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(54) Title: ADJUSTMENT DEVICE AND MASK INSPECTION DEVICE WITH SUCH AN ADJUSTMENT DEVICE

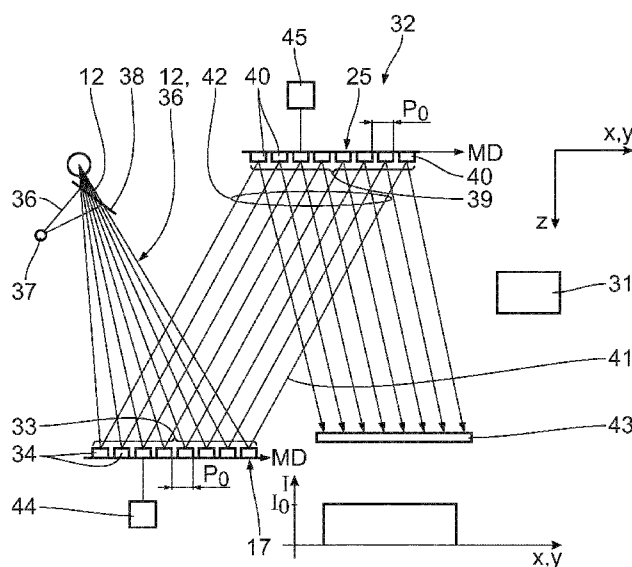


Fig. 5

(57) Abstract: An adjustment device (32) serves for
adjusting mirrors (17, 25) for guiding used radiation
(12) along a beam path. The adjustment device (32)
has at least a first adjustment mark (33) and at least a
second adjustment mark (39). At least one of the two
adjustment marks (33, 39) is fixedly connected to
one of the mirrors (17, 25) to be adjusted. The rela-
tive position of the adjustment marks (33, 39) with
respect to one another is a measure for an adjustment
parameter for the correspondence between an actual
adjustment position of the mirrors (17, 25) to be ad-
justed and an intended adjustment position. The ad-
justment device (32) includes a spatially resolving
detector (43) for detecting the adjustment parameter.
At least one of the mirrors to be adjusted is a facet
mirror (17, 25) with a plurality or multiplicity of
mirror facets or mirror facet groups. The result of
this is an adjustment device by means of which a
predetermined adjustment precision for the relative
position of the two mirrors with respect to one an-
other is achieved.

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Adjustment device and mask inspection device with such an adjustment device

The contents of German patent application DE 10 2012 208 514.9 are incorporated herein by reference.

The invention relates to an adjustment device for adjusting mirrors for guiding a beam of radiation along a beam path. Furthermore, the invention relates to a mask inspection device for inspecting a mask for projection lithography, with such an adjustment device.

Devices for adjusting mirrors are known from prior public use. US 6,842,248 B1 discloses a system and a method for calibrating mirrors of a stage assembly. DE 690 12 874 T2 discloses equipment for projecting a mask pattern onto a substrate. US 6,118,516 A discloses a projection exposure apparatus having a filter arranged in its projection optical system and a method for projecting circuit patterns. DE 29 05 635 A1 describes a method and a device for aligning image- and/or object areas in optical copying apparatuses. EP 1 349 009 A2 describes a lithographic apparatus and a method for producing an article. DE 295 20 171 U1 describes a micromechanical mirror array.

It is an object of the present invention to develop an adjustment device of the type mentioned at the outset in such a way that a predetermined adjustment precision for the relative position of the two mirrors with respect to one another is achieved.

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According to the invention, this object is achieved by an adjustment device for adjusting mirrors for guiding effective or used radiation along a beam path

- with at least a first adjustment mark,
- 5 - with at least a second adjustment mark,
- wherein at least one of the two adjustment marks is fixedly connected to one of the mirrors to be adjusted,
- wherein the relative position of the adjustment marks with respect to one another is a measure for an adjustment parameter for the corre-
- 10 spondence between an actual adjustment position of the mirrors to be adjusted and an intended adjustment position,
- with a spatially resolving detector for detecting the adjustment parameter,
- wherein at least one of the mirrors to be adjusted is a facet mirror with
- 15 a plurality or multiplicity of mirror facets or mirror facet groups.

According to the invention, it was discovered that the use of two adjustment marks together with a spatially resolving detector ensures a reproducible and precise adjustment of the relative position of the two mirrors to
20 be adjusted with respect to one another. The two mirrors to be adjusted can in turn be made up of a plurality of individually actuatable individual mirrors. However, such a configuration of individually actuatable individual mirrors is not mandatory. At least one of the mirrors to be adjusted is a facet mirror with a plurality or multiplicity of mirror facets or mirror facet
25 groups. In this mirror design, one of the mirror facets or a structure element of one of the mirror facets, e.g. the edge of a reflection surface of one of the mirror facets or a plurality of such edges, can be used as adjustment marker. The two mirrors to be adjusted relative to one another can respectively be a facet mirror with a plurality or a multiplicity of mirror facets. In

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particular, at least one of the mirrors to be adjusted can be an MEMS (microelectromechanical system) mirror array. Illumination optical units with such mirror facets, which are used in EUV projection lithography, are known from EP 0 955 641 A1 and DE 10 2008 009 600 A. The adjustment
5 device can be used for adjusting the relative position of two mirrors, in particular two facet mirrors, of the optical systems of such illumination optical units.

An adjustment device with an adjustment light source with an adjustment
10 wavelength which differs from an effective or used wavelength of the used radiation guided by the mirrors to be adjusted makes it possible to adjust mirrors which guide a used wavelength which, for adjustment purposes, can only be detected with difficulties or not at all. For the adjustment light source, use can be made of a laser with an adjustment wavelength in the
15 visible range (VIS) or in the ultraviolet range (UV) down to the deep ultraviolet range (DUV). The used wavelength can be significantly smaller once again and can, for example, lie in the extreme ultraviolet range (EUV).

Adjustment marks, in which the first adjustment mark is formed by a periodic sequence of reflecting first adjustment markers along a marker dimension on a mirror, leading in the beam path, of the mirrors to be adjusted,
20 with the second adjustment mark being formed by a periodic sequence of reflecting second adjustment markers along a marker dimension on a mirror, following in the beam path, of a mirrors to be adjusted,

25 - wherein a radiation intensity of a totality of adjustment radiation partial beams which is reflected by the first adjustment markers and subsequently reflected by the second adjustment markers is detected as adjustment parameter,

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can enable positional detection in the style of a moiré pattern. By means of this, the two mirrors can be adjusted with respect to one another in a number of degrees of freedom. Partial beams of the used radiation or partial beams of an adjustment radiation of a separate adjustment light source can
5 be used as adjustment radiation partial beams.

An embodiment of the adjustment device, according to which a periodicity of the adjustment markers on the mirrors to be adjusted is the same, wherein the adjustment radiation partial beams extend parallel to one another
10 between the adjustment marks, is simple and, in particular, enables the detection of tilt maladjustments.

An embodiment of the adjustment device, according to which a periodicity of the adjustment markers on the mirrors to be adjusted differs, wherein the
15 adjustment radiation partial beams extend in a divergent fashion with respect to one another or in a convergent fashion with respect to one another between the adjustment marks, in particular enables a detection of distance maladjustments.

20 An adjustment device, in which the first adjustment mark constitutes an object which is imaged onto an image in an arrangement plane of the second adjustment mark by the first mirror to be adjusted and/or the second mirror to be adjusted, wherein the second adjustment mark is fixedly connected to one of the two mirrors to be adjusted, wherein a distance between
25 the image of the first adjustment mark and the second adjustment mark is detected as adjustment parameter, can easily be realized and only makes small demands in respect of the design of the adjustment marks. Such an adjustment device can in particular measure translation maladjustments. To

- 5 -

the extent that the adjustment marks have a sufficient extent in space, this also allows the measurement of tilt maladjustments.

5 An intermediate image arrangement, according to which an intermediate image of the image of the first adjustment mark in the adjustment image lies between an object plane, in which the first adjustment mark is arranged, and the arrangement plane, renders possible a design of the adjustment device with increased sensitivity of the detected adjustment parameter in relation to a maladjustment of the mirrors to be adjusted.

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The adjustment facets forming adjustment markers, which adjustment facets are arranged outside of a beam guiding used area of the mirrors to be adjusted, can be embodied with different optical effects than the mirror regions, embodied for guiding the used radiation, of the mirrors to be adjusted. The adjustment facets can then have a specific beam guiding and in particular imaging effect for the adjustment radiation and can carry a coating which is optimized for reflecting the adjustment radiation.

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The adjustment facets forming adjustment markers, which adjustment facets are larger than the mirror facets or mirror groups used for beam guidance, avoid bothersome diffraction effects, which can occur, for example, if the mirror facets have an extent which is of the order of the adjustment wavelength. This can be the case if use is made of an adjustment wavelength which is significantly longer than a used radiation wavelength.

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The advantages of the adjustment device particularly come to bear in the case of mirrors to be adjusted, which are components of an optical system of a projection exposure apparatus. The projection exposure apparatus can be an EUV projection exposure apparatus. The mirrors to be adjusted can

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be components of an illumination optical unit and/or a projection optical unit of such a projection exposure apparatus. Such a projection exposure apparatus can be used to produce microstructured or nanostructured semiconductor components, in particular storage chips, with a very high structure resolution.

By controlling the adjustment parameter, an adjustment device can be used to realize a simple adjustment prescription. The adjustment device can also be used to monitor an adjustment state.

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It is possible to control the relative position of the mirrors to be adjusted with respect to one another by means of an adjustment device comprising a displacement drive for displacing the mirrors to be adjusted with respect to one another and with an open/closed-loop control unit which is signal-connected to the displacement drive.

