



(51) International Patent Classification:  
*G03F 9/00* (2006.01)

(21) International Application Number:  
PCT/EP2017/057534

(22) International Filing Date:  
30 March 2017 (30.03.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:  
16167077.3 26 April 2016 (26.04.2016) EP

(71) Applicant: ASML NETHERLANDS B.V. [NL/NL]; P.O. Box 324, 5500 AH Veldhoven (NL).

(72) Inventors: BROUWER, Cornelis, Melchior; P.O. Box 324, 5500 AH Veldhoven (NL). DE JONG, Frederik Eduard; P.O. Box 324, 5500 AH Veldhoven (NL).

(74) Agent: KETTING, Alfred; ASML Netherlands B.V., P.O. Box 324, 5500 AH Veldhoven (NL).

(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, DJ, 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, KH, KN, KP, KR, KW, 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,

(54) Title: METHOD AND APPARATUS FOR CONTROLLING ALIGNMENT

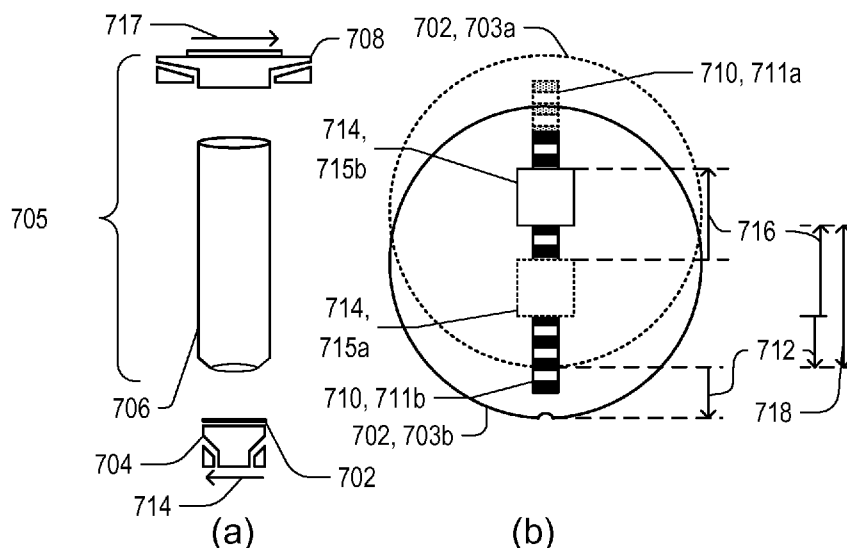


Fig. 7

(57) Abstract: A method of controlling alignment in a lithographic apparatus configured to expose a substrate (702) held by a substrate table (704) to an image of a pattern on a patterning device (708) via a projection system (706). The method comprises illuminating a target (710) on the substrate with an image (714) of an alignment mark on the patterning device, displacing the substrate table relative to the image of the alignment mark, collecting radiation scattered by the target during the displacing step at a detector. During the relative displacing, one or both of the patterning device and the substrate table. The relative displacement is independent of individual movements of the patterning device and the substrate table.

MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, 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))*

## METHOD AND APPARATUS FOR CONTROLLING ALIGNMENT

## CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of EP application 16167077.3 which was filed on  
5 2016-Apr-26 and which is incorporated herein in its entirety by reference.

## FIELD

[0002] The present invention relates to an alignment method for a lithographic apparatus. In  
particular, the present invention relates to a method for controlling alignment before exposure  
10 of a substrate.

## BACKGROUND

[0003] A lithographic apparatus is a machine constructed to apply a desired pattern onto a  
substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated  
15 circuits (ICs). In that circumstance, a patterning device, which is alternatively referred to as a  
mask or a reticle, may be used to generate a circuit pattern corresponding to an individual  
layer of the IC, and this pattern can be imaged onto a target portion (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  
20 portions that are successively exposed to a beam of radiation. Known lithographic apparatus  
include so-called steppers, in which each target portion is irradiated by exposing an entire  
pattern onto the target portion in one go, and so-called scanners, in which each target portion  
is irradiated by scanning the pattern through a beam of radiation in a given direction (the  
“scanning”-direction) while synchronously scanning the substrate parallel or anti-parallel to  
25 this direction.

[0004] Before a desired pattern can be applied to a substrate it is necessary to perform  
alignment measurements so as to position the patterning device correctly with respect to the  
substrate. Typically, alignment measurements are performed with respect to one or more  
reference points (which may also be referred to as “set points”). A reference point is a  
30 location on the surface of a substrate at which a particular measurement is to be carried out, such  
as an expected position that is within capture range of a sensor. Typically, a plurality of  
individual measurements are carried out at a number of spatially distributed reference points.

[0005] During the alignment measurement, the patterning device is aligned relative to the substrate table with respect to the one or more reference points. However, the substrate table and/or the patterning device may introduce translation errors during movement, e.g. due to small imperfections in the translation mechanism or the components of the apparatus. The translation errors may manifest as inaccuracies with respect to the location of reference points.

[0006] Inaccuracies in the positioning of the one or more reference points may negatively affect the accuracy of alignment of the patterning device of the lithographic apparatus. For example, reference point inaccuracies may result in patterning device load offsets, which in turn result in substrate lot offsets. Further, variation of expected reference point positions within a particular batch (which may also be referred to as a “lot”) of substrates may cause loss of performance, e.g. by causing heating of the patterning device.

[0007] A known method for mitigating such issues is to provide a high frequency calibration for the encoder scales. However, the known methods require a certain amount of time to set up, which increases production costs of substrates. Further, the accuracy and resolution of such calibration methods is limited, which means that it is not possible to completely overcome the above problems by using these methods.

## SUMMARY

[0008] The inventors have recognized that, by moving the patterning device while performing the alignment measurements, it becomes possible to mitigate or remove the errors related to the one or more reference points. By moving the patterning device, any such high frequency errors are averaged out.

[0009] The invention in a first aspect provides a method of controlling alignment in a lithographic apparatus, the apparatus being configured to expose a substrate held by a substrate table to an image of a pattern on a patterning device via a projection system, the method comprising:

- i) illuminating a target on the substrate with an image of an alignment mark on the patterning device;
- ii) displacing the substrate table relative to the image of the alignment mark;
- iii) collecting radiation scattered by the target during the displacing step at a detector;

further comprising moving the patterning device during displacing the substrate table, and

wherein the relative displacement between the image of the alignment mark and the substrate table is independent of individual movements of the patterning device and the substrate table.

**[0010]** By performing a scan that covers a number of reference points, any deviations of the expected reference point positions caused by the patterning device will be averaged out. As such deviations are typically larger than deviations in the positioning of the substrate table, which is controllable with only a small margin of error, the overall accuracy of the alignment process is increased. In an embodiment the collected scattered radiation is used to control at least one characteristic of the lithographic apparatus.

**[0011]** According to a second aspect of the present invention, there is provided a lithographic apparatus, the apparatus being configured to expose a substrate held by a substrate table to an image of a pattern on a patterning device via a projection system, comprising:

a radiation delivery system operable to illuminate a target on the substrate with an image of an alignment mark on the patterning device;

a displacement system operable to displace the substrate table relative to the image of the alignment mark;

a detector operable to collect radiation scattered by the target;

wherein the displacement system is operable to move the patterning device, and

wherein the relative displacement between the image of the alignment mark and the substrate table is independent of individual movements of the patterning device and the substrate table.

In an embodiment a control unit is operable to use the collected scattered radiation to control at least one characteristic of the lithographic apparatus.

**[0012]** Further aspects, features and advantages of the invention, as well as the structure and operation of various embodiments of the invention, are described in detail below with reference to the accompanying drawings. It is noted that the invention is not limited to the specific embodiments described herein. Such embodiments are presented herein for illustrative purposes only. Additional embodiments will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0013]** 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;  
      Figure 2 depicts a lithographic cell or cluster in which an inspection apparatus according to the present invention may be used;  
      Figure 3 illustrates the steps to expose target portions (e.g. dies) on a substrate in the apparatus of Figure 1;  
10       Figures 4a and 4b illustrate schematically a known alignment method for the apparatus of Figure 1;  
      Figures 5a, 5b and 6 illustrate schematically an alignment method according to a first embodiment of the invention;  
      Figures 7a, 7b and 8 shows schematically an alignment method according to a second  
15       embodiment of the invention;  
      Figure 9 is a schematic view of actuatable components of the apparatus of Figure 1;  
      Figure 10 is an exemplary alignment target comprising a plurality of target structures;  
      and  
      Figures 11a, 11b, 11c and 11d illustrate a number of exemplary displacement schemes  
20       for the lithographic apparatus of Figure 1.

## DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

**[0014]** Before describing embodiments of the invention in detail, it is instructive to present an example environment in which embodiments of the present invention may be  
25       implemented.

**[0015]** Figure 1 schematically depicts a lithographic apparatus LA. The apparatus includes an illumination system (illuminator) IL configured to condition a radiation beam B (e.g., UV radiation or DUV radiation), a patterning device support or support structure (e.g., a mask table) MT constructed to support a patterning device (e.g., a mask) MA and connected to a  
30       first positioner PM configured to accurately position the patterning device in accordance with certain parameters; two substrate tables (e.g., a wafer table) WTa and WTb each constructed to hold a substrate (e.g., a resist coated wafer) W and each connected to a second positioner PW configured to accurately position the substrate in accordance with certain parameters; and

a projection system (e.g., a refractive projection lens system) PS configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion C (e.g., including one or more dies) of the substrate W. A reference frame RF connects the various components, and serves as a reference for setting and measuring positions of the patterning device and substrate and of features on them.

[0016] The illumination system may include various types of optical components, such as refractive, reflective, magnetic, electromagnetic, electrostatic or other types of optical components, or any combination thereof, for directing, shaping, or controlling radiation.

[0017] The patterning device support holds the patterning device in a manner that depends 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 patterning device support can use mechanical, vacuum, electrostatic or other clamping techniques to hold the patterning device. The patterning device support MT may be a frame or a table, for example, which may be fixed or movable as required. The patterning device support may ensure that the patterning device is at a desired position, for example with respect to the projection system.

[0018] The term “patterning device” used herein should be broadly interpreted as referring to any 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 portion 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 portion of the substrate, for example if the pattern includes phase-shifting features or so called assist features. Generally, the pattern imparted to the radiation beam will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit.

[0019] As here depicted, the apparatus is of a transmissive type (e.g., employing a transmissive patterning device). Alternatively, the apparatus may be of a reflective type (e.g., employing a programmable mirror array of a type as referred to above, or employing a reflective mask). Examples of patterning devices include masks, programmable mirror arrays, and programmable LCD panels. Any use of the terms “reticle” or “mask” herein may be considered synonymous with the more general term “patterning device.” The term “patterning device” can also be interpreted as referring to a device storing in digital form pattern information for use in controlling such a programmable patterning device.

[0020] The term “projection system” used herein should be broadly interpreted as encompassing any type of projection system, including refractive, reflective, catadioptric, magnetic, electromagnetic and electrostatic optical systems, or any combination thereof, as appropriate for the exposure radiation being used, or for other factors such as the use of an immersion liquid 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”.

[0021] The lithographic apparatus may also be of a type wherein at least a portion of the substrate may be covered by a liquid having a relatively high refractive index, e.g., water, so as to fill a space between the projection system and the substrate. An immersion liquid may also be applied to other spaces in the lithographic apparatus, for example, between the mask and the projection system. Immersion techniques are well known in the art for increasing the numerical aperture of projection systems.

[0022] In operation, the illuminator IL receives a radiation beam from a radiation source SO. The source 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 including, for example, suitable directing mirrors and/or a beam expander. In other cases the source may be an integral part of the lithographic 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.

[0023] The illuminator IL may for example include an adjuster AD for adjusting the angular intensity distribution of the radiation beam, an integrator IN and a condenser CO. The illuminator may be used to condition the radiation beam, to have a desired uniformity and intensity distribution in its cross section.

[0024] The radiation beam B is incident on the patterning device MA, which is held on the patterning device support MT, and is patterned by the patterning device. Having traversed the patterning device (e.g., mask) MA, the radiation beam B passes through the projection system PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioner PW and position sensor IF (e.g., an interferometric device, linear encoder, 2-D encoder or capacitive sensor), the substrate table W<sub>Ta</sub> or W<sub>Tb</sub> can be moved accurately, e.g., so as to position different target portions C in the path of the radiation beam B. Similarly, the first positioner PM and another position sensor (which is not explicitly

depicted in Figure 1) can be used to accurately position the patterning device (e.g., mask) MA with respect to the path of the radiation beam B, e.g., after mechanical retrieval from a mask library, or during a scan.

[0025] Patterning device (e.g., mask) MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2. Although the substrate alignment marks as illustrated occupy dedicated target portions, they may be located in spaces between target portions (these are known as scribe-lane alignment marks). Similarly, in situations in which more than one die is provided on the patterning device (e.g., mask) MA, the mask alignment marks may be located between the dies. Small alignment mark may also be included within dies, in amongst the device features, in which case it is desirable that the markers be as small as possible and not require any different imaging or process conditions than adjacent features. The alignment system, which detects the alignment markers is described further below.

[0026] The depicted apparatus could be used in a variety of modes. In a scan mode, the patterning device support (e.g., mask table) MT and the substrate table WT are scanned synchronously while a pattern imparted to the radiation beam is projected onto a target portion C (i.e., a single dynamic exposure). The speed and direction of the substrate table WT relative to the patterning device support (e.g., mask table) MT may be determined by the (de-)magnification and image reversal characteristics of the projection system PS. In scan mode, the maximum size of the exposure field limits the width (in the non-scanning direction) of the target portion in a single dynamic exposure, whereas the length of the scanning motion determines the height (in the scanning direction) of the target portion. Other types of lithographic apparatus and modes of operation are possible, as is well-known in the art. For example, a step mode is known. In so-called “maskless” lithography, a programmable patterning device is held stationary but with a changing pattern, and the substrate table WT is moved or scanned.

[0027] Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

[0028] Lithographic apparatus LA is of a so-called dual stage type which has two substrate tables WTa, WTb and two stations – an exposure station EXP and a measurement station MEA – between which the substrate tables can be exchanged. While one substrate on one substrate table is being exposed at the exposure station, another substrate can be loaded onto the other substrate table at the measurement station and various preparatory steps carried out.

This enables a substantial increase in the throughput of the apparatus. The preparatory steps may include mapping the surface height contours of the substrate using a level sensor LS and measuring the position of alignment markers on the substrate using an alignment sensor AS. If the position sensor IF is not capable of measuring the position of the substrate table while it is at the measurement station as well as at the exposure station, a second position sensor may be provided to enable the positions of the substrate table to be tracked at both stations, relative to reference frame RF. Other arrangements are known and usable instead of the dual-stage arrangement shown. For example, other lithographic apparatuses are known in which a substrate table and a measurement table are provided. These are docked together when performing preparatory measurements, and then undocked while the substrate table undergoes exposure.

**[0029]** As shown in Figure 2, the lithographic apparatus LA forms part of a lithographic cell LC, also sometimes referred to a lithocell or cluster, which also includes apparatus to perform pre- and post-exposure processes on a substrate. Conventionally these include spin coaters SC to deposit resist layers, developers DE to develop exposed resist, chill plates CH and bake plates BK. A substrate handler, or robot, RO picks up substrates from input/output ports I/O1, I/O2, moves them between the different process apparatus and delivers them to the loading bay LB of the lithographic apparatus. These devices, which are often collectively referred to as the track, are under the control of a track control unit TCU which is itself controlled by the supervisory control system SCS, which also controls the lithographic apparatus via lithography control unit LACU. Thus, the different apparatus can be operated to maximize throughput and processing efficiency. The substrates processed by the track are then transferred to other processing tools for etching and other chemical or physical treatments within the device manufacturing process.

**[0030]** The lithographic apparatus control unit LACU controls all the movements and measurements of the various actuators and sensors described. LACU also includes signal processing and data processing capacity to implement desired calculations relevant to the operation of the apparatus. In the terminology of the introduction and claims, the combination of these processing and control functions referred to simply as the “controller”. In practice, control unit LACU will be realized as a system of many sub-units, each handling the real-time data acquisition, processing and control of a subsystem or component within the apparatus. For example, one processing subsystem may be dedicated to servo control of the substrate positioner PW. Separate units may even handle coarse and fine actuators, or

different axes. Another unit might be dedicated to the readout of the position sensor IF. Overall control of the apparatus may be controlled by a central processing unit, communicating with these sub-systems processing units, with operators and with other apparatuses involved in the lithographic manufacturing process.

5 [0031] Figure 3 illustrates the steps to expose target portions (e.g. dies) on a substrate W in the dual stage apparatus of Figure 1.

