



(51) International Patent Classification:
G03F 7/20 (2006.01)

(21) International Application Number:
PCT/EP2019/085573

(22) International Filing Date:
17 December 2019 (17.12.2019)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
10 2019 200 855.0
24 January 2019 (24.01.2019) DE

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(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM,

AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: METHOD FOR MONITORING THE STATE OF AN OPTICAL MIRROR OF AN EUV PROJECTION EXPOSURE APPARATUS

Fig. 2a

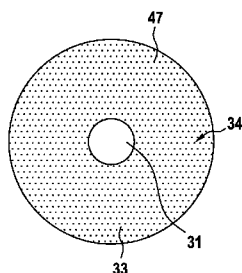
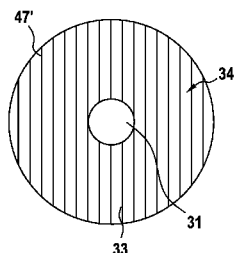


Fig. 2b



(57) Abstract: The invention relates to a method for monitoring the state of a collector mirror (34) of an EUV projection exposure apparatus (1), the method comprising the detection of anomalies of the topography (33) of the collector mirror (34) by means of a laser scanner (40) with a light source (41) and a detector (43).



Method for monitoring the state of an optical mirror of an EUV projection exposure apparatus

The present application claims the priority of the German patent application
5 DE 10 2019 200 855.0, the content of which is fully incorporated herein by reference.

The invention relates to a method for monitoring the state of an optical mirror, in particular a collector mirror, of an EUV projection exposure apparatus.

Projection exposure apparatuses for semiconductor lithography show a strong dependence on the quality of the illumination of the object plane with regard to their imaging quality. The electromagnetic radiation used for the illumination is generated by an illumination system and a light source, which is referred to hereinafter as the used light source. In the case of EUV lithography, the used light source is a comparatively complex plasma source, with which a plasma that emits electromagnetic radiation in
10 the desired short-wave frequency ranges is generated by means of laser irradiation of tin droplets.

The mirror reflecting part of the used light source, and normally the first reflecting EUV light, in the system is an EUV collector mirror, which collects the EUV light emitted by the plasma and directs it in a concentrated form into the illumination system of the EUV projection exposure apparatus. The radiation generated by the used light source in this case comprises not only radiation of the wavelength of the used light, which in the case of an EUV projection exposure apparatus lies in the range from 5 nm to 20 nm, in particular at 13.5 nm, but also radiation components of other wavelengths, such as for example IR radiation. The IR radiation is a radiation that is emitted by the laser for generating the plasma and is not intended to enter the optics of the illumination system or the projection optical unit, since it otherwise heats up the optical elements, which has adverse effects on the imaging quality.

A collector mirror focuses the emitted radiation of the plasma, the collector mirror usually including a main body, which is produced for example from ceramics or glasses. The collector mirror, like other mirrors used in the apparatus too, also comprises at least one layer system, for example a molybdenum-silicon multi-ply layer,

which allows high-precision working of the surface and/or a high reflectivity in the desired spectral range. The layer system often also has the task of filtering out undesired radiation components, such as for example the infrared radiation of the plasma and of the laser. For this purpose, specialized sublayers or grating structures may be incorporated in the coating. The described coatings of the collector mirror are generally exposed to great loading due to radiation and contamination by tin particles.

The short-wave used radiation of an EUV projection exposure apparatus is absorbed by any substances - including gases - within a few mm or cm, and so in an EUV projection exposure apparatus there is a vacuum. For technical process-related reasons and for the operation of the plasma, however, gases are often introduced into the vacuum, such as for example hydrogen at a partial pressure of 1 to 1000 Pa. This hydrogen serves for cleaning and for protection from contamination on optical surfaces and is predominantly in a molecular form (H_2). Due to the radiation emitted by the used light source, the H_2 is however split into atomic hydrogen (H), which in this configuration can diffuse into the coating of the mirrors, in particular the collector mirror. Due to mechanical stresses, the atomic hydrogen that has diffused into the material can recombine at boundary surfaces between layers into molecular hydrogen, that is to say H_2 , which then collects between the layers and/or in the main body. This leads to damage and detachment of the layer and the layer structure, which is manifested by the formation of bubbles and can lead to the peeling off of the layer. The bubbles and the locations at which the coating has already peeled off for their part lead to an inhomogeneous illumination of the so-called far field in the illumination optical unit, that is to say in particular also in the object plane. In addition, the substrate material that is used for the collector mirror reflects the parasitic IR radiation very well, and so, when there is a defective coating and consequently absent wavelength-specific reflection, this radiation is reflected directly into the illumination optical unit, whereby damage may occur due to local heating effects on the optical elements of the illumination optical unit.

Until now, instances of damage to the coating of the collector mirror have been detected by measuring the homogeneity of the far field, which has the disadvantage

that the measurement is laborious and leads to an interruption in the production process of the exposure apparatus. Another method for assessing the state of the collector mirror is a visual inspection, the collector mirror having to be removed from the projection exposure apparatus for this. In addition, it is not possible to predict the occurrence of the bubbles, and consequently the time of a possible failure of the system, and to plan a necessary exchange of the collector.

Furthermore, the German patent application DE 10 2015 201 139 A1 discloses a solution in which a camera records an image of the surface of an optical element and, on the basis of the different intensities of the reflected radiation, draws a conclusion with respect to particles or damaged locations. The size of the particles/damaged locations can be measured by varying the focal plane of the camera and/or the wavelength of the illumination. However, this solution has the disadvantage that a topography of the entire surface can only be determined with a large number of measurements, and consequently a very great effort, and the detection of small unevennesses or incipient bubbles can only be detected with difficulty.

The object of the present invention is to provide a method for the detection of anomalies of the topography of a collector mirror and a prediction of a necessary collector exchange.

This object is achieved by a method having the features of independent claim 1. The dependent claims relate to advantageous developments and variants of the invention.

A method according to the invention comprises the detection of anomalies of the topography of an optical mirror by means of a laser scanner with a light source and a detector.

The mirror may be for example a collector mirror, which may be formed in particular as an ellipsoidal mirror or spherical optical mirror. These have the property of collecting light from an object point in an imaging point, which is usually used for projecting an almost perfect image of object points of the plasma source on entry points of the illumination system of the projection exposure apparatus.

Modern laser scanners have a high resolution of up to 100 μm at a measuring distance of up to 300 mm and can record the entire three-dimensional topography or surface of the mirror in a few minutes. The method can consequently monitor in particular the optically active surface, that is to say the surface that focuses the radiation emitted by the used light source, in order in this way to detect anomalies, such as for example deposits of tin, deformations of the coating due to stresses or bubbles under the layer or defects in the coating. Preferably, the state of the mirror during the operation of the projection exposure apparatus or during a reticle exchange is monitored.

The simple determination of a three-dimensional image possible by the use of a laser scanner has the advantage that the extent of the anomaly, such as for example a bubble under the layer, can be determined immediately and it is not necessary for further additional complex measurements with multiple images to be carried out.

