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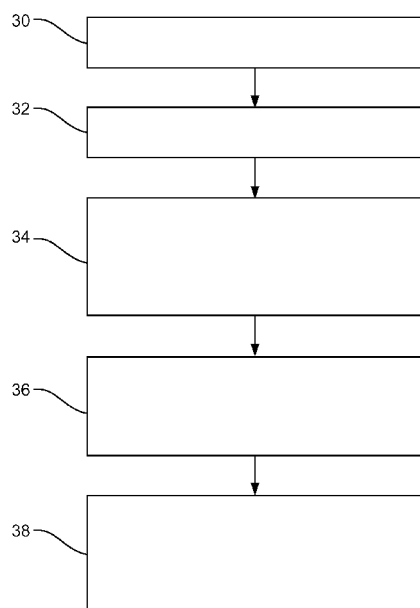


Fig. 4

(57) Abstract: A scanning exposure of a plurality of target regions on a substrate is performed such that an image of each of a plurality of markers is formed on each of the plurality of target regions. Each of the plurality of markers is of a form such that a property of the image of the marker is dependent on the contrast in a known manner. During the scanning exposure the substrate is moved in a scanning direction and at least one of: a difference between a rotation angle of the substrate and a rotation angle of a plane of best focus, about a first axis perpendicular to the scanning direction, a difference between a rotation angle of the substrate and a rotation angle of the plane of best focus about a second axis perpendicular to the first axis and perpendicular to the scanning direction, and a speed of the substrate in the scanning direction relative to the plane of best focus, is selected to be different for the scanning exposures of at least two of the plurality of target regions. Next the property of the image of each of the plurality of markers is determined.

Lithographic Apparatus and Method

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of EP application 16195245.2 which was filed on 2016-Oct-24 and which is incorporated herein in its entirety by reference.

FIELD

[0002] The present invention relates to methods for controlling the contrast of images formed by a lithographic apparatus. In particular, it relates to a method for determining at least one scanning path for a substrate within a scanning lithographic apparatus. The scanning path may be determined so as to optimise contrast of an image formed by the lithographic apparatus.

BACKGROUND

[0003] A lithographic apparatus is a machine that applies a desired pattern onto a target region of a substrate. Lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In that circumstance, a patterning device, which is alternatively referred to as a mask or a reticle, may be used to generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target region (e.g. comprising part of one or several dies) on a substrate (e.g. a silicon wafer) that has a layer of radiation-sensitive material (resist). In general, a single substrate will contain a network of adjacent target regions that are successively exposed. Known lithographic apparatus include so-called steppers, in which each target region is irradiated by exposing an entire pattern onto the target region in one go, and so-called scanners, in which each target region is irradiated by scanning the pattern through the beam in a given direction (the "scanning"-direction) while synchronously scanning the substrate parallel or anti parallel to this direction.

[0004] Ideally the pattern that is imaged on the target region of the substrate is in focus, i.e. a plane of best focus of a projection lens, i.e. a lens that projects the image onto the (target regions of the) substrate, is well aligned with target regions on the substrate. However, in practice, there will be some deviation from the ideal situation which may lead to imperfect images on the substrate, for example reduced contrast.

[0005] It is desirable to provide a lithographic apparatus that obviates or mitigates one or more of the problems of the prior art, whether identified herein or elsewhere.

SUMMARY

[0006] According to a first aspect of the invention, there is provided a method comprising: providing a substrate; providing a patterning device comprising a plurality of markers to impart a radiation beam with a pattern in its cross-section; projecting the radiation beam onto a target region of

a substrate via projection optics; performing scanning exposures, which have a plane of best focus, of a plurality of target regions on the substrate such that an image of each of the plurality of markers is formed on each of the plurality of target regions, wherein each of the plurality of markers is of a form such that a property of the image of the marker is dependent on the contrast in a known manner, and moving the substrate in a scanning direction during the scanning exposures, wherein , at least one of: a difference between a rotation angle of the substrate and a rotation angle of the plane of best focus about a first axis perpendicular to the scanning direction, a difference between a rotation angle of the substrate and a rotation angle of the plane of best focus about a second axis perpendicular to the first axis and perpendicular to the scanning direction, and a speed of the substrate in the scanning direction relative to the plane of best focus, is selected to be different for the scanning exposures of at least two of the plurality of target regions; and determining the property of the image of each of the plurality of markers within each of the plurality of target regions.

[0007] The method according to the first aspect of the invention is advantageous since it provides information relating to the contrast that can be achieved for a range of different substrate orientations and/or scan speeds relative to the plane of best focus for different parts of the field of view. For example the method may allow an optimal scanning orientation to be found for different parts of the field of view. During a scanning exposure of a substrate (for example a photoresist covered silicon wafer) within a scanning lithographic apparatus, the substrate is moved along a scanning direction through the path of a radiation beam focused by a projection lens. If the scanning direction is not well aligned with (i.e. generally parallel to) a plane of best focus of the projection lens for the scanning exposures of the target regions, e.g. if the plane of best focus moves with respect to the substrate during the scanning exposures, then the image formed by the lithographic apparatus on the substrate will lose contrast. The method of the first aspect allows an optimal substrate orientation during scanning to be found for a plurality of different parts of the field of view which can optimise contrast during exposure of substrates using, for example, a scanning lithographic apparatus.

[0008] The method of the first aspect additionally, or alternatively, allows an optimal optical correction parameter setting of projection optics used for the scanning exposures to be found for a plurality of different parts of the field of view which can optimise contrast during exposure of substrates using, for example, a scanning lithographic apparatus. For example, the property of the image of each of the plurality of markers within each of the plurality of target regions that is determined based on the different scanning orientations and/or speeds may be corrected for by a lens manipulator which is controlled by setting an associated optical correction parameter value.

[0009] The scanning direction may be generally linear and generally parallel to a surface of the substrate. A plane of the surface of the substrate may be referred to as the x-y plane. The scanning direction may be referred to as the y direction, i.e. along a y-axis, whereas the non-scanning direction may be referred to as the x direction, i.e. along an x-axis. The z-direction, or z-axis, is defined as a direction, or axis, perpendicular to the x-y plane.

[0010] The lithographic apparatus may comprise a frame and a substrate table for holding a substrate. The substrate table may be moveably mounted to the frame. The lithographic apparatus may further comprise a scanning mechanism operable to move the substrate table relative to the frame in the scanning direction. The different substrate orientations relative to the plane of best focus for the scanning exposures of the plurality of different target regions may be achieved by rotating the substrate table relative to the frame about the first and/or the second axis. The different substrate orientations relative to the plane of best focus may be characterised by a rotation angle about the non-scanning direction (i.e. the x direction and/or z-direction) of the substrate table relative to a nominal or reference position. These rotation angles may be referred to as R_x and R_z , with respect to the x- and z-axis, respectively.

[0011] Different substrate orientations relative to the plane of best focus for the scanning exposures of the plurality of target regions may also be achieved by rotating the plane of best focus about similar axes. This may be achieved, for example, by rotating a support structure that supports the patterning device about the first and/or second axis.

[0012] A different setting of a lens manipulator via setting an optical correction parameter value may for example comprise the setting of an asymmetric magnification to a specific value. An asymmetric magnification is a magnification having a first value in a direction along a first magnification axis and a second value, different from the first value, along a second magnification axis, different from the first magnification axis (e.g. perpendicular).

[0013] Prior art techniques have concentrated on optimising the best focus of lithographic machines in order to achieve good critical dimension uniformity (CDU). For example, one previous technique involves the use of static exposures of a substrate at a slight defocus. The static exposure may image a number, for example six, markers onto a static substrate at, for example, two different positions in the scanning direction (the y direction) and three different positions in the non-scanning direction (the x direction). An alignment parameter for each of the two of markers provides an indirect measurement of the difference in focal positions of the two markers. In turn, this is used to determine the rotation angle R_x from the reference position.

[0014] This prior art technique for determining the rotation angle R_x from the reference position has limited accuracy for a number of reasons. First, the prior art technique is sensitive to a range of other effects such as, for example, the telecentricity of the illumination of the markers, radiation dose, process and lens variation. Second, this prior art technique provides an indirect measurement using, for example, only the focus of 2 different y positions within the field of view. Third, it uses a static exposure and therefore does not take into account vibrations due the movement of the substrate table or contrast of the image.

[0015] It is a known problem in the field of lithography that isolated features and dense features are imaged differently. This can lead to size differences between the isolated features and the dense features, which is referred to as iso-dense bias. This can be corrected for to an extent using optical

proximity corrections, for example by using sub-resolution features adjacent to features to be imaged (also known as scattering bars). The inventor believes that loss of contrast within a scanning lithographic apparatus can result in differences in the images formed when using such optical proximity corrections. In turn, this can result in differences in the images formed using different lithographic apparatuses. It is therefore believed that optimising the contrast of images formed by scanning lithographic apparatuses using the method of the first aspect of the invention can reduce the sensitivity of images of reticles that use optical proximity corrections to the lithographic apparatus or system that they are imaged by.

[0016] Each of the plurality of markers may comprise at least one structure comprising a first portion across which the radiation beam may have a substantially constant intensity and a second portion across which the intensity of the radiation beam is patterned.

[0017] For example, the plurality of markers may comprise a plurality of said structures. It will be appreciated that here the second portions of the structures are of a higher resolution than the first portions. For example, the first portions comprise one or more first features and the second portions comprise one or more second features wherein the one or more second features have smaller sizes, e.g. widths in case the features are lines, than those of the one or more first features.

[0018] With such an arrangement, the property of the image of the marker that is dependent on the contrast in a known manner may comprise a position or displacement parameter. The position may be related to a position of a centre of mass of the structure and may be determined using an alignment or overlay detector that can resolve the image of the first portion of the structure (i.e. the or each individual first feature) but which cannot resolve the image of the second portion of the structure (i.e. the or each individual second features).

[0019] It will be appreciated that during the scanning exposure of a target region the patterning device imparts a pattern to a radiation beam and that this pattern comprises the plurality of markers. The first and second features may comprise a line, i.e. at least one elongate region of either lower or higher intensity relative to a surrounding region, or a square region, such as a hole. For example, the patterning device may comprise a binary transmissive mask or reticle and each line may correspond to a transparent portion of the reticle surrounded by opaque portions of the reticle. Alternatively, the patterning device may comprise a binary transmissive mask or reticle and each line may correspond to an opaque portion of the reticle surrounded by transparent portions of the reticle. It will be appreciated that this type of reticle is only an example of a patterning device. Other embodiments may use other types of patterning device such as, for example, reflective reticles and/or phase shift reticles.

[0020] The first and second features of the structures may comprise a line. For such embodiments, the structure may have an asymmetric profile. It will be appreciated that in this context the profile of a line is the shape of the intensity distribution of the patterned radiation beam in a direction perpendicular to an axis of the line. It will be further appreciated that an asymmetric profile is one which is asymmetric about a central axis of the line. The second portion may comprise a

plurality of smaller features, for example lines, having a smaller pitch than the pitch of the structure itself. Alternatively, the second portion may comprise another high resolution pattern. In general the second portion imparts a high resolution pattern to the intensity of the radiation beam. For example, rather than a plurality of lines, the second portion may comprise a plurality of holes, or square regions.

[0021] In general, for a marker which comprises first and second features with different dimensions, different parts of the marker will, in general, be affected differently by loss of contrast. In particular, the second portion of the, or each, structure will be more affected by the loss of contrast than the first portion because of the difference in size or dimension. Therefore a loss of contrast will cause the centre of mass of the structure to shift away from the second portion and towards the first portion. For embodiments wherein the, or each, structure comprises a first portion with first features and a second portion with second features wherein the first and second features have different dimensions, e.g. widths in case the features are lines, the structure comprises an asymmetric profile and, in general, the shape of the profile will be altered by loss of contrast during a scanning exposure because of the relative small dimension of the second features in the second portion of the structure with respect to that of the first features in the first portion of the structure. Since the structures and hence the markers have an asymmetric profile, in general, the shape of the profile will be altered by loss of contrast during a scanning exposure such that a position of the centre of mass of the profile is shifted. It will be appreciated that the property of the image of the marker that is dependent on the contrast in a known manner (which may, for example, be a position or displacement parameter) may be any parameter that can be determined from the image and which is dependent on the contrast of the image of the marker. In one embodiment, the displacement parameter is indicative of a position of the centre of mass of the profile of the, or each, structure.

[0022] Determining the property of the image of a marker within a target region may involve determining a displacement parameter for that image of the marker.

[0023] It will be appreciated that as used herein the term “position” refers to a position of an object (for example a structure within an image of a marker) and the “displacement parameter” refers to a shift in position of an object (for example a structure within an image of a marker). A displacement parameter may refer to an alignment parameter, which may be a position of an object (for example a structure within an image of a marker) relative to a known reference position. An alignment parameter may be determined using an alignment detector of the type that is often provided with lithographic apparatus. A displacement parameter may alternatively refer to an overlay parameter, which may be a measure of the difference in relative positions of two objects (for example two sets of structures as obtained in different exposures). An overlay parameter may be considered to be a special type of alignment parameter. An overlay parameter may be determined using an overlay detector of the type that is often provided separate from a lithographic apparatus. The displacement

parameter may be indicative of a position of the centre of mass of the image of one or more of the structures.

[0024] Each of the plurality of markers may comprise a first part comprising at least one structure and a second part comprising at least one structure, wherein the second part of the, or each, structure within the first part of the marker is disposed on one side of the first part of that structure and wherein the second part of the, or each, structure within the second part of the marker is disposed on an opposite side of the first part of that structure.

