanker array **9** and the substrate **165**. Preferably, the transparent adhesive layer **177** is of a material with a thermal expansion coefficient as close as possible to the materials of the substrate **165** and blanker array **9**.

[0088] Contrary to adhesive **175** shown in FIG. 9A, the adhesive layer **177** used in the embodiment of FIG. 9B is also in contact with the light sensitive element **107**. The material within the adhesive layer **177** preferably has a sufficiently high refractive index for reducing the opening angle of the light beam **170** exiting the optical fiber **163**. The use of the adhesive layer **177** with a sufficiently high refractive index has the advantage that the alignment tolerance is improved.

[0089] For example, in FIG. 9A, the light beam **170** exiting the optical fiber **163** has an opening angle α that is such that the light sensitive element **107** is entirely covered. However, if the alignment between the optical fiber **163** and the light sensitive element **107** is not perfect, a portion of the light will not fall onto the light sensitive element **107**. Consequently, the light output received by the light sensitive element **107** readily decreases upon imperfect alignment.

[0090] In FIG. 9B, due to the presence of the adhesive layer **177** comprising a material with a sufficiently high refractive index, the opening angle of the light exiting the fiber **163** has an opening angle α', where angle α' is smaller than angle α. The smaller opening angle reduces the spot size of the beamlet that falls onto the light sensitive element, while the light output of the spot is the same. Consequently, as schematically shown in FIG. 9B, even in case the optical fiber **163** and the light sensitive element are misaligned over a distance *dx*, the light sensitive element **107** still captures the entire beam **170**, and the light output received by the light sensitive element merely starts to reduce if misalignment becomes greater than such distance *dx*. The embodiment shown in FIG. 9B is thus less susceptible to reduced performance caused by small alignment errors.

[0091] A suitable material for the adhesive layer **177** is an epoxy adhesive or glue substantially transparent to the light emitted by the fiber **163** and having a sufficiently high refractive index, for example higher than 1.4, preferably higher than about 1.5.

[0092] It will be recognized that other fixating constructions may be used as well. For example, the substrate **165** and the blanker array **9** may be connected by using connector elements such as Dowel pins.

[0093] Furthermore, at least one of the beamlet blanker array and the fixated fiber substrate may be provided with one or more mutual locating elements. Examples of such location elements include, but are not limited to a protrusion and a stop.

[0094] Another possibility to limit the influence of alignment errors is to make the spot size of the light beam **170** is greater than the light sensitive surface of the light sensitive element **107**, as schematically depicted in FIG. 10. In such case, the intensity of the light beam portion that is projected onto the light sensitive element **107** should be sufficient for proper operation thereof. In the embodiment of FIG. 10, assuming the light is substantially homogeneously distributed throughout the beam **170**, misalignment of the optical fiber **163** with respect to the light sensitive element **107** over a distance *dx* or less does not have an influence on the amount of light being captured by the light sensitive element **107**. The light output received by the light sensitive element **107** starts to reduce if the misalignment exceeds such distance *dx*.

Consequently, the embodiment shown in FIG. 10 is less susceptible to reduced performance caused by small alignment errors.

[0095] FIG. 11 schematically shows a cross-sectional view of a portion of a fiber array. The fiber array comprises a substrate **165** with a plurality of apertures **180** arranged for accommodating a plurality of fibers **163**. For purposes of clarity, only a single aperture **180** and corresponding fiber **163** is shown in FIG. 11.

[0096] The substrate **165** has a fiber receiving surface side **185a**, also referred to as first surface, and a light transmitting surface side **185b**, also referred to as second surface. The apertures **180** extend through the substrate from the first surface to the second surface. The fiber **163** comprises a transmitting end **186a** and a trailing end **186b**. The length of the fiber **163** is typically much longer than the length shown in FIG. 11.

[0097] Placement of the fibers **163** in the apertures **180** may be done by inserting the fibers **163** in the apertures **180** from the first surface side such that a fiber end extends through at least the majority of the aperture **180**. In other words, the light transmitting end **186a** of the fiber **163** is in close proximity of the second surface side **185b** of the substrate **165**. After insertion, the one or more fibers **163** are bent such that the fiber extends in a direction that differs from the direction of the center line through the aperture (denoted in FIG. 11 by dashed line **181**).

[0098] The placement technique described above and schematically depicted in FIG. 11 makes use of the resilience of the fiber **163**. This resilience forces the fiber **163** towards a side of the aperture **180** (in FIG. 11 the side wall on the left side). In other words, the fiber bending applies a pre-load between fiber **163** and substrate **165** which moves the fiber towards an aperture side. Consequently, by bending the fiber **163** in a predetermined direction, the fiber **163** abuts a side wall of the aperture **180** at a predetermined position, i.e. generally opposite to the direction into which the fiber **163** is bent. The force that is created due to the bending depends on the stiffness of the fiber **163** and its bending radius. To minimize displacement and/or deformation of the substrate as a result of a force exerted by a bent fiber **163** onto the side wall of the aperture **180**, the substrate **165** is preferably secured during fiber placement, for example by using a chucking arrangement, such as a vacuum chuck arrangement.

[0099] The aperture size is preferably large compared to the outer diameter of the fiber **163** to improve the fiber placing tolerance. Typically, an optical fiber **163** comprises a core surrounded by a cladding layer, which in its turn is surrounded by an outer coating or “jacket”. In some embodiments, the fibers **163** are stripped prior to insertion, i.e. the outer coating is removed. In some other embodiments, the fibers **163** are not stripped. In case the portions of the fibers **163** that are to be inserted in the apertures **180** are stripped, the aperture size is preferably greater than the diameter of the fiber core and the cladding layer. In case the fibers **163** are not stripped, the aperture size **180** is preferably greater than the outer diameter of the fibers **163** including the outer coating. Most preferably, the aperture diameter is greater than the outer diameter of the unstripped fiber **163** to allow the use of unstripped fibers within the substrate **165**. The use of unstripped fibers **163** reduces the time consumed by fiber pre-processing because there is no need to strip the fibers **163**.

[00100] After insertion and bending of the fiber **163**, the fiber **163** may be secured, also referred to as fixated or fixation. Fixation may be achieved by using an adhesive, such as a suitable glue. Preferably, the adhesive has a low viscosity of about 100 – 500 mPas to allow capillary forces to distribute the adhesive in contact with the fiber **163**. Furthermore, the thermal expansion coefficient of the adhesive is preferably as close as possible to the material of the substrate **165**. In some embodiments, the adhesive is curable with UV light. Alternatively, the adhesive may be curable in a different way, for example by applying heat. Generally, curing is time consuming. Therefore, securing of the fibers **165** is preferably done after insertion and bending of all fibers **163**.

[00101] Alternatively, or additionally, it is also possible to use a different type of fixation, such as mechanical clamping. In case of the use of an adhesive, the adhesive may be provided onto the light transmitting fiber end **186a** prior to placement of the fiber **163** in the aperture **180**. Such procedure allows for accurate placement of the adhesive onto the fiber end **186a**, while the amount of adhesive being used may be limited. Curing of the adhesive may then take place after bending the respective fiber **163** or after insertion and bending of all other fibers.

[00102] To enhance the position tolerance of the fiber **163**, the aperture **170** preferably has a shape that guides the fiber **163** to abovementioned predetermined position as a result of fiber bending. FIGS. 12A, 12B schematically show a top view of an aperture **180** in a substrate **165** where the aperture **180** has an asymmetric shape to enable the fiber to move towards a predetermined position during bending. The cross-sectional

shape of the aperture **180** has two portions **191**, **192**. The first portion **191** is a circular portion **191** (denoted by the white dashed circle) with a diameter that is greater than the diameter of the fiber portion that is to be inserted in the aperture **180**. The second portion **192** is an additional portion directly adjacent to the circular portion **191** and takes the form of a groove. The shown shape of the additional portion **192** is a mere example. It will be well understood that alternative shapes may be used as well.

[00103] If, in the aperture shown in FIGS. 12A, 12B, a fiber **163** is inserted in the aperture **180** and then bent to the right, the fiber **163** will be forced to position itself in the additional "groove-shaped" portion **192** of the aperture **180** in a way as schematically shown in FIG. 12B. Due to the shape of the additional portion **192** the fiber position at which the fiber **163** sticks can be anticipated. The shape and size of the additional portion **174** thus enable the fiber **163** to position itself at a predetermined position at which the fiber abuts a side wall of the aperture. The shape and size of the additional portion **192** may be tailored to the type and/or size of the fiber **163** being used.

