(54) Title: ILLUMINATION OPTICS FOR MICROLITHOGRAPHY

Fig. 7

(57) Abstract: An illumination optics for microlithography comprises an optical assembly for guiding illumination light to an object field (19) to be illuminated in an object plane. According to a first aspect of the invention, the illumination optics (26) divides an illumination light radiation bundle (3) into a plurality of radiation sub-bundles (28 to 30) which are assigned to different illumination angles of the object field illumination. The illumination optics (26) is configured in such a way that at least some of the radiation sub-bundles (28 to 30) are superimposed in a superposition plane (16) which is spaced from the object plane and which is not imaged into the object plane in which superposition takes place. This superposition is such that edges (32) of the superimposed radiation sub-bundles (28 to 30) coincide at least partially. According to another aspect of the invention, a field intensity setting device (24) comprises a plurality of adjacent individual diaphragms (27) which at least attenuate illumination light (3) when exposed thereto. These individual diaphragms (27) are insertable into an illumination light radiation bundle (3) in a direction parallel to an object displacement direction (y). All individual diaphragms (27) of the field intensity setting device (24) are insertable into the illumination light radiation bundle (3) from one and the same side.

Illumination optics for microlithography

The invention relates to an illumination optics for microlithography. The invention further relates to an illumination system comprising an illumina-

5   tion optics of this type, a projection exposure apparatus comprising an illumination system of this type, a method of producing structured components, and a structured component produced according to a method of this type.

10   It is an object of the present invention to develop an illumination optics of the type mentioned at the outset in such a way that it is possible to influence and/or monitor an illumination intensity distribution across the object field such that an illumination angle distribution is affected to the least possible extent while simultaneously ensuring that a size of the illumination

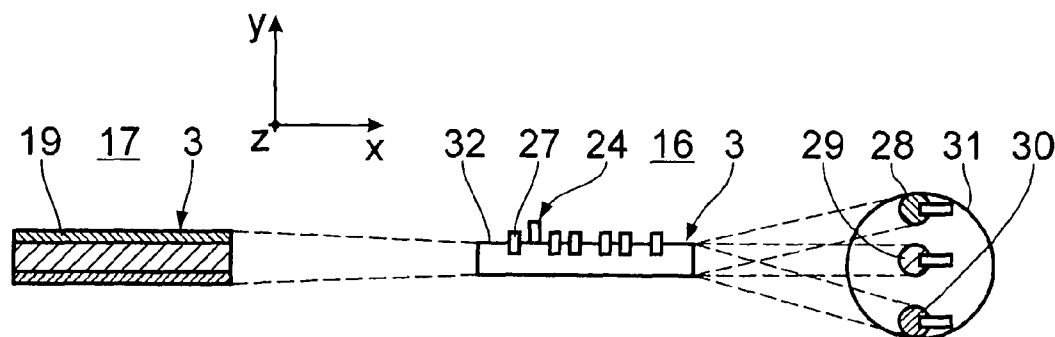15   optics is as small as possible.

This object is achieved according to the invention by an illumination optics for microlithography comprising
-    an optical assembly for guiding illumination light to an object field to

20   be illuminated in an object plane;
-    wherein the illumination optics divides an illumination light radiation bundle into a plurality of radiation sub-bundles which are assigned to different illumination angles of the object field illumination;
wherein the illumination optics is configured in such a way that at least

25   some of the radiation sub-bundles are superimposed in a superposition plane, which is spaced from the object plane and which is not imaged into the object plane in which superposition takes place, in such a way that edges of the superimposed radiation sub-bundles coincide at least partially.

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According to the invention, the object plane is spatially separated from the superposition plane of the radiation sub-bundles of the illumination light. The object plane and the superposition plane do not constitute planes that are imaged into one another; the object plane may therefore be arranged

5   directly next to the superposition plane. No optical components are re-quired between the object plane and the superposition plane for guiding the illumination light. In the superposition plane, a device may be arranged for setting an illumination intensity distribution across the object field or for monitoring the illumination intensity distribution across the object field by

10 means of a sensor, for example.

This arrangement is such that the device interacts with the illumination light at the point of coinciding superposition of the radiation sub-bundles in such a way that all superimposed radiation sub-bundles, in other words the

15 radiation sub-bundles from several or from all illumination angles, are de-tectable at the same time. As desired, the illumination light is therefore de-tectable in a superposition plane which is separated from the object plane. The illumination optics according to the invention can, but need not neces-sarily, include a facet mirror. It is conceivable as well to use a honeycomb

20 condenser, for example, i.e. a transmissive optical element which is divided into a plurality of individual channels, and/or at least one diffractive ele-ment for dividing the illumination light radiation bundle into the radiation sub-bundles. According to the invention, a partial superposition, in other words a coinciding superposition, of sub-bundle edge portions of the radia-

25 tion sub-bundles is sufficient. The remaining sub-bundle edge portions of the superimposed radiation sub-bundles need not coincide; in these por-tions, aberrations are tolerable. In the case of approximately rectangular radiation sub-bundles, for example, a superposition at one of the four sub-bundle edges is sufficient. At the point of superposition of the radiation

sub-bundles in the superposition plane, it is possible, for example, to decouple radiation for an illumination-angle-independent additional sensor system which is then able to provide valuable, illumination-angle-independent information about the object field illumination. The coinciding edge portions of the superimposed radiation sub-bundles form a common sub-bundle edge portion which is usually perpendicular to an object displacement direction of an object that is displaced during the microlithographic projection process. A displacement of this type takes place in a projection exposure apparatus designed as a scanner. By means of the inventive illumination optics, the radiation sub-bundles are superimposed in the superposition plane.

The object named at the outset is also achieved according to the invention by an illumination optics for microlithography comprising

-   an optical assembly for guiding illumination light to an object field to be illuminated in an object plane;

-   wherein the illumination optics comprises a field facet mirror with a plurality of field facets which are imaged into a superposition plane in such a way that edges of the images of the field facets coincide at least partially in the superposition plane;

and wherein the superposition plane is spaced from the object plane and is not imaged into the object plane.

The advantages thereof are the same as those already described above.

The superposition of the radiation sub-bundles by means of a field intensity setting device which is arranged in the superposition plane so as to be used as an intensity setting plane and serves for the adjustment of an intensity distribution of the illumination light across the object field, wherein the

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edges of the superimposed radiation sub-bundles coincide at the point where they are influencable by the field intensity setting device, provides for a virtually illumination-angle-independent effect of the field intensity setting device. In this case, the superposition plane serves as an intensity

5   setting plane. The field intensity setting device influences the superimposed radiation sub-bundles of the illumination light radiation bundle at their point of superposition. Consequently, the field intensity setting device influences all radiation sub-bundles which are superimposed at this point in the same way; in other words, the field intensity setting device has an ef-

10   fect which is independent with respect to these radiation sub-bundles and therefore with respect to the illumination angles which are assigned to these radiation sub-bundles. The superposition of the radiation sub-bundles takes place at least at the point where the field intensity setting device influences the illumination light radiation bundle. In the case of approxi-

15   mately rectangular radiation sub-bundles, for example, a superposition at the edge, which is influenced by the field intensity setting device, is sufficient. Naturally, a superposition of radiation sub-bundles or sub-bundle edge portions may also take place in regions which are not influenced by the field intensity setting device. A superposition of the radiation sub-

20   bundles in the superposition plane or intensity setting plane in order to reduce or virtually avoid an illumination angle impact of the field intensity setting device is, among other things, applicable in systems in which the field intensity setting device is able to influence the superimposed radiation sub-bundles from two sides. These may be illumination optics with an in-

25   termediate image or illumination optics with transmission masks. The field intensity setting device defines the intensity of the illumination light in the object plane. A superposition of the radiation sub-bundles at a point, which is in the range of impact of the field intensity setting device, furthermore allows an increased stability of the object field illumination to be achieved

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since a displacement of a light source used to generate the illumination light will, if at all, only have a minor impact on the effect of the field intensity setting device. This is advantageous in particular when an EUV plasma source is used.

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A field intensity setting device which comprises a plurality of individual diaphragms or stops that are arranged next to one another and at least attenuate illumination light when exposed thereto and are insertable into an illumination light radiation bundle in a direction parallel to an object dis-

10   placement direction provides for a sensitive adjustment of the intensity across an object field height of the object field, in other words an object field dimension perpendicular to an object displacement direction.

It is another object of the invention to develop an illumination optics of the

15   type named at the outset in such a way as to achieve an increased number of possible applications of the field intensity setting device.

This object is achieved according to the invention by an illumination optics for microlithography comprising

20   -   an optical assembly for guiding illumination light to an object field to be illuminated in an object plane;

-    a field intensity setting device for adjusting an intensity distribution across the object field with a plurality of individual diaphragms which are arranged next to one another and at least attenuate illumination

25   light when exposed thereto and are insertable into an illumination light radiation bundle in a direction parallel to an object displacement direction;

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wherein all individual diaphragms of the field intensity setting device are insertable into the illumination light radiation bundle from one and the same side.

5   It has been found according to the invention that if the individual diaphragms of the field intensity setting device are all insertable into the illumination light radiation bundle from one side, the field intensity setting device is even applicable in situations where the object field is arranged on a reflective object such as a reflective reticle. The field intensity setting

10   device may then be arranged in such a way that it does not interfere with the reflected light path of the illumination light radiation bundle.