[0025] For example, the first and second parts of each marker may comprise a plurality of structures, for example five structures. Within the first part of the marker, the second portion of each structure is disposed on one side of the first portion of that structure (for example the second portion of each structure may be disposed on the left of the first portion of that structure). Within the second part of the marker, the second portion of each structure is disposed on an opposite side of the first portion of that structure (for example the second portion of each structure may be disposed on the right of the first portion of that structure). The structures of the marker may be considered to be asymmetric and the asymmetry of the structures in the first part of the marker may be considered to be in an opposite sense to the asymmetry of the structures in the second part of the marker.

[0026] As explained above, in general, loss of contrast during a scanning exposure will result in a shift in a position of the centre of mass of the structure, for example a shift in position of the profile of a structure with an asymmetric profile. Having two portions, wherein the first and second portions of each structure within the first part of the marker are arranged in an opposite order to the first and second portions of each structure within the second part of the marker, will result in the position of the centre of mass of structures in the two different parts of the marker moving in opposite directions (either towards each other or away from each other). For such embodiments, the displacement parameter may be a measure of this relative shift of the centre of mass of the structures in the first part of the marker relative to the centre of mass of structures in the second part of the marker. Advantageously, this may result in the method being less sensitive to position accuracies of the substrate.

[0027] The displacement parameter for the image of each of the plurality of markers within each of the plurality of different target regions may be proportional to a relative shift in a position of a centre of mass of the profile of one or more structures within the image of the first part of the marker relative to a position of a centre of mass of the profile of one or more structures within the image of the second part of the marker. That is, the displacement parameter may be an overlay parameter.

[0028] The method may further comprise determining at least one scanning orientation of the substrate and/or determining a value of an optical correction parameter of the scanning exposure for the substrate, for example within a scanning lithographic apparatus.

[0029] For example, the method may comprise determining a scanning orientation for the substrate within a scanning lithographic apparatus for each marker on the patterning device which

achieves a desired contrast of the image of that marker formed on the substrate. Additionally or alternatively, the method may comprise determining a value of an optical correction parameter of the scanning exposure in order to compensate for the contrast loss. This allows a scanning orientation of the substrate and/or setting of optical correction parameters of the scanning exposures to be found for different parts of an image in different parts of the field of view.

[0030] The method may comprise determining a scanning orientation of the substrate and/or optical correction parameter value within the scanning lithographic apparatus for each marker on the patterning device which substantially maximises the contrast of the image of that marker formed on the substrate.

[0031] The method may further comprise, for at least one of the plurality of markers, determining a relationship between: (a) the property of the image of the marker that is dependent on the contrast in a known manner; and (b) a parameter that characterises the scanning orientation of the substrate with respect to the plane of best focus and/or optical correction parameter of the scanning exposure, for example within a scanning lithographic apparatus.

[0032] The parameter that characterises the scanning orientation of the substrate with respect to the plane of best focus within the scanning lithographic apparatus may, for example, be the rotation angle R_x and/or R_z with respect to a reference position. The optical correction parameter of the scanning exposure may, for example, be used as a correction setting of a lens element of projection optics for the scanning exposure, such as a lens manipulator which is arranged to set a lens anamorphism such as an asymmetric magnification. Asymmetric magnification is a magnification having a first value in a direction along a first magnification axis and a second value, different from the first value, along a second magnification axis, different from the first magnification axis (e.g. perpendicular).

[0033] Determining a scanning orientation of the substrate and/or an optical correction parameter value of the scanning exposure that substantially maximises contrast of the image of that marker formed on the substrate may comprise: determining the scanning orientation of the substrate and/or optical correction parameter of the scanning exposure such that the property of the image of the marker that is dependent on the contrast in a known manner is maximised or minimised. For example, a curve is fitted to a graph of the property of the image of the marker that is dependent on the contrast in a known manner against the parameter that characterises the scanning orientation of the substrate and/or optical correction parameter value of the scanning exposure.

[0034] The method may comprise using a scanning mechanism to move the substrate relative to a frame in the scanning direction relative to the plane of best focus such that the patterned radiation beam moves over a surface of the substrate.

[0035] The scanning orientation and/or optical correction parameter value may be an average of the scanning orientations and/or optical correction parameter values, respectively, that substantially maximises contrast of the image of the plurality of markers formed on the substrate.

[0036] Alternatively, the scanning orientation and/or optical correction parameter value may change during movement of the substrate by the scanning mechanism. For example, the instantaneous scanning orientation and/or optical correction parameter value may be an average of the scanning orientations and/or optical correction parameter values that substantially maximise contrast of the image of a subset of the plurality of markers, the subset of markers being those markers which correspond to a part of the patterning device that is currently being imaged.

[0037] According to a second aspect of the invention there is provided a lithographic apparatus that is operable to implement the method of the second aspect of the invention.

[0038] According to a third aspect of the invention there is provided a computer program that is operable to implement the method of the first and/or second aspects of the invention.

[0039] Various aspects and features of the invention set out above or below may be combined with various other aspects and features of the invention as will be readily apparent to the skilled person.

BRIEF DESCRIPTION OF THE DRAWINGS

[0040] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

- Figure 1 depicts a lithographic apparatus according to an embodiment of the invention;
- Figures 2A-2D illustrate the position of a band of radiation projected onto a target region of a substrate by the lithographic apparatus of Figure 1 and the positions of two masking blades during a dynamic exposure process;
- Figure 3 illustrates an alternative path that may be followed by an exposure slit of a lithographic apparatus over a substrate;
- Figure 4 is a flowchart for a method for determining at least one scanning orientation for a substrate within a scanning lithographic apparatus according to an embodiment of the present invention;
- Figure 5 is a flowchart showing the sub-steps that may form part of a step of the method shown in Figure 4;
- Figure 6A is a schematic side view illustration of exposure of a substrate in a first orientation;
- Figure 6B is a schematic side view illustration of exposure of a substrate in a second orientation;
- Figure 7A is a schematic illustration of a structure which may form part of a marker for use in the method of Figure 4;
- Figure 7B shows the profile of the structure shown in Figure 7A;
- Figures 8A, 8B and 8C each show, schematically, the relative orientations of a substrate and a plane of best focus during exposure for three different relative orientations and the profile of the

intensity distribution of the image of the structure of Figures 7A and 7B formed in each relative orientation;

- Figure 9 is a schematic representation of a first type of marker using a plurality of structures of the form shown in Figures 7A and 7B;

5 - Figure 10 is a schematic representation of a second type of marker using a plurality of structures of the form shown in Figures 7A and 7B; and

- Figures 11A and 11B are graphs of an overlay parameter as a function of an orientation angle of a substrate relative to a plane of best focus for two different substrate tables.

10 DETAILED DESCRIPTION

[0041] Although specific reference may be made in this text to the use of lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications, such as the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, liquid-crystal displays (LCDs), thin film magnetic
15 heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms “wafer” or “die” herein may be considered as synonymous with the more general terms “substrate” or “target region”, respectively. The substrate referred to herein may be processed, before or after exposure, in for example a track (a tool that typically applies a layer of resist to a substrate and develops the exposed resist) or a metrology or inspection tool. Where applicable, the
20 disclosure herein may be applied to such and other substrate processing tools. Further, the substrate may be processed more than once, for example in order to create a multi-layer IC, so that the term substrate used herein may also refer to a substrate that already contains multiple processed layers.

[0042] The terms “radiation” and “beam” used herein encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (e.g. having a wavelength of 365, 248, 193, 157 or 126
25 nm) and extreme ultra-violet (EUV) radiation (e.g. having a wavelength in the range of 5-20 nm), as well as particle beams, such as ion beams or electron beams.

[0043] The term “patterning device” used herein should be broadly interpreted as referring to a device that can be used to impart a radiation beam with a pattern in its cross-section such as to create a pattern in a target region of the substrate. It should be noted that the pattern imparted to the radiation
30 beam may not exactly correspond to the desired pattern in the target region of the substrate. Generally, the pattern imparted to the radiation beam will correspond to a particular functional layer in a device being created in the target region, such as an integrated circuit.

[0044] A patterning device may be transmissive or reflective. Examples of patterning device include masks, programmable mirror arrays, and programmable LCD panels. Masks are well known
35 in lithography, and include mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. An example of a programmable mirror array employs a

matrix arrangement of small mirrors, each of which can be individually tilted so as to reflect an incoming radiation beam in different directions; in this manner, the reflected beam is patterned.

[0045] The support structure holds the patterning device. In particular, it holds the patterning device in a way depending on the orientation of the patterning device, the design of the lithographic apparatus, and other conditions, such as for example whether or not the patterning device is held in a vacuum environment. The support can use mechanical clamping, vacuum, or other clamping techniques, for example electrostatic clamping under vacuum conditions. The support structure may be a frame or a table, for example, which may be fixed or movable as required and which may ensure that the patterning device is at a desired position, for example with respect to the projection system. Any use of the terms “reticle” or “mask” herein may be considered synonymous with the more general term “patterning device”.

[0046] The term “projection system” used herein should be broadly interpreted as encompassing various types of projection system, including refractive optical systems, reflective optical systems, and catadioptric optical systems, as appropriate for example for the exposure radiation being used, or for other factors such as the use of an immersion fluid or the use of a vacuum. Any use of the term “projection lens” herein may be considered as synonymous with the more general term “projection system”.

[0047] The illumination system may also encompass various types of optical components, including refractive, reflective, and catadioptric optical components for directing, shaping, or controlling the beam of radiation, and such components may also be referred to below, collectively or singularly, as a “lens”.

[0048] The lithographic apparatus may be of a type having two (dual stage) or more substrate tables (and/or two or more support structures). In such “multiple stage” machines the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposure.

[0049] The lithographic apparatus may also be of a type wherein the substrate is immersed in a liquid having a relatively high refractive index, e.g. water, so as to fill a space between the final element of the projection system and the substrate. Immersion techniques are well known in the art for increasing the numerical aperture of projection systems.

[0050] Figure 1 schematically depicts a lithographic apparatus according to a particular embodiment of the invention. The apparatus comprises:

- an illumination system (illuminator) IL to condition a radiation beam PB (e.g. UV radiation or EUV radiation).
- a support structure (e.g. a mask table) MT to support a patterning device (e.g. a mask) MA and connected to first positioning device PM to accurately position the patterning device with respect to item PL;

- a substrate table (e.g. a wafer table) WT for holding a substrate (e.g. a resist coated wafer) W and connected to second positioning device PW for accurately positioning the substrate with respect to item PL; and
- a projection system (e.g. a refractive projection lens) PL configured to image a pattern imparted to the radiation beam PB by patterning device MA onto a target region C (e.g. comprising one or more dies) of the substrate W.

[0051] As here depicted, the apparatus is of a transmissive type (e.g. employing a transmissive mask). Alternatively, the apparatus may be of a reflective type, e.g. employing a programmable mirror array of a type as referred to above or a reflective reticle.

[0052] The illuminator IL receives a beam of radiation from a radiation source SO. The source SO and the lithographic apparatus may be separate entities, for example when the source is an excimer laser. In such cases, the source is not considered to form part of the lithographic apparatus and the radiation beam is passed from the source SO to the illuminator IL with the aid of a beam delivery system BD comprising for example suitable directing mirrors and/or a beam expander. In other cases the source SO may be integral part of the apparatus, for example when the source is a mercury lamp. The source SO and the illuminator IL, together with the beam delivery system BD if required, may be referred to as a radiation system.

[0053] The illuminator IL may comprise adjusting means AM for adjusting the angular intensity distribution of the beam. Generally, at least the outer and/or inner radial extent (commonly referred to as σ -outer and σ -inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the illuminator IL generally comprises various other components, such as an integrator IN and a condenser CO. The illuminator IL provides a conditioned beam of radiation PB, having a desired uniformity and intensity distribution in its cross section.

[0054] The radiation beam PB is incident on the patterning device (e.g. mask) MA, which is held on the support structure MT. Having traversed the patterning device MA, the beam PB passes through the lens PL, which focuses the beam onto a target region C of the substrate W. With the aid of the second positioning device PW and position sensor IF (e.g. an interferometric device), the substrate table WT can be moved accurately, e.g. so as to position different target regions C in the path of the beam PB. Similarly, the first positioning device PM and another position sensor (which is not explicitly depicted in Figure 1) can be used to accurately position the patterning device MA with respect to the path of the beam PB, e.g. after mechanical retrieval from a mask library, or during a scan. In general, movement of the object tables MT and WT will be realized with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning), which form part of the positioning device PM and PW. Patterning device MA and substrate W may be aligned using patterning device alignment marks M1, M2 and substrate alignment marks P1, P2.

[0055] The projection system PL may apply a reduction factor to the radiation beam PB, forming an image with features that are smaller than corresponding features on the patterning device MA. For example, a reduction factor of 4 may be applied.

[0056] The depicted apparatus can be used in a scan mode, wherein the support structure MT and the substrate table WT are scanned synchronously while a pattern imparted to the beam PB is projected onto a target region C (i.e. a single dynamic exposure).

[0057] The shape and intensity distribution of the conditioned beam of radiation PB are defined by optics of the illuminator IL. In a scan mode, the conditioned radiation beam PB may be generally rectangular in cross section such that it forms a band of radiation on the patterning device MA. The band of radiation may be referred to as an exposure slit (or slit). The slit may have a longer dimension (which may be referred to as its length) and a shorter dimension (which may be referred to as its width). The width of the slit may correspond to a scanning direction and the length of the slit may correspond to a non-scanning direction. In scan mode, the length of the slit limits the extent in the non-scanning direction of the target region C that can be exposed during in a single dynamic exposure. In contrast, the extent in the scanning direction of the target region C that can be exposed during in a single dynamic exposure is determined by the length of the scanning motion.