[00104] FIG. 13 schematically shows a gripping device **200** that may be used to form an arrangement of optical fibers, such as a fiber array as discussed above. The gripping device **200** comprises a first gripper **210**, a second gripper **220** and a third gripper **230**. The first gripper **210** is arranged for holding the fiber **163** at a position closer to the trailing end **186b** than to the light transmitting end **186a**. The first gripper **210** may include a groove, such as a V-groove **211** for that purpose. The second gripper **220** is arranged for holding the fiber **163** at a position closer to the light transmitting end **186a** than to the trailing end **186b**. The second gripper **220** may also include a groove, such as a V-groove **221** for that purpose. The third gripper **230** is arranged for fixating the fiber for gluing. The third gripper may include a notch for that purpose. The gripping device **200** may be arranged to apply a pre-load onto the fiber such that the fiber is slightly pre-bend prior to insertion in a corresponding aperture. Applying a pre-load alleviates fiber handling.

[00105] FIGS. 14A-14F depict different stages in a method of forming an arrangement of optical fibers according to an embodiment of the invention. As is clear from these drawings, different types of gripping devices may be used.

[00106] FIG. 14A shows a situation in which the gripping device **200** is part of a larger apparatus comprising a rotating member **240** and a bending structure **250**. The gripping device is mounted onto the rotating member **240** such that it can rotate in a direction that enables the gripping device **200** to bend the fiber **163**.

[00107] In the shown embodiment, the gripping device is arranged to insert the fiber **163** in the corresponding aperture and then to bend the fiber **163** using the bending structure **250**. The bending is then such that the portion of the fiber **163** that extends from the first surface of the fiber array substrate can be bent over the bending structure **250**, or, in case other fibers **163** are already bent on top of this structure **250**, over already bent fibers **163**. The bending structure **250** enables bending with a predetermined curvature. A side view of the actual bending over the bending structure **250** is shown in FIG. 14B.

[00108] Preferably, in particular in case other fibers **163** have been bent earlier, prior to completion of bending, an adhesive **260** is applied to adhere the bent fiber onto a fiber **163** that has been bent earlier. Preferably, the fibers are stacked on top of each other in a predetermined spatial arrangement, for example a rectangular arrangement as schematically shown in FIG. 15. In a rectangular arrangement the fibers have a predetermined length. Knowledge of this length may improve the accuracy of controlling signals sent through the fibers.

[00109] After positioning the fiber **163** on top of another fiber **163**, the gripping device **200** may be used to fixate the upper fiber **163** for enabling curing of the adhesive **260** being applied previously. For this purpose, the third gripper **230** may be used, for example by employing a suitable notch. This situation is shown in FIG. 14D.

[00110] FIG. 14E shows the situation in which the last fiber is put on top. The packet of fibers is depicted as a hatched area.

[00111] FIG. 16 schematically shows an embodiment of the optical fiber arrangement in which the fibers **163** are, after placement in the apertures and subsequent bending, secured by using an adhesive material **360**, for example a suitable glue. As shown in this embodiment, the fibers **163** may extend through the apertures. Preferably, the height differences of the fibers **163** extending through the apertures in the substrate **165** is less than 0.2 microns. This may be achieved by polishing the substrate after placement and fixation of the fibers **163**.

[00112] The fibers **163** may be guided towards the apertures via a supporting unit **350** that is connected, permanently or temporarily, to the substrate **165**. The supporting unit **350** may simplify the bending of fibers **163**. Furthermore, the presence of the supporting unit **350** may avoid that defects, such as kinks, develop during the bending process. The entire arrangement of fibers **163** and substrate **165** may be strengthened even further by connecting the fibers **163** to each other, and, in case the supporting unit **350** is permanent, preferably also to the supporting unit **350**, for example by using an adhesive **260**. The adhesive **360** used within the apertures of the substrate **165** may be the same as the adhesive **260**. Fixating the fibers **163** into the fixation substrate **165** provides a robust fiber array which provides a reliable light output. Fixating the fibers **163** to each other, further improves the robustness of the design.

[00113] FIG. 17 shows a bonded fiber arrangement **410** that is positioned in close proximity of a plurality of light sensitive elements positioned on a surface of a beamlet blanker array **400**, for example a non-beam area **121** as depicted in FIG. 5, a lay-out of which is further explained with reference to FIG. 6. Structure **420** relates to a shield for shielding electromagnetic radiation. To form a bonded structure a mold may be formed around the plurality of bent fibers, and the mold may then be filled with an adhesive material. Finally, the adhesive material is cured, e.g. by using on eo more of UV-radiation, evaporation and heat. The resulting bonded structure is a robust structure that occupies limited space.

[00114] The invention has been described by reference to certain embodiments discussed above. It will be recognized that these embodiments are susceptible to various modifications and alternative forms well known to those of skill in the art without departing from the spirit and scope of the invention. Accordingly, although specific embodiments have been described, these are examples only and are not limiting upon the scope of the invention, which is defined in the accompanying claims.

WHAT IS CLAIMED IS:

1. A method of forming an optical fiber array, the method comprising:
   - providing a substrate having a first surface and an opposing second surface, the substrate being provided with a plurality of apertures extending through the substrate from the first surface to the second surface;
   - providing a plurality of fibers, the fibers having fiber ends with a diameter smaller than the smallest diameter of the apertures;
   - for each fiber, inserting, from the first surface side of the substrate, the fiber in a corresponding aperture such that the fiber end is positioned in close proximity of the second surface and bending the fiber in a predetermined direction such that the fiber abuts a side wall of the aperture at a predetermined position; and
   - bonding the bent fibers together using an adhesive material.

2. The method of claim 1, wherein all fibers are bent in the same direction.

3. The method of any one of the preceding claims, wherein the bent fibers are stacked in a predefined spatial arrangement.

4. The method of any one of the preceding claims, wherein the adhesive material comprises a glue, an epoxy, or an epoxy encapsulant.

5. The method of any one of the preceding claims, wherein the method further comprises securing the fiber ends within the apertures.

6. The method of claim 5, wherein securing the fiber ends is executed after insertion of all fibers in corresponding apertures in the substrate.

7. The method of claim 5 or 6, wherein the fiber ends are secured by using an adhesive, the method further comprising, prior to inserting, applying an adhesive onto the fiber ends.

8. The method of any one of the preceding claims, wherein the apertures have a cross-sectional shape consisting of a circular portion and an additional portion in the

form of a groove, and wherein the fibers are bent in such direction that the predetermined position at which the fibers abut the side wall of the apertures is within the additional portion.

9. The method of any one of the preceding claims, wherein the fibers are bent on top of a bending structure.

10. The method of any one of the preceding claims, wherein bonding the bent fibers together comprises:

- forming a mold around the plurality of bent fibers;
- filling the mold with an adhesive material; and
- curing the adhesive material.

11. An arrangement of optical fibers comprising:

- a substrate having a first surface and an opposing second surface, the substrate being provided with a plurality of apertures extending through the substrate from the first surface to the second surface;
- a plurality of fibers, each fiber having a fiber end with a diameter smaller than the smallest diameter of a corresponding aperture in the substrate;
- wherein each fiber is inserted from the first surface side of the substrate into the corresponding aperture so that the fiber end is positioned in close proximity of the second surface, the fiber having a length extending from the aperture out from the first surface;
- wherein the extending length of each fiber is bent in a predetermined direction so that the fiber abuts a side wall of the corresponding aperture at a predetermined position; and
- wherein the extending lengths of the fibers are bonded together using an adhesive.

12. The arrangement of claim 11, wherein the apertures in the substrate are arranged in an array at positions corresponding to an array of light sensitive elements, so that the fiber ends are positioned so that light emitted from the fiber ends is directed onto the light sensitive elements.

13. The arrangement of claim 11 or 12, wherein the extending lengths of the fibers are all bent in the same direction.

14. The arrangement of any one of claims 11-13, wherein the apertures in the substrate are arranged in a two-dimensional array having rows, the fibers inserted into a first row of the apertures having a portion of their extending lengths bent at a first radius of curvature, and the fibers inserted into a next adjacent row of the apertures having a portion of their extending lengths bent at a second greater radius of curvature.

15. The arrangement of any one of claims 11-13, wherein the apertures in the substrate are arranged in a two-dimensional array having rows, all of the fibers inserted into each row of the apertures having a portion of their extending lengths bent at a same radius of curvature, and the radius of curvature of the fibers of each row also being the same.

16. The arrangement of any one of claims 11-15, wherein at least a portion of the extending lengths of the fibers are stacked in a predefined spatial arrangement.

17. The arrangement of claim 16, wherein at least a portion of the extending lengths of the fibers run parallel to each other.

18. The arrangement of any one of claims 11-17, wherein at least a portion of the extending lengths of the fibers are bonded together using an adhesive.

19. The arrangement of any one of claims 11-18, wherein the fiber ends are secured within the apertures.

20. The arrangement of any one of claims 11-19, wherein the apertures have a cross-sectional shape consisting of a circular portion and an additional portion in the form of a groove, and wherein the fibers are bent in such direction that the predetermined position at which the fibers abut the side wall of the apertures is within the additional portion.