[0032] On the left hand side within a dotted box are steps performed at a measurement station MEA, while the right hand side shows steps performed at the exposure station EXP. From time to time, one of the substrate tables WTa, WTb will be at the exposure station, while the other is at the measurement station, as described above. For the purposes of this description, it is assumed that a substrate W has already been loaded into the exposure station. At step 200, a new substrate W' is loaded to the apparatus by a mechanism not shown. These two substrates are processed in parallel in order to increase the throughput of the lithographic apparatus.

15 [0033] Referring initially to the newly-loaded substrate W', this may be a previously unprocessed substrate, prepared with a new photo resist for first time exposure in the apparatus. In general, however, the lithography process described will be merely one step in a series of exposure and processing steps, so that substrate W' has been through this apparatus and/or other lithography apparatuses, several times already, and may have subsequent processes to undergo as well. Particularly for the problem of improving overlay performance, the task is to ensure that new patterns are applied in exactly the correct position on a substrate that has already been subjected to one or more cycles of patterning and processing. These processing steps progressively introduce distortions in the substrate that must be measured and corrected for, to achieve satisfactory overlay performance.

25 [0034] The previous and/or subsequent patterning step may be performed in other lithography apparatuses, as just mentioned, and may even be performed in different types of lithography apparatus. For example, some layers in the device manufacturing process which are very demanding in parameters such as resolution and overlay may be performed in a more advanced lithography tool than other layers that are less demanding. Therefore some layers may be exposed in an immersion type lithography tool, while others are exposed in a 'dry' tool. Some layers may be exposed in a tool working at DUV wavelengths, while others are exposed using EUV wavelength radiation.

[0035] At 202, alignment measurements using the substrate marks P1 etc. and image sensors (not shown) are used to measure and record alignment of the substrate relative to substrate table WTa/WTb. In addition, several alignment marks across the substrate W' will be measured using alignment sensor AS. These measurements are used in one embodiment to  
5 establish a "wafer grid", which maps very accurately the distribution of marks across the substrate, including any distortion relative to a nominal rectangular grid.

[0036] At step 204, a map of wafer height (Z) against X-Y position is measured also using the level sensor LS. Conventionally, the height map is used only to achieve accurate focusing of the exposed pattern. As will be explained further below, the present apparatus uses height  
10 map data also to supplement the alignment measurements.

[0037] When substrate W' was loaded, recipe data 206 were received, defining the exposures to be performed, and also properties of the wafer and the patterns previously made and to be made upon it. To these recipe data are added the measurements of wafer position, wafer grid and height map that were made at 202, 204, so that a complete set of recipe and  
15 measurement data 208 can be passed to the exposure station EXP. The measurements of alignment data for example comprise X and Y positions of alignment targets formed in a fixed or nominally fixed relationship to the product patterns that are the product of the lithographic process. These alignment data, taken just before exposure, are combined and interpolated to provide parameters of an alignment model. These parameters and the  
20 alignment model will be used during the exposure operation to correct positions of patterns applied in the current lithographic step. A conventional alignment model might comprise four, five or six parameters, together defining translation, rotation and scaling of the 'ideal' grid, in different dimensions. As described further in US 2013230797A1, advanced models are known that use more parameters.

[0038] At 210, wafers W' and W are swapped, so that the measured substrate W' becomes the substrate W entering the exposure station EXP. In the example apparatus of Figure 1, this swapping is performed by exchanging the supports WTa and WTb within the apparatus, so that the substrates W, W' remain accurately clamped and positioned on those supports, to preserve relative alignment between the substrate tables and substrates themselves.  
25 Accordingly, once the tables have been swapped, determining the relative position between projection system PS and substrate table WTb (formerly WTa) is all that is necessary to make use of the measurement information 202, 204 for the substrate W (formerly W') in control of the exposure steps. At step 212, reticle alignment is performed using the mask alignment

marks M1, M2. In steps 214, 216, 218, scanning motions and radiation pulses are applied at successive target locations across the substrate W, in order to complete the exposure of a number of patterns.

5 [0039] By using the alignment data and height map obtained at the measuring station in the performance of the exposure steps, these patterns are accurately aligned with respect to the desired locations, and, in particular, with respect to features previously laid down on the same substrate. The exposed substrate, now labeled W' is unloaded from the apparatus at step 220, to undergo etching or other processes, in accordance with the exposed pattern.

10 [0040] The reticle alignment step 212 described above may be carried out in a number of different ways, using one or more of a number of different measurement methods. One exemplary known alignment method will now be described with reference to Figure 4, which schematically shows a side view (Figure 4a) and a top view (Figure 4b) of a substrate in a lithographic apparatus. A substrate 402 is arranged on a substrate table 404 in a lithographic apparatus as described above. The lithographic apparatus has a radiation delivery system that  
15 comprises a projection system 406 and a patterning device 408. In the following, the projection system and the patterning device may collectively be referred to as a radiation delivery system 405. The radiation delivery system projects an image 414 of an alignment mark on the patterning device. The alignment mark have any suitable shape and position on the patterning device. In one embodiment, the alignment mark is substantially identical to the  
20 alignment marks M1 or M2 as described with reference to Figure 1 above. The substrate comprises at least one alignment target 410. It will of course be appreciated that the alignment target is not illustrated to scale with the substrate, but rather to facilitate the explanation of the method. In reality, an alignment target only takes up a very small percentage of the overall substrate surface.

25 [0041] In the present example, the alignment target 410 comprises a single target structure, i.e. a one-dimensional grating. It will, however be appreciated that, in principle, any suitable type of alignment target could be used. In other examples, the target comprises a plurality of target structures. In a specific example, the target comprises a first target structure and a second target structure, where the first target structure comprises a one-dimensional grating  
30 extending in a first direction, and where the second target structure comprises a one-dimensional grating extending in a direction perpendicular to the first direction.

[0042] In the known method, the substrate 402 is initially positioned in a first substrate position 403a relative to the radiation delivery system 405, as well as to the patterning device

408. During the measurement process, the substrate table 404, and by extension also the substrate 402, is displaced relative to image of the alignment mark 414 on the patterning device by moving the substrate table 404 and the substrate 402 (as indicated by arrows 412) in a direction parallel to the direction of the grating of the alignment target 410 and into a second substrate position 403b. It is to be noted that, in the following, the term “displacement” will be used exclusively to refer to relative displacement between two elements (e.g. the substrate table and the image of the alignment mark), indicating the amount, i.e. distance, and direction of relative displacement. The term “movement” will be used to refer to absolute movements, i.e. movements with respect to a fixed reference point (e.g. a stationary part of a lithographic apparatus). The alignment target 410 is moved from its first alignment target position 411a into its second alignment target position 411b in a similar manner as the substrate (because the alignment target is located on the substrate). The radiation scattered by the alignment target during the displacing step is collected by a detector (not shown) in a known manner. The scattered radiation may be collected continuously during the displacing step, or it may be collected in a number of discrete measurements at specific measurement points. The collected scattered radiation is subsequently used to control the lithographic process in a known manner.

**[0043]** An exemplary method will now be described with reference to Figures 5 and 6. For ease of comparison with Figure 4, elements of Figure 5 similar to corresponding elements of Figure 4 are labelled with reference signs similar to those used in Figure 4, but with prefix “5” instead of “4”.

**[0044]** In a first step 601, a target 510 on a substrate 502 is illuminated with an image 514 of an alignment mark on a patterning device 508. The substrate 502 is placed on a substrate table 504 as described above with reference to Figure 4. The radiation delivery system 505 may take any suitable form and may consist of any suitable number of components. In an example, the radiation delivery system is substantially identical to that described above with reference to Figure 4, i.e. it comprises a projection system 506 and a patterning device 508.

**[0045]** In a second step 602, the substrate table 504 is displaced relative to the radiation delivery system image 514 of the alignment mark. The relative displacement of the substrate table 504 may be in any suitable direction. In some examples, the displacement direction is dependent on the features of an alignment target to be measured. In the present example, the relative displacement of the substrate table 504 relative to the image 514 of the alignment mark is in a first direction. In the present example, the alignment target 510 comprises a

single target structure, i.e. a one-dimensional grating. The first direction is parallel to the direction of the grating of the alignment target 510. During the displacing step, the patterning device 508 is moved so as to cause the image 514 of the alignment mark to move from a first image position 515a into a second image position 515b (as indicated by arrow 516) in a second direction, the second direction being opposite to and parallel with the first direction. It will be realized that the movement 517 of the patterning device 508 in order to move the image 514 in the second direction is dictated by the specific properties of the projection system 506. In some examples, the image projected by the projection system 506 is inverted with respect to the pattern on the patterning device 508. In such examples, the patterning device 508 must be moved in the first direction in order to move the projected image (e.g. the image 514 of the alignment mark) in the second direction. In other examples, the projected image is not inverted with respect to the pattern on the patterning device. In such examples, the patterning device is moved in the second direction in order to cause the projected image to move in the, same, second direction.

