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(71) Applicant *(for all designated States except US)*: **CARL ZEISS SMT GMBH** [DE/DE]; Rudolf-Eber-Str. 2, 73447 Oberkochen (DE).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **HARTJES, Joachim** [DE/DE]; Sonnenstrasse 3, 73434 Aalen (DE).

(74) Agent: **COHAUSZ & FLORACK**; Bleichstraße 14, 40211 Düsseldorf (DE).

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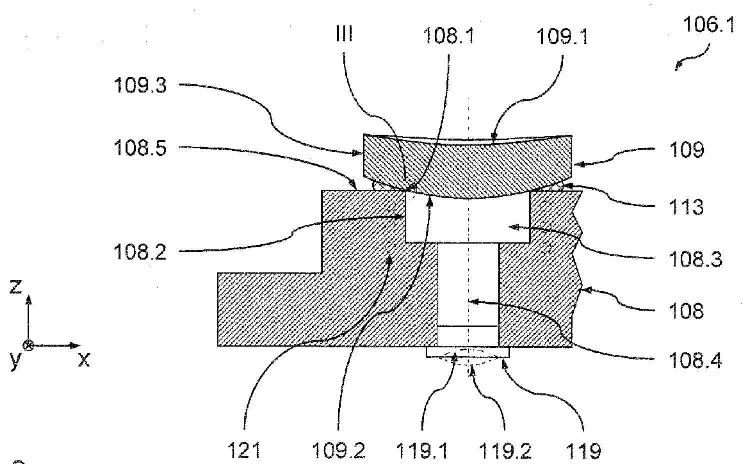

Fig. 2

(57) Abstract: There is provided a facet mirror device comprising a facet element and a support element, the support element supporting the facet element. The facet element comprises a curved first support section while the support element comprises a second support section, the second support section forming a support edge contacting the first support section in a region of contact to support the facet element.

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FACET MIRROR DEVICE

BACKGROUND OF THE INVENTION

The invention relates to a facet mirror device that may be used within an optical device used in exposure processes, in particular in microlithography systems. It further relates to an optical imaging arrangement comprising such a facet mirror device. It further relates to a method of supporting a facet element of a facet mirror device and a method of manufacturing a facet mirror device. The invention may be used in the context of photolithography processes for fabricating microelectronic devices, in particular semiconductor devices, or in the context of fabricating devices, such as masks or reticles, used during such photolithography processes.

Typically, the optical systems used in the context of fabricating microelectronic devices such as semiconductor devices comprise a plurality of optical element modules comprising optical elements, such as lenses, mirrors, gratings etc., in the light path of the optical system. Those optical elements usually cooperate in an exposure process to illuminate a pattern formed on a mask, reticle or the like and to transfer an image of this pattern onto a substrate such as a wafer. The optical elements are usually combined in one or more functionally distinct optical element groups that may be held within distinct optical element units. Facet mirror devices as the ones mentioned above, among others may serve to homogenize the exposure light beam, i.e. to effect a power distribution within the exposure light beam which is as uniform as possible.

Due to the ongoing miniaturization of semiconductor devices there is not only a permanent need for enhanced resolution but also a need for enhanced accuracy of the optical systems used for fabricating those semiconductor devices. This accuracy obviously not only has to be present initially but has to be maintained over the entire operation of the optical system. A particular problem in this context is proper heat removal from the optical components to avoid uneven thermal expansion of these components leading to uneven deformation of these components and, ultimately, to undesired imaging errors.

As a consequence highly sophisticated facet mirror devices have been developed such as they are disclosed, for example, in DE 102 05 425 A1 (Holderer et al.) and

DE 103 24 796 A1 (Roß-Meßemer), the respective entire disclosure of which is incorporated herein by reference.

Both these documents, among others, show facet mirror devices where facet elements with a spherical rear surface sit in an associated recess within a support element. The spherical rear surface rests against a corresponding spherical wall of the support element confining this recess. While such a sphere to sphere interface theoretically may provide a large area of contact with good heat transfer from the facet element to the support element, this large area contact mainly depends on the manufacturing accuracy of both, the facet element and the support element. In particular, the spherical recess is rather expensive to manufacture at an accuracy of a few microns or less as it is desirable in many cases in all three directions in space.

To overcome this problem DE 103 24 796 A1 (Roß-Meßemer) suggests to place a relatively soft coating (e.g. a gold coating) onto one of said spherical surfaces which compensates manufacturing tolerances by deformation. However, despite the low rigidity of this coating, due to the large contact area such deformation requires relatively large forces prone to introduce undesired deformation into the facet element.

Another approach is disclosed in DE 102 05 425 A1 (Holderer et al.) wherein the spherical rear surface of the facet element, more or less in a line contact, rests against a conical wall confining the recess receiving the facet element. This solution, due to the line contact provides a lower heat transfer while still not considerably reducing the manufacturing effort necessary for the conical wall to have the desired accuracy.

A third approach to support the facet elements is disclosed in DE 102 05 425 A1 (Holderer et al.) wherein the spherical rear surface of the facet element, more or less in a three point contact, rests against three small spheres each located at a free end of a support pin element. Here, the heat transfer is even worse while as well not considerably reducing the manufacturing effort necessary for the three small spheres to have the desired accuracy.

In all three cases outlined above, a manipulating lever is connected to the rear surface of the facet element, corresponding manipulators acting on said manipulating lever to adjust the position and, predominantly, the orientation of the facet element with respect to the support element. Furthermore, in some cases, the manipulating lever is used for fixing the facet element relative to the support element once it has bee adjusted, This solution has the disadvantage that the manipulating lever adds to the complexity and, ultimately, to the cost not only of the facet element but also of other components such as the support element. Furthermore, multiple manipulators are required generating mutually counteracting manipulation forces to allow accurate adjustment in a reasonable amount of time.

SUMMARY OF THE INVENTION

It is thus an object of the invention to, at least to some extent, overcome the above disadvantages and to provide a simple way of supporting a facet element of a facet mirror device at a high accuracy, in particular an accuracy of a few microns or less.

It is a further object of the invention to allow easy adjustment of the facet element to the desired position and orientation with respect to the support element.

These and other objects are achieved according to the invention which, on the one hand, is based on the teaching that it is possible to provide a simple and reliable, easily adjustable support to the facet element if the facet element is supported on a (preferably curved) support edge formed at the support element such that a general line contact exists between the support edge and the facet element. Such a curved support edge may be manufactured more easily at the desired accuracy.

Furthermore, such a high precision edge, as one possible variant to support the facet element, allows easy implementation of a further aspect of the invention, namely the use of negative pressure acting on the facet element to generate a contact load between the support element and the facet element. This has the advantage that the contact load (eventually adjustable via a corresponding adjustment of the negative pressure) generates a resistance against manipulation forces reducing the effort, in particular the number and/or complexity of the manipulators, necessary to adjust the facet element.

Thus, according to a first aspect of the invention there is provided a facet mirror device comprising a facet element and a support element, the support element supporting the facet element. The facet element comprises a curved first support section while the support element comprises a second support section, the second support section forming a support edge contacting the first support section in a region of contact to support the facet element.

According to a second aspect of the invention there is provided an optical imaging arrangement comprising a mask unit adapted to receive a pattern, a substrate unit adapted to receive a substrate, an illumination unit adapted to illuminate the pattern, an optical projection unit adapted to transfer an image of the pattern onto the substrate. At least one of the illumination unit and the optical projection unit comprises a facet mirror device, the facet mirror device comprising a facet element and a support element, the support element supporting the facet element. The facet element comprises a curved first support section, while the support element comprises a second support section, the second support section forming a support edge contacting the first support section in a region of contact to support the facet element.

According to a third aspect of the invention there is provided a method of supporting a facet element of a facet mirror device comprising providing a facet element and a support element, and supporting the facet element at a curved first support section of the facet element via a second support section of the support element, the second support section forming a support edge contacting the first support section in a region of contact to support the facet element.

According to a fourth aspect of the invention there is provided a method of manufacturing a facet mirror device comprising, in a preparation step, providing a facet element and a support element, the facet element having a front surface optically used during operation of the facet mirror device and a rear surface comprising a curved first support section, and the support element having a second support section forming a support edge, In a supporting step, the facet element is placed onto the support element such that the a curved support edge contacts the first support section in a region of contact to support the facet element.

According to a fifth aspect of the invention there is provided a method of manufacturing a facet mirror device comprising, in a preparation step, providing a facet element and a support element, the facet element having a front surface optically used during operation of the facet mirror device and a rear surface comprising a curved first support section, and the support element having a second support section. In a supporting step, the facet element is placed onto the support element such that the second support section contacts the first support section in a region of contact to support the facet element. In a contacting step of the supporting step, a negative pressure is generated, the negative pressure acting on a part of the rear surface of the facet element such that the first support section is pressed against the second support section.