As a result of the ever smaller devices, laser scanners can even be arranged in very confined installation spaces, as are usually present in a projection exposure apparatus.

In the case of an optical mirror of an EUV projection exposure apparatus, the mirrors are so well polished, and consequently so smooth, that only directed reflection of light occurs. The detector of the laser scanner can only detect the surface if it picks up the directed reflection of the mirror.

In order to ensure that light reflected by the mirror surface reaches the detector of the laser scanner, in particular scattering centres may be arranged on the topography of the optical mirror. The scattering centres may be formed as edges of a diffraction grating for frequency-dependent reflection, which has the additional advantage that the infrared light of the plasma source can be filtered out by means of this grating. Alternatively, scattering centres in the form of lines may also be specifically applied independently of a grating structure, which minimizes the surface loss of the mirror as compared with the use of a grating. A further minimization of the surface loss can be achieved by forming the scattering centres as points. The lines or points have a rough surface, the extent of which may have a preferred size of $< 1\text{ mm}$, in particular

of $< 100 \mu\text{m}$. As a result of the small extent, the optical imaging performance of the collector mirror is not impaired, since it is not in an object plane of the imaging system.

The creation of said scattering structures may be accomplished by lithographic means or by a coating by means of a mask. Alternatively, gratings, lines or points or other scattering centres may be incorporated in the surface of the mirror by introducing local surface defects by means of tools, which may for example be diamond-tipped.

However, it may also only be the operation of the mirror that causes the scattering centres to occur, and thereby allows the detection of the mirror surface by the laser scanner. For example, the operation of the EUV plasma source usually causes contamination of the surface of the collector by tin particles. This begins already shortly after the projection exposure apparatus is put into operation and, if these tin particles are present in a sufficient density on the surface of the mirror, the mirror is visible for the laser scanner.

The scattering centres allow conventional laser scanners to be used for measuring on mirrors of an EUV projection exposure apparatus. The radiation emitted by a light source of the laser scanner is scattered in all directions by the surface to be measured due to the scattering centres, and can thus return to a detector of the laser scanner irrespective of the angle of incidence of the radiation on the surface. As a result, anomalies on the topography of the collector, for example due to the influence of hydrogen, can be observed and measured.

To minimize fanning out of the measuring radiation as a result of the light source emitting the radiation into the collector mirror at an angle, the light source and the detector may be arranged as close as possible to the intermediate focus of the collector mirror. A stop that is likewise arranged in the vicinity of the intermediate focus to block the IR radiation may for example be designed as permeable to the measuring radiation. This allows the light source and the detector, and also the stop, to be advantageously arranged in the vicinity of the intermediate focus of the collector mirror.

In particular, the measuring radiation of the laser scanner may extend at an angle of about 45° to the centre axis of the collector mirror. The arrangement at an angle of 45° has the advantage that this region does not lie in the used light beam path, and thus measurements can also be made during the operation of the projection exposure apparatus.

In a variant of the invention, the light source and the detector may be arranged as spatially separate modules. This has the advantage that the laser scanner can adapt itself better to the requirements with respect to the installation space in a projection exposure apparatus. The detector may additionally be arranged such that the light of the light source is imaged by the mirror itself on the detector, and therefore the topography of the mirror can also be measured without scattering centres. If the transmitter of a laser scanner is arranged for example outside the used light path of an ellipsoidal mirror, the light of the light source of the laser scanner is likewise focused by it and leaves the used light path again after a focal point, but is in that case also strongly fanned out. However, then the detector would have to be just behind the focal point within the used light cone, which is not advantageous. For this reason, a collecting optical unit may be arranged between the optical mirror and the detector. This allows the detector also to be arranged outside the used light cone and further away from the focal point. The collecting optical unit can concentrate the reflected light fanned out widely after the focal point, and thus project an image onto the detector.

In a variant of the invention, the light source and the detector may be arranged in the direct vicinity of one another, as is the case with commercially available laser scanners. This has the advantage that laser scanners do not have to be specially developed or adapted.

In particular when using the directed reflection of the mirror, the measuring radiation can be reflected by a retroreflector. The retroreflector reflects the radiation in the direction from which it was incident on the retroreflector. The radiation is in turn reflected by the mirror in a directed manner, and can thus project an image onto the detector arranged in the direct vicinity of the light source. For covering the entire surface, multiple laser scanners may be arranged on a circular path around the centre

axis of the collector or a laser scanner may be moved on a circular path around the centre axis of the collector.

Irrespective of the arrangement of the light sources and detectors for the detection of the surface, the laser scanner may also comprise a narrow-band wavelength filter.

5 Specifically when determining the topography during operation, the radiation emitted by the used light source may disturb the detectors of the laser scanner, and so the use of a narrow-band filter may be of advantage here. Such a filter only allows the wavelength of the radiation emitted by the light source of the laser scanner to pass, and thus improves the quality of the measurement. Examples of such filters are inter-
10 ference filters, which exist for all of the commonly encountered laser wavelengths of laser scanners. The filter is mounted directly upstream of the receiver of the laser scanner.

In an advantageous embodiment of the invention, an anomaly of the surface may be detected by a comparison of a desired topography and a newly determined topogra-
15 phy. The desired topography may for example be a surface form derived from the design layout, such as for example a sphere, in the form of CAD models. For the detection of very small anomalies, measurements that were carried out after the production or the installation of the collector may also be used as desired topographies. The measurements may in this case be carried out with the measuring means in-
20 stalled in the projection exposure apparatus or else with external measuring means. The desired topographies thus calculated or determined may for example be stored in a central controller and, after the measurements carried out in the operation of the projection exposure apparatus, compared with the topographies thereby determined.

In particular, the imaging quality of the projection exposure apparatus may be calcu-
25 lated with the aid of suitable models on the basis of the anomalies thus determined. With suitable models and an assumption concerning the future use of the projection exposure apparatus, a prediction of a time at which the imaging quality will no longer meet the requirements can be made on the basis of the profile of the changes in the anomalies. Thus, a cleaning or an exchange of the collector can be planned at an
30 early time. This has the advantage that not only the risk of unforeseen machine

downtimes but also instances of damage to the illumination and projection optics can be greatly minimized.

Alternatively or in addition to the methods described above, stripe light projection may also be used. Stripe light projection has the advantage that a greater region can be covered simultaneously and, with the projection of multiple stripes, the entire surface of the collector can be recorded in one go. At the same time, the use of moving parts, as are often used in 3D laser scanners, can be avoided in the determination of the topography. This may reduce the risk of contamination and abrasion by the measuring means, which should especially be avoided in the vicinity of the optical elements of a projection exposure apparatus.