15

Closed-loop control of the adjustment, depending on the adjustment parameter detected by the detector, is possible using an adjustment device in which the open/closed-loop control unit is signal-connected to the detector.

20 In particular, the adjustment device can also ensure an optimization of the relative position of the mirrors within an installation during operation.

The advantages of a mask inspection device for inspecting a mask for projection lithography, with an adjustment device according to the invention, correspond to those which were already explained above with reference to the adjustment device.

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Exemplary embodiments of the invention will be explained in more detail below on the basis of the drawing. In detail:

- 7 -

- Figure 1 schematically shows a projection exposure apparatus for EUV projection lithography with a primary light source, an illumination optical unit and a projection optical unit;
- 5
- Figure 2 schematically shows an meridional section through the projection exposure apparatus according to Figure 1, wherein a beam path for some partial beams of illumination and imaging light is highlighted in detail;
- 10
- Figure 3 schematically shows a section of an illumination system of the illumination optical unit, according to Figure 1, with a first transmission partial optical unit for generating secondary light sources by imaging the primary light source, wherein a section of a first facet mirror with reflective effect is illustrated in more detail such that individual mirrors, which are comprised by the first facet mirror and provide the individual mirror illumination channels for guiding the illumination light to an illumination field of the projection exposure apparatus, can be seen separately from one another and wherein the guidance of partial beams of two individual mirror illumination channels to a facet of a second facet mirror of a second transmission partial optical unit for transmitting the illumination light from the secondary light sources to the illumination field is shown;
- 15
- 20
- 25

- Figure 4 shows a plan view of a section of the first facet mirror with first adjustment marks;
- Figure 5 schematically shows an adjustment device for adjusting the two facet mirrors of the illumination optical unit, wherein both the first adjustment mark on the first facet mirror and a second adjustment mark on the second facet mirror are respectively formed by a periodic sequence of reflecting adjustment markers, illustrated in a relative position of the two facet mirrors adjusted with respect to one another;
- Figure 6 shows, in an illustration similar to Figure 5, the adjustment device with the second facet mirror maladjusted in a tilted fashion with respect to the first facet mirror;
- Figure 7 shows, in an illustration similar to Figure 5, a further embodiment of the adjustment device, in which the periodicity of the adjustment markers on the two facet mirrors differs with respect to one another and adjustment radiation partial beams extend in a convergent fashion with respect to one another between the adjustment markers;
- Figure 8 shows a further variant of an adjustment device for adjusting two mirrors with respect to one another, once again using the example of adjusting the two facet mirrors of the illumination optical unit with respect to one

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5 another, wherein the first adjustment mark constitutes an object which is imaged on an image in an arrangement plane of the second adjustment mark by the first mirror to be adjusted, wherein the second adjustment mark is fixedly connected to the second mirror to be adjusted, illustrated in a relative position adjusted with respect to one another of the two mirrors to be adjusted with respect to one another; and

10 Figure 9 shows, in an illustration similar to Figure 8, the adjustment device according to Figure 8 with mirrors maladjusted with respect to one another along a translation coordinate.

15 Figure 1 shows a schematic illustration of a projection lithography projection exposure apparatus 1. The projection exposure apparatus 1 comprises inter alia a light-source unit 2 and an illumination optical unit 3 for illuminating an object field 4 in an object plane 5, in which a structure-bearing mask 6 is arranged, which mask is also referred to as reticle. The reticle 6
20 is held by a reticle holder 7.

In order to simplify the description of positional relations, a Cartesian xyz-coordinate system is plotted in Figure 1 as a global coordinate system of the projection exposure apparatus 1. The x-axis extends perpendicular to
25 the plane of the drawing of Figure 1 and into the latter. The y-axis extends to the right. The z-axis extends downward.

The reticle can be displaced along the y-direction in the object plane 5 with the aid of the reticle holder 7 which comprises a displacement drive.

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A further component of the projection exposure apparatus 1 is a projection lens 8 for imaging the structure-bearing mask 6 on a substrate 9, the so-called wafer. This substrate 9 contains a photo-sensitive layer which is
5 modified chemically during exposure. This is referred to as a lithographic step. Here, the structure-bearing mask 6 is arranged in the object plane 5 and the substrate 9 is arranged in an image plane 10 of the projection lens 8. During the exposure, the wafer 9 is likewise displaced along the y-direction by means of a wafer holder 11 comprising a further displacement
10 drive, to be precise in a synchronous fashion with the displacement of the substrate holder 7. During the exposure, the object field 4 is imaged in an image field 10a in the image plane 10. A beam path of illumination and imaging light 12 between the light-source unit 2 and the wafer 9 is indicated very schematically in Figure 1. In the following text, the illumination
15 light 12 is also referred to as used radiation.

The illumination optical unit 3 and the projection lens 8 comprise a plurality of optical elements. Here, these optical elements can be designed in both a refractive and reflective fashion. Combinations of refractive and
20 reflective optical elements within the illumination optical unit 3 or the projection lens 8 are also possible. The structure-bearing mask 6 can equally have a reflective or transmissive design. Such projection exposure apparatuses consist completely of reflective components in particular when they are operated with radiation with a wavelength of <193 nm, in particular
25 with a wavelength in the extreme ultraviolet range (EUV) of 5 to 15 nm. Projection exposure apparatuses 1 are often operated as so-called scanners. This means that the structure-bearing mask 6 is moved through a slit-shaped illumination field, which coincides with the object field 4, along the scanning direction y, while the substrate 9 is moved synchronously there-

with in the image plane 10 of the projection lens 8. The ratio of the speeds of structure-bearing mask 6 and substrate 9 in this case corresponds to the magnification of the projection lens 8, which is usually less than 1, in particular equal to $\frac{1}{4}$.

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Figure 2 shows an embodiment of the projection exposure apparatus 1 with the illumination optical unit 3 and the projection lens 8 in more detail.

Here, the illumination optical unit 3 comprises a first transmission partial optical unit 13 for generating secondary light sources 14 by imaging a primary light source in the form of a source plasma 15 of the light-source unit 2. The first transmission partial optical unit 13 includes an integral or multipart collector mirror 16, which collects the EUV radiation of the source plasma in the wavelength range between 5 nm and 15 nm, and a first facet mirror in the form of a field facet mirror 17. The illumination light 12 impinges on the field facet mirror 17 with a convergent beam path.

The light-source unit 2 can be configured in various embodiments. A laser plasma source (LPP) is illustrated. In this source type, the tightly restricted source plasma 15 is generated by virtue of a small material droplet being produced by a droplet generator 18 and being moved to a predetermined location. There, the material droplet is irradiated by a high-energy laser 19 such that the material converts into a plasma state and emits radiation in the wavelength range 5 to 15 nm. Here, the laser 19 is arranged in such a way that the laser radiation passes through an opening 20 in the collector mirror 16 before it impinges on the material droplet. By way of example, an infrared laser, in particular a CO₂ laser, with a wavelength of 10 μ m is used as a laser 19. Alternatively, the light-source unit 2 can also be designed as a discharge source, in which the source plasma 15 is created with the aid of a discharge.

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The first facet mirror 17 comprises individual mirrors 21 (cf. Figure 3), which provide individual mirror illumination channels 22 for guiding the illumination light 12 to the illumination field 4. The individual mirrors 21
5 can be embodied both with planar reflection surfaces and curved reflection surfaces. Radii of curvature of the reflection surfaces of the individual mirrors 21 can differ from individual mirror 21 to individual mirror 21. The individual mirrors 21 have a mirror surface such that the individual mirror illumination channels 22 illuminate illumination field sections in the illumination field 4, which illumination field sections are smaller than the entire illumination field 4. Figure 2 does not illustrate the individual individual mirrors 21, but rather groups 23 of individual mirrors, wherein the individual mirrors 21 of respectively one of the groups 23 illuminate illumination field sections which complement one another to form the whole illumination field 4. The radii of curvature of the individual mirrors 21 can
15 differ from group 23 to group 23.

Downstream of the first transmission partial optical unit 13 in the beam path, the illumination optical unit 3 has a second transmission partial optical unit 24 for guiding the illumination light 12 from the secondary light
20 sources 14 into the illumination field 4. The second transmission partial optical unit 24 comprises a second facet mirror 25 in the form of a pupil facet mirror, which is arranged downstream of the first facet mirror 17 in the beam path of the illumination light 12. The secondary light sources 14
25 are produced in the region of a reflection of the illumination light 12 on the second facet mirror 25. The pupil facet mirror 25 has a plurality of pupil facets 26, which are also referred to as second facets.

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A first telescopic mirror 27 and a second telescopic mirror 28 are arranged in the light path downstream of the pupil facet mirror 25, with both telescopic mirrors being operated in the region of perpendicular incidence, i.e. the illumination light 12 impinges on the two mirrors 27, 28 with an angle of incidence of between 0° and 45° . Here, the angle of incidence is understood to mean the angle between the incident radiation and the normal of the reflective optical surface. Arranged downstream of this in the beam path is a deflection mirror 29, which deflects the radiation incident thereon onto the object field 4 in the object plane 5. The deflection mirror 29 is operated under grazing incidence, i.e. the illumination light 12 impinges on the mirror at an angle of incidence of between 45° and 90° . The reflective structure-bearing mask 6, which is imaged in the image field 10a in the image plane 10 with the aid of the projection lens 8, is arranged at the location of the object field 4. The projection lens 8 comprises six mirrors M1, M2, M3, M4, M5 and M6, which are numbered in the sequence of the beam path of the imaging light 3. All six mirrors M1 to M6 of the projection lens 8 respectively have a reflective optical surface, which extends along a surface rotationally symmetric about the optical axis oA.