Further aspects and embodiments of the invention will become apparent from the dependent claims and the following description of preferred embodiments which refers to the appended figures. All combinations of the features disclosed, whether explicitly recited in the claims or not, are within the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic representation of a preferred embodiment of an optical imaging arrangement according to the invention which comprises a preferred embodiment of a facet mirror device according to the invention and with which preferred embodiments of methods according to the invention may be executed;

Figure 2 is a schematic sectional representation of a part of a facet mirror device according to the invention, the facet mirror device being a part of the optical imaging arrangement of Figure 1 (in a section along line VII-VII of Figure 8);

Figure 3 is a schematic sectional representation of the detail III of Figure 2;

Figure 4 is a schematic sectional representation of the part of the facet mirror device of Figure 2 in a first manufacturing stage;

Figure 5 is a schematic sectional representation of the part of the facet mirror device of Figure 2 in a second manufacturing stage;

Figure 6 is a schematic sectional representation of the part of the facet mirror device of Figure 2 during operation of the optical imaging arrangement of Figure 1;

Figure 7 is a schematic sectional representation of the facet mirror device of Figure 2 to 6 (in a section along line VII-VII of Figure 8);

Figure 8 is a schematic top view of the facet mirror device of Figure 2 to 7;

Figure 9 is a schematic top view of a part of the support element the facet mirror device of Figure 2 to 8;

Figure 10 is a block diagram of a preferred embodiment of a method of manufacturing a facet mirror device comprising a preferred embodiment of a method of supporting the facet element according to the invention which may be used for the optical imaging arrangement of Figure 1.

Figure 11 is a schematic sectional representation of a detail of a further preferred embodiment of a facet mirror device according to the invention in a first manufacturing stage;

Figure 12 is a schematic sectional representation of the detail of Figure 11 in a second manufacturing stage;

Figure 13 is a schematic top view of a part of the support element the facet mirror device of Figure 11 and 12.

DETAILED DESCRIPTION OF THE INVENTION

First embodiment

In the following, a first preferred embodiment of an optical imaging arrangement 101 according to the invention will be described with reference to Figures 1 to 10. In order to facilitate the explanations given below an x,y,z-coordinate system has been introduced into the Figures and will be used throughout the following description. In the following, the z-direction designates the vertical direction. However, it will be appreciated that, with other embodiments of the invention, any other orientation in space of this x,y,z-coordinate system and the components of the optical imaging arrangement, respectively, may be chosen.

Figure 1 is a schematic and not-to-scale representation of the optical imaging arrangement in the form of an optical exposure apparatus 101 used in a microlithography process during manufacture of semiconductor devices. The optical exposure apparatus 101 comprises an illumination unit 102 and an optical projection unit 103 adapted to transfer, in an exposure process, an image of a pattern formed on a mask 104.1 of a mask unit 104 onto a substrate 105.1 of a substrate unit 105. To this end, the illumination unit 102 illuminates the mask 104.1. The optical projection unit 103 receives the light coming from the mask 104.1 and projects the image of the pattern formed on the mask 104.1 onto the substrate 105.1, e.g. a wafer or the like.

The illumination unit 102 comprises an optical element system 106 (only shown in a highly simplified manner in Figure 1) including a plurality of optical element units such as optical element unit 106.1. As will be explained in further detail below, the optical element unit 106.1 is formed as a preferred embodiment of a facet mirror device according to the invention. The optical projection unit 103 comprises a further optical element system 107 including a plurality of optical element units 107.1. The optical element units of the optical element systems 106 and 107 are aligned along a folded optical axis 101.1 of the optical exposure apparatus 101.

In the embodiment shown, the optical exposure apparatus 101 operates using light in the EUV range at a wavelength between 5 nm to 20 nm, more precisely at a wavelength of 13 nm. Thus, the optical elements used within the illumination unit 102 and the optical projection unit 103 are exclusively reflective optical elements. However, it will be appreciated that, with other embodiments of the invention working at different wavelengths, any type of optical elements (refractive, reflective or diffractive) may be used alone or in an arbitrary combination. The optical element system 107 may comprise a further facet mirror device according to the invention.

As can be seen from Figure 2 to 9, in particular from Figure 7 and 8, the facet mirror device 106.1 comprises a support element 108 supporting a plurality of facet elements 109. In the embodiment shown 900 facet elements 109 are supported on the support element 108. However, it will be appreciated that, with other embodiments of the invention, at any other number of facet elements 109 may be carried by the support element 108. For example, with certain preferred embodiments of the invention, up to 2000 facet elements 109 or even more are supported on the support element 108.

In the embodiment shown, the facet elements 109 are arranged such that a small gap of less than 0.05 mm is left between them. Hence, as can be seen in particular from Figure 8, a regular rectangular matrix of facet elements 109 is formed on the support element 108 providing a minimum amount of loss in radiant power. However, it will be appreciated that, with other embodiments of the invention, any other arrangement of facet elements may be chosen according to the optical needs of the imaging device, the facet mirror device is used for.

As can be further seen from Figure 2 to 9, in particular from Figure 8, each facet element 109, in a top view (along the z-direction), has an outer contour of substantially rectangular shape, more precisely of substantially squared shape. However, with other embodiments of the invention, any other geometry of this outer contour may be chosen such as, for example, an arbitrarily curved outer contour, a circular outer contour, an elliptic outer contour, a polygonal outer contour or arbitrary combinations thereof.

In the embodiment shown, each facet element has a concave front surface 109.1, a convex rear surface 109.2 and a lateral surface 109.3. The front surface 109.1 is a reflective surface optically used during operation of the optical imaging arrangement 101 in order to provide homogenization of the exposure light provided by the illumination unit 102. The reflective surface 109.1 may be provided via a reflective coating applied to the front surface 109.1 which is adapted to the wavelength of the exposure light used (typically, in order to provide maximum reflectivity at the respective wavelength).

In the embodiment shown, the front surface 109.1 is a spherical surface. However, it will be appreciated that, with other embodiments of the invention, any other shape of the front surface may be chosen depending on the optical task to be performed by the facet mirror device. Hence, apart from such spherical surfaces, aspherical as well as planar surfaces as well as arbitrary combinations thereof may be used. Furthermore, convex front surfaces may also be used.

Furthermore, in the embodiment shown, the rear surface 109.2 also is a spherical surface which is free from any protrusions radially protruding beyond this spherical surface defined by the first support section 109.4 of the rear surface 109.2. On the one hand, this has the advantage that the parts of the rear surface 109.2 contacting the support element 108 (i.e. the first support section 109.4) and the parts of the rear surface 109.2 reaching into the recess 108.3 may be easily produced in a typical, well-established lens manufacturing process providing excellent accuracy of the rear surface 109.2.

Using such well-established lens manufacturing processes the radius of curvature of the front surface 109.1 and the rear surface 109.2, the outer contour of the lateral surface 109.3, the centering of the facet element 109, the central as well as the lateral thickness (dimension in the z-direction) may be manufactured at a very high precision using such conventional lens manufacturing techniques.

On the other hand, since (other than with the known designs mentioned initially) no radially protruding manipulating levers or the like are mounted to the rear surface 109.2, there is no risk that such a mounting process introduces deformations adversely affecting the geometric accuracy of the rear surface 109.2.

In the embodiment shown, a part of the rear surface 109.2 of the facet element 109 forms a spherical first support section 109.4 contacting a second support section formed by a support edge 108.1 of the support element 108. The support edge 108.1 is formed at an end of a cylindrical wall 108.2 confining a cylindrical recess 108.3 within the support element 108.

As can be seen from figure 9, the recess 108.3 is of circular cross-section, such that the curvature of the support edge 108.1 in the xy-plane corresponds to the curvature of the rear surface 109.2 in the region of contact between the first support section 109.4 and the second support section, i.e. the support edge 108.1.

Furthermore, the support edge 108.1 is formed as a sharp edge having an edge radius, i.e. a minimum radius of curvature, which is less than 0.5 mm to 3 mm. Preferably, the edge radius ranges from 1.0 mm to 2.0 mm. This minimum radius of curvature is measured in a radial plane which, in the embodiment shown, contains the axis 108.4 of the recess 108.3.

It will be appreciated that, typically, the edge radius is about 5% to 20%, preferably about 10% to 15%, of the maximum dimension of the facet element 109 in its plane of main extension (here: xy-plane). In the embodiment shown, this maximum dimension is about 5 mm to 10 mm, although smaller or larger dimensions may be chosen depending on the optical requirements for the facet mirror device.

