



(43) International Publication Date
6 October 2016 (06.10.2016)

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

(21) International Application Number:
PCT/EP2016/053120

(22) International Filing Date:
15 February 2016 (15.02.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
15161817.0 31 March 2015 (31.03.2015) EP

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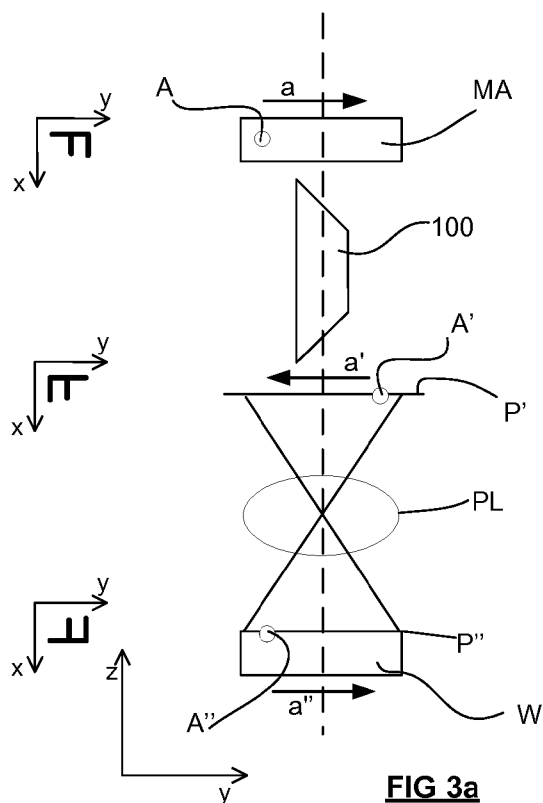
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(81) Designated States (unless otherwise indicated, for every
kind of national protection available): AE, AG, AL, AM,
AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY,
BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM,
DO, DZ, EC, EE, EG, ES, FI, GB, GD,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

(84) Designated States (unless otherwise indicated, for every
kind of regional protection available): ARIPO (BW, GH,
GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ,
TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU,
TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE,
DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU,
LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,

[Continued on next page]

(54) Title: Lithographic Apparatus and Method



(57) Abstract: During a scanning exposure a support structure is move-
able relative to a beam of radiation conditioned by an illuminator along
a scanning path, and a substrate table is movable relative to the pat-
terned radiation beam along a scanning path. An image transformation
optic is arranged between the support structure and the substrate table.
The image transformation optic is movable so as to control the charac-
teristics of the image formed on the substrate such that the image can be
transformed between a first configuration and a second configuration,
the second configuration being inverted relative to the first configura-
tion in a direction along the scanning path.



SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG). **Published:**

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

Lithographic Apparatus and Method

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of EP application 15161817.0 which was filed on
5 2015-Mar-31 and which is incorporated herein in its entirety by reference.

FIELD

[0002] The present invention relates to a lithographic apparatus and a device
manufacturing method. In particular, it relates to a scanning lithographic apparatus.

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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
15 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
20 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] It is desirable to provide, a lithographic apparatus that obviates or mitigates one or
25 more of the problems of the prior art, whether identified herein or elsewhere.

SUMMARY

[0005] According to a first aspect of the invention, there is provided a lithographic
apparatus comprising: a support structure for supporting a patterning device; an illumination
30 system for conditioning a radiation beam and directing the conditioned radiation beam to the
support structure so that a patterning device supported by the support structure imparts a
pattern in the cross-section of the radiation beam, forming a patterned radiation beam; a
substrate table for holding a substrate; and a projection system for projecting the patterned
radiation beam onto a target region of the substrate so as to form an image on the substrate;

wherein during a scanning exposure the support structure is moveable relative to the beam of radiation conditioned by the illuminator along a scanning path and the substrate table is movable relative to the patterned radiation beam along the scanning path; and wherein the lithographic apparatus further comprises an image transformation optic arranged between the support structure and the substrate table, the image transformation optic being movable so as to control the characteristics of the image formed on the substrate such that the image can be transformed between at least a first configuration and a second configuration, the second configuration being inverted relative to the first configuration in a direction along the scanning path.

[0006] Effectively, the image transformation optic is operable to alter the image inversion characteristics of the optical system that is disposed between the support structure and the substrate table. This allows the lithographic apparatus to form an image of the patterning device on the substrate in both: a first scanning mode wherein the movement of the support structure is parallel to that of the substrate table; and a second scanning mode wherein the movement of the support structure is anti-parallel to (i.e. aligned with but in the opposite direction to) that of the substrate table. Advantageously, such an arrangement allows for a plurality of target regions on a substrate to be irradiated in a particularly efficient manner.

[0007] The lithographic apparatus may be operable in a plurality of scanning modes, comprising at least: a first scanning mode, wherein the support structure is moved in a first direction along the scanning path, the substrate table is moved synchronously in the same direction along the scanning path and the image is in the first configuration; and a second scanning mode, wherein the support structure is moved in a second direction along the scanning path, the substrate table is moved synchronously in the opposite direction along the scanning path and the image is in the second configuration.

[0008] Moving the support structure in opposite directions in the first and second modes respectively allows two target regions to be irradiated without requiring the support structure to be moved between exposures of the two target regions, thus increasing the throughput of the lithographic apparatus. Further, inverting the image in the scanning direction between two successive exposures allows the substrate table to be moved in the same direction during both exposures. This allows an image of the patterning device to be formed on two target regions without requiring the direction of travel of the substrate table to be altered between exposures of the two target regions. This allows actuators which are responsible for moving the substrate table to be smaller and lighter. Further, it reduces the acceleration that the

substrate table undergoes, which, in turn, results in a better dynamic performance of the lithographic apparatus.

[0009] The second configuration of the image formed on the substrate may be rotated relative to the first configuration of the image by 180° about an optical axis of the lithographic apparatus.

[0010] Advantageously, this effectively ensures that substantially the same image is formed on each target region of the substrate, only the orientation of the image varying between the first and second configurations. Alternatively, the second configuration of the image formed on the substrate may be a reflection of the first configuration of the image by through a plane extending perpendicular to the scanning direction.

[0011] The image transformation optic may comprise one or more image inverting optics, the or each image inverting optics being arranged to invert the image in an inversion direction, the or each image inverting optic being rotatably mounted in the path of the patterned radiation beam such that it can rotate about an axis between at least a first position and a second position.

[0012] Transformation of the image between the first and second configurations can be achieved by rotation of the or each image inverting optic about the axis between the first and second positions.

[0013] The image transformation optic may comprise a single image inverting optic.

[0014] In the first configuration the image inverting optic may be arranged such that inversion direction is aligned with the scanning path. In the second configuration the image inverting optic may be arranged such that the inversion direction is perpendicular to the scanning path.

[0015] Alternatively, the image transformation optic may comprise a plurality of image inverting optics.

[0016] An advantage of an arrangement wherein the image transformation optic comprises a plurality of image inverting optics (as opposed to one) is that the total angular displacement of each image that is required to transform the image between first and second configurations may be reduced.

[0017] The image transformation optic may comprise n image inverting optics. In one of the first and second configurations, each of the image inverting optics may be arranged such that its inversion direction is disposed at an angle to the scanning path, a magnitude of the angle being $90/n^\circ$. In the other of the first and second configurations, each of the image inverting optics may be arranged such that its inversion direction is aligned with the scanning

path. Transformation of the image transformation device between the first and second configurations may be achieved by rotation of each of the n image inverting optics about a central axis of the lithographic apparatus by an angle with a magnitude of $90/n^\circ$. Increasing the number n of image inverting optics therefore reduces the magnitude of the total angular displacement of each image inverting optic. In turn this reduces the torque and power required to rotate each image inverting optic so as to transform between the first and second configurations.

[0018] The image transformation optic may comprise an even number of image inverting optics. For example, the image transformation optic may comprise two image inverting optics.

[0019] An advantage of an arrangement wherein the image transformation optic comprises an even number of image inverting optics is that the image transformation optic inverts the image of the patterning device in both the scanning and non-scanning directions. That is the image formed on the substrate is equivalent to the pattern on the patterning device, the equivalent images being related by a rotation about an optical axis of the lithographic apparatus. This may be desirable since it may simplify the process of designing and manufacturing patterning devices for the lithographic apparatus.

[0020] The or each image inverting optic may be a prism. The prism may for example be a Dove prism, a Pechan prism or an Abbe-Koenig prism.

[0021] The or each image inverting optic may be a reflective image inverting optic, comprising a plurality of mirrors.

[0022] The image inverting optic may comprise one or more optical elements which are moveable between a first arrangement wherein they cause the patterned radiation beam to converge and cross before it is projected onto the target region of the substrate and a second arrangement wherein the one or more optical elements do not cause the patterned radiation beam to converge and cross before it is projected onto the target region of the substrate.

[0023] For example, the image inverting optic may comprise an optical element which is provided with a pair of opposed convex surfaces and a second pair of opposed surfaces, and wherein when disposed in the first position the optical element is arranged such that the patterned radiation beam passes through the pair of opposed convex surfaces and wherein when disposed in the second position, the optical element is arranged such that the radiation beam passes through the second pair of opposed surfaces. Each of the second pair of opposed surfaces may be either concave or flat.

[0024] Alternatively, the image inverting optic may comprise one or more reflective optical elements.

[0025] The image transformation optic may comprise one or more optic that is movable in to and out of the path of the patterned radiation beam, the transition between the first and second configurations of the image being effected by movement of the one or more optics. The movement may be a translation, a rotation or a combination thereof.

[0026] The image transformation optic may comprise two substantially identical image inverting optics, each being movable in to and out of the path of the patterned radiation beam, a first one of the image inverting optics being arranged to invert the image in a first inversion direction when disposed in the path of the patterned radiation beam, and a second one of the image inverting optics being arranged to invert the image in a second inversion direction when disposed in the path of the patterned radiation beam, the first and second inversion directions being substantially perpendicular.

[0027] The use of two substantially identical prisms ensures that equivalent images are formed on the substrate in the two different configurations, the equivalent images being related by a rotation (not a reflection). Further, it ensures that the optical path length and attenuation of the radiation beam are the same in both configurations.

[0028] The two image inverting optics may each comprise a Dove prism or a Pechan prism.

[0029] The image transformation optic may comprise a single prism, the prism being movable in to and out of the path of the patterned radiation beam, and being arranged to fully invert the image in when disposed in the path of the patterned radiation beam.

[0030] Again, the use of a single optic which performs a full inversion ensures that the images formed in the first and second configurations are equivalent, being related by a rotation (not a reflection).

[0031] The image transformation optic may comprise one or more sensors and a controller, wherein the one or more sensors are operable to determine the position and/or orientation of the image transformation optic and output a signal indicative thereof to the controller.

[0032] The image transformation optic may comprises one or more actuators and the controller may be operable in response to the signal output by the one or more sensors to use the one or more actuators to control the position and/or orientation of the image transformation optic.

[0033] The controller may be operable in response to the signal output by the one or more sensors to control the position and/or orientation of the support structure and/or the substrate table.

[0034] According to a second aspect of the present invention there is provided a method
5 for forming an image on a plurality of target regions of a substrate comprising: providing a substrate with a plurality of target regions; providing a beam of radiation using an illumination system; providing a patterning device for imparting the radiation beam with a pattern in its cross-section; providing a projection system for projecting the patterned radiation beam onto a target region of the substrate so as to form an image on the substrate;
10 providing an image rotation device which is operable to control a configuration of the image formed on the substrate; forming an image on a first target region of the substrate by moving the support structure in a first direction along a scanning path relative to the radiation beam such that the radiation beam scans across the patterning device whilst simultaneously moving the substrate table in the same direction long the scanning path such that the patterned
15 radiation beam scans across the first target region forming an image with a first configuration; using the image rotation device to invert the image formed on the substrate in a direction along the scanning path to a second configuration; and forming an image on a second target region of the substrate by moving the support structure in a second, opposite direction along a scanning path relative to the radiation beam such that the radiation beam
20 scans across the patterning device whilst simultaneously moving the substrate table in the opposite direction along the scanning path such that the patterned radiation beam scans across the first target region forming an image with a second configuration.

[0035] The substrate may comprise a plurality of columns of target regions. Each column of target regions may extend in a direction along the scanning path of the lithographic
25 apparatus. The substrate table may be moved relative to the patterned radiation beam such that an exposure region of the patterned radiation beam follows a path which extends along each column of target regions in turn, alternating in direction between each pair of adjacent columns.

[0036] As the exposure region moves along a column of target regions on the substrate
30 one in n target regions are exposed.

