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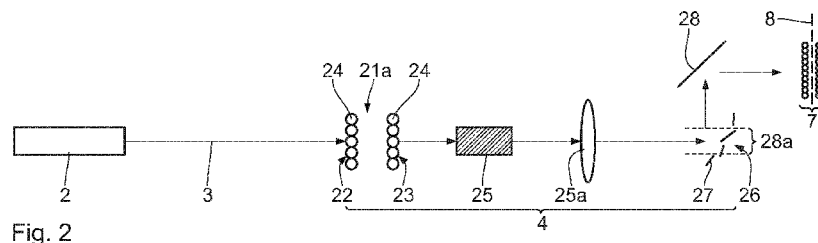


Fig. 2

(57) Abstract: An illumination optical unit for projection lithography serves for illuminating an object field, in which a structure to be imaged can be arranged, with illumination light (3). The illumination optical unit has a mirror array (26) comprising a multiplicity of individual mirrors (27). The mirror array (26) is arranged in the illumination optical unit such that a change in an intensity distribution of the illumination light (3) on the mirror array (26) leads to a change in an illumination angle distribution of the illumination light (3) on the object field (5). A ray deflecting device (25) for deflecting the illumination light (3) is arranged upstream of the mirror array (26) in the beam path of the illumination light (3). The ray deflecting device (25) is embodied in such a way that an intensity distribution (28a) of the illumination light (3) on the mirror array (26) is displaced on account of the ray deflection by the ray deflecting device (25). This results in an illumination optical unit which makes it possible to vary an illumination angle distribution for illuminating the object field between successive illumination processes with a tenable outlay and rapidly if possible.

Illumination optical unit for projection lithography

The contents of German patent application DE 10 2011 076 436.4 is incorporated by reference.

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The invention relates to an illumination optical unit for projection lithography for illuminating an object field, in which a structure to be imaged can be arranged, with illumination light. Furthermore, the invention relates to an optical system comprising an illumination optical unit of this type and a projection optical unit for imaging the object field into an image field. Furthermore, the invention relates to a projection exposure apparatus comprising an optical system of this type, a production method for producing a micro- or nanostructured component, and a component produced by said method.

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A projection exposure apparatus of the type mentioned in the introduction is known from WO 2009/135586 A1. An illumination optical unit for projection lithography is furthermore known from WO 2005/026843 A, EP 1 262 836 A and US 2009/0116093 A1.

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It is an object of the present invention to develop an illumination optical unit of the type mentioned in the introduction in such a way that it is possible to vary an illumination angle distribution for illuminating the object field between successive illumination processes with a tenable outlay and rapidly if possible.

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This object is achieved according to the invention by means of an illumination optical unit comprising the features specified in Claim 1.

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The illumination optical unit according to the invention makes it possible, on account of the ray deflecting device, in particular, to change an illumination setting, that is to say to change an illumination angle distribution for illuminating the object field, between successive sections to be illuminated of the structure to be imaged. This is also designated as changing the illumination setting from die to die. Alternatively or additionally, the ray deflecting device makes it possible to change the illumination angle distribution for illuminating the object field between regions of one and the same section to be illuminated, that is to say within a die. Again alternatively or additionally, it is possible, with the aid of the ray deflecting device, to bring about a change in an illumination setting such that one and the same region of the structure to be imaged is exposed with different illumination settings, that is to say a double or multiple exposure with different illumination angle distributions. The intensity distribution can be changed by the displacement of an impingement region of the illumination light on the mirror array or alternatively by a redistribution of the intensity distribution within one and the same impingement region. A displacement of the impingement region can occur as a result of a change in the position of the impingement region on the mirror array and/or as a result of a change in the size or cross section of the impingement region on the mirror array.

An embodiment of the ray deflecting device according to Claim 2 allows a high throughput of the illumination optical unit. Changeover times in the range of a few 10 ms can be adapted to a change of object. Shorter changeover times in the range of a few ms or the less can be adapted to a pulse frequency of a typical laser illumination light source of a projection exposure apparatus in which the illumination optical unit can be used.

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Deflection angles according to Claim 3 reduce the requirements made of the ray deflecting device. The illumination optical unit can be embodied such that even very small deflection angles lead to a sufficient change in the intensity distribution of the illumination light on the mirror array.

5

A fly's eye condenser according to Claim 4 serves for the light mixing of the illumination light. The fly's eye condenser can generate, in particular, an angular spectrum of the illumination light passing through the fly's eye condenser which is converted into an intensity distribution on the mirror
10 array. Other optical components or optical assemblies which make possible such light mixing or such conversion of the angular spectrum into the intensity distribution can also be used.

The repetition rate of the ray deflecting device can be, in particular, 25 Hz.
15 This corresponds to typical change rates of sections to be illuminated in projection exposure apparatuses for producing micro- or nanostructured semiconductor components. The repetition rate of the ray deflecting device and thus the change in the illumination setting can be effected in a manner synchronized with a change in the object section to be illuminated or in a
20 manner synchronized with a change of object. A repetition rate of the ray deflecting device can be significantly greater than 10 Hz and can be, for example, in the range of up to 100 kHz. The repetition rate can be 6 kHz, for example, and can thus be adapted to a pulse frequency of a typical laser illumination light source of a projection exposure apparatus in which the
25 illumination optical unit can be used. The ray deflecting device can be synchronized with the pulse frequency of the light source. This makes possible a pulse-to-pulse change of the illumination setting. In the illumination optical unit, a field defining element can be arranged downstream of the mirror

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array in the beam path of the illumination light, in order to define transverse dimensions of the object field.

5 A ray deflecting device according to Claim 5 can be embodied as a cylindrical lens. The cylindrical lens can be part of a cylindrical lens pair.

A ray deflecting device according to Claim 6 can be embodied as an optical wedge and can be part of a pair of optical wedges.

10 The ray deflecting device according to Claim 7 can have a dove prism.

The ray deflecting device according to Claim 8 can be embodied as a tilting mirror.

15 Drives of the ray deflecting device according to Claims 6 to 8 can be embodied as piezo drives or, in the case of continuous rotation of the optical element of the ray deflecting device, as rotational drives.

20 An electro-optical deflector as an example of the ray deflecting device can comprise a component composed of BBO, KDP, DKDP, LBO or SiO₂ that is optically transparent to the illumination light. An optoacoustic deflector as an example of the ray deflecting device can comprise a component composed of LiNbO₃ or composed of SiO₂ that is optically transparent to the illumination light.

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An arrangement of the ray deflecting device according to Claim 10 is compact. A fly's eye condenser can be arranged upstream of the Fourier optical unit of the illumination optical unit, said condenser generating an angular spectrum of the illumination light passing through the fly's eye condenser,

- 5 -

which is converted into an intensity distribution on the mirror array. The ray deflecting device can be arranged between the fly's eye condenser and the Fourier optical unit.

- 5 In the case of an optical distance according to Claim 11, even small deflections generated by means of the ray deflecting device lead to large deflection distances transversely with respect to the ray direction in the region of the mirror array.
- 10 The advantages of an optical system according to Claim 12, of a projection exposure apparatus according to Claim 13, of a production method according to Claim 14 and of a component according to Claim 15 correspond to those which have already been explained above with reference to the illumination optical unit according to the invention. During the operation of
- 15 the projection exposure apparatus, the illumination angle distribution for projecting the reticle section is changed on account of the effect of the ray deflecting device.

Exemplary embodiments of the invention are explained in greater detail
20 below with reference to the drawing, in which:

Figure 1 schematically shows a projection exposure apparatus for the lithographic production of a patterned semiconductor component with an illumination optical unit
25 comprising a ray deflecting device having a high repetition rate;

Figure 2 shows schematically, but in greater detail in comparison with figure 1, part of the illumination optical unit

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according to figure 1 with a laser illumination light source;

5 Figure 3 shows, in an illustration modified in comparison with figure 2 and in even greater detail, part of the projection optical unit between a fly's eye condenser and a mirror array;

10 Figure 4 shows a first variant of an illumination of the mirror array, wherein the latter is illustrated in a plan view, together with an $I(x)$ diagram characterizing an intensity distribution of the illumination over the mirror array;

15 Figure 5 shows, likewise in a plan view, an intensity distribution in a pupil plane of the illumination optical unit which results in the case of the illumination of the mirror array according to figure 4;

20 Figure 6 shows, in an illustration similar to figure 4, an illumination of the mirror array changed on account of the effect of the ray deflecting device and a correspondingly changed $I(x)$ diagram,

25 Figure 7 shows, likewise in a plan view, an intensity distribution in a pupil plane of the illumination optical unit which results in the case of the illumination of the mirror array according to figure 6;

- Figure 8 shows, in an illustration significantly more finely resolved in comparison with figures 5 and 7, an illumination intensity of the pupil plane which results on account of illumination of the mirror array after deflection by the ray deflecting device by one individual-mirror column in a first ray deflecting direction;
- Figure 9 shows, in an illustration similar to figure 8, the illumination of the pupil plane which results after a deflection of the illumination intensity of the mirror array by one individual-mirror column in the other, opposite ray deflecting direction;
- Figure 10 shows a difference between the illumination intensities in the pupil plane in accordance with figures 8 and 9;
- Figure 11 shows, in a meridional section, a cylindrical lens pair as an embodiment of the ray deflecting device in the relative position “nine ray deflection”;
- Figure 12 shows the cylindrical lens pair according to figure 11 in the relative position “ray deflection downward”;
- Figure 13 shows an optical wedge pair as a further embodiment of the ray deflecting device in a side view in the relative position “ray deflection downward”;
- Figure 14 shows the wedge pair according to figure 13, rotated by 90° about an axis of rotation parallel to the direc-

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tion of incidence of illumination light, such that, in the plane of the drawing according to figure 14, the relative position of the wedges “no ray deflection” results;

5 Figure 15 shows, in an illustration similar to figures 13 and 14, the wedge pair, rotated further by 90° about the axis of rotation again in comparison with figure 14, in the relative position of the wedges “ray deflection upward”;

10 Figure 16 shows a further embodiment of the ray deflecting device in the form of a dove prism;

 Figure 17 shows the ray deflecting device according to figure 16 with further optical components of the illumination optical unit in a first ray deflection rotation position of the dove prism;

15

 Figure 18 shows the optical components according to figure 17 in a second ray deflection rotation position of the dove prism;

20

 Figure 19 schematically shows the axial relationships between an optical axis of the illumination optical unit, an axis of rotation of the dove prism and a ray deflecting device;

25 Figure 20 shows a further embodiment of the ray deflecting device in the form of a mirror element driven in a pivotable manner;

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- Figure 21 shows a further embodiment of part of the illumination optical unit into which the ray deflecting device according to figure 20 is integrated;
- 5 Figure 22 shows, in an illustration similar according to figure 2, a further embodiment of the illumination optical unit comprising a mirror array and a ray deflecting device having a high repetition rate; and
- 10 Figures 23 to 25 show an intensity profile of an illumination light beam depending on the distance between a location of the profile measurement and the laser light source.

