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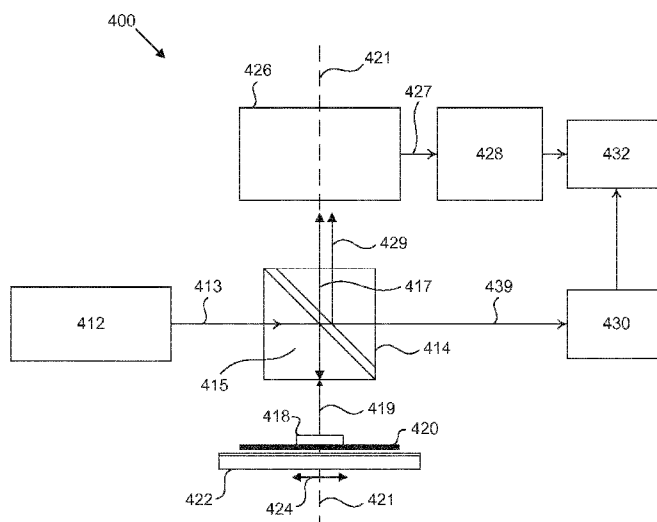


FIG. 4A

(57) Abstract: An alignment system obtains the characteristics of the light coming back from a wafer stack. A beam analyzer measures changes in wavelength, polarization, and beam profile. This measured information allows for in-line process variation corrections. The correction provides optical monitoring of individual mark stack variations, and in turn provides information to reduce individual mark process variation-induced accuracy error.



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ALIGNMENT SYSTEM WAFER STACK BEAM ANALYZER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of US Provisional Patent Application No. 5 62/345,678, which was filed on June 3, 2016, and which is incorporated herein in its entirety by reference.

FIELD

[0002] The present disclosure relates to an alignment system that may be used, for 10 example, in a lithographic apparatus.

BACKGROUND

[0003] A lithographic apparatus is a machine that applies a desired pattern onto a target 15 portion of a substrate. Lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In that circumstance, a patterning device, which is alternatively referred to as a mask or a reticle, may be used to generate a circuit pattern corresponding to an individual layer of the IC, and this pattern can be imaged onto a target 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 portions 20 that are successively exposed. 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 the beam in a given direction (the “scanning”-direction) while synchronously scanning the substrate parallel or anti parallel to this direction. It is also possible to transfer the pattern from 25 the patterning device to the substrate by imprinting the pattern onto the substrate. Another lithographic system is an interferometric lithographic system where there is no patterning device, but rather a light beam is split into two beams, and the two beams are caused to interfere at a target portion of substrate through the use of a reflection system. The interference causes lines to be formed on at the target portion of the substrate.

[0004] During lithographic operation, different processing steps may require different 30 layers to be sequentially formed on the substrate. Accordingly, it may be necessary to position

the substrate relative to prior patterns formed thereon with a high degree of accuracy. Generally, alignment marks are placed on the substrate to be aligned and are located with reference to a second object. A lithographic apparatus may use an alignment system for detecting positions of the alignment marks and for aligning the substrate using the alignment marks to ensure accurate exposure from a mask. Misalignment between the alignment marks at two different layers is measured as overlay error.

[0005] Ideally, overlay error is solely a product of positioning of the substrate within the lithographic system. In practice, however, overlay error originates from the interaction between the alignment system and the substrate. Variations in the alignment system and substrate can produce errors in assessing the true location of the alignment marks. Such errors are known as “on-process” accuracy errors. Alignment system optics contain manufacturing aberrations and, thus, cannot be made identical. Substrates (e.g., wafer stacks), likewise, have properties variations stemming from manufacturing and post-manufacturing processes. This “on-process” accuracy problem limits the robustness of the alignment system.

[0006] Accordingly, there is a need to compensate for variations in the alignment system and process variations in the substrate.

SUMMARY

[0007] According to an embodiment, an alignment system includes a radiation source that generates light, an optical modulating unit, an optical splitter, an interferometer, one or more detectors, a beam analyzer, and a processor.

[0008] In an embodiment, light generated by the radiation source is directed towards a substrate. The optical splitter splits a beam of light diffracted from a pattern on the substrate, or reflected from the substrate into sub-beams of light. The interferometer interferes at least one sub-beams of the light and produces output light from the interference. The one or more detector receives the output light from the interferometer, and determines an alignment status of the substrate. The beam analyzer receives from the optical splitter at least one of the sub-beams of light that has been diffracted from the pattern on the substrate, or reflected from the substrate, and provides an overlay offset measurement of the pattern or an optical state of the beam profile. The beam analyzer may also determine a product stack profile based on the beam profile. The processor utilizes a correction algorithm to determine overlay offset errors based on the

information received from the one or more detectors and beam analyzer, and generates a correction table using the determined overlay offset errors and product stack profile. The processor uses the correction table to determine corrections for each mark and feed corrections back to the alignment system for correcting errors in the overlay offset. The processor may repeat the above process for each mark and create a self-learning feedback loop for improving the alignment status of the substrate. The processor may then direct the alignment system to place the substrate at an updated position for improved alignment accuracy.

[0009] Further 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/FIGURES

[0010] The accompanying drawings, which are incorporated herein and form part of the specification, illustrate the present invention and, together with the description, further serve to explain the principles of the invention and to enable a person skilled in the relevant art(s) to make and use the invention.

[0011] FIG. 1A is a schematic illustration of a reflective lithographic apparatus according to an embodiment.

[0012] FIG. 1B is a schematic illustration of a transmissive lithographic apparatus according to an embodiment.

[0013] FIG. 2 is a more detailed schematic illustration of the reflective lithographic apparatus, according to an embodiment.

[0014] FIG. 3 is a schematic illustration of a lithographic cell, according to an embodiment.

[0015] FIGs. 4A and 4B are schematic illustrations of enhanced alignment systems, according to various embodiments.

[0016] FIG. 5 is a computer system that may be used in an apparatus according to an embodiment.

[0017] FIGs. 6 is a flowchart of a method for inspecting a wafer using an enhanced alignment system, according to various embodiments and using the information to provide more accurate alignment.

[0018] The features and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings, in which like reference characters identify corresponding elements throughout. In the drawings, like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements. The drawing in which an element first appears is indicated by the leftmost digit(s) in the corresponding reference number. Unless otherwise indicated, the drawings provided throughout the disclosure should not be interpreted as to-scale drawings.

DETAILED DESCRIPTION

[0019] This specification discloses one or more embodiments that incorporate the features of this invention. The disclosed embodiment(s) merely exemplify the invention. The scope of the invention is not limited to the disclosed embodiment(s). The invention is defined by the claims appended hereto.

[0020] The embodiment(s) described, and references in the specification to “one embodiment,” “an embodiment,” “an example embodiment,” *etc.*, indicate that the embodiment(s) described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is understood that it is within the knowledge of one skilled in the art to effect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described.

[0021] Before describing such embodiments in more detail, however, it is instructive to present an example environment in which embodiments of the present invention may be implemented.

[0022] *Example Reflective and Transmissive Lithographic Systems*

[0023] FIGs. 1A and 1B are schematic illustrations of a lithographic apparatus 100 and lithographic apparatus 100', respectively, in which embodiments of the present invention may be

implemented. Lithographic apparatus 100 and lithographic apparatus 100' each include the following: an illumination system (illuminator) IL configured to condition a radiation beam B (for example, deep ultra violet or extreme ultra violet radiation); a support structure (for example, a mask table) MT configured to support a patterning device (for example, a mask, a reticle, or a dynamic patterning device) MA and connected to a first positioner PM configured to accurately position the patterning device MA; and, a substrate table (for example, a wafer table) WT configured to hold a substrate (for example, a resist coated wafer) W and connected to a second positioner PW configured to accurately position the substrate W. Lithographic apparatus 100 and 100' also have a projection system PS configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion (for example, comprising one or more dies) C of the substrate W. In lithographic apparatus 100, the patterning device MA and the projection system PS are reflective. In lithographic apparatus 100', the patterning device MA and the projection system PS are transmissive.

[0024] The illumination system IL may include various types of optical components, such as refractive, reflective, catadioptric, magnetic, electromagnetic, electrostatic, or other types of optical components, or any combination thereof, for directing, shaping, or controlling the radiation beam B.

[0025] The support structure MT holds the patterning device MA in a manner that depends on the orientation of the patterning device MA with respect to a reference frame, the design of at least one of the lithographic apparatus 100 and 100', and other conditions, such as whether or not the patterning device MA is held in a vacuum environment. The support structure MT may use mechanical, vacuum, electrostatic, or other clamping techniques to hold the patterning device MA. The support structure MT can be a frame or a table, for example, which can be fixed or movable, as required. By using sensors, the support structure MT can ensure that the patterning device MA is at a desired position, for example, with respect to the projection system PS.