The use of such a sharp support edge 108.1 has the advantage that the support edge 108.1 may be easily manufactured at very high precision. The only comparatively simple manufacturing steps to be taken are to provide the cylindrical recess 108.3 and a planar upper surface 108.5 of the support element 108. Both operations may be comparatively easily performed at very high precision. For example, high precision manufacturing techniques such as chemical-mechanical polishing (CMP), pitch polishing, magneto-rheological fluid polishing (MRFP) and robotic polishing may be used when producing the support edge 108.1.

Hence, in the embodiment shown, a distance tolerance between axes 108.4 of adjacent recesses 108.3 of a few microns, typically about 5 μm, may be obtained. Furthermore, the angular deviation of the axis 108.4 from a surface normal on the upper surface 108.5 is less than 0.005°.

Consequently, generally, a continuous annular line contact exists between the spherical first support section 109.4 of the rear surface 109.2 and the continuous ring-shaped support edge 108.1. Obviously, manufacturing tolerances (as indicated in Figure 3 by the dashed contours

110 and 111) may still lead to a deviation from this (ideal) line contact. However, in the embodiment shown, the support edge and the facet element are manufactured at a manufacturing accuracy which is selected such that, at any edge point of support edge 108.1, a width GW of a manufacturing tolerance related local gap between the support edge 108.1 and the rear surface 109.2 of the facet element 109 is less than 0.5 μm to 10 μm, preferably less than 1 μm to 5 μm. As shown in Figure 3, this gap width GW is the dimension in a direction of a surface normal of the rear surface 109.2 extending through the respective edge point.

As will be explained now in greater detail with reference to Figures 2 to 10 the facet mirror device 106.1 is manufactured according to a preferred embodiment of the method according to invention using a preferred embodiment of the method of supporting a facet element according to the invention.

According to Figure 10, in a preparation step 112.1, the support element 108 and the facet elements 109 are manufactured as it has been outlined above. In the embodiment shown, the facet elements are made of silicon (Si), while the support element is made of silicon carbide (SiC). With such a material pairing and beneficial heat transfer from the facet elements 109 (typically reaching temperatures of 100°C to 150°C during operation of the imaging arrangement 101) may be obtained.

However, it will be appreciated that, with other embodiments of the invention, the facet element may be made of silicon carbide (SiC), quartz (SiO_2), nickel plated copper or steel, while the support element may be made of silicon infiltrated silicon carbide (SiSiC) or tungsten carbide (WC).

Then, in a contacting step 112.3 of a supporting step 112.2, a facet element 109 is placed from above along the z-direction on the support edge 108.1 (using a suitable handling device not shown) after a ring of an adhesive bonding material 113 has been placed on the upper surface 108.5 of the support element 108 adjacent to the support edge 108.1 (see Figure 4).

Slightly before or after the facet element 109 has been placed on the support edge 108.1 a negative pressure is generated within the recess 108.3 using a suction device 114 controlled by a control device 115. To this end, the suction device 114 is connected to a connector 116 which in turn is connected to a connector section 108.6 of the wall 108.2.

This negative pressure within the recess 108.3 has the effect that the rear surface 109.2 of facet element 109 is pressed against the support edge 108.1 holding the facet element in place without any need for additional manipulators, clamping devices etc. The high precision of the support edge 108.1 and the rear surface 109.2 themselves (due to the only very small gap present in the worst case) already guarantee that even only a slight negative pressure within the recess 108.3 is sufficient to reliably generate a well-defined line load between the support edge 108.1 and facet element 109 reliably holding the latter in place.

Furthermore, even if there was a gap (with a gap width GW) due to manufacturing tolerances, the adhesive material 113 would be sucked into this gap sealing the latter. Hence, in any case, the negative pressure generated by the suction device 114 provides proper holding forces holding the facet element 109 in place.

In the embodiment shown, the suction device 114 generates a pressure of about $5 \cdot 10^{-3}$ mbar within the recess 108.3. However, it will be appreciated that, with other embodiments of the invention, any other pressure level may be provided in the recess, the pressure level being selected as a function of the forces to be generated for holding the facet element in place.

It will be appreciated that the viscosity of the adhesive material 113 may be selected sufficiently high to avoid excess intake of adhesive material 113 into the recess 108.3 through such eventual gaps. Hence, in any case, the adhesive material forms a sealing ring (at least predominantly) located outside the recess 108.3 (i.e. on a side of the support edge 108.1 facing away from the recess 108.3) and surrounding the contact region between the facet element 109 and the support element 108 (see e.g. Figures 2 and 4 to 7).

Then, in an adjustment step 112.4 of the supporting step 112.2, the orientation of the facet element 109 with respect to the support element 108 is adjusted according to the optical requirements for the facet mirror device 106.1 during later operation in the imaging arrangement 101.

To this end, a contactless manipulator 117 controlled by the control device 115 is used to generate a corresponding adjustment force on the front surface 109.1 of the facet element 109 as it is shown in Figure 5. The manipulator is a pneumatic manipulator generating a jet of air 117.1 expelled towards the front surface 109.1 thereby exerting an adjustment force on the facet element 109. Under the control of the control device 115 a relative motion may be generated between the manipulator 117 and the facet mirror device 106.1 is such that the manipulation force F generated by the jet of air 117.1 may act on the facet element 109 at the appropriate location to provide proper adjustment of the latter.

However, it will be appreciated that, with other embodiments of the invention, and any other contactless or contact type manipulator (such as a tactile manipulator, a cantilever spring manipulator etc) or combinations thereof may be chosen to exert the adjustment force on to the facet element. In particular, as a further contactless manipulator an acoustic manipulator may be used generating standing acoustic waves, the acoustic pressure of which generating the manipulating force F acting on the facet element.

Assessment of the adjustment of the optically used front surface 109.1 is performed using the measurement results of a measurement device 118. In the present embodiment, the measurement device 118 is an optical device comprising an emitter 118.1 emitting a measurement light beam 118.2 towards the front surface 109.1. The measurement light beam 118.2 is reflected at the front surface 109.1 and reaches a sensor 118.3 of the measurement device 118.

In the embodiment shown, the emitter is a conventional emitter using measurement light at a wavelength of 633 nm. Hence, it may be necessary to provide a measurement section 119 at the front surface 109.1 having a reflective coating adapted to this wavelength of the measurement light (provided that the reflective coating of the front surface 109.1 adapted to the exposure light does not provide sufficient reflection at the measurement light wavelength). However, it will be appreciated that, with other embodiments of the invention, other wavelengths may be used for the measurement light, such that, eventually, no such additional measurement section may be necessary.

The signals of the sensor 118.3 are forwarded to the control device 115 which, in turn, performs the assessment of the adjustment of the front surface 109.1 using these signals. It will be appreciated that the control device 115, as a function of the signals of the sensor 118.3, controls the suction device 114 and the manipulator 117 to provide rapid proper adjustment of the front surface 109.1.

It will be appreciated that, in the embodiment shown, the front surface 109.1 is adjusted at an angular accuracy of less than 100 µrad. However, it will be appreciated that, with other embodiments of the invention, depending on the optical requirements during later operation of the imaging arrangement 101, any other angular accuracy may be chosen.

For example, under the control of the control device 115, the negative pressure within the recess 108.3 may be reduced to reduce the holding force exerted on the facet element 109. This in turn reduces the amount of the manipulation force to be exerted by the manipulator 117 in order to achieve an adjustment movement of the front surface 109.1. On the other hand, once it has been detected that the proper alignment of the front surface 109.1 has been achieved, the control device 115 may cause the suction device 114 to increase the negative pressure to securely hold the facet element in place.

Consequently, in a highly beneficial way, this suction device 114 forms a holding device generating the negative pressure in the recess 108.3 which in a very simple, contactless manner generates a stabilizing contact force between the facet element 109 and the support element 108. This contact force in turn leads to an adjustable resistance against dislocation of the facet element 109 without any risk of dislocating the facet element 109 due to a malfunction of the holding device.

It will be appreciated that this stabilizing effect may be achieved in a very simple manner using the specific design of the support element 108 with the support edge 108.1 as outlined above. However, the inventive concept of generating a negative pressure acting on the facet element to hold the latter in place is independent of the design of the cooperating support sections of the support element and the facet element as long as a sufficiently air tight connection between the support sections is exists such that the negative pressure may generate the stabilizing contact force between the support element and the facet element.