A projection exposure apparatus 1 illustrated schematically in figure 1
15 serves for lithographically producing micro- or nanostructured semiconductor components, in particular memory microchips.

The projection exposure apparatus 1 has a laser light source 2 for generating illumination and imaging light 3. A beam path of the illumination and
20 imaging light 3 is illustrated highly schematically in figure 1. In reality, the illumination and imaging light 3 is present in the form of a cross-sectionally extended light beam which, depending on the embodiment of the projection exposure apparatus 1, can be split in sections into a multiplicity of partial beams. The beam path of the illumination and imaging
25 light 3 can additionally be folded. Downstream of the light source 2, the illumination and imaging light 3 firstly passes through a pupil shaping optical assembly 4, which is designated hereinafter as PDE (Pupil Defining Element). The PDE 4 serves for predefining an illumination angle distribution of the illumination of an object field 5 in an object plane 6. Disposed

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downstream of the PDE 4 is a field shaping optical assembly 7, which is designated hereinafter as FDE (Field Defining Element). The FDE 7 serves for predefining an intensity distribution of the illumination light 3 in the object field 5, that is to say in particular for predefining transverse measurements of an illumination of the object field 5. A pupil plane 8 of an illumination optical unit 9 is arranged in the region of the FDE 7. In this case, the illumination optical unit 9 comprises all beam shaping optical components between the light source 2 and the object field 5.

10 A Fourier optical unit 10 is disposed downstream of the FDE 7 in the beam path of the illumination and imaging light 3. An optical assembly 11 for predefining a boundary form of the object field 5 is disposed downstream of the Fourier optical unit 10, said optical assembly being designated hereinafter as REMA (Reticle Masking System, system for masking the object or reticle). An intermediate field plane 12 of the illumination optical unit 9 is arranged in the region of the REMA 11.

A REMA lens 13 is disposed downstream of the REMA 11 in the beam path of the illumination and imaging light 3. Said lens images the intermediate field plane 12 into the object plane 6.

A reticle 14, that is to say a lithography mask, is arranged in the region of the object plane. The reticle 14 bears the structures to be imaged by means of the projection exposure apparatus 1. Those structures of the reticle 14 which are situated in the object field 5 are imaged in this case. In the schematic illustration in figure 1, the reticle 14 is illustrated as an element that is transmissive with respect to the illumination and imaging light 3. A configuration of the projection exposure apparatus 1 for illuminating a reflec-

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tive reticle is alternatively possible. The reticle 14 is carried by a reticle holder 15.

5 A projection optical unit 16 images the object field 5 into an image field 17 in an image plane 18. A wafer 19 is arranged in the image plane 18. The structures in the object field 5 are imaged onto that section of the wafer 19 which is arranged in the image field 17. The wafer 19 is carried by a wafer holder 20.

10 During the projection exposure, a light-sensitive layer on the wafer 19 is exposed by the imaging light 3, such that, through subsequent development of the light-sensitive layer, the structures on the reticle 14 are transferred to the wafer 19. During the projection exposure, the reticle holder 15 and the wafer holder 20 are displaced in a synchronized manner with respect to one
15 another. This can be done in a stepwise manner in the case where the projection exposure apparatus 1 is embodied as a stepper, or continuously in the case where the projection exposure apparatus 1 is embodied as a scanner. A section of the wafer 19 that is exposed during an exposure process of the projection exposure apparatus 1 is also designated as a die.

20

A micro- or nanostructured component, in particular a semiconductor component, for example a micro- or nano-memory chip, is produced in this way.

25 Together with the illumination optical unit 9, the projection optical unit 16 forms an optical system 21 of the projection exposure apparatus 1.

A basic construction of the illumination optical unit 9 is known from WO 2009/135586 A1, to the entire contents of which reference is made.

Figure 2 shows an excerpt from the illumination optical unit 9. The illustration shows schematically, but in greater detail in comparison with figure 1, a beam path of the illumination light 3 between the light source 2 and the FDE 7.

A fly's eye condenser 21a comprising two microlens element arrays 22, 23 arranged one behind the other constitutes one component of the PDE 4. Only some of the microlens elements 24 are illustrated in figure 2. A ray deflecting device 25 is arranged between the fly's eye condenser 21a and a Fourier optical unit 25a of the PDE 4, said Fourier optical unit being illustrated schematically as an individual lens element in figure 2, said ray deflecting device being explained in even greater detail below. The Fourier optical unit 25a has a focal length of 15 m.

A mirror array 26 is arranged in the beam path downstream of the Fourier optical unit 10. The mirror array 26 is also designated as MMA (Micro Mirror Array). The mirror array 26 has a multiplicity of individual mirrors 27 arranged in rows and columns. The mirror array 26 is arranged in the illumination optical unit 9 such that a change in an intensity distribution of the illumination light 3 on the mirror array 26 leads to a change in an illumination angle distribution of the illumination light 3 on the object field 5.

Besides the fly's eye condenser 21a, the ray deflecting device 25, the Fourier optical unit 25a and the mirror array 26 belong to the PDE 4.

A plane 90° deflection mirror 28 is arranged between the mirror array 26 and the FDE 7.

The individual mirrors 27 of the mirror array 26 are individually tiltable. This is indicated schematically and by way of example in figure 2 for the small number of individual mirrors 27 illustrated in representative fashion therein. Depending on the tilting positions of the individual mirrors 27, the
5 FDE 7 is illuminated with a predetermined intensity distribution in the pupil plane 8, which is assigned to a correspondingly assigned illumination angle distribution of the illumination light 3 on the object field 5.

The ray deflecting device 25 is embodied such that an intensity distribution
10 28a of the illumination light 3 on the mirror array 26 changes on account of the ray deflection of the illumination light 3 by the ray deflecting device 25. The ray deflecting device 25 deflects the illumination light 3 with a deflection angle of $\pm 40 \mu\text{rad}$. Other deflection angles of 5 mrad or less, that is to say of $\pm 2.5 \text{ mrad}$ or less, are also possible, for example deflec-
15 tion angles of $\pm 500 \mu\text{rad}$, $\pm 250 \mu\text{rad}$, $\pm 100 \mu\text{rad}$, $\pm 50 \mu\text{rad}$. Deflection angles which are less than $\pm 40 \mu\text{rad}$ are also possible. This change in the intensity distribution 28a can be effected by displacement of an impingement region of the beam of the illumination light 3 on the mirror array 26. Such a displacement of the impingement region can be effected by
20 a change in the position of the impingement region on the mirror array 26, that is to say by a displacement of an impingement location of the beam of the illumination light 3 on the mirror array 26. Alternatively or additionally, it is possible that, as a result of the ray deflecting effect of the ray deflecting device 25, a change in the size or cross section of the impingement
25 region on the mirror array 26 is effected by a corresponding change in the size or cross section of the beam of the illumination light 3 on account of the effect of the ray deflecting device 25. A further variant for a change in the intensity distribution of the illumination light 3 on the mirror array 26 that is brought about by the effect of the ray deflecting device 25 is a rear-

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5 rangement of the intensity within an impingement region of the illumination light 3 on the mirror array 26, wherein, during such an intensity rearrangement or intensity redistribution, a change in the size or cross section of the impingement region need not be effected, but can of course additionally be effected.

10 The ray deflecting device 25 is embodied in such a way as to result in a ray deflection of the illumination light 3 with a changeover time of 100 ms or less. In this case, the changeover time is that time period which is necessary in order to change over, with the aid of the ray deflecting device 25, between a first desired intensity distribution of the illumination light 3 on the mirror array 26 and a second, changed desired intensity distribution of the illumination light 3 on the mirror array 26. The changeover time can be less than 100 ms and can be, for example, 50 ms. Significantly shorter
15 changeover times in the region of 10 ms, 2 ms, 1.6 ms, 1 ms or even shorter changeover times are also possible.

The ray deflecting device 25 can be embodied in such a way that a ray deflection is effected at a high repetition rate, which is greater than 10 Hz.
20 Even greater repetition rates of up to 60 kHz are possible. The ray deflection of the ray deflecting device 25 is synchronized with an object displacement by the reticle holder 15 or with a change of object that can be achieved with the reticle holder 15, or is coordinated with said change of object. Alternatively or additionally, it is possible to synchronize the ray
25 deflection of the ray deflecting device 25 with a pulse frequency of the light source 2 or to coordinate it with said pulse frequency.

Figure 3 shows in even greater detail an excerpt from the illumination optical unit 9 between the fly's eye condenser 21a and the mirror array 26. In

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figure 3, the optical components are illustrated as symmetrical about an optical axis oA and the beam path of the illumination light 3 is illustrated as non-folded overall.

5 Between the Fourier optical unit 25a disposed downstream of the ray deflecting device 25 and the mirror array 26, firstly a converging lens 29 and directly downstream thereof a focusing microlens element array 30 are arranged in the beam path of the illumination light 3. Between the fly's eye condenser 21a and the Fourier optical unit 25a, the illumination light 3
10 passes divergently with an expanding divergence angle of 1 mrad. This divergence of 1 mrad corresponds to an output-side numerical aperture of the fly's eye condenser 21a. Starting from the Fourier optical unit 25a, the illumination light 3 passes as a beam having a total beam diameter A of 30 mm.

15

Figure 3 schematically illustrates the effect of the ray deflecting device 25. A beam path 31 of the illumination light 3 deflected by $40\ \mu\text{rad}$ is depicted in a dashed manner starting from the ray deflecting device 25. This ray deflection leads, in a mirror plane 32 of the mirror array 26, to a ray deflection by exactly a distance B between two adjacent individual mirrors 27,
20 that is to say to a ray deflection by exactly one mirror column. In this case, it is assumed that the mirror array has tens of columns.

Since the illumination of the mirror array 26 over the area thereof by the
25 beam of the illumination light 3 is not homogeneous, a deflection of the beam of the illumination light 3 which leads to a displacement of the beam on the mirror array 26 automatically leads to a change in the intensities impinging on the respective individual mirrors 27.