Furthermore, there is the possibility of using ultrasonic sensors. The ultrasonic sensors may for example be arranged in the main body of the collector, the measuring face of the ultrasound probe being able to form a plane with the surface of the main body. After the coating, the thickness of the layer or the layers can be measured by the ultrasound probe. A change in the thickness of the layer, for example due to depositing of tin or other particles, is similarly detected, as is the incorporation of bubbles produced by hydrogen under the layers. The arrangement and number of the ultrasound probes depend on the requirements for the resolution and measuring accuracy. This measuring method is particularly advantageous for the continuous measurement of the topography, and can detect both deposits on the layer and any detachment of layers. Arrangement in the main body has the advantage that the sensor is protected from soiling and radiation.

Similarly, the use of structure-borne sound is conceivable. In this case, the surface to be measured may be excited by a structure-borne sound wave, which propagates in the surface of the collector. The structure-borne sound wave may in this case be measured by a so-called surface acoustic wave (SAW) sensor, while the measured items of information may be visually represented. Every change in the topography of the collector, such as for example a deposition or detachment of the layer, may result in a change in the structure-borne sound wave. The anomaly of the topography can

be concluded from this. An advantage of the method is that the excitation and measurement can take place at the circumference of the collector, as a result of which the measuring means is not directly in contact with radiation and/or contamination.

Exemplary embodiments and variants of the invention are explained in more detail
5 below with reference to the drawing, in which:

Figure 1 shows the basic construction of an EUV projection exposure apparatus, in which the invention can be implemented,

Figures 2a, b show a schematic representation of a collector mirror in plan view,

Figure 3 shows a schematic representation of a collector mirror,

10 Figure 4 shows a schematic representation of a further embodiment of the invention,

Figure 5 shows a schematic representation of a further embodiment of the invention,

15 Figures 6a, b show a schematic representation of a further embodiment of the invention,

Figure 7 shows a schematic representation of a further embodiment of the invention and

Figure 8 shows a schematic representation of a further embodiment of the invention.

20 Figure 1 shows an example of the basic construction of a microlithographic EUV projection exposure apparatus 1, in which the invention can be used. An illumination system of the projection exposure apparatus 1 has, in addition to a light source 3, an illumination optical unit 4 for the illumination of an object field 5 in an object plane 6. EUV radiation 14 in the form of optical used radiation generated by the light source 3
25 is aligned by means of a collector, which is integrated in the light source 3, in such a way that it passes through an intermediate focus in the region of an intermediate focal plane 15 before it is incident on a field facet mirror 2. Downstream of the field facet

mirror 2, the EUV radiation 14 is reflected by a pupil facet mirror 16. With the aid of the pupil facet mirror 16 and an optical assembly 17 having mirrors 18, 19 and 20, field facets of the field facet mirror 2 are imaged into the object field 5.

5 A reticle 7 arranged in the object field 5 and held by a schematically represented reticle holder 8 is illuminated. A merely schematically represented projection optical unit 9 serves for imaging the object field 5 into an image field 10 in an image plane 11. A structure on the reticle 7 is imaged on a light-sensitive layer of a wafer 12 arranged in the region of the image field 10 in the image plane 11 and held by a likewise partly
10 represented wafer holder 13. The light source 3 can emit used radiation, in particular in a wavelength range of between 5 nm and 30 nm.

Figure 2a shows a schematic representation of the surface of a collector mirror 34, on which point-like scattering centres 47 are arranged. These scatter the measuring radi-
15 ation of the light source of the laser scanner, not represented in Figure 2a, in all directions, whereby at least some of the measuring radiation returns to the detector of the laser scanner, which is likewise not represented in Figure 2a, and is used there for the determination of the topography 33 of the collector mirror 34.

20 Figure 2b shows a schematic representation of the surface of a collector mirror 34, arranged on which are line-like scattering centres 47', which act in a similar way to the scattering centres 47 represented in Figure 2a.

Apart from the scattering centres 47, 47' represented in Figures 2a and 2b, the edges
25 of a grating arranged for frequency-dependent reflection on the mirror surface may also be used. The scattering centres 47, 47' may for example be applied to the surface of the collecting mirror 34 by lithographic means or by a coating by means of a mask. Alternatively, scattering centres may also be produced by introduction of local surface defects, in particular with the aid of diamond tools. Also the already mentioned tin par-
30 ticles that are released during plasma generation may likewise act as scattering centres and be used for the reflection of the measuring radiation 42.

Figure 3 shows a section of a schematic construction of a collector mirror 34 with a coating 32 and a light source 3, which is arranged underneath the collector mirror 34. The light source 3, which may be formed as a laser, emits IR radiation 35 through a clearance 31 in the main body 30 of the collector mirror 34 onto a tin droplet 36, which is kept in suspension at a first focal point 38 of the collector mirror 34. The irradiation of the tin droplet 36 by the light source 3 produces a plasma, which emits used radiation 14, that is to say light for the imaging of an object onto an image plane, at a wavelength of 13.5 nm. Apart from the used radiation 14, also emitted are IR radiation 35 and radiation of other wavelengths, which are collectively referred to hereinafter as parasitic radiation 35. The collector mirror 34 focuses the light emitted by the plasma wavelength-specifically, and so the used radiation 14 is focused at a second focal point 39. The parasitic radiation 35 is focused at a third focal point 54, which lies in a plane with the second focal point 39. The first focal point 38 and the second focal point 39 lie in this case on the centre axis 55 of the collector mirror 34, the third focal point 54 being arranged in the vicinity of the centre axis 55. The wavelength-specific reflection is realized by Bragg reflection at a structure formed on or in the coating 32 of the collector mirror 34. Likewise arranged in the plane perpendicular to the centre axis 55, at the height of the second focal point 39, is a stop 37, which prevents parasitic radiation 35 from getting into the illumination optical unit 4, which is not represented in Figure 3.

The various possible positions of the laser scanners 40 and also the measuring radiation 42 emitted by the laser scanners are represented in Figure 3 by dashed lines. The laser scanner 40 above the stop 37 may in this case comprise an optional narrow-band filter 44, which is arranged in place of the stop 37 and is set up such that it filters out all of the wavelengths of the parasitic radiation 35 and of the used light 14 apart from the measuring radiation 42. Thus, the accuracy of the laser scanner 40 can be advantageously increased and a measurement carried out during the operation of the projection exposure apparatus 1.

A further alternative for monitoring the surface of a collector mirror 34 is an acoustic wavefront sensor 60, which comprises a structure-borne sound transmitter 58 and a structure-borne sound pickup 59. The monitoring of the topography 33 of the collector mirror 34 may take place continuously and in situ, that is to say during the operation of

the apparatus. The continuous determination of the current topography 33 allows a prediction of the imaging quality of a projection exposure apparatus 1, and allows possibly necessary measures, such as for example cleaning or exchange of the collector mirror 34, to be predicted well.

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Two laser scanners 40, which are positioned in such a way that the measuring radiation 42 emitted by them and recorded extends at an angle of about 45° to the centre axis 55, can also be seen well in Figure 3. This arrangement has the advantage that conflicts do not occur between the used beam path and the path of the measuring radiation 42.