[0026] The term "patterning device" MA should be broadly interpreted as referring to any device that can be used to impart a radiation beam B with a pattern in its cross-section, such as to create a pattern in the target portion C of the substrate W. The pattern imparted to the radiation beam B can correspond to a particular functional layer in a device being created in the target portion C to form an integrated circuit.

[0027] The patterning device MA may be transmissive (as in lithographic apparatus 100' of FIG. 1B) or reflective (as in lithographic apparatus 100 of FIG. 1A). Examples of patterning devices MA include reticles, 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. The tilted mirrors impart a pattern in the radiation beam B which is reflected by a matrix of small mirrors.

10 [0028] The term "projection system" PS can encompass 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 on the substrate W or the use of a vacuum. A vacuum environment can be used for EUV or electron beam radiation since other gases can absorb too much radiation or electrons. A vacuum environment can therefore be provided to the whole beam path with the aid of a vacuum wall and vacuum pumps.

15 [0029] Lithographic apparatus 100 and/or lithographic apparatus 100' can be of a type having two (dual stage) or more substrate tables WT (and/or two or more mask tables). In such "multiple stage" machines, the additional substrate tables WT can be used in parallel, or preparatory steps can be carried out on one or more tables while one or more other substrate tables WT are being used for exposure. In some situations, the additional table may not be a substrate table WT.

20 [0030] Referring to FIGs. 1A and 1B, the illuminator IL receives a radiation beam from a radiation source SO. The source SO and the lithographic apparatus 100, 100' can be separate physical entities, for example, when the source SO is an excimer laser. In such cases, the source SO is not considered to form part of the lithographic apparatus 100 or 100', and the radiation beam B passes from the source SO to the illuminator IL with the aid of a beam delivery system BD (in FIG. 1B) including, for example, suitable directing mirrors and/or a beam expander. In other cases, the source SO can be an integral part of the lithographic apparatus 100, 100'—for example when the source SO is a mercury lamp. The source SO and the illuminator IL, together with the beam delivery system BD, if required, can be referred to as a radiation system.

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[0031] The illuminator IL can include an adjuster AD (in FIG. 1B) for adjusting the angular intensity distribution of the radiation 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 can
5 comprise various other components (in FIG. 1B), such as an integrator IN and a condenser CO. The illuminator IL can be used to condition the radiation beam B to have a desired uniformity and intensity distribution in its cross section.

[0032] Referring to FIG. 1A, the radiation beam B is incident on the patterning device (for example, mask) MA, which is held on the support structure (for example, mask table) MT,
10 and is patterned by the patterning device MA. In lithographic apparatus 100, the radiation beam B is reflected from the patterning device (for example, mask) MA. After being reflected from the patterning device (for example, mask) MA, the radiation beam B passes through the projection system PS, which focuses the radiation beam B onto a target portion C of the substrate W. With the aid of the second positioner PW and position sensor IF2 (for example, an interferometric
15 device, linear encoder, or capacitive sensor), the substrate table WT can be moved accurately (for example, 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 IF1 can be used to accurately position the patterning device (for example, mask) MA with respect to the path of the radiation beam B. Patterning device (for example, mask) MA and substrate W can be aligned using mask
20 alignment marks M1, M2 and substrate alignment marks P1, P2.

[0033] Referring to FIG. 1B, the radiation beam B is incident on the patterning device (for example, mask MA), which is held on the support structure (for example, mask table MT), and is patterned by the patterning device. Having traversed the mask MA, the radiation beam B
25 passes through the projection system PS, which focuses the beam onto a target portion C of the substrate W. The projection system has a pupil PPU conjugate to an illumination system pupil IPU. Portions of radiation emanate from the intensity distribution at the illumination system pupil IPU and traverse a mask pattern without being affected by diffraction at a mask pattern and create an image of the intensity distribution at the illumination system pupil IPU.

[0034] With the aid of the second positioner PW and position sensor IF (for example, an
30 interferometric device, linear encoder, or capacitive sensor), the substrate table WT can be moved accurately (for example, 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 (not shown in FIG. 1B) can be used to accurately position the mask MA with respect to the path of the radiation beam B (for example, after mechanical retrieval from a mask library or during a scan).

[0035] In general, movement of the mask table MT can be realized with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning), which form part of the first positioner PM. Similarly, movement of the substrate table WT can be realized using a long-stroke module and a short-stroke module, which form part of the second positioner PW. In the case of a stepper (as opposed to a scanner), the mask table MT can be connected to a short-stroke actuator only or can be fixed. Mask MA and substrate W can 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 can be located in spaces between target portions (known as scribe-lane alignment marks). Similarly, in situations in which more than one die is provided on the mask MA, the mask alignment marks can be located between the dies.

[0036] Mask table MT and patterning device MA can be in a vacuum chamber, where an in-vacuum robot IVR can be used to move patterning devices such as a mask in and out of vacuum chamber. Alternatively, when mask table MT and patterning device MA are outside of the vacuum chamber, an out-of-vacuum robot can be used for various transportation operations, similar to the in-vacuum robot IVR. Both the in-vacuum and out-of-vacuum robots need to be calibrated for a smooth transfer of any payload (e.g., mask) to a fixed kinematic mount of a transfer station.

[0037] The lithographic apparatus 100 and 100' can be used in at least one of the following modes:

[0038] 1. In step mode, the support structure (for example, mask table) MT and the substrate table WT are kept essentially stationary, while an entire pattern imparted to the radiation beam B is projected onto a target portion C at one time (i.e., a single static exposure). The substrate table WT is then shifted in the X and/or Y direction so that a different target portion C can be exposed.

[0039] 2. In scan mode, the support structure (for example, mask table) MT and the substrate table WT are scanned synchronously while a pattern imparted to the radiation beam B is projected onto a target portion C (i.e., a single dynamic exposure). The velocity and direction

of the substrate table WT relative to the support structure (for example, mask table) MT can be determined by the (de-)magnification and image reversal characteristics of the projection system PS.

[0040] 3. In another mode, the support structure (for example, mask table) MT is kept substantially stationary holding a programmable patterning device, and the substrate table WT is moved or scanned while a pattern imparted to the radiation beam B is projected onto a target portion C. A pulsed radiation source SO can be employed and the programmable patterning device is updated as required after each movement of the substrate table WT or in between successive radiation pulses during a scan. This mode of operation can be readily applied to maskless lithography that utilizes a programmable patterning device, such as a programmable mirror array.

[0041] Combinations and/or variations on the described modes of use or entirely different modes of use can also be employed.

[0042] In a further embodiment, lithographic apparatus 100 includes an extreme ultraviolet (EUV) source, which is configured to generate a beam of EUV radiation for EUV lithography. In general, the EUV source is configured in a radiation system, and a corresponding illumination system is configured to condition the EUV radiation beam of the EUV source.

[0043] FIG. 2 shows the lithographic apparatus 100 in more detail, including the source collector apparatus SO, the illumination system IL, and the projection system PS. The source collector apparatus SO is constructed and arranged such that a vacuum environment can be maintained in an enclosing structure 220 of the source collector apparatus SO. An EUV radiation emitting plasma 210 may be formed by a discharge produced plasma source. EUV radiation may be produced by a gas or vapor, for example Xe gas, Li vapor or Sn vapor in which the very hot plasma 210 is created to emit radiation in the EUV range of the electromagnetic spectrum. The very hot plasma 210 is created by, for example, an electrical discharge causing an at least partially ionized plasma. Partial pressures of, for example, 10 Pa of Xe, Li, Sn vapor or any other suitable gas or vapor may be required for efficient generation of the radiation. In an embodiment, a plasma of excited tin (Sn) is provided to produce EUV radiation.

[0044] The radiation emitted by the hot plasma 210 is passed from a source chamber 211 into a collector chamber 212 via an optional gas barrier or contaminant trap 230 (in some cases also referred to as contaminant barrier or foil trap) which is positioned in or behind an opening in

source chamber 211. The contaminant trap 230 may include a channel structure. Contamination trap 230 may also include a gas barrier or a combination of a gas barrier and a channel structure. The contaminant trap or contaminant barrier 230 further indicated herein at least includes a channel structure, as known in the art.