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Figures 4 to 7 illustrate on the basis of an example the effect of such a ray deflection of the illumination light 3 by one mirror column.

Figure 4 schematically shows the mirror array 26 in a plan view as a 4x8 array having a total of 32 individual mirrors 27 arranged in four rows and
5 eight columns. An intensity impingement I of the individual mirrors 27 with the illumination light 3, that is to say the intensity distribution 28a, rises column by column from left to right between a lowest intensity I_1 in the left-hand column in figure 4 and a highest intensity I_8 in the right-hand
10 column in figure 4. This stepped rise in intensity is illustrated in an $I(x)$ diagram in figure 4. On account of an instantaneously set tilting position of the individual mirrors 27, this results in an intensity impingement of the FDE 7 in the pupil plane 8 which is shown in figure 5.

15 On account of the effect of the ray deflecting device 25, the beam of the illumination light 3, proceeding from the intensity impingement according to figure 4, is deflected by one mirror column toward the left. A resulting intensity impingement of the mirror array 26 after this deflection is illustrated in figure 6. The intensity I_2 now impinges on the mirror column on
20 the far left in figure 6, and the intensity I_9 impinges on the column on the far right in figure 6, said intensity I_9 in turn also being a step higher than the intensity I_8 .

Correspondingly, the intensity of the impingement in the pupil plane 8 of
25 the FDE 7 has also changed, as is illustrated in figure 7.

The change in a distribution of an intensity impingement of the mirror array 26 can, as explained above, occur as a result of a change in the position of the intensity distribution 28a of the illumination light 3 on the mirror

array 26, that is to say as a result of displacement by one mirror column, or alternatively as a result of a change in the intensity distribution within an impingement region of the illumination light 3 on the mirror array 26, which impingement region is unchanged in terms of its position and, for
5 example, its marginal dimensions.

As a result of the change in a distribution of an intensity impingement of the mirror array 26, it is therefore possible to influence, for example, a maximum illumination angle σ with which the object field 5 is illuminated,
10 and/or it is possible to change a pole angle of a multipole illumination angle distribution with which the object field 5 is illuminated. Generally, it is therefore possible to modify an existing illumination setting or it is possible to convert an existing illumination setting into another illumination setting. Examples of illumination settings which can be used as initial illumination
15 setting before the modification or as target illumination setting after the conversion are described in DE 10 2008 021 833 A1.

Figures 8 and 9 show, corresponding to figures 5 and 7, an intensity impingement of the FDE 7 in the pupil plane 8 in two deflection positions of the ray deflecting device 25. In contrast to figures 5 and 7, the illustrations according to figures 8 and 9 are less schematic, but rather correspond to a more realistic, higher number of the individual mirrors 27 of the mirror array 26 and a resulting higher spatial resolution of the intensity distribution in the pupil plane 8. Figure 8 shows the intensity distribution in the
20 deflection position “displaced toward the left”, that is to say displaced by a maximum ray deflection in the negative x-direction, and figure 9 correspondingly shows the ray deflection “displaced toward the right”.

Figure 10 shows a difference between the two intensity illuminations according to figures 8 and 9, that is to say $\Delta I(x, y) = I(\text{displaced toward the left}) - I(\text{displaced toward the right})$.

- 5 The intensity of the illumination of the pupil plane 8 is displaced radially outward. An increase in an illumination angle of an annular illumination setting has therefore been achieved by the ray deflection, the resultant displacement of the intensity illumination of the mirror array 26 and the associated change in the intensity illumination $I(x, y)$ of the pupil plane 8.
- 10
- Depending on the setting of the tilting angles of the individual mirrors 27, other changes in the illumination setting can also be achieved by means of the ray deflecting device 25, for example a change in an annular illumination setting in such a way that a minimum illumination angle remains practically constant and a maximum illumination angle changes, for example
- 15 increases or decreases. An ellipticity of an illumination setting can also be changed by the effect of the ray deflecting device 25. Mixed settings composed of an annular and a multipole setting, for example, can also be influenced on account of the effect of the ray deflecting device 25 such that the
- 20 intensity ratios of the mixture change such that, for example, a multipole portion decreases or increases in comparison with the annular portion of the illumination setting.

As a result of the effect of the ray deflecting device 25, it is possible to

25 bring about a change in the illumination setting when changing between two objects or structure sections to be illuminated (die to die change). Objects illuminated successively by the illumination optical unit 9 are then illuminated with different illumination angle distributions. This can be used

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to adapt the illumination optical unit 9 to the illumination requirements of varying object geometries or can be used to compensate for example for edge effects on the wafer 19, that is to say for example different illumination conditions in the comparison between the illumination of a center of
5 the wafer 19 and the illumination of an edge of the wafer 19.

The ray deflecting device 25 can also have an effect such that the illumination setting is changed during the illumination of one and the same object by the illumination optical unit 9. This can be used, for example, when the
10 object to be illuminated has, in a first object section to be illuminated, requirements made of an illumination angle distribution that differ from the requirements in a further object section. One example of this is an object to be illuminated in the form of a memory chip pattern, in which the structure distribution present centrally is different from that present marginally.
15

Finally, the ray deflecting device 25 can be used, if very short changeover times are available, to change the illumination setting between successive pulses of a light source 2 operating with a specific pulse frequency. This can be used, for example, to readjust or track the illumination angle distribution. Temporal effects can also be compensated for by this change possibility.
20

Different variants of the ray deflecting device 25 are described below with reference to figures 11 to 20. Components and functions corresponding to
25 those which have already been explained above with reference to the ray deflecting device 25 according to figures 1 to 10 will not be discussed in specific detail again.

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In the embodiment according to figures 11 and 12, the ray deflecting device 25 is constructed as a pair of cylindrical lens elements 33, 34. The latter are illustrated in a section perpendicular to the cylinder axis in figures 11 and 12. The cylindrical lens element 33 is embodied in planoconcave fashion and the cylindrical lens element 34 is embodied in planoconvex fashion. Plane surfaces of the two cylindrical lens elements 33, 34 face away from one another. The radius of curvature of a concave lens element surface 35 of the cylindrical lens element 33 corresponds to the radius of curvature of a convex lens element surface 36 of the cylindrical lens element 34. In the exemplary embodiment under consideration, the radius of curvature of the curved optical surfaces of the two cylindrical lens elements 33, 34 is 100 mm in each case. The two lens element surfaces 35, 36 therefore extend at an approximately constant, small distance from one another.

In a neutral position according to figure 11, an entrance surface 37 of the cylindrical lens element 33 and an exit surface 38 of the cylindrical lens element 34 run parallel to one another. The ray deflecting device 25 according to figures 11 and 12 therefore has no ray deflecting effect in the neutral position.

20

In a deflection position according to figure 12, the cylindrical lens element 34, proceeding from the neutral position, is pivoted by an angle α about a pivoting axis 39 coinciding with the cylinder axis of the cylindrical lens element 34. This pivoting is effected by means of a pivoting drive 40 indicated schematically in figure 12. The pivoting drive 40 can attain a deflection repetition rate in the kHz range with a displacement speed in the range of less than 10 cm/s. The pivoting drive 40 can be realized as a piezo drive. The exit surface 38 now correspondingly extends at the angle α with re-

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spect to the entrance surface 37. This leads to a corresponding refractive deflection of the illumination light 3 by an angle δ , as illustrated in figure 12. The following holds true: $\delta = (n-1) \alpha$.

- 5 The pivoting angle α is illustrated with a greatly exaggerated size in figure 12. In the case of a pivoting angle α of 80 μrad , a sufficiently large deflection δ of 40 μrad results. A refractive index of $n = 1.5$ that is typical of optical material is assumed in this case.
- 10 Given a total diameter A of the light beam of the illumination light 3 of 26 mm, said deflection can be achieved by a displacement of the cylindrical lens element 34 of the order of magnitude of 10 μm by means of the pivoting drive 40. The pivoting drive 40 can be realized by an ultrasonic vibration drive.
- 15 The cylindrical lens element 34 constitutes a refractive optical element which is displaceable in a driven manner transversely with respect to the ray direction of the illumination light 3.
- 20 A further example of the ray deflecting device 25 is described with reference to figures 13 to 15. Components corresponding to those which have already been explained above with reference to figure 12 bear the same reference numerals and will not be discussed in more specific detail again.
- 25 The ray deflecting device 25 according to figures 13 to 15 is embodied as a pair of optical wedges 41, 42.

In the case of the ray deflecting device 25 according to figures 13 to 15, a projection of the actual deflection angle of the illumination light 3 onto the plane of the drawing in figures 13 to 15 is regarded as deflection angle α .

- 5 In the case of the position according to figure 13 “maximum ray deflection toward the right”, the normals to wedge surfaces 43, 44 lie in the plane of the drawing in figure 13. The entrance surface 37 of the wedge 41 and the exit surface 38 of the wedge 42 run parallel to one another. In the position according to figure 13, a distance between the wedges 41, 42 increases
10 from the bottom toward the top on account of the wedge profile of the wedge surfaces 43, 44.

Figure 14 shows the wedge pair 41, 42 rotated by 90° in the counterclockwise direction about a rotational axis 45 that coincides with a direction of
15 incidence of the illumination light 3 on the entrance surface 37, as seen in the ray direction of the illumination light 3. A rotary drive 46 for this rotation is illustrated schematically in figure 14. In the plane of the drawing in figure 14, the wedge surfaces 43, 44 now have no ray deflecting effect. The position of the wedges 41, 42 according to figure 14 is therefore a neutral
20 position of the ray deflecting device 25.

Figure 15 shows the ray deflecting device 25 rotated relative the neutral position according to figure 14 by a further 90° in the counterclockwise direction, as seen in the ray direction of the illumination light 3, about the
25 axis of rotation 45.

The rotary drive 46 can be realized by a rotation drive. Corresponding rotation drives are known for polygon mirrors from laser TV development.

The two wedges 41, 42 constitute refractive optical elements which are rotatable or pivotable in a driven manner about the axis of rotation 45 running along the ray direction of the illumination light 3.

5

A further variant for the ray deflecting device 25 is described with reference to figures 16 to 19.

10 The guiding element in the beam path of the illumination light 3 in the ray deflecting device 25 according to figures 16 to 19 is a dove prism 47. The latter is rotatable or pivotable about a prism axis of rotation 49 by means of a rotary drive 48 illustrated schematically in figure 16. As emerges from figure 19, the prism axis of rotation 49 and the optical axis oA coinciding with a direction of incidence of the illumination light 3 do not coincide. In
15 a plane perpendicular to a ray deflecting direction 50, that is to say in the plane of the drawing in figure 19, there is an angle β between the optical axis oA and the prism axis of rotation 49.