[0037] 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

[0038] 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:

- 5 - Figure 1 depicts a lithographic apparatus according to an embodiment of the invention;
- Figure 2 is a schematic cross sectional view of a Dove prism, which may form part of an image transformation optic according to an embodiment of the invention;
- Figure 3 is a schematic view of a portion of a lithographic apparatus including an
10 image transformation optic according to an embodiment of the invention, with the image transformation optic disposed in (a) a first configuration and (b) a second configuration;
- Figure 4 illustrates a path that may be followed by an exposure slit of a lithographic apparatus over a substrate in accordance with a method according to an embodiment of the invention;
- 15 - Figure 5 illustrates another path that may be followed by an exposure slit of a lithographic apparatus over a substrate in accordance with a method according to an embodiment of the invention;
- Figure 6 illustrates an alternative path that may be followed by an exposure slit of a lithographic apparatus over a substrate;
- 20 - Figure 7 is a schematic view of a reflective optical system which may form part of an image transformation optic according to an embodiment of the invention;
- Figure 8 is a schematic view of an alternative optical element which may form part of an image transformation optic according to an embodiment of the invention;
- Figure 9 is a schematic view of a portion of a lithographic apparatus including an
25 image transformation optic according to another embodiment of the invention, with the image transformation optic disposed in (a) a first configuration and (b) a second configuration;
- Figure 10 is a schematic cross sectional view of a first embodiment of the image transformation optic of Figure 9, with the image transformation optic disposed in (a) a first configuration and (b) a second configuration; and
- 30 - Figure 11 is a schematic cross sectional view of a second embodiment of the image transformation optic of Figure 9, with the image transformation optic disposed in (a) a first configuration and (b) a second configuration.

DETAILED DESCRIPTION

[0039] 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 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 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.

[0040] 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 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.

[0041] 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 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.

[0042] 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 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.

[0043] 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”.

[0044] 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”.

[0045] 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”.

[0046] 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.

[0047] 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.

[0048] 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.

[0049] 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.

[0050] 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.

[0051] 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.

[0052] 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.

[0053] 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.

[0054] 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).

[0055] 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.

[0056] 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.

[0057] 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.

[0058] 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.

[0059] In order to form an image of the patterning device MA on the substrate W, the substrate table WT should be 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 .

[0060] 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 blades of the illuminator IL may 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 substrates respectively. At the start of a single dynamic exposure of a target region C, a first one of the blades of the slit may be disposed in the path of the radiation beam, acting as a shutter, such that no part of either of the exposure regions receives radiation. As a leading edge of the target region C of the substrate W that is being exposed moves into the exposure region, the first blade moves such that only the portion of the target region C that is disposed in the exposure region receives radiation (i.e. no parts of the substrate outside of the target region are exposed). Midway through the exposure of the target region C, both blades may be retracted out of the path of the radiation beam such that the entire exposure region receives radiation. As the leading edge of the target region C of the substrate moves out of the exposure region, a second one of the blades moves such that only the portion of the target region C that is disposed in the exposure region receives radiation.

[0061] 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 blades of the illuminator are not disposed in the path of the radiation beam PB.

[0062] Using the scan mode, the lithographic apparatus is operable to expose a target region C of the substrate W with 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.

[0063] During a scanning exposure: the support structure MT is moveable relative to the beam of radiation PB conditioned by the illuminator IL along a scanning path; and the substrate table WT is movable relative to the patterned radiation beam along the scanning path. For example, the first positioning device PM and a second position sensor (not shown) may be used to accurately position the support structure MT with respect to the path of the conditioned radiation beam PB. For example, the second positioning device PW and a position sensor IF may be used to accurately position the substrate table WT with respect to the path of the radiation beam projected by the projection system PL.

[0064] The lithographic apparatus further comprises an image transformation optic 100 arranged between the support structure MT and the projection system PL. The image transformation optic 100 is operable to control the characteristics of the image formed on the substrate W. In particular, the image transformation optic 100 allows the image formed on the substrate to be transformed between at least a first configuration and a second configuration, wherein the second configuration is inverted relative to the first configuration in the scanning direction. For example, relative to the first configuration the second configuration may be rotated by 180° about an optical axis of the lithographic apparatus (which axis may be generally perpendicular to the plane of the substrate W).

[0065] The image transformation optic 100 may be controlled (e.g. moved) so as to control the image reversal characteristics of the image formed on the substrate W in the scanning direction.

[0066] In order to accurately control the image transformation optic 100, it may be provided with one or more sensors 102, one or more actuators 104 and a controller CN. The one or more sensors 102 may be operable to determine the position and/or orientation of the image transformation optic 100 and output a signal (indicated by dashed arrow in Figure 1) indicative thereof to the controller CN. The controller CN may be operable in response to these signals to use the one or more actuators 104 to control the position and/or orientation of the image transformation optic 100. To achieve this the controller CN may be operable to send a control signal (indicated by dashed arrow in Figure 1) to the one or more actuators 104. The sensors 102, controller CN and actuators 104 therefore form a feedback loop which allows the position and orientation of the image transformation optic 100 to be controlled accurately.

[0067] To ensure that equivalent images are formed on the substrate W in the first and second configurations, the equivalent images being related by a rotation (not a reflection), it may be desirable to accurately control the position and orientation of the image

transformation optic 100 relative to the patterning device MA and the wafer W. The lithographic apparatus may be operable to compensate for manufacturing tolerances, rotation errors and/or translation errors of the image transformation optic 100. One mechanism by which the lithographic apparatus may achieve this is by way of the feedback loop provided by sensors 102, controller CN and actuators 104.

[0068] Additionally or alternatively, the lithographic apparatus may be operable to compensate for any errors in the position of the image transformation optic 100 relative to the patterning device MA and/or the wafer W by translation and/or rotation of the support structure MT and/or the substrate table WT. For example, in response to the signals received by the controller CN from the sensors 102, the controller CN may be further operable to output a signal (indicated by dashed arrow in Figure 1) to the first and/or second positioning devices PM, PW.

[0069] In one embodiment, the image transformation optic 100 comprises a Dove prism. As shown in Figure 2, in cross section, Dove prism 200 is trapezium shaped and comprises parallel, opposed rear and front faces 202, 204, and two opposed side faces 206, 208. Each side face 206, 208 is inclined at an angle of 45° to each of the rear and front faces 202, 204 such that Dove prism 200 is of the form of a truncated right-angle prism. The Dove prism 200 may be disposed such that the radiation beam PB that has been patterned by the patterning device MA propagates through the Dove prism 200 between, and parallel to, the rear and front faces 202, 204.

[0070] The patterned radiation beam passes through one of the sides faces 206 and is refracted towards the rear face 202. At the rear face 202 the patterned radiation beam undergoes total internal reflection and is directed towards the other side face 208, where it is refracted so that the outgoing radiation beam B_{out} extends parallel to the incoming radiation beam B_{in} . The dove prism 200 has a central axis 210. A ray R_1 of radiation that is aligned with the central axis 210 when the radiation is incident on the first side face 206 of the dove prism 200 is also be aligned with the central axis 210 as the ray R_1 leaves the dove prism 200.

[0071] A ray R_2 of radiation that is closer to the front face 204 of the Dove prism 200 when the radiation is incident on the Dove prism 200 is closer to the rear face 202 of the Dove prism 200 as the radiation leaves the Dove prism 200. Similarly, a ray R_3 of radiation that is closer to the rear face 202 of the Dove prism 200 when the radiation is incident on the Dove prism 200 is closer to the front face 204 of the Dove prism 200 as the radiation leaves the Dove prism 200. That is, the patterned radiation beam is inverted in the direction extending between the front and rear faces 202, 204 which may be referred to as the inversion

direction of the Dove prism 200. The patterned radiation beam is not inverted in the perpendicular direction. Therefore the an image formed after the Dove prism 200 is a reflection of the pattern imparted to the patterned radiation beam B_{in} , the reflection being through a plane that passes through the central axis and is perpendicular to the plane of Figure 2.

[0072] In one embodiment, the image transformation optic 100 comprises a Dove prism 200 that is disposed in the path of the radiation beam PB such that it can be rotated about its central axis 210 and is aligned such that the radiation beam PB that has been patterned by the patterning device MA propagates through the Dove prism 200 between, and parallel to, the rear and front faces 202, 204.

[0073] Referring to Figure 3, an image transformation optic 100 comprising a Dove prism 200 is shown in a first position (see Figure 3a) and a second position (see Figure 3b). The central axis 210 of Dove prism 200 is aligned with an optical axis O of the lithographic apparatus (which may coincide with a ray which represents the centre of the radiation beam as it propagates through the lithographic apparatus). Each point A on the patterning device MA has a conjugate point A' in a plane P' between the image transformation optic 100 and the projection system PL and a conjugate point A'' in the plane P'' of the substrate W.

[0074] In the first position, the Dove prism 200 is arranged such that the inversion direction (extending between the front and rear faces 202, 204) is aligned with the scanning direction (y direction). As such, in the scanning direction conjugate point A' in plane P' is disposed on an opposite side of the optical axis O of the lithographic apparatus to point A. Further, conjugate point A' moves in an opposite direction to that of point A, as indicated by arrows a and a'. The image of the patterning device MA in plane P' is inverted in the scanning direction and is not inverted in the non-scanning direction. That is, it is a mirror image of the pattern on the mask MA, having been reflected through a plane which extends through the optical axis O and parallel to the non-scanning direction (i.e. the x direction, out of the plane of Figure 3). The projection system PL fully inverts the image, i.e. in the plane P'' of the substrate W, the image formed in plane P' is rotated by 180° about the optical axis O. As such, in the scanning direction the conjugate point A'' (in the plane of substrate W) of point A (on the patterning device MA) is disposed on the same side of the optical axis O of the lithographic apparatus as point A. Further, said conjugate point A'' moves in the same direction as point A, as indicated by arrows a and a''. Therefore, when the image transformation optic 100 is disposed in its first position, the substrate table WT should be moved in the same direction as the support structure MT.

[0075] In the second position, the Dove prism 200 is arranged such that the inversion direction (extending between the front and rear faces 202, 204) is aligned with the non-scanning direction (x direction). As such, in the scanning direction conjugate point A' in plane P' is disposed on the same side of the optical axis O of the lithographic apparatus to point A. Further, conjugate point A' moves in the same direction to that of point A, as indicated by arrows a and a'. The image of the patterning device MA in plane P' is inverted in the non-scanning direction and is not inverted in the scanning direction. That is, it is a mirror image of the pattern on the mask MA, having been reflected through a plane which extends through the optical axis O and parallel to the scanning direction (i.e. the y direction, in the plane of Figure 3). The projection system PL fully inverts the image, i.e. in the plane P'' of the substrate W, the image formed in plane P' is rotated by 180° about the optical axis O. As such, in the scanning direction the conjugate point A'' (in the plane of substrate W) of point A (on the patterning device MA) is disposed on the opposite side of the optical axis O of the lithographic apparatus to point A. Further, said conjugate point A'' moves in the opposite direction to point A, as indicated by arrows a and a''. Therefore, when the image transformation optic 100 is disposed in its second position, the substrate table WT should be moved in the opposite direction to the support structure MT.

[0076] Transformation between the first and second position of Dove prism 200 is achieved by rotation of the Dove prism 200 about its central axis 210 by an angle of 90°. This effectively rotates the image formed in plane P' by an angle of 180°, transforming the image between the first and second configurations.

[0077] In order to achieve rotation of the Dove prism 200 about its axis 210, the Dove prism may be provided with any suitable actuator and may be supported by any suitable bearing. The bearing may for example comprise an active magnetic bearing, which may allow the image transformation optic 100 to achieve high resolution. The rotation of the Dove prism 200 about its central axis 210 between the first and second positions may be in the same direction as rotation of the Dove prism 200 about its central axis 210 between the second and first positions. Alternatively, in some embodiments, the rotation of the Dove prism 200 between the first and second positions may be in the opposite direction to the rotation of the Dove prism 200 between the second and first positions such that the Dove prism rotates back and forth between the first and second positions.

[0078] Effectively, the image transformation optic 100 is operable to alter the image inversion characteristics of the optical system that is disposed between the support structure MT and the substrate table WT. This allows the lithographic apparatus to form an image of

the patterning device MA on the substrate W in both: a first scanning mode wherein the movement of the support structure MT is parallel to that of the substrate table WT; and a second scanning mode wherein the movement of the support structure MT is anti-parallel to that of the substrate table WT. Such an arrangement allows for a plurality of target regions C on a substrate W to be irradiated in a particularly efficient manner, as now described.

[0079] Moving the support structure MT in opposite directions in the first and second modes respectively allows two target regions C to be irradiated without requiring the support structure MT to be moved between exposures of the two target regions. Further, inverting the image in the scanning direction (for example by rotating the image by 180°) between two successive exposures allows the substrate table WT to be moved in the same direction during both exposures. This allows an image of the patterning device MA to be formed on two target regions without requiring the direction of travel of the substrate table WT to be altered between exposures of the two target regions. This allows actuators which are responsible for moving the substrate table WT (e.g. second positioning device PW) to be smaller and lighter. Further, it reduces the acceleration that the substrate table WT undergoes, which, in turn, results in a better dynamic performance of the lithographic apparatus. That is, it reduces vibrations, improving the image formed on the substrate W.