21. A modulation device for use in a charged-particle multi-beamlet lithography system, the modulation device comprising:

- a beamlet blanker array for patterning the plurality of beamlets in accordance with a pattern, and
- an arrangement of optical fibers according to any one of claims 11-20;

wherein the beamlet blanker array comprising a plurality of modulators and a plurality of light sensitive elements, a light sensitive element being arranged to receive pattern data carrying light beams and to convert the light beams into electrical signals, the light sensitive element being electrically connected to one or more modulators for providing the received pattern data to the one or more modulators; and
wherein the fibers within the arrangement of optical fibers are arranged for providing the pattern data carrying light beams.

22. A charged-particle multi-beamlet lithography system for transferring a pattern onto the surface of a target using a plurality of charged particle beamlets, the system comprising:

- a beam generator for generating a plurality of charged particle beamlets;
- a beamlet blanker array for patterning the plurality of beamlets in accordance with a pattern; and
- a projection system for projecting the patterned beamlets onto the target surface;

wherein the beamlet blanker array comprises a plurality of modulators and a plurality of light sensitive elements, a light sensitive element being arranged to receive pattern data carrying light beams and to convert the light beams into electrical signals, the light sensitive element being electrically connected to one or more modulators for providing the received pattern data to the one or more modulators; and
wherein the beamlet blanker array is coupled to an arrangement of fibers according to any one of claims 11-20.

AMENDED CLAIMS
received by the International Bureau on 25 September 2012 (25.09.12)

1. A method of forming an optical fiber array, the method comprising:
   - providing a substrate having a first surface and an opposing second surface, the substrate being provided with a plurality of apertures extending through the substrate from the first surface to the second surface;
   - providing a plurality of fibers, the fibers having fiber ends with a diameter smaller than the smallest diameter of the apertures;
   - providing a bending structure at the first surface side of the substrate;
   - for each fiber, inserting, from the first surface side of the substrate, the fiber in a corresponding aperture such that the fiber end is positioned in close proximity of the second surface and bending the fiber over the bending structure in a predetermined direction such that the fiber abuts a side wall of the aperture at a predetermined position; and
   - bonding the bent fibers together using an adhesive material.

2. The method of claim 1, wherein all fibers are bent in the same direction.

3. The method of any one of the preceding claims, wherein the bent fibers are stacked in a predefined spatial arrangement.

4. The method of any one of the preceding claims, wherein the adhesive material comprises a glue, an epoxy, or an epoxy encapsulant.

5. The method of any one of the preceding claims, wherein the method further comprises securing the fiber ends within the apertures.

6. The method of claim 5, wherein securing the fiber ends is executed after insertion of all fibers in corresponding apertures in the substrate.

7. The method of claim 5 or 6, wherein the fiber ends are secured by using an adhesive, the method further comprising, prior to inserting, applying an adhesive onto the fiber ends.

8. The method of any one of the preceding claims, wherein the apertures have a cross-sectional shape consisting of a circular portion and an additional portion in the form of a

groove, and wherein the fibers are bent in such direction that the predetermined position at which the fibers abut the side wall of the apertures is within the additional portion.

9. The method of any one of the preceding claims, wherein bonding the bent fibers together comprises:

- forming a mold around the plurality of bent fibers;
- filling the mold with an adhesive material; and
- curing the adhesive material.

10. An arrangement of optical fibers comprising:

- a substrate having a first surface and an opposing second surface, the substrate being provided with a plurality of apertures extending through the substrate from the first surface to the second surface;
- a plurality of fibers, each fiber having a fiber end with a diameter smaller than the smallest diameter of a corresponding aperture in the substrate;
- a supporting unit connected to the substrate at the first surface side;

wherein each fiber is inserted from the first surface side of the substrate into the corresponding aperture so that the fiber end is positioned in close proximity of the second surface, the fiber having a length extending from the aperture out from the first surface; wherein the extending length of each fiber is bent over the supporting unit in a predetermined direction so that the fiber abuts a side wall of the corresponding aperture at a predetermined position; and

wherein the extending lengths of the fibers are bonded together using an adhesive.

11. The arrangement of claim 10, wherein the apertures in the substrate are arranged in an array at positions corresponding to an array of light sensitive elements, so that the fiber ends are positioned so that light emitted from the fiber ends is directed onto the light sensitive elements.

12. The arrangement of claim 10 or 11, wherein the extending lengths of the fibers are all bent in the same direction.

13. The arrangement of any one of claims 10-12, wherein the apertures in the substrate are arranged in a two-dimensional array having rows, the fibers inserted into a first row of the

apertures having a portion of their extending lengths bent at a first radius of curvature, and the fibers inserted into a next adjacent row of the apertures having a portion of their extending lengths bent at a second greater radius of curvature.

14. The arrangement of any one of claims 10-12, wherein the apertures in the substrate are arranged in a two-dimensional array having rows, all of the fibers inserted into each row of the apertures having a portion of their extending lengths bent at a same radius of curvature, and the radius of curvature of the fibers of each row also being the same.

15. The arrangement of any one of claims 10-14, wherein at least a portion of the extending lengths of the fibers are stacked in a predefined spatial arrangement.

16. The arrangement of claim 15, wherein at least a portion of the extending lengths of the fibers run parallel to each other.

17. The arrangement of any one of claims 10-16, wherein at least a portion of the extending lengths of the fibers are bonded together using an adhesive.

18. The arrangement of any one of claims 10-17, wherein the fiber ends are secured within the apertures.

19. The arrangement of any one of claims 10-18, wherein the apertures have a cross-sectional shape consisting of a circular portion and an additional portion in the form of a groove, and wherein the fibers are bent in such direction that the predetermined position at which the fibers abut the side wall of the apertures is within the additional portion.

20. The arrangement of any one of claims 10-19, wherein the extending lengths of the fibers are further bonded to the supporting unit using an adhesive.

21. A modulation device for use in a charged-particle multi-beamlet lithography system, the modulation device comprising:

- a beamlet blanker array for patterning the plurality of beamlets in accordance with a pattern, and
- an arrangement of optical fibers according to any one of claims 10-20;

wherein the beamlet blanker array comprising a plurality of modulators and a plurality of light sensitive elements, a light sensitive element being arranged to receive pattern data carrying light beams and to convert the light beams into electrical signals, the light sensitive element being electrically connected to one or more modulators for providing the received pattern data to the one or more modulators; and
wherein the fibers within the arrangement of optical fibers are arranged for providing the pattern data carrying light beams.

22. A charged-particle multi-beamlet lithography system for transferring a pattern onto the surface of a target using a plurality of charged particle beamlets, the system comprising:

- a beam generator for generating a plurality of charged particle beamlets;
- a beamlet blanker array for patterning the plurality of beamlets in accordance with a pattern; and
- a projection system for projecting the patterned beamlets onto the target surface;

wherein the beamlet blanker array comprises a plurality of modulators and a plurality of light sensitive elements, a light sensitive element being arranged to receive pattern data carrying light beams and to convert the light beams into electrical signals, the light sensitive element being electrically connected to one or more modulators for providing the received pattern data to the one or more modulators; and
wherein the beamlet blanker array is coupled to an arrangement of fibers according to any one of claims 10-20.

STATEMENT UNDER ARTICLE 19 (1)

The present invention relates to a method of forming an optical fiber array and an arrangement of optical fibers. The method comprises providing a substrate provided with apertures extending through the substrate from a first surface to an opposing second surface, providing a plurality of fibers with fiber ends with a diameter smaller than the smallest diameter of the apertures, and providing a bending structure at the first surface side of the substrate. Then, for each fiber, the fiber is inserted in a corresponding aperture from the first surface side, and then bent over the bending structure in a predetermined direction such that the fiber abuts a side wall of the aperture at a predetermined position. Finally, the bent fibers are bonded together using an adhesive material. The arrangement of optical fibers comprises a substrate as discussed above, a plurality of fibers, and a supporting unit connected to the substrate at the first surface side. The fiber ends of the fibers are positioned in the corresponding apertures in close proximity of the second surface of the substrate and the extending length of each fiber is bent over the supporting unit in a predetermined direction so that the fiber abuts a side wall of the corresponding aperture at the predetermined position.