**[0046]** During the displacing step, the substrate table 504 does not contribute to, or affect, the relative displacement between the substrate table 504 and the image 514 of the alignment mark, i.e. the substrate table does not move in the first direction (i.e. opposite to the second direction). In the present example, the substrate 502 remains in the first position 503a and, hence, the alignment target 510 remains in the first alignment target position 511a, while the image 514 of the alignment mark is moved from the first image position 515a to the second image position 515b.

**[0047]** However, it is to be noted that, according to the invention, the relative displacement between the image 514 of the alignment mark and the substrate table 504 is independent of individual movements of the patterning device 508 and the substrate table 504. In other words, individual movements of the patterning device 508 and the substrate table 504 do not influence the relative displacement between the image of the alignment mark and the substrate table, i.e. the direction and amount (distance) of this relative displacement remains the same and is not changed by these individual movements of the pattern device and the substrate table. For example, the substrate table is not necessarily kept stationary in an absolute sense, i.e. with respect to the lithographic apparatus or any stationary part of the same. It is, in principle, possible for the image 514 of the alignment mark and the substrate table 504 to perform a synchronized movement that does not impact the relative displacement between the patterning device 508 and the substrate table 504 during the displacing step. In

some examples, in addition to the above-described movements in the first and second directions, both the patterning device 508 and the substrate table 504 may perform a synchronized movement in a third direction. The third direction may in one example be orthogonal to the first direction (and by extension in this example also orthogonal to the second direction). This will be explained in more detail in examples described in the following.

[0048] It will be noted that the relative displacement 514 between the substrate 502 and the patterning device 508 in the example of Figure 5 is identical to the relative displacement 412 of Figure 4, but in opposite directions.

[0049] In a third step 603, radiation scattered by the target during the displacing of the substrate table is collected at a detector. The detector may be positioned in any convenient position. It will be realized that the specific position of the detector is dependent on the type of measurement being performed.

[0050] The scattered radiation is subsequently used in order to control the alignment of the patterning device relative to the substrate table prior to performing any exposure steps of the lithographic process used in the lithographic apparatus.

[0051] An second exemplary method will now be described with reference to Figures 7 and 8. For ease of comparison with Figures 4 and 5, elements of Figure 7 similar to corresponding elements of Figures 4 and 5 are labelled with reference signs similar to those used in Figures 4 and 5, but with prefix “7” instead of “4” or “5”.

[0052] In a first step 801, a target 710 on a substrate 702 is illuminated with an image 714 of an alignment mark on a patterning device 708. The substrate 702 is placed on a substrate table 704 in a manner similar to that described above with reference to Figures 4 and 5.

[0053] In a second step 802, the substrate table 704 is displaced relative to the image 714 of the alignment mark. In a similar manner to that described with respect to Figure 5, the patterning device 708 is moved so as to cause the image 714 of the alignment mark to move in a second direction from a first image position 715a into a second image position 715b (as indicated by arrow 716). The movement of the patterning device 708 is indicated by arrow 717. As discussed above, it will be realized that the movement 717 of the patterning device 708 in order to move the image in the second direction is dictated by the specific properties of the projection system 706. In some examples, the image projected by the projection system 706 is inverted with respect to the pattern on the patterning device 708. In such examples, the patterning device 708 must be moved in the first direction in order to move the projected

image (e.g. the image 714 of the alignment mark) in the second direction. In other examples, the projected image is not inverted with respect to the pattern on the patterning device 708. In such examples, the patterning device 708 is moved in the second direction in order to cause the projected image to move in the second direction.

5   **[0054]** Additionally, the substrate 702 is moved in a first direction from a first substrate position 703a into a second substrate position 703b (as indicated by arrow 712). Synchronously with the movement of the substrate 702, the alignment target 710 is moved from a first alignment target position 711a into a second alignment target position 711b (as the target is located on the substrate 702). It will of course be appreciated that the first and  
10   second directions are exemplary only, as described with reference to Figures 5 and 6 above.

**[0055]** It will be noted that, when compared to the example of Figure 5, the patterning device 708 is moved over a shorter absolute distance than in Figure 5. However, this is offset by the substrate table 703 being moved a corresponding distance in the first direction, such that the relative displacement 718 between the patterning device 708 and the substrate  
15   identical to the relative displacement 516 between the patterning device 508 and the substrate 502 of Figure 5.

**[0056]** In a third step 803, radiation scattered by the target during the displacing of the substrate table is collected at a detector. As described above, the detector may be positioned in any convenient position, the specific position being dependent on the type of measurement  
20   being performed.

**[0057]** In the examples discussed above, either or both of the patterning device or the substrate table are moved to result in a relative displacement between the substrate table and the image of the alignment mark on the patterning device. However, lithographic apparatuses typically comprise a plurality of components, in addition to the patterning device and  
25   substrate table, that may be actuated to control the lithographic process. Figure 9 illustrates schematically an exemplary optical system for a lithographic apparatus in which the above-described methods may be implemented.

**[0058]** The optical system 900 comprises a radiation delivery system, the radiation delivery system comprising a projection system 906 and a patterning device 908. Further, the optical  
30   system 900 comprises a radiation source SO, a beam delivery system BD and an illumination system IL, as described above with reference to Figure 1. The illumination system IL, in this example, comprises an adjuster AD, an integrator IN and a condenser CO. It is to be noted

that this is exemplary only, and that the beam delivery system and illumination system may comprise additional or alternative components.

[0059] The projection system 906 may have any suitable form and may comprise any suitable number of optical elements. In some examples, the projection system 906 may  
5 comprise a catadioptric system. In an example, the projection system 906 comprises at least first 920a, second 920b and third 920c optical components.

[0060] One or more of the optical components of the beam delivery system, illumination system or the projection system may be actuatable. In practice, such actuatable components are used to control the illuminating radiation in the lithographic apparatus so as to improve  
10 the quality of the patterned products. However, it is, in principle, equally possible to actuate one or more of the actuatable components in order to introduce relative movement between the substrate table and the radiation delivery system.

[0061] It will be appreciated that the above methods are exemplary only, and that a number of specific implementations may be envisaged. The skilled person will realize that the  
15 methods may be implemented in a plurality of different measurement systems utilizing different specific measurement methods to align the patterning device relative to the substrate.

[0062] In the above examples, the substrate comprises an alignment target with a single target structure. Specifically, in the above examples, the alignment target structure is a one-  
20 dimensional grating, i.e. the grating structure extends in a single direction. It will be appreciated, of course, that this is for exemplary purposes only.

[0063] Figure 10 illustrates an exemplary alignment target 1000 that comprises a first alignment target structure 1002 and a second alignment target structure 1004. The first alignment target structure comprises a one-dimensional grating that extends in a first  
25 direction 1006. The second alignment target structure comprises a one-dimensional grating that extends in a second direction 1008 that is orthogonal to the first direction 1006.

[0064] During the alignment process, a plurality of specific measurements may be performed on both the first and second alignment target structures. In one example, a plurality of measurements are performed at a plurality of first points 1010 on the first  
30 alignment target structure 1002. During the measurements, the substrate table is displaced relative to the image of the alignment mark on the patterning device in a direction parallel to the first direction 1006. Subsequently, a plurality of measurements are performed at a plurality of second points 1012 on the second alignment target structure 1004. During the

measurements, the substrate table is displaced relative to the image of the alignment mark on the patterning device in a direction parallel to the second direction 1008.

[0065] Figure 11 shows schematically a number of non-limiting exemplary relative displacement schemes. Figure 11(a) shows the known relative displacement scheme (as described with reference to Figure 4) in which a substrate 1102 is initially positioned in a first substrate position 1103a. The substrate 1102 is then moved (indicated by arrow 1108) into a second substrate position (indicated by 1103b in figure 11a) in a first direction. Throughout the movement of the substrate 1102, an image 1104 of an alignment mark on a patterning device remains stationary in a first image position 1105a. The total relative displacement between the substrate table (and also the substrate) and the patterning device is indicated by arrow 1106.

[0066] Figure 11(b) shows the exemplary relative displacement scheme described with reference to Figure 5 above. In this example, the substrate 1112 remains stationary in a first substrate position 1113a. The image 1114 of the alignment mark on the patterning device is moved in a second direction (indicated by arrow 1119) from a first image position 1115a into a second image position 1115b. The total relative displacement between the substrate table (and also the substrate) and the patterning device is indicated by arrow 1116.