[0080] The sequence in which target regions C of the substrate W are exposed according to an embodiment of the invention will now be described with reference to Figure 4. During exposure of a target region C, the projection system PL is operable to project a band of radiation (the slit) onto an exposure region 105 in the plane of the substrate W. The substrate W is mounted on the substrate table WT of the lithographic apparatus, which moves the substrate W relative to the projection system PL such that the exposure region 105 moves over the substrate W. In particular, the motion is such that the exposure region 105 follows path 110 indicated by dashed line. In Figure 4, the y-direction corresponds to the scanning direction of the lithographic apparatus and the x-direction corresponds to a non-scanning direction.

[0081] The substrate W comprises a plurality of generally rectangular target regions C, which form a two dimensional array across the surface of the substrate W. The two dimensional array of target regions C may be considered to comprise a plurality of columns 121-127 of target regions C, each column 121-127 of target regions C extending in the scanning direction of the lithographic apparatus. The two dimensional array of target regions C may also be considered to comprise a plurality of rows of target regions C, each row of target regions C extending in the non-scanning direction of the lithographic apparatus. The

path 110 extends along each column 121-127 of target regions C in turn, alternating in direction between each pair of adjacent columns 121-127. That is, path 110 extends along a first column 121 of target regions C in a first direction along the scanning direction (i.e. positive y direction), then extends along a second column 122 of target regions C in an opposite direction along the scanning direction (i.e. negative y direction) and so on.

[0082] As the exposure region 105 moves along a column of target regions C on the substrate W one or more target regions C in that row are exposed to radiation. In some embodiments, each target region C in the column is exposed in turn. For such embodiments, once the exposure region 105 has been scanned over the entire path 110, all of the target regions C on the substrate will have been exposed. As explained above, as the exposure region 105 scans over the substrate W, the exposure of the substrate W to radiation may be controlled using the pair of blades in the illuminator IL.

[0083] In other embodiments, as the exposure region 105 moves along a column of target regions C on the substrate W one in n target regions C may be exposed. For example, one in two target regions C may be exposed (by exposing every other target region C). This may allow sufficient time for the image transformation optic 100 to transform the image formed on the substrate between the first and second configurations. For such embodiments, the substrate table WT may move so as to cause the exposure region 105 to follow path 110, or a similar path, n times such that once the exposure region 105 has been scanned over the entire substrate W n times, all of the target regions C on the substrate W have been exposed.

[0084] In an alternative embodiment, as in Figure 5, the exposure region 105 may follow an alternative path 112. The path 112 passes over each column 121-127 of target regions in turn. The path 112 extends along each column 121-127 of target regions C first in one direction (e.g. positive y direction) and then in the opposite direction (e.g. negative y direction). Such a path 112 may for example be used in embodiments wherein as the exposure region 105 moves along a column of target regions C on the substrate W one in two target regions C are exposed. For example as the exposure region 105 passes over each column 121-127 of target regions C in the first direction a first half of the target regions C may be exposed. Then, when the exposure region 105 passes over each column 121-127 of target regions C in the opposite direction a second half of the target regions C may be exposed.

[0085] The provision of the image transformation optic 100 allows the exposure of two consecutive target regions C to be achieved with the support structure MT travelling in opposite directions (which can improve throughput) and with the substrate table WT moving

in the same direction (which avoids very high accelerations associated with changing direction between each exposure of a target region C). Without the image transformation optic 100, in order to move the support structure MT in two opposite directions for the exposure of two subsequent target regions, the substrate table WT would also need to be moved in opposite directions for the two exposures. For such an arrangement, the same patterning device MA is used for both exposures and so the support structure MT may simply oscillate back and forth in the scanning direction. However, in addition to the back and forth scanning motion in the scanning direction, the substrate table WT also needs to be moved such that a different target region C is exposed.

[0086] One way to achieve this is to perform a meander scan wherein the exposure region 105 traces out a path that will be described with reference to Figure 6. During a meander scan, each row of target regions C (which extends in the non-scanning direction) is exposed in turn. Figure 6 illustrates the path 114 that the exposure region 105 follows over the surface of the substrate W during the exposure of a single row 130 of target regions. As each target region C is exposed, the exposure region 105 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 is adjacent to the next target region C) and changes direction in the scanning direction. A meander scan may lead to demanding acceleration requirements and may, for example, require the substrate table WT to undergo accelerations of the order of tens of m/s^2 or above. Further a meander scan may require a complex substrate table WT design which can deal with the high forces and high heat loads that are generated during the scan.

[0087] In contrast, the provision of the image transformation optic 100 allows the scan paths described above (with reference to Figures 4 and 5) and avoids the use of a meander scan. This allows actuators which are responsible for moving the substrate table WT to be smaller and lighter. Further, it reduces the acceleration that the substrate table undergoes (for a given throughput) and results in a better dynamic performance. That is, it reduces the level of vibrations that result from the acceleration of the substrate table WT due to residual forces from the substrate table WT. In turn, this may result in a better printing performance of the lithographic apparatus. For example, the image formed on the substrate may be sharper and the lithographic apparatus may have better overlay control (i.e. better alignment between different layers of patterns on the substrate W).

[0088] In the above described embodiment, the image transformation optic 100 comprises image inverting optics (Dove prism 200) that are rotatably mounted such that they

can rotate about the optical axis O of the lithographic apparatus. The mass of the image transformation optic 100 may be significantly less than that of the substrate table WT, in particular significantly less than that of a short-stroke module (used for fine positioning) of the second positioning device PW. Therefore, if an equivalent controller is used for the image transformation optic 100 and the short-stroke module of the second positioning device PW then one would expect the image transformation optic 100 to have higher control bandwidth than the short-stroke module of the second positioning device PW. This higher control bandwidth results in an increase in the accuracy with which the substrate table WT can be positioned by the second positioning device PW (i.e. a reduction in the positioning error of the substrate table WT). In one embodiment, the total moving mass of the image transformation optic 100 may, for example, be around 10 kg. For example, the mass of the image transformation optic 100 may be of the order of 5 kg. Further, the image transformation optic 100 may be provided with a housing and a motor, which may have a combined mass of around 5 kg. As explained above, in order to transition between the first and second configurations, the image inverting optic (for example Dove prism 200) should rotate through an angle of 90° .

[0089] In an embodiment, the exposure region 105 is scanned continuously across each column of target regions C at a speed v_s of the order of 1 m/s and every other target region C is exposed during this scan (i.e. one in two target regions C are exposed during the scan). Such selective exposure of target regions C (e.g. exposure of every other target region C) may for example be achieved using the blades of the illuminator IL to block the radiation while the exposure region 105 is scanned over a target region C which is not exposed. As the exposure region 105 is scanned over a target region C which is not being exposed (in between two target regions C which are exposed), the image transformation optic 100 should rotate through an angle of 90° . This rotation should be completed in the time taken for the exposure region 105 to move over a single target region C. For example, assuming that the length of each target region in the scanning direction is around 33 mm, the image transformation optic should rotate through an angle of 90° in a time of around 33 ms or less. Assuming that the image transformation optic undergoes constant angular acceleration (i.e. a second order motion profile), the angular acceleration should be at least 5800 rad/s^2 and the maximum angular velocity will be at least 95 rad/s. If the rotational moment of inertial of the total moving mass is around 0.1 kgm^2 , a torque of 580 Nm or more is required.

[0090] Although in the above described embodiment, a Dove prism 200 is used as an image inverting optic, in alternative embodiments other types of image inverting prisms may

be used. For example, a Pechan prism or an Abbe prism may be used in place of a Dove prism.

[0091] Although in the above described embodiment, a Dove prism 200 is used as an image inverting optic, in alternative embodiments a reflective image inverting optic, comprising a plurality of mirrors may be used. For example, as shown in Figure 7, a system 300 of three mirrors M_1 , M_2 , M_3 may be used to achieve an equivalent image inversion to that of the Dove prism of Figure 2. Such a system may also be mounted on a rotatable housing in a similar way to the Dove prism 200 described above. Such an arrangement using reflective optics (i.e. mirrors) rather than transmissive optics (e.g. prisms) may be used for embodiments wherein the radiation beam comprises extreme ultraviolet (EUV) radiation.

[0092] In the above described embodiments, the image transformation optic 100 comprises image inverting optics that are rotatably mounted such that they can rotate about the optical axis of the lithographic apparatus. In alternative embodiments, the image transformation optic may comprise one or more optics that can be moved in and out of the path of the patterned radiation beam (e.g. by translation or rotation) to effect a change between first and second configurations. For example, two identical Dove prisms may be provided, each being moveable by translation into and out of the path of the radiation beam. A first one of the Dove prisms may be orientated to invert the image in the scanning direction when it is disposed in the path of the radiation beam. A second one of the Dove prisms may be orientated to invert the image in the non-scanning direction when it is disposed in the path of the radiation beam. The use of two identical prisms ensures that equivalent images are formed on the substrate W in the two different configurations, the equivalent images being related by a rotation (not a reflection). Further, it ensures that the optical path length and attenuation of the radiation beam are the same in both configurations.

[0093] Alternatively, a single prism which is operable to fully invert the image (in both the scanning and non-scanning directions) may be provided such that it can be moved into and out of the path of the radiation beam PB. Again, the use of a single optic which performs a full inversion ensures that the images formed in the first and second configurations are equivalent, being related by a rotation (not a reflection). For such embodiments, the first and second configurations may be subject to different levels of attenuation of the radiation beam. This may be corrected for by adjusting an attenuation of the radiation beam elsewhere in the lithographic apparatus. For example, the moveable fingers in the illuminator IL may be used to adjust the level of attenuation provided by the illuminator IL when the image transformation optic transitions between the first and second configurations.

[0094] In an alternative embodiment, the image transformation optic 100 may comprise one or more optical elements which are moveable between a first arrangement wherein they cause the patterned radiation beam PB to converge and cross before it is projected onto a target region of the substrate W and a second arrangement wherein the one or more optical elements do not cause the patterned radiation beam PB to converge and cross before it is projected onto the target region of the substrate W.

[0095] For example, the image transformation optic 100 may comprise a rotatable optical element which is provided with a pair of opposed convex surfaces and a pair of opposed concave or flat surfaces. Such an image transformation optic is shown in Figure 8. The optical element 400 is generally spherical, having a generally spherical surface 402 which is provided with two opposed spherical concave recesses 404, 406. In an alternative embodiment, the generally spherical surface 402 may be provided with two opposed flat portions or the concave recesses may be non-spherical. The optical element 400 is supported for rotation about an axis 410 which is perpendicular to the optical axis O of the lithographic apparatus and is aligned with a non-scanning direction (i.e. the x direction, into the plane of Figure 8).

[0096] In Figure 8, an image transformation optic 100 comprising optical element 400 is shown in a first position (see Figure 8a) and a second position (see Figure 8b). Each point B on the patterning device MA has a conjugate point B' in a plane P' between the image transformation optic 100 and the projection system PL and a conjugate point B'' in the plane P'' of the substrate W.

[0097] In the first position, the optical element 400 is arranged such that the radiation beam passes through opposed (convex) sections of spherical surface 402. As such, the image in plane P' is inverted such that in both the scanning direction and the non-scanning direction conjugate point B' in plane P' is disposed on an opposite side of the optical axis O of the lithographic apparatus to point B. Further, conjugate point B' moves in an opposite direction to that of point B. The image of the patterning device MA in plane P' is fully inverted (in both the scanning and non-scanning directions) such that in plane P', the image formed is rotated by 180° about the optical axis O. The projection system PL fully inverts the image, i.e. in the plane P'' of the substrate W, the image formed in plane P' is rotated by 180° about the optical axis O. That is, the image of the patterning device MA in plane P'' is erect. As such, in the scanning direction the conjugate point B'' (in the plane of substrate W) of point B (on the patterning device MA) is disposed on the same side of the optical axis O of the lithographic apparatus as point B. Further, said conjugate point B'' moves in the same

direction as point B. Therefore, when the image transformation optic 100 is disposed in its first position, the substrate table WT should be moved in the same direction as the support structure MT.

[0098] In the second position, the optical element 400 is arranged such that the radiation beam passes through opposed concave recesses 404, 406. As such, the image of the patterning device MA in plane P' is erect, such that in both the scanning direction and the non-scanning direction conjugate point B' in plane P' is disposed on the same side of the optical axis O of the lithographic apparatus as point B. Further, conjugate point B' moves in the same direction as that of point B. The projection system PL fully inverts the image, i.e. in the plane P'' of the substrate W, the image formed in plane P' is rotated by 180° about the optical axis O. As such, in the scanning direction the conjugate point B'' (in the plane of substrate W) of point B (on the patterning device MA) is disposed on the opposite side of the optical axis O of the lithographic apparatus to point B. Further, said conjugate point B'' moves in the opposite direction to point B. Therefore, when the image transformation optic 100 is disposed in its second position, the substrate table WT should be moved in the opposite direction to the support structure MT.

[0099] Transformation between the first and second positions is achieved by rotation of the optical element 400 about its central axis 410 by an angle of 90°. This effectively rotates the image formed in plane P' by an angle of 180°, transforming the image between the first and second configurations.