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In addition, a variant in which the light source 41 and the detector 43 are not arranged at one location is shown in Figure 3. In this case, the measuring radiation 42 emitted by the light source 41 is deflected onto the detector 43 by way of the collector mirror 34. This may be of advantage in the case of greatly confined installation spaces in a projection exposure apparatus 1.

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Figure 4 shows a section through a collector mirror 34, which may for example be formed as an ellipsoidal mirror and which reflects used radiation 14 emanating from the first focal point 38 in a directed manner and concentrates it at the second focal point 39. The laser scanner 40 comprises a light source 41, which is arranged outside the used beam path 14 and emits the measuring radiation 42 onto the surface of the collector mirror 34, and a detector 43, which is arranged spatially separate, to the side of the collector mirror 34. The measuring radiation 42 is reflected by the collector mirror 34 in a directed manner, the measuring radiation 42 being fanned out again after being concentrated at a focal point. The measuring radiation is incident on a collecting optical unit 48, which is arranged between the edge of the collector mirror 34 and the detector 43. The collecting optical unit 48 may for example be formed as an optical arrangement with multiple lenses and/or mirrors or as an individual collecting lens, and images the fanned-out measuring radiation 42 on the detector 43. For covering the entire topography 33 of the collector mirror 34, multiple corresponding laser scanners, with an arrangement of a light source 41, a collecting optical unit 48 and a detector 43 as

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described further above, may be used. Furthermore, also conceivable is an arrangement with a light source 41, a collecting optical unit 48 and a detector 43 that can rotate about the centre axis (not separately denoted in the figure) of the collector mirror 34, and thus can sequentially measure the topography 33 of the collector mirror 34.

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Figure 5 likewise shows a section through a collector mirror 34 as already shown in Figure 4. As a difference from the variant shown in Figure 4, the detector 43 is arranged in the direct vicinity of the light source 41. The fanned-out measuring radiation 42 is reflected at a retroreflector 49 arranged laterally alongside the collector mirror 34, the reflected measuring radiation 42 in turn being reflected by the collector mirror 34 in a directed manner and thus imaged on the detector 43. The retroreflector 49 may for example be formed as a film. This has the advantage that commercially available laser scanners 40 can be used and the arrangement of the laser scanner 40 can be flexibly adapted to the requirements of the distribution of installation space in a projection exposure apparatus 1.

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Figure 6a shows a schematic representation of the collector mirror 34 comprising a main body 30 with a clearance 31 and a laser scanner 40. The laser scanner 40 scans the entire surface of the collector mirror 34 with a measuring beam 42 emitted by a light source 41. The scanning direction 46, which is represented in Figure 6a by double-headed arrows, may take place line by line or on the basis of specific grids. The measuring radiation 42 reflected by the coating 32 is recorded on the detector 43. The latter determines the distance of the laser scanner 40 from the surface of the collector mirror 34 and determines from it the topography 33 of the collector mirror 34, which can thus be continuously scanned and monitored. By a comparison with a desired surface 45 of the collector mirror 34, which is represented in Figure 6a by dashed lines, anomalies can be detected.

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Figure 6b likewise shows a schematic representation of a collector mirror 34 and an alternative sensor arrangement 40'. As in Figure 6a, the light source 41 emits a measuring radiation 42, which is reflected by the coating 32 of the collector mirror 34 onto the detector 43. As a difference from the variant represented in Figure 6a, the light source 41 produces a two-dimensional illumination of the surface of the collector mirror

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34, while this may be formed as a strip pattern. Apart from strip patterns, other patterns are also conceivable, such as for example a grating or a chequerboard pattern. In another variant, the light source 41 may also produce the strip pattern by a line-like measuring beam 42, which is scanned over the surface.

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The continuous monitoring allows a prediction concerning the imaging quality of the projection exposure apparatus 1 to be made from the changes in the anomalies. This has the advantage that a possible failure of the collector mirror 34 can be avoided, and a possibly necessary exchange of the collector mirror 34 can be planned. The surface of the collector mirror 34 in Figures 6a and 6b comprises scattering centres 37, 37' for scattering the measuring radiation 42 in all directions, which are not represented in Figures 6a and 6b.

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Figure 7 shows a schematic representation of a portion of a collector mirror 34 that comprises a main body 30 and multiple ultrasonic sensors 50. The ultrasonic sensors 50 are arranged in the main body 30 of the collector mirror 34 such that the side transmitting and receiving ultrasound terminates with the coated surface of the main body 30. The ultrasonic sensor 50 can thus measure the thickness 51 of the coating 32 of the collector mirror 34. The ultrasound waves emitted and reflected are represented in Figure 4 as arrows. An advantage of the ultrasonic method is that changes in the coating 32 consisting of multiple layers can also be detected. Thus, for example, defects 53 such as detachments of layers can also be detected by incorporation of hydrogen between various layers. In the representation of the ultrasound signal 56, each crossing of a boundary between two materials, in particular between a solid material and a gaseous material, is visually represented by a peak. The distance between the peaks correlates with the thickness 51 of the coating 32. A defect 53 produces a further peak in the ultrasound signal at a distance 52 from the peaks caused by the boundaries of the coating 32. A further advantage of this sensor arrangement 40'' is that regions of the collector mirror 34 that are exposed to the used radiation 14 and parasitic radiation 35, which are not represented in Figure 7, and all of the other ambient conditions can be measured directly, without the ultrasonic sensor 50 itself being exposed to these conditions. A continuous measurement of the thickness allows any type of deposit and

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defects on or in the coating 32 to be detected and to be used for predicting the imaging quality.

Figure 8 shows a schematic representation of a surface of the collector mirror 34 with
5 visually represented structure-borne sound waves 57. The structure-borne sound wave 57 is introduced by a structural-borne sound generator 58 into the main body 30 or the coating 32 of the collector mirror 34, which are both not represented in Figure 8, and is measured by a structural-borne sound pickup 59, which is likewise not represented in Figure 8. The arrangement of a structure-borne sound sensor 60, which comprises
10 a structure-borne sound generator 58 and structure-borne sound pickup 59, is represented by way of example in Figure 3. The topography 33 of the surface of the collector mirror 34 can be concluded from the structure-borne sound waves 57 thus determined. As also by the ultrasonic sensor 50, not only the topography 33 but also defects in the material of the main body 30 or the coating 32 can be detected by the acoustic structure-borne sound sensor 60. This form of a sensor arrangement is very robust and the
15 structure-borne sound pickup 59 can in principle also be arranged on the rear side of the collector mirror 34 or at a greater distance, and so this variant of a sensor arrangement is very flexible.