Once the adjustment of the facet element 109 is completed, in a facet fixation step 112.5 of the supporting step 112.2, the facet element 109 is fixed in place by curing the adhesive bonding material 113 such that a fixed adhesive connection is established between the facet element 109 and the support element 108. However, it will be appreciated that, with other embodiments of the invention, apart from the gluing technique as outlined above, any other suitable bonding technique may be used alone or in arbitrary combination to provide proper connection and relative fixation between the facet elements and the support element. Such suitable bonding techniques include, for example, soldering, laser soldering, welding, laser welding, diffusion bonding etc. It will be appreciated that, if diffusion bonding is used, the negative pressure in the recess 108.3 may be increased to at least support the contact pressure needed in the bonding process.

It will be appreciated that, with other embodiments of the invention, the bonding material 113 may also be applied at any point in time during or after the adjustment of the facet element as it has been outlined above.

It will be further appreciated that the adhesive material 113 may be selected to have a high thermal conductivity such that good heat transfer from the facet element 109 to the support element 108 achieved. Furthermore, in cases where high thermal conductivity of the bond between the facet element and the support element is crucial, other bonding techniques (e.g. soldering, welding, diffusion bonding) providing better heat transfer may be used.

In a step 112.6 it is then checked if a further facet element 109 is to be mounted to the support element 108. If this is the case the method jumps back to step 112.3 for executing the supporting step for the next facet element 109 to be mounted. Otherwise, the method ends in step 112.7

In certain embodiments of the present invention, at the end of the fixation step 112.5 or at any later point in time (in particular after mounting all of the facet elements 109), the recess 108.3 may be filled with a liquid heat transfer medium having high thermal conductivity to improve heat transfer from the facet element 109 to the support element 108. To this end, the recess 108.3 may be sealed using a cap 120 as it is shown in Figure 2.

The cap 120 may be provided with an elastic portion compensating thermal expansion of the heat transfer medium by elastic deformation as it is indicated in Figure 2 by the contours 120.1 and 120.2. By this means excessive load on the facet element 109 (caused by such a thermal expansion of the heat transfer medium) can be avoided which might otherwise lead to an undesired deformation of the facet element 109, in particular the reflective front surface 109.1 optically used during operation.

It will be appreciated that this introduction of a heat transfer medium into the respective recess 108.3 may be a one-time operation since the ring-shaped adhesive material 113 and the cap 120 provide long-term sealing of the recess 108.3. However, regular exchange refill of the heat transfer medium may be provided (e.g. via the cap 120) if necessary.

Heat removal from the facet mirror device 106.1 during operation of the imaging arrangement 101 may be achieved using a cooling medium circulating through cooling channels as they are indicated by the dashed contours 121 (see e.g. Figures 2 to 6).

With further embodiments of the invention, the respective recess 108.3 itself forms part of a cooling channel system, wherein, during operation of the imaging arrangement 101, a cooling medium is circulated by a cooling device 122 (controlled by the control device 115) connected to the recess 108.3 via the connector 116 as it is shown in Figure 6.

With certain embodiments of the invention, e.g. at a later stage after initial manufacture of the facet mirror device 106.1 repair and exchange of one or more facet elements 109 may be executed using repair variants of the methods as outlined above.

To this end, in a dismounting step of the preparation step 112.1, a thermal load may be applied to the respective facet element 109 to be repaired or exchanged. This thermal load is selected to cause a sufficiently high and/or rapid thermal expansion difference between the facet element 109 and the support element 108 causing failure (e.g. fracture or disintegration) of the bonding material 113. At this stage, the facet element 109 may then be removed from the support element 108. This step may be repeated for any facet element 109 to be removed.

Furthermore, in a further working step of the preparation step 112.1, the support element may be worked (e.g. removing any residue of the broken or disintegrated bonding material 113) in order to allow mounting of replacement facet element 109. Once this is done, the method may proceed to step 112.2 and be executed as it has been outlined above to mount a replacement facet element 109 for any facet element 109 removed previously.

Second embodiment

In the following, a second embodiment of the facet mirror device 206.1 according to the invention will be described with reference to Figures 11 to 13. The facet mirror device 206.1 in its basic design and functionality largely corresponds to the facet mirror device 106.1 and may replace the facet mirror device 106.1 in the optical imaging device 101 of Figure 1. In particular, the method of supporting a facet element and the method of manufacturing the facet mirror device as they have been described above in relation to the first embodiment (Figure 10) may be executed as well in the context of this facet mirror device 206.1. Thus, it is here mainly referred to the explanations given above and only the differences with respect to the facet mirror device 106.1 will be explained in further detail. In particular, similar parts are given the same reference numeral raised by the amount 100 and (unless explicitly described in the following) in respect to these parts reference is made to the explanations given above in the context of the first embodiment.

The only difference with respect to the facet mirror device 106.1 lies within the fact that the support edge 208.1 is provided with eight small radial slots 208.7 (evenly distributed at the circumference of the support edge 208.1). Hence, the support edge 208.1 is a segmented edge comprising eight support edge segments 208.8 mutually separated by one of the radial slots 208.7. However, it will be appreciated that, with other embodiments of the invention, any other number and/or arrangement of the radial slots may be chosen.

As can be seen from Figure 11 and 12 were radial slots 208.7 and the fact that the negative pressure within the recess 208.3 draws off any inclusions of air 223 (see Figure 11) between the adhesive material 113 and the contact region between the rear surface 109.2 of the facet element 109 and the support edge 208.1.

In the embodiment shown, the dimensions of the respective radial slot 208.7, the viscosity of the adhesive material 113 and the negative pressure are mutually adapted such that, on the one hand, the adhesive material is partially drawn into the respective slot 208.7 about that, on the other hand, no substantial intake of adhesive material 113 into the recess 208.3 takes place.

Such a configuration has the advantage that a comparatively large surface of both the support element of 208 and the rear surface 109.2 of the facet element 109 is reliably and fully wetted by the adhesive material leading to a good adhesive contact between the adhesive material 113 and the facet element 109 and the support element 208, respectively.

In the foregoing, the invention has been described in the context of a plurality of embodiments where the first support section on the rear surface of the facet element is a spherical surface while the support edge is a planar circular edge. However, it will be appreciated that, with other embodiment of the invention, any other design with mating (arbitrary) curvatures between the first support section and the support edge may be chosen. For example, a configuration may be chosen wherein the first support section on the rear surface of the facet element is a cylindrical surface contacting a curved support edge (substantially extending along the circumference of the cylindrical surface). In addition or as an alternative the cylindrical surface of the first support section may contact at least one straight support edge (substantially extending parallel to the longitudinal axis of the cylindrical surface).

In the foregoing, the invention has been described in the context of embodiments where the optical module according to the invention is used in the illumination unit. However, it will be appreciated that the optical module according to the invention may provide its beneficial effects as well in the optical projection unit.

In the foregoing, the invention has been described in the context of embodiments working in the EUV range. However, it will be appreciated that the invention may also be used at any other wavelength of the exposure light, e.g. in systems working at 193 nm etc.

Finally, in the foregoing, the invention has been described solely in the context of microlithography systems. However, it will be appreciated that the invention may also be used in the context of any other optical device using facet mirror devices.

* * * * *

What is claimed is:

1. A facet mirror device comprising

- a facet element and
- a support element;
- said support element supporting said facet element;
- said facet element comprising a curved first support section;
- said support element comprising a second support section;
- said second support section forming a support edge contacting said first support section in a region of contact to support said facet element.

2. The facet mirror device according to claim 1, wherein at least one of

- said region of contact has a first curvature and said second support section has a second curvature corresponding to said first curvature in such a manner that generally a line contact exists between said support edge and said facet element;

and

- said support edge is formed by at least one edge segment;

and

- said support edge is a continuous ring shaped edge;

and

- said support edge is formed at an end of a wall confining a recess within said support element;

and

- said first support section has a spherical surface in said region of contact.

3. The facet mirror device according to claim 1, wherein at least one of

- said facet element is connected to said support element by an adhesive bond;

and

- said facet element is connected to said support element via a bonding material located adjacent to said support edge;

and

- said facet element is adhesively connected to said support element in a region of contact between said support edge and said first support section;

and

- said facet element is connected to said support element by at least one bonding technique selected from a group of bonding techniques consisting of gluing, soldering, laser soldering, welding, laser welding, diffusion bonding.