20 A lens 51 comprising two lens elements 52, 53 is disposed downstream of the dove prism 47 in the beam path of the illumination light 3. The lens 51 images a ray deflecting object plane 54 arranged upstream of the dove prism 47 in the beam path of the illumination light 3 into a ray deflecting image plane 55 disposed downstream of the lens 51.

25 In the case of the ray deflecting device 25 comprising the dove prism 47, a projection of a total ray deflection onto a ray deflecting plane is again considered. The latter is perpendicular to the plane of the drawing according to figure 19 and contains the optical axis oA.

The lens 51 and the dove prism 47 can also interchange their position in the beam path of the illumination light 3 within the ray deflecting device 25.

- 5 The dove prism 47 constitutes a refractive optical element which is pivotable or rotatable in a driven manner about the pivoting axis or axis of rotation 49, which extends at the angle β with respect to the ray direction of the illumination light 3. The angle β is less than 45° .
- 10 A further variant of the ray deflecting device 25 is illustrated in figure 20.

The ray deflecting device 25 according to figure 20 has exactly one mirror 56 which is tiltable in a driven manner. The mirror 56 reflects the illumination light 3. A tilting drive 57 for the mirror 56 is illustrated schematically

15 in figure 20. The tilting mirror 56 is tiltable in a driven manner about a pivoting axis 57a running transversely with respect to the ray direction of the illumination light 3. A displacement speed of the tilting drive 57 in the range of a few mm/s likewise enables a repetition rate of the ray deflection of the illumination light 3 in the kHz range. The tilting drive 57 can be re-

20 alized as a piezo drive. In order to generate a deflection angle δ downstream of the mirror 56 of $40 \mu\text{rad}$, said mirror has to be tilted by a tilting angle χ of $20 \mu\text{rad}$. Assuming a diameter of the mirror 56 of 26 mm, the mirror 56 has to be tilted marginally by 260 nm by means of the tilting drive 57.

25

Figure 21 shows a possible arrangement of the mirror 56 of the ray deflecting device 25 according to figure 20 in the illumination optical unit 9.

Components and functions corresponding to those which have already been

- 25 -

explained above with reference to figures 1 to 20, in particular with reference to the description of the illumination optical unit 9, bear the same reference numerals and will not be discussed in more specific detail again. Figure 21 illustrates the beam path of the illumination light 3 between the fly's eye condenser 21a and the focusing microlens element array 30.

Those optical components which have the function of the Fourier optical unit 25a and of the converging lens 29 according to figure 3 are split into two optical component groups 58, 59 in the embodiment according to figure 21, said component groups being illustrated schematically by in each case three lens elements arranged successively in figure 21. A first optical component group 58 is arranged between the fly's eye condenser 21a and the mirror 60. A stationary deflection mirror 60 is disposed downstream of the tilting mirror 56 in the beam path of the illumination light 3. The further optical component group 59 is arranged between the deflection mirror 56 and the focusing microlens element array 30. A tilting of the tilting mirror 56 leads to a deflection of the illumination light and accordingly to an offset of the illumination light on the mirror array 26 disposed downstream of the focusing microlens element array 30 in the beam path of the illumination light 3.

A further embodiment of an illumination optical unit 61 is described below with reference to figures 22 to 25. Components and functions corresponding to those which have already been explained above with reference to figures 1 to 21 bear the same reference numerals and will not be discussed in more specific detail again.

In the case of the illumination optical unit 61, the ray deflecting device 25 is disposed directly downstream of the laser illumination light source 2. A

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first deflection mirror 62 is arranged in the beam path between the ray deflecting device 25 and the mirror array 26. A further deflection mirror 63 is arranged in the beam path of the illumination light 3 between the mirror array 26 and the FDE 7. The two deflection mirrors 62, 63 can also be realized as the optical surfaces of one and the same optical prism.

An illumination optical unit comprising two deflection mirrors of this type and an interposed mirror array is known from US 2009/0116093 A1.

10 The arrangement of the two deflection mirrors 62, 63 is such that, when the mirror array 26 is present in a neutral position, the illumination light 3 downstream of the further deflection mirror 63 again passes along the optical axis oA along which the illumination light impinged on the first deflection mirror 62.

15

Between the ray deflecting device 25 and the mirror array 26 there is an optical distance of the illumination light 3 which is principally predefined by a distance L between the ray deflecting device 25 and the first deflection mirror 62. If the optical distance L is of corresponding length, small ray deflections of the ray deflecting device 25 lead to a large offset of the illumination light 3 on the mirror array 26, such that the effect of the ray deflecting device 25 in the illumination optical unit 61 corresponds to the effect of the ray deflecting device 25 in the illumination optical unit 9 according to figures 1 to 21. Depending on the length of the optical distance L of between 3 m and 20 m, a maximum deflection angle of the ray deflecting device 25 in the range of between 50 mrad and 330 mrad may be necessary.

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In the case of the illumination optical unit 61, too, a displacement of the beam of the illumination light 3 on the mirror array 26 leads to a change in the intensity impingement of the individual mirrors 27 on account of divergence-governed intensity differences over a cross section of the illumination light 3 generated by the laser illumination light source 2. This is explained below with reference to figures 23 to 25.

Figure 23 shows an intensity profile of the beam of the illumination light 3 transversely with respect to the ray direction directly after the emergence of the illumination light 3 from the light source 2. The intensity profile is approximately rectangular.

Figure 24 shows the intensity profile approximately half way along the optical distance L. The x-scaling in figure 24 is compressed in comparison with that in figure 23.

Figure 25 shows the intensity profile at the end of the path distance L. The x-scaling in figure 25 is compressed in comparison with that in figure 24.

The intensity profile in accordance with figure 24 is a divergent flat-top profile. A value of the full width at half maximum of the beam of the illumination light 3 is significantly greater than directly downstream of the laser light source 2.

The intensity profile according to figure 25 is approximately a Gaussian distribution. At the end of the optical distance L, the value of the full width at half maximum of the beam of the illumination light 3 is again significantly greater than half way along said distance. Particularly at the flanks of the Gaussian distribution according to figure 25, small ray deflections

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lead to significant changes in the intensity of the illumination light impingement, for example at the locations x_1 , x_2 . These changes in intensity lead to corresponding changes in the intensity impingement at the location of the pupil plane 8 and thus to changes to the illumination setting, as described above.

The ray deflection can be effected, in particular, at a repetition frequency in the range of between 1 kHz and 10 kHz, for example at 6 kHz. This repetition frequency corresponds to the repetition rate of an excimer laser that can be used as the laser light source 2.

The ray deflecting device 25 can also be realized as a galvanometer, can be realized as an acousto-optical component or can be realized as an electro-optical component.

An electro-optical deflector can be used as the electro-optical component. Beta-barium borate (BBO), potassium dihydrogen phosphate (KDP), deuterated potassium hydrogen phosphate (DKDP) or lithium triborate (LBO) can be used as optically transparent material of the electro-optical deflector. A voltage to be applied to the electro-optical deflector is in the range of a few 100 V.

Other typical materials for the optically transparent material of the electro-optical deflector, for example potassium hydrogen arsenate (KDA) or deuterated potassium hydrogen arsenate (DKDA), can also be used.

In principle, also on account of the small deflection angles necessary, the use of quartz, SiO_2 , would be possible.

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In the case of acousto-optical embodiment of the ray deflecting device 25, the latter can be embodied as an optoacoustic deflector. In this case, an acoustic wave is applied to the acoustic deflector material, which is likewise optically transparent. The typical materials for the acousto-optical modulation, for example lithium niobate (LiNbO_3), can be used.

Usable materials for the electro-optical or acousto-optical use are known from Marvin J. Weber, Handbook of Optical Materials, CRC Press 2003. Quartz, in particular high-purity quartz, can also be used as an acousto-optical material.

The illumination optical units 9 and 61 can also be embodied with reflective components in their entirety. In this case, EUV radiation can also be used as illumination light 3.

Patent Claims

1. Illumination optical unit (9; 61) for projection lithography for illuminating an object field (5), in which a structure to be imaged can be arranged, with illumination light (3),
 - comprising a mirror array (26) comprising a multiplicity of individual mirrors (27), which is arranged in the illumination optical unit (9) such that a change in an intensity distribution of the illumination light (3) on the mirror array (26) leads to a change in an illumination angle distribution of the illumination light (3) on the object field (5),
 - comprising a ray deflecting device (25) for deflecting the illumination light (3), said ray deflecting device being arranged in the beam path of the illumination light (3) upstream of the mirror array (26),
 - wherein the ray deflecting device (25) is embodied in such a way that an intensity distribution of the illumination light (3) on the mirror array (26) changes on account of the ray deflection by the ray deflecting device (25).
2. Illumination optical unit according to Claim 1, **characterized in that** the ray deflecting device (25) is embodied in such a way as to result in a ray deflection with a changeover time of 100 ms or less.
3. Illumination optical unit according to Claim 1 or 2, **characterized in that** the ray deflecting device (25) is embodied in such a way as to result in a ray deflection with a deflection angle of 5 mrad or less.
4. Illumination optical unit according to any of Claims 1 to 3, **characterized by** a fly's eye condenser (21a), wherein the ray deflecting device

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(25) is arranged downstream of the fly's eye condenser (21a) in the beam path of the illumination light (3).

5. Illumination optical unit according to any of Claims 1 to 4, **characterized in that** the ray deflecting device (25) has at least one refractive optical element (34) which is displaceable in a driven manner transversely with respect to a ray direction of the illumination light (3).
6. Illumination optical unit according to any of Claims 1 to 5, **characterized in that** the ray deflecting device (25) has at least one refractive optical element (41, 42) which is pivotable in a driven manner about a pivoting axis (45) running along the ray direction of the illumination light (3).
7. Illumination optical unit according to any of Claims 1 to 6, **characterized in that** the ray deflecting device (25) has a refractive optical element (47) which is pivotable in a driven manner about a pivoting axis (49) running at an angle (β) with respect to the ray direction (oA) of the illumination light (3), said angle being less than 45 degrees.
8. Illumination optical unit according to any of Claims 1 to 7, **characterized in that** the ray deflecting device (25) has a reflective optical element (56) which is displaceable in a driven manner about a pivoting axis (57a) running transversely with respect to the ray direction of the illumination light (3).