[0058] The illuminator IL may comprise a plurality of movable fingers. Each movable finger may be independently movable between at least a retracted position wherein it is not disposed in the path of the radiation beam and an inserted position wherein it partially blocks the radiation beam. By moving the fingers, the shape and/or the intensity distribution of the slit can be adjusted. The fingers may not be in a field plane and the field may be in the penumbra of the fingers such that the fingers do not sharply cut off the radiation beam PB. Movement of the fingers between their retracted and inserted positions may be in a direction perpendicular to the length of the slit. The fingers may be arranged in pairs, each pair comprising one finger on each side of the slit. The pairs of fingers may be arranged along the length of the slit. The pairs of fingers may be used to apply a different level of attenuation of the radiation beam PB along the length of the slit.

[0059] The illuminator IL may comprise two blades (not shown). Each of the two blades may be generally parallel to the length of the slit, the two blades being disposed on opposite sides of the slit. Each blade may be independently movable between a retracted position wherein it is not disposed in the path of the radiation beam and an inserted position wherein it partially blocks the radiation beam. By moving the blades into the path of the radiation beam, the profile of the radiation beam PB can be truncated thus limiting the extent of the field of radiation beam PB in a scanning direction.

[0060] In the scan mode, the first positioning device PM is operable to move the support structure MT relative to the beam of radiation PB that has been conditioned by the illuminator IL along a scanning path. In an embodiment, the support structure MT is moved linearly in a scanning direction at a constant scan speed v_M . As described above, the slit is orientated such that its width extends in the scanning direction (which may, for example, coincide with the y-direction of Figure 1).

At any instance each point on the patterning device MA that is illuminated by the slit will be imaged by the projection system PL onto a single conjugate point in the plane of the substrate W. As the support structure MT moves in the scanning direction, the pattern on the patterning device MA moves across the width of the slit with the same velocity as the support structure MT. In particular, each point on the patterning device MA moves across the width of the slit in the scanning direction at speed v_M . As a result of the motion of this support structure MT, the conjugate point in the plane of the substrate W corresponding to each point on the patterning device MA will move relative to the slit in the plane of the substrate table WT.

[0061] In order to form an image of the patterning device MA on the substrate W, the substrate table WT is moved such that the conjugate point in the plane of the substrate W of each point on the patterning device MA remains stationary with respect to the substrate W. The velocity (both magnitude and direction) of the substrate table WT relative to the projection system PL is determined by the demagnification and image reversal characteristics of the projection system PL (in the scanning direction). In particular, if the characteristics of the projection system PL are such that the image of the patterning device MA that is formed in the plane of the substrate W is inverted in the scanning direction then the substrate table WT should be moved in the opposite direction to the support structure MT. That is, the motion of the substrate table WT should be anti-parallel to the motion of the support structure MT. Further, if the projection system PL applies a reduction factor F to the radiation beam PB then the distance travelled by each conjugate point in a given time period will be less than that travelled by the corresponding point on the patterning device by a factor of F. Therefore the speed v_S of the substrate table WT should be v_M/F .

[0062] The best image of the patterning device MA is formed by using the substrate table WT to control both the orientation and the speed of the substrate W in three dimensions (x, y and z). The orientation of the substrate W in three dimensions (x, y and z) may be characterised by a rotation angle R_x , R_y , R_z about the three directions x, y, z of the substrate table WT relative to a nominal or reference position. The speed of the substrate W in three dimensions may be characterised by a speed v_x , v_y , v_z in each of the three directions x, y, z.

[0063] As discussed above, at first order the substrate table WT may be considered to move at a speed v_S in the scanning direction (y direction). However, the speed v_S of the substrate table WT in the scanning direction may be dynamically altered during the scanning exposure such that there are higher order corrections to the average of the speed v_S of the substrate table WT in the scanning direction. Furthermore, the substrate table WT is, in general, also moved to a lesser extent in the x and z directions. For example, the substrate W may be moved in the z direction in a manner which is dependent on a previously determined topology of the substrate W being exposed, so as to keep the substrate W in best focus during the scanning exposure. Errors in the speed in the x and y directions can lead to distortion of features in the image formed on the substrate W whereas errors in the speed in the z direction can lead to a loss of focus.

[0064] The illuminator IL illuminates an exposure region of the patterning device MA with radiation beam PB and the projection system PL focuses the radiation at an exposure region in a plane of the substrate W. The masking blades of the illuminator IL can be used to control the width of the slit of radiation beam PB, which in turn limits the extent of the exposure regions in the planes of the patterning device MA and the substrate W respectively. That is the masking blades of the illuminator serve as a field stop for the lithographic apparatus. As example of how the masking blades are used is now described with reference to Figure 2.

[0065] Figure 2 illustrates the positions of two masking blades B1, B2 at different stages during the exposure of a target region C of a substrate W. Target region C may, for example, be any one of the target regions C illustrated in Figure 1.

[0066] As shown in Figure 2A, at the start of a single dynamic exposure of the target region C, the exposure region 10 in the plane of the substrate W (i.e. the portion of the substrate that the slit is projected onto by projection system PL) is adjacent to the target region C. The extent of the exposure region 10 in the non-scanning direction (x-direction) is substantially the same as that of the target region C and the exposure region 10 is aligned with the target region C in the non-scanning direction (x-direction). The extent of the exposure region 10 in the scanning direction (y-direction) may be different from that of the target region C. In the scanning direction (y-direction) the exposure region 10 is adjacent to the target region C such that the exposure region 10 neither overlaps nor is spaced apart from the target region C (i.e. a leading edge 12 of the exposure region 10 substantially coincides with an edge of the target region C).

[0067] In Figures 2A-D, projections of the two masking blades B1, B2 onto the plane of the substrate W are shown as dashed lines. At the start of the dynamic exposure of target region C (with the target region C disposed as shown in Figure 2A) a first one of the masking blades B1 of the slit is disposed in the path of the radiation beam, acting as a shutter, such that no part of the substrate W receives radiation. This ensures that an adjacent target region is not exposed to radiation.

[0068] As a leading edge 14 of the target region C of the substrate W that is being exposed moves into the exposure region 10, the first masking blade B1 moves such that only the target region C receives radiation (i.e. no parts of the substrate outside of the target region C are exposed). That is, the masking blade B1 is disposed such that only the overlap between the exposure region 10 and the target region C receives radiation, as shown in Figure 2B. The transition from the arrangement shown in Figure 2A (at the start of the exposure) to the arrangement shown in Figure 2B is achieved by both the target region C of the substrate W and the first masking blade B1 moving relative to the exposure region 10 (in the left hand direction as shown in Figures 2A-D) while the second masking blade B2 remains stationary.

[0069] As shown in Figure 2C, midway through the exposure of the target region C both masking blades B1, B2 are retracted out of the path of the radiation beam such that the entire exposure region 10 receives radiation. As the target region C of the substrate W moves out of the exposure

region (i.e. a trailing edge 16 of the target region C passes the leading edge 12 of the exposure region 10), a second one of the masking blades B2 moves such that only the portion of the target region C that is disposed in the exposure region 10 receives radiation. This is illustrated in Figure 2D.

[0070] The exposure region of the patterning device MA and the exposure region in a plane of the substrate W may be defined by the slit of radiation when the masking blades of the illuminator are not disposed in the path of the radiation beam PB.

[0071] Using the scan mode, the lithographic apparatus is operable to expose a target region C of the substrate W with a substantially fixed area to radiation. For example, the target region C may comprise part of one or several dies. A single wafer may be exposed to radiation in a plurality of steps, each step involving the exposure of a target region C followed by a movement of the substrate W. After exposure of a first target region C, the lithographic apparatus may be operable to move the substrate W relative to the projection system PL so that another target region C can be exposed to radiation. For example, between exposures of two different target regions C on the substrate W, the substrate table WT may be operable to move the substrate W so as to position the next target region so that it is ready to be scanned through the exposure region. This may be achieved, for example, by moving the substrate W so that the next target region is disposed adjacent to the exposure region 10.

[0072] For example, the substrate table WT may be operable to perform a meander scan wherein the exposure region 10 traces out a path that will be described with reference to Figure 3. The substrate W comprises a plurality of target regions C arranged in a grid. A line of adjacent target regions C extending in the scanning direction may be referred to as a column of target regions C and a line of adjacent target regions C extending in the non-scanning direction may be referred to as a row of target regions C. During a meander scan, each row of target regions C (which extends in the non-scanning direction) is exposed in turn. Figure 3 illustrates the path 18 that the exposure region 10 follows over the surface of the substrate W during the exposure of a single row of target regions. As each target region C is exposed, the exposure region 10 moves in the scanning direction. In between each pair of consecutive target regions C the path steps along in the non-scanning direction (so that the exposure region 10 is adjacent to the next target region C) and changes direction in the scanning direction. It will be appreciated that the above-described meander scan is merely an example of a pattern of movement of a substrate W that may be achieved using the substrate table WT and that, additionally or alternatively, the substrate table WT may be operable to perform other patterns of movement as desired.

[0073] Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

[0074] Embodiments of the present invention generally relate to methods for improving the contrast of images formed by a lithographic apparatus. An embodiment of the present invention relates to a method for determining at least one scanning orientation for a substrate and/or determining a value of an optical correction parameter of a scanning exposure so as to optimise contrast of an

image formed by the lithographic apparatus. An embodiment of the invention relates to a lithography method wherein a substrate W is moved in a scanning direction with at least one determined scanning orientation for a substrate and/or at least one value of an optical correction parameter of the scanning exposure.

5 **[0075]** As explained above, during exposure of a substrate W within the lithographic apparatus, a plane of the surface of the substrate W may be referred to as the x-y plane, the scanning direction defining a y-direction and the non-scanning direction defining an x-direction. A z-direction is defined as being perpendicular to the x-y plane. In general, the scanning direction is linear and generally parallel to a surface of the substrate W. A range of different scanning orientations for the substrate
10 with respect to a plane of best focus for a scanning exposure of a target region may be achieved by rotating the substrate table WT relative to the frame BF about the non-scanning direction. The different scanning orientations with respect to a plane of best focus may be characterised by a rotation angle R_x and/or R_z about a non-scanning direction (i.e. the x- and/or z- direction) of the substrate table relative to a nominal or reference position. Alternatively, a range of different scanning
15 orientations with respect to a plane of best focus for a scanning exposure of a target region may be achieved by rotating the plane of best focus. This can be achieved by rotating the patterning device MA relative to the frame BF about the non-scanning direction. The value of the optical correction parameter of the scanning exposure may additionally, or alternatively, be determined by a range of different values of the speed of the substrate table in the y-direction relative to the plane of best focus
20 for the target regions. The value of the optical correction parameter of the scanning exposure may additionally, or alternatively, be determined by a range of different orientations about the x- or z-axis of the substrate with respect to the plane of best focus.

[0076] A method according to an embodiment of the invention is now described with reference to Figure 4.

25 **[0077]** At step 30, a substrate W is provided. The substrate W may comprise a silicon wafer provided with a layer of photoresist. The substrate W may be considered to comprise an array of different target regions C, as described above.

[0078] At step 32, a patterning device is provided. The patterning device comprises a plurality of markers. It will be appreciated that the number of markers and their distribution across the field of
30 view may vary for different embodiments. Preferably, the plurality of markers is generally evenly distributed over the patterning device. In one embodiment, the plurality of markers is provided as an array across the patterning device, with 19 rows and 13 columns. Each marker is such that a property of the images of the marker formed on the substrate W is dependent on the contrast during the scanning exposure in a known manner, as will be discussed in further detail below.

35 **[0079]** At step 34 a scanning exposure of a plurality of target regions C on the substrate W is performed such that an image of each of the plurality of markers is formed on each of the plurality of target regions C. The scanning exposure of each target region C is substantially as described above. In

particular, during the scanning exposure the substrate W is moved in a scanning direction such that the target region C moves through an exposure region 10 defined by the projection lens PL. Different scanning orientations and or scanning speed values with respect to the plane of best focus are used for the scanning exposure of different target regions C.

[0080] Step 34 of the method shown in Figure 4 may comprise the following sub-steps, as now described with reference to Figure 5. At step 34a, a rotation angle R_x of the substrate table WT relative to the reference position is set to an initial value $R_{x,min}$, which rotation is about the x-axis, which is the axis perpendicular to the scanning direction in the plane of the substrate table. At step 34b a target region C disposed below the projection lens PL is exposed as a scanning exposure. At step 34c, an assessment is made as to whether or not all of the target regions C have been exposed. If not, at step 34d, the substrate table WT is used to move the substrate W so as to position the next target region below the projection lens PL. As explained above, it will be appreciated that the substrate table WT is in fact used to move the substrate W so as to position the next target region C such that it is adjacent to the exposure region 10. At step 34d the substrate table WT is also used to change the rotation angle R_x relative to the reference position. In particular, the rotation angle R_x may be incremented by a fixed amount. Following step 34d, steps 34b and 34c are repeated. If at step 34c all of the target regions C have been exposed, then the method proceeds to step 36 (see Figure 4). The fixed amount by which the rotation angle R_x is incremented at step 34d may be chosen in dependence on the number of target regions C to be exposed such that the rotation angle R_x is varied through a range of values from the initial value $R_{x,min}$ to a desired end value $R_{x,max}$. It should be noted that, alternatively of additionally, the rotation angle R_z about the z-axis may be varied similarly as is described above for R_x . Furthermore, alternatively of additionally, the scanning speed v_y in the y-direction may be varied similarly as is described above for R_x .