List of reference signs

1	Projection exposure apparatus
2	Facet mirror
3	Light source
4	Illumination optical unit
5	Object field
6	Object plane
7	Reticle
8	Reticle holder
9	Projection optical unit
10	Image field
11	Image plane
12	Wafer
13	Wafer holder
14	EUV radiation
15	Intermediate field focal plane
16	Pupil facet mirror
17	Assembly
18	Mirror
19	Mirror
20	Mirror
30	Main body
31	Clearance
32	Coating
33	Topography
34	Collector mirror
35	IR radiation
36	Tin droplet
37	Stop
38	First focal point

39	Second focal point
40, 40', 40''	Laser scanner; alternative sensor arrangement
41	Light source of measuring radiation
42	Measuring radiation
43	Detector
44	Filter
45	Desired surface
46	Scanning direction
47, 47'	Scattering centre
48	Collecting optical unit
49	Retroreflector
50	Ultrasonic sensor
51	Thickness of layer stack S
52	Distance of defect D
53	Defect
54	Third focus
55	Centre axis
56	Ultrasound signal
57	Structure-borne sound waves
58	Structure-borne sound generator
59	Structure-borne sound pickup
60	Acoustic wavefront sensor

Patent claims

1. Method for monitoring the state of an optical mirror (34) of an EUV projection exposure apparatus (1),

characterized in that

the method comprises the detection of anomalies of the topography (33) of the mirror (34) by means of a laser scanner (40) with a light source (41) and a detector (43), the anomaly being detected by a comparison of a desired topography (45) and a newly determined topography (33).

2. Method according to Claim 1,

characterized in that

scattering centres (37, 37') are arranged on the topography (33) of the optical mirror (34).

3. Method according to either of Claims 1 and 2,

characterized in that

the light source (41) and the detector (43) are arranged in the vicinity of an intermediate focus (38, 39) of the mirror (34).

4. Method according to either of Claims 1 and 2,

characterized in that

the measuring radiation (42) of the laser scanner (40) extends at an angle of 45° to the centre axis (55) of the mirror (34).

5. Method according to one of the preceding claims,

characterized in that

the light source (41) and the detector (43) are arranged as spatially separate modules.

6. Method according to Claim 5,

characterized in that

a collecting optical unit (48) is arranged between the optical mirror (34) and the detector (43).

7. Method according to one of Claims 1 to 4,

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characterized in that

the light source (41) and the detector (43) are arranged in the direct vicinity of one another.

8. Method according to Claim 7,

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characterized in that

the measuring radiation (42) is reflected by a retroreflector (49).

9. Method according to one of the preceding claims,

characterized in that

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the laser scanner (40) also comprises a narrow-band filter (45).

10. Method according to one of the preceding claims,

characterized in that

the determined items of information concerning the anomaly are used for

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predicting the imaging quality of the projection exposure apparatus (1).

11. Method according to one of the preceding claims,

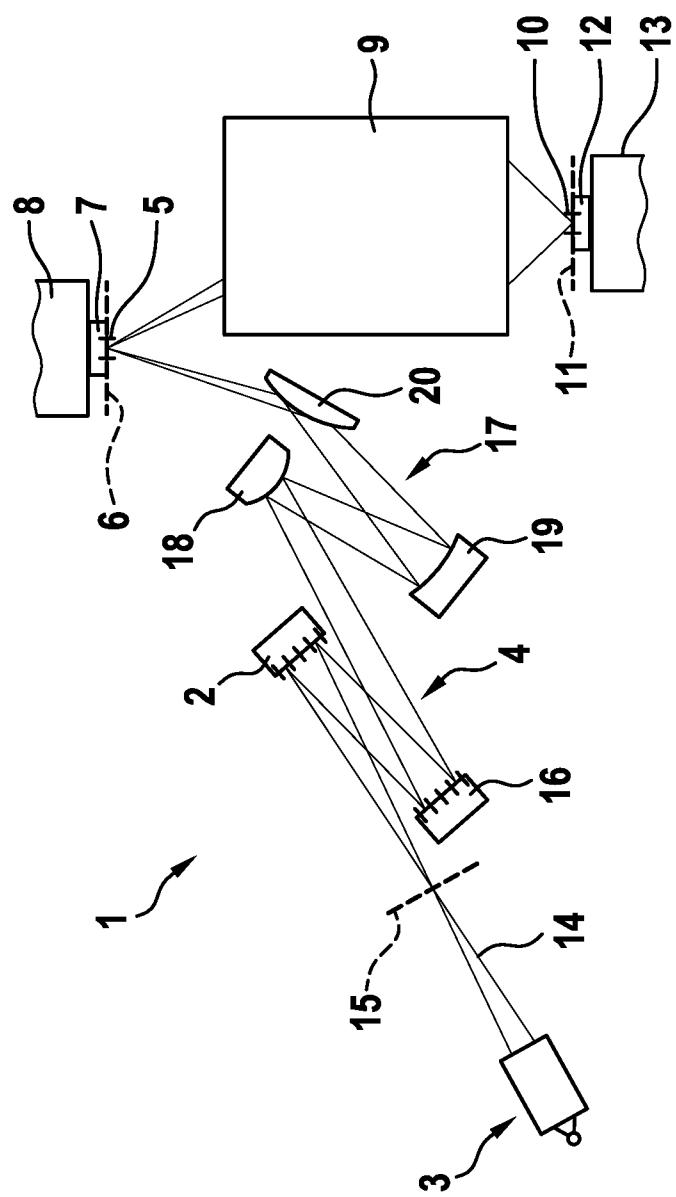
characterized in that

the determined items of information concerning the anomaly are used for

25

determining a planned exchange or cleaning of the mirror (34).