Figure 3 shows a section of the illumination optical unit 3 between the source plasma 15 of the light source and one of the pupil facets 26 of the pupil facet mirror 25. In Figure 3, the components of the first transmission partial optical unit 13 and, additionally, one of the individual mirror groups 23 of the field facet mirror 17 are illustrated. Furthermore, the profiles of a plurality of selected individual rays of the illumination light 12, which are associated with the illustrated mirror group 23 of the field facet mirror 17, are also illustrated.

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Depending on the embodiment of the illumination optical unit 3, the field facet mirror 17 has an imaging effect or a purely deflecting effect for the illumination light 12. In Figure 3, the pupil facets 26 of the pupil facet mirror 25 are illustrated by a mirror surface with concave curvature.

5

From the illustration according to Figure 3 it becomes clear that, in the first transmission partial optical unit 13, the collector mirror 16 images the primary light source, i.e. the source plasma 15, onto the secondary light source 14 in the region of the pupil facet 26, which is associated with the individual mirrors 21 of the mirror group 23 via a group illumination channel. The group illumination channel includes the individual mirror illumination channels 22 of the individual mirrors 21 of this mirror group 23.

10

Apart from pure beam deflection, the field facet mirror 17 contributes nothing to this imaging.

15

In the case of this imaging, the secondary light sources 14 constitute a first light-source image in the beam path of the illumination light 2 after the primary light source, i.e. after the source plasma 15.

20 In actual fact, as can be gathered from Figure 2, each of the mirror groups 23 is illuminated by the illumination light and respectively images the source plasma 15 on a selected one of the pupil facets 26 of the pupil facet mirror 25 in the form of a secondary light source 14. The secondary light sources 14 do not have to lie exactly at the point of reflection on the pupil facets 26, but can rather also be created in the beam path of the illumination light 12 adjacent to the reflection on the pupil facets 26.

25

Each of the mirror groups 23 of the field facet mirror 17 has a plurality of individual mirrors 21. Via the respective individual mirror illumination

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channels 22, the individual mirrors 21 respectively reflect the illumination light 12 into illumination field sections, which are smaller than the entire illumination field or object field 4 and complement one another to form the entire object field 4 for the individual mirrors 21 of respectively one of the mirror groups 23. Thus, one of the mirror groups 23 has the function of a field facet of a field facet mirror or a first scanning element according to, for example, US 6,438,199 B1 or US 6,658,084 B2. A corresponding subdivision of field facets into individual mirrors such that the effect of an individual mirror group corresponds to the effect of a field facet is known from DE 10 2008 009 600 A.

The individual mirrors 21 respectively of one of the mirror groups 23 are associated with exactly one pupil facet 26, i.e. one of the facets of the second facet mirror 25, by means of their respective individual mirror illumination channels 22. Within such a mirror group 23 there can be more than ten individual mirrors 21, more than twenty-five individual mirrors 21, more than fifty individual mirrors 21 or else more than one hundred individual mirrors 21.

In one embodiment of the illumination optical unit 3, each of the individual mirrors 21 is in a mechanical functional connection with an associated actuator 30 for a tilt-displacement of the respective individual mirror 21, which is illustrated in an exemplary fashion for one of the individual mirrors 21 in Figure 3. By means of the actuators 30, the individual mirrors 21 can be tilted between at least two tilt positions in such a way that, in a first one of the tilt positions of the individual mirrors 21, a first illumination distribution of the facets 26 of the second facet mirror 25 and, in a second one of the tilt positions of the individual mirrors 21, a second illumination distribution of the facets 26 of the second facet mirror 25 is illuminated via

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the individual mirrors 21 which are respectively associated by the individual mirror illumination channels 22.

In the tilt position of the individual mirrors 21 according to Figure 3, the individual mirrors 21 of the illustrated individual mirror group 23 deflect the illumination light 12 onto precisely one of the pupil facets 26, which, in Figure 3, is denoted as pupil facet 26₁. This illumination is shown for precisely two of the individual mirrors 21.

The actuators 30 of the individual mirrors 21 are signal-connected (not illustrated) to a central control apparatus 31. The control apparatus 31 prescribes the respective tilt positions of the individual mirrors 21.

In a further embodiment of the illumination optical unit 3, the respective mirror group 23 has a monolithic design. The individual mirrors 21 of the mirror group 23 are then tilted individually and can, depending on the curvature of the reflection surfaces of the mirrors 21, have a different beam guiding effect, but cannot be actuated individually. In this case, each of the mirror groups 23 is equipped with a group actuator for common tilting of all individual mirrors 21.

The pupil facets 26 of the pupil facet mirror 25 lie in an illumination pupil plane of the illumination optical unit 3.

The size of the individual mirrors 21 is illustrated in a greatly exaggerated fashion in Figure 3, since the ratio between the size of the respective individual mirror 21 and the distance between the collector 16 and the field facet mirror 17 with the mirror groups 23 is very much smaller in practice than illustrated in the schematic Figure 4.

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Figure 5 shows an adjustment device 32 for adjusting mirrors for guiding beams of radiation along a beam path, using the example of adjusting the field facet mirror 17 relative to the pupil facet mirror 25. In a similar fashion as to will be explained below on the basis of these two mirrors 17, 25, it is possible, using the adjustment device 32, to adjust the relative position of arbitrary pairs of mirrors relative to one another, which are arranged in succession in a beam path for guiding used radiation. Examples of such pairs of mirrors are the mirrors of the illumination optical unit 3 or the mirrors of the projection optical unit 8 of the projection exposure apparatus 1.

10

The adjustment device 32 has a first adjustment mark 33 in the form of a periodic sequence of reflecting first adjustment markers 34 along a marker dimension MD on the field facet mirror 17, i.e. on the guiding mirror in the beam path of the illumination light 12. The marker dimension MD can be a dimension parallel to the x- or y-coordinate, as indicated in Figure 5 by the schematically plotted Cartesian xyz-coordinate system.

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Figure 4 shows a plan view of the field facet mirror 17. A section of a support plate 35 of the field facet mirror 17 with a mirror group 23, arranged thereon and illustrated in an exemplary fashion, with individual mirrors 21 and several adjustment markers 34 of the adjustment mark 33 is illustrated.

20

In the plane of the support plate 35, the reflection surfaces of the respective adjustment markers 34 have an extent which is so large that there are no diffraction effects at the adjustment markers 34, even in the case of an adjustment wavelength of adjustment radiation 36, guided over the beam path of the illumination light 12, which is significantly longer than the wavelength of the illumination light 12. The adjustment radiation 36 has a wave-

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- length of, for example, 193 nm, i.e. a wavelength which is longer by approximately a factor of 10 than the wavelength of the illumination light 12. The adjustment markers 34 have x- and y-extents of, for example, 10 μm , i.e. they can be embodied as square mirrors on the support plate 35 with
- 5 reflection surfaces with extents of 10 $\mu\text{m} \times 10 \mu\text{m}$. Larger reflection surfaces of the adjustment markers 34 are also possible, for example surfaces with typical edge lengths of 50 μm , 100 μm , 250 μm , 500 μm , 1 mm, 2 mm or 5 mm.
- 10 The adjustment radiation 36 is generated by an adjustment radiation source 37 (cf. Figure 5) and coupled into the beam path of the illumination light 12 via a coupling-in mirror 38, which can, for example, be folded in and is folded into the beam path of the illumination light 12 during adjustment
- 15 1. pauses outside of the operating times of the projection exposure apparatus

The adjustment device 32 furthermore includes a second adjustment mark 39 on the pupil facet mirror 25. The second adjustment mark 39 is likewise formed by a periodic sequence of reflecting second adjustment markers 40

20 along a marker dimension MD on the pupil facet mirror 25, i.e. on the following mirror, of the mirrors to be adjusted, in the beam path of the illumination light 12 and the adjustment radiation 36. In the case of a correct adjustment of the two mirrors 17, 25 with respect to one another, as illustrated in Figure 5, the two marker dimensions MD of the adjustment marks

25 33, 39 extend parallel to one another and, for example, relative to the x-direction or parallel to the y-direction. Both the adjustment markers 34 and the adjustment markers 40 have planar reflection surfaces.

The adjustment markers 34 reflect the adjustment radiation 36 in such a way that adjustment radiation partial beams 41 of the adjustment radiation 36 extend parallel to one another between the adjustment marks 33, 39. In the embodiment of the adjustment device 32 according to Figures 5 and 6, the periodicity P_0 of the adjustment markers 34 and 40 of the adjustment marks 33 and 39 is the same. In the mirrors 17, 25 adjusted in accordance with Figure 5, an effective period of a totality 42 of the adjustment radiation partial beams 41 on the pupil facet mirror 25 has the same length as the period P_0 of the adjustment markers 40 of the second adjustment mark 39. Moreover, if the mirrors 17, 25 are adjusted correctly with respect to one another, the adjustment markers 40 of the second adjustment mark 39 are aligned precisely with respect to the adjustment radiation partial beams 41, both in the x-direction and in the y-direction, such that said adjustment radiation partial beams can be reflected with the greatest reflectivity from the adjustment markers 40 to a spatially resolving detector 43 in the form of a camera.

The adjustment markers 40 are aligned in such a way that the adjustment radiation partial beams 41 extend parallel to one another even after the reflection on the adjustment markers 40.

A radiation intensity I of the totality 42 of the adjustment radiation partial beams 41 which is reflected by the first adjustment markers 34 and subsequently reflected by the second adjustment markers 40 serves as adjustment parameter detected by the camera 43. In the case of a perfect adjustment of the two mirrors 17, 25 with respect to one another, the radiation intensity detected with the camera 43 along the marker dimension MD, which can extend along the x-axis or along the y-axis, has a top hat profile $I(x, y)$, wherein a detected intensity I_0 reaches a predetermined value (cf.