4. The facet mirror device according to claim 3, wherein at least one of

- said support edge is formed at an end of a wall confining a recess within said support element, at least a majority of said bonding material being located at a side of said support edge facing away from said recess;

and

- said bonding material is sealing a gap between said facet element and said support element;

5. The facet mirror device according to claim 1, wherein at least one of

- said support edge is a sharp edge defining a minimum edge radius of curvature, said minimum radius of edge curvature being less than 0.5 mm to 3 mm

and

- said support edge and said facet element are manufactured at a manufacturing accuracy, said manufacturing accuracy being selected such that, at any edge point of said support edge, a width of a manufacturing tolerance related gap between said support edge and said facet element is less than 0.5 µm to 10 µm

6. The facet mirror device according to claim 1, wherein

- said facet element comprises an at least partially reflective front surface and a rear surface, said first support section being part of said rear surface,

wherein at least one of

- said rear surface is substantially free from protrusions;

and

- said first support section is part of a rear surface of said facet element, said first support section defining a continuously curved shell, in particular a spherical shell, and said rear surface being substantially free from protrusions protruding from said rear surface beyond said spherical shell;

and

- at least said rear surface of said facet element is manufactured in a lens manufacturing process;

and

- said front surface of said facet element comprises a reflective surface area adapted to be used in an orientation adjustment operation during mounting of said facet element to said support element;

and

- said front surface of said facet element has an outer contour that is at least one of at least section wise curved and at least section wise polygonal.

7. The facet mirror device according to claim 1, wherein at least one of

- said facet element is made of a first material selected from a first material group consisting of silicon (Si), silicon carbide (SiC), quartz (SiO_2), nickel plated copper and steel;

and

- said support element is made of a second material selected from a second material group consisting of silicon carbide (SiC), silicon infiltrated silicon carbide (SiSiC) and tungsten carbide (WC).

8. The facet mirror device according to claim 1, wherein at least one of

- said support edge is formed at an end of a wall confining a recess within said support element, said wall being provided with a connector section adapted to connect a suction means to said recess generating a negative pressure within said recess, said negative pressure adjustably fixing said facet element relative to said support element during mounting of said facet element to said support element;

and

- said support element comprises at least one cooling duct adapted to receive a cooling medium during operation of said facet mirror device;

and

- said support edge is formed at an end of a wall confining a recess within said support element, said recess being filled with one of a cooling medium and a heat transfer medium, said heat transfer medium improving heat transfer from said facet element to said support element.

9. The facet mirror device according to claim 1, wherein at least one of

- said support element comprises a plurality of further second support sections, each of said further second support sections supporting a further facet element;

and

- said support element supports at least 1000 facet elements.

10. An optical imaging arrangement comprising

- a mask unit adapted to receive a pattern,
- a substrate unit adapted to receive a substrate;
- an illumination unit adapted to illuminate said pattern;
- an optical projection unit adapted to transfer an image of said pattern onto said substrate;
- at least one of said illumination unit and said optical projection unit comprising a facet mirror device,
- said facet mirror device comprising a facet element and a support element;
- said support element supporting said facet element;
- said facet element comprising a curved first support section;
- said support element comprising a second support section;
- said second support section forming a support edge contacting said first support section in a region of contact to support said facet element.

11. A method of supporting a facet element of a facet mirror device comprising

- providing a facet element and a support element;

- supporting said facet element at a curved first support section of said facet element via a second support section of said support element;
- said second support section forming a support edge contacting said first support section in a region of contact to support said facet element.

12. The method according to claim 11, wherein at least one of

- said facet element is connected to said support element by an adhesive bond;

and

- said facet element is connected to said support element via a bonding material located adjacent to said support edge;

and

- said facet element is adhesively connected to said support element in a region of contact between said support edge and said first support section;

and

- said facet element is connected to said support element by at least one bonding technique selected from a group of bonding techniques consisting of gluing, soldering, laser soldering, welding, laser welding, diffusion bonding.

13. The method according to claim 12, wherein at least one of

- said support edge is formed at an end of a wall confining a recess within said support element, a majority of said bonding material being located at a side of said support edge facing away from said recess;

and

- said bonding material is sealing a gap between said facet element and said support element;

and

- said support edge is formed at an end of a wall confining a recess within said support element, said recess being filled with one of a cooling medium and a heat transfer medium, said heat transfer medium improving heat transfer from said facet element to said support element.

14. A method of manufacturing a facet mirror device comprising,

- in a preparation step, providing a facet element and a support element, said facet element having a front surface optically used during operation of said facet mirror device and a rear surface comprising a curved first support section, and said support element having a second support section forming a support edge;

- in a supporting step, placing said facet element onto said support element such that said a curved support edge contacts said first support section in a region of contact to support said facet element.

15. The method according to claim 14, wherein at least one of,

- in a contacting step of said supporting step, a negative pressure is generated, said negative pressure acting on a part of said rear surface of said facet element such that said first support section is pressed against said support edge;

and

- in a facet adjustment step of said supporting step, an adjustment of at least one of a position and an orientation of said facet element with respect to said support element is performed according to optical needs during operation of said facet mirror device

and

- in a facet fixation step of said supporting step, an fixation of said facet element with respect to said support element is performed.

16. The method according to claim 15, wherein at least one of

- in said contacting step, said negative pressure is generated in a recess within said support element, said recess being confined by a wall forming said support edge;

and

- in said facet adjustment step, at least a fraction of said negative pressure is maintained such that said adjustment has to be performed against a resistance resulting from a contact load between said support edge and said facet element;

and

- in said facet adjustment step, said negative pressure is at least temporarily increased upon completion of said adjustment to secure said facet element against relative motion with respect to said support element;

and

- in said facet fixation step, an adhesive bond is generated between said facet element and said support element.

and

- in said facet fixation step, said facet element is connected to said support element by at least one bonding technique selected from a group of bonding techniques consisting of gluing, soldering, laser soldering, welding, laser welding, diffusion bonding.

and

- after said facet fixation step, a recess confined by a wall forming said support edge is filled with one of a cooling medium and a heat transfer medium, said heat transfer medium improving heat transfer from said facet element to said support element.

17. The method according to claim 16, wherein

- in one of said contacting step, said facet adjustment step and said facet fixation step, a bonding material is located adjacent to said support edge,

wherein at least one of

- said bonding material at least one of contacts said facet element and said support element and seals a gap between said facet element and said support element;

and

- said support edge is formed at an end of a wall confining a recess within said support element, a majority of said bonding material being located at a side of said support edge facing away from said recess.

18. The method according to claim 15, wherein, in said adjustment step, at least one of

- a manipulator is used to provide said adjustment, said manipulator interacting with at least one of said front surface and a lateral surface of said facet element;

and

- a manipulator is used to provide said adjustment, said manipulator being selected from a manipulator group consisting of a tactile manipulator, a cantilever spring manipulator, a contactless acoustic manipulator and a contactless pneumatic manipulator;

and

- a measurement unit is used to provide signals representative of an actual adjustment of said facet element, said measurement unit being selected from a measurement unit group consisting of a tactile measurement unit contacting a surface of said facet element, a contactless measurement unit cooperating with said facet element and an optical measurement cooperating with a reflective surface section of said facet element.

19. The method according to claim 14, wherein, in said preparation step, at least one of

- at least said rear surface of said facet element is manufactured in a lens manufacturing process;

and

- said facet element is made of a first material selected from a first material group consisting of silicon (Si), silicon carbide (SiC), quartz (SiO_2), nickel plated copper and steel;

and

- said support element is made of a second material selected from a second material group consisting of silicon carbide (SiC), silicon infiltrated silicon carbide (SiSiC) and tungsten carbide (WC).

and

- said support edge is formed at an end of a wall confining a recess within said support element;

and

- said support edge is formed using a working technique selected from a group of working techniques consisting of polishing, chemical-mechanical polishing (CMP), pitch polishing, magneto-rheological fluid polishing (MRFP) and robot polishing;

and

- said support edge is formed as a sharp edge defining a minimum edge radius of curvature, said minimum radius of edge curvature being less than 0.5 mm to 3 mm

and

- said support edge and said facet element are manufactured at a manufacturing accuracy, said manufacturing accuracy being selected such that, at any edge point of said support edge, a width of a manufacturing tolerance related gap between said support edge and said facet element is less than 0.5 μm to 10 μm

20. The method according to claim 14, wherein, at least one of

- in at least one further support step, at least one further facet element is supported on a further second support section of said support element;