[00100] With this embodiment, when the optical element 400 is disposed in the first position it will cause the radiation beam PB to converge such that beams on opposing sides of the radiation beam PB will cross before entering the projection system PL. Note that in alternative embodiments this may be achieved by any two opposed convex surfaces which will cause beams on opposing sides of the radiation beam PB to cross before entering the projection system PL. In particular, the two convex surfaces may not be identical. For example, they may in general have different radii of curvature.

[00101] When the optical element 400 is disposed in the second position it will cause the radiation beam PB to diverge. The divergence may be such that the entire radiation beam PB still enters an aperture of the projection system PL. Alternatively, when the optical element 400 is disposed in the second position additional optics (not shown) may be used to ensure that the entire radiation beam PB still enters an aperture of the projection system PL. In a variation of this embodiment, rather than two opposed spherical concave recesses 404, 406, the generally spherical surface 402 is provided with two opposed flat portions. With such an

arrangement, when the optical element is disposed in the second configuration the radiation beam PB will neither diverge nor converge. Note that in alternative embodiments opposed spherical concave recesses 404, 406 may be replaced by any two opposed surfaces which will cause radiation beam PB to either remain parallel or diverge before entering the projection system PL. In particular, the two opposed surfaces may not be identical. As already described, the two opposed optical surfaces may both be concave or may both be flat. In alternative embodiments, the two opposed optical surfaces comprise a concave surface and a flat surface or, alternatively, they may comprise a concave surface and a convex surface.

[00102] In an alternative embodiment, the optical element 400 may be provided within the projection system PL.

[00103] Although in the above described embodiment, a transmissive optical element 400 is used as an image inverting optic, in alternative embodiments a reflective image inverting optic, comprising a plurality of mirrors, may be used. For example, a system comprising a plurality of movable mirrors may be used to achieve an equivalent image inversion to that of the optical element 400 of Figure 8.

[00104] In the embodiment described above with reference to Figure 3, the image transformation optic 100 comprises an image inverting optic (e.g. Dove prism 200) that is disposed in the path of the radiation beam PB. A central axis of the image inverting optic is aligned with the optical axis O of the lithographic apparatus such that the radiation beam PB that has been patterned by the patterning device MA propagates through the inverting optic. As patterned radiation beam PB propagates through the image inverting optic the patterned radiation beam is inverted in an inversion direction (which is generally perpendicular to the optical axis O of the lithographic apparatus). The image inverting optic is arranged such that it can be rotated about its central axis. Rotation of the image inverting optic about its central axis rotates the inversion direction of the optic and therefore rotates the patterned radiation beam about the optical axis O of the lithographic apparatus. As explained above, in order to transition between the first and second configurations of the image formed on substrate W, the image inverting optic (Dove prism 200) rotates through an angle of 90°. Further, in some embodiments, this rotation should be completed in the time taken for the exposure region 105 to move over a single target region C (e.g. if every other target region C is to be exposed in each pass). For a given throughput (which determines a scan speed v_s of the exposure region 105 over the substrate W) this leads to a required angular acceleration and a required torque.

[00105] In an alternative embodiment, the image transformation optic 100 may comprise a plurality of image inverting optics. Each of the plurality of image inverting optics may for

example comprise a Dove prism substantially as shown in Figure 2 and as described above. Such an image transformation optic 500 (which comprises a plurality of image inverting optics) is now described with reference to Figures 9, 10 and 11.

[00106] The image transformation optic 500 shown in Figure 9 may be the used as the
5 image rotation optic 100 of Figure 1. Therefore, in use, the image transformation optic 500 is disposed in the path of the radiation beam PB such that the radiation beam PB (which has been patterned by the patterning device MA) propagates through it. Each of the plurality of image inverting optics which form part of the image transformation optic 500 can be independently moved through a range of positions, as will be described further below with
10 reference to Figures 10 and 11. A set of positions of each of the plurality of image inverting optics may be referred to as a configuration of the image transformation optic 500.

[00107] As patterned radiation beam PB propagates through the image transformation optic 500 the patterned radiation beam PB is inverted in an inversion direction. The inversion direction lies in a plane that is generally perpendicular to the optical axis O of the
15 lithographic apparatus (i.e. the inversion direction lies in the x-y plane of Figure 9). In some embodiments of image transformation optic 500 the patterned radiation beam PB is also inverted in the direction within that plane which is perpendicular to the inversion direction. In other embodiments of image transformation optic 500 the patterned radiation beam PB is not inverted in the direction within that plane which is perpendicular to the inversion
20 direction. The inversion direction of the image transformation optic 500 is dependent upon the configuration of image transformation optic 500 (i.e. the positions and/or orientations of each of the plurality of image inverting optics).

[00108] An orientation of each of the plurality of image inverting optics may be characterized by a signed angle measured from a reference direction to the inversion direction
25 of that image inverting optic. For example, the reference direction may be the scanning direction (i.e. the y direction in Figures 9, 10 and 11). The sign of the angle between a reference direction and the inversion direction may be determined by the direction in which the angle is measured from the reference direction to the inversion direction. For example, one sign convention is that if the angle is measured in a clockwise sense from the reference
30 direction to the inversion direction then the angle is negative and if the angle is measured in an anti-clockwise sense from the reference direction to the inversion direction then the angle is positive. This sign convention will be used in the following. An alternative sign convention may be that if the angle is measured in a clockwise sense from the reference direction to the inversion direction then the angle is positive and if the angle is measured in

an anti-clockwise sense from the reference direction to the inversion direction then the angle is negative.

[00109] In Figure 9 the image transformation optic 500 is shown in a first configuration (see Figure 9a) and a second configuration (see Figure 9b). Each point A on the patterning device MA has a conjugate point A' in a plane P' between the image transformation optic 500 and the projection system PL and a conjugate point A'' in the plane P'' of the substrate W.

[00110] In the first configuration, the image transformation optic 500 is arranged such that its inversion direction is aligned with the scanning direction (y direction). As such, in the scanning direction conjugate point A' in plane P' is disposed on an opposite side of the optical axis O of the lithographic apparatus to point A. Further, conjugate point A' moves in an opposite direction to that of point A, as indicated by arrows a and a'. As illustrated by two example images 520a, 520b, the image of the patterning device MA in plane P' may either be: (a) inverted in the scanning direction and not inverted in the non-scanning direction; or (b) inverted in both the scanning and non-scanning directions. That is, the image may be either: (a) a mirror image of the pattern on the mask MA, as reflected through a plane which extends through the optical axis O and parallel to the non-scanning direction; or (b) a rotation of the pattern on the mask MA by 180° about the optical axis O.

[00111] In the second configuration, the image transformation optic 500 is arranged such that its inversion direction is aligned with the non-scanning direction (x direction). As such, in the scanning direction conjugate point A' in plane P' is disposed on the same side of the optical axis O of the lithographic apparatus to point A. Further, conjugate point A' moves in the same direction to that of point A, as indicated by arrows a and a'. As illustrated by two example images 530a, 530b, the image of the patterning device MA in plane P' may either be: (a) inverted in the non-scanning direction and not inverted in the scanning direction; or (b) erect (i.e. not inverted in either of scanning direction or the non-scanning direction). That is, the image may be either: (a) a mirror image of the pattern on the mask MA, as reflected through a plane which extends through the optical axis O and parallel to the scanning direction; or (b) the pattern on the mask MA.

[00112] The projection system PL fully inverts the image, i.e. in the plane P'' of the substrate W, the image formed in plane P' is rotated by 180° about the optical axis O.

[00113] When the image transformation optic 500 is disposed in the first configuration, in the scanning direction the conjugate point A'' (in the plane of substrate W) of point A (on the patterning device MA) is disposed on the same side of the optical axis O of the lithographic

apparatus as point A. Further, said conjugate point A'' moves in the same direction as point A, as indicated by arrows a and a''. Therefore, when the image transformation optic 500 is disposed in its first configuration, the substrate table WT should be moved in the same direction as the support structure MT.

5 [00114] In contrast, when the image transformation optic 500 is disposed in the second configuration, in the scanning direction the conjugate point A'' (in the plane of substrate W) of point A (on the patterning device MA) is disposed on the opposite side of the optical axis O of the lithographic apparatus to point A. Further, said conjugate point A'' moves in the opposite direction to point A, as indicated by arrows a and a''. Therefore, when the image
10 transformation optic 100 is disposed in its second configuration, the substrate table WT should be moved in the opposite direction to the support structure MT.

[00115] Transformation of the image transformation optic 500 between the first and second configurations is achieved by rotation of the individual image inverting optics, as now described.

15 [00116] In a first embodiment, as shown in Figure 10, the image transformation optic 500 comprises two Dove prisms 502, 504 (depicted schematically as rectangles). The central axes of the two Dove prisms 502, 504 are aligned and define a central axis 510 of the image transformation optic 500. In use, central axis 510 is aligned with the optical axis O of the lithographic apparatus such that the radiation beam PB (patterned by the patterning device
20 MA) propagates through each of the Dove prisms 502, 504 in turn. Each of the Dove prisms 502, 504 is arranged such that it can be rotated about central axis 510. This allows the inversion direction of each Dove prism 502, 504 (which extends between the front and rear faces 202, 204 of that Dove prism) to be varied.

[00117] Referring to Figure 10, image transformation optic 500 is shown in a first
25 configuration (see Figure 10a) and a second configuration (see Figure 10b). In Figure 10, the orientation of the patterned radiation beam PB is illustrated in three planes P₁, P₂, P₃ which are perpendicular to the central axis 510. In use, plane P₁ is disposed between the patterning device MA and a first Dove prism 502; plane P₂ is disposed between the first Dove prism 502 and a second Dove prism 504; and plane P₃ is disposed between the second Dove prism 504
30 and the projection system PL (and may correspond to plane P' in Figure 9).

[00118] In the first configuration (see Figure 10a), the first Dove prism 502 is orientated such that its inversion direction is disposed at an angle of +45° to the scanning direction (y direction). The second Dove prism 504 is orientated such that its inversion direction is perpendicular to that of the first Dove prism 502, i.e. the inversion direction of the second

Dove prism 504 is disposed at an angle of -45° to the scanning direction (y direction). In an alternative embodiment, the first Dove prism 502 may be orientated such that its inversion direction is disposed at an angle of -45° to the scanning direction and the second Dove prism 504 may be orientated such that its inversion direction is disposed at an angle of $+45^\circ$ to the scanning direction. Therefore, for embodiments comprising two Dove prisms 502, 504 the first configuration may be achieved with more than one set of positions of the individual Dove prisms. In the first configuration, in plane P_3 the image is inverted the scanning direction. Since this embodiment of the image transformation optic 500 comprises an even number (two) of Dove prisms, in plane P_3 the image of the patterning device MA is inverted in both the scanning and non-scanning directions. That is, the image transformation optic 500 rotates the image of the pattern on the mask MA by 180° about the optical axis O.

[00119] In the second configuration (see Figure 10b), the first Dove prism 502 is arranged such that its inversion direction is aligned with the scanning direction (y direction). The second Dove prism 504 is also arranged such that its inversion direction is aligned with the scanning direction (y direction). As such, in plane P_3 the image is erect. That is, in plane P_3 the image is the same as the pattern on the mask MA (i.e. it is not inverted in either the scanning direction or the non-scanning direction).

[00120] Transformation of image transformation device 500 between the first and second configurations is achieved by rotation of both Dove prisms 502, 504 about central axis 510 by an angle of $\pm 45^\circ$. This effectively rotates the image formed in plane P_3 by an angle of 180° , transforming the image between first and second configurations.

[00121] Image transformation optic 500 comprises two Dove prisms 502, 504, each of which rotates through an (absolute) angle of 45° to transform the image between first and second configurations. This can be compared with the image transformation optic illustrated in Figure 3, which comprises a single Dove prism 200 which rotates through an angle of 90° in order to transform the image between first and second configurations. Therefore, by increasing the number of image inverting optics, the magnitude of the angle through which each one should be rotated in order to transform the image between first and second configurations is decreased. If it is desirable to transform the image between first and second configurations in a given switching time, the torque which must be supplied by the actuators that rotate the two Dove prisms 502, 504 of image transformation optic 500 is significantly less than the torque which must be supplied by the actuator of the single Dove prism 200 of the image transformation optic illustrated in Figure 3.

[00122] The mass of each Dove prism 502, 504 may be significantly less than that of the substrate table WT, in particular significantly less than that of a short-stroke module (used for fine positioning) of the second positioning device PW. Therefore, if an equivalent controller is used for each of the Dove prisms 502, 504 and the short-stroke module of the second positioning device PW then one would expect the Dove prisms 502, 504 to have higher control bandwidth than the short-stroke module of the second positioning device PW. In one embodiment, the total moving mass associated with each Dove prism 502, 504 may, for example, be around 10 kg. For example, the mass of each Dove prism 502, 504 may be of the order of 5 kg. Further, each Dove prism 502, 504 may be provided with a housing and a motor, which may have a combined mass of around 5 kg.

[00123] In an embodiment, the exposure region 105 is scanned continuously across each column of target regions C at a constant speed v_s and every other target region C is exposed during this scan. For such embodiments, each of the Dove prisms 502, 504 should rotate through an angle with a magnitude of 45° in the time taken for the exposure region 105 to move over a single target region C. For example, speed v_s may be of the order of 1 m/s and the length of each target region in the scanning direction may be around 33 mm. Therefore, for such an example, each of the Dove prisms 502, 504 should rotate through an angle of 45° in a time of around 33 ms or less.