- 20 -

Figure 5). A maladjustment is present if, in a predetermined detection region of the camera 43, the radiation intensity value $I = I_0$ is not reached and/or if the measured radiation intensity profile is not a top hat profile.

- 5 Figure 6 clarifies the effects of a tilt maladjustment of the mirror 25 relative to the mirror 17 about a tilt angle α . This reduces an effective period P_{eff} of the adjustment markers 40 of the second adjustment mark 39 to a value $P_{\text{eff}} = P_0 \times \cos \alpha$, wherein P_0 is the period of the adjustment markers 40 of the second adjustment mark 39 along the marker dimension. Accord-
- 10 ingly, only part of the totality of the adjustment radiation partial beams 41, which are incident on the pupil facet mirror 25, is reflected with the greatest reflectivity by the adjustment markers 40. In the example according to Figure 6, this is a central adjustment radiation partial beam 41_m . The further the other adjustment radiation partial beams 41 are distanced from this
- 15 central adjustment radiation partial beam 41_m , the lower a reflection efficiency of the adjustment radiation partial beams 41 is on the adjustment markers 40. This is due to the fact that the following applies to the periodicities: $P_{\text{eff}} < P_0$. A radiation intensity profile, which is illustrated below the camera 43 in Figure 6, emerges as adjustment parameter on the image
- 20 field of the camera 43. As long as the peak intensity value I_0 is still reached, it is still possible to gather from this approximately Gaussian radiation intensity profile that there is only a tilt maladjustment. If the intensity maximum value, I_0 , is no longer reached in the radiation intensity profile according to Figure 6, this is an indication that there also is a translation maladjustment in addition to a tilt maladjustment, since none of the
- 25 adjustment partial beams are then reflected at the adjustment markers 34 or 40 with the highest reflectivity.

- 21 -

The adjustment markers 34 and 40 can be formed by adjustment facets, which are arranged outside of a beam guiding used region of the mirrors 17, 25 to be adjusted. A boundary of this beam guiding used region is indicated in Figure 4 by a dash-dotted line between the adjustment markers 34
5 arranged outside of the beam guiding used region and the mirror groups 23 arranged within the beam guiding used region.

In accordance with what was explained above in the context of Figure 4 and the field facet mirror 17, the adjustment markers 40 are arranged on a
10 support plate of the pupil facet mirror 25, outside of a beam guiding used region, in which the pupil facets 26 of the pupil facet mirror 25 are arranged.

The adjustment device 32 furthermore includes a first displacement drive
15 44 for displacing the field facet mirror 17, which is mechanically connected to the support plate 35, and a second displacement drive 45 for displacing the pupil facet mirror 25, which is mechanically connected to the support plate thereof. The two displacement drives 44 and 45 and also the camera 43 are signal-connected to the open/closed-loop control unit 31,
20 which is not illustrated in detail in Figure 5.

A lookup table is stored in the open/closed-loop control unit 31, which lookup table associates specific change patterns for the radiation intensity profile measured by the camera 43 with specific relative displacements be-
25 tween the mirrors 17, 25, which displacements can be prescribed by the displacement drives 44, 45. In order to adjust the two mirrors 17, 25 with respect to one another, some test displacements of the mirrors 17, 25 with respect to one another are played through and the mirror intensity profile changes measured thereby are established by the displacement patterns in

- 22 -

the lookup table. As a result of this, the open/closed-loop control apparatus 31 establishes an actual position of the two mirrors 17, 25 and subsequently actuates the displacement drives 44, 45 in such a way that these actual positions of the mirrors 17, 25 correspond to previously predetermined, perfectly adjusted intended positions. This is how the mirrors 17, 25 are adjusted. The relative position of the adjustment marks 33 with respect to one another is a measure for the adjustment parameter for the correspondence between an actual adjustment position of the mirrors 17, 25 to be adjusted and an intended adjustment position.

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Figure 7 shows a further embodiment of an adjustment device 46, which can be used in place of the adjustment device 32 for adjusting the two mirrors 17, 25 or another pair of mirrors of the projection exposure apparatus 1 or of a different optical system. Components which correspond to those which were already explained above with reference to Figures 1 to 6 and, in particular, with reference to Figures 4 to 6 are denoted by the same reference signs and will not once again be discussed in detail.

In the adjustment device 46, the periodicity P_0 of the first adjustment mark 33 on the mirror 17 differs from the periodicity P_1 of the second adjustment mark 39 on the mirror 25. The following applies: $P_1 < P_0$. In the adjustment device 46, the adjustment radiation partial beams 41 extend in a convergent fashion between the adjustment marks 33 and 39 between the two mirrors 17 and 25 to be adjusted. The convergence angle is matched to the ratio P_1/P_0 in such a way that, in the case of mirrors 17, 25 correctly adjusted with respect to one another, the distance between the adjustment radiation partial beams 41 on the reflection on the adjustment markers 40 corresponds to the periodicity of these adjustment markers 40 on the second mirror 25 adjusted in this way. In the case of mirrors 17, 25 that are ad-

justed perfectly with respect to one another, the adjustment radiation partial beams 41 are thus reflected with highest reflectivity by both the adjustment markers 34 of the first adjustment mark 33 and the adjustment marks 40 of the second adjustment mark 39.

5

In the adjustment device 46, the camera 43 is arranged downstream of an intermediate focus Z, through which the adjustment radiation partial beams 41 pass as a result of the convergent guidance thereof. In the case of a correct adjustment of the two mirrors 17, 25 with respect to one another, the camera once again detects a radiation intensity profile $I(x)$ or $I(y)$ in the form of a top hat profile $I = I_0$ as adjustment parameter. In the case of a maladjustment of the two mirrors 17, 25, in particular in the case of a maladjustment of the mirror 25 relative to the mirror 17 in the z-direction, this results in a deviation of the measured radiation intensity profile from this top hat profile, as illustrated in Figure 7 in a dashed manner. In particular in the case of a maladjustment along the z-direction, the periodicity of the adjustment radiation beam deviates from the periodicity of the second adjustment markers 40 as a result of the convergence of the adjustment radiation beam 41 in the region of the reflection at the second mirror 25 adjusted thus so that not all of the adjustment radiation partial beams are reflected at the second adjustment markers 40 with the same high reflectivity. The adjustment device 46 is therefore particularly sensitive in respect of a maladjustment of the two mirrors 17, 25 with respect to one another along the z-direction, i.e. perpendicular to the marker dimension MD.

25

The following emerges for this effective period P_{JT} of the adjustment radiation partial beams at the adjustment device 46, dependent on a maladjustment z:

- 24 -

$$P_{JT} = P_1 \times (z_0 - z) / z_0.$$

Here, a measure for z_0 is at which z -distance the adjustment radiation partial beams 41 would meet at a focus if the second mirror 25 were omitted.

5

The adjustment sensitivity of the two adjustment devices 32, 46 emerges from the principle of a moiré pattern.

In place of a convergent beam path between the two mirrors 17, 25, use can also be made of a divergent beam path in an alternative embodiment of an adjustment device. In this case, the periodicity P_1 of the adjustment markers 40 on the second mirror 25 in the beam path is greater than the periodicity P_0 of the adjustment markers 34 of the first adjustment mark on the first mirror 17.

15

On the basis of Figures 8 and 9, a further embodiment of an adjustment device 47 for adjusting mirrors 17, 25 for beam guidance of radiation along a beam path is described below, once again using the example of the two facet mirrors 17, 25. Components which correspond to those which were already explained above with reference to Figures 1 to 7 are denoted by the same reference signs and will not once again be discussed in detail.

20

As first adjustment mark, the adjustment device 47 has an adjustment object 48, which can, for example, be a cross, which is illustrated in a plan view in an insert of Figure 8. The bars of the cross of the adjustment mark 48 extend parallel to the x -direction and parallel to the y -direction. The adjustment object 48 and imaging adjustment mirrors 49, 50 on the two mirrors 17, 25 to be adjusted are arranged in such a way that the adjustment object 48 is imaged onto an adjustment image 51 on at least one of the two

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- 25 -

mirrors 17, 25 as a result of the imaging effect. An intermediate image ZB of this image lies between an adjustment object plane 52, in which the adjustment object 48 is arranged, and an adjustment image plane 53, in which the adjustment image 51 is arranged. The first mirror 17 images the adjustment object 48 into the intermediate image ZB. The second mirror 25 images the intermediate image ZB into the adjustment image 51.

The intermediate image plane 53 coincides with an arrangement plane of a second adjustment mark 54. The second adjustment mark 54 is fixedly, i.e. rigidly, connected to the first mirror 17, as indicated in Figure 8 by a connecting arm 55.

The adjustment marks 48 and 54 of the adjustment device 47 can, in particular, be realized by edges of reflection surfaces of mirror facets on the mirrors 17, 25.

In the case of correctly adjusted mirrors, the adjustment image 51 coincides with the second adjustment mark 54.

The second adjustment mark 54 can in turn be embodied as an xy-cross in the style of the adjustment object 48. An x/y-distance, i.e. firstly an x-distance and secondly a y-distance, between the adjustment image 51 and the second adjustment mark 54 is captured by the camera 43 as an adjustment parameter. In the case of correctly adjusted mirrors 17, 25, this x/y-distance is 0.