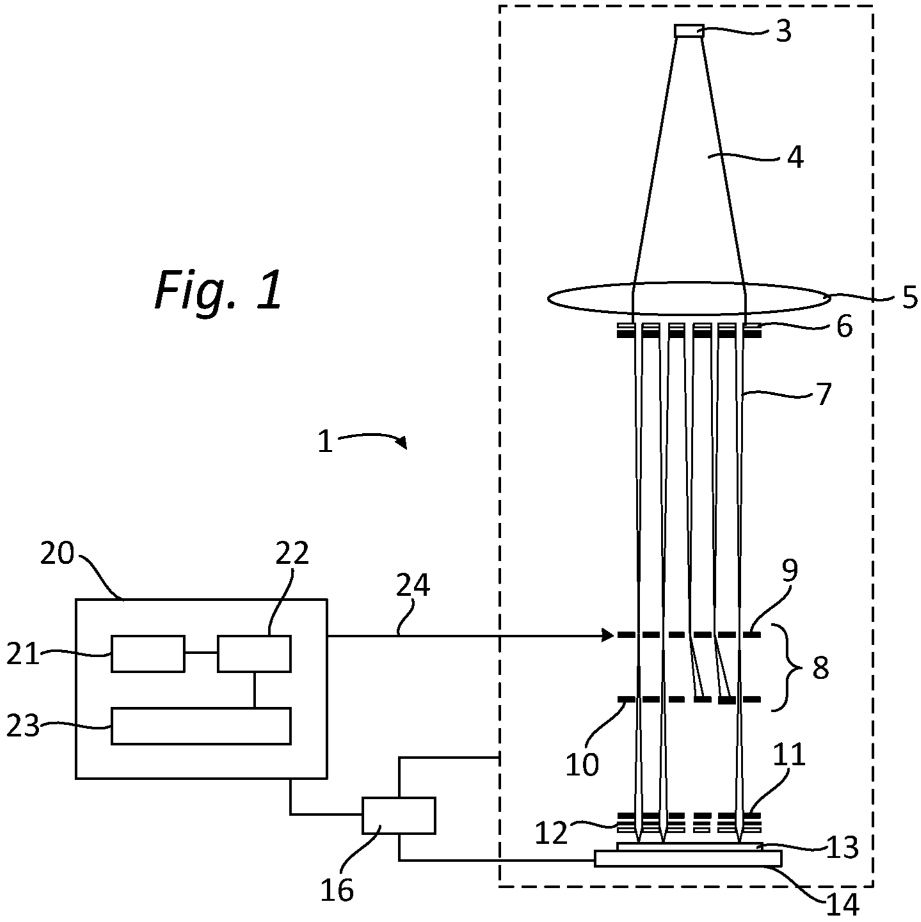
US-patent 3969816 (D1) discloses an interconnection system suitable for transmission lines, which may include optical fibers. D1 does not disclose a method of forming the array in which the fibers are bent over a bending structure or a supporting unit connected to the substrate. Furthermore, the bending in D1 is not established such that the fibers abut a side wall of the corresponding aperture at a predetermined position.

European patent application 1441247 (D3) discloses a light signal transmitting device comprising a light guide body using optical fibers. In D3 the fibers are bent prior to insertion into corresponding apertures (see for example FIG. 6 and paragraphs [0046]-[0048]).

US-patent application 2005/0123231 (D4) discloses an optical wiring board/optical bus comprising a planar optical waveguide and a plurality of optical fibers connected thereto. In D4, the fibers are first bent, then temporarily fixed, and finally glued (see FIGS. 3A, and 4A-4D). D4 does not disclose insertion of fibers into corresponding apertures prior to bending.

The claimed arrangement of optical fibers and method of forming an optical fiber array provide a fiber array with very accurate positioning of the fibers while the fibers occupy limited space. Consequently, the fiber array is particularly suitable for use in applications that need extremely accurate and reliable data transfer, for example multi-beamlet lithography systems.

Fig. 1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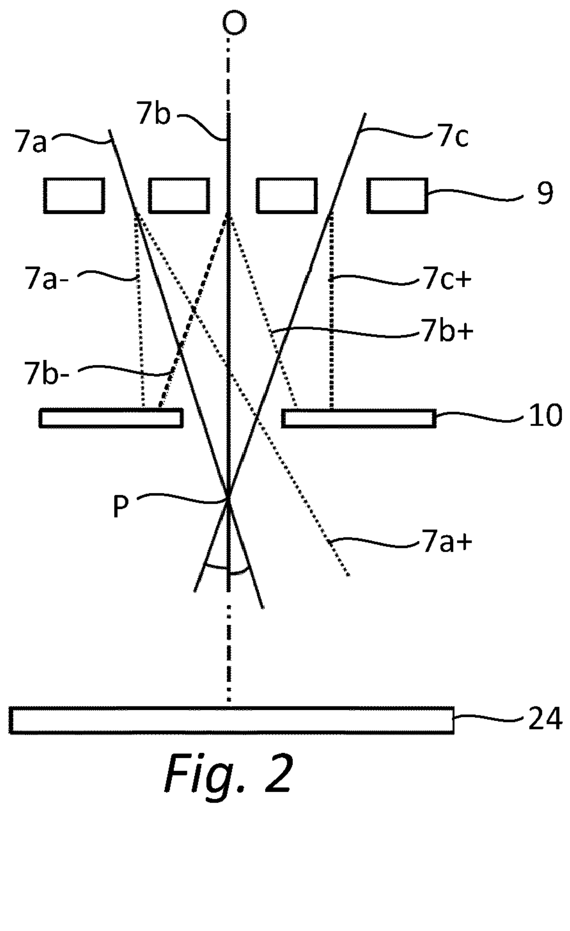
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7b+
7b-
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P
7a+
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Fig. 2

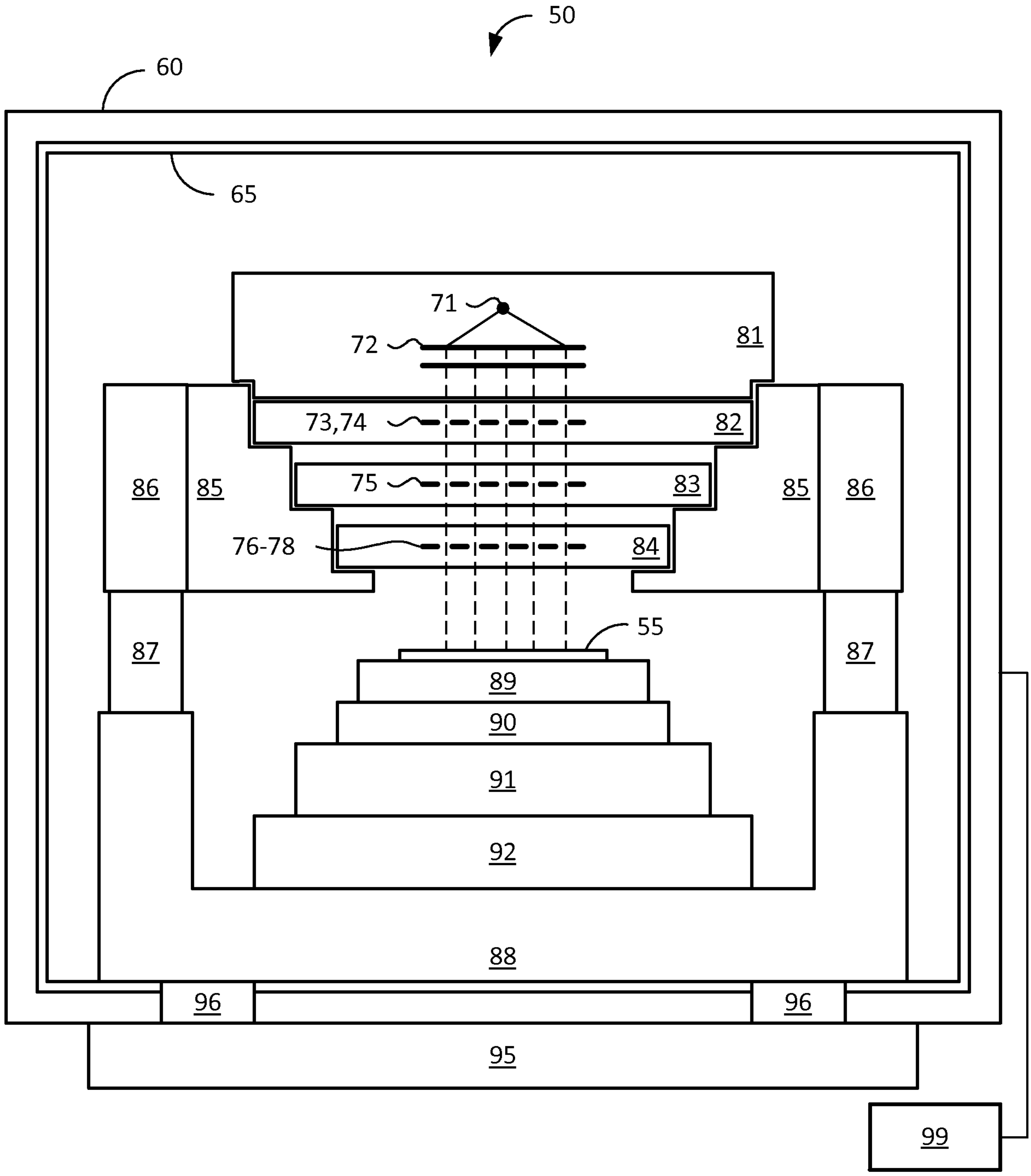
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Fig. 3