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9. Illumination optical unit according to Claim 1, **characterized in that** the ray deflecting device (25) is embodied as an optical deflector, selected from the following group:
- electro-optical deflector,
 - 5 - optoacoustic deflector.
10. Illumination optical unit according to any of Claims 1 to 9, **characterized in that** a Fourier optical unit (25a) is arranged in the beam path upstream of the mirror array (26), wherein the ray deflecting device
- 10 (25) is arranged in the beam path upstream of at least some components (59) of the Fourier optical unit (25a).
11. Illumination optical unit (61) according to any of Claims 1 to 10, **characterized by** an optical distance (L) between the ray deflecting
- 15 device (25) and the mirror array (26) that is greater than 10 m.
12. Optical system (21) comprising an illumination optical unit (9; 61) according to any of Claims 1 to 11 and a projection optical unit (16) for imaging the object field (5) into an image field (17).
- 20
13. Projection exposure apparatus
- comprising an optical system according to Claim 12,
 - comprising a light source (2) for generating the illumination light (3), which simultaneously also serves as imaging light,
 - 25 - comprising a reticle holder (15) for mounting the structure to be imaged,
 - comprising a wafer holder (20) for mounting a wafer (19), on which the structure to be imaged is imaged.

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14. Method for producing a microstructured component comprising the following method steps:
- providing a reticle (14) having the structure to be imaged,
 - providing a wafer (19) having a coating that is light-sensitive to the illumination light (3),
 - projecting at least one section of the reticle (14) onto the wafer (19) with the aid of the projection exposure apparatus (1) according to Claim 13,
 - developing the light-sensitive layer exposed by means of the illumination light (3) on the wafer (19).

15. Component produced according to the method according to Claim 14.

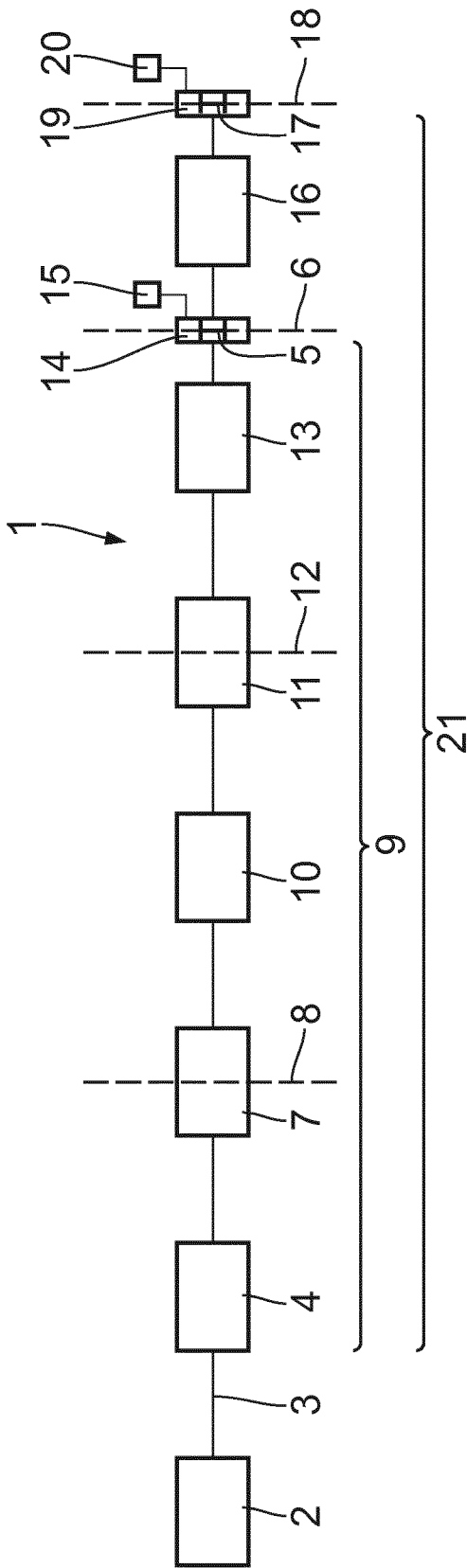


Fig. 1

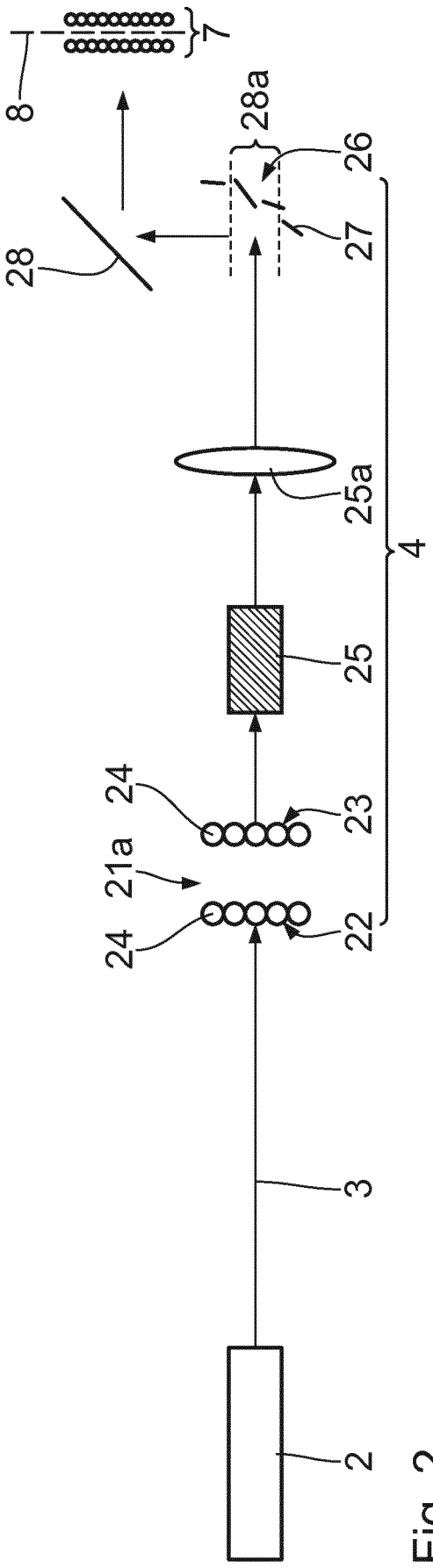


Fig. 2

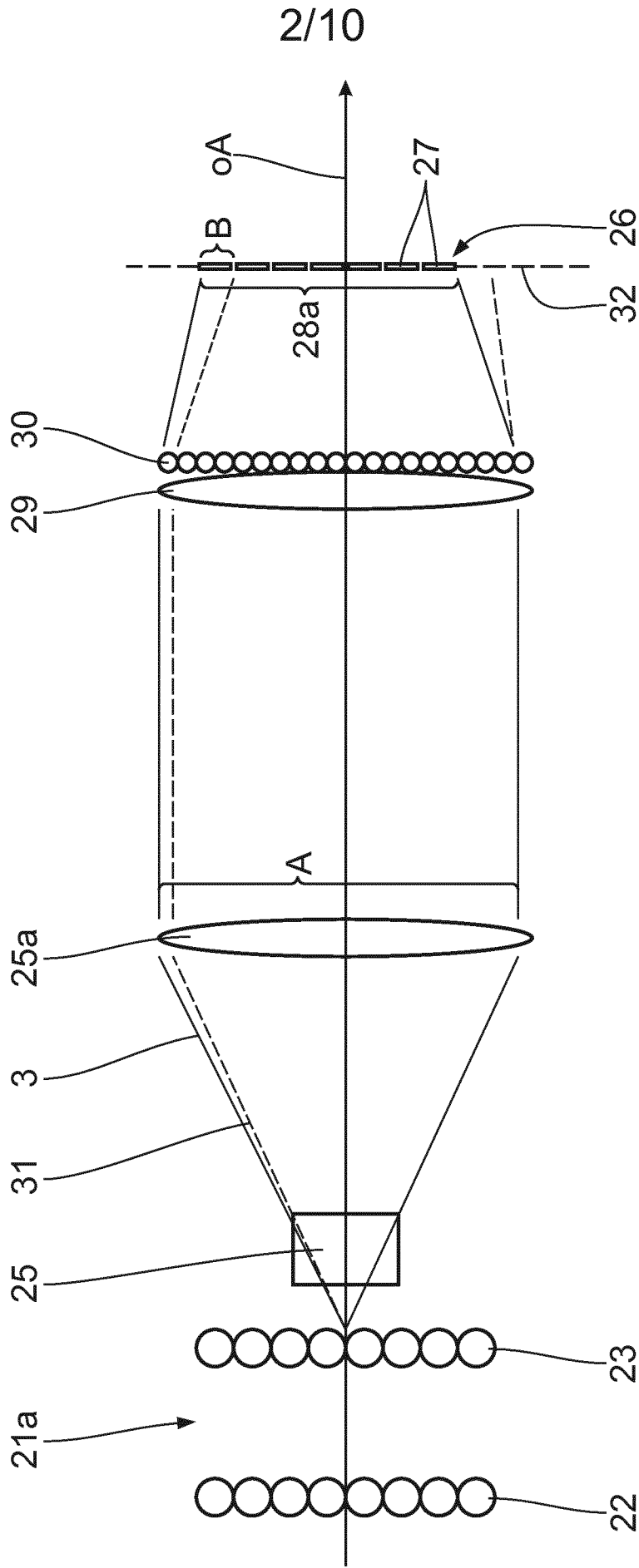


Fig. 3

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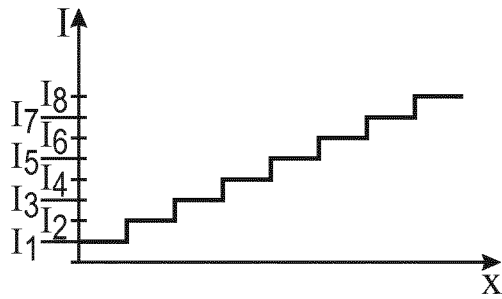