In the case of a maladjustment between the mirrors 17 and 25, this results in a corresponding x/y-displacement of the adjustment image 51 relative to the second adjustment mark 54, as illustrated in Figure 9. In the case of

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magnifying imaging of the adjustment object 48 into the adjustment image 51, a corresponding magnification of a sensitivity of the adjustment device 47 in relation to an adjustment displacement of the mirrors 17, 25 with respect to one another can be achieved, as illustrated in Figure 9. A displacement error Δx of the mirror 17 is, in the process, converted into an enlarged distance $\Delta x'$ of the adjustment image 51 from the second adjustment mark 54.

The adjustment devices 46 and 47 can also interact with displacement drives for the mirrors 17, 25 and with an open/closed-loop control apparatus 31 for closed-loop control of the mirror adjustment, as was already explained above in conjunction with the adjustment device 32.

During the production of a microstructured or nanostructured component, the wafer 9 is initially provided, on which wafer a layer made of a light-sensitive material is applied at least in part. Provision is moreover made for the reticle 6, which has structures to be imaged. Furthermore, the projection exposure apparatus 1 is provided with one of the above-described embodiments of the first transmission partial optical unit 13 and a pupil facet mirror 25, in which the number of pupil facets 26 is an integer multiple of the number of individual mirror groups 23; for example, it is greater by a factor of three to ten. Prior to the actual projection exposure, the mirrors 17, 25 and optionally further pairs of mirrors of the optical system of the projection exposure apparatus 1, i.e. of the illumination optical unit 3 and/or the projection optical unit 8, i.e. in particular also the mirrors M1 to M6, are adjusted with respect to one another with the aid of the adjustment devices 32, 46 or 47 explained above. An illumination setting is thereupon prescribed; i.e. those pupil facets 26 of the pupil facet mirror 25 which should be illuminated are selected so that a predetermined illumination an-

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gular distribution results during the illumination of the object field 4, in which the reticle 6 is arranged. In accordance with this prescription, the open/closed-loop control apparatus 31 prescribes the tilt position of the individual mirrors 21 of all individual mirror groups 23 of the first facet
5 mirror 17. Subsequently, at least part of the reticle 6 is projected onto a region of the light-sensitive layer with the aid of the projection optical unit 8 of the projection exposure apparatus 1.

The above-described embodiments of the adjustment devices 32, 46 and 47
10 can also be used for adjusting two mirrors to be adjusted in a mask inspection device. Such a mask inspection device is described in WO 2011/144389 A1, the content of which is referred to in its entirety. Such a mask inspection device comprises an illumination optical unit for illuminating the mask, i.e., for example, the reticle 6, a magnifying imaging optical unit for illuminating an illuminated object field, which coincides with a
15 section of the mask, and a detection apparatus for capturing a light intensity of the illumination and imaging light in the image field. The mirrors to be adjusted with respect to one another can in each case be two of the illumination mirrors B1 to B3 and/or two of the projection mirrors M1 to M4 of
20 the mask inspection device described in this document. Such a mask inspection device can be used, in particular, to measure optical parameters of the mask and/or detect structure defects on the mask.

Patent claims

1. Adjustment device (32; 46; 47) for adjusting mirrors (17, 25) for guiding used radiation (12) along a beam path
 - 5 - with at least a first adjustment mark (33; 48),
 - with at least a second adjustment mark (39; 54),
 - wherein at least one of the two adjustment marks (33, 39; 54) is fixedly connected to one of the mirrors (17, 25; 17) to be adjusted,
 - wherein the relative position of the adjustment marks (33, 39; 48, 10 54) with respect to one another is a measure for an adjustment parameter for the correspondence between an actual adjustment position of the mirrors (17, 25) to be adjusted and an intended adjustment position,
 - with a spatially resolving detector (43) for detecting the adjustment 15 parameter,
 - wherein at least one of the mirrors to be adjusted is a facet mirror (17, 25) with a plurality or multiplicity of mirror facets (21) or mirror facet groups (23).
- 20 2. Adjustment device according to Claim 1, **characterized by** an adjustment light source (37) with an adjustment wavelength which differs from a used wavelength of the used radiation guided by the mirrors to be adjusted.
- 25 3. Adjustment device according to Claim 1 or 2, **characterized in that** the first adjustment mark (33) is formed by a periodic sequence of reflecting first adjustment markers (34) along a marker dimension (MD) on a mirror (17), leading in the beam path, of the mirrors (17, 25) to be adjusted, with the second adjustment mark (39) being formed by a pe-

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riodic sequence of reflecting second adjustment markers (40) along a marker dimension (MD) on a mirror (25), following in the beam path, of the mirrors (17, 25) to be adjusted,

- 5 - wherein a radiation intensity (I) of a totality (42) of adjustment radiation partial beams (41) which is reflected by the first adjustment markers (34) and subsequently reflected by the second adjustment markers (40) is detected as adjustment parameter.
- 10 4. Adjustment device according to Claim 3, **characterized in that** a periodicity (P_0) of the adjustment markers (34, 40) on the mirrors (17, 25) to be adjusted is the same, wherein the adjustment radiation partial beams (41) extend parallel to one another between the adjustment marks (33, 39).
- 15 5. Adjustment device according to Claim 3, **characterized in that** a periodicity (P_0 , P_1) of the adjustment markers (34, 40) on the mirrors (17, 25) to be adjusted differs, wherein the adjustment radiation partial beams (41) extend in a divergent fashion with respect to one another or in a convergent fashion with respect to one another between the adjustment marks (33, 39).
- 20 6. Adjustment device according to Claim 1 or 2, **characterized in that** the first adjustment mark (48) constitutes an object which is imaged onto an image (51) in an arrangement plane (53) of the second adjustment mark (54) by the first mirror (17) to be adjusted and/or the second mirror (25) to be adjusted, wherein the second adjustment mark (54) is fixedly connected to one of the two mirrors (17) to be adjusted, wherein a distance ($\Delta x'$) between the image (51) of the first adjustment mark
- 25

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(48) and the second adjustment mark (54) is detected as adjustment parameter.

- 5 7. Adjustment device according to Claim 6, **characterized in that** an intermediate image (ZB) of the image of the first adjustment mark (48) in the adjustment image (51) lies between an object plane (53), in which the first adjustment mark (48) is arranged, and the arrangement plane (53).
- 10 8. Adjustment device according to one of Claims 3 to 7, **characterized in that** the adjustment markers (34; 40) are formed by adjustment facets which are arranged outside of a beam guiding used area of the mirrors (17, 25) to be adjusted.
- 15 9. Adjustment device according to one of Claims 3 to 8, **characterized in that** the adjustment markers (34; 40) are formed by adjustment facets which are larger than the mirror facets (21) or mirror groups (23) used for the beam guidance.
- 20 10. Adjustment device according to one of Claims 1 to 9, **characterized in that** the mirrors (17, 25) to be adjusted are components of an optical system (3, 8) of a projection exposure apparatus (1).
- 25 11. Adjustment device according to one of Claims 1 to 10, **characterized by** a displacement drive (44, 45) for displacing the mirrors (17, 25) to be adjusted with respect to one another and with an open/closed-loop control unit (31) which is signal-connected to the displacement drive (44, 45).

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12. Adjustment device according to Claim 11, **characterized in that** the open/closed-loop control unit (31) is signal-connected to the detector (43).
- 5 13. Mask inspection device for inspecting a mask (6) for projection lithography, with an adjustment device (32; 46; 47) according to one of Claims 1 to 12.

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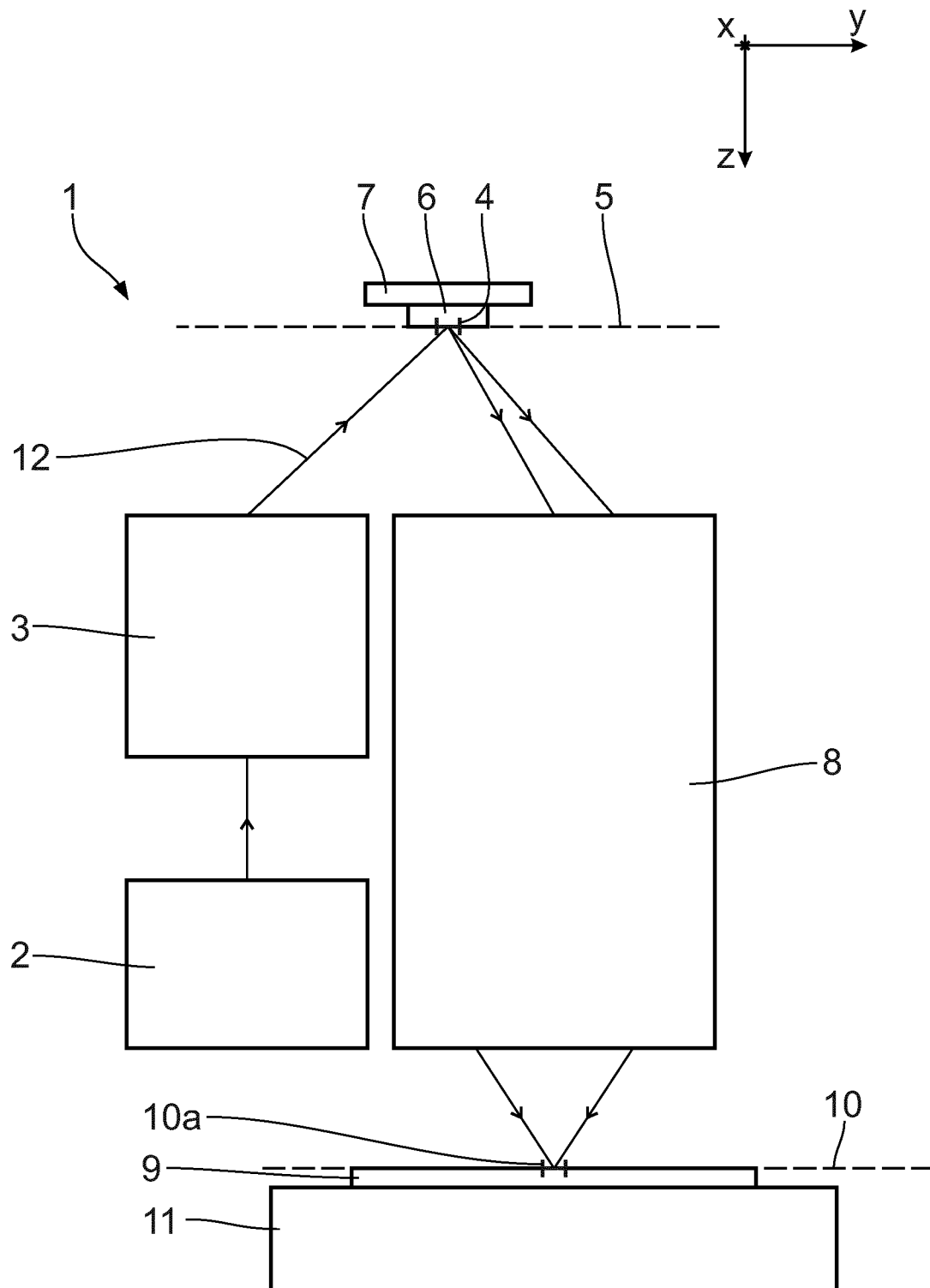