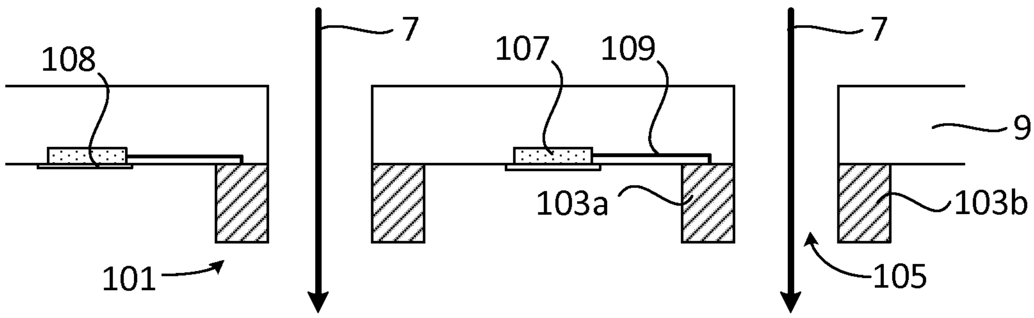


Fig. 4

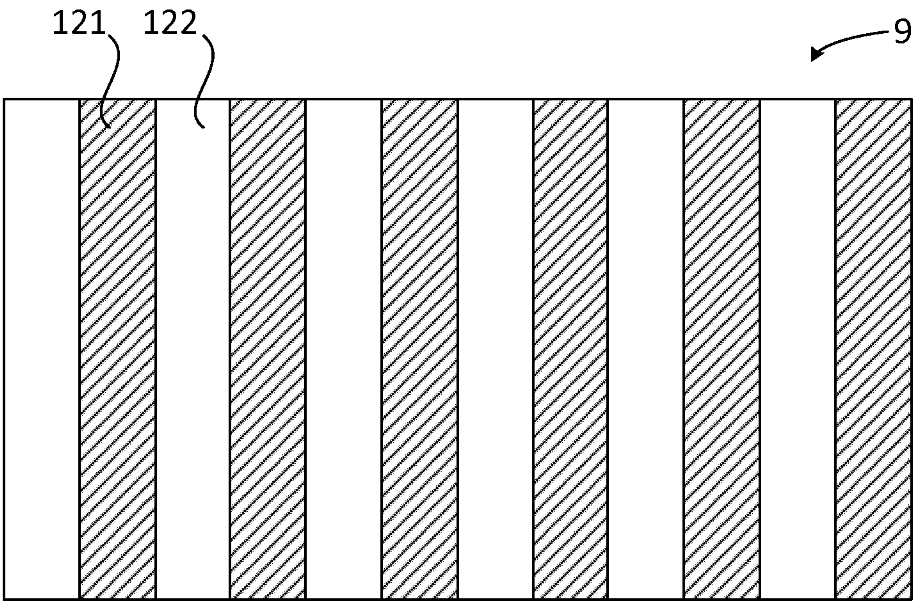


Fig. 5

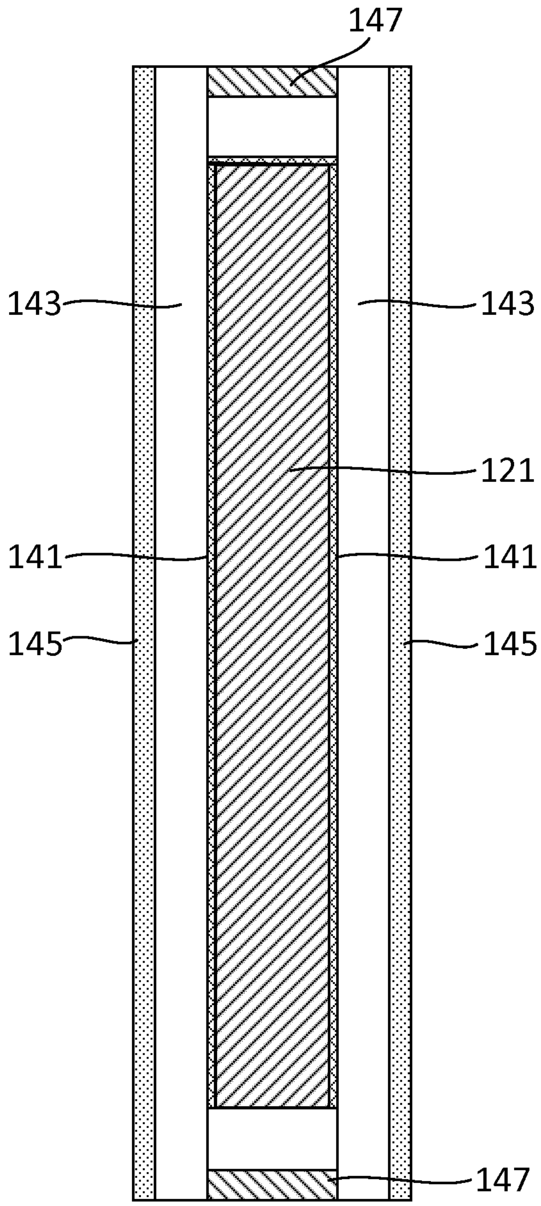


Fig. 6

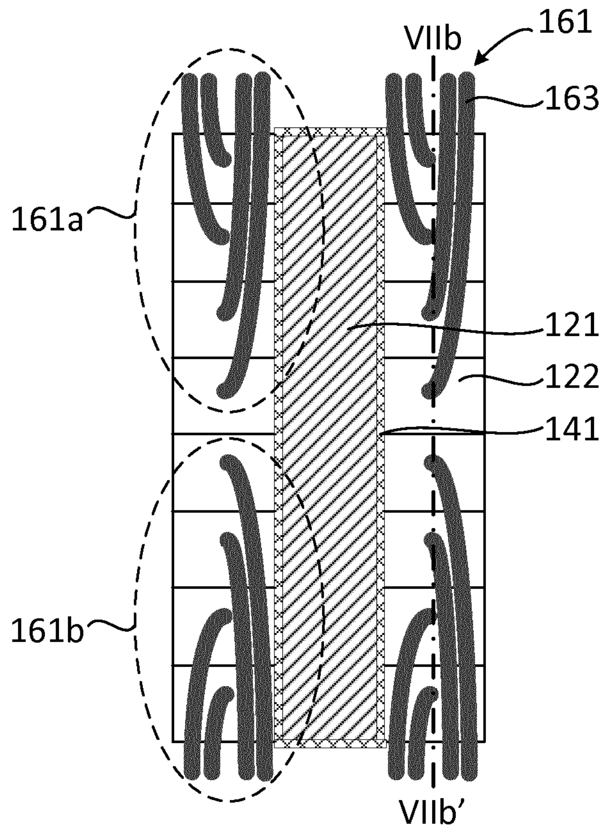


Fig. 7A

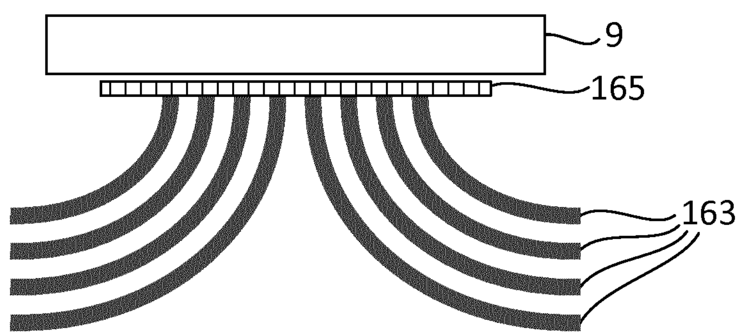


Fig. 7B

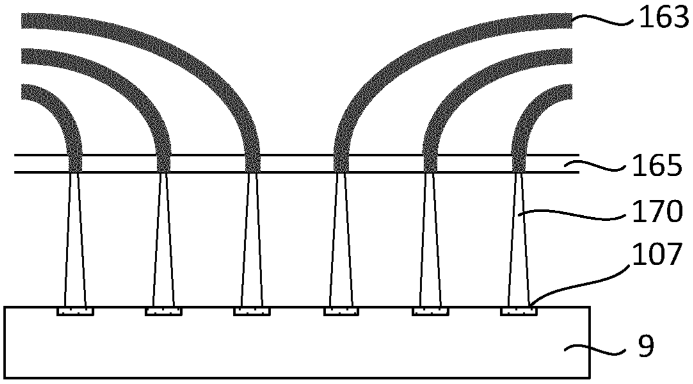


Fig. 8

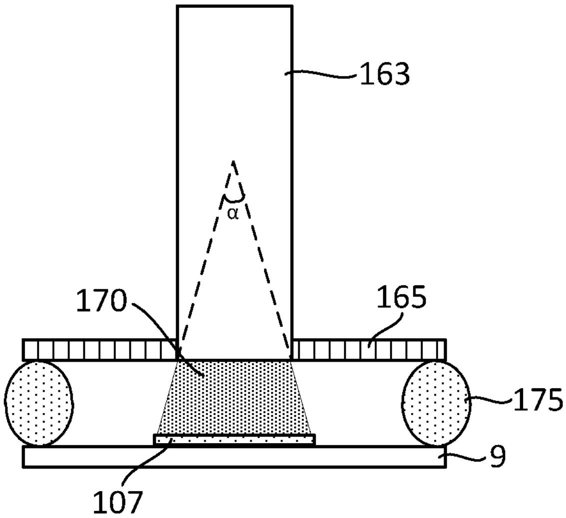


Fig. 9A

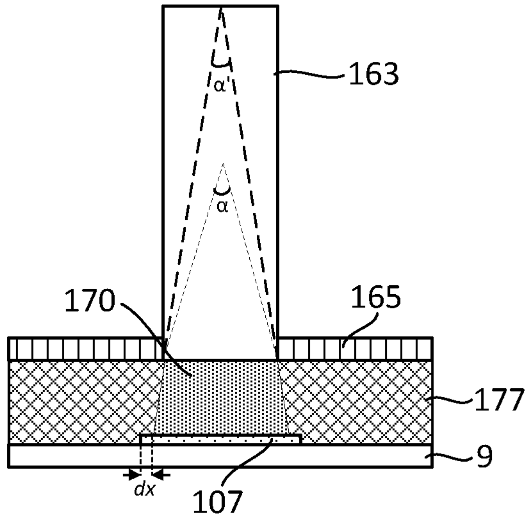
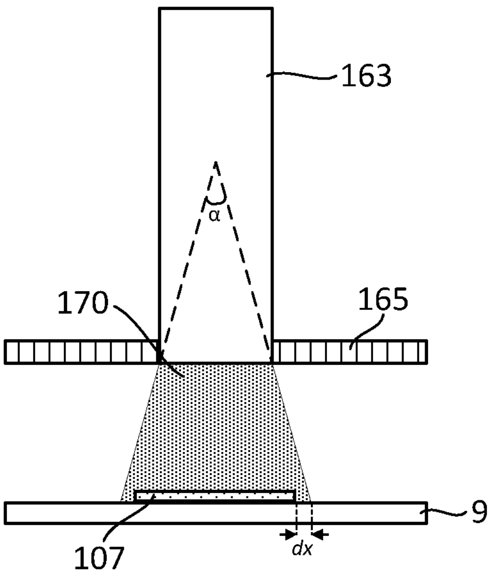