[00124] Each Dove prism 502, 504 may undergo constant angular acceleration (i.e. a second order motion profile), wherein the angular velocity of each Dove prism 502, 504 increases linearly from zero up to a maximum angular velocity and then decreases linearly back to zero. Assuming such a second order motion profile, the maximum angular velocity $\omega_{\max}$ is given by $2\theta/t$, where θ is the magnitude of the total angular displacement of the Dove prism 502, 504 (i.e. 45° for this embodiment) and t is the time taken for the rotation. The magnitude of the angular acceleration is given by $2\omega_{\max}/t$ or, equivalently, $4\theta/t^2$. The required torque T is given by the product of the angular acceleration and the rotational moment of inertia of the total moving mass, I . Further, the required power is given by a product of the required torque and the angular velocity. Therefore, the maximum power required is given by $8I\theta^2/t^3$.

[00125] From the above discussion, it can be seen that by reducing the magnitude of the total angular displacement of each Dove prism 502, 504 by a factor of two (i.e. from 90° to 45°), the torque required to be applied to each Dove prism 502, 504 is reduced by a factor of two and the power required is reduced by a factor of four.

[00126] In a second embodiment, as shown in Figure 11, the image transformation optic 500 comprises three Dove prisms 502, 504, 506. The central axes of the three Dove prisms 502, 504, 506 are aligned and define a central axis 510 of the image transformation optic 500. In use central axis 510 is aligned with the optical axis O of the lithographic apparatus such that the radiation beam PB (patterned by the patterning device MA) propagates through each of the Dove prisms 502, 504, 506 in turn. Each of the Dove prisms 502, 504, 506 is arranged such that it can be rotated about central axis 510. This allows the inversion direction of each Dove prism 502, 504, 506 (which extends between the front and rear faces 202, 204 of that Dove prism) to be varied.

[00127] Referring to Figure 11, image transformation optic 500 is shown in a first configuration (see Figure 11a) and a second configuration (see Figure 11b). In Figure 11, the orientation of the patterned radiation beam PB is illustrated in four planes P_1 , P_2 , P_3 , P_4 which are perpendicular to the central axis 510. In use, plane P_1 is disposed between the patterning device MA and a first Dove prism 502; plane P_2 is disposed between the first Dove prism 502 and a second Dove prism 504; plane P_3 is disposed between the second Dove prism 504 and a third Dove prism 506; and plane P_4 is disposed between the third Dove prism 506 and the projection system PL (and may correspond to plane P' in Figure 9).

[00128] In the first configuration (see Figure 11a), the Dove prisms 502, 504, 506 are arranged such that in plane P_3 the image is inverted the scanning direction. Since this embodiment of the image transformation optic 500 comprises an odd number (three) of Dove prisms, in plane P_3 the image of the patterning device MA is inverted in the scanning direction and not inverted in the non-scanning direction. That is, the image is a mirror image of the pattern on the mask MA, as reflected through a plane which extends through the optical axis O and parallel to the non-scanning direction. For such an embodiment comprising three Dove prisms 502, 504, 506, this first configuration may be achieved with more than one set of positions of the individual Dove prisms. In the example shown in Figure 11, in the first configuration each one of the Dove prisms 502, 504, 506 is arranged such that its inversion direction is aligned with the scanning direction (y direction). In general, in the first configuration two of the Dove prisms 502, 504 may be arranged such that their inversion directions are aligned (and therefore they will have no net effect on the image orientation) and a third of the Dove prisms 506 may be arranged such that its inversion direction is aligned with the scanning direction (y direction).

[00129] In the second configuration (see Figure 11b), the Dove prisms 502, 504, 506 are arranged such that in plane P_3 the image is inverted in the non-scanning direction and not

inverted in the scanning direction. That is, the image is a mirror image of the pattern on the mask MA, as reflected through a plane which extends through the optical axis O and parallel to the scanning direction. Again, for such an embodiment comprising three Dove prisms 502, 504, 506, this second configuration may be achieved with more than one set of positions of the individual Dove prisms. In the example shown in Figure 11, in the second configuration (see Figure 11b), the first Dove prism 502 is orientated such that its inversion direction is disposed at an angle of -30° to the scanning direction (y direction); the second Dove prism 504 is orientated such that its inversion direction is disposed at an angle of $+30^\circ$ to the scanning direction; and the third Dove prism 506 is orientated such that its inversion direction is disposed at an angle of -30° to the scanning direction.

[00130] Transformation of image transformation device 500 between the first and second configurations is achieved by rotation of each of the Dove prisms 502, 504, 506 about central axis 510 by an angle of $\pm 30^\circ$. This effectively rotates the image formed in plane P_4 by an angle of 180° , transforming the image between first and second configurations. Therefore the image transformation optic 500 of Figure 11 comprises three Dove prisms 502, 504, 506, each of which rotates through an (absolute) angle of 30° to transform the image between first and second configurations.

[00131] In general, the image transformation device 500 of Figure 9 may comprise n image inverting optics (where $n \geq 2$). Transformation of the image transformation device 500 between the first and second configurations may be achieved by rotation of each of the n image inverting optics about central axis 510 by an angle with a magnitude of $90/n^\circ$. Increasing the number n of image inverting optics therefore reduces the magnitude of the total angular displacement of each image inverting optic. As explained above, in turn this reduces the torque and power required to rotate each image inverting optic so as to transform between the first and second configurations.

[00132] Although in the above described embodiments, the image transformation optic 500 comprises a plurality of Dove prisms, in alternative embodiments other types of image inverting prisms may be used. For example, a Pechan prism or an Abbe prism may be used in place of a Dove prism.

[00133] Embodiments of the image transformation optic 500 which comprise an even number of image inverting optics invert the image of the patterning device MA in both the scanning and non-scanning directions. That is the image formed on the substrate W is equivalent to the pattern on the mask MA, the equivalent images being related by a rotation

about the optical axis O (and not a reflection), which may be desirable since it may simplify the process of mask MA design and manufacture.

[00134] In general embodiments of the invention may comprise an image transformation optic comprising at least one image inverting optics (for example Dove prisms). The
5 embodiments of Figures 3 and 9 are both examples of such an arrangement, and the embodiment of Figure 3 (comprising only one image inverting optic) may be thought of as the simplest example such an arrangement.

[00135] Although in the above described embodiments, the image transformation optic 100 is arranged between the support structure MT and the projection system PL, in
10 alternative embodiments the image transformation optic 100 may be arranged elsewhere between the support structure MT and the substrate table WT.

[00136] 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 lithographic apparatus comprising:

a support structure for supporting a patterning device;

5 an illumination system for conditioning a radiation beam and directing the conditioned radiation beam to the support structure so that a patterning device supported by the support structure imparts a pattern in the cross-section of the radiation beam, forming a patterned radiation beam;

a substrate table for holding a substrate; and

10 a projection system for projecting the patterned radiation beam onto a target region of the substrate so as to form an image on the substrate;

wherein during a scanning exposure the support structure is moveable relative to the beam of radiation conditioned by the illuminator along a scanning path and the substrate table is movable relative to the patterned radiation beam along the scanning path; and

15 wherein the lithographic apparatus further comprises an image transformation optic arranged between the support structure and the substrate table, the image transformation optic being movable so as to control the characteristics of the image formed on the substrate such that the image can be transformed between at least a first configuration and a second configuration, the second configuration being inverted relative to the first configuration in a
20 direction along the scanning path.

2. The lithographic apparatus of claim 1, wherein the lithographic apparatus is operable in a plurality of scanning modes, comprising at least:

a first scanning mode, wherein the support structure is moved in a first direction along
25 the scanning path, the substrate table is moved synchronously in the same direction along the scanning path and the image is in the first configuration; and

a second scanning mode, wherein the support structure is moved in a second direction along the scanning path, the substrate table is moved synchronously in the opposite direction along the scanning path and the image is in the second configuration.

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3. The lithographic apparatus of claim 1 or claim 2, wherein the second configuration of the image formed on the substrate is rotated relative to the first configuration of the image by 180° about an optical axis of the lithographic apparatus.

4. The lithographic apparatus of any preceding claim, wherein the image transformation optic comprises one or more image inverting optics, the or each image inverting optic being arranged to invert the image in an inversion direction, the or each image inverting optic being rotatably mounted in the path of the patterned radiation beam such that it can rotate about an axis between at least a first position and a second position.

5. The lithographic apparatus of claim 4, wherein the image transformation optic comprises a single image inverting optic.

10 6. The lithographic apparatus of claim 5, wherein in the first configuration the image inverting optic is arranged such that inversion direction is aligned with the scanning path.

7. The lithographic apparatus of claim 5 or claim 6, wherein in the second configuration, the image inverting optic is arranged such that the inversion direction is perpendicular to the scanning path.

8. The lithographic apparatus of claim 4, wherein the image transformation optic comprises a plurality of image inverting optics.

20 9. The lithographic apparatus of claim 8, wherein the image transformation optic comprises n image inverting optics,

wherein in one of the first and second configurations, each of the image inverting optics is arranged such that its inversion direction is disposed at an angle to the scanning path, a magnitude of the angle being $90/n^\circ$; and

25 wherein in the other of the first and second configurations, each of the image inverting optics is arranged such that its inversion direction is aligned with the scanning path.

10. The lithographic apparatus of any one of claims 5 to 7, wherein the image inverting optic comprises one or more optical elements which are moveable between a first arrangement wherein they cause the patterned radiation beam to converge and cross before it is projected onto the target region of the substrate and a second arrangement wherein the one or more optical elements do not cause the patterned radiation beam to converge and cross before it is projected onto the target region of the substrate.

11. The lithographic apparatus of any one of claims 1 to 3, wherein the image transformation optic comprises one or more optic that is movable in to and out of the path of the patterned radiation beam, the transition between the first and second configurations of the image being effected by movement of the one or more optics.

5

12. The lithographic apparatus of claim 11, wherein the image transformation optic comprises two substantially identical image inverting optics, each being movable in to and out of the path of the patterned radiation beam, a first one of the image inverting optics being arranged to invert the image in a first inversion direction when disposed in the path of the patterned radiation beam, and a second one of the image inverting optics being arranged to invert the image in a second inversion direction when disposed in the path of the patterned radiation beam, the first and second inversion directions being substantially perpendicular.

10

13. The lithographic apparatus of any preceding claim, wherein the image transformation optic comprises one or more sensors and a controller, wherein the one or more sensors are operable to determine the position and/or orientation of the image transformation optic and output a signal indicative thereof to the controller.

15

14. The lithographic apparatus of claim 13, wherein the image transformation optic comprises one or more actuators and wherein the controller is operable in response to the signal output by the one or more sensors to use the one or more actuators to control the position and/or orientation of the image transformation optic.

20

15. A method for forming an image on a plurality of target regions of a substrate comprising:

25

providing a substrate with a plurality of target regions;

providing a beam of radiation using an illumination system;

providing a patterning device for imparting the radiation beam with a pattern in its cross-section;

providing a projection system for projecting the patterned radiation beam onto a target region of the substrate so as to form an image on the substrate;