Fig. 1



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Fig. 2a

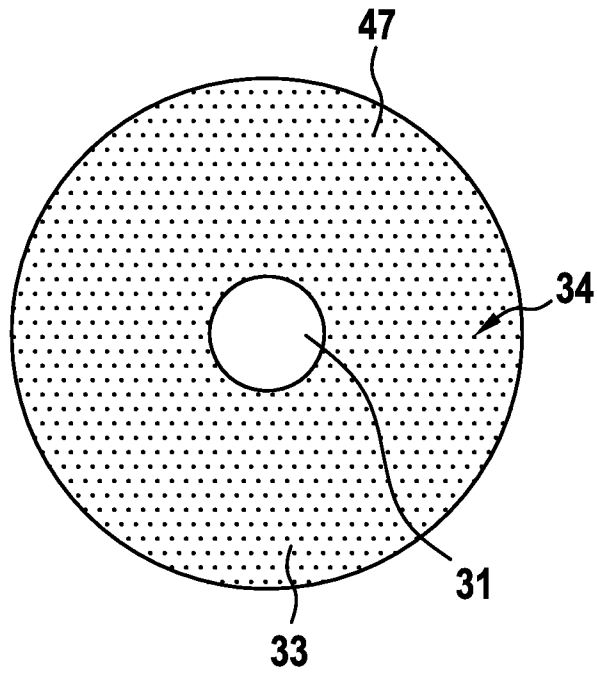
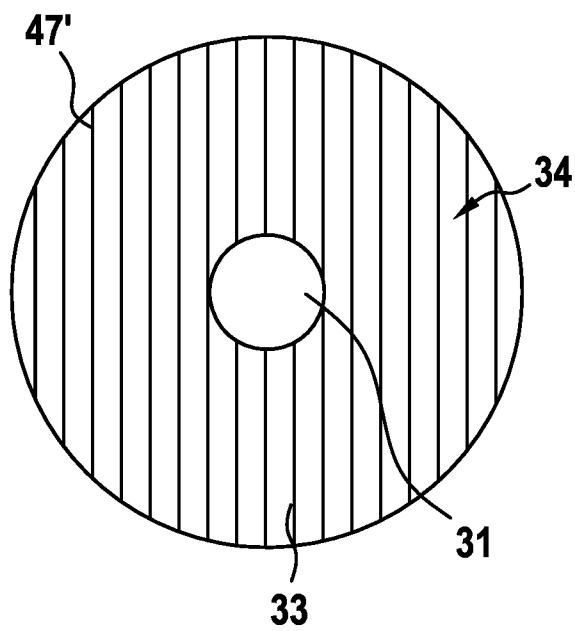
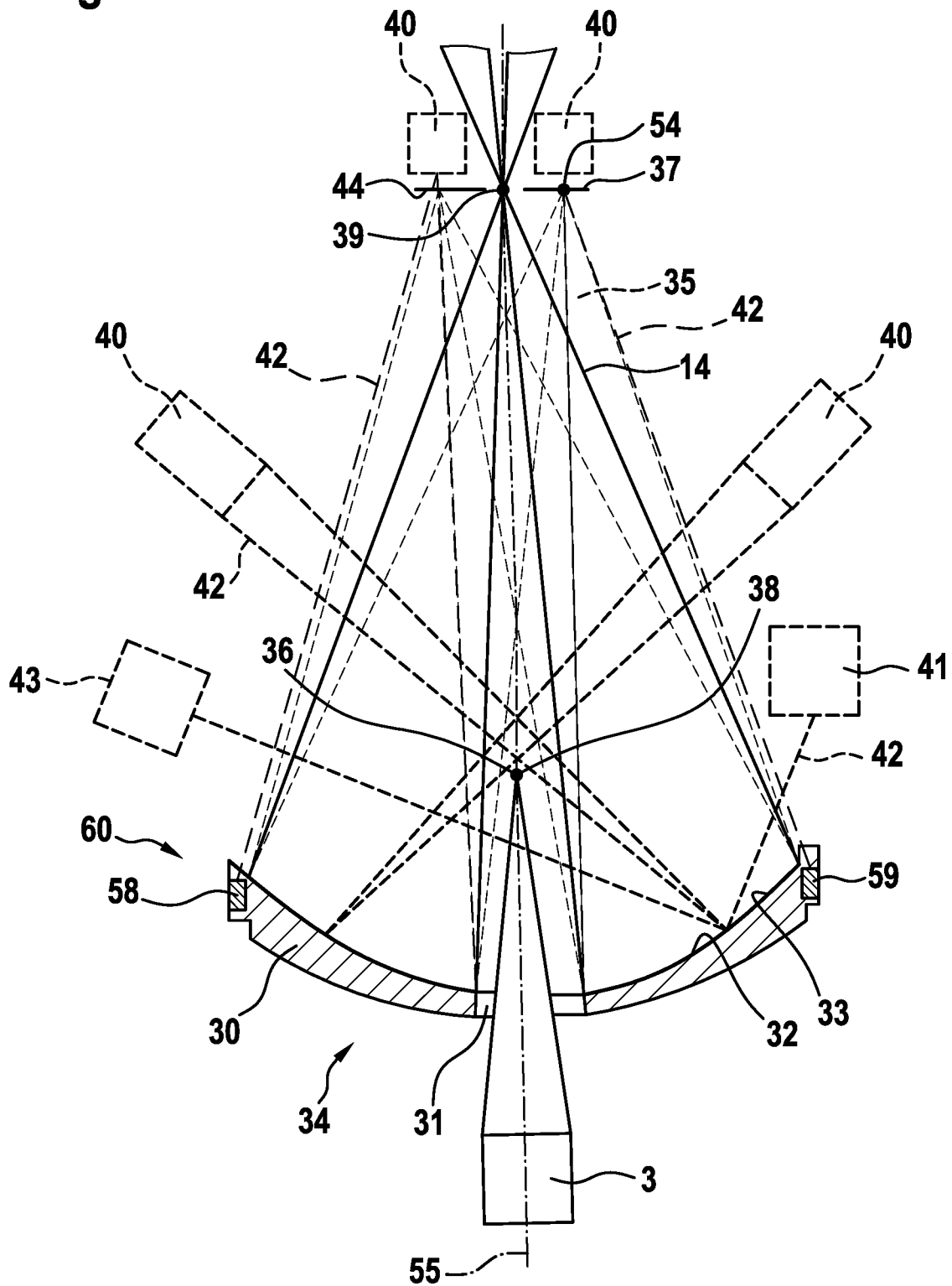