Fig. 4

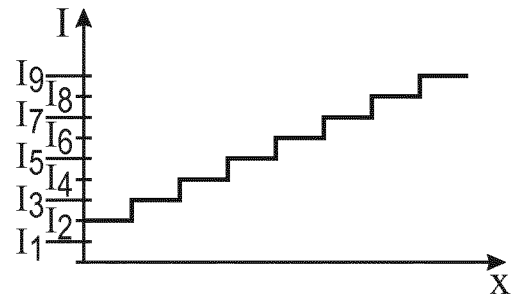


Fig. 6

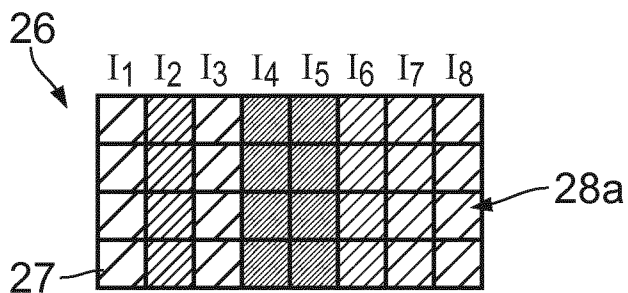


Fig. 5

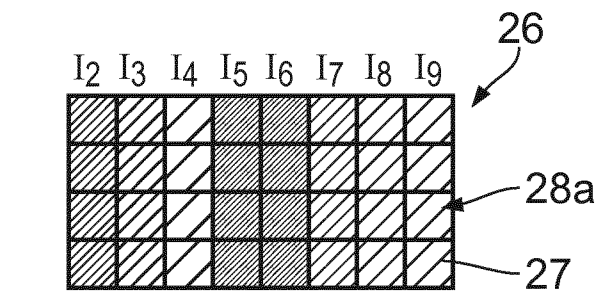
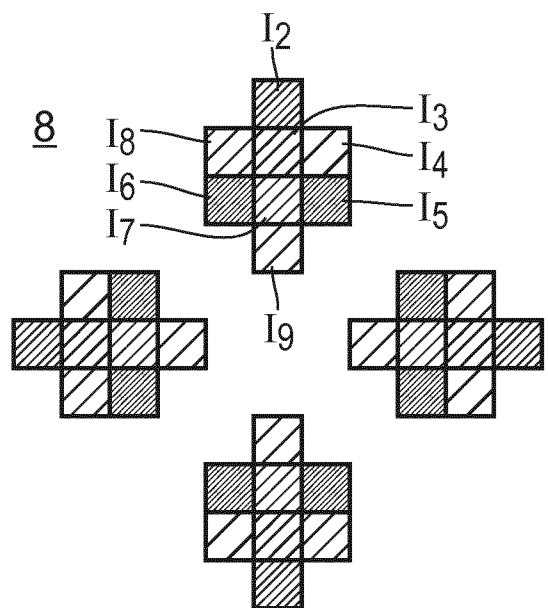
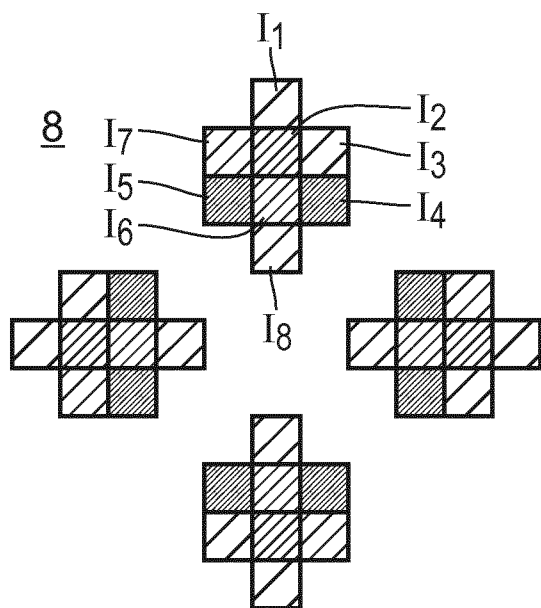