Fig. 1

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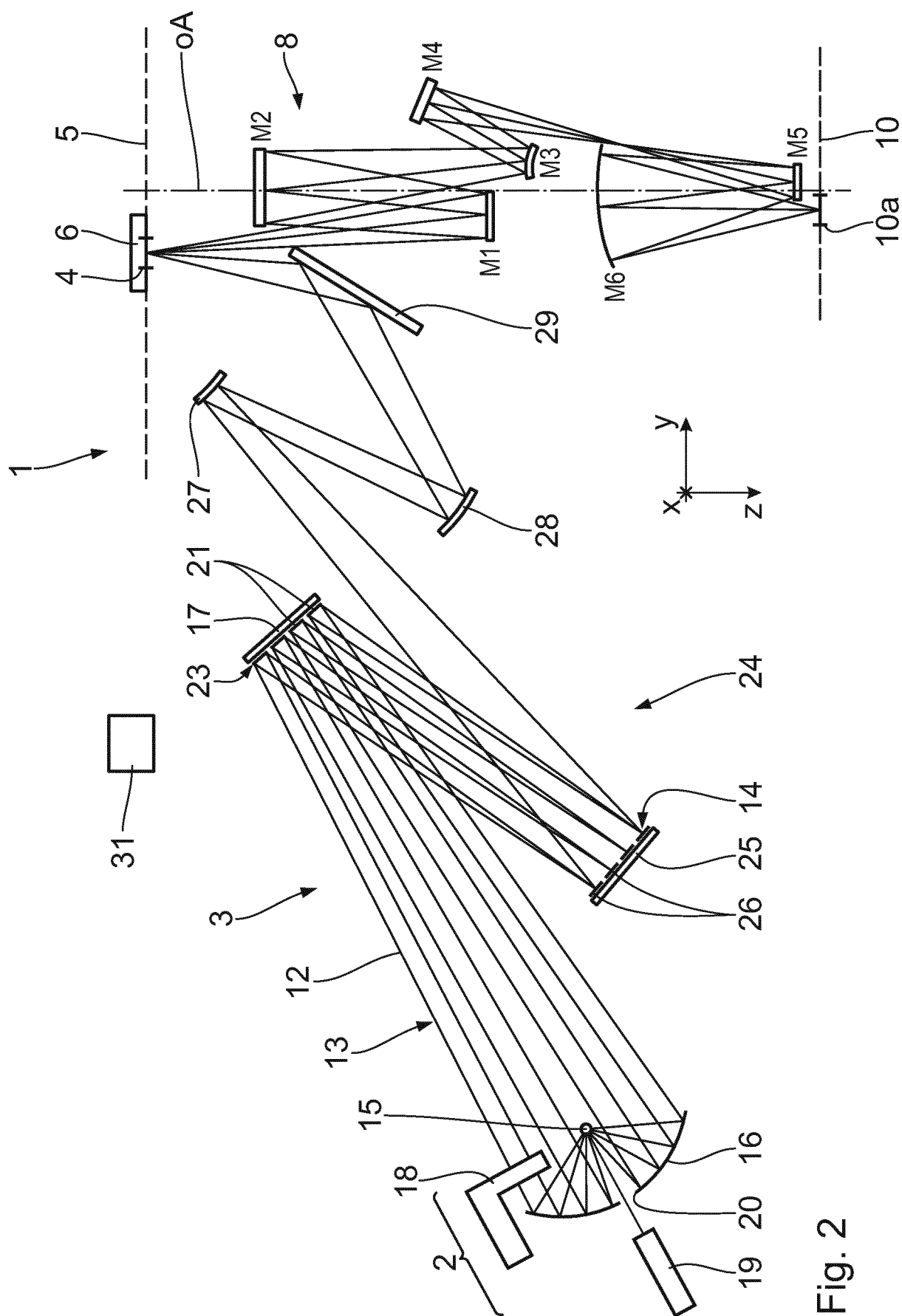


Fig. 2

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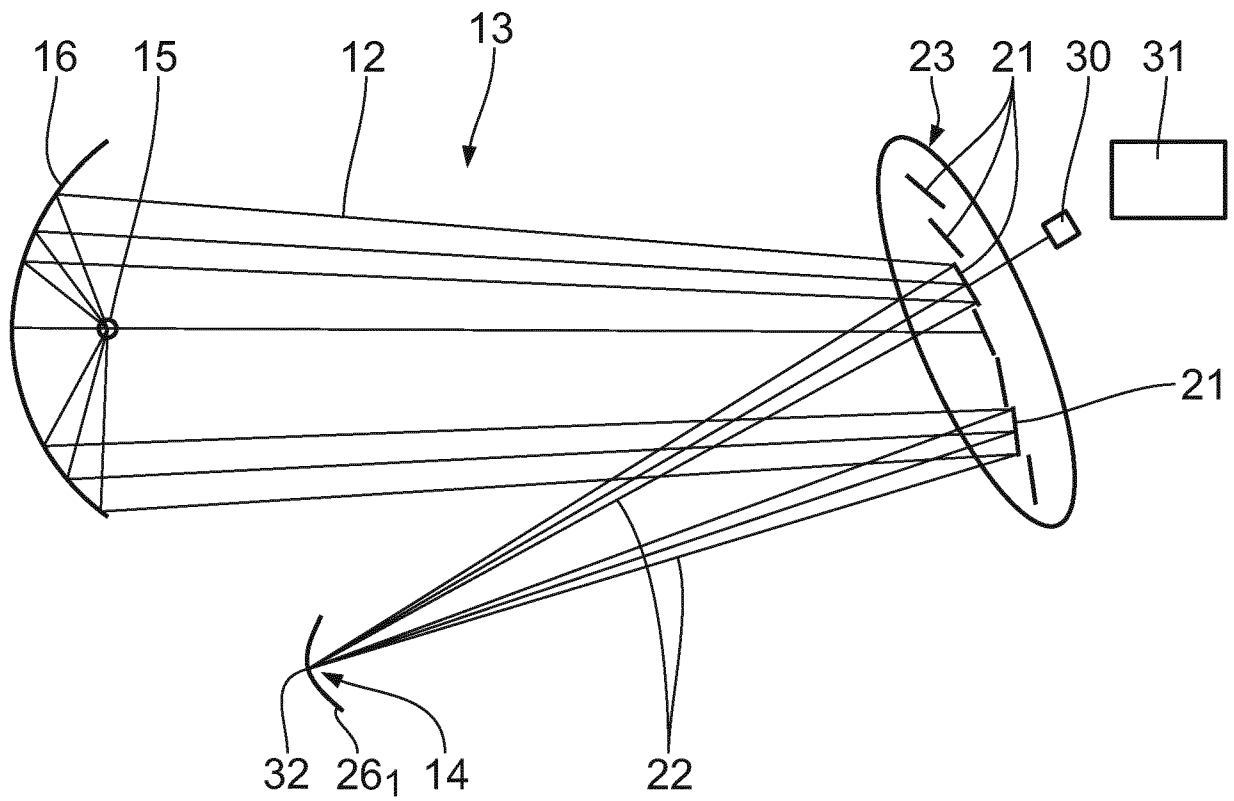