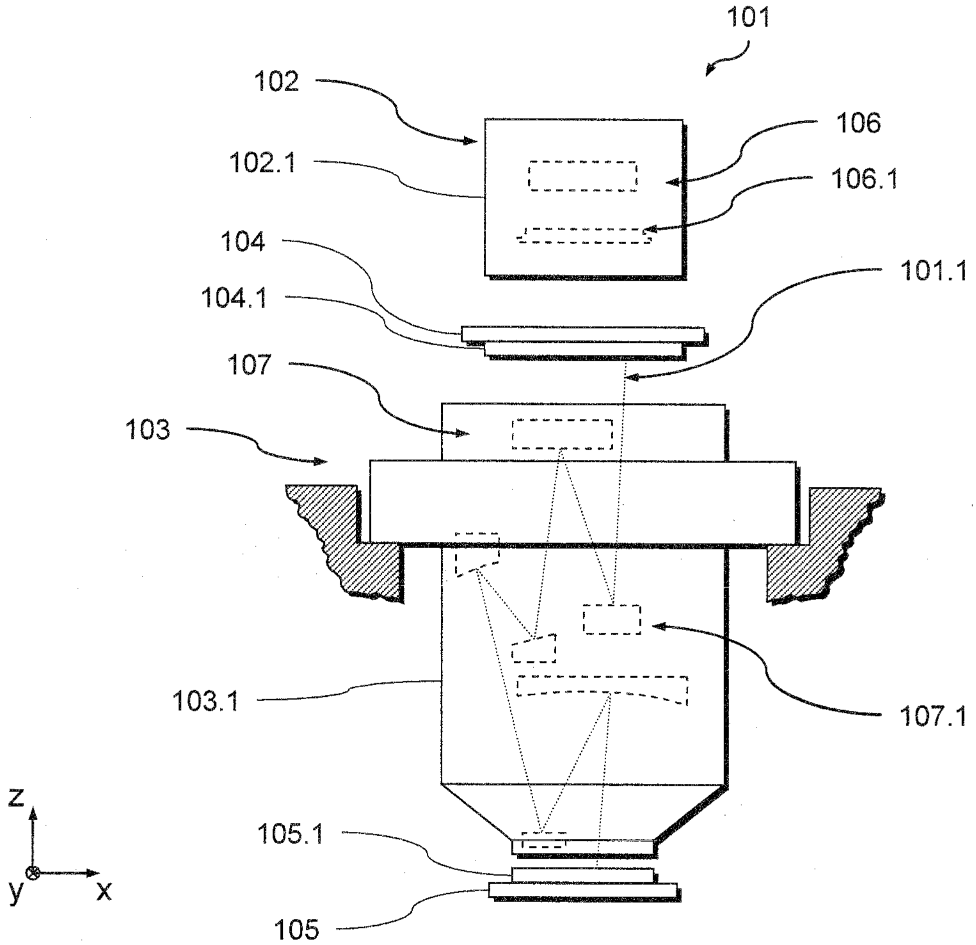
and

- in a disassembly step prior to said support step, a predecessor facet element mounted to said support element is removed from contact with said support edge using a definable thermal load imposed on said predecessor facet element, said definable thermal load causing thermal expansion of said predecessor facet element, said thermal expansion being sufficient to lead to disintegration of an adhesive connection between said predecessor facet element and said support element.

21. A method of manufacturing a facet mirror device comprising,

- in a preparation step, providing a facet element and a support element, said facet element having a front surface optically used during operation of said facet mirror device and a rear surface comprising a curved first support section, and said support element having a second support section;
- in a supporting step, placing said facet element onto said support element such that said second support section contacts said first support section in a region of contact to support said facet element;
- in a contacting step of said supporting step, generating a negative pressure, said negative pressure acting on a part of said rear surface of said facet element such that said first support section is pressed against said second support section.

* * * * *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102
102.1
106
106.1
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104.1
101.1
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103
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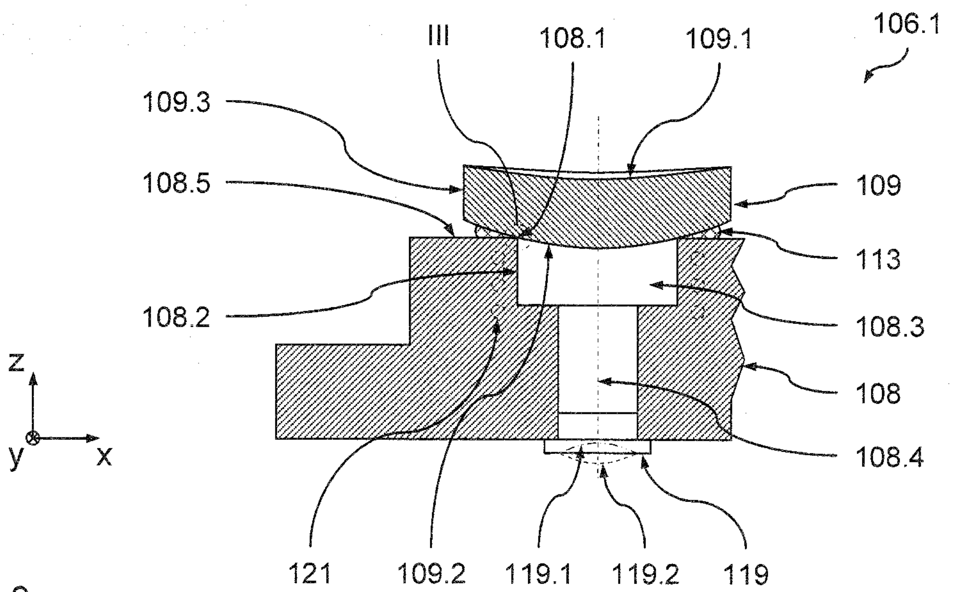
z
y
x

Fig. 1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108.1
109.1
109.3
108.5
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108.3
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108.4
121
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119.2
119
z
y
x