[0067] Figure 11(c) shows the relative displacement scheme described with reference to Figure 7, wherein both substrate 1122 and the image 1124 of the alignment mark on the patterning device are moved in opposite directions. The substrate is moved from a first substrate position 1123a into a second substrate position 1123b in a first direction (indicated by arrow 1128). The image 1124 of the alignment mark on the patterning device is moved from a first image position 1125a and into a second image position 1125b in a second direction (indicated by arrow 1129). The total relative displacement between the substrate table (and also the substrate) and the patterning device is indicated by arrow 1126.

[0068] It is to be noted that, while only one of the substrate or the image of the alignment target may contribute to the relative displacement in the above examples, this should not be interpreted as meaning that the non-contributing element is stationary, i.e. that the element has a speed that is equal to zero. It is, in principle, possible for both the image of the alignment mark and the substrate to perform a synchronized movement along an additional movement vector as long as the relative displacement does not change and remains the same (constant). One such example is shown in Figure 11(d). In this example, the substrate 1132 is initially positioned in a first substrate position 1133a. During the movement, it is moved into

a second substrate position 1133b. As can be seen, the substrate is moved both in the X-direction and in the Y-direction (as indicated by arrow 1138). Similarly, the image 1134 of the alignment mark on the patterning device is initially positioned in a first image position 1135a, and is moved (as indicated by arrow 1139) into a second image position 1135b. Although the movement of the substrate table (and also the substrate) and the patterning device differs from that shown in the examples of Fig. 11(a), 11(b) and 11(c), it will be appreciated that the relative displacement between the substrate and the image of the alignment mark on the patterning device is identical to that shown in the examples of Fig. 11(a), 11(b) and 11(c), (as indicated by arrow 1136).

[0069] It is further to be noted that the above-described examples are exemplary only, and that many specific implementations may be envisaged by the skilled person. In particular, it will be clear to the skilled person from the above that a number of movement schemes for the absolute and relative movement of the substrate table and the patterning device, as well as any other components or elements of the lithographic apparatus that may be moved, may be envisaged.

[0070] 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, flat-panel displays, 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 portion”, 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), a metrology tool and/or an 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.

[0071] Although specific reference may have been made above to the use of embodiments of the invention in the context of optical lithography, it will be appreciated that the invention may be used in other applications, for example imprint lithography, and where the context allows, is not limited to optical lithography. In imprint lithography a topography in a

patterning device defines the pattern created on a substrate. The topography of the patterning device may be pressed into a layer of resist supplied to the substrate whereupon the resist is cured by applying electromagnetic radiation, heat, pressure or a combination thereof. The patterning device is moved out of the resist leaving a pattern in it after the resist is cured.

5 [0072] The terms “radiation” and “beam” used herein encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (e.g. having a wavelength of or about 365, 355, 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.

10 [0073] The term “lens”, where the context allows, may refer to any one or combination of various types of optical components, including refractive, reflective, magnetic, electromagnetic and electrostatic optical components.

[0074] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. For example, the  
15 invention may take the form of a computer program containing one or more sequences of machine-readable instructions describing a method as disclosed above, or a data storage medium (e.g. semiconductor memory, magnetic or optical disk) having such a computer program stored therein.

[0075] The descriptions above are intended to be illustrative, not limiting. Thus, it will be  
20 apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the claims set out below.

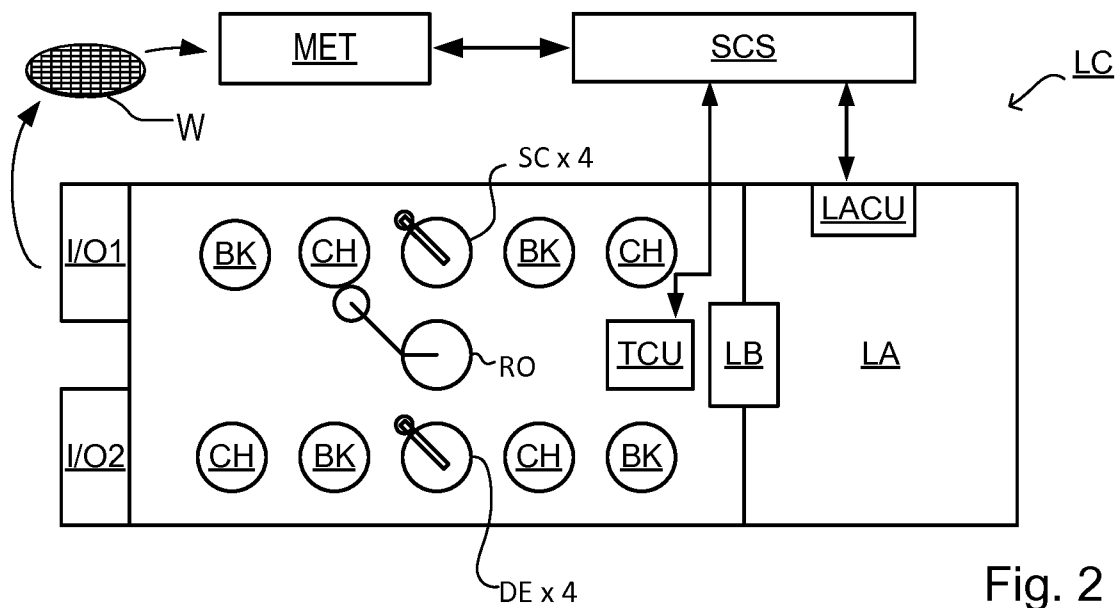
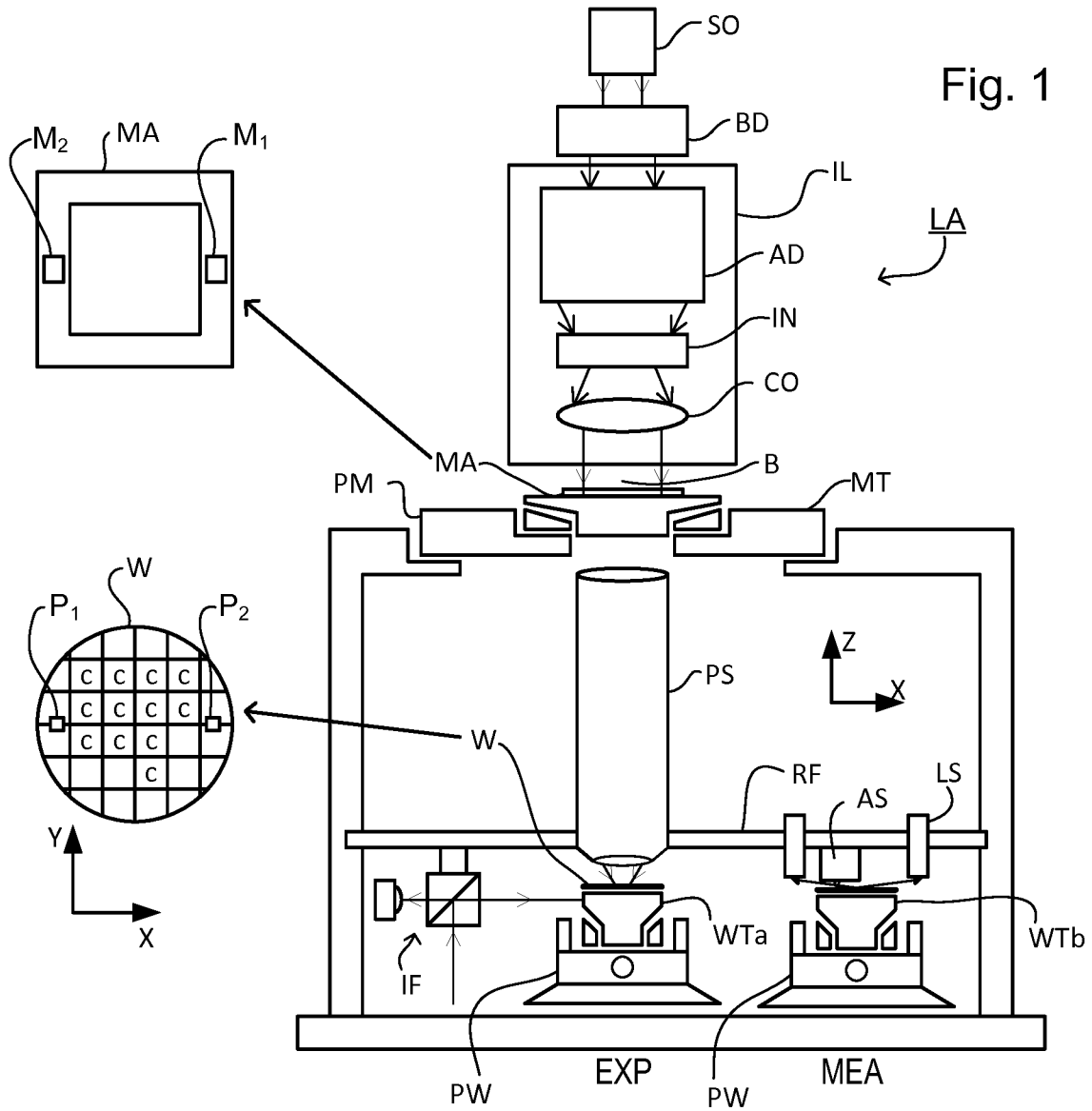
## CLAIMS:

1. A method of controlling alignment in a lithographic apparatus, the apparatus being configured to expose a substrate held by a substrate table to an image of a pattern on a patterning device via a projection system, the method comprising:
  - 5           illuminating a target on the substrate with an image of an alignment mark on the patterning device;
  - displacing the substrate table relative to the image of the alignment mark;
  - collecting radiation scattered by the target during the displacing step at a detector;
  - 10           moving the patterning device during the displacing of the substrate table, wherein the relative displacement between the image of the alignment mark and the substrate table is independent of individual movements of the patterning device and the substrate table.
- 15   2. A method according to claim 1, wherein the displacement of the substrate table relative to the image of the alignment mark on the patterning device is in a first direction, and wherein the patterning device is moved so as to cause the image of the alignment mark to move in a second direction, the second direction being opposite to and parallel with the first direction.
- 20   3. A method according to claim 1 or 2, wherein the displacing step further comprises moving the substrate table in at least the first direction.
4. A method according to claim 2 or 3, wherein the displacing step further comprises  
25           moving at least one optical component of the projection system in one of the first or second direction.
5. A method according to any of claims 2 to 4, wherein the displacing step further comprises: moving the patterning device so as to cause the image of the alignment  
30           mark to move in a third direction; and moving the substrate table in the third direction.

6. A method according to claim 5, wherein the third direction is orthogonal to the first direction.
7. A lithographic apparatus, the apparatus being configured to expose a substrate held by a substrate table to an image of a pattern on a patterning device via a projection system, comprising:
- 5 a radiation delivery system operable to illuminate a target on the substrate with an image of an alignment mark on the patterning device;
- 10 a displacement system operable to displace the substrate table relative to the image of the alignment mark;
- a detector operable to collect radiation scattered by the target during the displacing step at a detector;
- wherein the displacement system is operable to move the patterning device, and
- 15 wherein the relative displacement between the image of the alignment mark and the substrate table is independent of individual movements of the patterning device and the substrate table.
8. A lithographic apparatus according to claim 7, wherein the displacement of the substrate table relative to the image of the alignment mark on the patterning device is in a first direction, and wherein the patterning device is moved so as to cause the image of the alignment mark to move in a second direction, the second direction being opposite to and parallel with the first direction.
- 20
9. A lithographic apparatus according to claim 7 or 8, wherein the displacing step further comprises moving the substrate table in at least the first direction.
- 25
10. A lithographic apparatus according to claim 8 or 9, wherein the displacement system is further operable to move at least one optical component of the projection system in one of the first or second direction.
- 30
11. A lithographic apparatus according to any of claims 8 to 10, wherein the displacement system is further operable to: move the patterning device so as to cause the image of

the alignment mark to move in a third direction; and move the substrate table in the third direction.

12. A lithographic apparatus according to claim 11, wherein the third direction is  
5 orthogonal to the first direction.
13. A method of manufacturing devices wherein device features and metrology targets are formed on a series of substrates by a lithographic process, wherein properties of the alignment targets on one or more substrates are measured by a method as claimed in  
10 any of claims 1 to 6, and wherein the measured properties are used to adjust parameters of the lithographic process.
14. A computer program product comprising machine-readable instructions for causing a processor to control a lithographic apparatus during the displacing step of a method as  
15 claimed in any of claims 1 to 6.
15. A computer program product according to claim 14, further comprising machine-readable instructions for causing a processor to perform the using step of a method as claimed in any of claims 1 to 6.