An arrangement of the field intensity setting device in an intensity setting plane, which coincides with a field plane of the optical assembly, may

15   again ensure an illumination-angle-independent effect of the field intensity setting device. The field plane of the optical assembly describes the plane where the illumination light radiation bundle is constricted due to the bundle-guiding effect of the optical assembly, and where radiation sub-bundles are superimposed if an illumination light radiation bundle is divided into

20   several radiation sub-bundles. The field plane of the optical assembly is usually the plane into which the object-field-forming components of the optical assembly are imaged. In spite of this, the field plane of the optical assembly is generally position-independent of a plane which is imaged by a downstream projection optics of a microlithographic projection exposure

25   apparatus and which is usually referred to as object plane. In all prior-art illumination optics, the field plane of the optical assembly coincides with the object plane. This is not the case in the inventive illumination optics. Here, it is the field intensity setting device which is arranged in the field plane of the optical assembly and not the object, which is usually a reticle,

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to be imaged. Prior-art field intensity setting devices are usually arranged upstream of a reticle which is arranged in the field plane of the optical assembly, in other words they are not arranged in this field plane. Consequently, the prior-art field intensity setting device has a greater impact on

5   radiation sub-bundles of the illumination light radiation bundle which are assigned to particular illumination angles than on radiation sub-bundles assigned to other illumination angles; the prior-art field intensity setting devices have therefore an undesired illumination-angle-dependent effect across the object field. This problem was recognized by the inventors and

10   eliminated by arranging the field intensity setting device in the field plane of the optical assembly. Surprisingly, this allows the object to be moved out of the field plane of the optical assembly without any problems. This applies in particular if a projection exposure apparatus, which includes the illumination optics, is designed as a scanning apparatus. Moreover, this

15   applies in particular if the illumination of the object field is carried out using a numerical aperture of the illumination light radiation bundle, which is smaller than or equal to 0.1.

An arrangement in which the object plane is adjacent to the intensity set-

20   ting plane in such a way that there is no pupil plane of the optical assembly between the intensity setting plane and the object plane is particularly compact.

An arrangement in which a distance between the intensity setting plane and

25   the object plane is in the range of between 5 mm and 20 mm prevents spatial conflicts or dosing errors, in other words unwanted aberrations in the illumination intensity entering the object field. Preferred distances are in the range of between 10 mm and 20 mm, in particular in the range of 15 mm or 16 mm.

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An arrangement in which the optical assembly comprises a field facet mirror with a plurality of field facets whose images are at least partially superimposed in the object field permits easy control of an illumination angle distribution of the illumination of the object field.

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A configuration of the field facets such that the field facets have a higher x/y aspect ratio than the object field, which means that proportionally speaking, they are narrower than the object field when seen in the object displacement direction, may avoid an overexposure of the object field as a

10   result of diverging field facet images in the object plane or in the reticle plane due to the fact that the object is not disposed in the field plane, also referred to as diaphragm plane, of the optical assembly in which the partial fields, in other words the images of object-field-forming components of the optical assembly of the illumination optics, are arranged in such a way that

15   the feedback on the illumination angle distribution is minimized.

An arrangement in which an edge of the illumination light radiation bundle facing the individual diaphragms is illuminated by all field facets of the field facet mirror ensures a relatively homogeneous impact of the field in-

20   tensity setting device on all field facet images, thus avoiding an unwanted impact on the illumination angle distribution during the use of the field intensity setting device. As long as sharp images of the field facets are produced in the intensity setting plane, this ensures a particularly high system stability, wherein in particular a spatial displacement of a light source of

25   the illumination light is more or less unproblematic. This is advantageous in particular when the light source is an EUV plasma source.

An arrangement in which an edge of the illumination light radiation bundle facing the individual diaphragms is illuminated in the field plane by a sub-

group of all field facets of the field facet mirror ensures an illumination-angle-independent effect of the field intensity setting device even if a coincidence of the field facet images at the edge of the illumination light radiation bundle in the field plane facing the individual diaphragms is not

5   achievable for all field facet images.

An assignment of a given distribution of illumination angles to the field facets of the subgroup improves an illumination angle independence of the field intensity setting device in those cases in which a perfect superposition

10   at the edge of the illumination light radiation bundle in the field plane facing the individual diaphragms is not achievable at all or only to a minor extent. The defined distribution of illumination angles may for instance be generated by means of a statistical function. This not only ensures an illumination angle independence of the intensity setting device but also guar-

15   antees a defined impact on the illumination angles.

A pupil facet mirror with a plurality of pupil facets which are assigned to the field facets in the light path of the illumination light permits easy control of an illumination angle distribution across the object field.

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Pupil facets which are tiltable for adjusting a superposition of the illumination light in the intensity setting plane allow the individual radiation sub-bundles of the illumination light radiation bundle to be selectively displaced and oriented in the intensity setting plane in order to optimize the

25   subposition of these radiation sub-bundles in a region that is in the range of impact of the field intensity setting device.

Individual diaphragms which are, at least in some portions, at least partially transparent enhance the sensitivity of the intensity effect of the field inten-

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sity setting device with respect to a displacement of individual diaphragms and with respect to a change of position of the field intensity setting device relative to illumination light radiation bundle.

5   When using the illumination optics for guiding EUV illumination light with a wavelength of between 5 nm and 30 nm to the object field, the advantages described above become even more apparent.

The object named at the outset is also achieved according to the invention
10   by an illumination optics for microlithography comprising
     -   an optical assembly for guiding illumination light with a wavelength of between 5 nm and 30 nm to an object field to be illuminated in an object plane;
     -   a field intensity setting device for adjusting an intensity distribution of
15   the illumination light across the object field;
     -   wherein the field intensity setting device has such an effect on a cross-section, which is formed by the illumination light and is perpendicular to an illumination light radiation bundle, that an edge of the bundle cross-section opposite to the field intensity setting device remains un-
20   changed downstream of the field intensity setting device;
     and wherein an effect of the field intensity setting device is independent of an illumination angle on the object field.

The advantages thereof are the same as those already described above.
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The advantages of an illumination system which comprises an illumination optics according to the invention and a light source, of a projection exposure apparatus comprising an illumination system according to the invention and a projection objective for imaging the object field into an image

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plane, of a method of producing a structured component comprising the steps of

-    providing a wafer to at least part of which is applied a layer of a light-sensitive material;

5   -   providing a reticle which comprises structures to be imaged;

-    providing a projection exposure apparatus according to the invention; and

-    projecting at least a part of the reticle onto a region of the layer on the wafer by means of the projection exposure apparatus,

10   as well as a component produced in such a way are the same as those described above with reference to the illumination optics. The light source may in particular be an EUV light source with a wavelength of useful light in the range of between 5 nm and 30 nm. The projection exposure apparatus is used for lithographic production of a microstructured or nanostruc-

15   tured component.

Embodiments of the invention will hereinafter be explained in more detail by means of the drawing in which

20   Fig. 1   shows a schematic view of a meridional section, relative to an illumination optics, through a projection exposure apparatus for microlithography;

Fig. 2   shows an enlarged sectional view of Fig. 1 in the vicinity

25   of a reticle plane;

Fig. 3   shows a view of a field intensity setting device of the projection exposure apparatus from direction III in Fig. 2;

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Fig. 4   shows a view of a facet arrangement of a field facet mirror
              of the illumination optics of the projection exposure appa-
              ratus according to Fig. 1;

5   Fig. 5   shows a view of a facet arrangement of a pupil facet mirror
              of the illumination optics of the projection exposure appa-
              ratus according to Fig. 1;

     Fig. 6   shows an illustration, similar to Fig. 4, of a facet arrange-
10   ment of another embodiment of a field facet mirror;

     Fig. 7   shows a schematic view of a light path through the illumi-
              nation optics between a pupil plane of the illumination op-
              tics and a reticle plane for three selected radiation sub-
15   bundles which are assigned to in each case particular illu-
              mination angles;

     Fig. 8   shows a field facet of an embodiment of the field facet
              mirror according to Fig. 4;

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     Fig. 9   shows a field facet of another embodiment of the field
              facet mirror according to Fig. 4;

     Fig. 10 shows a superposition of three radiation sub-bundles,
25   which are assigned to different illumination angles accord-
              ing to the illustration of Fig. 7, in a plane of the field inten-
              sity setting device at an alternative illumination setting;

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Figs. 11 to 16   show diagrams for illumination parameters of the illumina-
tion of a reticle as a function of an attenuation (in percent)
by the field intensity setting device at a first illumination
geometry; and

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Figs. 17 to 22   show diagrams for the same illumination parameters at
another illumination geometry which is optimized to mini-
mize the change of these illumination parameters which is
caused by the attenuation of the field intensity setting de-

10   vice.

A projection exposure apparatus 1 for microlithography serves to produce a
microstructured or nanostructured electronic semiconductor component. A
light source 2 emits EUV radiation in the wavelength range of between 5

15   nm and 30 nm, for example. In the projection exposure apparatus 1, a bun-
dle 3 of useful radiation serves for illumination and projection. Down-
stream of the light source 2, the bundle 3 of useful radiation initially passes
through a collector 4 which may for example be a nested collector with a
prior-art multiple-shell configuration. Downstream of the collector 4, the

20   bundle 3 of useful radiation initially passes through an intermediate focal
plane 5 which may be used to separate unwanted portions of radiation or
particles from the bundle 3 of useful radiation. Having passed through the
intermediate focal plane 5, the bundle 3 of useful radiation initially hits a
field facet mirror 6.

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The drawing includes in each case an xyz coordinate system in order to
facilitate the description of positional relationships. In Fig. 1, the x-axis
extends into said plane perpendicular thereto. The y-axis extends towards
the left in Fig. 1.The z-axis extends upwardly in Fig. 1.