5 [0045] The collector chamber 212 may include a radiation collector CO which may be a so-called grazing incidence collector. Radiation collector CO has an upstream radiation collector side 251 and a downstream radiation collector side 252. Radiation that traverses collector CO can be reflected off a grating spectral filter 240 to be focused in a virtual source point IF. The virtual source point IF is commonly referred to as the intermediate focus, and the source
10 collector apparatus is arranged such that the intermediate focus IF is located at or near an opening 219 in the enclosing structure 220. The virtual source point IF is an image of the radiation emitting plasma 210. Grating spectral filter 240 is used in particular for suppressing infra-red (IR) radiation.

[0046] Subsequently the radiation traverses the illumination system IL, which may
15 include a faceted field mirror device 222 and a faceted pupil mirror device 224 arranged to provide a desired angular distribution of the radiation beam 221, at the patterning device MA, as well as a desired uniformity of radiation intensity at the patterning device MA. Upon reflection of the beam of radiation 221 at the patterning device MA, held by the support structure MT, a patterned beam 226 is formed and the patterned beam 226 is imaged by the projection system PS
20 via reflective elements 228, 230 onto a substrate W held by the wafer stage or substrate table WT.

[0047] More elements than shown may generally be present in illumination optics unit IL and projection system PS. The grating spectral filter 240 may optionally be present, depending upon the type of lithographic apparatus. Further, there may be more mirrors present than those
25 shown in the FIGs., for example there may be 1- 6 additional reflective elements present in the projection system PS than shown in FIG. 2.

[0048] Collector optic CO, as illustrated in FIG. 2, is depicted as a nested collector with grazing incidence reflectors 253, 254 and 255, just as an example of a collector (or collector
30 mirror). The grazing incidence reflectors 253, 254 and 255 are disposed axially symmetric around an optical axis O and a collector optic CO of this type is preferably used in combination with a discharge produced plasma source, often called a DPP source.

[0049] *Example Lithographic Cell*

[0050] He FIG. 3 shows a lithographic cell 300, also sometimes referred to a lithocell or cluster. Lithographic apparatus 100 or 100' may form part of lithographic cell 300. Lithographic cell 300 may also include 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.

[0051] *Example Alignment System*

[0052] In order to control the lithographic process to place device features accurately on the substrate, alignment marks are generally provided on the substrate, and the lithographic apparatus includes one or more alignment systems by which positions of marks on a substrate must be measured accurately. These alignment systems are effectively position measuring apparatuses. Different types of marks and different types of alignment systems are known from different times and different manufacturers. A type of system widely used in current lithographic apparatus is based on a self-referencing interferometer as described in U.S. Pat. No. 6,961,116 (den Boef *et al.*). Generally marks are measured separately to obtain X- and Y-positions. A combined X- and Y-measurement can be performed using the techniques described in published patent application US 2009/195768 A (Bijnen *et al.*), however. The full contents of both of these disclosures are incorporated herein by reference.

[0053] FIG. 4A illustrates a schematic of a cross-sectional view of an alignment system 400 that can be implemented as a part of lithographic apparatus 100 or 100', according to an embodiment. In an example of this embodiment, alignment system 400 may be configured to align a substrate (e.g., substrate W) with respect to a patterning device (e.g., patterning device MA). Alignment system 400 may be further configured to detect positions of alignment marks on the substrate and to align the substrate with respect to the patterning device or other components of lithography apparatus 100 or 100' using the detected positions of the alignment

marks. Such alignment of the substrate may ensure accurate exposure of one or more patterns on the substrate.

[0054] According to an embodiment, alignment system 400 may include an illumination system 412, a beam splitter 414, an interferometer 426, a detector 428, a beam analyzer 430, and an overlay calculation processor 432, according to an example of this embodiment. Illumination system 412 may be configured to provide an electromagnetic narrow band radiation beam 413 having one or more passbands. In an example, the one or more passbands may be within a spectrum of wavelengths between about 500 nm to about 900 nm. In another example, the one or more passbands may be discrete narrow passbands within a spectrum of wavelengths between about 500 nm to about 900 nm. Illumination system 412 may be further configured to provide one or more passbands having substantially constant center wavelength (CWL) values over a long period of time (e.g., over a lifetime of illumination system 412). Such configuration of illumination system 412 may help to prevent the shift of the actual CWL values from the desired CWL values, as discussed above, in current alignment systems. And, as a result, the use of constant CWL values may improve long-term stability and accuracy of alignment systems (e.g., alignment system 400) compared to the current alignment systems.

[0055] Beam splitter 414 may be configured to receive radiation beam 413 and split radiation beam 413 into at least two radiation sub-beams, according an embodiment. In an example, radiation beam 413 may be split into radiation sub-beams 415 and 417, as shown in FIG. 4A. Beam splitter 414 may be further configured to direct radiation sub-beam 415 onto a substrate 420 placed on a stage 422. In one example, the stage 422 is movable along direction 424. Radiation sub-beam 415 may be configured to illuminate an alignment mark or a target 418 located on substrate 420. Alignment mark or target 418 may be coated with a radiation sensitive film in an example of this embodiment. In another example, alignment mark or target 418 may have one hundred and eighty degree symmetry. That is, when alignment mark or target 418 is rotated one hundred and eighty degrees about an axis of symmetry perpendicular to a plane of alignment mark or target 418, rotated alignment mark or target 418 may be substantially identical to an unrotated alignment mark or target 418. The target 418 on substrate 420 may be (a) a resist layer grating comprising bars that are formed of solid resist lines, or (b) a product layer grating, or (c) a composite grating stack in an overlay target structure comprising a resist grating overlaid or interleaved on a product layer grating. The bars may alternatively be etched

into the substrate. This pattern is sensitive to chromatic aberrations in the lithographic projection apparatus, particularly the projection system PL, and illumination symmetry and the presence of such aberrations will manifest themselves in a variation in the printed grating. One in-line method used in device manufacturing for measurements of line width, pitch and critical dimension makes use of a technique known as “scatterometry”. Methods of scatterometry are described in Raymond et al., “Multiparameter Grating Metrology Using Optical Scatterometry”, J. Vac. Sci. Tech. B, Vol. 15, no. 2, pp. 361-368 (1997) and Niu et al., “Specular Spectroscopic Scatterometry in DUV Lithography”, SPIE, Vol. 3677 (1999), which are both incorporated by reference herein in their entireties. In scatterometry, light is reflected by periodic structures in the target, and the resulting reflection spectrum at a given angle is detected. The structure giving rise to the reflection spectrum is reconstructed, e.g. using Rigorous Coupled-Wave Analysis (RCWA) or by comparison to a library of patterns derived by simulation. Accordingly, the scatterometry data of the printed gratings is used to reconstruct the gratings. The parameters of the grating, such as line widths and shapes, may be input to the reconstruction process, performed by processing unit PU, from knowledge of the printing step and/or other scatterometry processes.

[0056] Beam splitter 414 may be further configured to receive diffraction radiation beam 419 and split diffraction radiation beam 419 into at least two radiation sub-beams, according to an embodiment. In an example, radiation beam 419 may be split into diffraction radiation sub-beams 429 and 439, as shown in FIG. 4A.

[0057] It should be noted that even though a beam splitter 414 is shown to direct radiation beam 415 towards alignment mark or target 418 and to direct diffracted radiation sub-beam 429 towards interferometer 426, the disclosure is not so limiting. It would be apparent to a person skilled in the relevant art that other optical arrangements may be used to obtain the similar result of illuminating alignment mark or target 418 on substrate 420 and detecting an image of alignment mark or target 418.

[0058] As illustrated in FIG. 4A, interferometer 426 may be configured to receive radiation sub-beam 417 and diffracted radiation sub-beam 429 through beam splitter 414. In an example embodiment, diffracted radiation sub-beam 429 may be at least a portion of radiation sub-beam 415 that may be reflected from alignment mark or target 418. In an example of this embodiment, interferometer 426 comprises any appropriate set of optical-elements, for example,

a combination of prisms that may be configured to form two images of alignment mark or target 418 based on the received diffracted radiation sub-beam 429. It should be appreciated that a good quality image need not be formed, but that the features of alignment mark 418 should be resolved. Interferometer 426 may be further configured to rotate one of the two images with respect to the other of the two images one hundred and eighty degrees and recombine the rotated and unrotated images interferometrically.

[0059] In an embodiment, detector 428 may be configured to receive the recombined image and detect interference as a result of the recombined image when alignment axis 421 of alignment system 400 passes through a center of symmetry (not shown) of alignment mark or target 418. Such interference may be due to alignment mark or target 418 being one hundred and eighty degree symmetrical, and the recombined image interfering constructively or destructively, according to an example embodiment. Based on the detected interference, detector 428 may be further configured to determine a position of the center of symmetry of alignment mark or target 418 and consequently, detect a position of substrate 420. According to an example, alignment axis 421 may be aligned with an optical beam perpendicular to substrate 420 and passing through a center of image rotation interferometer 426. Detector 428 may be further configured to estimate the positions of alignment mark or target 418 by implementing sensor characteristics and interacting with wafer mark process variations.