[0081] At step 34d the substrate table WT is used to change the rotation angle R_x of the substrate table WT relative to the reference position. Since the plane of best focus remains fixed, as the substrate table WT changes the rotation angle R_x , the angle between the scanning orientation of the substrate and the plane of best focus changes. In an alternative embodiment, at step 34 the different scanning orientations relative to the plane of best focus for the scanning exposures of the plurality of different target regions C may be achieved by rotating the plane of best focus. This may be achieved, for example, by rotating the support structure MT that supports the patterning device PA about the non-scanning direction. For example, at step 34a, a rotation angle that characterises the position of the support structure MT relative to a reference position may be set to an initial value and at 34d the support table MT may be used to change the rotation angle that characterises the position of the support structure MT relative to the reference position. If the orientation of the substrate table WT remains fixed (i.e. the rotation angle R_x is fixed), as the support structure MT changes the rotation angle relative to the reference position, the angle between the scanning orientation of the substrate and the plane of best focus changes.

[0082] At step 36 (see Figure 4) the property of the image of each of the plurality of markers within each of the plurality of different target regions C is determined. Typically, this involves some processing of the wafer W followed by an inspection of the images of each of the plurality of markers within each of the plurality of different target regions C using a metrology tool.

5 **[0083]** Following exposure to radiation within the lithographic apparatus, a photoresist covered wafer W typically undergoes a number of processing steps. First, the photoresist is baked so as to fix the pattern formed in the photoresist. Following the bake, the wafer may be developed so as to remove the portion of the photoresist that has been exposed and leaving the portion of the photoresist that was not exposed or vice versa. This development is then typically followed by a number of steps that are
10 necessary to form the current layer of an integrated circuit (for example etching, selective doping, deposition of metals etc.) in a known way. For the present invention, step 36 typically only employs the post exposure bake of the substrate W, which is often sufficient to ensure that the pattern in the photoresist can be visually inspected using a metrology tool.

[0084] The type of visual inspection metrology tool used at step 36 to determine the property of
15 the image of each of the plurality of markers within each of the plurality of different target regions C is dependent on the general form of the markers. It will be appreciated that as used herein the form of a marker is intended to mean the pattern imparted to the radiation beam PB by that marker. The general form of a marker may for example refer to the shape, size and layout of features (such as, for example, chopped lines) which the marker comprises. However, as will be described further below, in
20 one embodiment the markers comprise one or more asymmetric structures and the metrology tool may be of the form of an alignment or overlay tool that is operable to determine a position of the image of the marker that is dependent on the contrast at which it was formed in the lithographic apparatus.

[0085] It will be appreciated that an image of each marker has been formed on each target region C. For example, if 90 target regions C are exposed at step 34 then there will be 90 images of each
25 marker on the patterning device: one image on each target region C and each formed using a different scanning orientation and/or different scanning speed of the substrate relative to the plane of best focus. At step 38, for each marker on the patterning device, a scanning orientation and/or optical correction parameter value of the projection lens that substantially maximises a contrast of the image of that marker formed on the substrate W is determined. For example, as will be described in greater
30 detail below, at step 38, for each marker on the patterning device an optimum rotation angle R_x about the non-scanning direction of the substrate table WT relative to a nominal or reference position may be determined.

[0086] The method as shown in Figure 4 is advantageous since it allows an optimal scanning orientation of the substrate and/or optimal value of the optical correction parameter of the projection
35 lens for contrast of image to be found for different parts of the field of view. As explained above with reference to Figure 2, during a scanning exposure of a substrate (for example a photoresist covered silicon wafer) within the scanning lithographic apparatus, the substrate is moved along a scanning

direction through the path of a radiation beam focused by a projection lens. Figure 6A is a schematic side view illustration of exposure of a substrate W. The radiation beam PB (as patterned by the patterning device M) is projected onto the substrate W by the projection lens PL. The substrate W is moved parallel to the plane of its surface, in the y-direction through the exposure region 10. The direction of movement of the substrate is indicated by arrow 44. The plane of best focus 40 of the projection lens is also shown. In general, the plane of the substrate is disposed at an angle 42 with respect to the plane of best focus 40. If the scanning direction is not well aligned with (i.e. generally parallel to) the plane of best focus 40 of the projection lens PL (i.e. angle 42 is non-zero) then the image formed by the lithographic apparatus will lose contrast.

[0087] To prevent this loss of contrast, as shown in Figure 6B the substrate table WT can be used to rotate the substrate W about the x-direction with respect to the projection lens PL (or the plane of best focus). Now the orientation of the substrate W, as indicated by arrow 44, is aligned with the plane of best focus 40 of the projection lens PL (i.e. angle 42 is zero) and, as a result, the contrast of the image formed by the lithographic apparatus is optimised. It will be appreciated that in an alternative embodiment, rather than using the substrate table WT to rotate the substrate W about the x-direction with respect to the projection lens PL, alternatively, the plane of best focus 40 may be rotated about the x-direction such that it is aligned with the orientation of the substrate W.

[0088] Typically, the angle through which the substrate table WT is rotated may be of the order of tens of micro-radians (μrad). However, the angles involved have been exaggerated in Figures 6A and 6B so that they can be more clearly distinguished.

[0089] Prior art techniques have concentrated on optimising the best focus of lithographic machines in order to achieve good critical dimension uniformity (CDU). For example, one previous technique involves the use of static exposures of a substrate at a slight defocus. The static exposure may image a number, for example six, markers onto a static substrate at, for example, two different positions in the scanning direction (the y direction) and three different positions in the non-scanning direction (the x direction). An alignment parameter or position shift for each of the two of markers provides an indirect measurement of the difference in focal positions of the two markers. In turn, this is used to determine the rotation angle R_x from the reference position.

[0090] This prior art technique for determining the rotation angle R_x from the reference position has limited accuracy for a number of reasons. First, the prior art technique is sensitive to a range of other effects such as, for example, the telecentricity of the illumination of the markers, radiation dose, process and lens variation. Second, this prior art technique provides an indirect measurement using, for example, only the focus of 2 different y positions within the field of view. Third, it uses a static exposure and therefore does not take into account vibrations due the movement of the substrate table WT or contrast of the image.

[0091] It is a known problem in the field of lithography that isolated features and dense features are imaged differently. This can lead to linewidth differences between the isolated features and dense

features, which is referred to as iso-dense bias. This can be corrected for to an extent using optical proximity corrections, for example by using sub-resolution features adjacent to features to be imaged (also known as scattering bars). The inventor believes that loss of contrast within a scanning lithographic apparatus can result in differences in the images formed using such optical proximity corrections. In turn, this can result in differences in the images formed using different lithographic apparatuses. It is therefore believed that providing better control over the contrast of images formed by scanning lithographic apparatuses by using the method shown in Figure 4 can reduce the sensitivity of images to patterning devices that use optical proximity corrections to the lithographic apparatus or system that they are imaged by.

[0092] As stated above, the plurality of markers on the patterning device are each of a general form such that a property of the image of the marker is dependent on the contrast in a known manner. Examples of suitable markers are now discussed.

[0093] Each marker may comprise at least one structure, and an example of such a structure is shown in Figures 7A and 7B. The structure comprises a first portion across which the radiation beam may have a substantially constant intensity and a second portion across which the intensity of the radiation beam is patterned and comprising a plurality of features, in this examples lines, which have a smaller width than the feature, in this example line, of the first portion. The structure may also be described as a chopped line. For arrangements wherein the marker comprises a plurality of structures, the smaller lines have a smaller pitch than a pitch of the structures. In alternative embodiments, the second portion of each structure may comprise another high resolution pattern. In general the second portion imparts a high resolution pattern to the intensity of the radiation beam. For example, rather than a plurality of lines, the second portion may comprise a plurality of holes.

[0094] It will be appreciated that during the scanning exposure of a target region C the patterning device imparts a pattern to the radiation beam PB wherein this pattern comprises the plurality of markers. It will be appreciated that the plurality of markers results in the radiation beam being patterned such that the intensity of the radiation beam across its cross sectional area comprises at least one structure, i.e. at least one elongate region of either lower or higher intensity relative to a surrounding region. For example, the patterning device may comprise a binary transmissive mask or reticle and each structure may correspond to a transparent portion of the reticle surrounded by opaque portions of the reticle. Alternatively, the patterning device may comprise a binary transmissive mask or reticle and each structure may correspond to an opaque portion of the reticle surrounded by transparent portions of the reticle. It will be appreciated that this type of reticle is only an example of a patterning device. Other embodiments may use other types of patterning device such as, for example, reflective reticles and/or phase shift reticles.

[0095] The, or each, structure may be considered to have an asymmetric profile. It will be appreciated that in this context the profile of a structure is the shape of the intensity distribution of the

patterned radiation beam PB in a direction perpendicular to an axis of the structure. It will be further appreciated that an asymmetric profile is one which is not symmetric about a central axis of the structure 50. Figure 7B shows the profile 58 of the structure 50 shown in Figure 7A.

[0096] Different parts of a marker which has a non-constant profile or line shape, for example a marker comprising one or more structures 50 of the form shown in Figures 7A and 7B, will, in general, be affected differently by loss of contrast. Therefore, in general, the shape of the profile will be altered by loss of contrast during a scanning exposure. Furthermore, for markers which have an asymmetric profile, in general, the shape of the profile will be altered by loss of contrast during a scanning exposure such that a position of the centre of mass of the profile is shifted, as now described with reference to Figures 8A to 8C.

[0097] Figures 8A, 8B and 8C each show, schematically, the relative orientations of the substrate W and the plane of best focus 40 during an exposure and the profile of the intensity distribution of the image of the structure of Figures 7A and 7B formed during that exposure. Figure 8A shows an arrangement wherein the substrate W coincides with the plane of best focus 40. For such an arrangement, the marker will be imaged well and the profile 58a of the image is very similar to the profile 58 of the structure 50. The centre of mass 60a of the profile 58a is substantially the same as that of the profile 58 of the structure 50. Figure 8B shows an arrangement wherein the plane of the substrate W forms a non-zero angle 42 with the plane of best focus 40. For such an arrangement, contrast of the formed image is reduced. The high resolution lines 56 in the second portion 54 of the structure 50 are thinner than the first portion of the structure 50 and are therefore affected more by the loss of contrast. As a result, the height of image of the high resolution lines 56 in the second portion 54 of the structure 50 is reduced relative to the height of the image of the first portion 52 of the structure 50. As a result, the profile 58b of the image is different to the profile 58 of the structure 50. In particular, the centre of mass 60b of the profile 58b is shifted relative to that of the profile 58 of the structure 50 in a direction towards the first portion 52 of the structure 50. Figure 8C shows an arrangement wherein the plane of the substrate W forms a non-zero angle 42 with the plane of best focus 40 but wherein the tilt of the substrate W is in an opposite sense to that as shown in Figure 8B. For such an arrangement, again contrast of the image is reduced and the height of image of the high resolution lines 56 in the second portion 54 of the structure 50 is reduced relative to the height of the image of the first portion 52 of the structure 50. As a result, the profile 58c of the image is different to the profile 58 of the structure 50. In particular, the centre of mass 60c of the profile 58c is shifted relative to that of the profile 58 of the structure 50 in a direction towards the first portion 52 of the structure 50. Note that for a tilt in either direction, the shift of the centre of mass of the profile is the same. At least for small rotation angles ΔR_x away from best focus, the shift of the centre of mass is proportional to the square of ΔR_x (and/or ΔR_z).

[0098] With such an arrangement, the property of the image of the marker that is dependent on the contrast in a known manner may comprise a position or a displacement parameter. In particular,

the property of the image of the marker that is dependent on the contrast in a known manner may comprise a shift in a position of the centre of mass of the profile of structures 50 in the formed image. The shift in position may be determined using an alignment or overlay detector that can resolve the image of the main structure but which cannot resolve the image of the substructure (for example the lines 56 or some other high resolution pattern imparted to the intensity of the radiation beam by the second portion 54 of structures 50). That is, the alignment or overlay detector may be able to distinguish between individual structures 50 of the marker but may not be able to distinguish between individual lines 56 of the second portions. Rather, to the alignment or overlay detector, the second portion 54 of the structures 50 may appear to have a generally uniform intensity or height, which may be an average intensity or height of the image and which may be dependent on the contrast during the exposure that formed the image.

[0099] Determining the property of the image of a marker within a target region may involve determining a displacement parameter for that image of the marker. The displacement parameter may be dependent on the contrast of the image of the marker.

[00100] It will be appreciated that as used herein the term “position” refers to a position of an object (for example a structure or a feature within an image of a marker) and the “displacement parameter” refers to a shift in position of an object (for example a structure or a feature within an image of a marker). A displacement parameter may refer to an alignment parameter, which may be a position of an object (for example a structure or a feature within an image of a marker) relative to a known reference position. An alignment parameter may be determined using an alignment detector of the type that is often provided with lithographic apparatus. A displacement parameter may alternatively refer to an overlay parameter, which may be a measure of the difference in relative positions of two objects (for example two sets of structures or features). An overlay parameter may be determined using an overlay detector of the type that is often provided separate from a lithographic apparatus. An overlay parameter may be considered to be a special type of alignment parameter. In general, overlay parameters may be easier to determine accurately than other, more general, types of alignment parameter.

[00101] Markers made from structures 50 of the form shown in Figures 7A and 7B can have various different geometries as now discussed with reference to Figures 9 and 10.

[00102] Figure 9 is a schematic representation of a first type of marker 62 using a plurality of structures 50 of the form shown in Figures 7A and 7B. The marker 62 comprises four portions 62a, 62b, 62c, 62d, each of which comprises five structures 50 of the form shown in Figures 7A and 7B (the second portions 54 of the structures 50 are represented by dotted rectangles to aid the clarity of the Figure).