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Fig. 4 shows, by way of example, a facet arrangement of field facets 7 of

the field facet mirror 6. The field facets 7 are rectangular and have in each

case the same x/y aspect ratio. The field facets 7 define a reflective surface

of the field facet mirror 6 and are arranged in four columns of in each case

5   six field facet groups 8. The field facet groups 8 usually comprise in each

case seven field facets 7. The two field facet groups 8 near the edge, which

are included in the two central field facet columns, comprise in each case

four additional field facets 7 and therefore comprise a total of eleven field

facets 7. Between the two central facet columns and between the third and

10   fourth facet row, the facet arrangement of the field facet mirror 6 has gaps

9 in which the field facet mirror 6 is shadowed by support spokes of the

collector 4.

Having been reflected at the field facet mirror 6, the bundle 3 of useful ra-

15   diation, which is divided into radiation sub-bundles assigned to the indi-

vidual facets 7, hits a pupil facet mirror 10.

Fig. 5 shows, by way of example, a facet arrangement of round pupil facets

11 of the pupil facet mirror 10. The pupil facets 11 are arranged in facet

20   rings which are arranged one inside the other such as to surround a center

12. Each of the radiation sub-bundles of the bundle 3 of useful radiation,

which are reflected by one of the field facets 7, is assigned to a pupil facet

11 in such a way that a respectively exposed pair of facets, which com-

prises one of the field facets 7 and one of the pupil facets 11, defines one

25   radiation guide channel for the assigned radiation bundle of the bundle 3 of

useful radiation. The channel assignment between the pupil facets 11 and

the field facets 7 takes place in dependence on a desired illumination by

way of the projection exposure apparatus 1. In order to give access to par-

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ticular pupil facets 11, the field facets 7 are individually tilted about the x-axis on the one hand and about the y-axis on the other.

The pupil facet mirror 10 and a downstream transmission optics 15, which comprises three EUV mirrors 12, 13, 14, serve to image the field facets 7 into a field plane 16 of the projection exposure apparatus 1. The EUV mirror 14 is a grazing incidence mirror. A reticle plane 17 is disposed downstream of the field plane 16 at a distance of approximately 5 mm to 20 mm when seen in the z-direction, in which reticle plane 17 is arranged a reticle 18 which, by means of the bundle 3 of useful radiation, illuminates an illumination region which coincides with an object field 19 of a downstream projection optics 20 of the projection exposure apparatus 1. In the projection exposure apparatus 1, the field plane 16, into which the field facets 7 are imaged to form facet images by means of the transmission optics 15, does not coincide with the reticle plane 17 which simultaneously forms the object plane of the projection optics 20. The bundle 3 of useful radiation is reflected by the reticle 18.

The projection optics 20 images the object field 19 in the reticle plane 17 into an image field 21 in an image plane 22. In this image plane 22 is arranged a wafer 23 which carries a light-sensitive layer that is exposed to light during the projection exposure by way of the projection exposure apparatus 1. During the projection exposure, both the reticle 18 as well as the wafer 23 are scanned in the y-direction in a synchronized manner. The projection exposure apparatus 1 is a scanner. The scanning direction is hereinafter also referred as object displacement direction.

In the field plane 16 is arranged a field intensity setting device 24 which will hereinafter be explained in more detail. The field intensity setting de-

- 16 -

vice 24 serves to define a scan-integrated intensity distribution, in other words an intensity distribution which is integrated in the y-direction, across the object field 19. Therefore, the field plane 16 is at the same time an intensity setting plane of the illumination optics 26. The field intensity set-

5   ting device 24 is actuated by a control device 25.

The field facet mirror 6, the pupil facet mirror 10, the mirrors 12 to 14 of the transmission optics 15, as well as the field intensity setting device 24 are components of an illumination optics 26 of the projection exposure ap-

10   paratus 1. The components 6, 10, 12, 13 and 14 form an optical assembly 26a of the illumination optics 26 for guiding the bundle 3 of useful radiation.

There is no pupil plane of the optical assembly 26a between the field plane

15   16 and the reticle plane 17.

Figs. 2 and 3 show a more detailed illustration of the field intensity setting device 24. The field intensity setting device 24 has a plurality of finger-like individual diaphragms 27 which are arranged next to one another. In the

20   embodiment according to Figs. 2 and 3, there are a total of twenty-six individual diaphragms 27 with a width of in each case 4 mm. These individual diaphragms 27 are either arranged directly next to one another or partially overlap with each other. If they partially overlap with each other, neighbors of the individual diaphragms 27 need to be disposed perpendicular to the

25   beam direction of the illumination light radiation bundle 3 in planes which are as close as possible to each other.

All individual diaphragms 27 are inserted into the bundle 3 of useful radiation from one and the same side.

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The control device 25 allows the individual diaphragms 27 to be placed independently of each other at a given position along the y-direction. Depending on the field height, in other words the x-direction, of an object point on the reticle 18 passing through the object field 19, the scanning

5   path of this object point in the y-direction, and therefore the integrated intensity of the useful radiation to which this object point is exposed, is determined by the y-position of the respective individual diaphragm 27. In this way, the intensity of useful radiation to which the reticle 18 is exposed may be homogenized or distributed in a given way by defining the y-

10   positions of the individual diaphragms 27. The field intensity setting device 24 is also referred to as UNICOM.

Fig. 6 shows another embodiment of a field facet mirror 6. Components which are equivalent to those explained above with reference to the field

15   facet mirror according to Fig. 4 have the same reference numerals and are only described if they differ from the components of the field facet mirror 6 according to Fig. 4. The field facet mirror according to Fig. 6 has a field facet arrangement with curved field facets 7. These field facets 7 are arranged in a total of five columns with in each case a plurality of field facet

20   groups 8. The field facet arrangement is inscribed in a circular boundary of a carrier plate 9a of the field facet mirror.

The field facets 7 of the embodiment according to Fig. 6 have in each case the same surface area and the same ratio of width (in x-direction) to height

25   (in y-direction), which corresponds to the x/y aspect ratio of the field facets 7 of the embodiment according to Fig. 4.

The field intensity setting device 24 has an intensity effect which has virtually no impact on an illumination angle distribution of the object field 19.

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This will hereinafter be explained by means of Fig. 7. The Figure sche-
matically illustrates the path of three radiation sub-bundles 28, 29 and 30
from a pupil plane 31, in which is arranged the pupil facet mirror 10, across
the field plane 16 up to the reticle plane 17. The planes 31, 16 and 17,

5   which are in practice arranged in succession in the light path of the three
radiation sub-bundles 28, 29 and 30, are shown next to one another in Fig.
7 for illustrative purposes. The following is based on the idealized assump-
tion that the field facets 7 of the field facet mirror 6 according to Fig. 4 are
imaged into the field plane 16 in such a way as to coincide perfectly. An

10   edge boundary of the bundle 3 of useful radiation in the field plane 16
therefore has the same extension in both the x-direction and the y-direction
as a single image of one of the field facets 7. Consequently, in the event of
such a perfect superposition, the bundle 3 of useful radiation has an x/y
aspect ratio which is perfectly equal to the x/y aspect ratio of the field fac-

15   ets 7. All radiation sub-bundles 28, which are assigned to different illumi-
nation directions of the field plane 16 and therefore include the radiation
sub-bundles 28 to 30 as well, coincide in the field plane 16 across their en-
tire cross-section. In particular an edge 32 of the bundle 3 of useful radia-
tion facing the individual diaphragms 27 is formed and illuminated by all

20   of the three radiation sub-bundles 28 to 30 at the same time. Consequently,
the individual diaphragms 27, which cover the bundle 3 of useful radiation
from the edge 32, have exactly the same, in other words an illumination-
angle-independent, intensity effect on all radiation sub-bundles 28 to 30.
For the radiation sub-bundles 28 to 30, this is schematically indicated in the

25   pupil plane 31 on the right-hand side of Fig. 7 by rectangular shadows
which are active on one side. These shadows in the pupil plane 31 do not
constitute real diaphragms.

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The field facet images in the field facet plane 16 need not coincide perfectly in the x-direction, in other words perpendicular to the scanning direction, for the field intensity setting device 24 to have an illumination-angle-independent effect according to the above description; in fact, the

5   field facet images may very well be arranged at a certain offset with respect to each other. If the field facet images in the field facet plane 16 coincide well even in the x-direction, this may be used for intensity detection by decoupling useful radiation.

10   In the reticle plane 17, which is arranged in the light path of the bundle 3 of useful radiation at for instance 20 mm behind the field plane 16 when seen in the z-direction, the three radiation sub-bundles 28 to 30 have slightly diverged in particular in the y-direction in such a way that for instance the radiation sub-bundle 28 slightly projects upwardly in the y-direction and

15   beyond the radiation sub-bundle 29 in the center of the object field 19, while the radiation sub-bundle 30 slightly projects beyond the radiation sub-bundle 29 downwardly in the y-direction. As the reticle is scanned by the object field 19 in the y-direction, the reticle sees scan-integrated all of the three radiation sub-bundles 28 to 30 to their full extent; consequently,

20   the mentioned y-offset between the respective radiation sub-bundles 28 to 30 in the reticle plane 17 does not have any negative effects.

Compared to a given x/y aspect ratio of the field facets 7, the x/y aspect ratio of the object field 19 is smaller due to the above-described y-offset of

25   the radiation sub-bundles 28 to 30.

Fig. 8 shows a rectangular field facet 7 of the field facet mirror 6 according to Fig. 4 with an x/y aspect ratio which corresponds to a given x/y aspect ratio in the field plane 16. If the given x/y aspect ratio is not to be gener-

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ated in the field plane 16 but in the reticle plane 17, a field facet mirror 6
needs to be used which comprises field facets 33 whose x/y aspect ratio is
greater than the x/y aspect ratio of the object field 19. Therefore, a field
facet mirror 6 needs to be used in practice whose field facets 33 are nar-
5   rower in the y-direction (cf. Fig. 9). A y-extension y_{33} of the field facets is
thus smaller than a y-extension y_7 of the field facets 7.