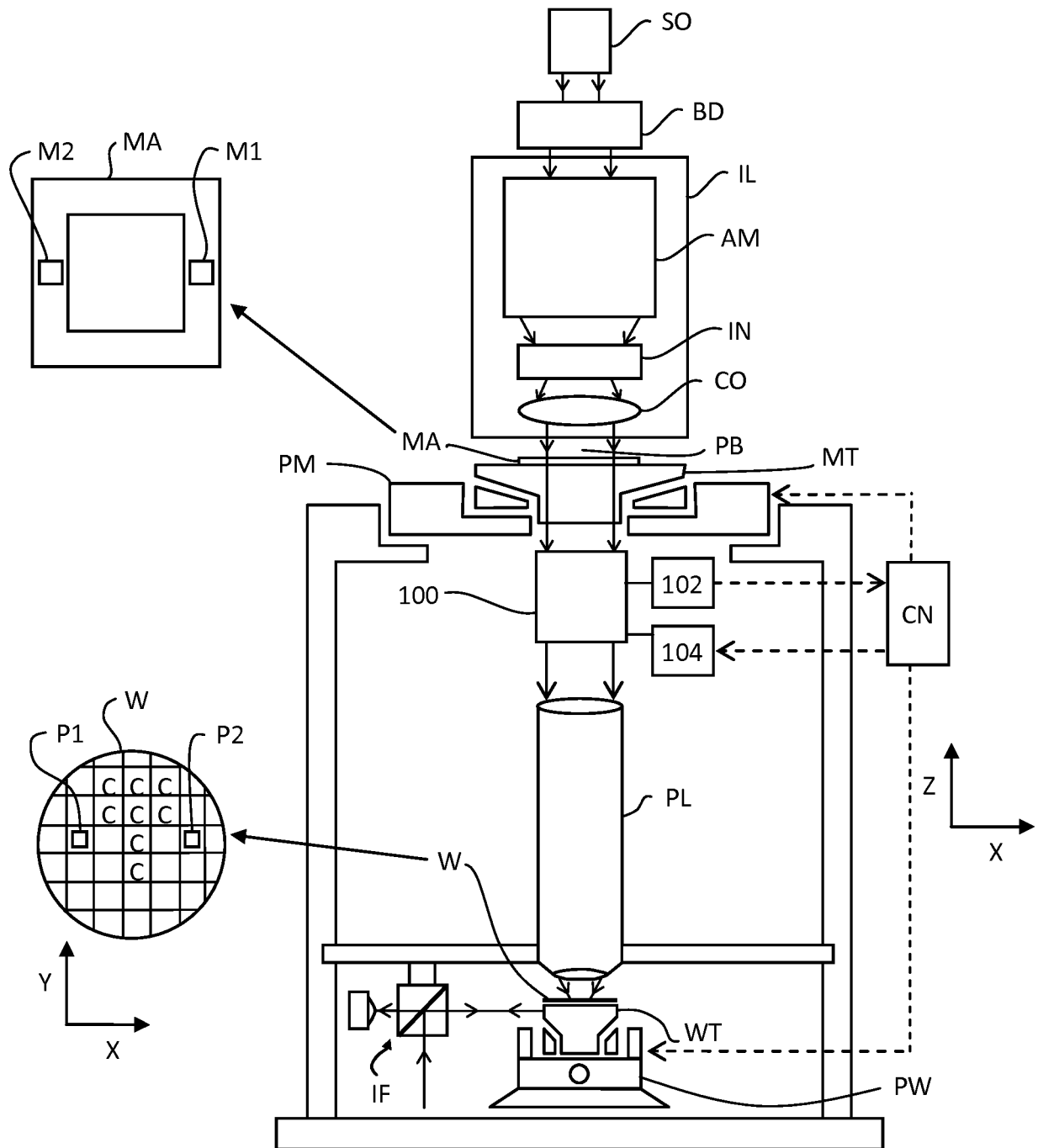
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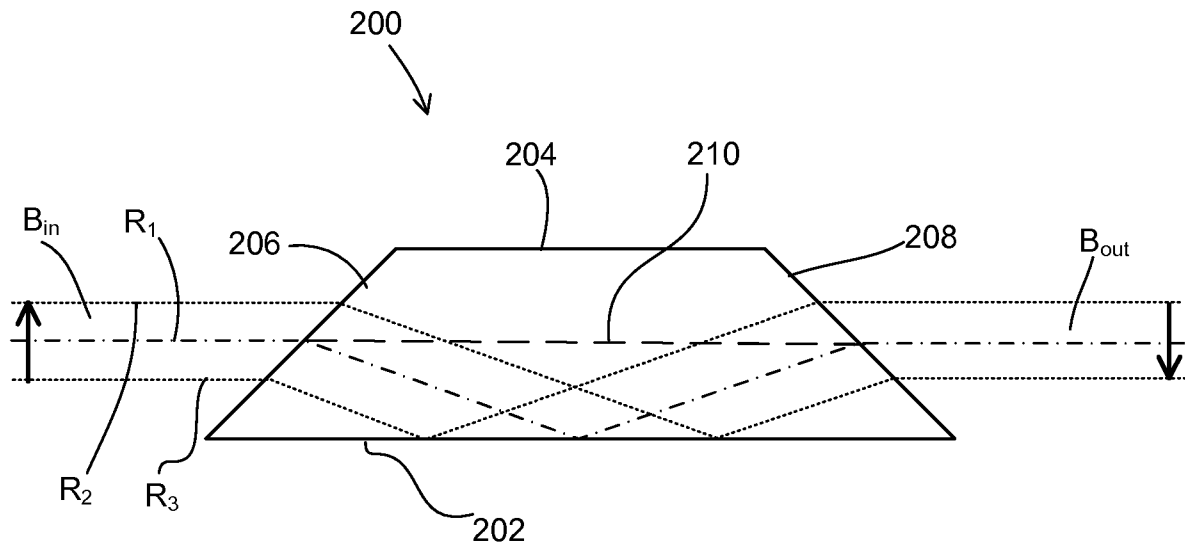
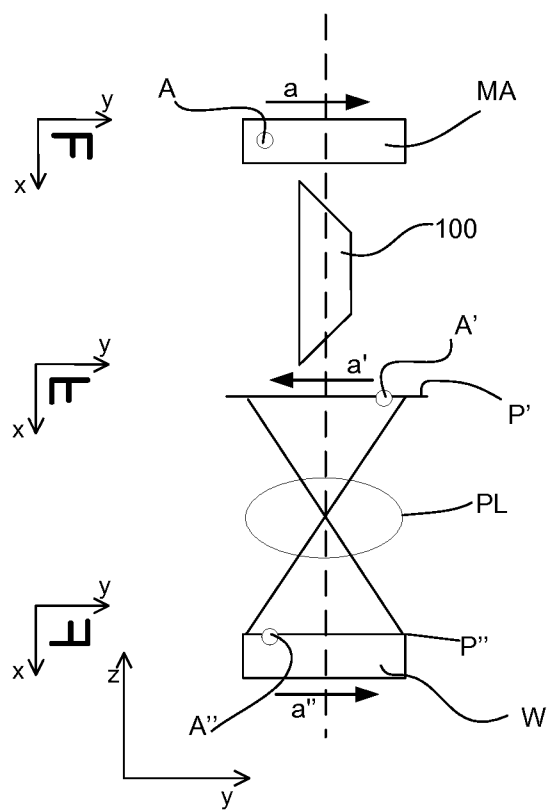
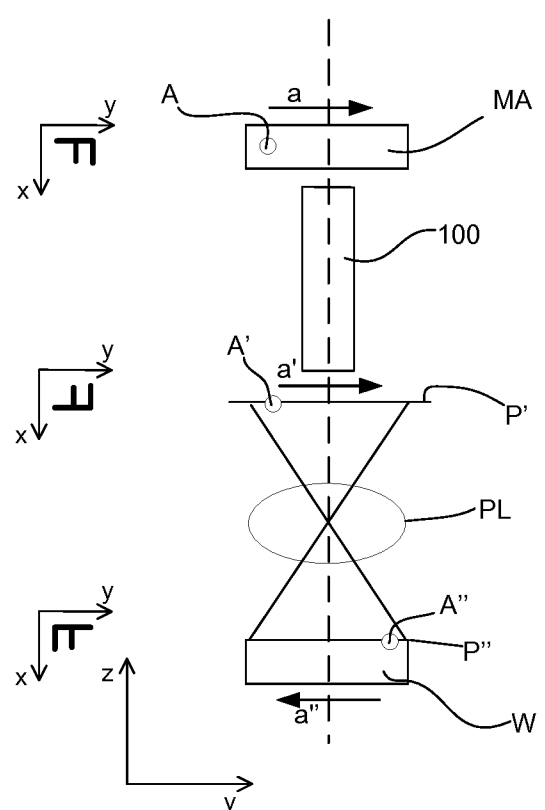
providing an image rotation device which is operable to control a configuration of the image formed on the substrate;

forming an image on a first target region of the substrate by moving the support structure in a first direction along a scanning path relative to the radiation beam such that the radiation beam scans across the patterning device whilst simultaneously moving the substrate table in the same direction long the scanning path such that the patterned radiation beam
5 scans across the first target region forming an image with a first configuration;

using the image rotation device to invert the image formed on the substrate in a direction along the scanning path to a second configuration; and

forming an image on a second target region of the substrate by moving the support structure in a second, opposite direction along a scanning path relative to the radiation beam
10 such that the radiation beam scans across the patterning device whilst simultaneously moving the substrate table in the opposite direction along the scanning path such that the patterned radiation beam scans across the first target region forming an image with a second configuration.