[00103] The structures 50 of the first and third portions 62a, 62c are mutually parallel. In the first portion 62a of the marker 62 the second portions 54 of the structures 50 are disposed on one side of the first portions 52 of the structures 50 (the right hand side in Figure 9) whereas in the third portion

62c of the marker 62 the second portions 54 of the structures 50 are disposed on an opposite side of the first portions 52 of the structures 50 (the left hand side in Figure 9). The asymmetry of the profile of a line may be characterized in terms of the direction in which the centre of mass of the structure shifts upon loss of contrast. As explained above, upon loss of contrast the centre of mass of structure 50 shifts in a direction away from the second portion 54 and towards the first portion 52 of the structure 50. Therefore the asymmetry of the structures 50 in the first portion 62a may be considered to be in an opposite sense to the asymmetry of the structures 50 in the third portion 62c.

[00104] Similarly, the structures 50 of the second and fourth portions 62b, 62d are mutually parallel. In the second portion 62b of the marker 62 the second portions 54 of the structures 50 are disposed on one side of the first portions 52 of the structures 50 (the bottom in Figure 9) whereas in the fourth portion 62d of the marker 62 the second portions 54 of the structures 50 are disposed on an opposite side of the first portions 52 of the structures 50 (the top in Figure 10). Therefore the asymmetry of the structures 50 in the second portion 62b may be considered to be in an opposite sense to the asymmetry of the structures 50 in the fourth portion 62d.

[00105] The structures 50 of the second and fourth portions 62b, 62d are oriented substantially perpendicular to the structures 50 of the first and third portions 62a, 62c.

[00106] As explained above, in general, loss of contrast during a scanning exposure will result in a shift in a position of the centre of mass of the profile of an image of a structure 50 with an asymmetric profile. Having two portions wherein the first and second portions 52, 54 of each structure 50 within one portion (for example 62a or 62b) are arranged in an opposite order to the first and second portions 52, 54 of each structure 50 within the other portion (for example 62c or 62d) will result in moving of the position of the centre of mass of two portions in opposite directions (either towards each other or away from each other). For such embodiments, the property of the image of the marker that is dependent on the contrast in a known manner (which may be referred to as an overlay parameter) may be a measure of this relative shift of the centre of mass of the structures in the first portion relative to the centre of mass of lines in the second portion. This may be referred to as an overlay parameter. Advantageously, this may result in the method being less sensitive to position accuracies of the substrate W.

[00107] Figure 10 is a schematic representation of a second type of marker 64 using a plurality of structures 50 of the form shown in Figures 7A and 7B. The marker 64 comprises four outer structures 66a-66d which are generally arranged so as to define an outer square and four inner structures 68a-68d which are generally arranged so as to define an inner square. All of the outer and inner structures 66a-66d, 68a-68d are of the form shown in Figures 7A and 7B (again the second portions 54 of the structures 50 are represented by dotted rectangles to aid the clarity of the Figure).

[00108] The inner and outer squares are generally concentric. Adjacent structures from the inner square and outer square are arranged such that the second portion 54 of one of the structures is disposed on one side of the first portion 52 of that structure and the second portions 54 of the other

structure is disposed on an opposite side of the first portion 52 of that structure. The marker 64 may be referred to as a box in box marker or target.

[00109] Any conventional position measurement system as used in a lithographic apparatus or any conventional external overlay metrology tool may be used to measure the shift in position of the one or more structures of the markers 62, 64.

[00110] For embodiments wherein the property of the image of the marker that is dependent on the contrast in a known manner is an alignment parameter, a measurement system of the type used in a lithographic apparatus may be used. For example, the Smart Alignment Sensor Hybrid (or SMASH) is an example of a known position measurement system that may be used to determine the shift in centre of mass of the profile of the structures. Information relating to SMASH may be found in U.S. patent number 6,961,116. It is to be understood that the present invention is not limited to use with the SMASH position measurement system. Other position measurement systems may be used. For example, the position measurement system may be of the type described in U.S. patent number 6,297,876 (otherwise known as Advanced Technology using High order Enhancement of Alignment, or ATHENA). As a further example, the position measurement system may utilize the well-known "Through The Lens (TTL)" position measurement technique in which radiation diffracted by an alignment mark is formed on a detector grating to produce a periodic alignment signal which may be used with the present invention. It will be apparent to the skilled person that other (optical) arrangements may be used to obtain the same result of illuminating two marks on a target, detecting resulting radiation and determining a separation between the marks therefrom.

[00111] For embodiments wherein the property of the image of the marker that is dependent on the contrast in a known manner is an overlay parameter, a conventional external overlay metrology tool may be used. For example, the Yieldstar range (including the Yieldstar S-250D and the Yieldstar T-250D) available from ASML Holding of Veldhoven, the Netherlands, are examples of a metrology tools which allows measurement of on-product overlay and focus using diffraction based overlay (μ DBO) and diffraction based focus (DBF) techniques. The Archer Series machines, available from KLA-Tencor Corporation of Milpitas, California, USA are an alternative example of optical overlay metrology systems.

[00112] An example of how a scanning parameter that substantially maximises a contrast of the image of a marker formed on the substrate W may be determined (in step 38 of the method of Figure 4) is now discussed. It will be appreciated that an image of each marker has been formed on each target region C, each target region C having been exposed using a different scanning orientation (for example a different rotation angle R_x and/or R_z and/or a different scanning speed v_y).

[00113] The step of determining an optimum value of a scanning orientation and/or optimum value of an optical correction parameter that substantially maximises contrast of the image of that marker formed on the substrate W may comprise: (a) determining the property of the image of the marker that is dependent on the contrast in a known manner (for example a displacement parameter)

as a function of the scanning orientation of the substrate with respect to the plane of best focus (for example the rotation angle R_x) and/or scanning speed during the scanning exposure and (b) determining a scanning orientation and/or optical correction parameter value of the scanning exposure as a local maximum or minimum in the displacement parameter. For example, a curve may be fitted to a graph of the displacement parameter against the parameter that characterises the scanning orientation of the substrate and/or value of the optical correction parameter for the scanning exposure. An example will now be described with reference to Figures 11A and 11B.

[00114] Figures 11A and 11B are graphs of an overlay parameter AO as a function of an orientation angle of a substrate relative to a plane of best focus for two different substrate tables. The horizontal axis shows the rotation angle R_x about the non-scanning direction (i.e. the x-direction) of the substrate table relative to a reference position and the vertical axis shows the determined overlay parameter AO, both in arbitrary units. Both Figures 11A and 11B relate to an overlay parameter AO for a marker of the type shown in Figure 9. The overlay parameter AO shown on the vertical axis is the difference between an alignment parameter of two portions of the marker wherein the first and second portions 52, 54 of each structure 50 within one of the two portions are arranged in an opposite order to the first and second portions 52, 54 of each structure 50 within the other one of the two portions. These two portions are either the first and third portions 62a, 62c or the second and fourth portions 62b, 62d. One of these two pairs of portions 62a, 62c; 62b, 62d is orientated such that a loss of contrast causes a change in the relative positions of the two portions in the scanning direction whereas the other pair of portions 62a, 62c; 62b, 62d is orientated such that a loss of contrast causes a change in the relative positions of the two portions in the non-scanning direction. Each of Figures 11A and 11B shows two curves: one for the alignment parameter difference between the two portions with an asymmetry in the scanning direction (dashed line) and one for the alignment parameter difference between the two portions with an asymmetry in the non-scanning direction (dashed line). In both Figures, the difference between these two curves is negligible.

[00115] It can be seen from Figures 11A and 11B that, in general, the optimum scanning orientation (or, equivalently, optimum value of the rotation angle R_x and/or R_z relative to the reference position) is different for different substrate tables WT.

[00116] Similarly, an optimum value of an optical correction parameter of projection optics can be determined from graphs of the rotation angles R_x and/or R_z and, additionally or alternatively, the scanning speed v_y . The optical correction parameter may for example control a lens manipulator that is arranged to set an asymmetric magnification that is dependent on the value of the optical correction parameter. An asymmetric magnification is a magnification having a first value in a direction along a first magnification axis and a second value, different from the first value, along a second magnification axis, different from the first magnification axis (e.g. perpendicular).

[00117] It will be appreciated that the above-described method may be performed as part of a calibration of a lithographic apparatus. The scanning orientations and/or optical correction parameter

values determined using the above-described method may then be used during subsequent normal operation of the lithographic apparatus, as now described.

[00118] During a scanning exposure of a substrate (generally as described above with reference to Figures 1 to 3) a substrate W may be moved relative to an exposure region 10 in a scanning direction such that a radiation beam PB as patterned by a patterning device moves over a surface of the substrate W. According to embodiments of the invention, the scanning orientation of the substrate used for such an exposure of the substrate W is dependent on at least one scanning orientation for the substrate and/or an optical correction parameter value of the projection optics as (previously) determined according to the above-described method (for example as shown in Figure 4).

[00119] There is more than one way in which the scanning orientations and/or an optical correction parameter values as previously determined according to the above-described method can be used. Two embodiments are now described.

[00120] In a first embodiment, the scanning orientation (for example as characterised by the rotation angle R_x about the non-scanning direction relative to a reference position) and/or the optical correction parameter value (for example as characterised by a setting for an asymmetric magnification) used during normal operation of the lithographic apparatus is an average of the scanning orientations and/or optical correction parameter values that substantially maximises contrast of the image of the plurality of markers formed on the substrate. That is, an optimum scanning orientation and/or optical correction parameter value is found for each of the markers distributed across the field of view and, subsequently, the exposure of substrates W is performed using an average value of said optimum scanning orientations and/or optical correction parameter values.

[00121] In a second embodiment, the scanning orientation (for example as characterised by the rotation angle R_x about the non-scanning direction relative to a reference position) and/or the optical correction parameter value (for example as characterised by a setting of an asymmetric magnification) used during normal operation of the lithographic apparatus is, in general, dynamically changed during movement of the substrate W across the exposure region 10. For such embodiments, the instantaneous scanning orientation and/or optical correction parameter value may be an average of the optimum scanning orientations and/or optical correction parameter values for a subset of the plurality of markers used in the above-described method, the subset of markers being those markers which correspond to a portion of the patterning device that is currently being imaged. For example, during a scanning exposure, the support structure MT moves so that a patterning device MA supported thereby moves through an exposure region defined by the radiation beam PB. In a similar way, during step 34 of the method shown in Figure 4, a scanning exposure of a plurality of different target regions C on a substrate W is performed such that an image of each of the plurality of markers is formed on each of the plurality of different target regions C. During each such scanning exposure, the patterning device comprising the markers is moved through the exposure region. In this embodiment, during a normal exposure of a substrate, the instantaneous scanning orientation of the substrate and/or instantaneous

optical correction parameter value of the projection optics is an average of the optimum scanning orientations and/or optical correction parameter values for those markers which during the above-described method were disposed on the part of the support structure MT which is currently disposed in the exposure region.

5 **[00122]** Although the above-described embodiments use markers that comprise at least one structure having an asymmetric profile, it will be appreciated that any type of marker of a general form such that a property of the image of the marker is dependent on the contrast in a known manner may be used. For example, in the above described embodiments, each structure 50 comprises a first
10 portion 52 and a second portion 54 that imparts a high resolution pattern to the radiation beam. Upon loss of contrast, the center of mass of such an asymmetric structure 50 will shift towards the first portion 52 and the property of the image of the marker that is dependent on the contrast in a known manner is related to this shift. In alternative embodiments, markers with structure with symmetric profiles (about a central axis of the lines) may alternatively be used, for example comprising structure wherein a high resolution grating is provided in both sides of a central, generally uniform portion. For
15 such embodiments, loss of contrast does not result in a shift in the center of mass of the lines. However, it will result in a change in the profile of the images of the structure. For such embodiments, metrology tools may be used to measure contrast loss. For example the critical dimension (CD) response as a function of radiation dose may be determined since the CD is proportional to the radiation dose, the constant of proportionality providing a measure for the optical contrast.
20 Additionally or alternatively, the profile of the marker image may be reconstructed using a metrology tool with sufficient resolution.

[00123] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The description is not intended to limit the invention.

CLAIMS:

1. A method comprising:
providing a substrate;
providing a patterning device comprising a plurality of markers to impart a radiation beam
5 with a pattern in its cross-section;
projecting the radiation beam onto a target region of a substrate via projection optics;
performing scanning exposures, which have a plane of best focus, of a plurality of target
regions on the substrate such that an image of each of the plurality of markers is formed on each of
the plurality of target regions, wherein each of the plurality of markers is of a form such that a
10 property of the image of the marker is dependent on the contrast in a known manner, and moving the
substrate in a scanning direction during the scanning exposures, wherein at least one of:
a difference between a rotation angle of the substrate and a rotation angle of the plane
of best focus about a first axis perpendicular to the scanning direction,
a difference between a rotation angle of the substrate and a rotation angle of the plane
15 of best focus about a second axis perpendicular to the first axis and perpendicular to the
scanning direction, and
a speed of the substrate in the scanning direction relative to the plane of best focus,
is selected to be different for the scanning exposures of at least two of the plurality of target regions;
and
20 determining the property of the image of each of the plurality of markers within each of the
plurality of target regions.
2. The method of claim 1 wherein each of the plurality of markers comprises at least one
structure comprising a first portion across which the radiation beam may have a substantially constant
25 intensity and a second portion across which the intensity of the radiation beam is patterned.
3. The method of claim 2 wherein determining the property of the image of a marker within a
target region involves determining a displacement parameter for that image of the marker.
- 30 4. The method of claim 2 or 3 wherein each of the plurality of markers comprises a first part
comprising at least one structure and a second part comprising at least one structure, wherein the
second portion of the or each structure within the first part of the marker is disposed on one side of the
first portion of that structure and wherein the second portion of the or each structure within the second
part of the marker is disposed on an opposite side of the first portion of that structure.
- 35 5. The method of claim 4 when dependent on claim 3 wherein the displacement parameter for
the image of each of the plurality of markers within each of the plurality of different target regions is

proportional to a relative shift in a position of a centre of mass of the profile of one or more structures within the image of the first part of the marker relative to a position of a centre of mass of the profile of one or more structures within the image of the second part of the marker.