In practice, the superposition in the field plane 16 of the radiation sub-
bundles, which are assigned to the individual channels, deviates from the
10   perfect superposition shown in Fig. 7 due to a plurality of imaging effects.
This may have numerous causes.

First of all, a mutual shadowing of the field facets 7 caused by the illumina-
tion geometry of the field facet mirror 10 may result in individually formed
15   images of the field facets 7 in the field plane 16.

Furthermore, the transmission optics 15 may have different imaging scales
for different channels, in other words for different radiation sub-bundles,
depending on the respectively observed radiation bundle. Likewise, these
20   different imaging scales also result in a superposition of the radiation bun-
dle in the field plane 16 which deviates from the perfect superposition.

Depending on the respective inclination of the field facets 7, a facet projec-
tion with an individual facet size is obtained perpendicular to the direction
25   of exposure with the bundle 3 of useful radiation. This has an impact on the
superposition in the field plane 16 as well.

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Another reason for an imperfect superposition in the field plane 16 lies in that due to the grazing incidence mirror 14, the radiation sub-bundles to be superimposed in the field plane 16 may have different curvatures.

5   In case the superposition in the field plane 16 is not perfect, the illumination optics 26 is therefore adjusted in such a way that the individual radiation sub-bundles, which image the respective field facets 7, coincide in the best possible way in the region of the edge 32 facing the individual diaphragms 27. This is schematically illustrated in Fig. 10. An imperfect superposition of the radiation sub-bundles at an edge 33a opposite to the edge 33 is acceptable, as it is indicated by the boundaries 34, 35 of individual radiation sub-bundles which deviate from each other in the y-direction.

In the worst case, a perfect superposition of the radiation sub-bundles is not
15   even achievable at least at the edge 32 facing the individual diaphragms 27. This is the case if the radiation sub-bundles, which coincide at the edge 32, have for instance differently curved edges. In this case, the illumination optics needs to be adjusted by tilting in particular the pupil facets 11 in such a way as to minimize the impact of the field intensity setting device
20   24 on the illumination angles.

This will hereinafter be explained by means of Figs. 11 to 22. Figs 11 to 16 show illumination parameters in the object field 19 in the event of a non-optimized superposition of the radiation sub-bundles which is generated by
25   the illumination optics 26, while Figs. 17 to 22 show the same illumination parameters in the event of a correspondingly optimized superposition of the radiation sub-bundles.

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The optical illumination parameters which are discussed below are telecentricity values tx, ty, which are variations of an initial value with an ineffective field intensity setting device ($I_{rel} = 1$), as well as corresponding variations ΔE of ellipticity values as well as the maximum values max(Δt),

5   max(ΔE) thereof occurring on the object field 19.

tx and ty are defined as follows:

In each field point of the illumination object field 19 is defined a centroid beam of a light bundle which is assigned to this field point. The centroid

10   beam has the energy-weighted direction of the light bundle which is emitted by this field point. In the ideal case, the centroid beam of each field point is parallel to the principal beam defined by the illumination optics 26 or the projection optics 20.

15   The direction of the centroid beam $\vec{s}_0$ (x, y) is known due to the design data of the illumination optics 26 or the projection optics 20. The principal beam at a field point is defined by the connection line between the field point and the center of the entrance pupil of the projection optics 20. The direction of the centroid beam at a field point x, y in the object field 19 is

20   obtained as follows:

$$\vec{s}(x,y) = \frac{1}{\widetilde{E}(x,y)} \int du\, dv \begin{pmatrix} u \\ v \end{pmatrix} E(u,v,x,y)$$

25   E(u, v, x, y) is the energy distribution for the field point x, y as a function of the pupil coordinates u, v, in other words as a function of the illumination angle seen by the respective field point x, y.

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$\widetilde{E}(x, y) = \int du dv E(u, v, x, y)$ is the total energy to which the point x, y is exposed.

For instance, a central object field point x_0, y_0 sees the radiation of partial radiation sub-bundles from directions u, v which are defined by the position of the respective pupil facets 11. At this illumination setting, the centroid beam s extends along the principal beam only if the different energies or intensities, respectively, of the partial radiation sub-bundles, which are assigned to the pupil facets 11, combine to form a centroid beam direction which is integrated over all pupil facets 11 and which is parallel to the principal beam direction. This can be achieved only at ideal circumstances. In practice, there is a deviation between the centroid beam direction $\vec{s}$ (x, y) and the principal beam direction $\vec{s}_0$ (x, y) which is referred to as telecentricity error $\vec{t}(x, y)$:

$$\vec{t}(x, y) = \vec{s}(x, y) - \vec{s}_0(x, y)$$

In the practical use of the projection exposure apparatus 1, it is not the static telecentricity error at a particular object field that must be corrected but the scan-integrated telecentricity error at $x = x_0$. This telecentricity error is obtained as follows:

$$\vec{T}(x_0) = \frac{\int dy \widetilde{E}(x_0, y) \vec{t}(x_0, y)}{\int dy \widetilde{E}(x_0, y)}$$

As a result, the telecentricity error is corrected which is integrated by a point (x, e.g. x_0) on a reticle 18 moving through the object field in the reti-

- 24 -

cle plane 17 during a scanning process, wherein a difference is made between an x-telecentricity error (Tx) and a y-telecentricity error (Ty). The y-telecentricity error is defined as deviation of the centroid beam from the principal beam perpendicular to the scanning direction. The x-telecentricity

5   error is defined as the deviation of the centroid beam from the principal beam in the scanning direction.

The ellipticity is another parameter for determining the quality of illumination of the object field 19 in the reticle plane 17. The determination of the

10   ellipticity helps to obtain more precise information with regard to the distribution of energy or intensity, respectively, across the entrance pupil of the projection optics 20. To this end, the entrance pupil is divided into eight octants which are numbered in an anticlockwise direction from O_1 to O_8, as it is common practice in mathematics. The contribution of energy or in-

15   tensity, respectively, delivered by the octants O_1 to O_8 of the entrance pupil for illuminating a field point is hereinafter referred to as energy or intensity contribution, respectively, I_1 to I_8.

The following quantity is referred to as –45°/45°-ellipticity (Elly, $E_{-45°/+45°}$,

20   E_{45}):

$$E_{-45/45} = \frac{I_1 + I_2 + I_5 + I_6}{I_3 + I_4 + I_7 + I_8}.$$

The following quantity is referred to as 0°/90°-ellipticity (Ellx, $E_{0°/90°}$, E_{90}):

25

$$E_{0/90} = \frac{I_1 + I_8 + I_4 + I_5}{I_2 + I_3 + I_6 + I_7}.$$

- 25 -

Likewise, the ellipticity for a particular object field point x_0, y_0 or even for

a scan-integrated illumination ($x = x_0$, y-integrated) may also be deter-

mined according to the above description regarding the telecentricity error.

Fig. 11 shows the deviation of an x-telecentricity from an initial value for

5   five different field heights as a function of the amount of intensity which is

allowed to pass through by the assigned individual diaphragm 27 at this

field height. At an attenuation of 15%, in other words at a transmission rate

of 0.85, there are telecentricity deviations Δtx in particular at the field edge

of approximately +/- 0.75 mrad (cf. Fig. 11) and of Δty of approximately -

10   2.4 mrad (cf. Fig. 14). Depending on the field height, an ellipticity varia-

tion $\Delta E90$ at a transmission rate of 0.85 varies between 2.5% and -1%

compared to a non-attenuated value (cf. Fig. 12).

At a transmission rate of 0.85, the value $\Delta E45$ reaches a maximum value of

15   -2% or approximately 4.5%, respectively (cf. Fig. 15).

A maximum telecentricity variation reaches a value of 2.5% (cf. Fig. 13).

A maximum ellipticity variation max(ΔE) reaches values in the range of

20   4.5% (cf. Fig. 16).

Figs. 17 to 22 clearly show the impact of the optimized superposition on

the radiation sub-bundles in the region of the edge 32 in the field plane 16.

A maximum telecentricity variation rate of 0.5 is not exceeded at any field

25   height (cf. Fig. 19). Likewise, a maximum ellipticity variation rate of 2% is

not exceeded at any field height either (cf. Fig. 22). These maximum varia-

tions apply for an attenuation up to a transmission rate of 0.85. If the at-

tenuation reaches a transmission rate of 0.9, the telecentricity variation

does not exceed a value of 0.4 mrad and the ellipticity variation does not
exceed a value of 1%.