Fig. 2b



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Fig. 3



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Fig. 4

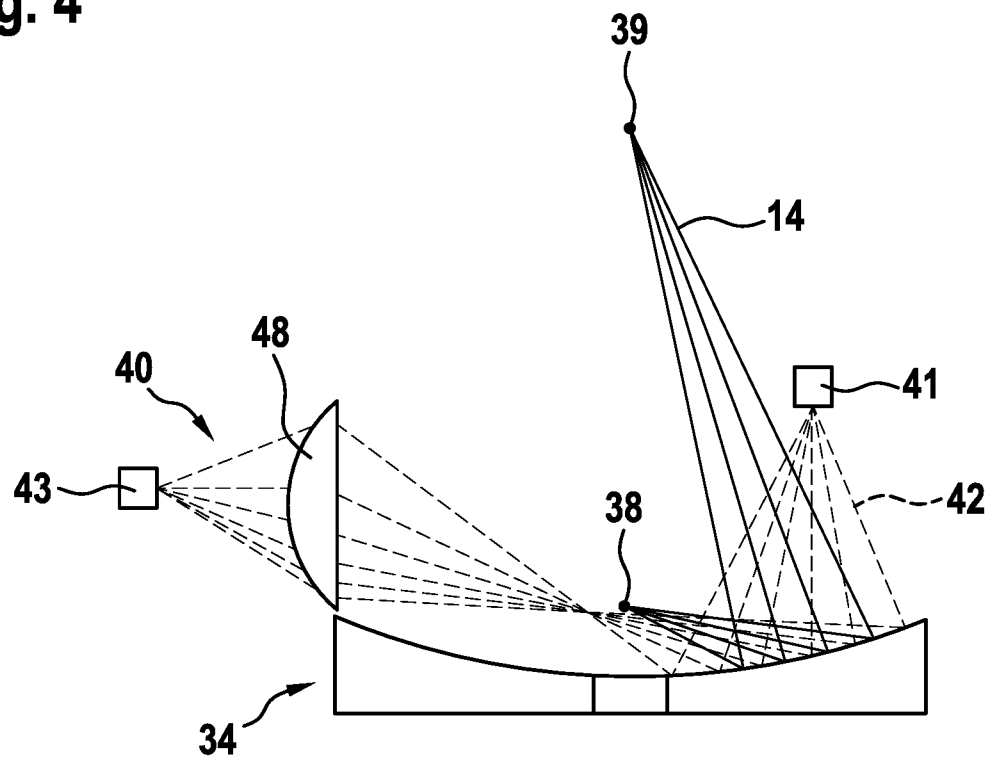
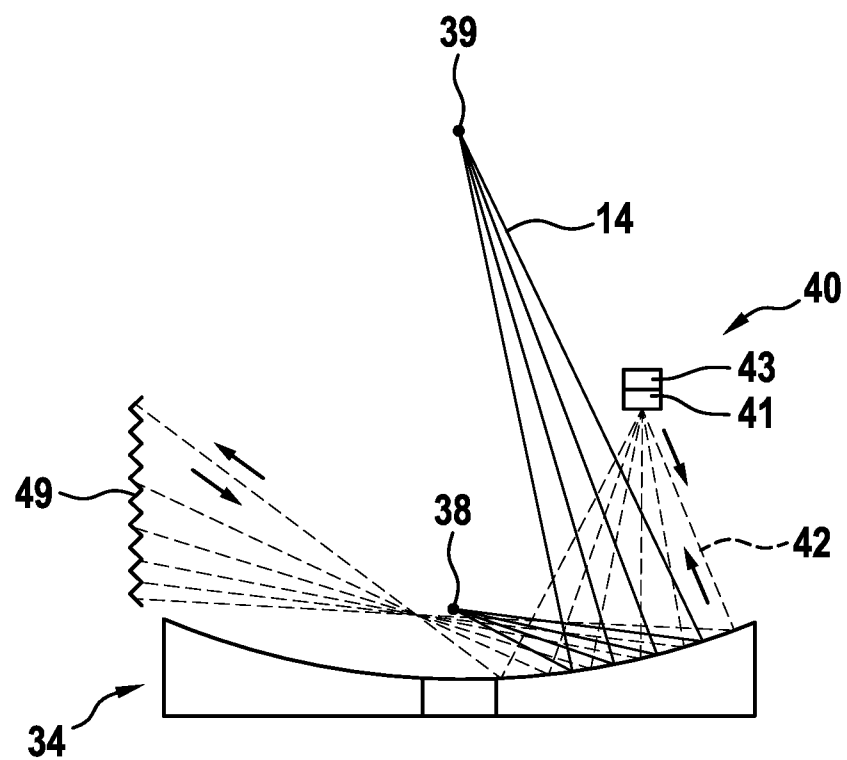


Fig. 5



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Fig. 6a

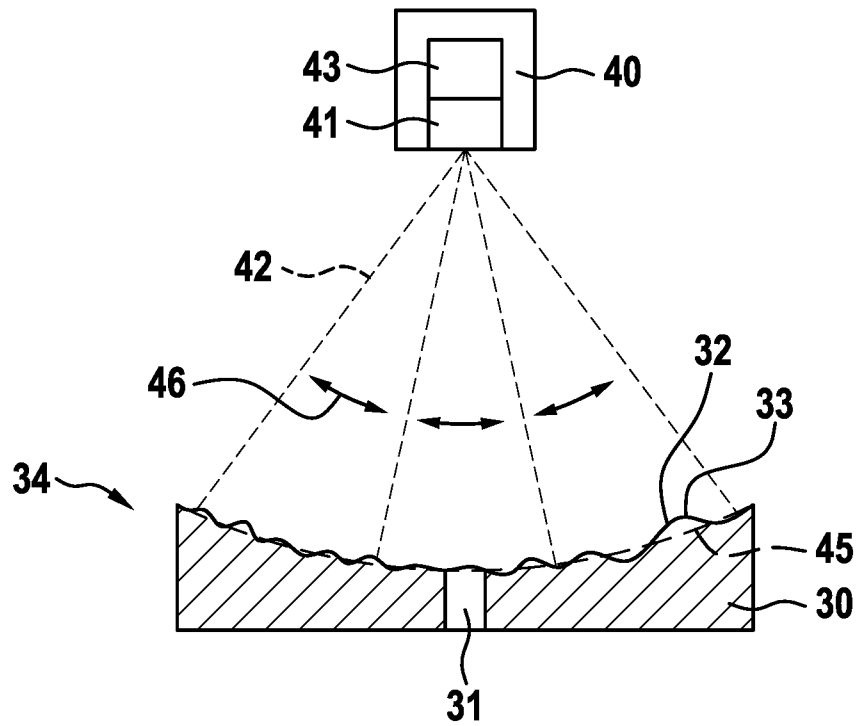
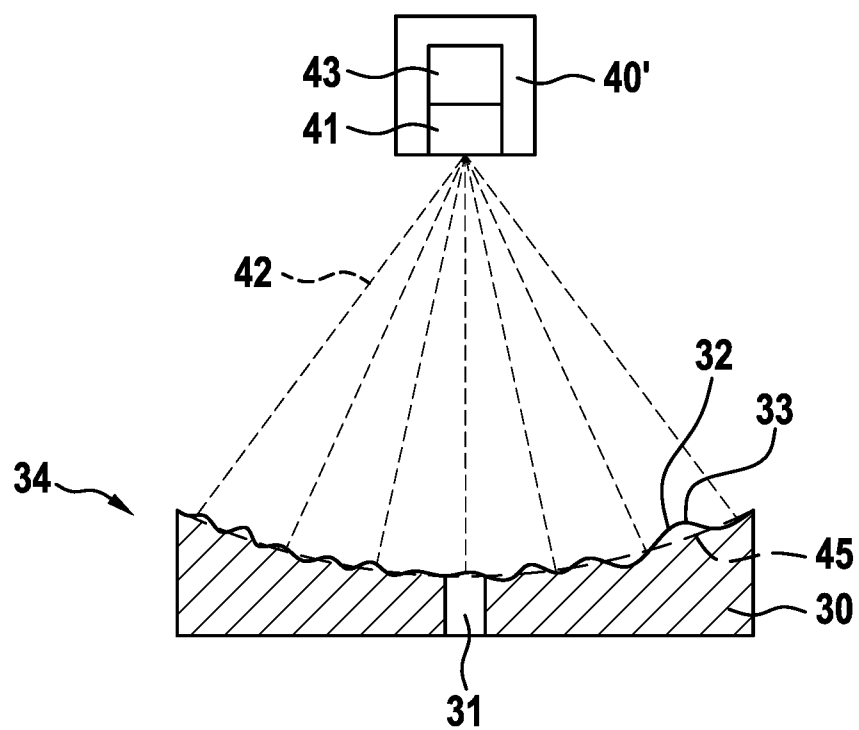