Fig. 3

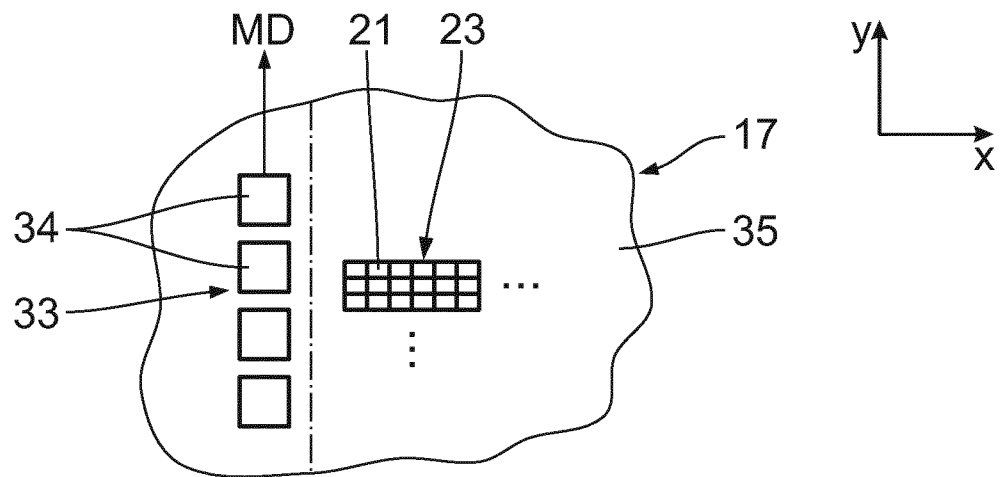


Fig. 4

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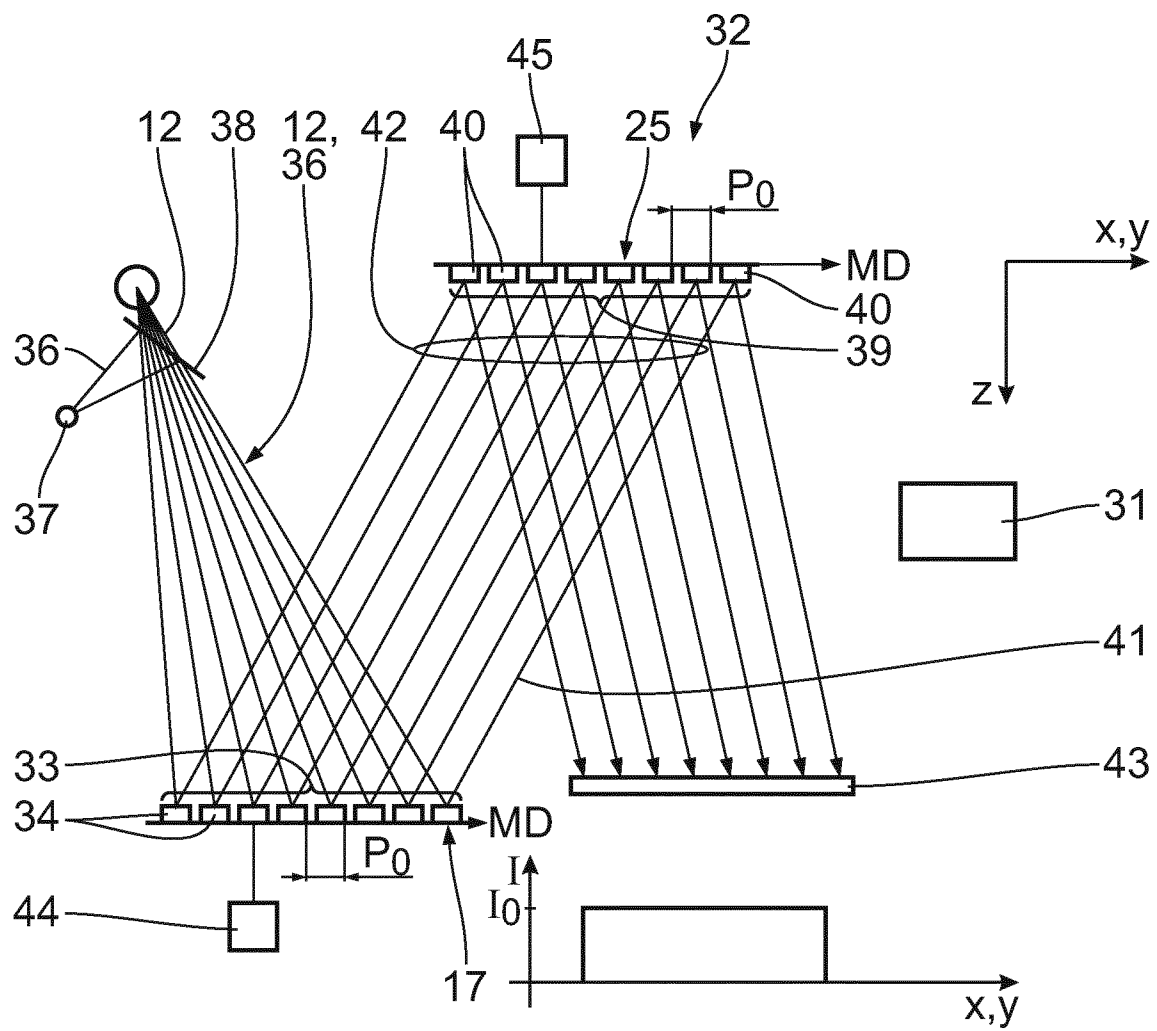


Fig. 5

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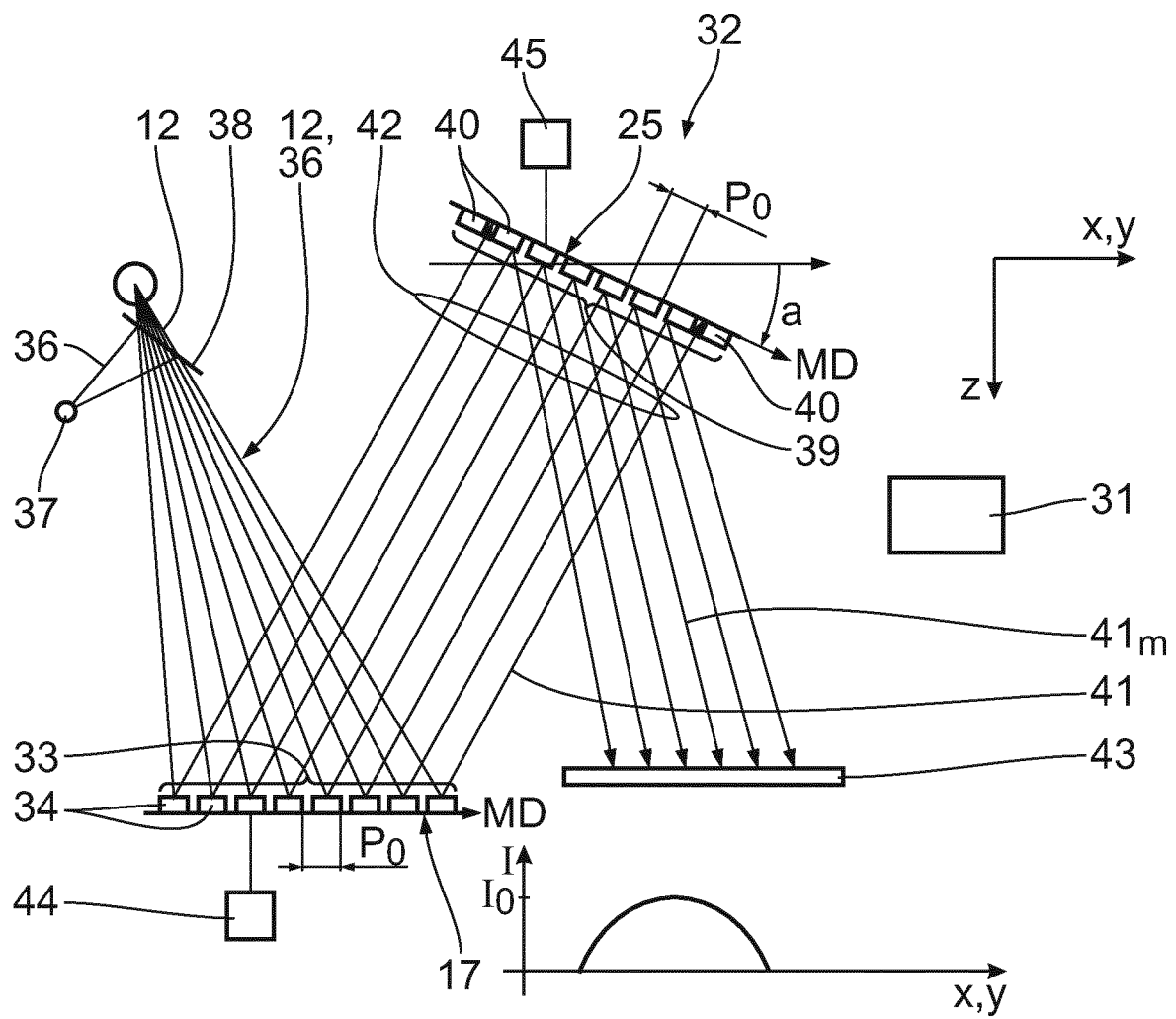