5   In an alternative embodiment of coinciding radiation sub-bundles in the
field plane 16, the edge 32 facing the individual diaphragms 27 of the field
intensity setting device 24 is not illuminated by all field facets 7 but by a
subgroup of the field facets 7. This subgroup of the field facets 7 is selected
in such a way that the field facets 7 of the subgroup represent all illumina-
tion angles, which are achieved at a given illumination by means of the

10   illumination optics 26, in a preferably equally distributed manner. The sub-
group of field facets 7 may for instance be formed by in each case one field
facet 7 from the field facet group 8. The subgroup may in each case include
the central field facet mirror 6 or one of the two central field facet mirrors 6
of the respective field facet group 8. By way of example, field facets 7

15   serving as the selected field facets 8a in the field facet mirror 6 according
to Fig. 6 are indicated by means of hatched lines The respective field facet,
which is selected for the subgroup, may for instance be slightly wider in
the y-direction than the remaining field facets 7 of the field facet group 8.
For example, the subgroup field facet may be a field facet 7 according to

20   Fig. 8 and the other field facets 7 of the field facet group 8 may be field
facets 7 according to Fig. 9. A subgroup selection may also be achieved by
an individual guidance of radiation sub-bundles for the channels which are
formed by the field facets 7 of the field facet subgroup; to this end, the pu-
pil facets 11 are tilted correspondingly. A region between the edge 32 and a

25   boundary 36 within the bundle 3 of useful radiation is only illuminated by
the field facets 7 of the field facet subgroup (cf. Fig 10). Seen from the
edge 32, the radiation sub-bundles of all other channels are disposed be-
yond the boundary 36. The field facets 7 of the subgroup are selected in
such a way as to ensure that the radiation sub-bundles thereof coincide in

- 27 -

the best possible way in the field plane 16 near the edge 32. The individual diaphragms 27 only have an impact on the intensities of the radiation sub-bundles which are associated with these field facets 7 of the subgroup. As the channels, which are associated with these field facets 7 of the subgroup,

5   are equally distributed across the pupil facet mirror 10, this alternative embodiment of the coinciding radiation sub-bundles in the field plane 16 also guarantees an illumination-angle-independent effect of the field intensity setting device 24.

10   The individual diaphragms 27 may at least in some portions be semi-permeable and/or transparent, thus allowing for a selective setting. Adjacent individual diaphragms 27 may partially overlap with each other in the x-direction. In particular in this case, it is advantageous for the individual diaphragms 27 to have a variable transmission across their extension.

15

Transmission distributions which are applicable for the individual diaphragms 27 are for example described in WO 2005/040927 A2.

Instead of finger diaphragms, other embodiments of field intensity setting

20   devices acting in a plane are applicable as well. Examples thereof are described in EP 1 291 721 A1.

The individual diaphragms 27 may have a structured end side, as it is for example explained in US 2006/0244941 A1, in particular in Figs. 10 to 12.

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Claims

1. Illumination optics (26) for microlithography comprising

    -   an optical assembly (26a) for guiding illumination light to an object field (19) to be illuminated in an object plane (17);

    -   wherein the illumination optics (26) divides an illumination light radiation bundle (3) into a plurality of radiation sub-bundles (28 to 30) which are assigned to different illumination angles of the object field illumination;

    wherein the illumination optics (26) is configured in such a way that at least some of the radiation sub-bundles (28 to 30) are superimposed in a superposition plane (16), which is spaced from the object plane (17) and which is not imaged into the object plane (17) in which superposition takes place, in such a way that edges (32) of the superimposed radiation sub-bundles (28 to 30) coincide at least partially.

2. Illumination optics (26) for microlithography comprising

    -   an optical assembly (26a) for guiding illumination light to an object field (19) to be illuminated in an object plane (17);

    -   wherein the illumination optics (26) comprises a field facet mirror (6) with a plurality of field facets (7) which are imaged into a superposition plane (16) in such a way that edges (32) of the images of the field facets (7) coincide at least partially in the superposition plane (16);

    and wherein the superposition plane (16) is spaced from the object plane (17) and is not imaged into the object plane (17).

3. Illumination optics according to claim 1 or 2, **characterized by** a field intensity setting device (24) which is arranged in the superposition

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plane (16) then serving as an intensity setting plane, wherein the field intensity setting device (24) serves for the adjustment of an intensity distribution of the illumination light across the object field (19), wherein the edges (32) of the superimposed radiation sub-bundles (28 to 30) coincide at the point where they are influencable by the field intensity setting device (24).

4. Illumination optics (26) according to claim 3, **characterized in that** the intensity setting device (24) comprises a plurality of individual diaphragms (27) which are arranged next to one another and at least attenuate illumination light when exposed thereto and are insertable into an illumination light radiation bundle (3) in a direction parallel to an object displacement direction (y).

5. Illumination optics (26) for microlithography comprising
    - an optical assembly (26a) for guiding illumination light to an object field (19) to be illuminated in an object plane (17);
    - a field intensity setting device (24) for adjusting an intensity distribution across the object field (19) with a plurality of individual diaphragms (27) which are arranged next to one another and at least attenuate illumination light when exposed thereto and are insertable into an illumination light radiation bundle (3) in a direction parallel to an object displacement direction (y);
    wherein all individual diaphragms (27) of the field intensity setting device (24) are insertable into the illumination light radiation bundle (3) from one and the same side.

6. Illumination optics according to one of claims 3 to 5, **characterized in that** the field intensity setting device (24) is arranged in an intensity

- 30 -

setting plane (16) which coincides with a field plane of the optical as-
sembly (26a).

7. Illumination optics according to claim 6, **characterized in that** the
   object plane (17) is adjacent to the intensity setting plane (16) in such a
   way that there is no pupil plane of the optical assembly (26a) between
   the intensity setting plane (16) and the object plane (17).

8. Illumination optics according to claim 7, **characterized in that** a dis-
   tance between the intensity setting plane (16) and the object plane (17)
   is in the range of between 5 mm and 20 mm.

9. Illumination optics according to one of claims 1 to 8, **characterized in
   that** the optical assembly (26a) comprises a field facet mirror (6) with
   a plurality of field facets (7) whose images are at least partially super-
   imposed in the object field (19).

10. Illumination optics according to claim 9, **characterized in that** the
    field facets (7) have a higher aspect ratio (x/y) than the object field
    (19), which means that proportionally speaking, they are narrower than
    the object field (19) when seen in the object displacement direction (y).

11. Illumination optics according to claim 9 or 10, **characterized in that**
    an edge (32) of the illumination light radiation bundle (3) facing the
    individual diaphragms (27) is illuminated in the field plane (16) by all
    field facets (7) of the field facet mirror (6).

12. Illumination optics according to claim 9 or 10, **characterized in that**
    an edge (32) of the illumination light radiation bundle (3) facing the

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individual diaphragms (27) is illuminated in the field plane (16) by a
subgroup of all field facets (7) of the field facet mirror (6).

13. Illumination optics according to claim 12, **characterized in that** a
5   given distribution of illumination angles is assigned to the field facets
       (7) of the subgroup.

14. Illumination optics according to one of claims 9 to 13, **characterized
    in that** the optical assembly (26a) comprises a pupil facet mirror (10)
10   with a plurality of pupil facets (11) which are assigned to the field fac-
       ets (7) in the light path of the illumination light.

15. Illumination optics according to claim 14, **characterized in that** the
    pupil facets (11) are tiltable for adjusting a superposition of the illumi-
15   nation light in the intensity setting plane (16).

16. Illumination optics according to one of claims 4 to 15, **characterized
    in that** the individual diaphragms (27) are, at least in some portions, at
    least partially transparent.
20

17. Illumination optics according to one of claims 1 to 16 for guiding illu-
    mination light with a wavelength of between 5 nm and 30 nm to the
    object field (19).

25 18. Illumination optics (26) for microlithography comprising
       -   an optical assembly (26a) for guiding illumination light with a
           wavelength of between 5 nm and 30 nm to an object field (19) to
           be illuminated in an object plane (17);

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- a field intensity setting device (24) for adjusting an intensity distribution of the illumination light across the object field (19);

- wherein the field intensity setting device (24) has such an effect on a cross-section, which is formed by the illumination light perpendicular to an illumination light radiation bundle (3), that an edge (33a) of the bundle cross-section opposite to the field intensity setting device (24) remains unchanged downstream of the field intensity setting device (24);

and wherein an effect of the field intensity setting device (24) is independent of an illumination angle on the object field (19).

19. Illumination system comprising an illumination optics according to one of claims 1 to 18 and a light source (2).

20. Illumination system according to claim 19, **characterized in that** the light source (2) is an EUV light source.

21. Projection exposure apparatus (1) comprising

- an illumination system according to claim 19 or 20,

- a projection objective (20) for imaging the object field (19) into an image plane (21).

22. Method of producing structured components comprising the following steps:

- providing a wafer (23) to at least part of which is applied a layer of a light-sensitive material;

- providing a reticle (18) which comprises structures to be imaged;

- providing a projection exposure apparatus (1) according to claim 21;

- 33 -

- projecting at least a part of the reticle (18) onto a region of the
  layer on the wafer (23) by means of the projection exposure appa-
  ratus (1).