Fig. 9B

Fig. 10



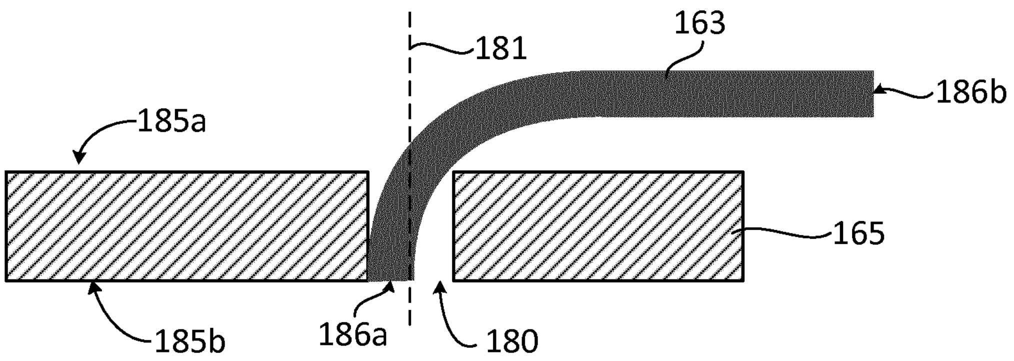


Fig. 11

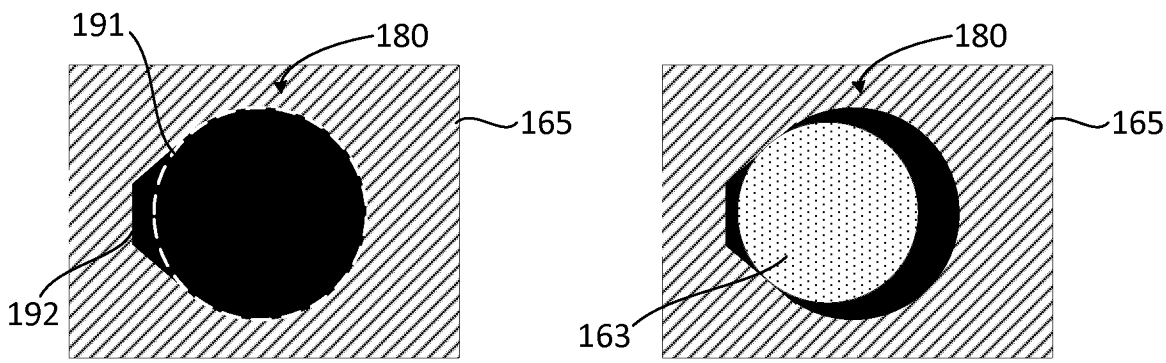


Fig. 12A

Fig. 12B

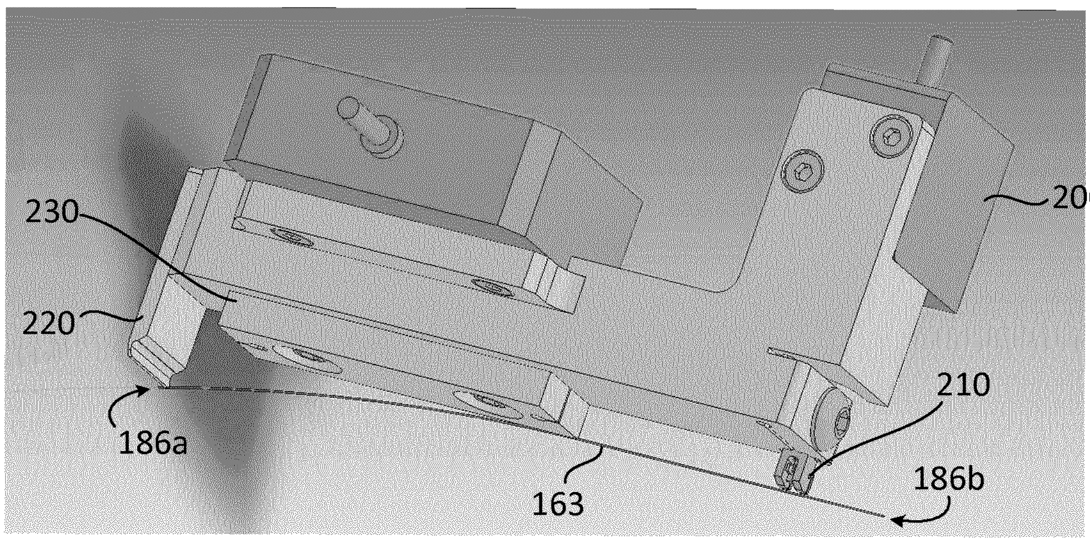


Fig. 13

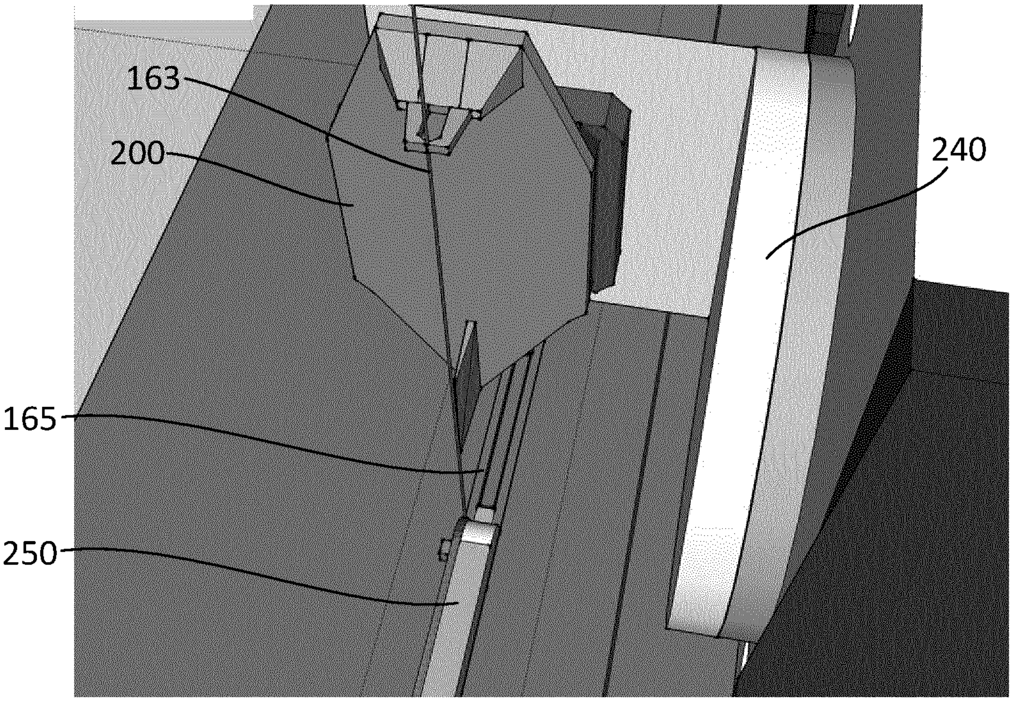


Fig. 14A

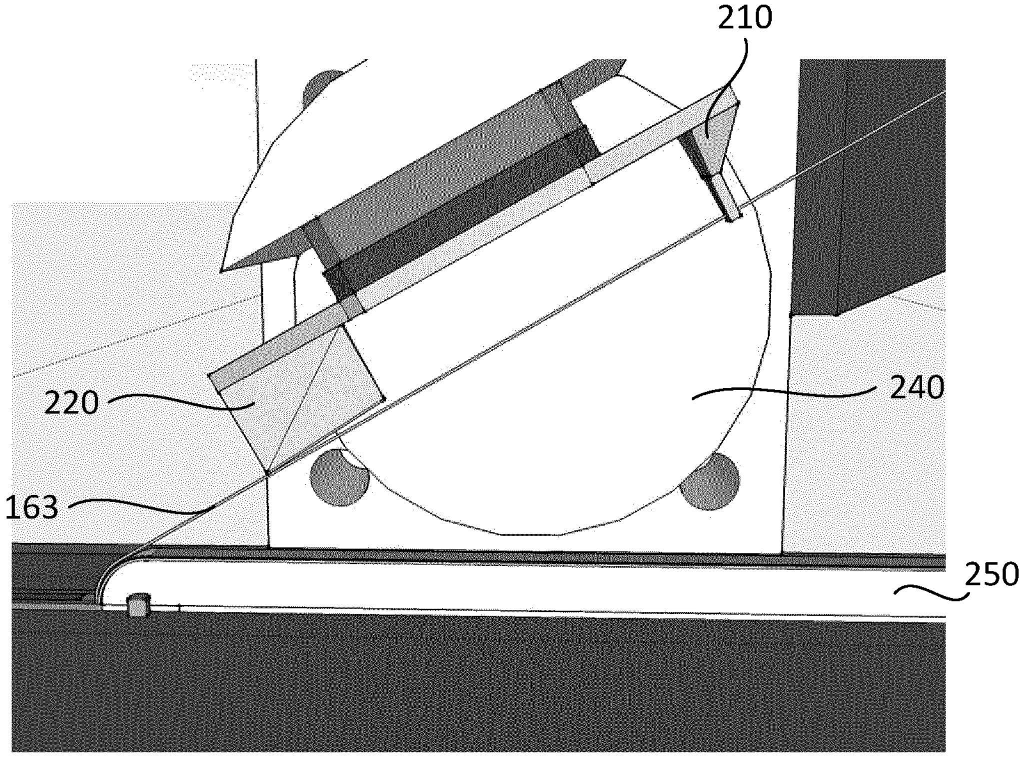


Fig. 14B

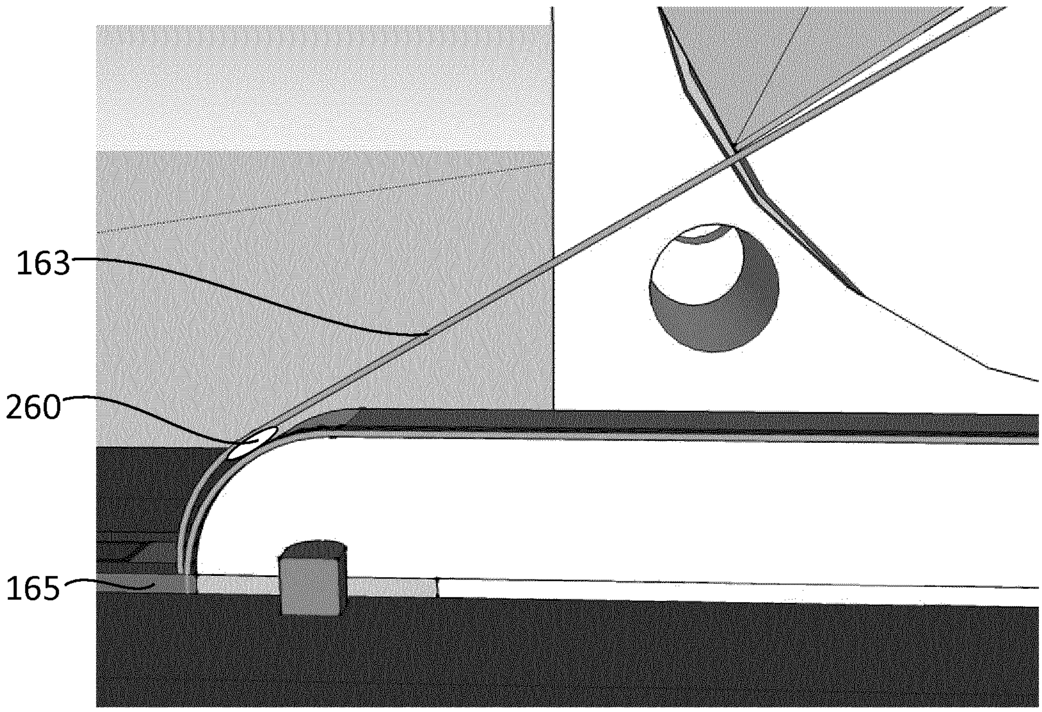


Fig. 14C

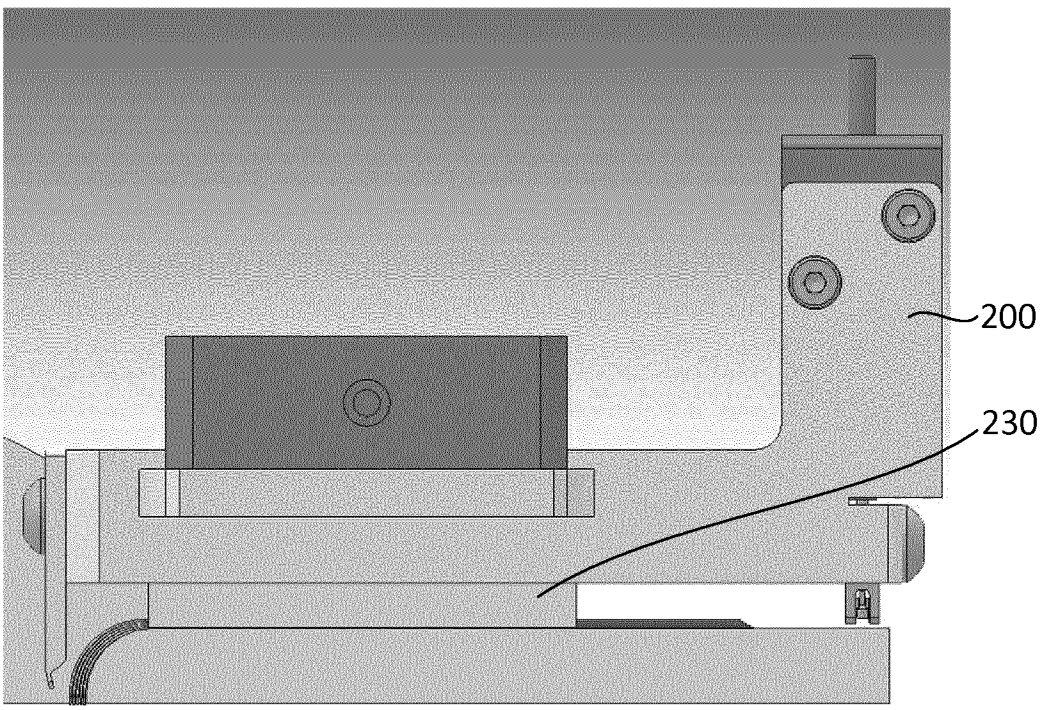


Fig. 14D

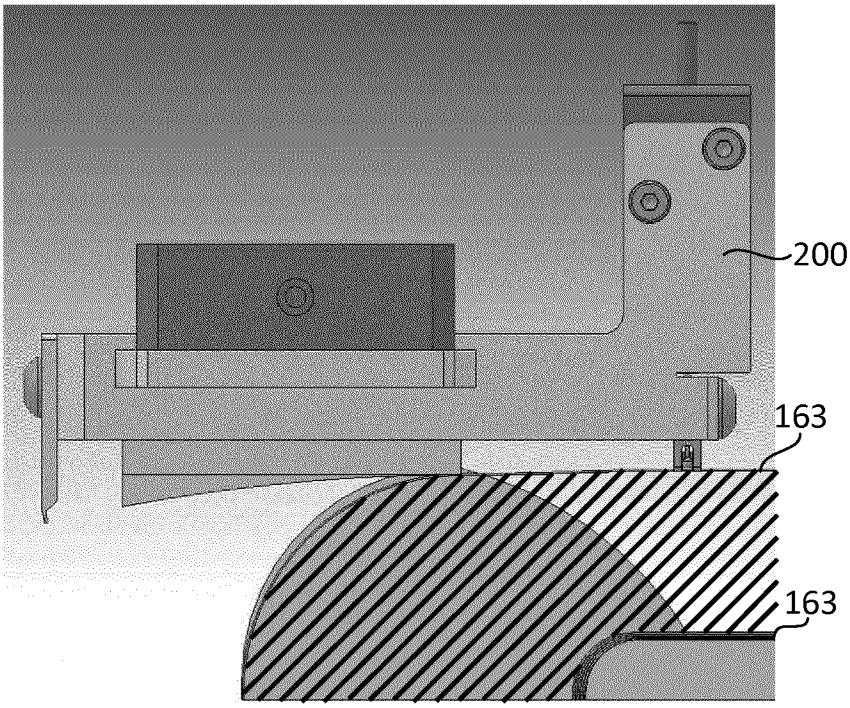


Fig. 14E

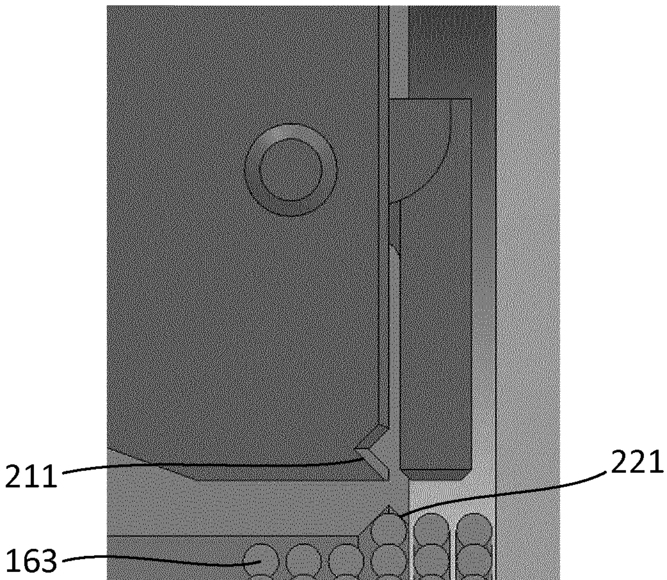


Fig. 15

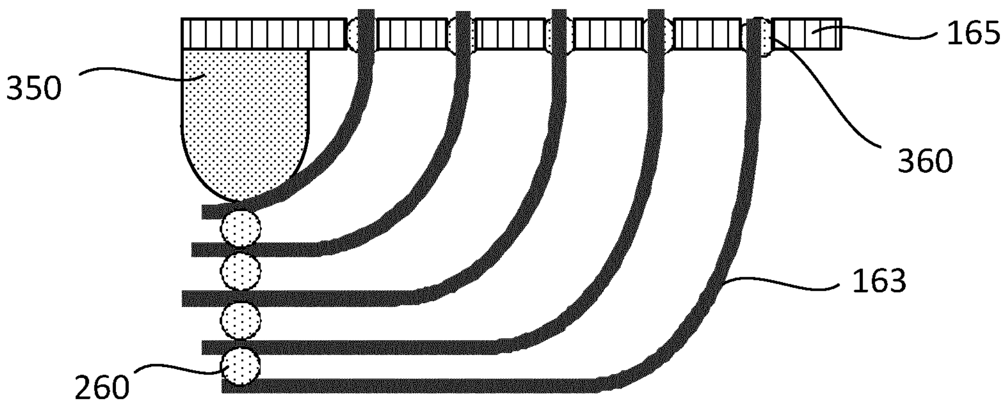

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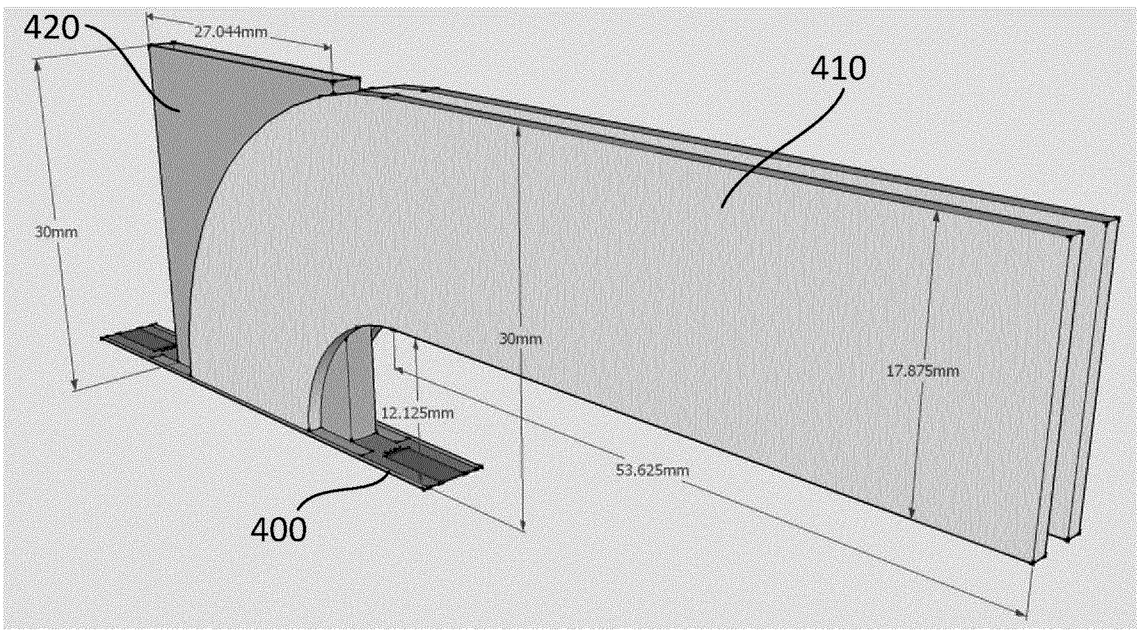
Fig. 16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12.125mm
53.625mm
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Fig. 17

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/057331

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01J37/04 H01J37/22 H01J37/317 G02B6/36
ADD.

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)
H01J G03F H01L G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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

EPO-Internal, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3 969 816 A (SWENGEL SR ROBERT CHARLES ET AL) 20 July 1976 (1976-07-20)	1-7, 9-12, 15-19