**FIG 1**

**FIG 2****FIG 3a****FIG 3b**

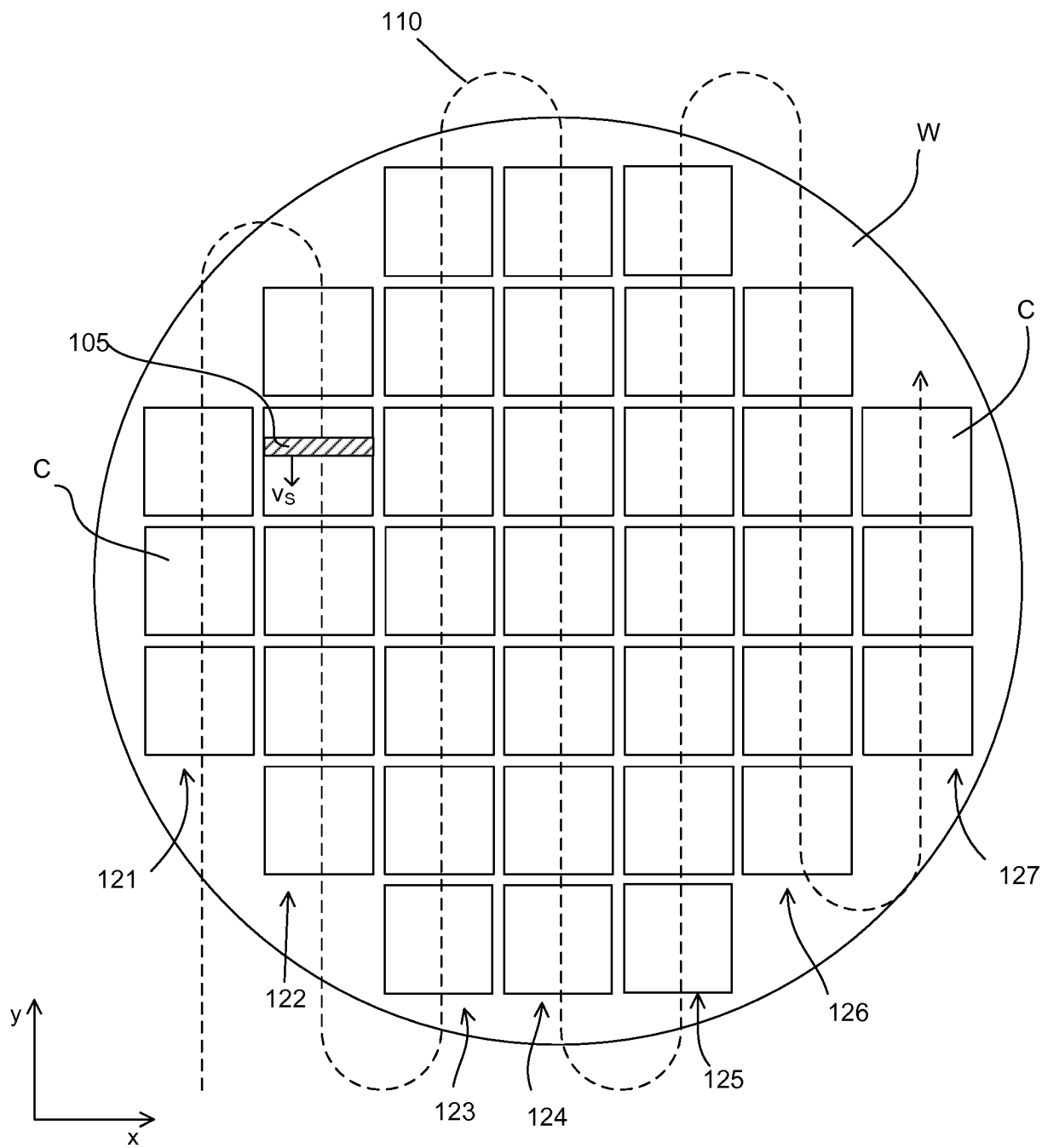
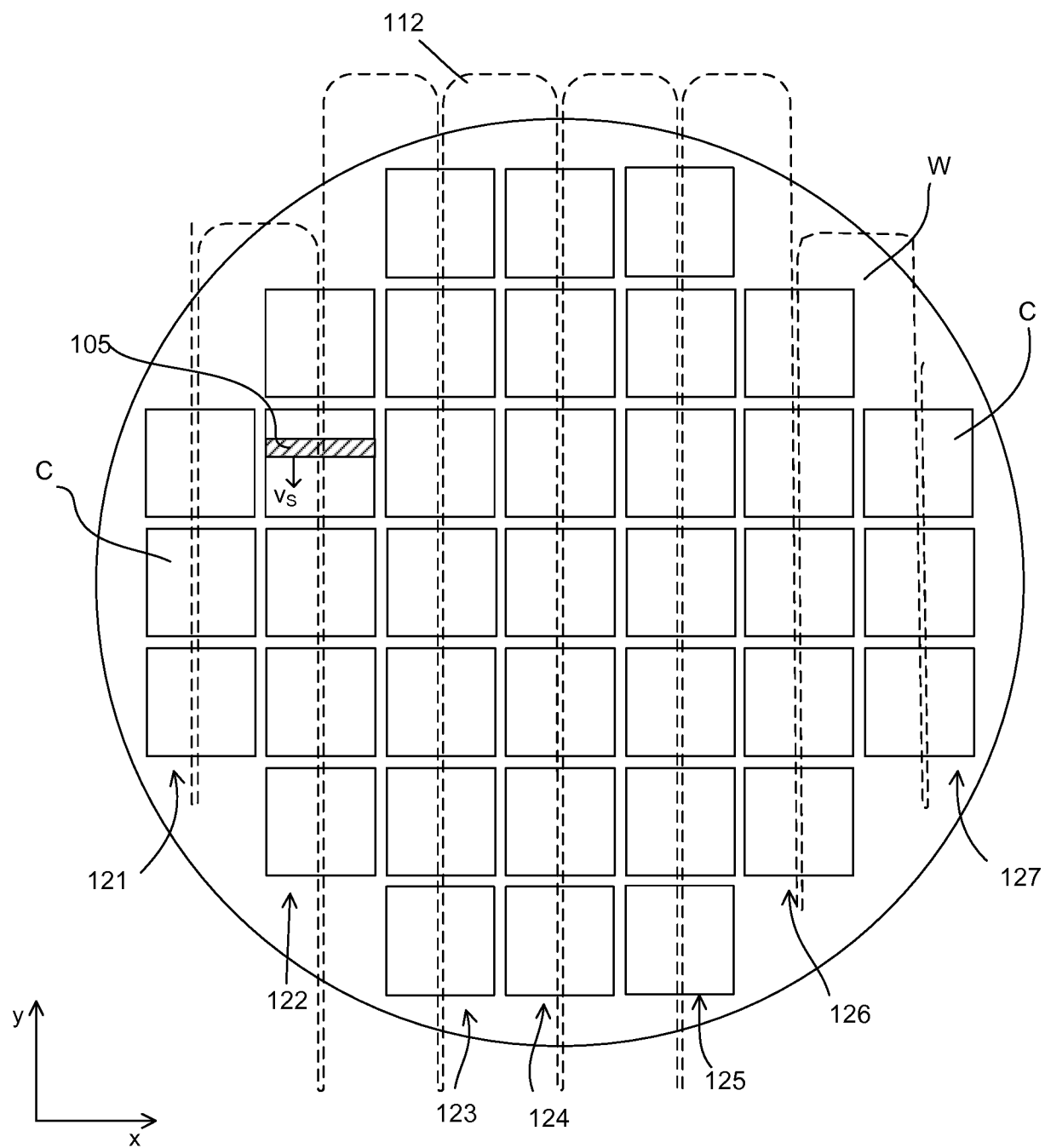
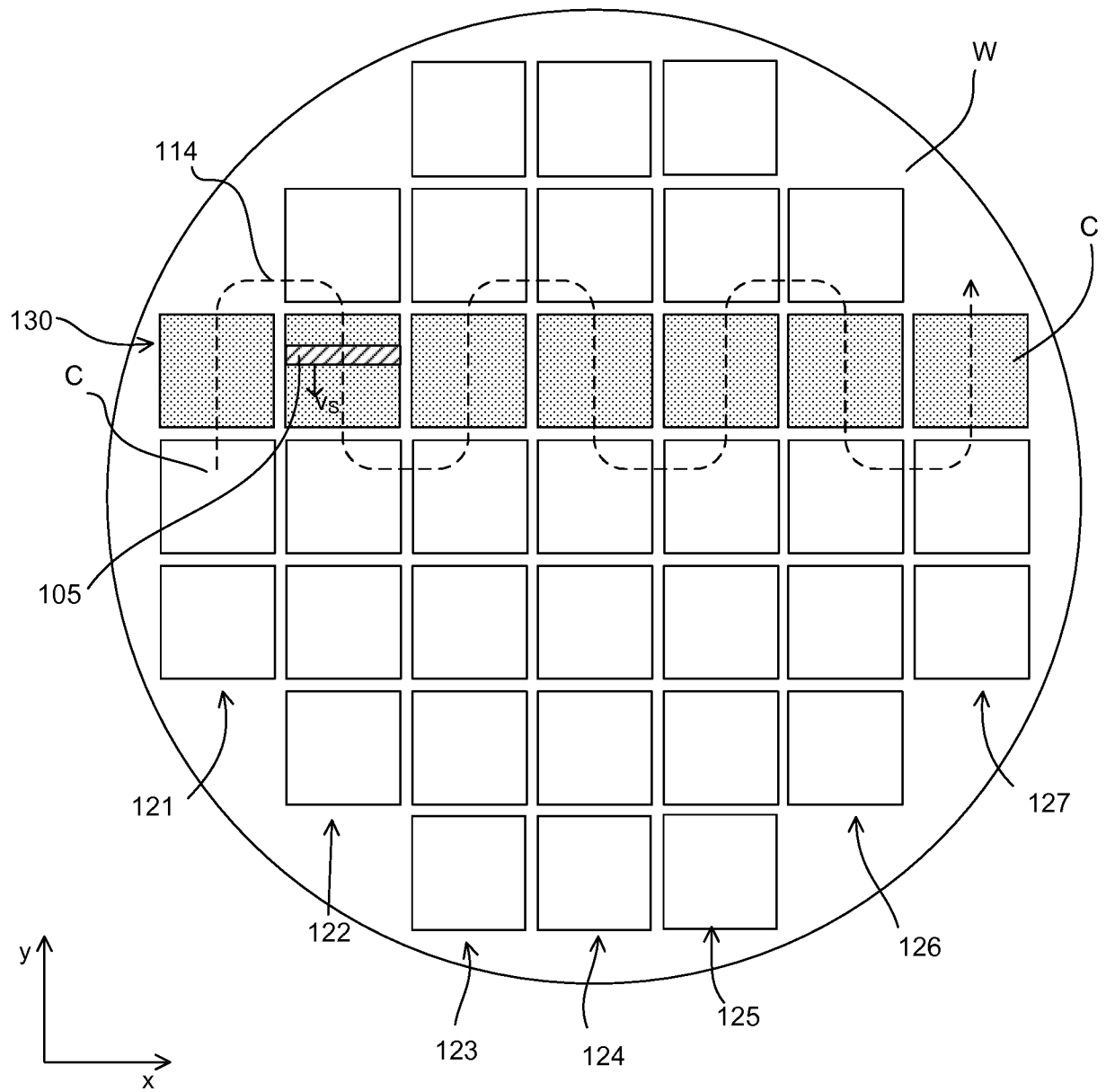
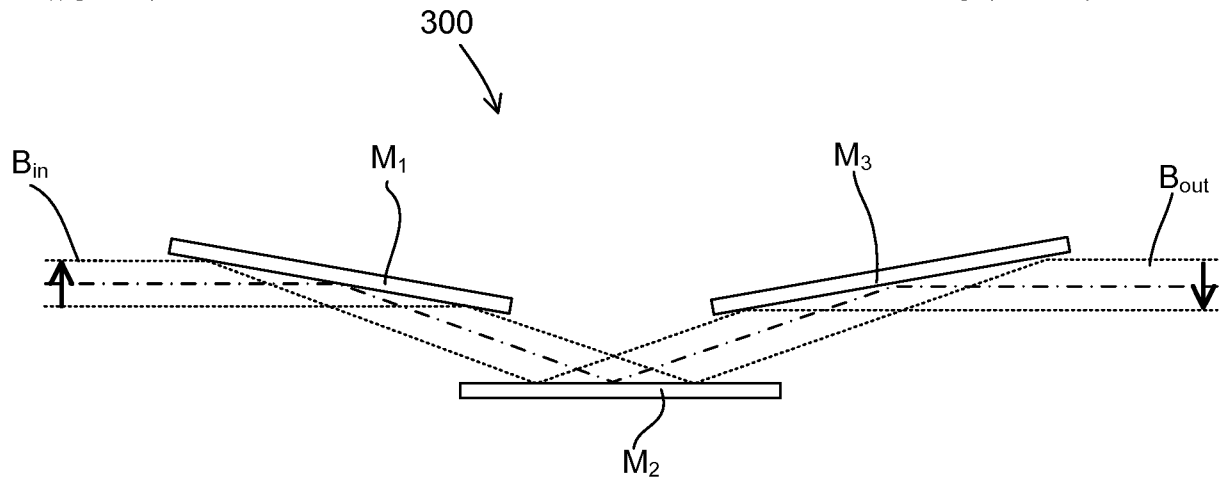
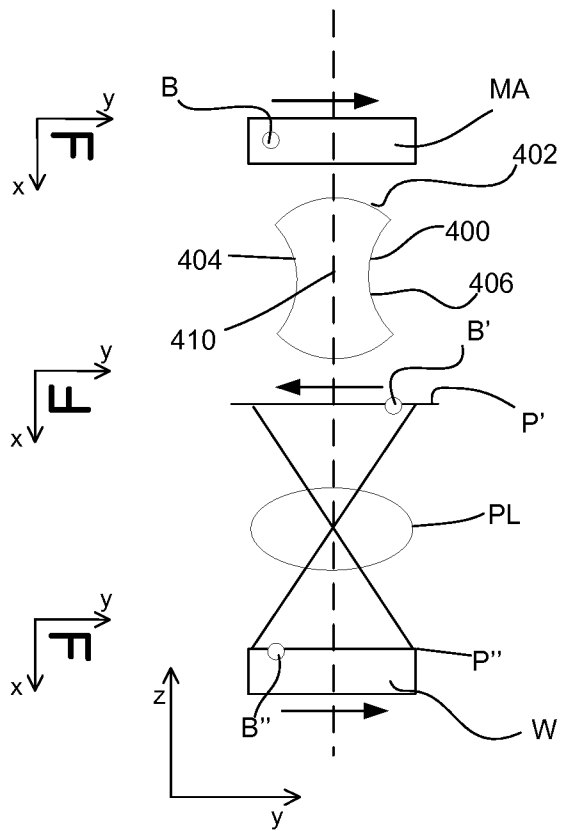
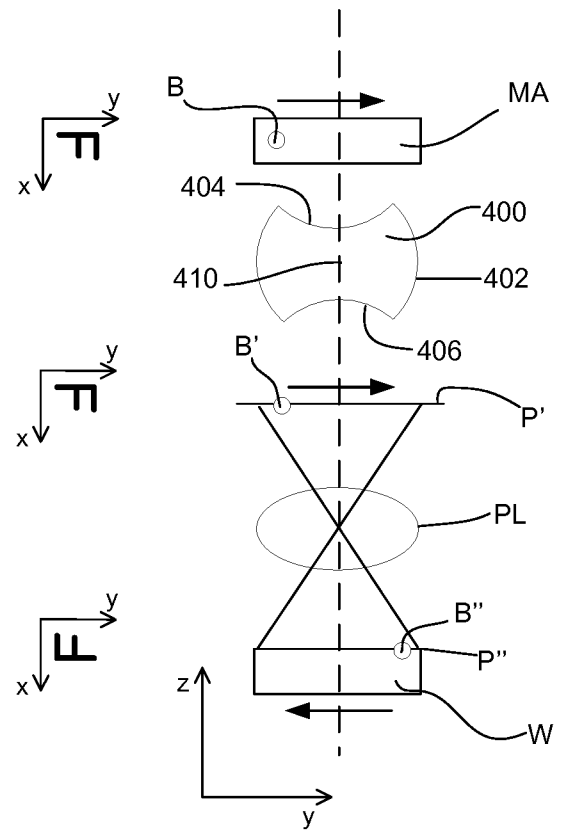