Fig. 6

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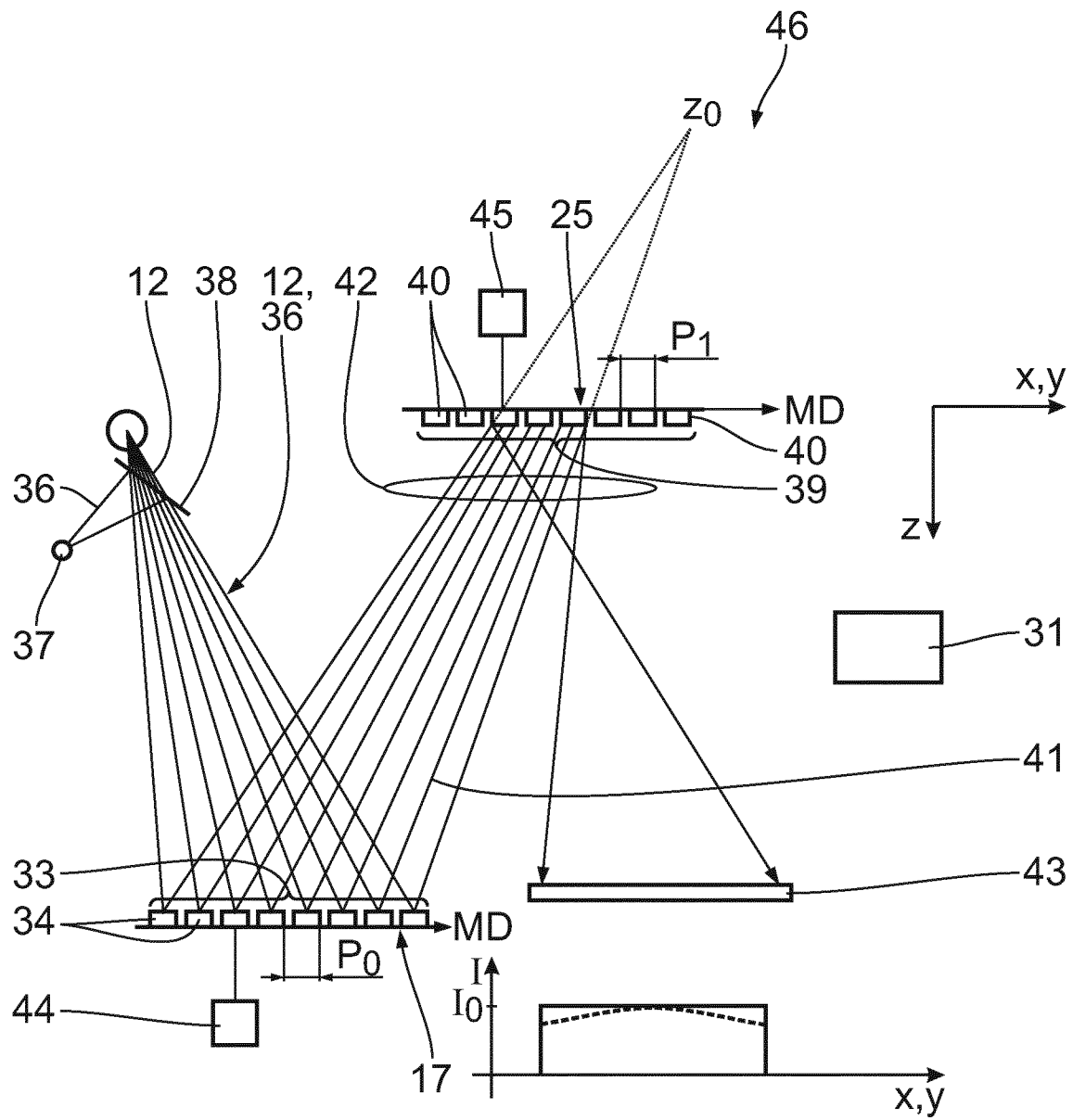


Fig. 7

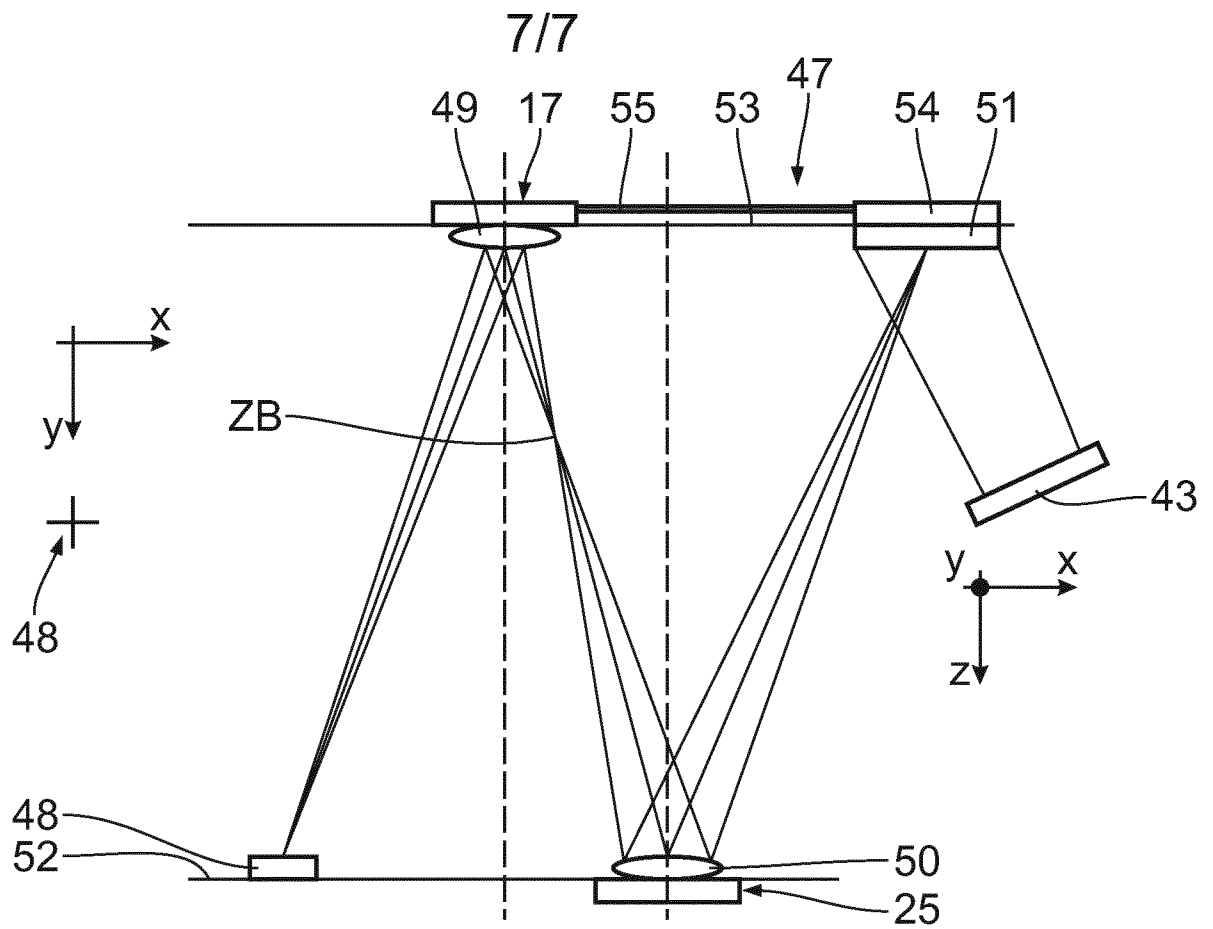


Fig. 8

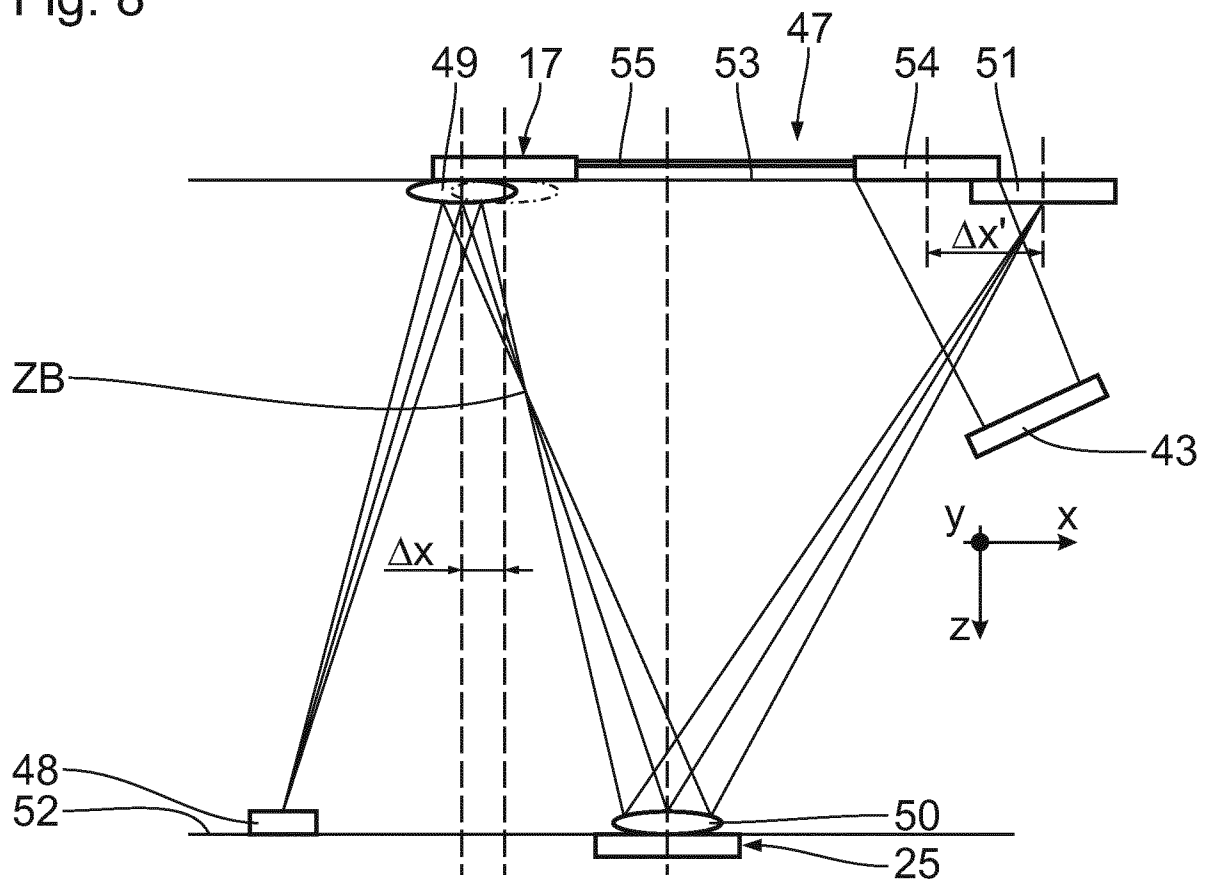


Fig. 9