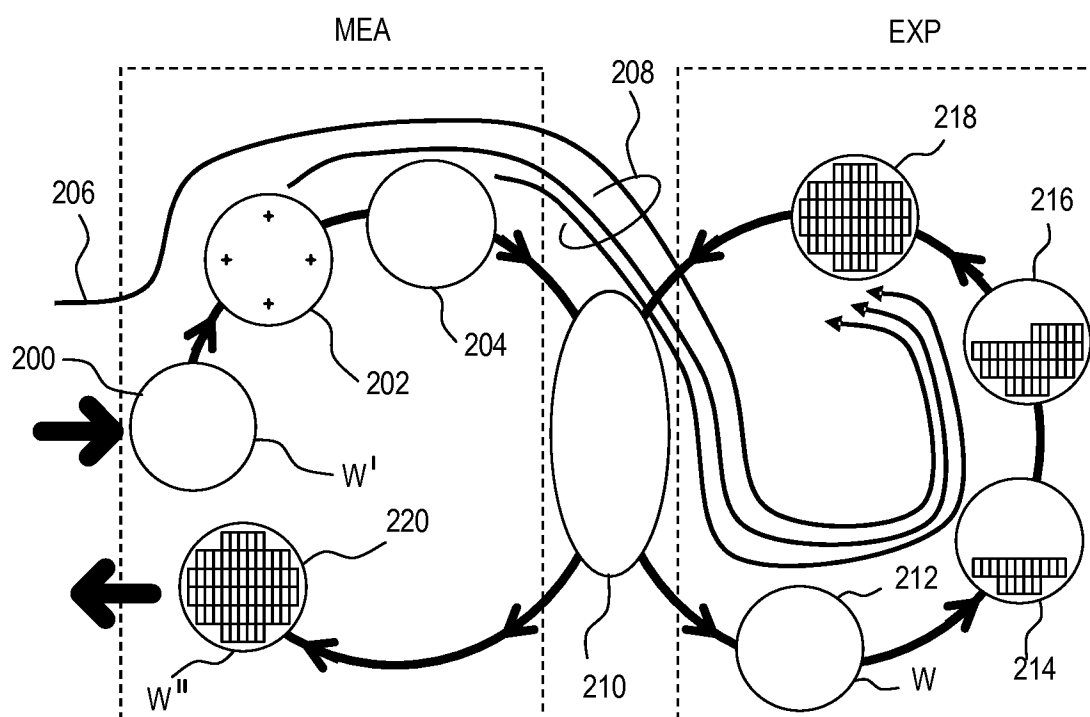


Fig. 3

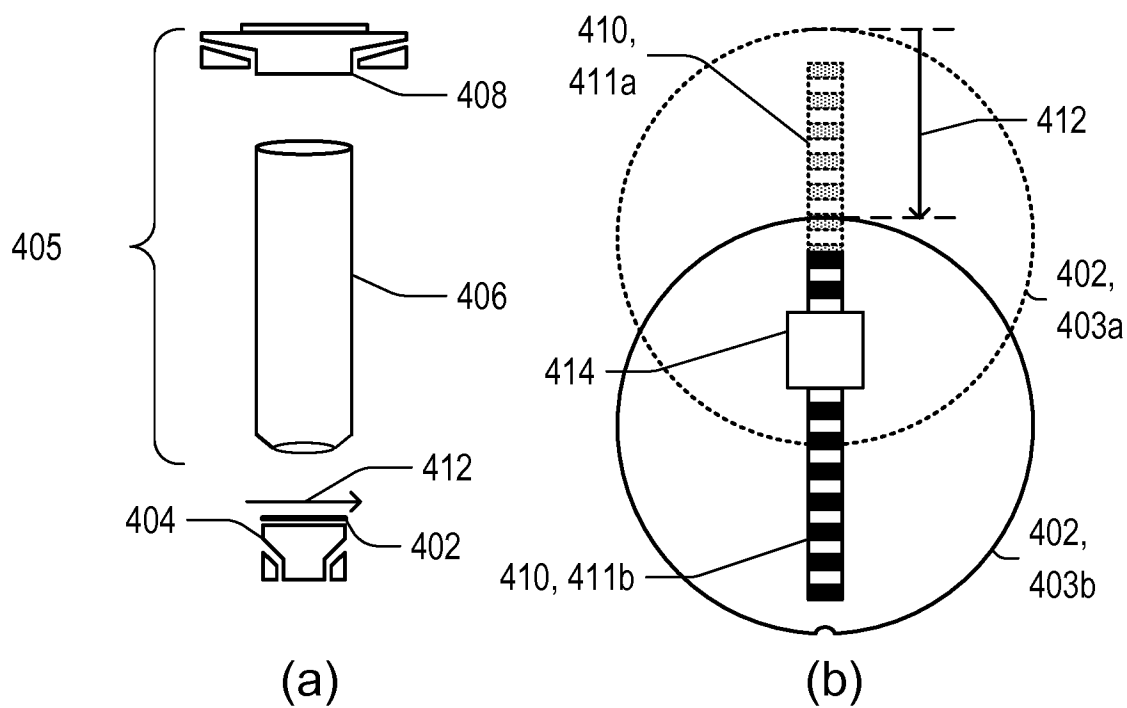


Fig. 4

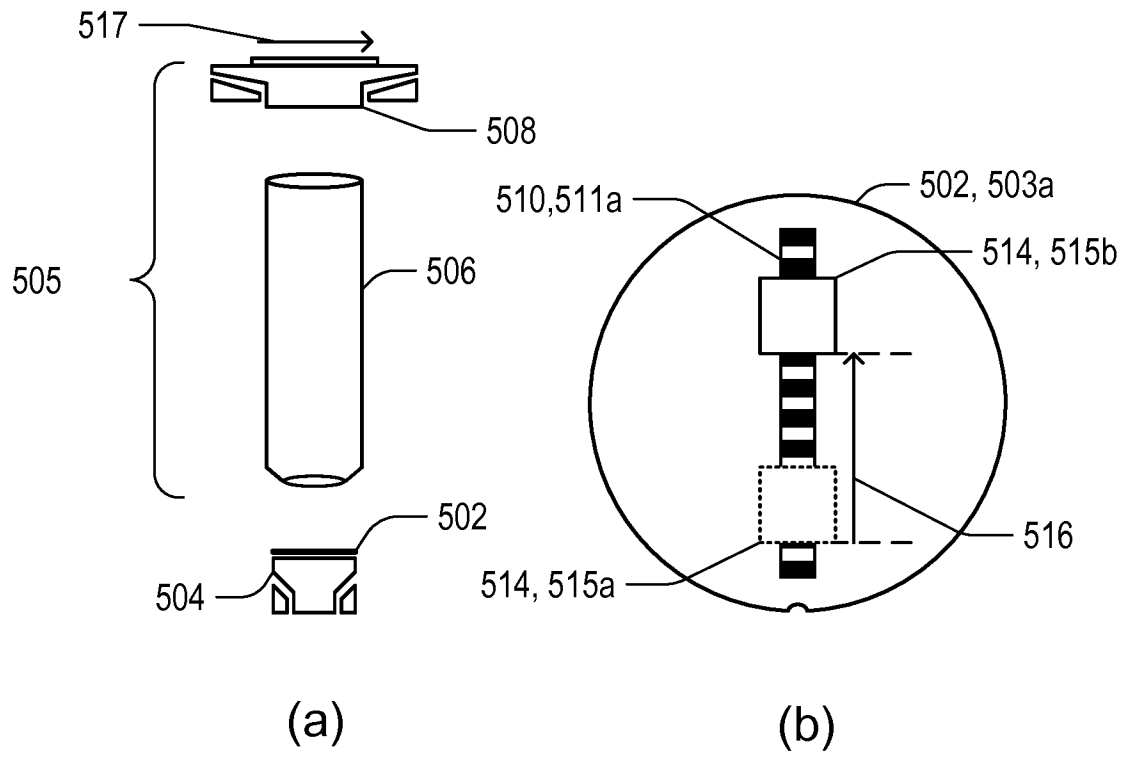


Fig. 5

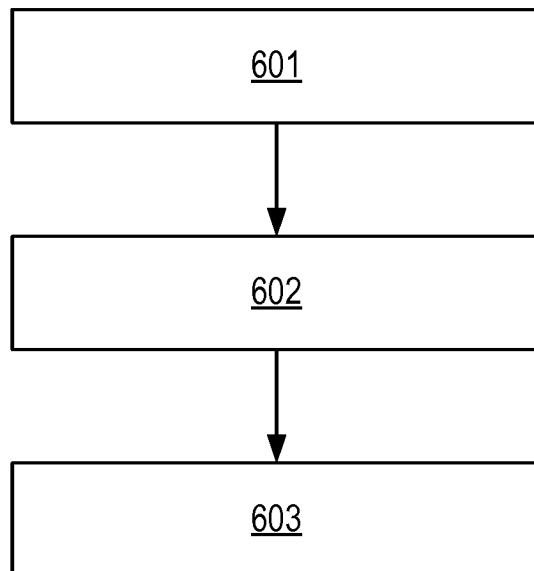


Fig. 6

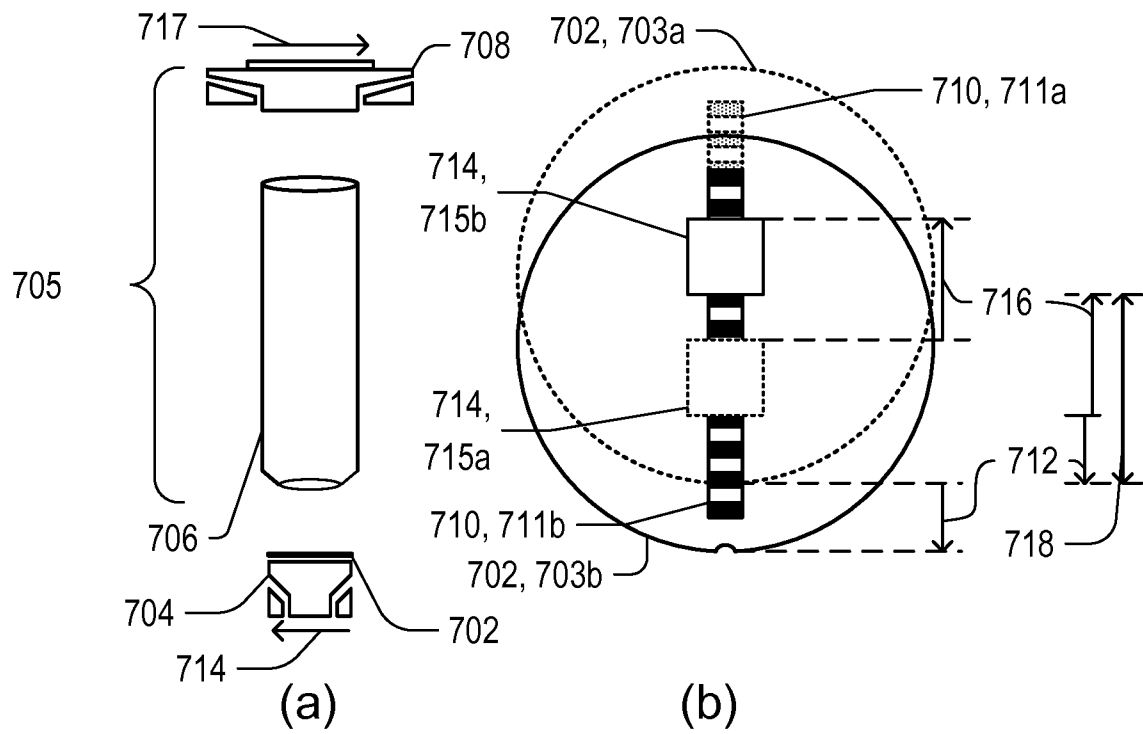


Fig. 7

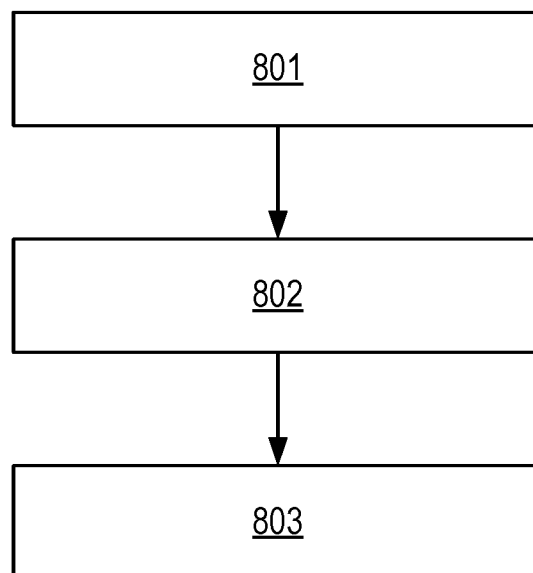


Fig. 8

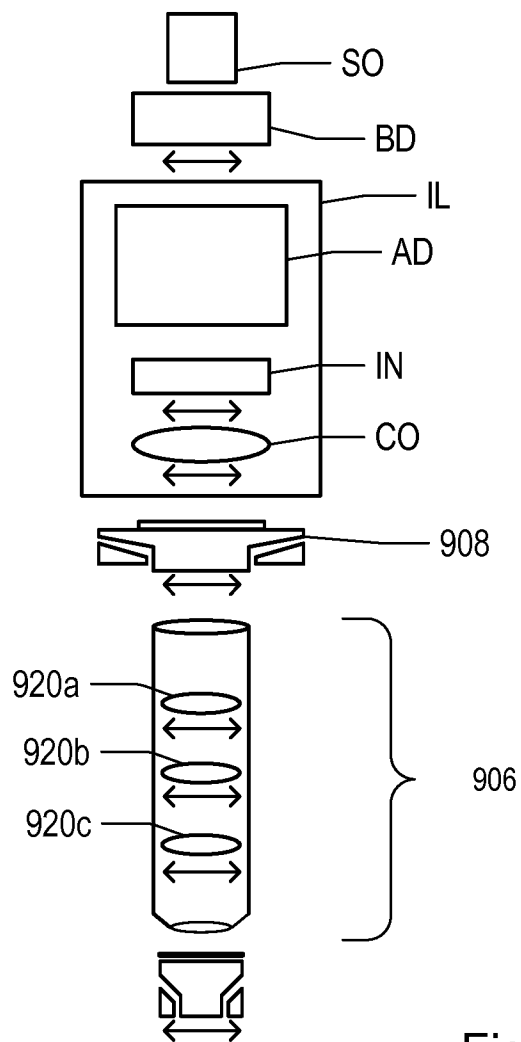


Fig. 9

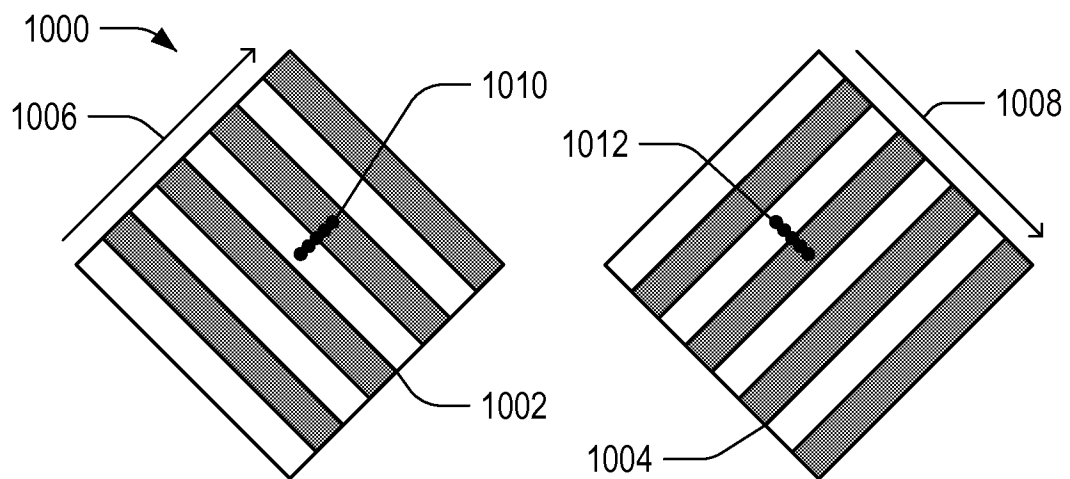


Fig. 10

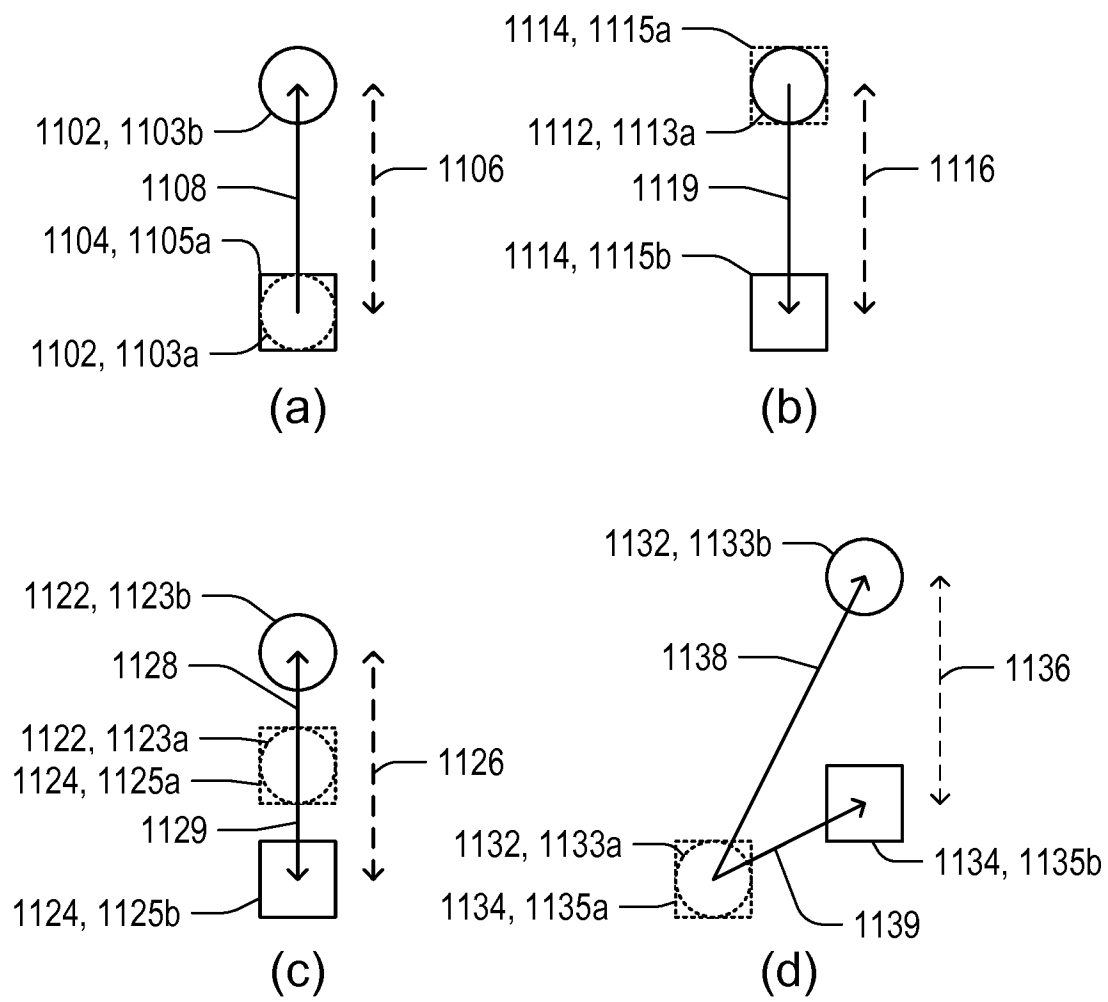


Fig. 11

# INTERNATIONAL SEARCH REPORT

International application No  
PCT/EP2017/057534

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

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

## B. FIELDS SEARCHED

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

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

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

EPO-Internal, WPI Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                          | Relevant to claim No. |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| X         | US 5 838 450 A (MCCOY JOHN H [US] ET AL)<br>17 November 1998 (1998-11-17)<br>abstract<br>figures 1,9a,9b<br>column 1, lines 13-15<br>column 3, lines 24-45<br>column 6, line 40 - column 7, line 2<br>----- | 1-15                  |



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

21 June 2017

Date of mailing of the international search report

07/07/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040,  
Fax: (+31-70) 340-3016

Authorized officer

Andersen, Ole

## INTERNATIONAL SEARCH REPORT

### Information on patent family members

International application No

PCT/EP2017/057534

| Patent document<br>cited in search report |   | Publication<br>date |    | Patent family<br>member(s) |  | Publication<br>date |
|-------------------------------------------|---|---------------------|----|----------------------------|--|---------------------|
| US 5838450                                | A | 17-11-1998          | JP | H07270119 A                |  | 20-10-1995          |
|                                           |   |                     | US | 5838450 A                  |  | 17-11-1998          |
| -----                                     |   |                     |    |                            |  |                     |