[0060] In a further embodiment, detector 428 determines the position of the center of symmetry of alignment mark or target 418 by performing one or more of the following measurements: 1. measuring position variations for various wavelengths (position shift between colors); 2. measuring position variations for various orders (position shift between diffraction orders); and 3. measuring position variations for various polarizations (position shift between polarizations). This data can for example be obtained with any type of alignment sensor, for example a SMASH (SMart Alignment Sensor Hybrid) sensor, as described in U.S. Pat. No. 6,961,116 that employs a self-referencing interferometer with a single detector and four different wavelengths, and extracts the alignment signal in software, or Athena (Advanced Technology using High order ENhancement of Alignment), as described in U.S. Pat. No. 6,297,876, which directs each of seven diffraction orders to a dedicated detector, which are both incorporated by reference herein in their entireties.

[0061] In an embodiment, beam analyzer 430 may be configured to receive and determine an optical state of diffracted radiation sub-beam 439. The optical state may be a measure of beam wavelength, polarization, or beam profile. Beam analyzer 430 may be further configured to determine a position of stage 422 and correlate the position of stage 422 with the position of the center of symmetry of alignment mark or target 418. As such, the position of alignment mark or target 418 and consequently, the position of substrate 420 may be accurately known with reference to stage 422. Alternatively, beam analyzer 430 may be configured to determine a position of alignment system 400 or any other reference element such that the center of symmetry of alignment mark or target 418 may be known with reference to alignment system 400 or any other reference element. The beam analyzer can be a point or an imaging polarimeter with some form of wavelength-band selectivity. According to an embodiment, the beam analyzer 430 may be directly integrated into the alignment system 400, or connected via fiber optics of several types: polarization preserving single mode, multimode or imaging, according to other embodiments.

[0062] In an embodiment, beam analyzer 430 may be further configured to determine the overlay data between two patterns on substrate 420. One of these patterns may be a reference pattern on a reference layer. The other pattern may be an exposed pattern on an exposed layer. The reference layer may be an etched layer already present on substrate 420. The reference layer may be generated by a reference pattern exposed on the substrate by the lithographic apparatus. The exposed layer may be a resist layer exposed adjacent to the reference layer. The exposed layer may be generated by an exposure pattern exposed on substrate 420 by the lithographic apparatus. The exposed pattern on substrate 420 may correspond to a movement of substrate 420 by the stage 422. In an embodiment, the measured overlay data may also indicate an offset between the reference pattern and the exposure pattern. The measured overlay data may be used as calibration data to calibrate the exposure pattern exposed by the lithographic apparatus, such that after the calibration, the offset between the exposed layer and the reference layer may be minimized.

[0063] In an embodiment, beam analyzer 430 may be further configured to determine a model of the product stack profile of substrate 420, and may be configured to measure overlay, critical dimension and focus of target 418 in a single measurement. The product stack profile contains information on the stacked product such as alignment mark, target 418 or substrate 420,

and may include mark process variation-induced optical signature metrology that is a function of illumination variation. The product stack profile may also include product grating profile, mark stack profile, and mark asymmetry information. An example of beam analyzer 430 is Yieldstar™, manufactured by ASML, Veldhoven, The Netherlands, as described in U.S. Pat. No. 8,706,442, which is incorporated by reference herein in its entirety. Beam analyzer 430 may be further configured to process information related to a particular property of an exposed pattern in that layer and might be an overlay parameter (an indication of the positioning accuracy of the layer with respect to a previous layer on the substrate or the positioning accuracy of the first layer with respect to marks on the substrate), a focus parameter and/or a critical dimension parameter (line width and its variations) of the depicted image in the layer. Other parameters are image parameters relating to the quality of the depicted image of the exposed pattern. An array of detectors may be connected to beam analyzer 430, and allows the possibility of accurate stack profile detection as discussed below. For the detector array, a number of options are possible: a bundle of multimode fibers, discrete pin detectors per channel, or CCD or CMOS (linear) arrays. The use of a bundle of multimode fibers enables any dissipating elements to be remotely located for stability reasons. Discrete PIN detectors offer a large dynamic range but each need separate pre-amps. The number of elements is therefore limited. CCD linear arrays offer many elements that can be read-out at high speed and are especially of interest if phase-stepping detection is used.

[0064] In an embodiment, a second beam analyzer 430' may be configured to receive and determine an optical state of diffracted radiation sub-beam 429, as shown in Fig. 4B. The optical state may be a measure of beam wavelength, polarization, or beam profile. The second beam analyzer 430' may be identical to beam analyzer 430, or may be configured to perform at least all the functions of beam analyzer 430, such as determining a position of stage 422 and correlating the position of stage 422 with the position of the center of symmetry of alignment mark or target 418. As such, the position of alignment mark or target 418 and consequently, the position of substrate 420, may be accurately known with reference to stage 422. Second beam analyzer 430' may also be configured to determine a position of alignment system 400, or any other reference element, such that the center of symmetry of alignment mark or target 418 may be known with reference to alignment system 400, or any other reference element. Second beam analyzer 430' may be further configured to determine the overlay data between two patterns and

a model of the product stack profile of substrate 420. Second beam analyzer 430' may also be configured to measure overlay, critical dimension, and focus of target 418 in a single measurement.

[0065] In an embodiment, second beam analyzer 430' may be directly integrated into alignment system 400, or it can be connected via fiber optics of several types: polarization preserving single mode, multimode or imaging, according to other embodiments. Alternatively, second beam analyzer 430' and beam analyzer 430 may be combined to form a single analyzer configured to receive and determine the optical states of both diffracted radiation sub-beams 429 and 439.

[0066] In an embodiment, overlay calculation processor 432 receives information from detector 428 and beam analyzer 430. The information may comprise a model of the product stack profile constructed by beam analyzer 430. Alternatively, the overlay calculation processor 432 may construct a model of the product mark profile using the received information about the product mark. In either case, the overlay calculation processor 432 constructs a model of the stacked product and overlay mark profile using or incorporating a model of the product mark profile. The stack model is then used to determine the overlay offset and minimizes the spectral effect on the overlay offset measurement. Processor 432 may create a basic correction algorithm based on the information received from detector 428 and beam analyzer 430, including but not limited to the optical state of the illumination beam, the alignment signals and associated position estimates, the optical state in the pupil, image and additional planes. Processor 432 may utilize the basic correction algorithm to characterize the alignment system 400 with reference to wafer marks.

[0067] In an embodiment, overlay calculation processor 432 may be further configured to determine printed pattern position offset error with respect to the sensor estimate for each mark based on the information received from detector 428 and beam analyzer 430. The information includes but is not limited to the product stack profile, measurements of overlay, critical dimension and focus of each alignment marks or target 418 on substrate 420. Overlay calculation processor 432 may utilize a clustering algorithm to group the marks into sets of similar constant offset error, and create an alignment error offset correction table based on the information. The clustering algorithm may be based on overlay measurement, the position estimates and additional optical stack process information associated with each set of offset errors. The overlay is

calculated for a number of different marks, for example, overlay targets having a positive and a negative bias around a programmed overlay offset. The target which measures the smallest overlay is taken as reference (as it is measured with the best accuracy). From this measured small overlay, and the known programmed overlay of its corresponding target, the overlay error can be deduced. Table 1 illustrates how this may be performed. The smallest measured overlay in the example shown is -1 nm. However this is in relation to a target with a programmed overlay of -30 nm. Consequently the process must have introduced an overlay error of 29 nm.

Table 1							
Programmed overlay	-70	-50	-30	-10	10	30	50
Measured overlay	-38	-19	-1	21	43	66	90
Difference between measured and programmed overlay	32	31	29	31	33	36	40
Overlay error	3	2	-	2	4	7	11

The smallest value can be taken to be the reference point and, relative to this, the offset can be calculated between measured overlay and that expected due to the programmed overlay. This offset determines the overlay error for each mark or the sets of marks with similar offsets. Therefore, in the Table 1 example, the smallest measured overlay was -1 nm, at the target position with programmed overlay of 30 nm. The difference between the expected and measured overlay at the other targets is compared to this reference. A table such as Table 1 can also be obtained from marks and target 418 under different illumination settings, the illumination setting which results in the smallest overlay error, and its corresponding calibration factor, may be determined and selected. Following this, the overlay calculation processor 432 may group marks into sets of similar overlay error. The criteria for grouping marks may be adjusted based on different process controls, such as different error tolerances for different processes.