Fig. 2

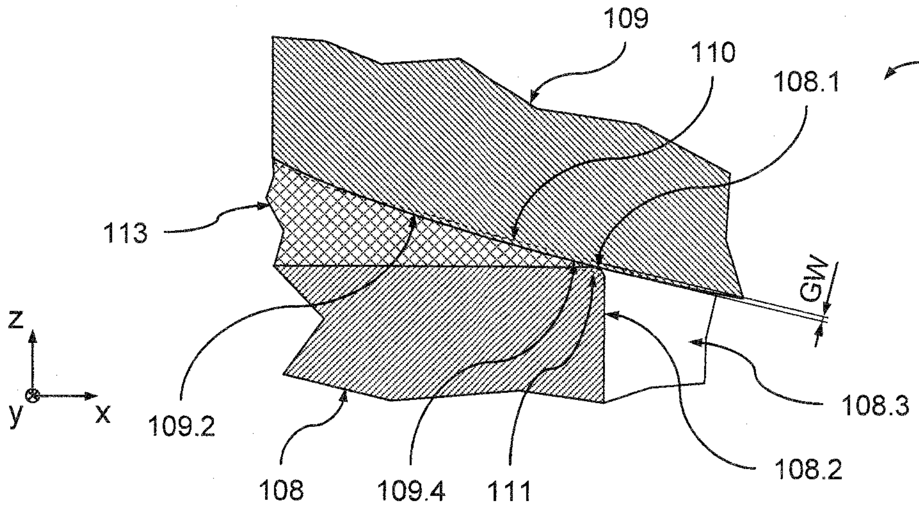


Fig. 3

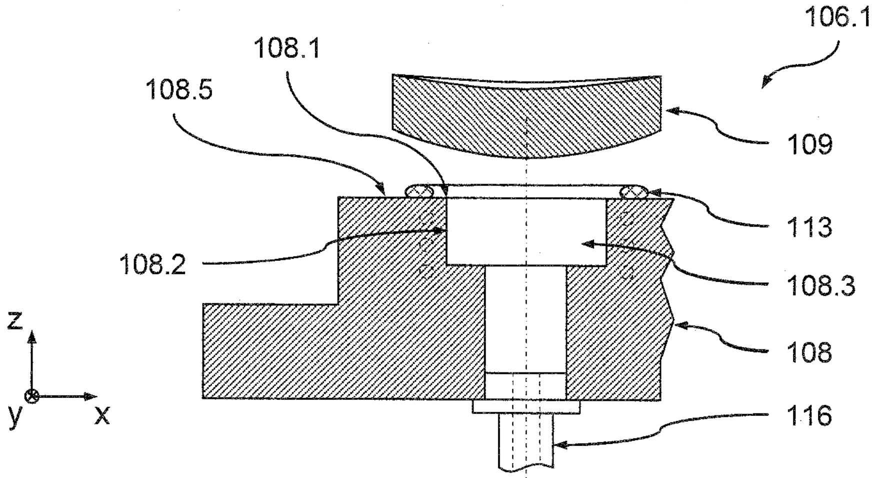


Fig. 4

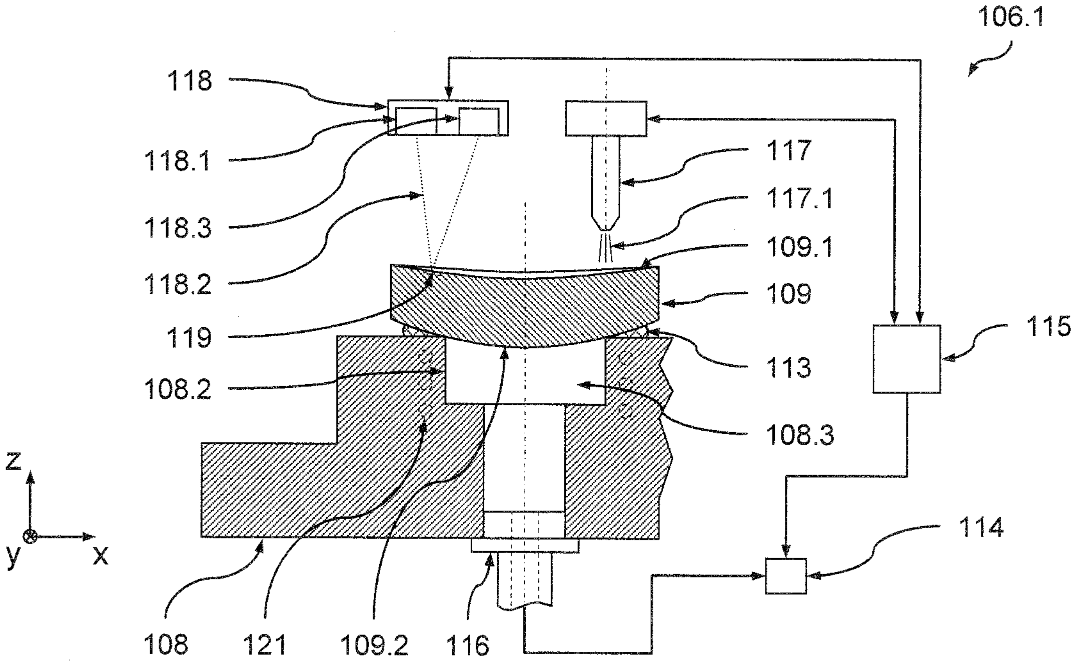


Fig. 5

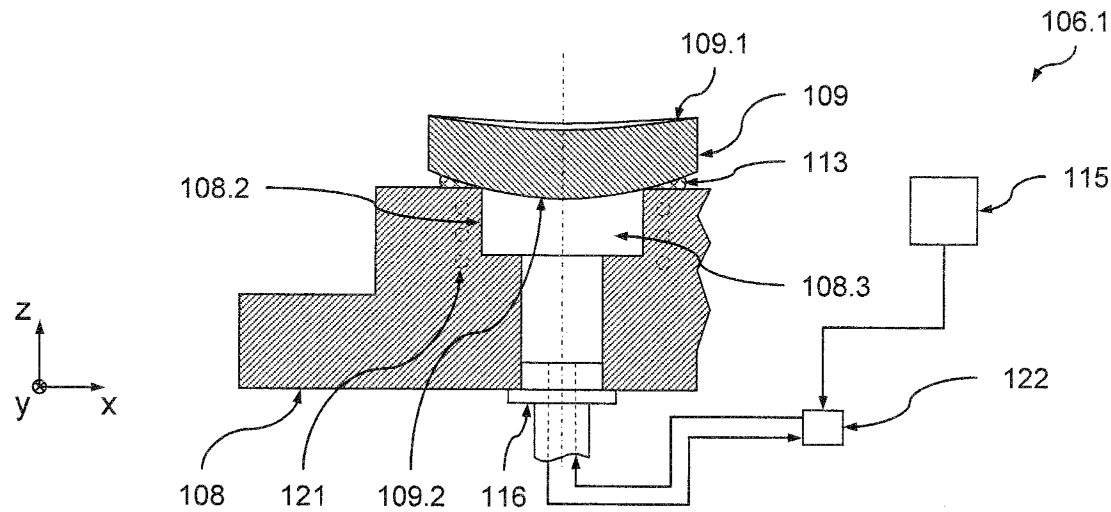


Fig. 6

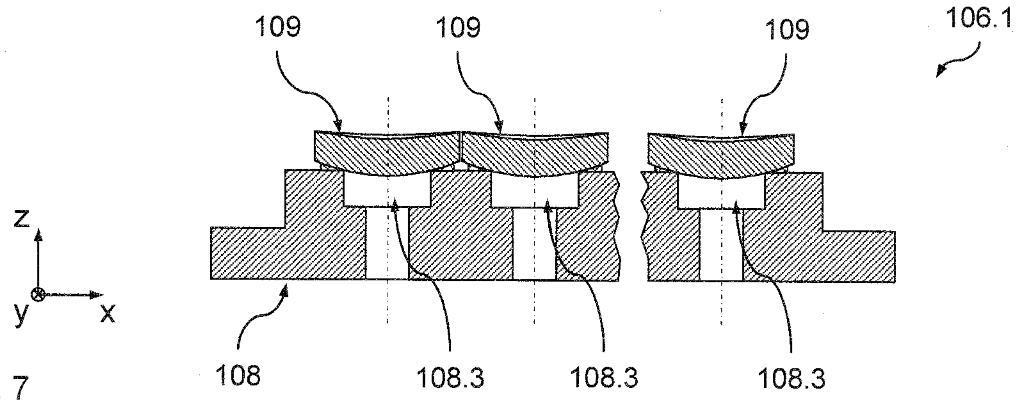


Fig. 7

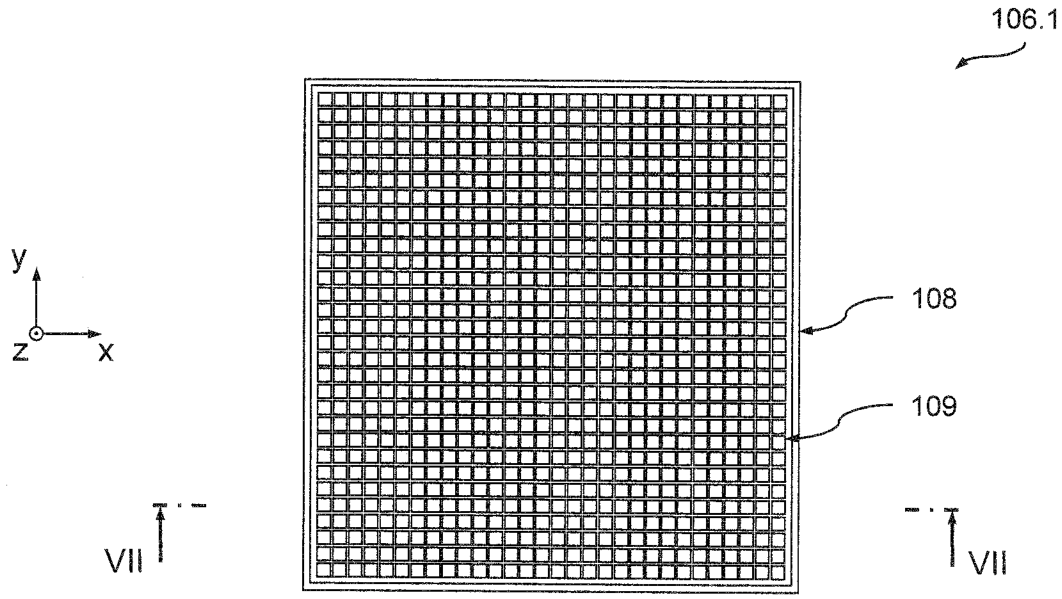
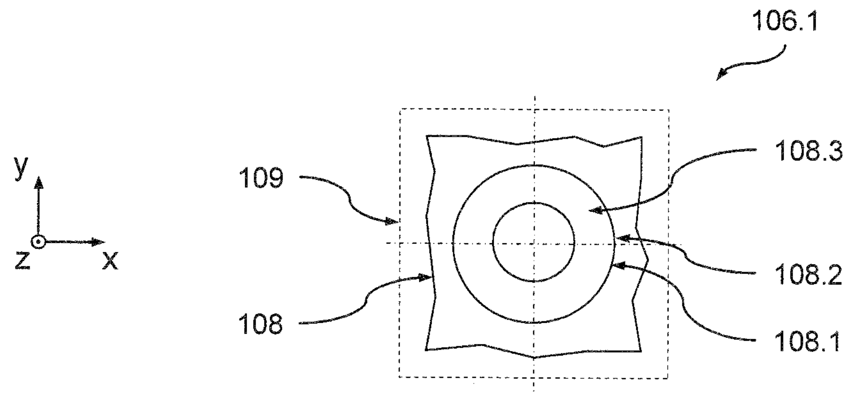