5 6. The method of any preceding claim wherein the method comprises determining a scanning orientation for the substrate and/or determining a value of an optical correction parameter of the scanning exposure for each marker on the patterning device which achieves a desired contrast of the image of that marker formed on the substrate.

10 7. The method of any preceding claim wherein the method further comprises, for at least one of the plurality of markers, determining a relationship between: (a) the property of the image of the marker that is dependent on the contrast in a known manner; and (b) a parameter that characterises the scanning orientation of the substrate with respect to the plane of best focus and/or an optical correction parameter of the scanning exposure.

15 8. The method of any preceding claim further comprising:
 using a scanning mechanism to move the substrate relative to a frame in the scanning direction relative to the plane of best focus such that the patterned radiation beam moves over a surface of the substrate.

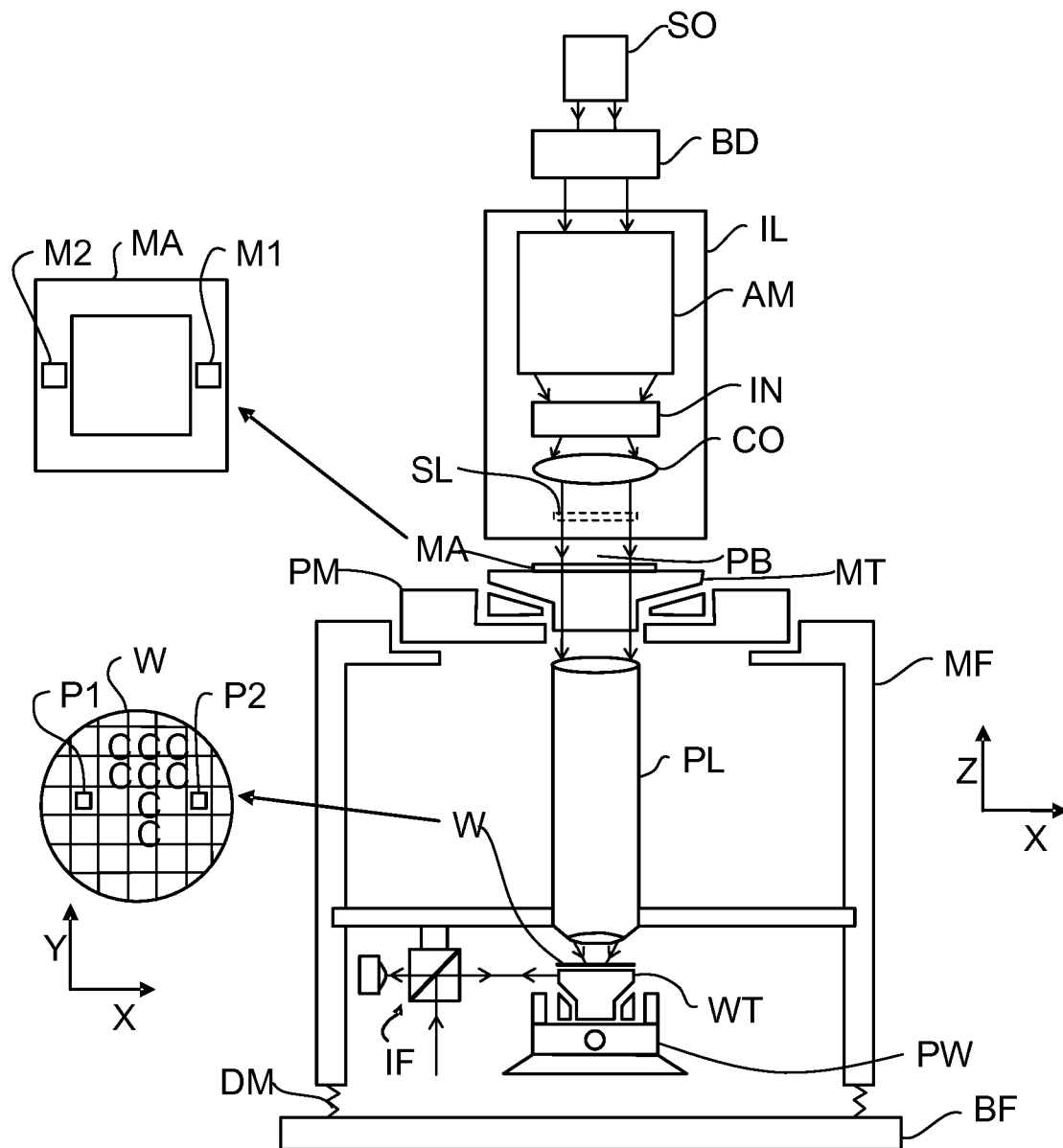
20 9. The method of any one of claims 6 to 8 wherein the scanning orientation and/or optical correction parameter value is an average of the scanning orientations and/or optical correction parameter values, respectively, that substantially maximises contrast of the image of the plurality of markers formed on the substrate.

25 10. The method of claim 8 or 9 wherein the scanning orientation and/or optical correction parameter value changes during movement of the substrate by the scanning mechanism.

30 11. The method of claim 10 wherein the instantaneous scanning orientation and/or optical correction parameter value is an average of the scanning orientations and/or optical correction parameter values that substantially maximise contrast of the image of a subset of the plurality of markers, the subset of markers being those markers which correspond to a part of the patterning device that is currently being imaged.

35 12. A lithographic apparatus operable to implement the method of any one of claims 1 to 11.

13. A computer program operable to implement the method of any one of claims 1 to 11.

**Fig. 1**

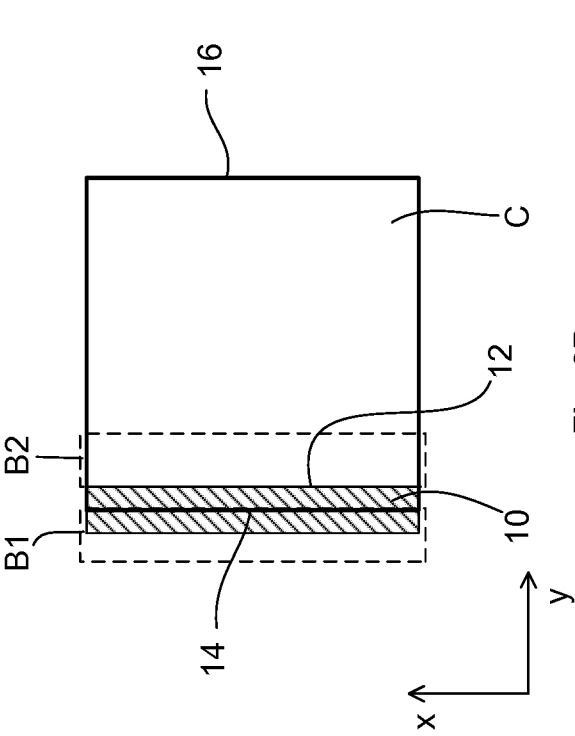


Fig. 2A

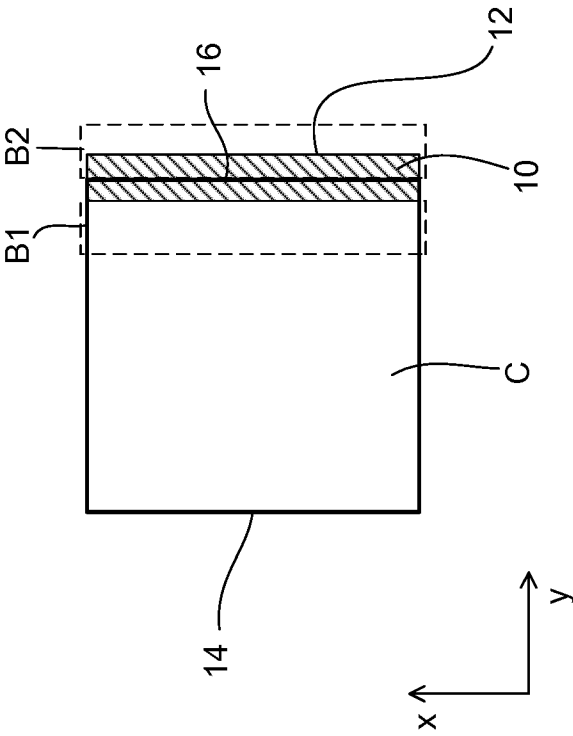


Fig. 2B

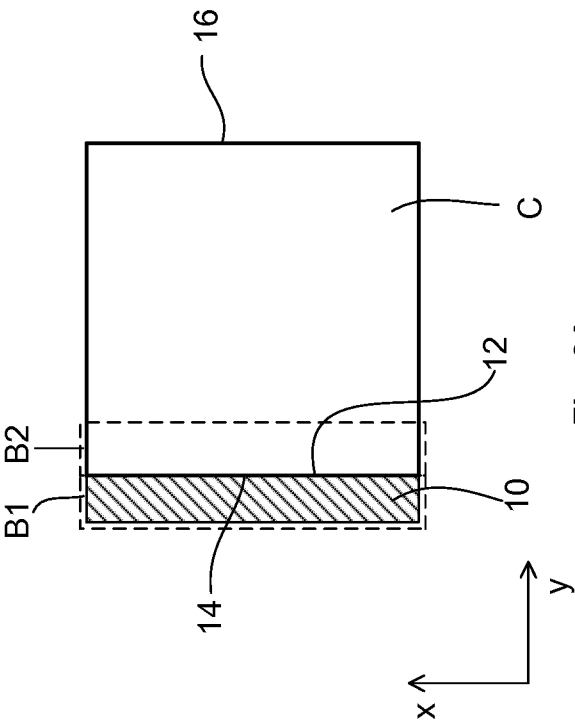


Fig. 2C

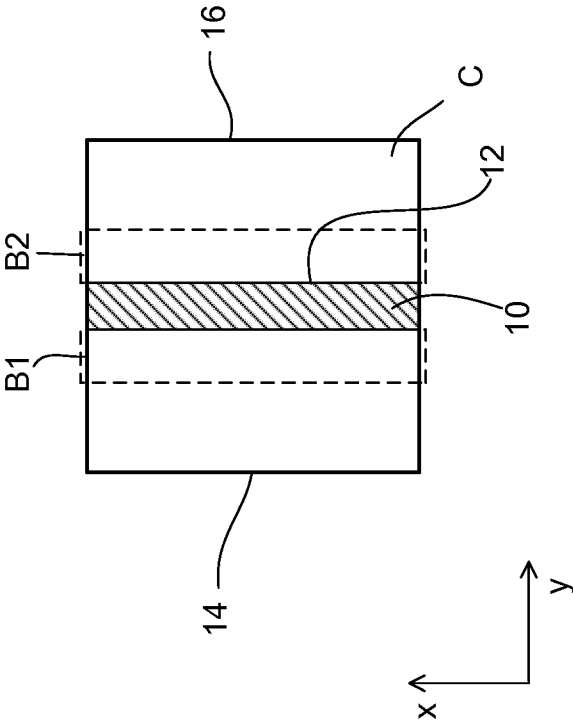
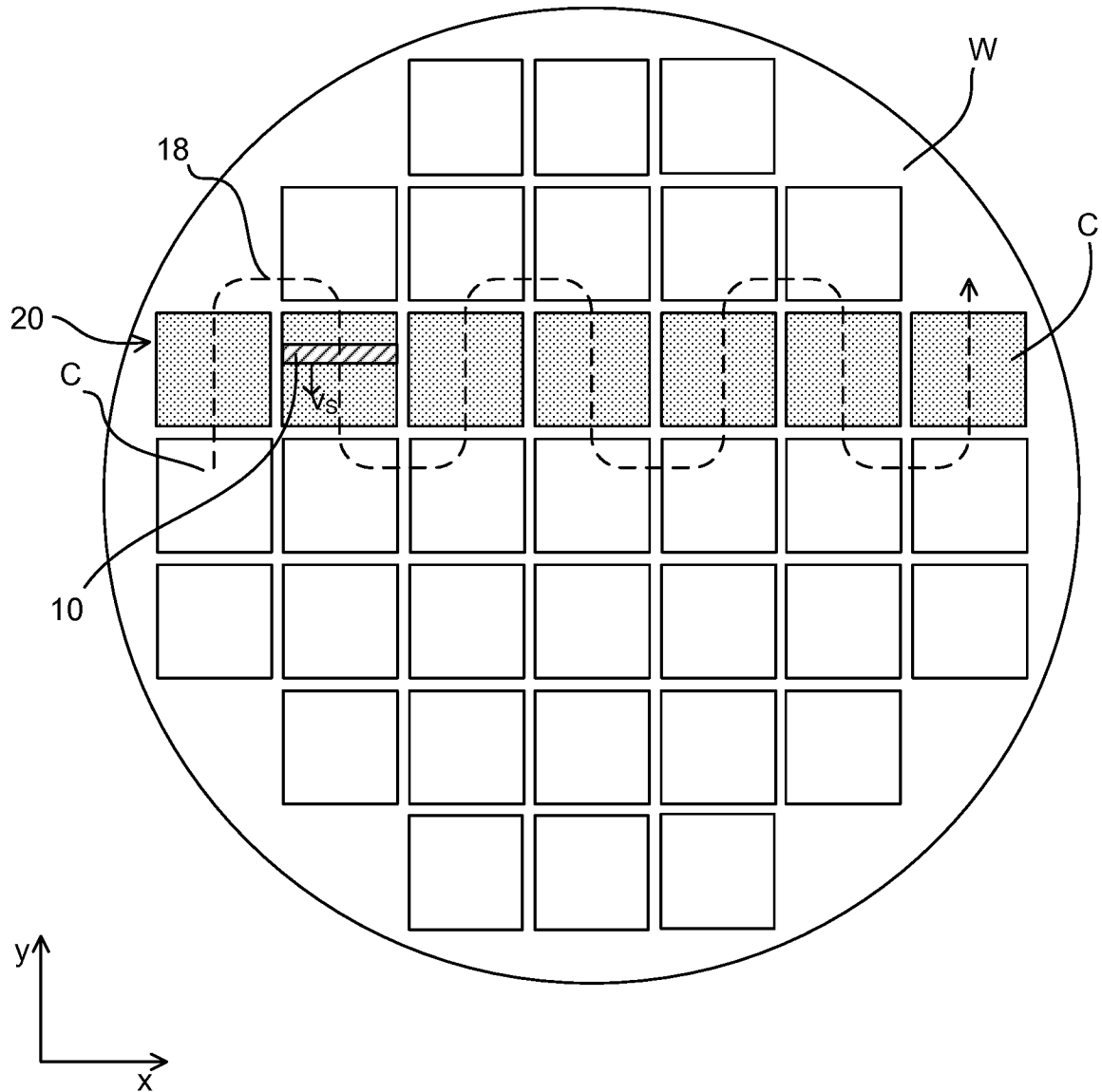