Fig. 7



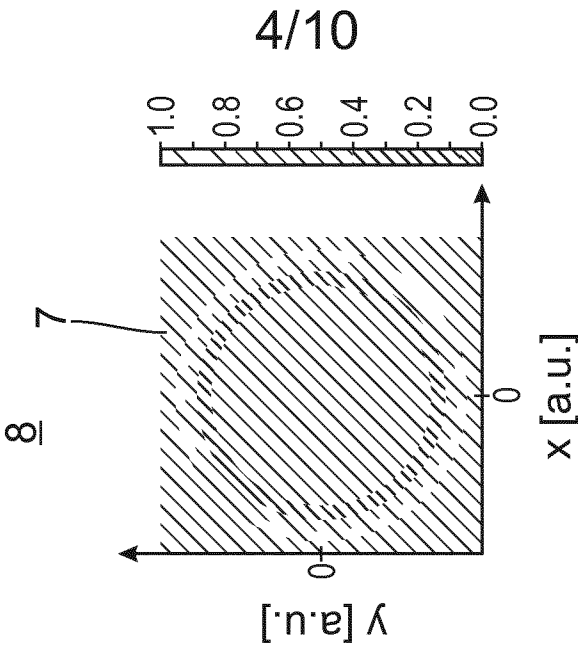


Fig. 10

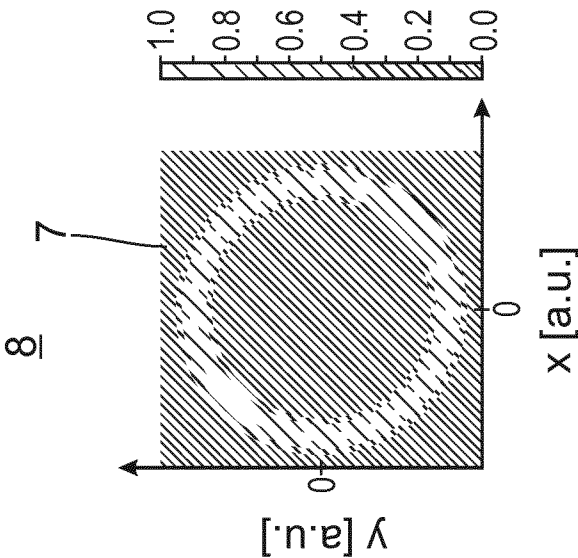


Fig. 9

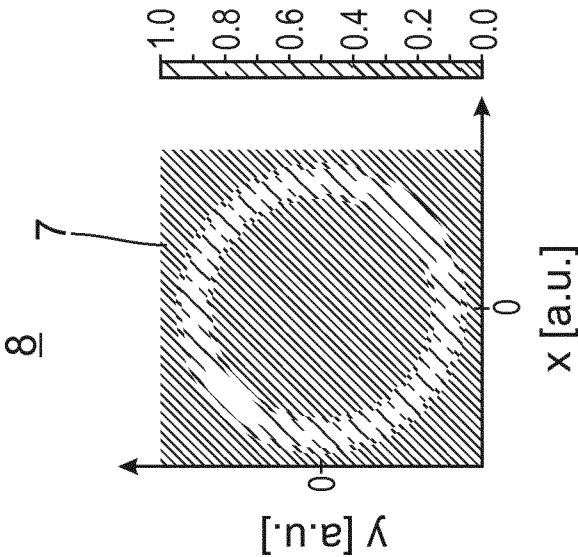


Fig. 8

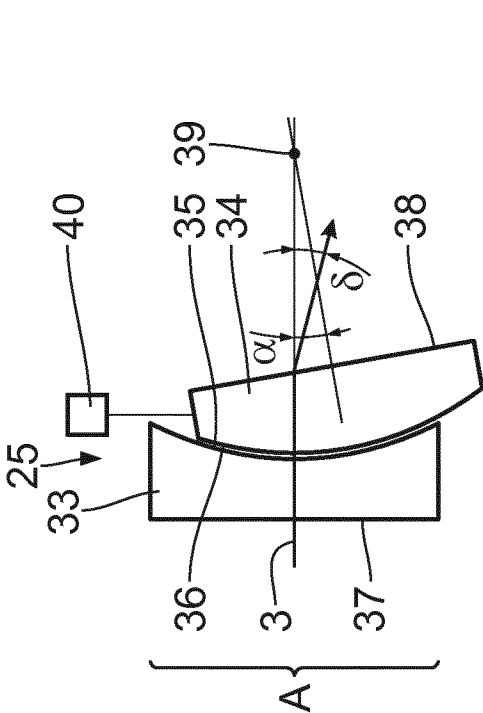


Fig. 11

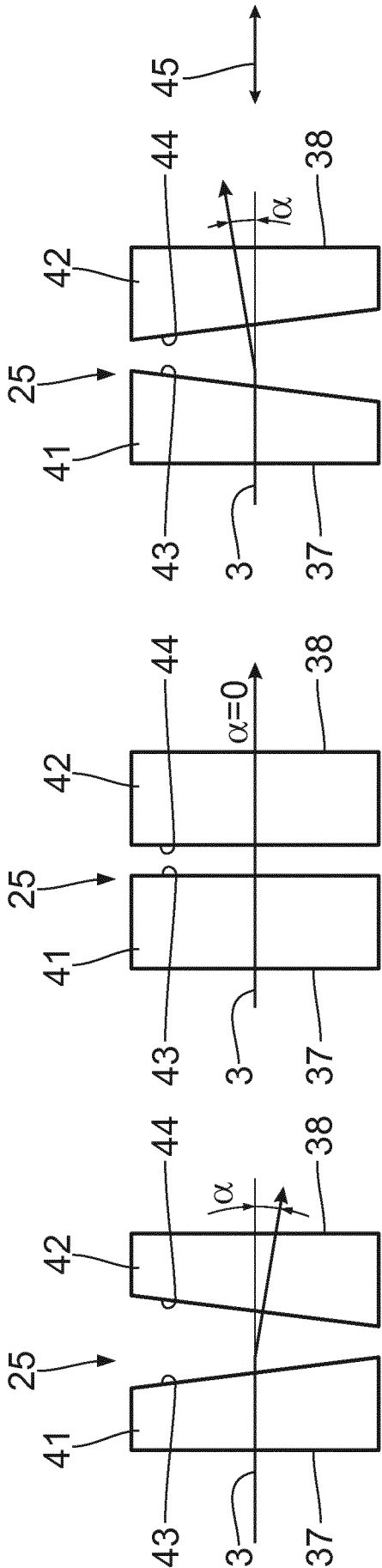


Fig. 12

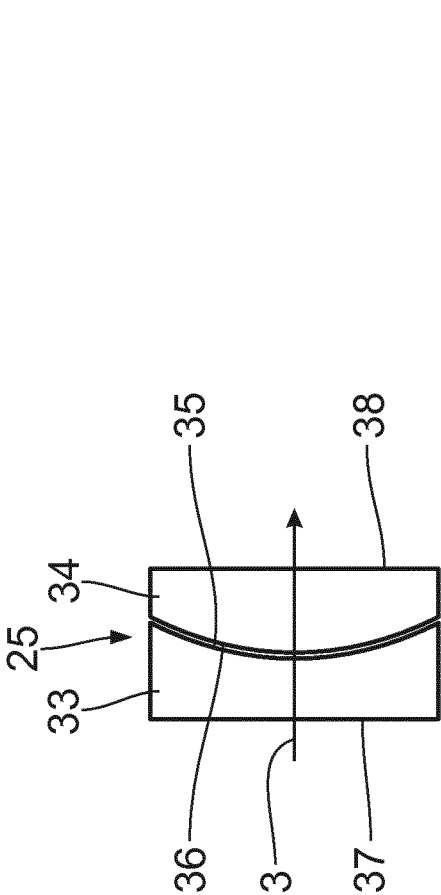


Fig. 13

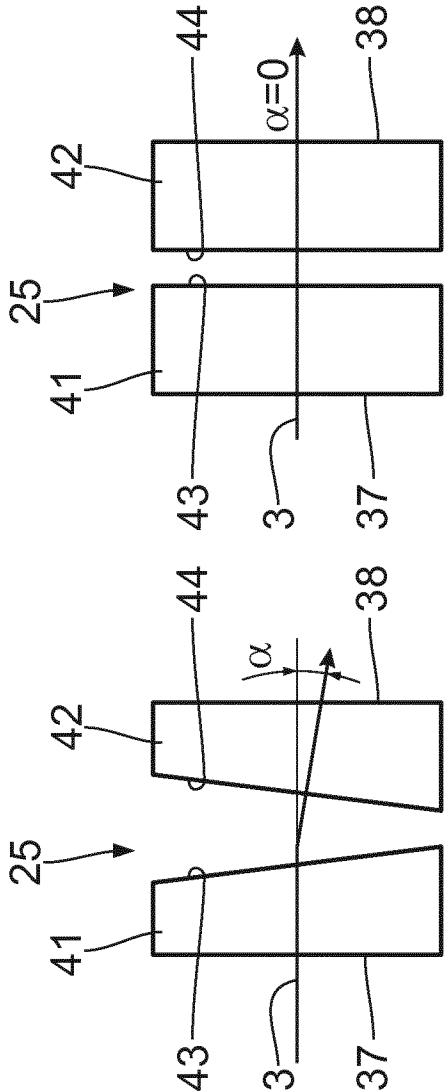


Fig. 14

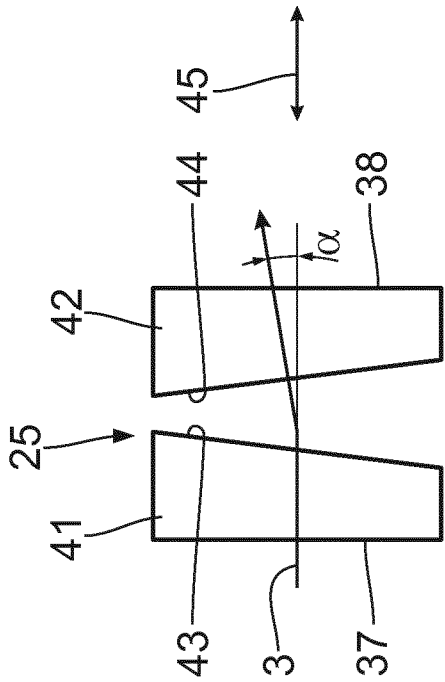


Fig. 15

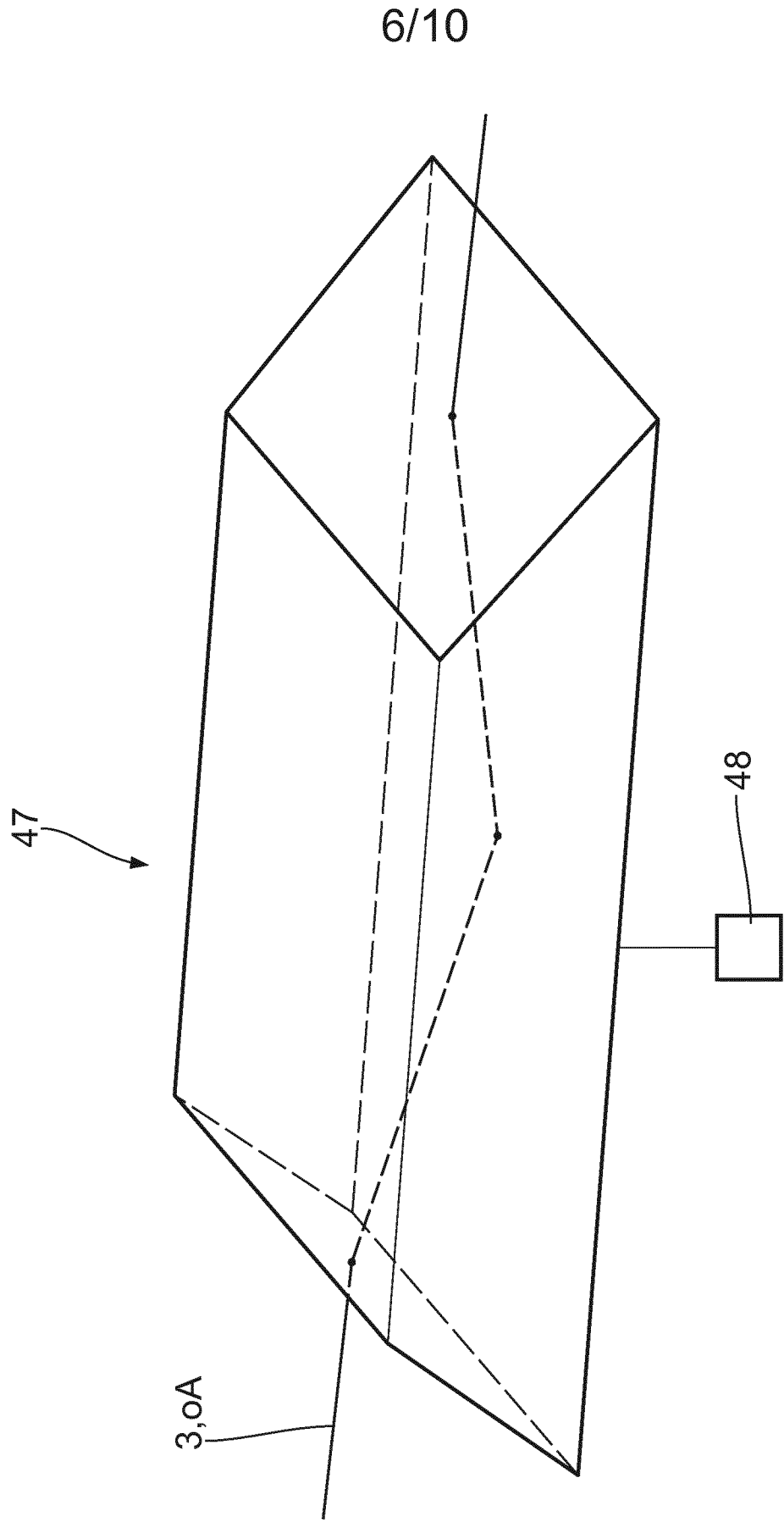


Fig. 16

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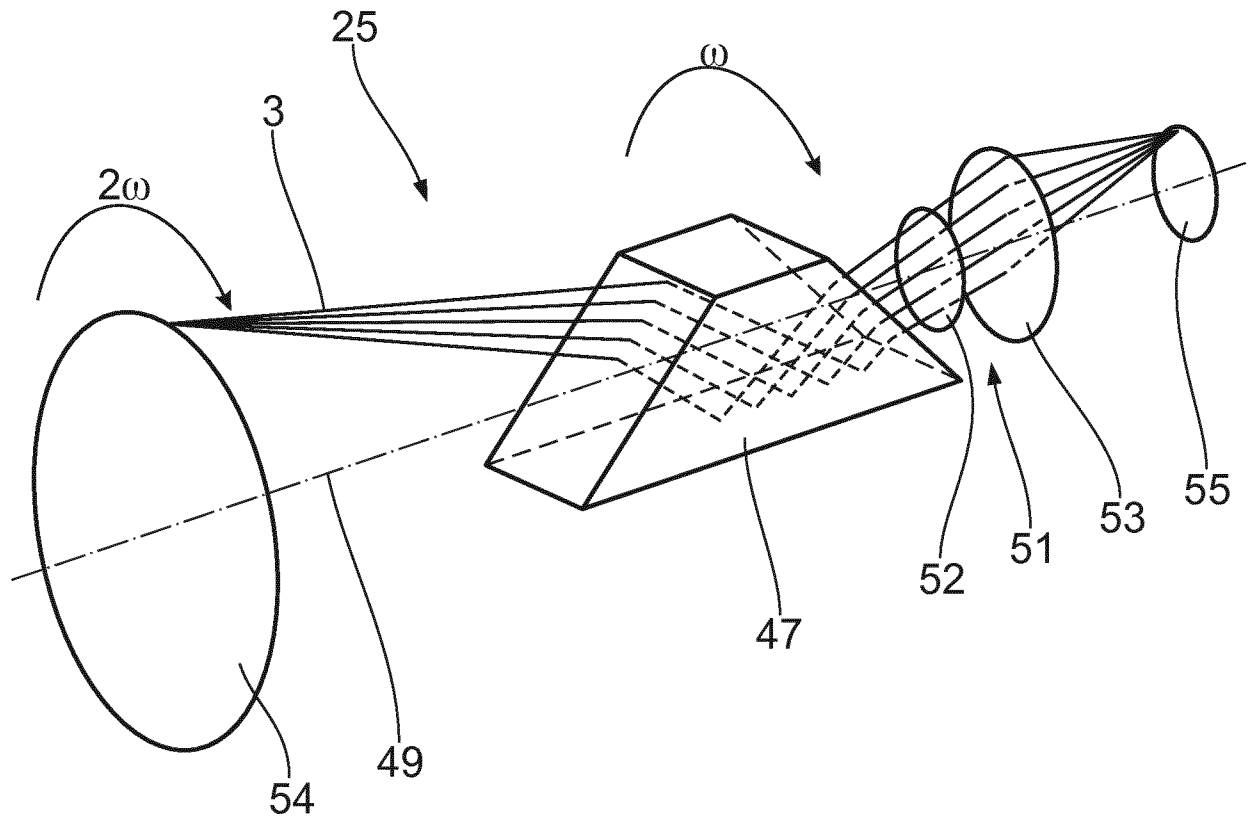