Fig. 8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y
z
x
109
108
108.3
108.2
108.1

Fig. 9

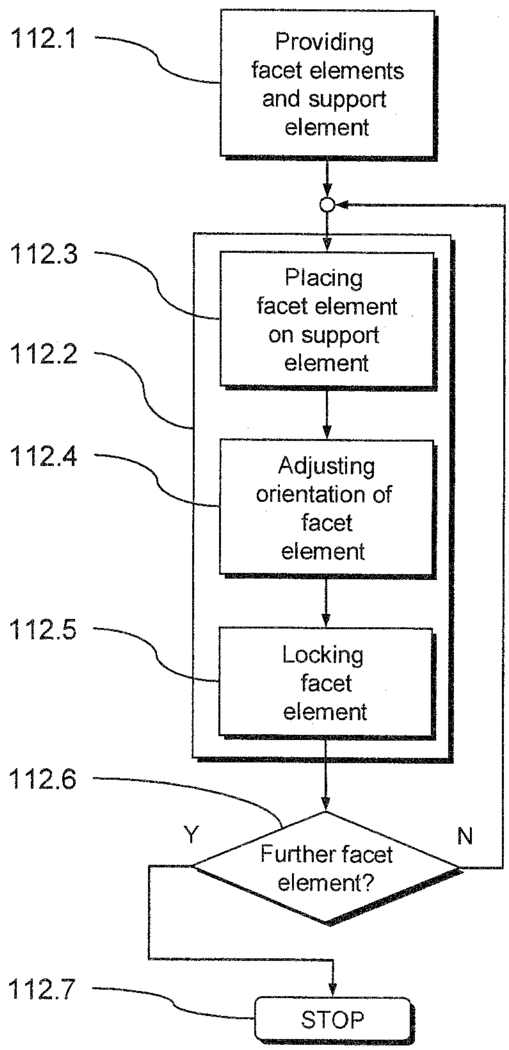
112.1
Providing facet elements and support element
112.3
Placing facet element on support element
112.2
112.4
Adjusting orientation of facet element
112.5
Locking facet element
112.6
Y
N
Further facet element?
112.7
STOP

Fig. 10

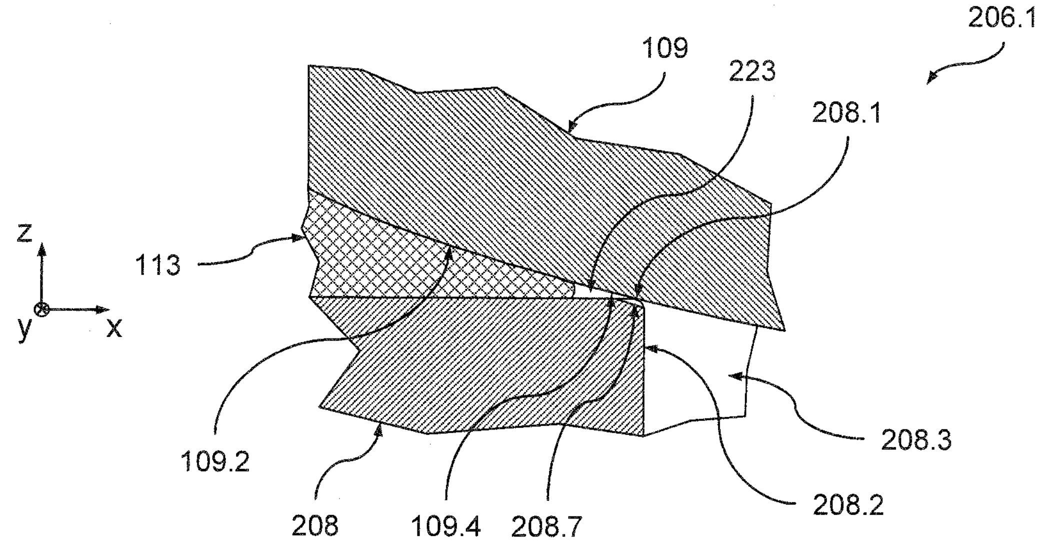

Fig. 11

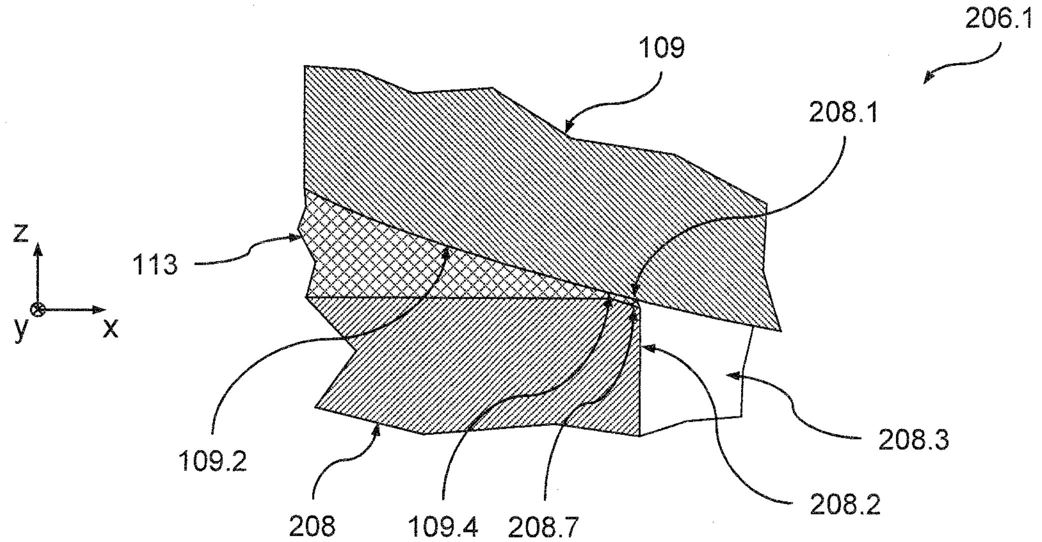

Fig. 12

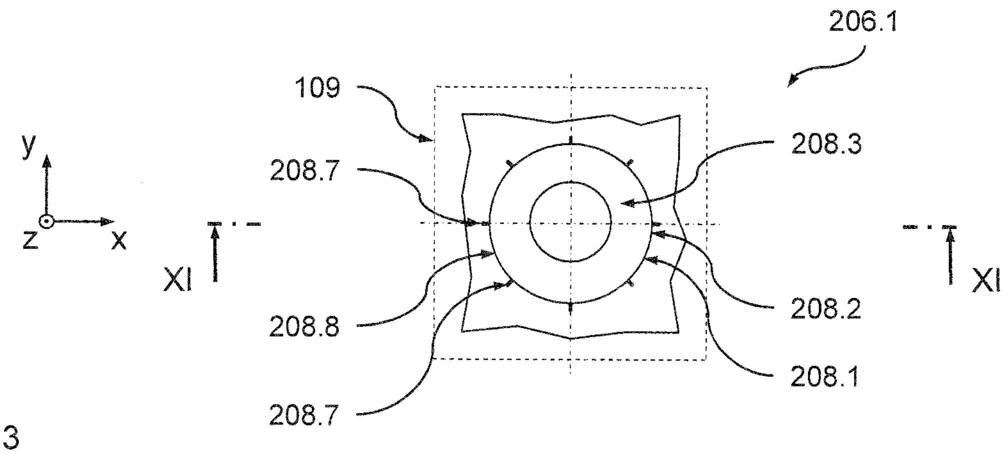

Fig. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2010/060955

A. CLASSIFICATION OF SUBJECT MATTER
INV. G02B5/09 G02B5/08 G03F7/20 G02B7/182
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)
G02B G03F

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 practical, 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 2006/103908 A1 (LOOPSTRA ERIK [NL] ET AL) 18 May 2006 (2006-05-18)	1,2, 5-11,14, 18-21
Y	figures 4-5 paragraph [0038] - paragraph [0044] -----	3,4,12, 13,15-17
Y	WO 2008/101656 A2 (ZEISS CARL SMT AG [DE]; WARM BERNDT [DE]; RENNON SIGFRIED [DE]; DINGER) 28 August 2008 (2008-08-28) claim 4 -----	3,4,12, 13,15-17
A	EP 0 598 950 A1 (OCE NEDERLAND BV [NL] OCE TECH BV [NL]) 1 June 1994 (1994-06-01) * abstract; figure 1 -----	1,10,11, 14,21

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

* Special categories of cited documents :

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"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.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 January 2011	19/01/2011

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Lehtiniemi, Henry

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2010/060955

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