Y	abstract; figures column 9, line 26 - column 11, line 13	13,14, 21,22
A	column 14	8,20
Y	US 2004/094328 A1 (FJELSTAD JOSEPH C [US] ET AL) 20 May 2004 (2004-05-20) abstract; figures 18b, 19b, 19c, 19n	13,14
X	EP 1 441 247 A1 (FUJI XEROX CO LTD [JP]; FUJI PHOTO FILM CO LTD [JP]) 28 July 2004 (2004-07-28) abstract; figures	1,15

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"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

"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

"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

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Date of the actual completion of the international search

12 July 2012

Date of mailing of the international search report

25/07/2012

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Fax: (+31-70) 340-3016

Authorized officer

Opitz-Coutureau, J

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/057331

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2005/123231 A1 (NIITSU TAKEHIRO [JP] ET AL) 9 June 2005 (2005-06-09) abstract; figures -----	1
Y	US 6 958 804 B2 (WIELAND MARCO JAN-JACO [NL] ET AL) 25 October 2005 (2005-10-25)	21,22
A	the whole document -----	1-20

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2012/057331

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 3969816 A	20-07-1976	NONE	
US 2004094328 A1	20-05-2004	AU 2003302044 A1	15-06-2004
		US 2004094328 A1	20-05-2004
		WO 2004047509 A1	03-06-2004
EP 1441247 A1	28-07-2004	CN 1518245 A	04-08-2004
		EP 1441247 A1	28-07-2004
		JP 2004226584 A	12-08-2004
		KR 20040067806 A	30-07-2004
		US 2005100282 A1	12-05-2005
US 2005123231 A1	09-06-2005	JP 3952722 B2	01-08-2007
		JP 2003114353 A	18-04-2003
		US 2005123231 A1	09-06-2005
US 6958804 B2	25-10-2005	AT 538412 T	15-01-2012
		AU 2003274829 A1	13-05-2004
		CN 1717631 A	04-01-2006
		EP 1554634 A2	20-07-2005
		EP 2302457 A2	30-03-2011
		EP 2302458 A2	30-03-2011
		EP 2302459 A2	30-03-2011
		EP 2302460 A2	30-03-2011
		EP 2336830 A1	22-06-2011
		JP 2006504134 A	02-02-2006
		JP 2010171446 A	05-08-2010
		KR 20050083820 A	26-08-2005
		KR 20110031251 A	24-03-2011
		KR 20110044334 A	28-04-2011
		TW I300308 B	21-08-2008
		US 2004135983 A1	15-07-2004
		US 2006006349 A1	12-01-2006
		US 2007187625 A1	16-08-2007
		US 2008061247 A1	13-03-2008
		US 2008158536 A1	03-07-2008
		US 2008158537 A1	03-07-2008
		US 2012043457 A1	23-02-2012
		WO 2004038509 A2	06-05-2004