Fig. 17

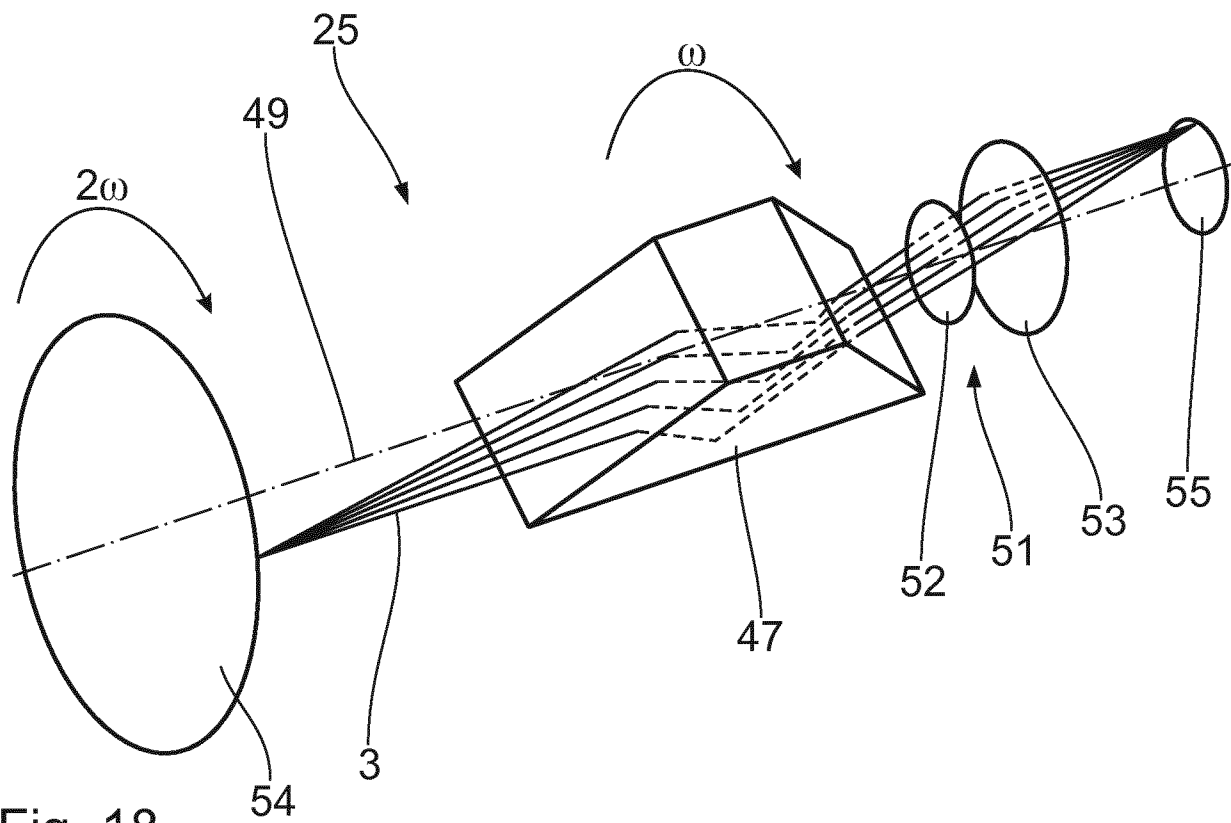


Fig. 18

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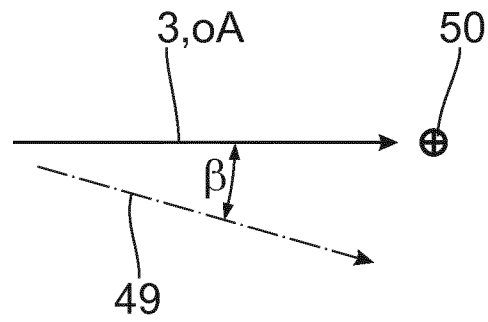


Fig. 19

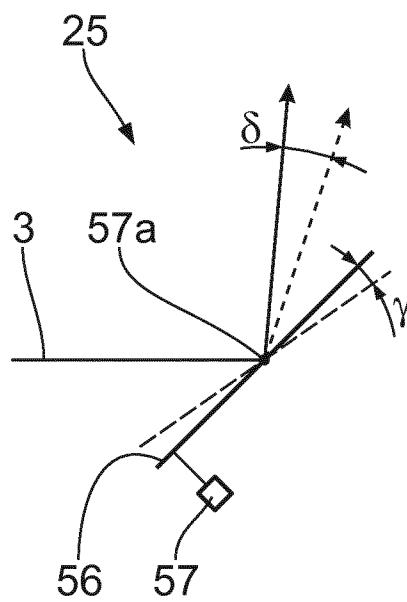


Fig. 20

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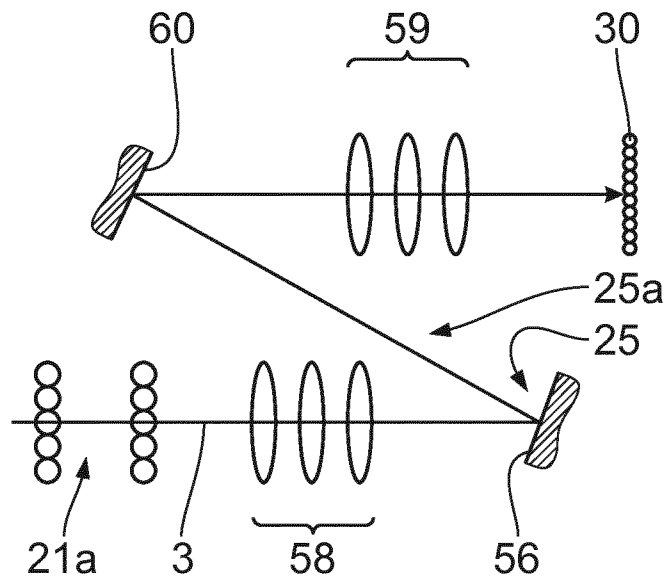


Fig. 21

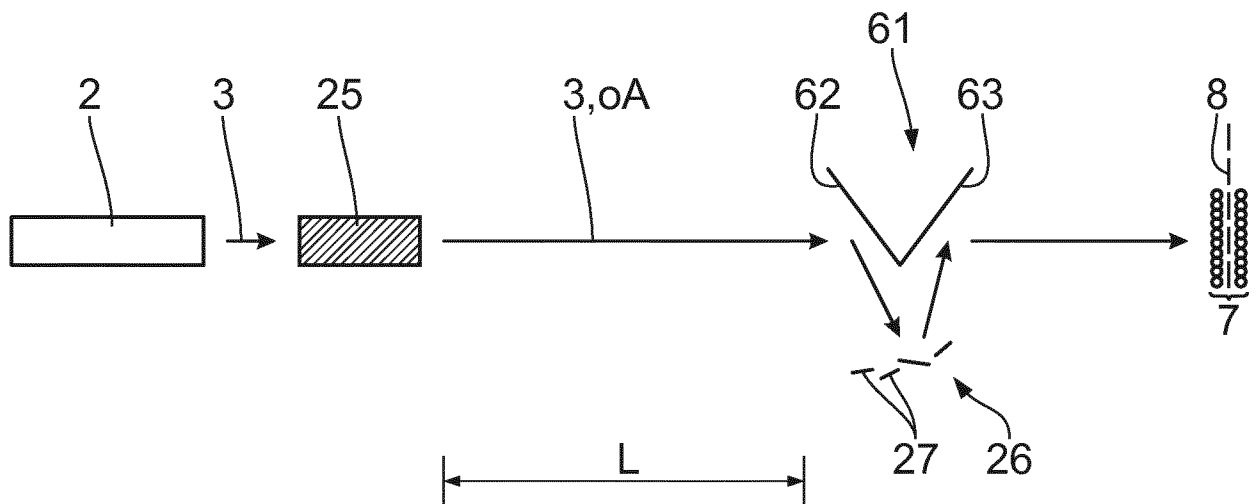


Fig. 22

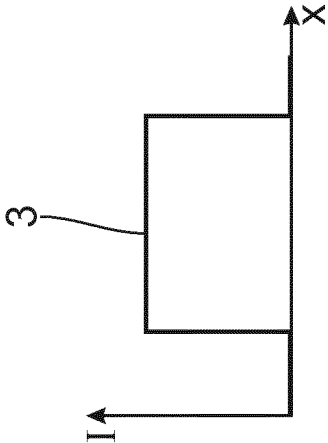


Fig. 23

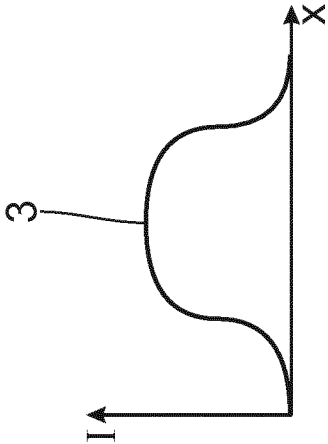


Fig. 24

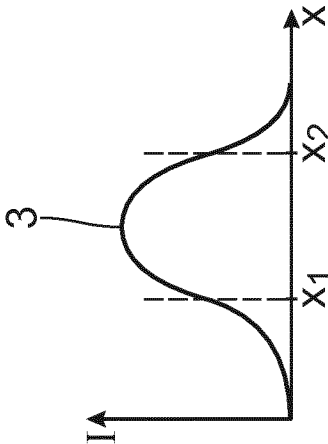


Fig. 25

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/059491

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 G02B H01L

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.
X	US 2009/135395 A1 (MELZER FRANK [DE] ET AL) 28 May 2009 (2009-05-28) abstract figures 9,10,11a,11b paragraphs [0002], [0095] - [0104] -----	1-15
X	WO 2009/060991 A1 (NIPPON KOGAKU KK [JP]; MURAMATSU KOUJI [JP]) 14 May 2009 (2009-05-14) abstract figure 1 paragraphs [0001], [0014], [0042] - [0047] ----- -/--	1-4,8, 10,12-15



Further documents are listed in the continuation of Box C.



See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search

18 July 2012

Date of mailing of the international search report

01/08/2012

Name and mailing address of the ISA/

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Authorized officer

Andersen, Ole

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2012/059491

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	NL 2 005 331 A (ASML NETHERLANDS BV [NL]) 19 May 2011 (2011-05-19) abstract figures 1,4,5 paragraphs [0001], [0006], [0042] - [0047] -----	1-4,8, 10,12-15

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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