Fig. 6b



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Fig. 7

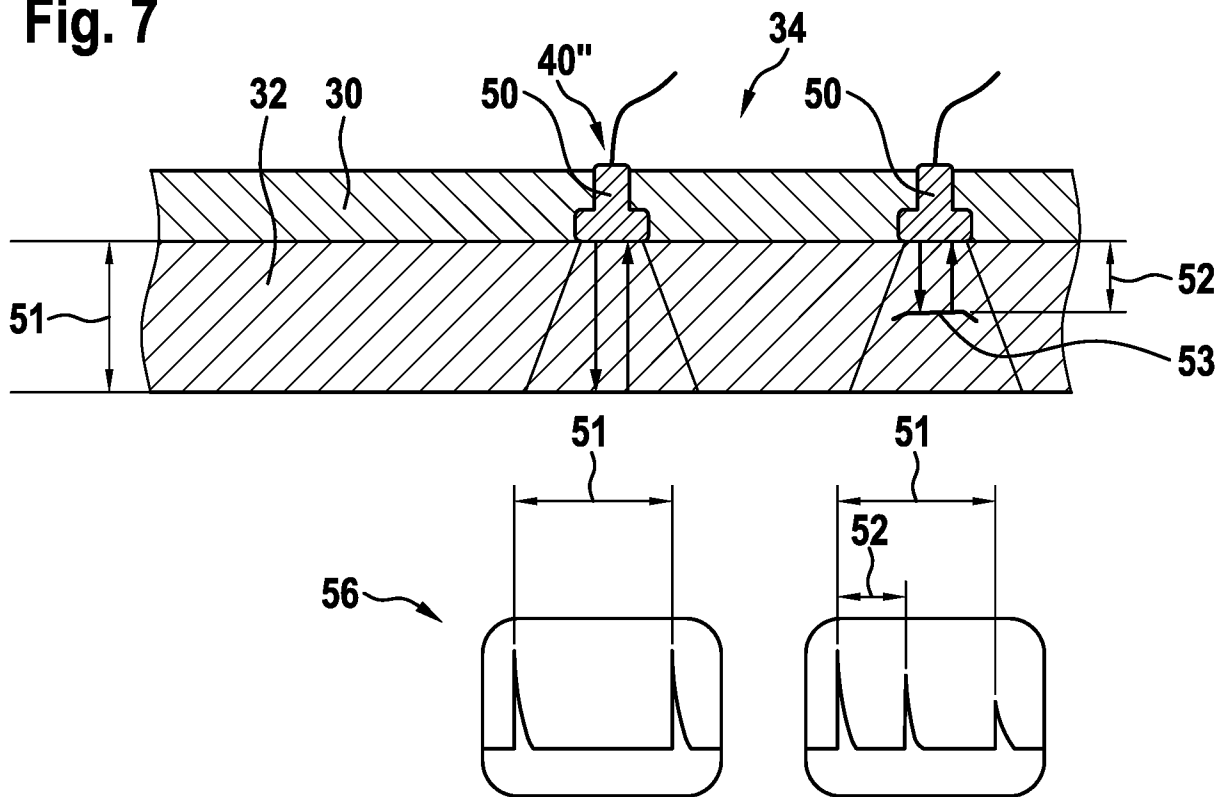
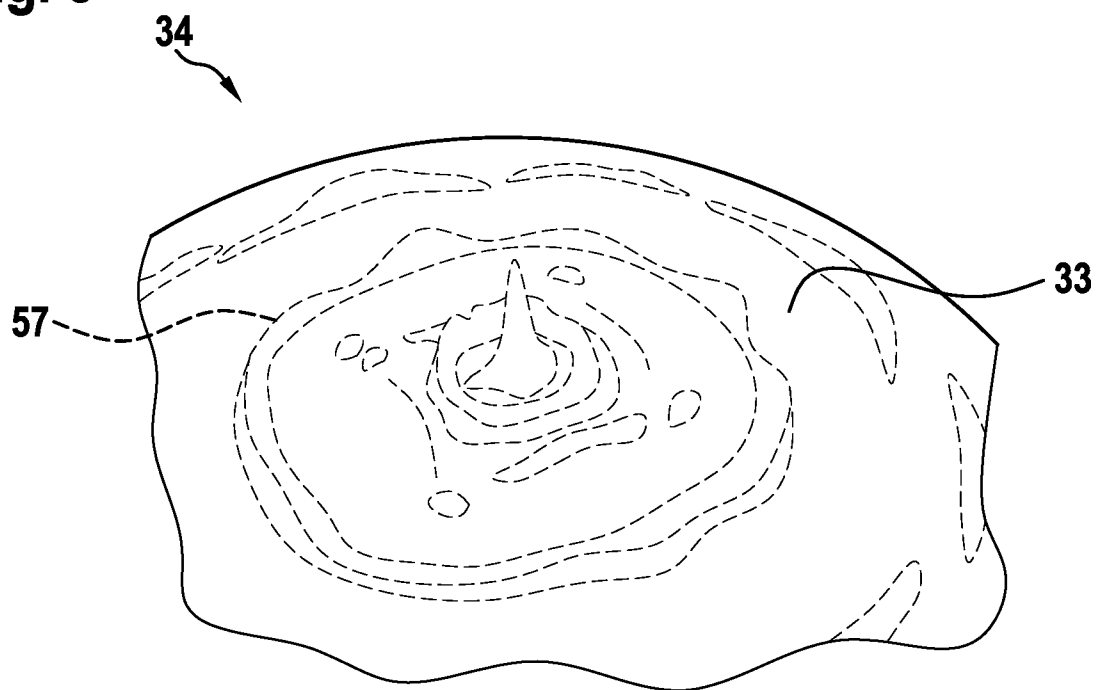


Fig. 8



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/085573

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/20
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)
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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 10 2014 218087 A1 (ZEISS CARL SMT GMBH [DE]) 22 October 2015 (2015-10-22) abstract figure 1 paragraphs [0001], [0042] - [0045], [0052]	1-11
A	----- "Real Time Visual Inspection of a Collector Mirror", RESEARCH DISCLOSURE, KENNETH MASON PUBLICATIONS, HAMPSHIRE, UK, GB, vol. 617, no. 27, 1 September 2015 (2015-09-01), page 3, XP007144342, ISSN: 0374-4353 [retrieved on 2015-08-17] the whole document ----- -/-	1-11



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

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Date of the actual completion of the international search

26 March 2020

Date of mailing of the international search report

06/04/2020

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Authorized officer

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/085573

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	DE 10 2015 201139 A1 (ZEISS CARL SMT GMBH [DE]) 16 April 2015 (2015-04-16) cited in the application abstract figures 1-4 paragraphs [0001], [0036] - [0047] -----	1-11
A	US 2007/132989 A1 (KALLER JULIAN [DE] ET AL) 14 June 2007 (2007-06-14) abstract figures 1-4 paragraphs [0002], [0031], [0070], [0072], [0107] - [0109], [0130], [0134] -----	1-11

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2019/085573

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