[0068] In an embodiment, overlay calculation processor 432 may confirm that all or most members of the group have similar offset errors, and apply an individual offset correction from the clustering algorithm to each mark, based on its additional optical stack metrology. Overlay calculation processor 432 may determine corrections for each mark and feed the corrections back

to the lithographic apparatus 100 for correcting errors in the overlay, for example by feeding corrections into the alignment system 400.

[0069] It should be understood that the overlay calculation processor 432 may be implemented in one or more computer systems 50 as shown in FIG. 5. The computer system 50
5 may be a dedicated computer in the form of an overlay calculation processor 432, according to some embodiments or, alternatively, be a central computer controlling the lithographic apparatus. The computer system 50 may be arranged for loading a computer program product comprising computer executable code. This may enable the computer system 50, when the computer program product is downloaded, to control aforementioned uses of lithographic and inspection
10 apparatuses.

[0070] The memory 29 connected to processor 27 may store locations of one or more sets of substrate alignment marks or overlay metrology targets available for selection and selection rules to select suitable substrate alignment marks or overlay metrology targets from this at least one set. The selection rules are based on experimental or theoretical knowledge about
15 which substrate alignment mark or overlay metrology targets locations are optimal in dependence on one or more selection criteria. Memory 29 may comprise a number of memory components like a hard disk 31, Read Only Memory (ROM) 62, Electrically Erasable Programmable Read Only Memory (EEPROM) 63 or Random Access Memory (RAM) 64. Not all aforementioned memory components need to be present. Furthermore, it is not essential that
20 aforementioned memory components are physically in close proximity to the processor 27 or to each other. They may be located at a distance away.

[0071] The processor 27 may also be connected to user interfaces, for instance a keyboard 65 or a mouse 66. A touch screen, track ball, speech converter or other interfaces that are known to persons skilled in the art may also be used.

[0072] The processor 27 may be connected to a reading unit 67, which is arranged to read data, e.g., in the form of computer executable code, from and under some circumstances store data on a data carrier, like a floppy disc 68 or a CDROM 69. Also DVD's or other data carriers known to persons skilled in the art may be used.

[0073] The processor 27 may also be connected to a printer 70 to print out output data on
30 paper as well as to a display 71, for instance a monitor or LCD (Liquid Crystal Display), of any other type of display known to a person skilled in the art.

[0074] The processor 27 may be connected to a communications network 72, for instance a public switched telephone network (PSTN), a local area network (LAN), a wide area network (WAN) etc. by means of transmitters/receivers 73 responsible for input/output (I/O). The processor 27 may be arranged to communicate with other communication systems via the communications network 72. In an embodiment of the invention external computers (not shown), for instance personal computers of operators, can log into the processor 27 via the communications network 72.

[0075] The processor 27 may be implemented as an independent system or as a number of processing units that operate in parallel, wherein each processing unit is arranged to execute sub-tasks of a larger program. The processing units may also be divided in one or more main processing units with several subprocessing units. Some processing units of the processor 27 may even be located a distance away of the other processing units and communicate via communications network 72.

[0076] *Example Methods of Calibration an Alignment System*

[0077] FIG. 6 illustrates a flowchart 600 for using an enhanced alignment system to measure the position of a target on a substrate, according to an embodiment. The enhanced alignment system provides a traditional measurement of the mark location with the traditional accuracy errors previously mentioned. In addition, it provides additional optical information about both the mark and sensor that can be used to reduce the on-produce alignment error. Solely for illustrative purposes, the steps illustrated in FIG. 6 will be described with reference to example operating environments illustrated in FIGs. 1-5. However, flowchart 600 is not limited to these embodiments. It is to be appreciated that steps can be performed in a different order or not performed depending on specific applications.

[0078] In step 602, a basic correction calibration is performed on alignment system 400 using monitor wafers. Monitor wafers have been previously exposed using a special reticle containing special scatterometry marks. According to an embodiment, at least one of the monitor wafers is substrate 420. Processor 432 may create a basic correction algorithm based on the information received from detector 428 and beam analyzer 430, including but not limited to the optical state of the illumination beam, the alignment signals and associated position estimates, the optical state in the pupil, image and additional planes. Processor 432 may utilize the basic correction algorithm to characterize the alignment system 400 with reference to wafer marks.

[0079] In step 604, basic alignment system calibration is performed on alignment system 400 using process wafers. Processor 432 may update the basic correction algorithm and characterize the alignment system 400 with reference to wafer marks based on the information received from detector 428, beam analyzer 430, and second beam analyzer 430', including but
5 not limited to the optical state of the illumination beam, the alignment signals and associated position estimates, the optical state in the pupil, image and additional planes.

[0080] In step 606, overlay calculation processor 432 may determine printed pattern position offset errors on process wafers with respect to the sensor estimate for each mark based on the information received from detector 428 and beam analyzer 430. Overlay calculation
10 processor 432 may utilize a clustering algorithm to group the marks into sets of similar constant offset error, and create an alignment error offset correction table based on the information. Overlay calculation processor 432 may also utilize calibration information obtained from steps 602 and 604 to determine corrections for each mark.

[0081] In step 608, overlay calculation processor 432 may feed corrections back to the
15 lithographic apparatus 100 for correcting errors in the overlay offset, for example by feeding corrections into the alignment system 400, and process the substrate 420 using the calibrated system. The substrate 420 may be processed using known manufacturing processes by a lithographic projection apparatus, and a pattern (e.g., overlay marker or a product pattern in a reticle) is imaged onto substrate 420 that is at least partially covered by a layer of radiation-
20 sensitive material (resist). Prior to this imaging, substrate 420 may undergo various procedures, such as priming, resist coating and a soft bake. Substrate 420 may be aligned in calibrated alignment system 400 prior to exposure. After exposure, substrate 420 may be subjected to other procedures, such as a post-exposure bake (PEB), development, a hard bake and measurement/inspection of the imaged features. Thus, substrate 420 is exposed with an overlay
25 marker along with a product pattern and the resist is developed to print the overlay marker on the stacked wafer.

[0082] In step 610, overlay calculation processor 432 may measure printed pattern position offset error with respect to the sensor estimate for each alignment mark or target 418 on exposed substrate 420. The measurement information includes but is not limited to the product
30 stack profile, measurements of overlay, critical dimension and focus of each alignment mark or target 418 on substrate 420. Overlay calculation processor 432 may utilize a clustering algorithm

to group the marks into sets of similar constant offset errors, and create an alignment error offset correction table based on the information. The clustering algorithm may be based on overlay measurement, the position estimates and additional optical stack process information associated with each set of offset errors. From this measured overlay and the known programmed overlay of its corresponding target, the overlay error can be deduced.

[0083] In step 612, overlay calculation processor 432 may determine corrections for each mark and feed corrections back to the lithographic apparatus 100 for correcting errors in the overlay, for example by feeding corrections into the alignment system 400. Thus the process creates a self-learning feedback loop for calibrating alignment system 400.

10 **[0084]** *Final Remarks*

[0085] 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.

25 **[0086]** 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, E-beam, and particle 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

30

combination thereof. The patterning device is moved out of the resist leaving a pattern in it after the resist is cured.

[0087] It is to be understood that the phraseology or terminology herein is for the purpose of description and not of limitation, such that the terminology or phraseology of the present specification is to be interpreted by those skilled in relevant art(s) in light of the teachings herein.

[0088] In the embodiments described herein, the terms “lens” and “lens element,” where the context allows, can refer to any one or combination of various types of optical components, including refractive, reflective, magnetic, electromagnetic, and electrostatic optical components.

[0089] Further, the terms “radiation,” “beam,” and “light” used herein encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (for example, having a wavelength λ of 365, 248, 193, 157 or 126 nm), extreme ultraviolet (EUV or soft X-ray) radiation (for example, having a wavelength in the range of 5-20 nm such as, for example, 13.5 nm), or hard X-ray working at less than 5 nm, as well as particle beams, such as ion beams, electron beams, atoms, or molecules. They can expose a resist layer or create a pattern directly.

Generally, radiation having wavelengths between about 400 to about 700 nm is considered visible radiation; radiation having wavelengths between about 780-3000 nm (or larger) is considered IR radiation. UV refers to radiation with wavelengths of approximately 100-400 nm. Within lithography, the term “UV” also applies to the wavelengths that can be produced by a mercury discharge lamp: G-line 436 nm; H-line 405 nm; and/or, I-line 365 nm. Vacuum UV, or VUV (i.e., UV absorbed by gas), refers to radiation having a wavelength of approximately 100-200 nm. Deep UV (DUV) generally refers to radiation having wavelengths ranging from 126 nm to 428 nm, and in an embodiment, an excimer laser can generate DUV radiation used within a lithographic apparatus. It should be appreciated that radiation having a wavelength in the range of, for example, 5-20 nm relates to radiation with a certain wavelength band, of which at least part is in the range of 5-20 nm.