FIG 4

**FIG 5**

**FIG 6**

**FIG 7****FIG 8a****FIG 8b**

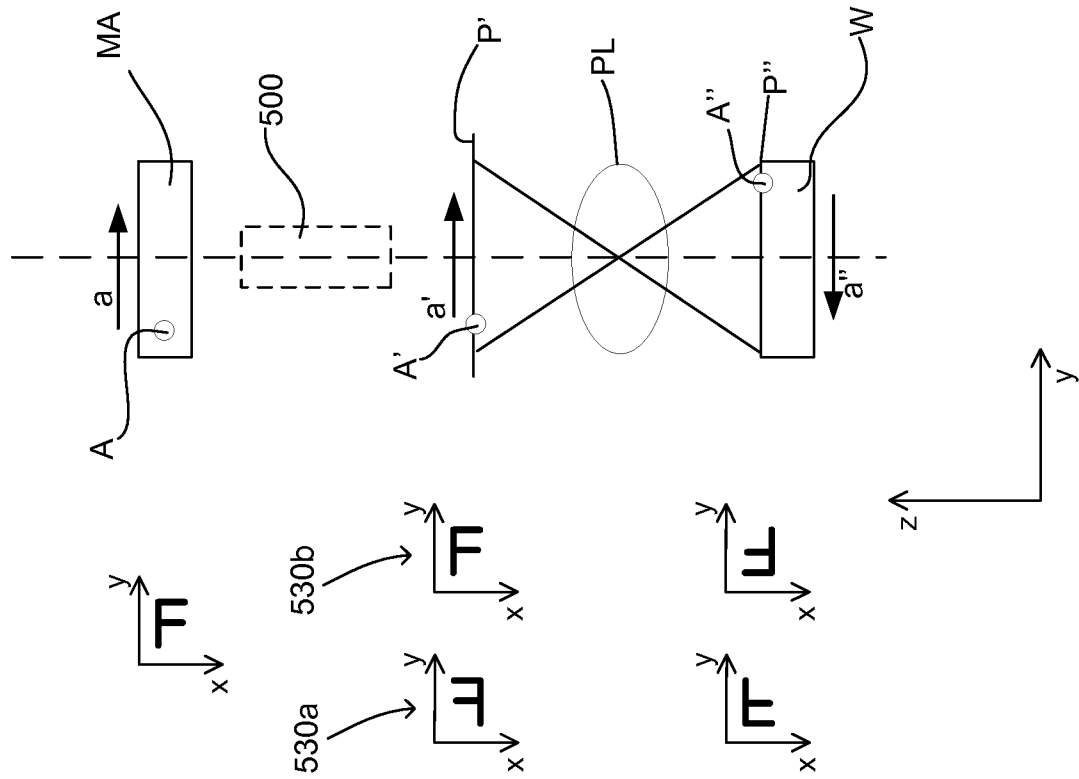


FIG 9a

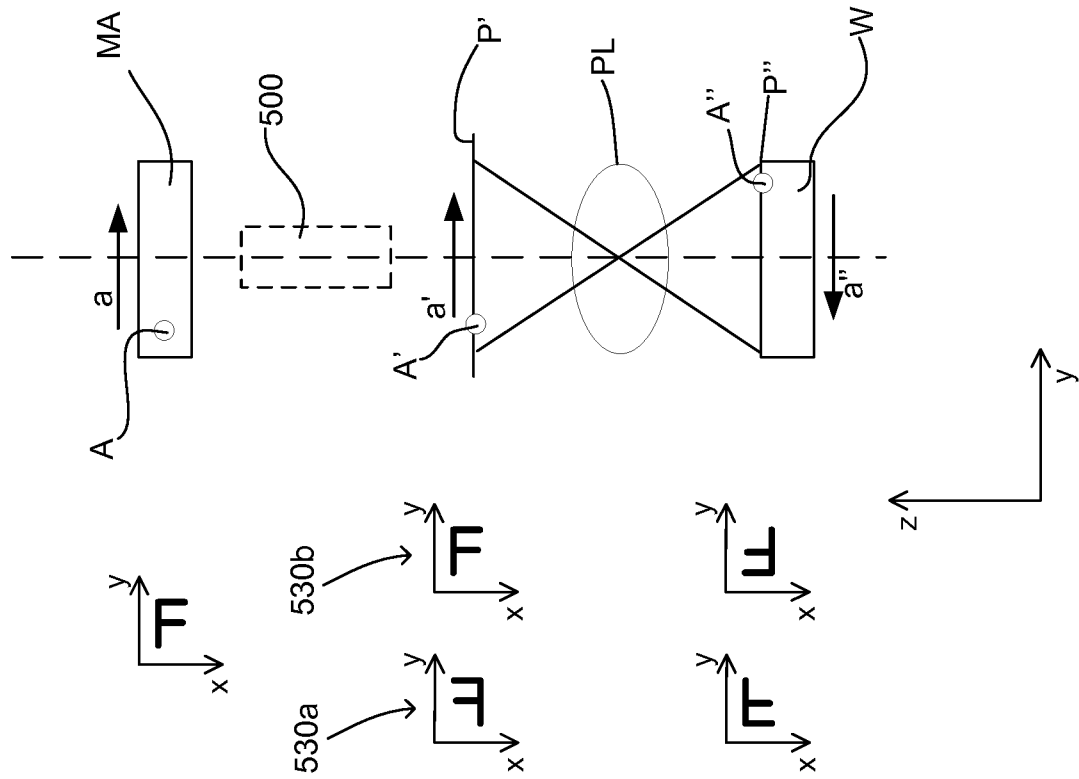


FIG 9b

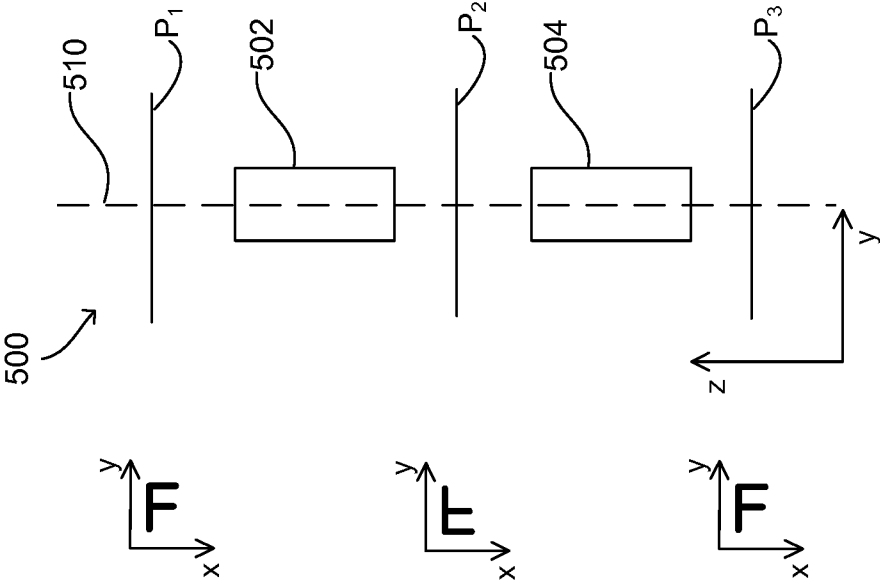


FIG 10a

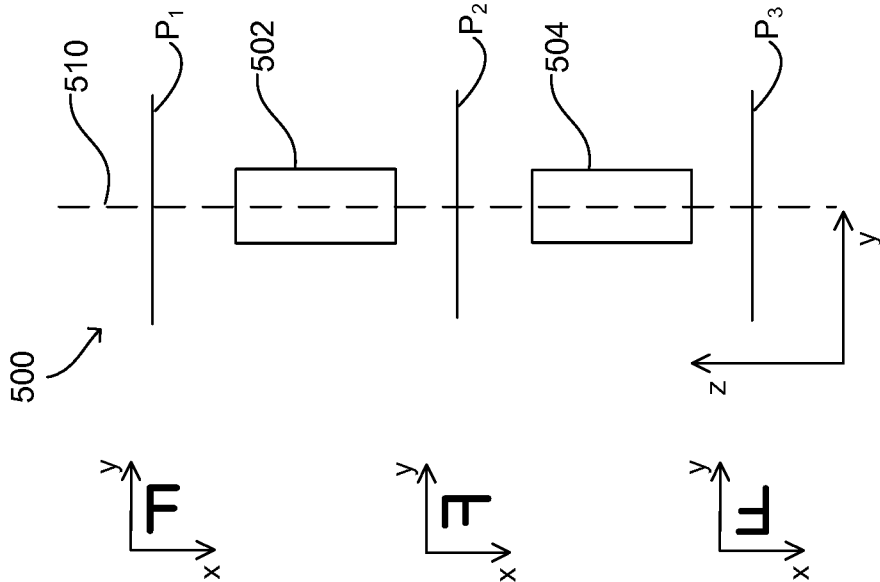


FIG 10b

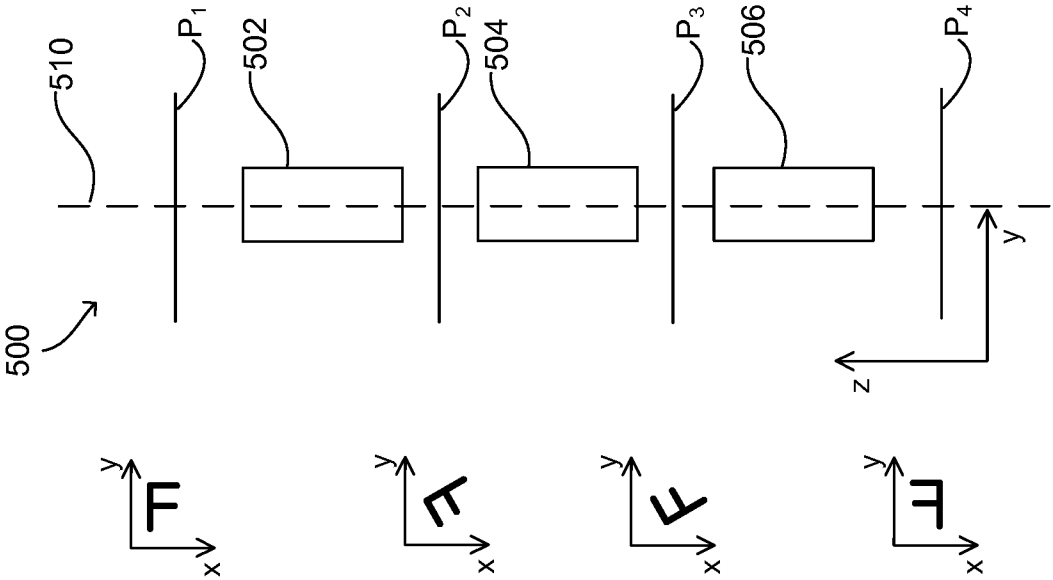


FIG 11a

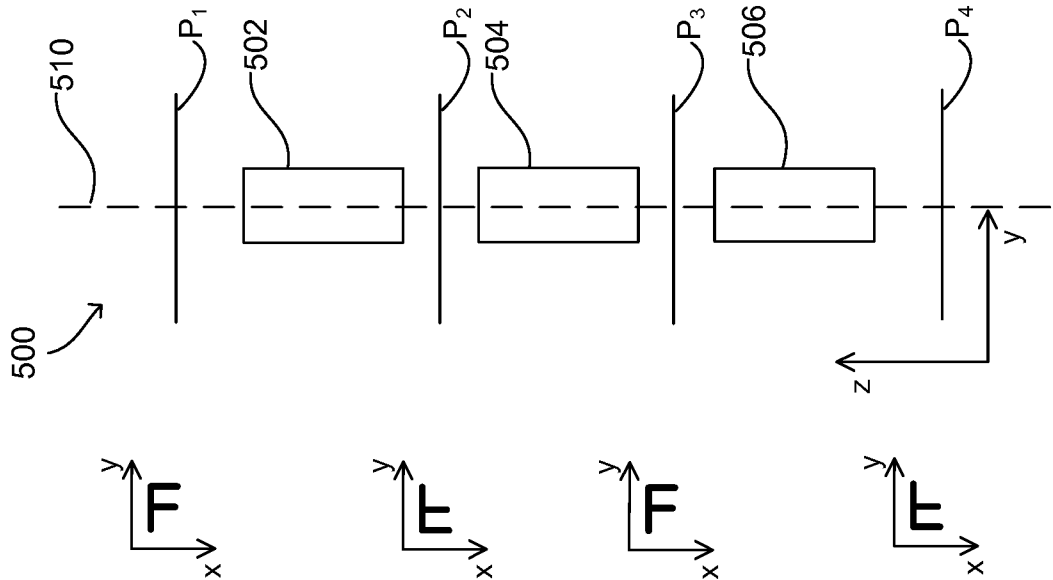


FIG 11b

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2016/053120

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

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

B. FIELDS SEARCHED

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

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

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

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011/102757 A1 (BUTLER HANS [NL] ET AL) 5 May 2011 (2011-05-05)	1-7,15
A	paragraphs [0049] - [0058]; figure 1 -----	8-14
Y	US 3 574 459 A (HARTWIG KARL ET AL) 13 April 1971 (1971-04-13) columns 1-2; figures 1, 2 -----	1-7,15
X	US 2009/073407 A1 (OKITA SHINICHI [JP]) 19 March 2009 (2009-03-19) paragraphs [0178] - [0189]; figure 20 -----	1,11
A	US 4 103 991 A (KRAMER CHARLES J) 1 August 1978 (1978-08-01) columns 1-2; figure 1 -----	1
A	US 3 994 580 A (HOFFMAN DANIEL S) 30 November 1976 (1976-11-30) columns 1-3; figures 1-3 -----	1



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

16 June 2016

Date of mailing of the international search report

24/06/2016

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Authorized officer

Eisner, Klaus

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2016/053120

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011102757 A1	05-05-2011	JP 2011097056 A US 2011102757 A1	12-05-2011 05-05-2011
US 3574459 A	13-04-1971	BE 719781 A NL 6811955 A US 3574459 A	24-02-1969 27-01-1969 13-04-1971
US 2009073407 A1	19-03-2009	EP 2023379 A1 JP 5218049 B2 KR 20090023545 A TW 200815936 A US 2009073407 A1 WO 2007138834 A1	11-02-2009 26-06-2013 05-03-2009 01-04-2008 19-03-2009 06-12-2007
US 4103991 A	01-08-1978	NONE	
US 3994580 A	30-11-1976	CA 1045429 A DE 2555398 A1 FR 2301838 A1 GB 1527755 A JP S5198016 A NL 7514964 A US 3994580 A	02-01-1979 02-09-1976 17-09-1976 11-10-1978 28-08-1976 26-08-1976 30-11-1976