Fig. 2D

**Fig. 3**

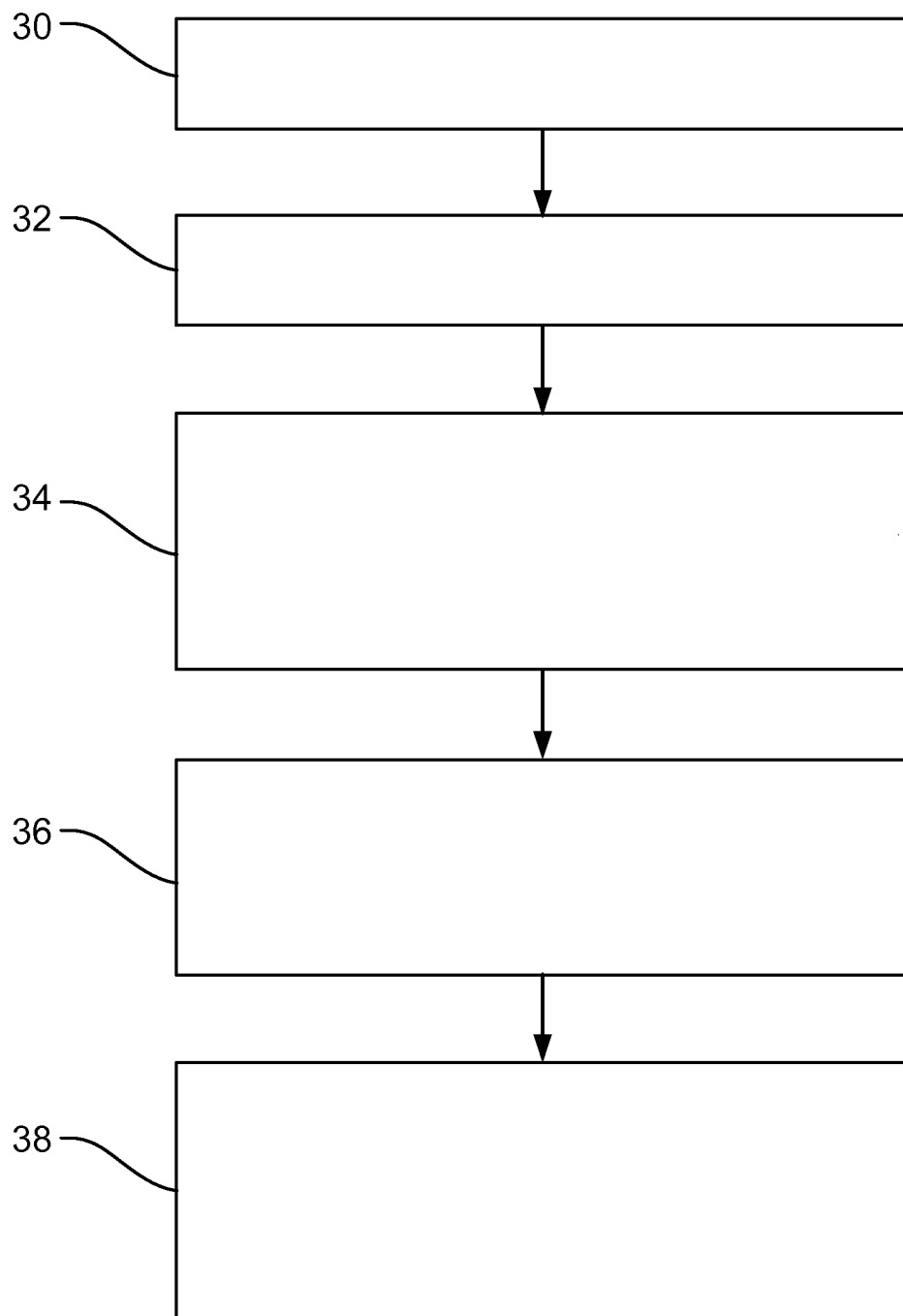


Fig. 4

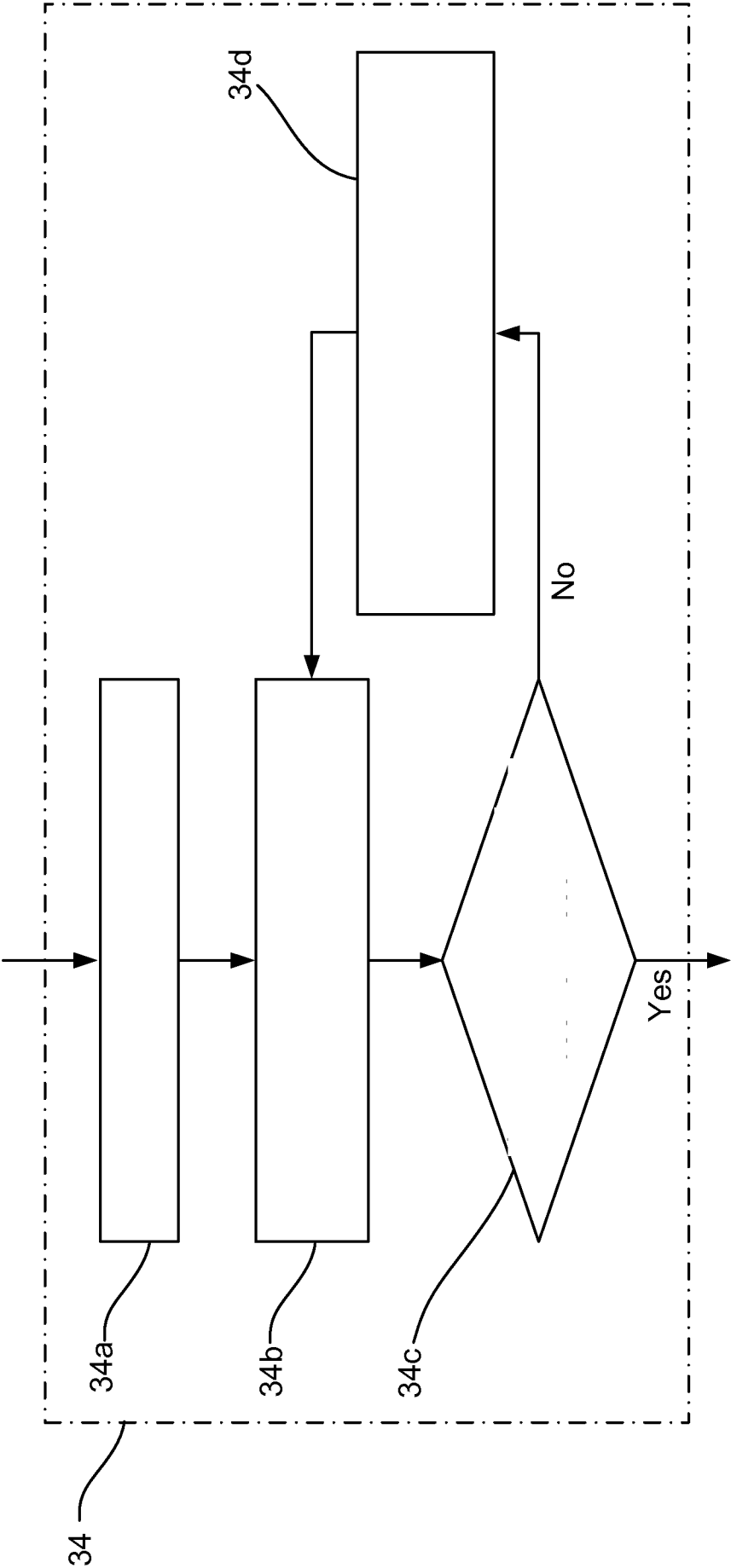


Fig. 5

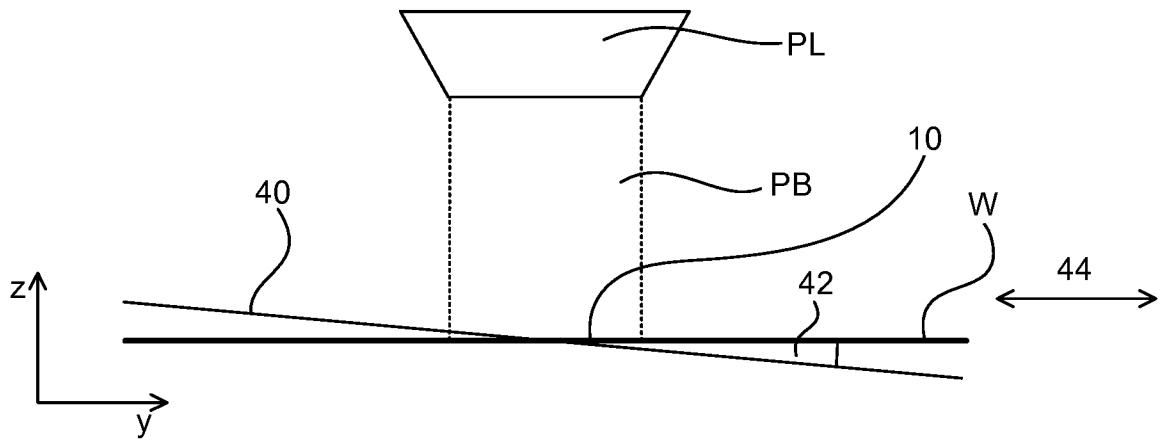


Fig. 6A

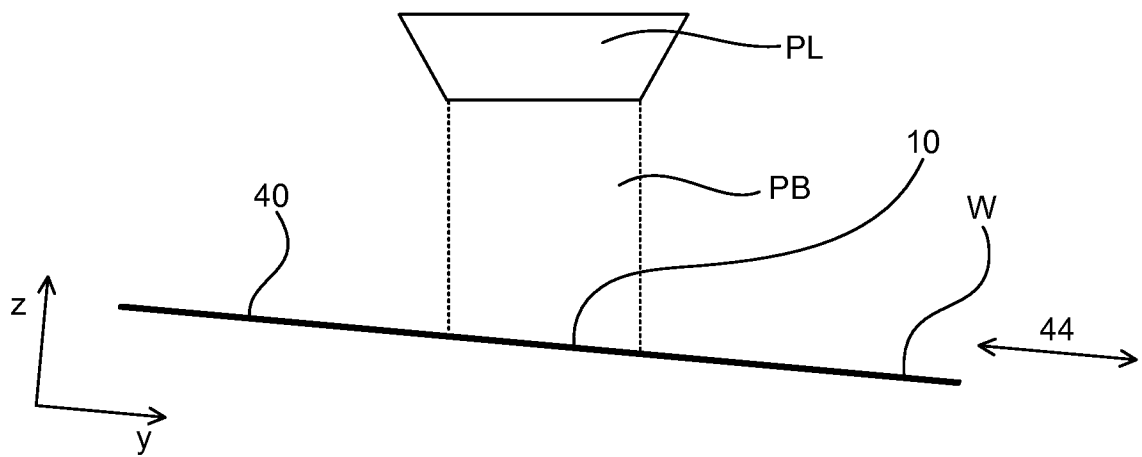


Fig. 6B

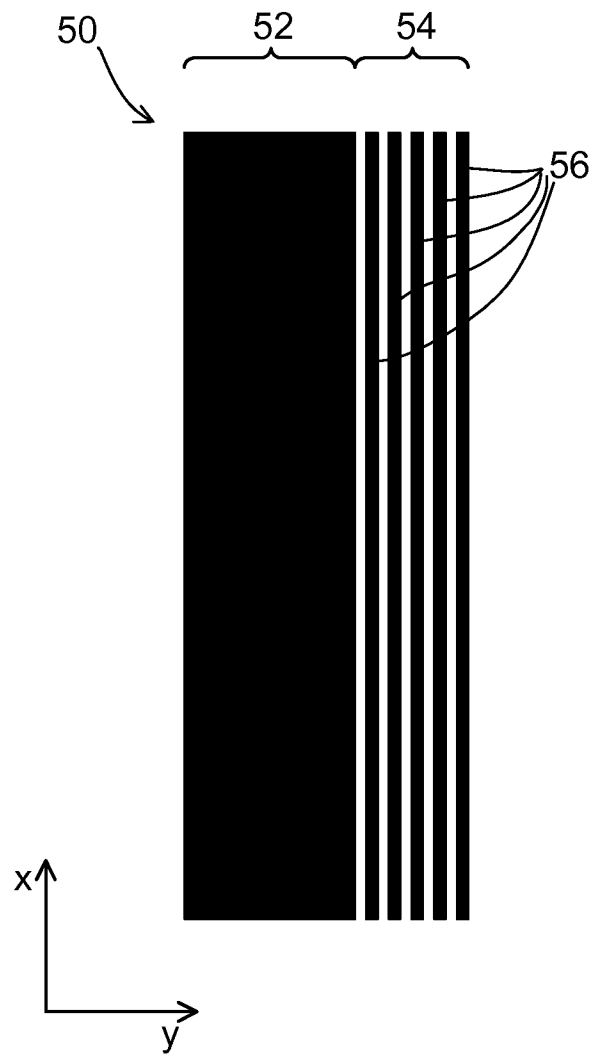


Fig. 7A

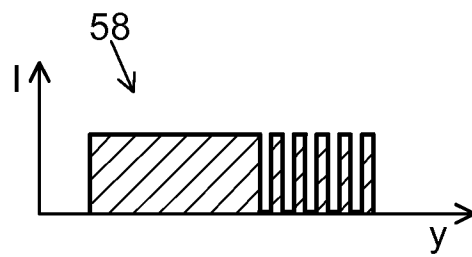


Fig. 7B

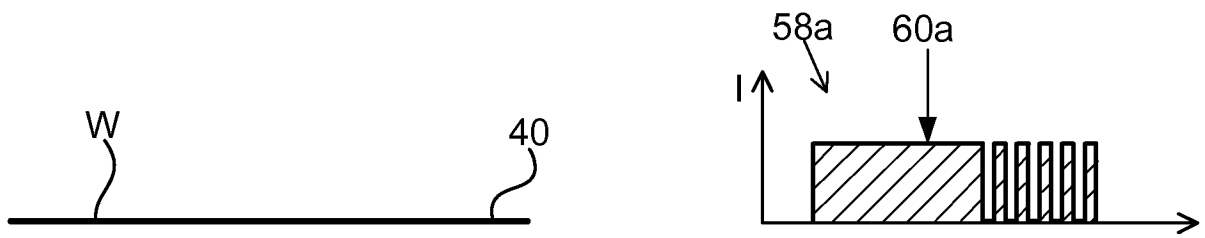


Fig. 8A

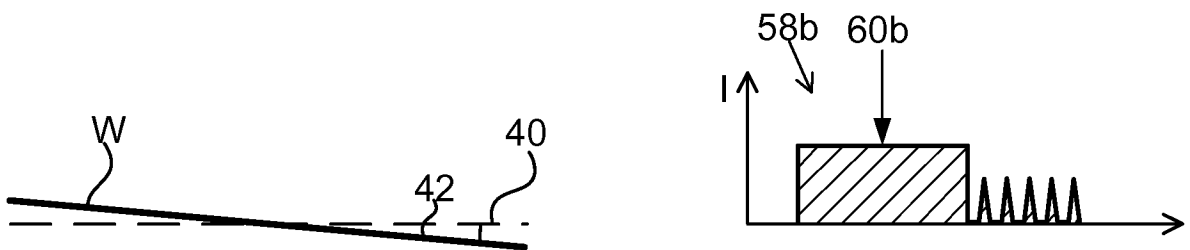


Fig. 8B

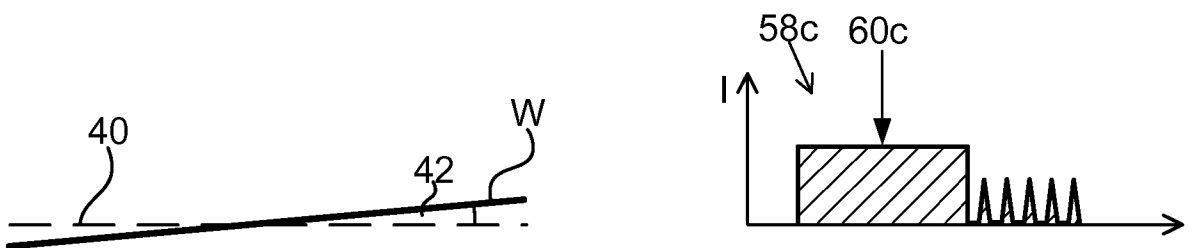


Fig. 8C

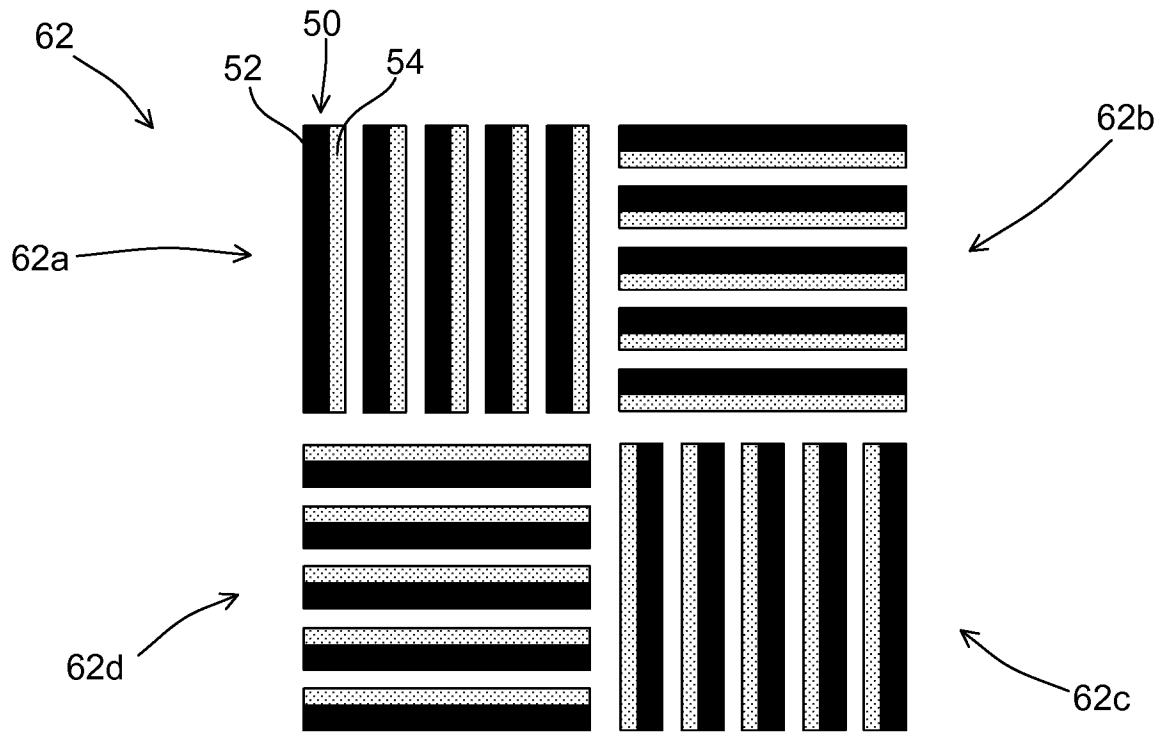


Fig. 9

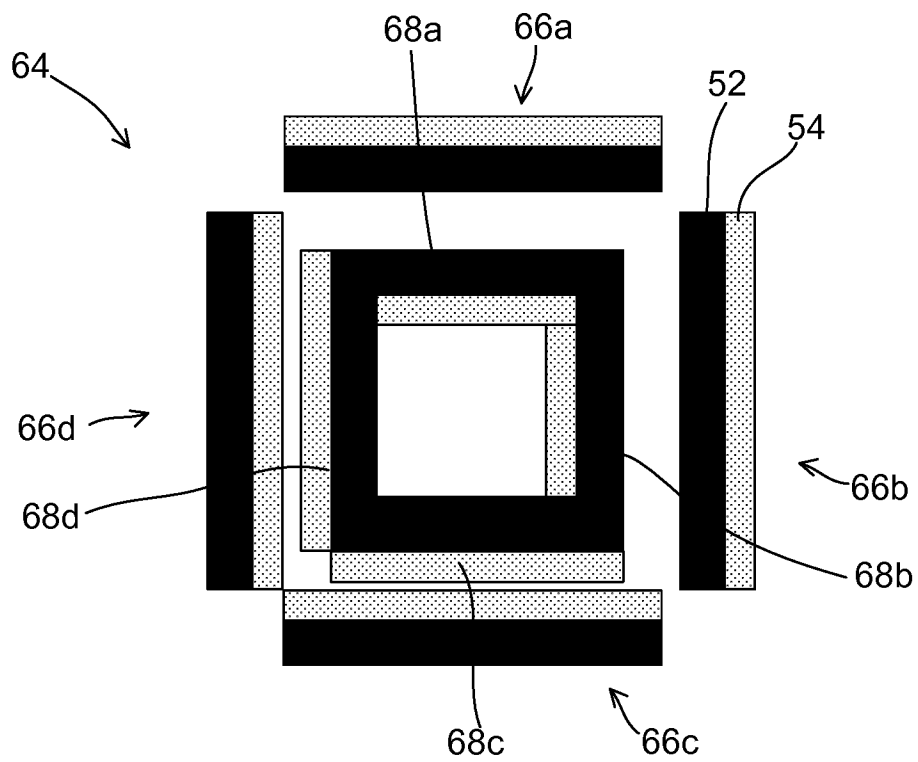


Fig. 10

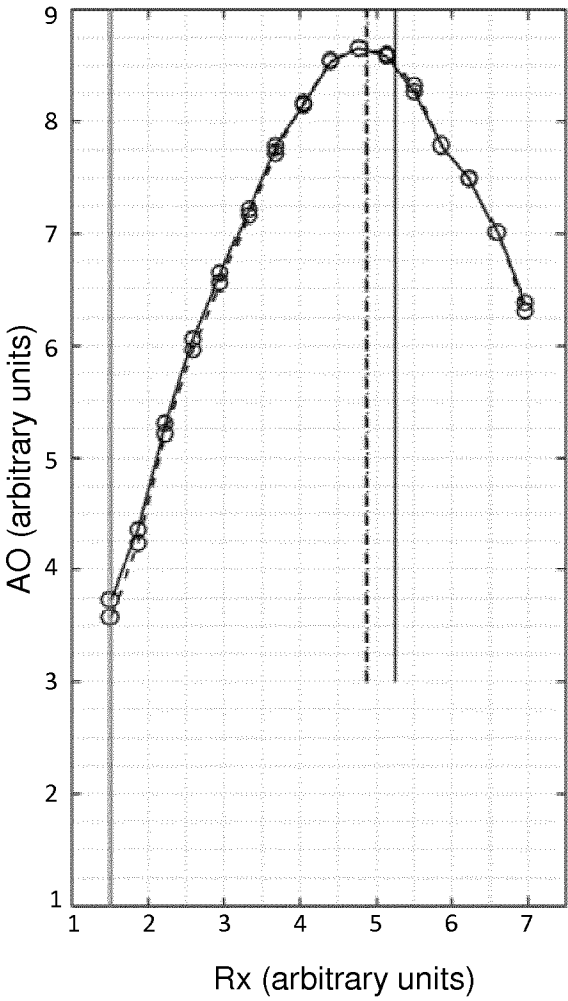


Fig. 11A

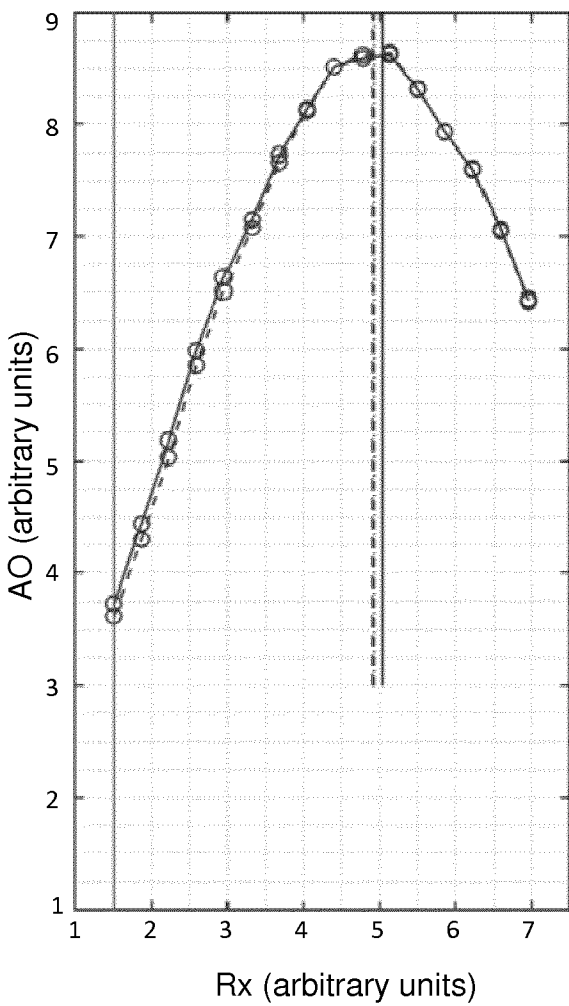


Fig. 11B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/075382

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/20 G03F9/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G03F

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

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

EPO-Internal, WPI Data

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A	paragraph [0033] - paragraph [0038] figures 3-6	1,12,13
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A	paragraph [0162]; figure 24	1,12,13
Y	----- US 2010/157266 A1 (ZIMMERMANN JOERG [DE] ET AL) 24 June 2010 (2010-06-24)	9
A	paragraph [0045]; figure 6	1,12,13
	----- -/-	



Further documents are listed in the continuation of Box C.



See patent family annex.

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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

"&" document member of the same patent family

Date of the actual completion of the international search

19 December 2017

Date of mailing of the international search report

03/01/2018

Name and mailing address of the ISA/

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Authorized officer

Meixner, Matthias

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/075382

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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Information on patent family members

International application No

PCT/EP2017/075382

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