5 23. Structured component which is produced according to a method ac-
  cording to claim 22.
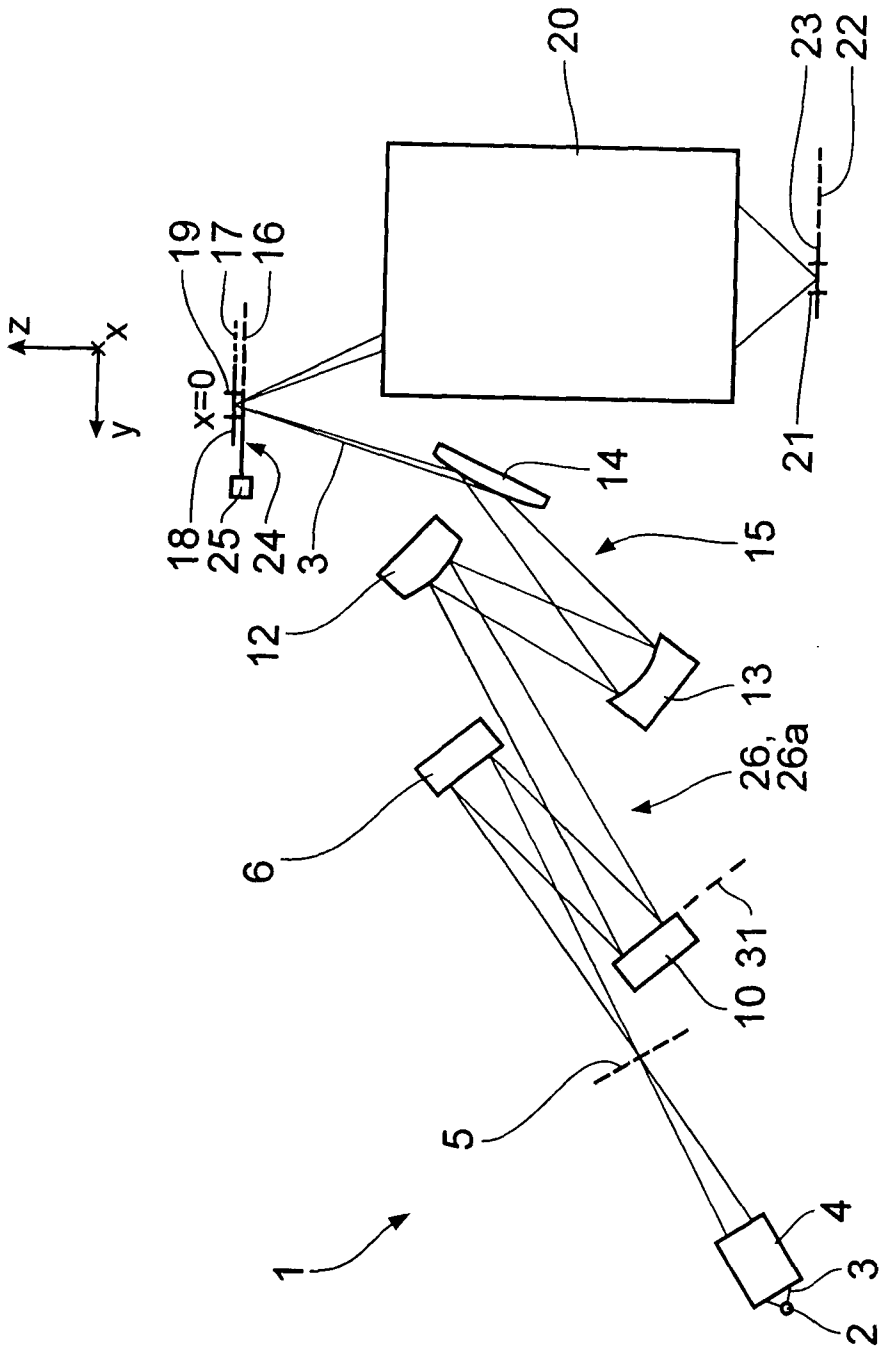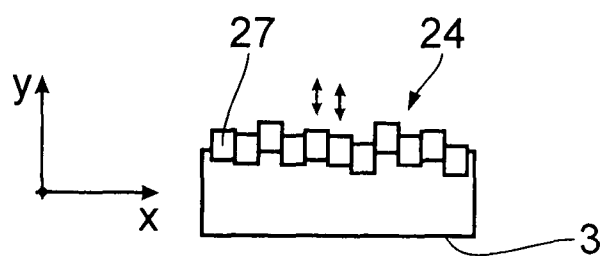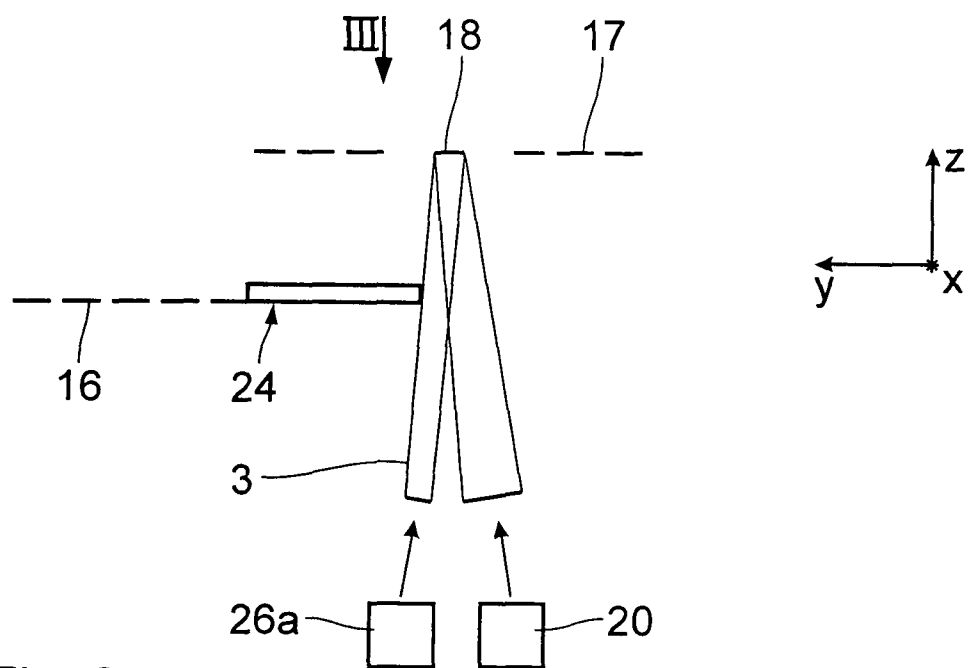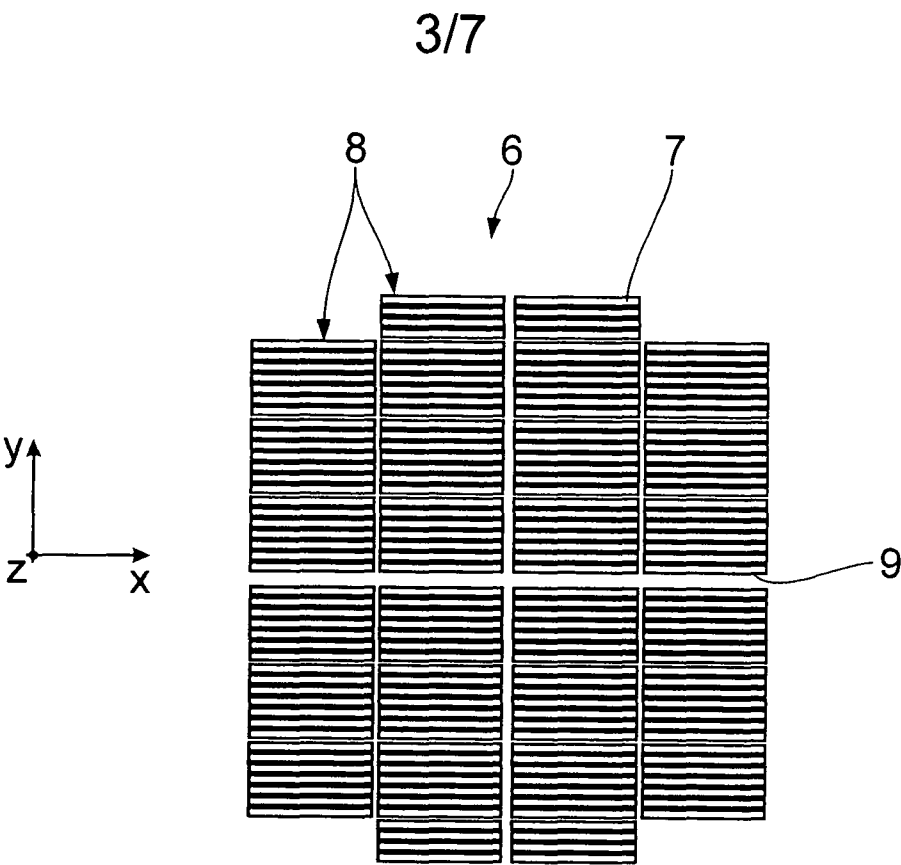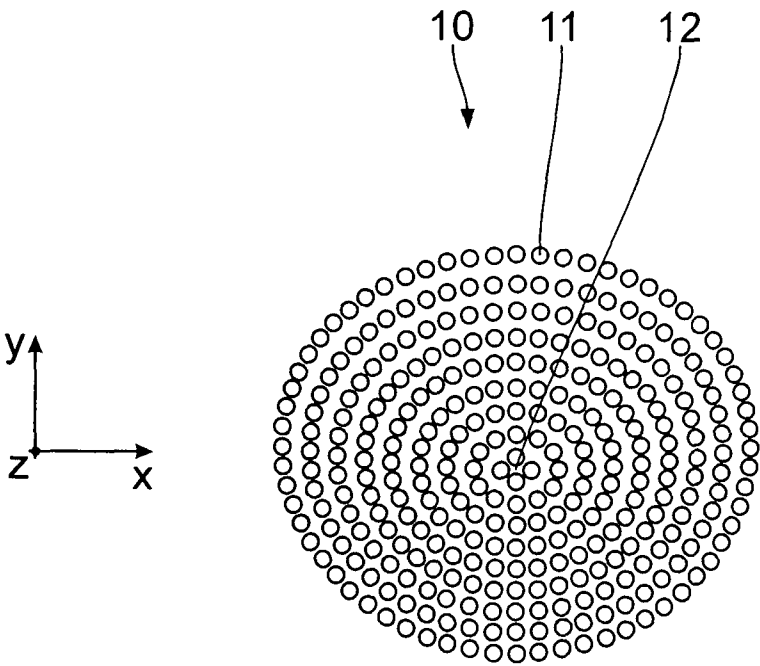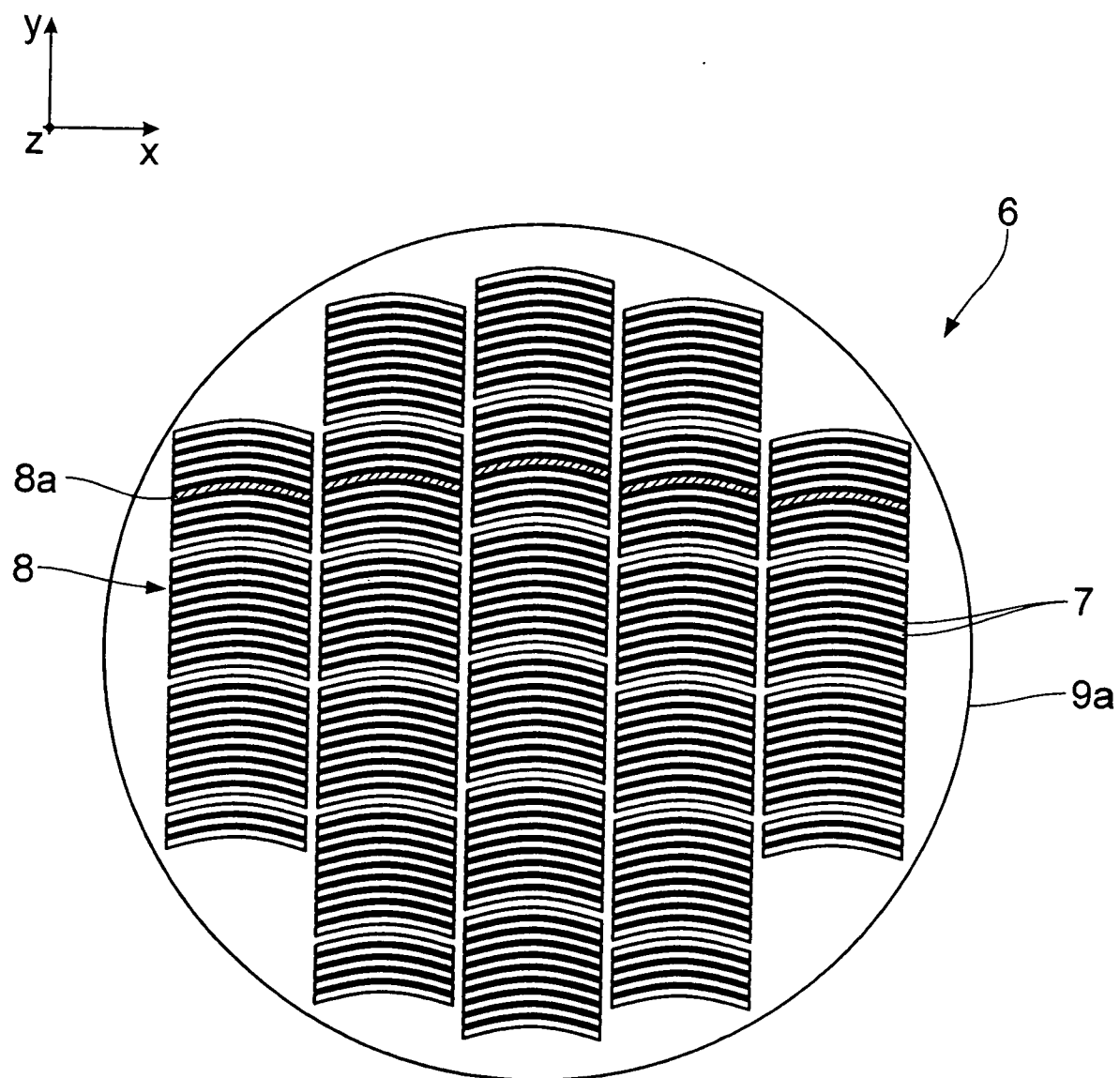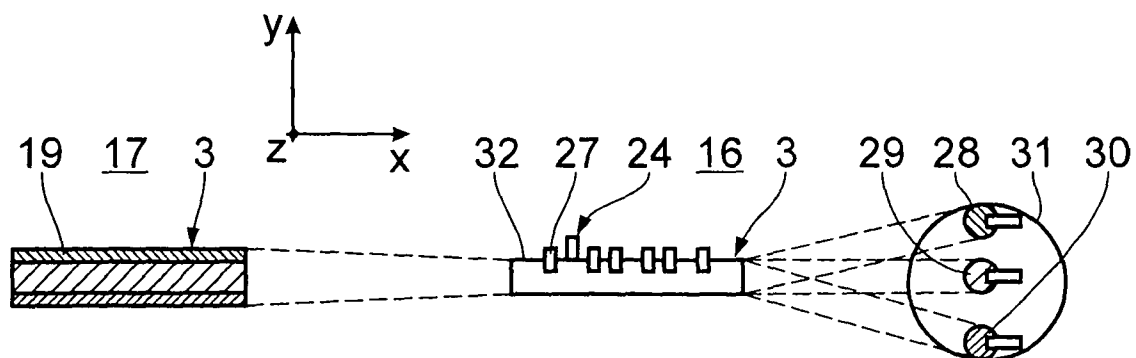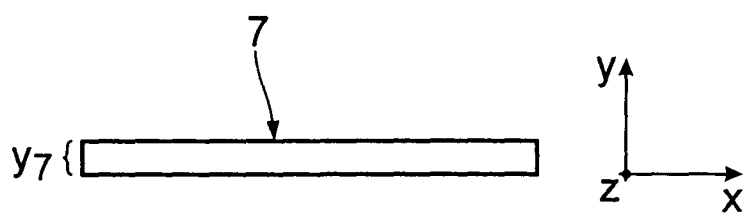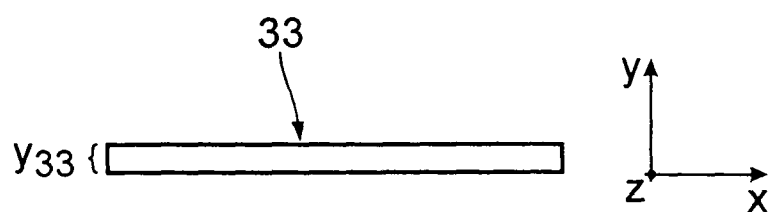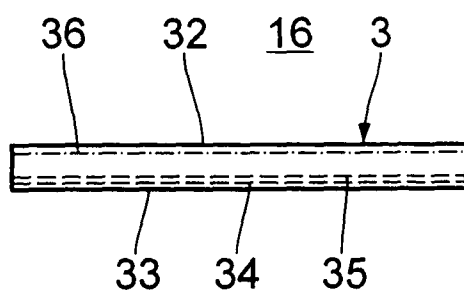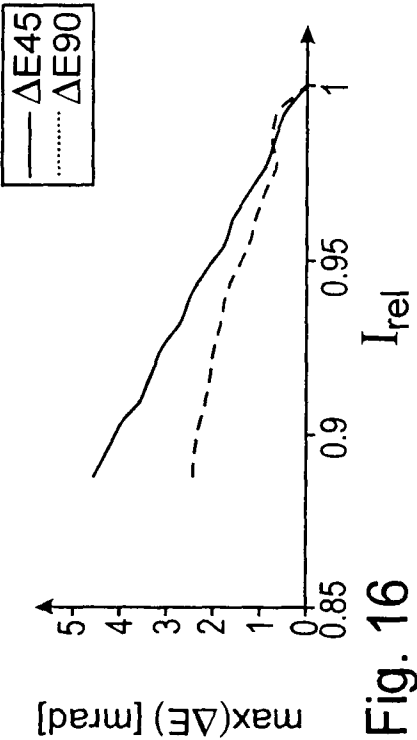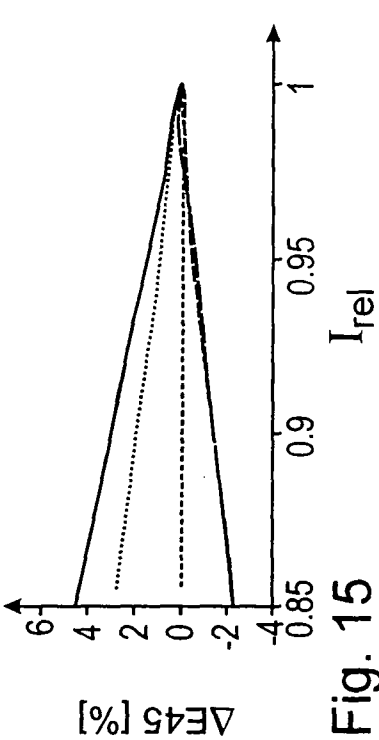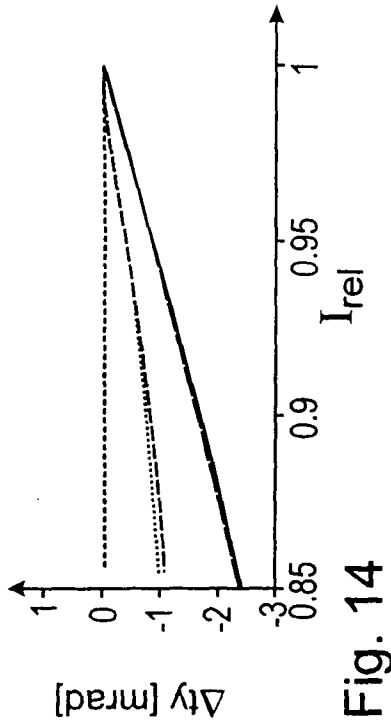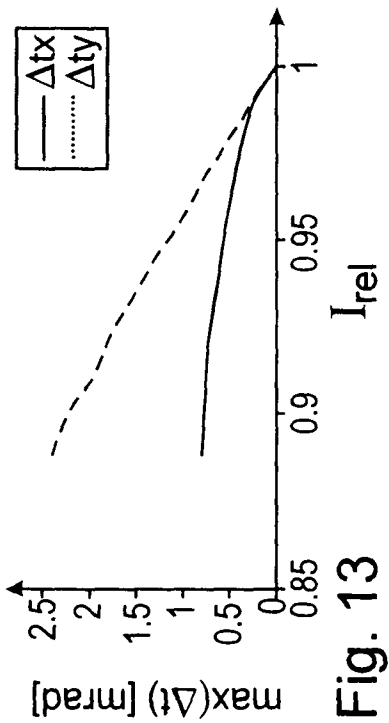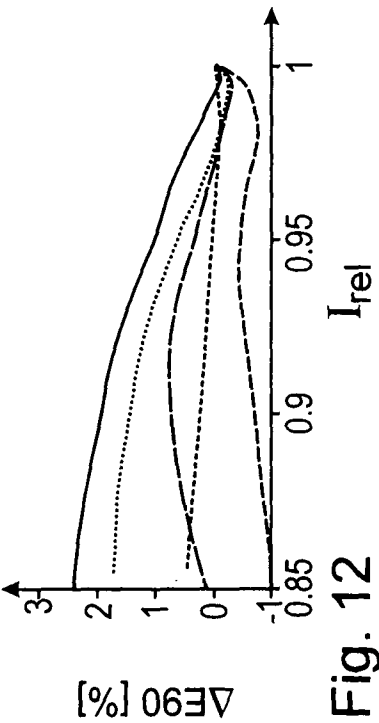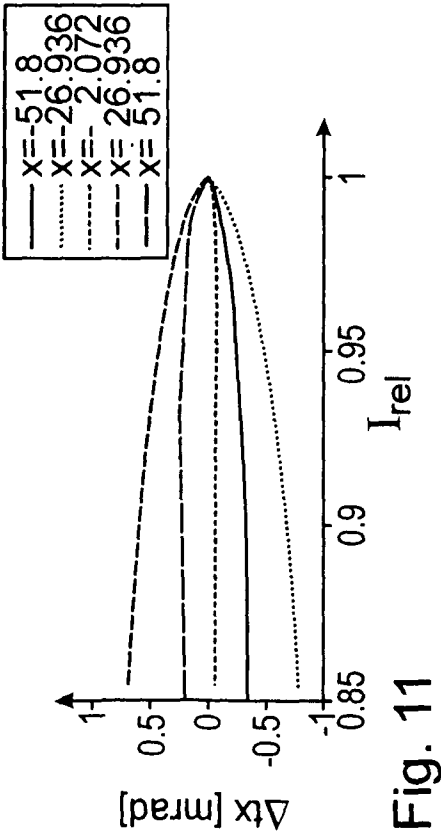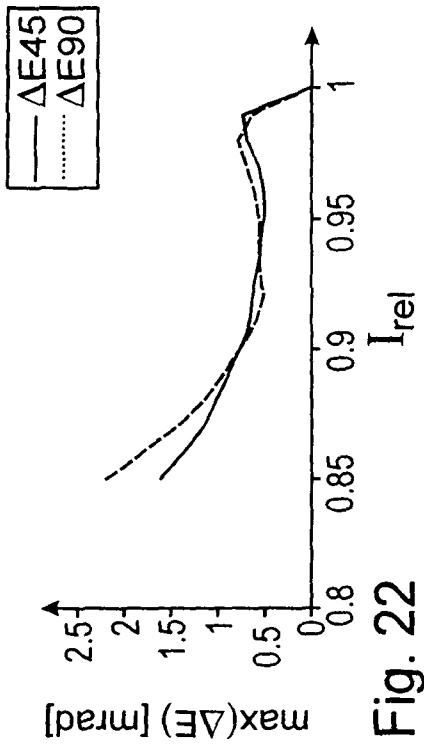