[0090] The term “substrate” as used herein generally describes a material onto which subsequent material layers are added. In embodiments, the substrate itself may be patterned and materials added on top of it may also be patterned, or may remain without patterning.

[0091] 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.

[0092] It is to be appreciated that the Detailed Description section, and not the Summary and Abstract sections, is intended to be used to interpret the claims. The Summary and Abstract sections may set forth one or more but not all exemplary embodiments of the present invention as contemplated by the inventor(s), and thus, are not intended to limit the present invention and
5 the appended claims in any way.

[0093] The present invention has been described above with the aid of functional building blocks illustrating the implementation of specified functions and relationships thereof. The boundaries of these functional building blocks have been arbitrarily defined herein for the convenience of the description. Alternate boundaries can be defined so long as the specified
10 functions and relationships thereof are appropriately performed.

[0094] The foregoing description of the specific embodiments will so fully reveal the general nature of the invention that others can, by applying knowledge within the skill of the art, readily modify and/or adapt for various applications such specific embodiments, without undue experimentation, without departing from the general concept of the present invention. Therefore,
15 such adaptations and modifications are intended to be within the meaning and range of equivalents of the disclosed embodiments, based on the teaching and guidance presented herein.

[0095] 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 invention may take the form of a computer program containing one or more sequences of
20 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.

[0096] The breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the
25 following claims and their equivalents.

WHAT IS CLAIMED IS:

1. An alignment system, comprising:
 - a radiation source configured to generate light;
 - 5 an objective projection system configured to receive the generated light and direct the generated light towards a substrate having a plurality of targets thereon;
 - an optical splitter configured to receive light from the substrate and to split the received light into first and second beams;
 - a beam analyzer configured to measure the first beam;
 - 10 an interferometer configured to produce an interference pattern based on the second beam that has been reflected from the pattern on the substrate and a reference beam;
 - a detector configured to receive the interference pattern from the interferometer; and
 - a processor configured to receive and process measurement of the first beam and the interference pattern, and direct the alignment system to place the substrate at a position based on
 - 15 the process result.
2. The alignment system of claim 1, wherein the beam analyzer is further configured to measure the second beam.
- 20 3. The alignment system of claim 2, wherein the beam analyzer is further configured to measure wavelength, polarization, and beam profile of the first beam, and determine an overlay offset of each of the plurality of targets based on the first beam.
4. The alignment system of claim 3, wherein the processor is further configured to
- 25 determine optical stack process information for each of the plurality of targets using the measurement of the first beam and the interference pattern.
5. The alignment system of claim 4, wherein the optical stack process information comprises mark process variation-induced optical information.

6. The alignment system of claim 5, wherein the processor is further configured to determine an overlay offset associated with each of the plurality of targets by measuring a distance between a printed pattern position and each of the plurality of targets.
- 5 7. The alignment system of claim 6, wherein the processor is further configured to determine an overlay offset error for each of the plurality of targets by comparing the overlay offsets.
8. The alignment system of claim 7, wherein the processor is further configured to group
10 similar overlay offset errors into sets.
9. The alignment system of claim 8, wherein the processor is further configured to create an offset correction table using the sets of overlay offset errors.
- 15 10. The alignment system of claim 9, wherein the processor is further configured to calibrate the alignment system using the offset correction table.
11. A method for aligning a substrate, comprising:
generating light using a radiation source light;
20 receiving the generated light in an objective projection system and direct the generated light towards a substrate having a plurality of targets thereon;
receiving light from the substrate in an optical splitter that splits the received light into first and second beams;
measuring the first beam;
25 producing an interference pattern based on the second beam that has been reflected from the pattern on the substrate and a reference beam;
receiving the interference pattern from the interferometer in a detector; and
receiving and processing the measurement of the first beam and the interference pattern in a processor, and directing the alignment system to place the substrate at a position based on
30 the process result.

12. The method of claim 11, further comprising measuring the second beam.

13. The method of claim 12, wherein measuring the first beam further comprises measuring wavelength, polarization, and beam profile of the first beam, and determining an overlay offset
5 of each of the plurality of targets based on the first beam.

14. The method of claim 13, wherein the processing further comprises determining optical stack process information for each of the plurality of targets using the measurement of the first beam and the interference pattern.
10

15. The method of claim 14, wherein the optical stack process information comprises mark process variation-induced optical information.

16. The method of claim 15, wherein the processing further comprises determining an overlay offset associated with each of the plurality of targets by measuring a distance between a printed pattern position and each of the plurality of targets.
15

17. The method of claim 16, wherein the processing further comprises determining an overlay offset error for each of the plurality of targets by comparing the overlay offsets.
20

18. The method of claim 17, wherein the processing further comprises grouping similar overlay offset errors into sets.

19. The method of claim 18, wherein the processing further comprises creating an offset correction table using the sets of overlay offset errors.
25

20. The method of claim 19, wherein the processing further comprises calibrating the alignment system using the offset correction table.