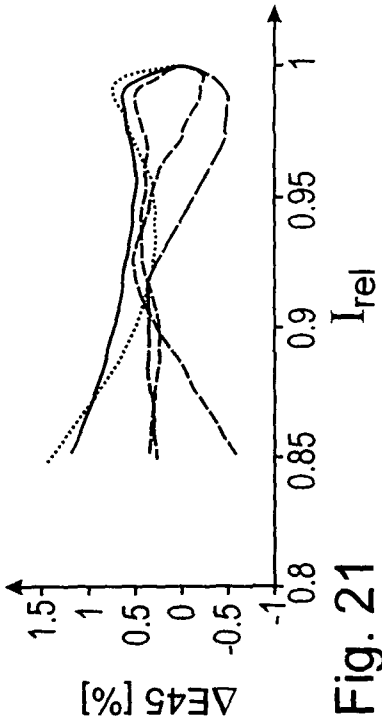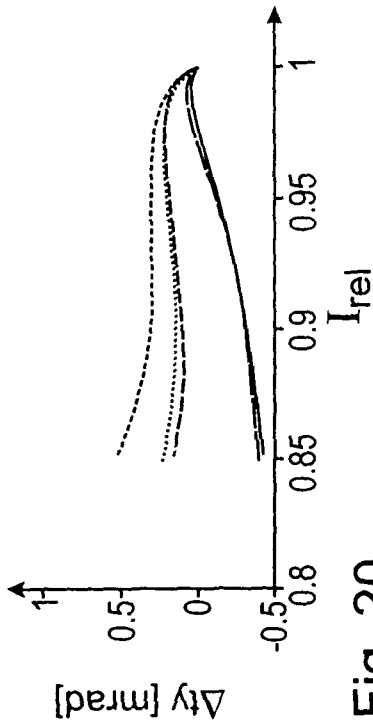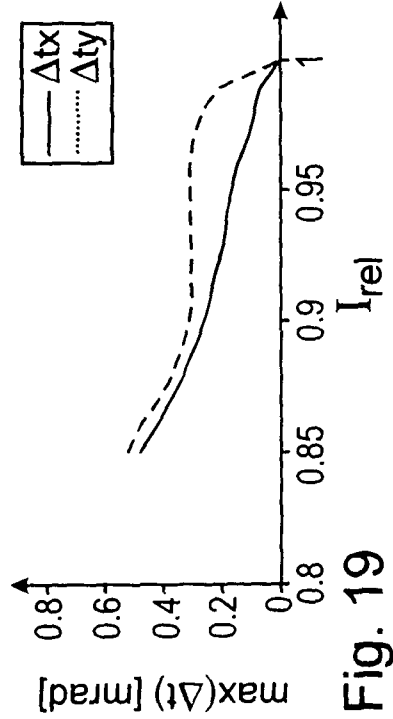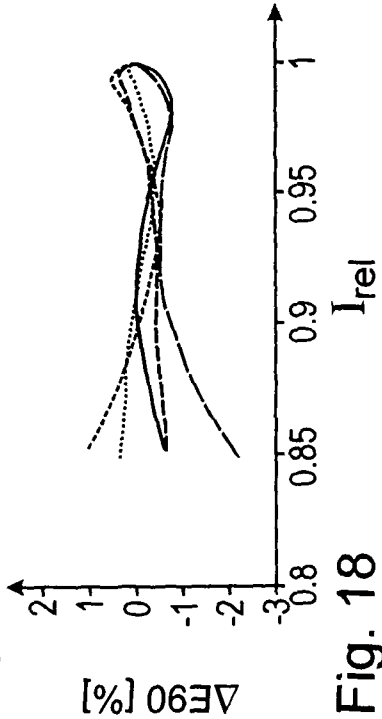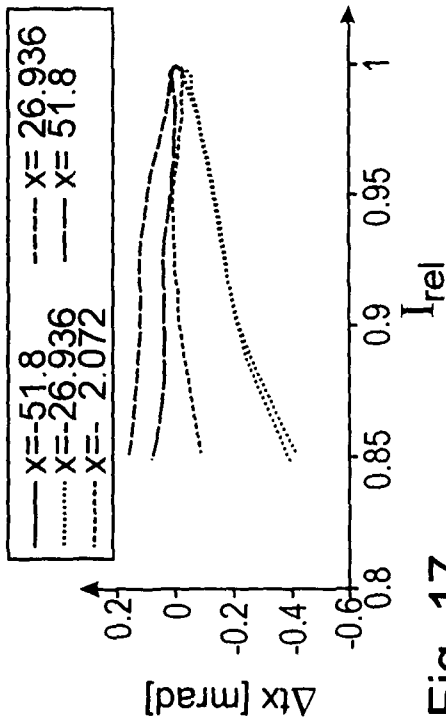
1/7

Fig. 1

2/7

III↓ 18   17

16   24

3

26a   20

Fig. 2

z
y   x

27   24

y

x

3

Fig. 3

3/7

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10

6/7

Fig. 14

Fig. 15

Fig. 16

Fig. 11

Fig. 12

Fig. 13

Fig. 17

Fig. 18

Fig. 19

Fig. 20

Fig. 21

Fig. 22

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/20

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   H01L   G02B

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

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

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	G. ZHANG ET AL: "Illumination Pupil Fill Measurement and Analysis and Its Application in Scanner V-H Bias Characterization for 130nm Node and Beyond" PROCEEDINGS OF SPIE, OPTICAL MICROLITHOGRAPHY XVI, vol. 5040, 2003, pages 45-56, XP002518791 page 46, second paragraph figure 2a	1,3,4, 10,19, 21-23
X	WO 03/093902 A (ZEISS CARL SMT AG [DE]; MELZER FRANK [DE]; SINGER WOLFGANG [DE]) 13 November 2003 (2003-11-13) figures 1,4 abstract page 7, line 33 – page 8, line 6	2,9,14, 15,20

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

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 March 2009	23/03/2009

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

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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