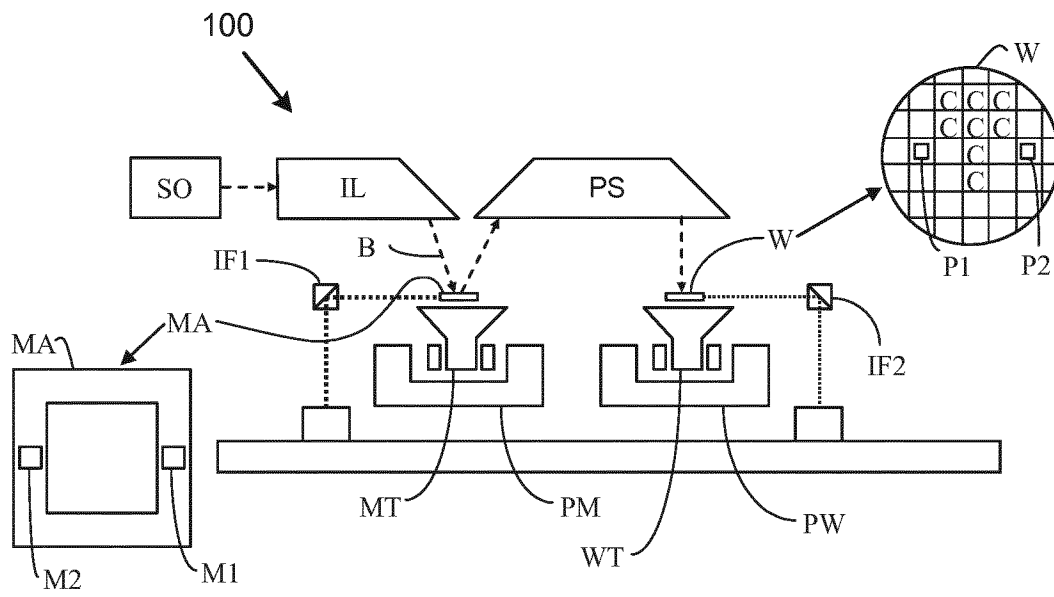


FIG. 1A

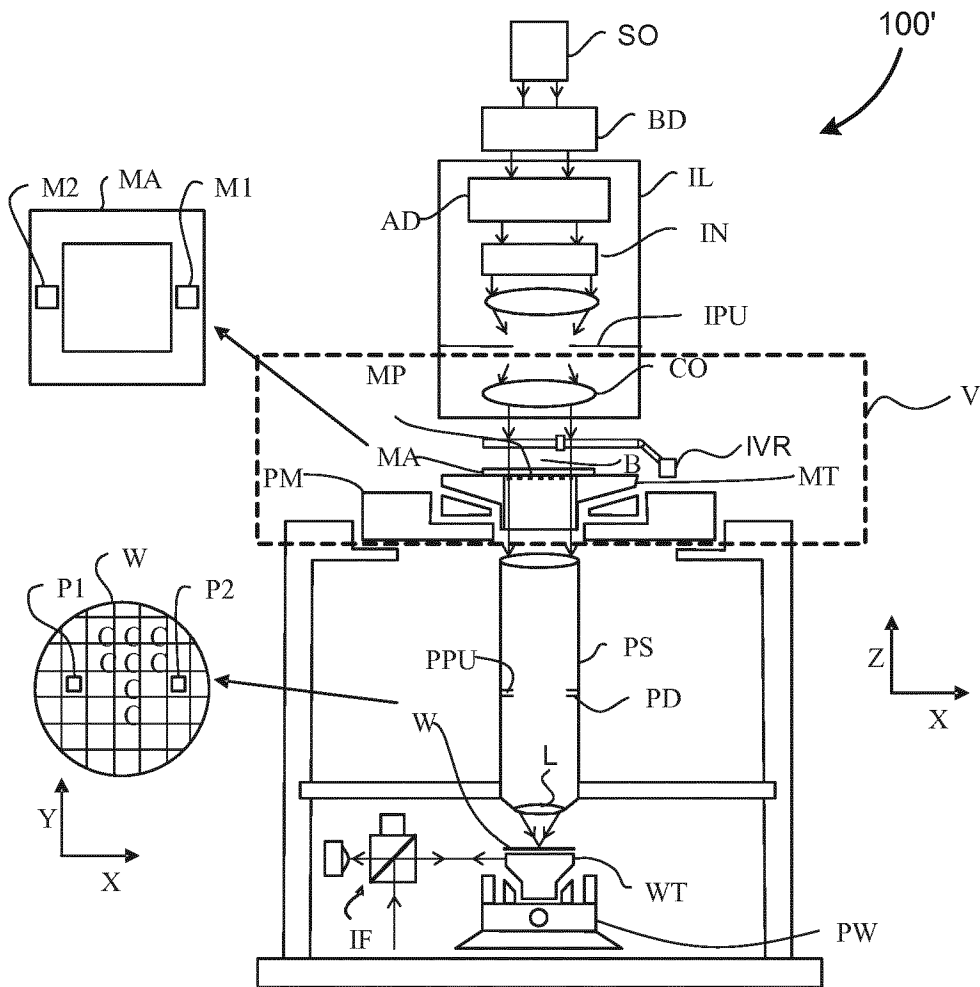


FIG. 1B

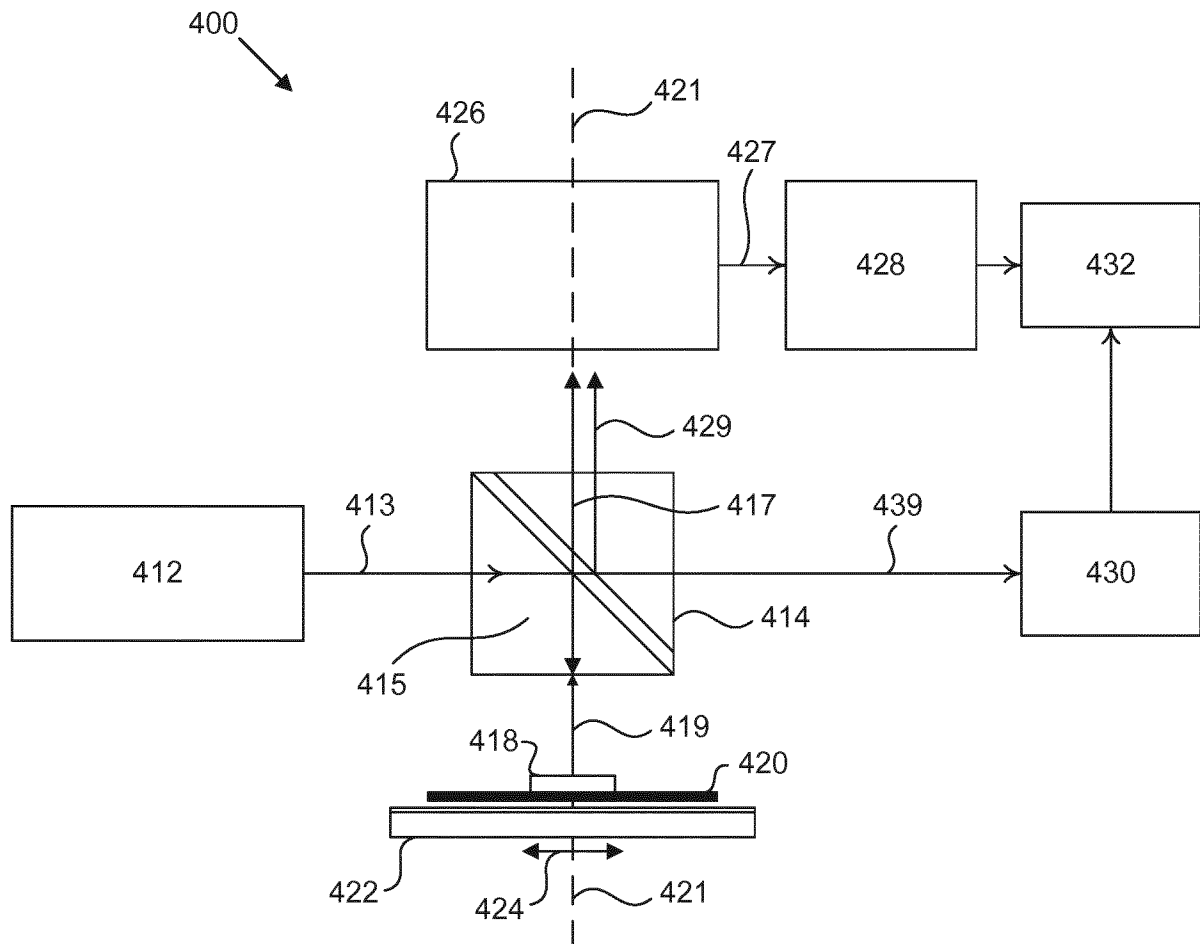


FIG. 4A

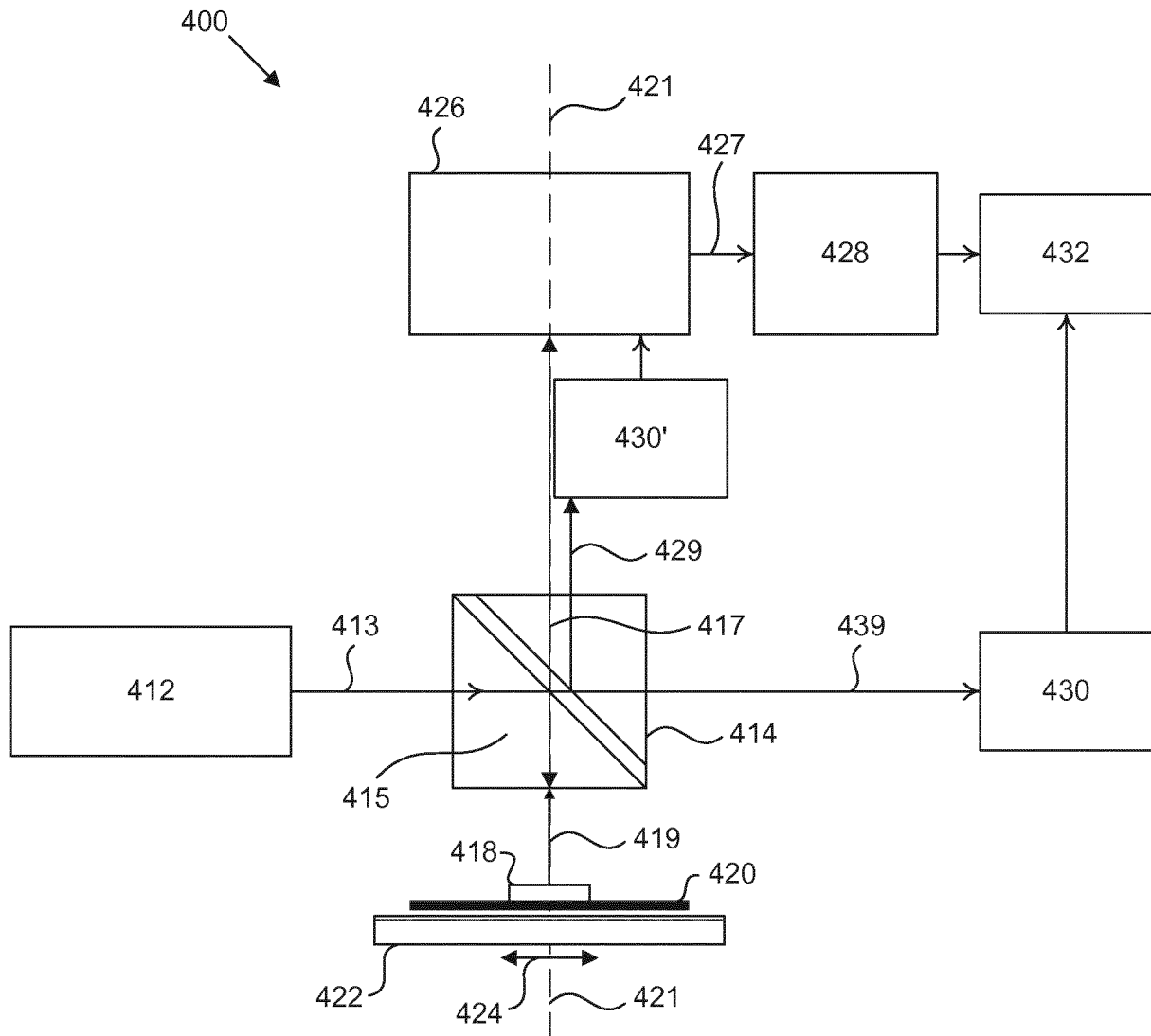
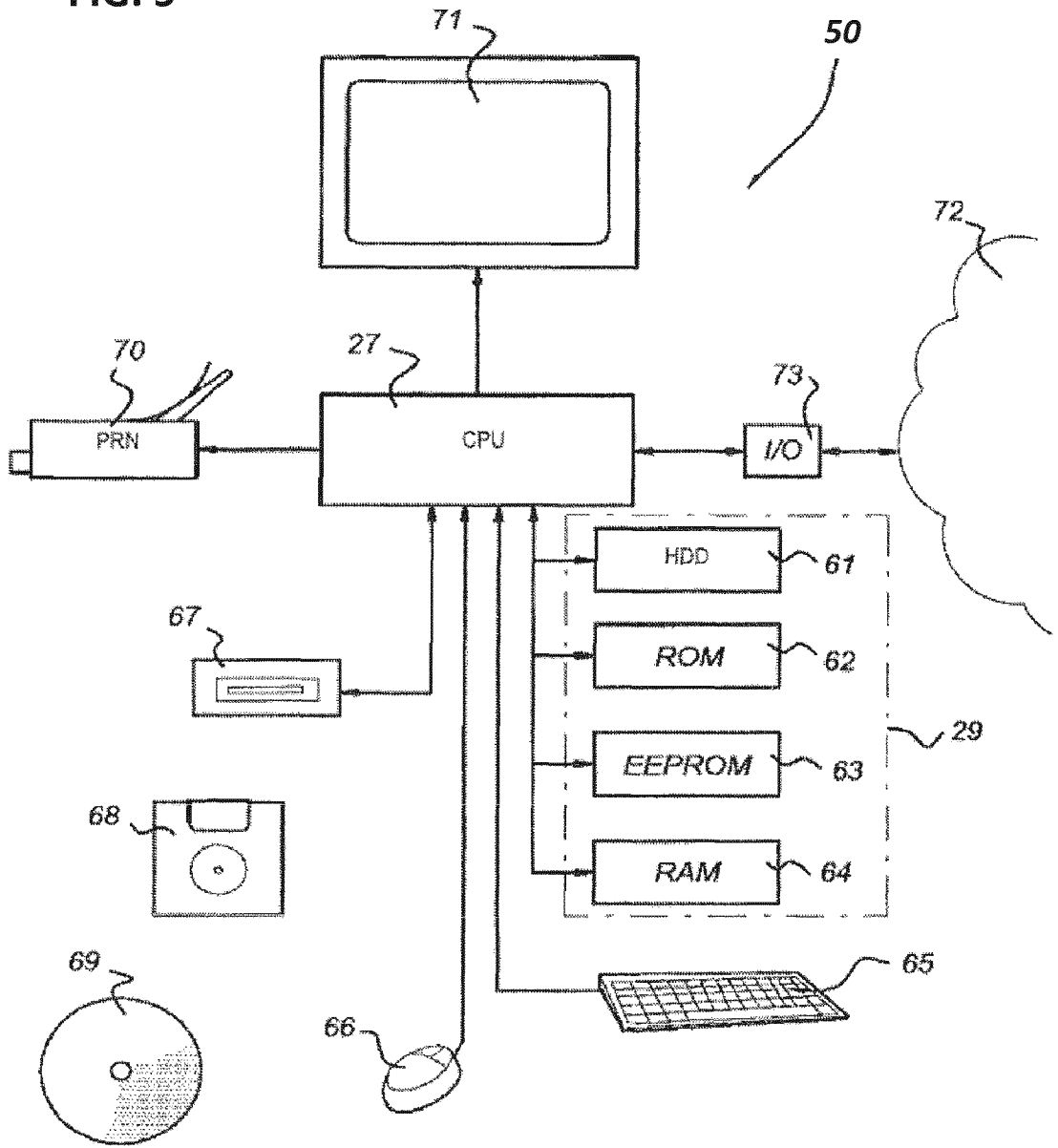


FIG. 4B

FIG. 5



7/7

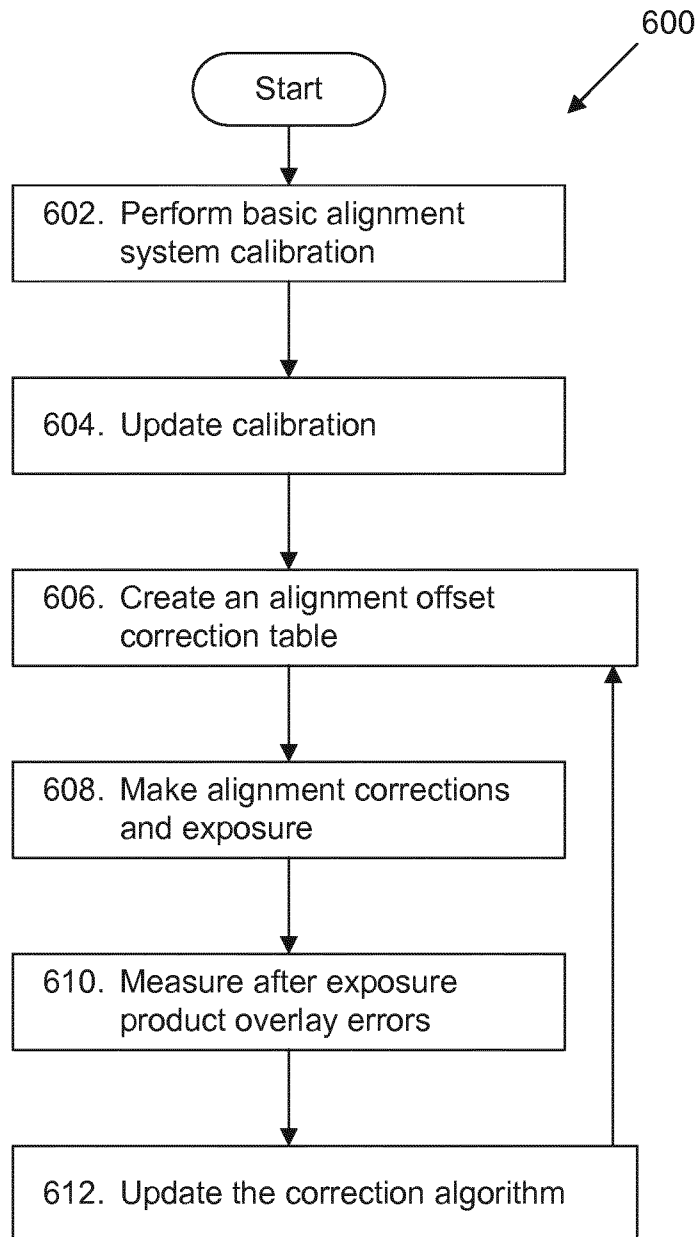


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/061779

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, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 8 706 442 B2 (ASML NETHERLANDS BV [NL]) 22 April 2014 (2014-04-22) cited in the application column 9, line 35 - line 40; claim 15 -----	1-20
A	US 6 961 116 B2 (ASML NETHERLANDS BV [NL]) 1 November 2005 (2005-11-01) cited in the application figures 2,3 -----	1-20
A	US 6 297 876 B1 (BORNEBROEK FRANK [NL]) 2 October 2001 (2001-10-02) cited in the application figures 4,6 -----	1-20
	-/--	

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 14 November 2017	Date of mailing of the international search report 23/11/2017
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 Angioni, Catherine

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/061779

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012/062863 A1 (BIJNEN FRANCISCUS GODEFRIDUS CASPER [NL] ET AL) 15 March 2012 (2012-03-15) figure 2	1-20
A	----- US 6 633 831 B2 (KLA TENCOR TECHNOLOGIES [US]) 14 October 2003 (2003-10-14) claim 1; figure 7	1-20
A	----- US 6 731 374 B1 (SEWELL HARRY [US]) 4 May 2004 (2004-05-04) figure 3b	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2017/061779

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