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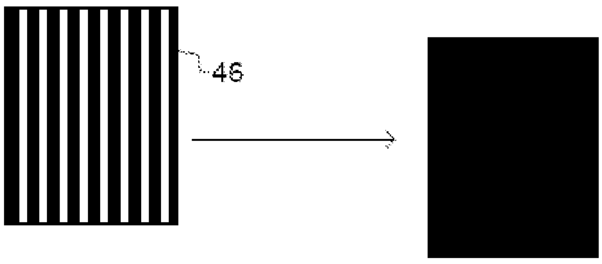
Fig. 6



(57) Abstract: An mark used in the determination of overlay error comprises sub-features (46), the sub-features having a smallest pitch approximately equal to the smallest pitch of the product features. The sensitivity to distortions and aberrations is therefore the same as that for the product features. However, when the mark is developed the sub-features merge and only the outline of the larger feature is developed.

INSPECTION METHOD FOR LITHOGRAPHY

BACKGROUND

Field of the Invention

[0001] The present invention relates to methods of inspection usable, for example, in the manufacture of devices by lithographic techniques and to methods of manufacturing devices using lithographic techniques.

Background Art

[0002] A lithographic apparatus is a machine that applies a desired pattern onto a substrate, usually onto a target portion of the substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In that instance, a patterning device, which is alternatively referred to as a mask or a reticle, may be used to generate a circuit pattern to be formed on an individual layer of the IC. This pattern can be transferred onto a target portion (e.g., comprising part of, one, or several dies) on a substrate (e.g., a silicon wafer). Transfer of the pattern is typically via imaging onto a layer of radiation-sensitive material (resist) provided on the substrate. In general, a single substrate will contain a network of adjacent target portions that are successively patterned. Known lithographic apparatus include so-called steppers, in which each target portion is irradiated by exposing an entire pattern onto the target portion at one time, and so-called scanners, in which each target portion is irradiated by scanning the pattern through a radiation 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 the patterning device to the substrate by imprinting the pattern onto the substrate.

[0003] In order to monitor the lithographic process, it is necessary to measure parameters of the patterned substrate, for example the overlay error between successive layers formed in or on it. There are various techniques for making measurements of the microscopic structures formed in lithographic processes, including the use of scanning electron microscopes and various specialized tools. One form of specialized inspection tool is a scatterometer in which a beam of radiation is directed onto a target on the surface of the substrate and properties of the scattered or reflected beam are measured. By comparing the properties of the beam before and after it has been reflected or scattered by the substrate, the properties of the substrate can be determined. This can be done, for example, by comparing the reflected beam with data stored in a library of known measurements associated with known substrate properties. Two main types of scatterometer are known. Spectroscopic scatterometers direct a broadband radiation beam onto the substrate and measure the spectrum (intensity as a function of wavelength) of the radiation scattered into a particular narrow angular range. Angularly resolved scatterometers use a monochromatic radiation beam and measure the intensity of the scattered radiation as a function of angle.

[0004] To determine the overlay error between layers a pattern on the second layer is superimposed over a pattern on the first layer. A radiation beam is then projected onto the patterns and the diffraction pattern determined. The patterns used for determining the overlay error are in the order of a few hundred nanometers, whereas the product features are of the order of a few tens of nanometers. The projection system, through which the projection beam is projected to expose the substrate is not perfect and induces aberrations and distortions. Some of the aberrations and distortions are dependent on the pitch, as features having different pitches will be projected through different portions of the pupil. Thus aberrations experiences by the product features may not be experienced by the pattern used for determining the overlay error and vice versa. This can result in errors in the calculated overlay error, particularly if feedback loops are used to control the overlay error.

SUMMARY

[0005] It is desirable to provide a method for determining overlay error which experiences the same sensitivity as the product features.

[0006] According to an embodiment of the invention, there is provided a method of measuring a characteristic comprising the following steps. Projecting a beam of radiation having a pattern onto a substrate, the pattern comprising a product comprising a plurality of product features and a mark comprising plurality of mark features, at least one feature comprising a plurality of sub-features. Forming the pattern on the substrate. Projecting a beam of radiation onto the pattern. Detecting a diffraction pattern from the pattern.

Determining the overlay error between the pattern and an underlying pattern based on the diffraction pattern. The sub-features have a smallest pitch substantially equal to a pitch of the product features and when the pattern is formed the outline of the mark features and the product features are formed, but the shape of the sub-features is not formed.

[0007] According to a further embodiment of the invention there is provided a method of measuring a characteristic comprising the following steps. Projecting a beam of radiation having a pattern onto a substrate, the pattern comprising a product comprising a plurality of product features and a mark comprising plurality of mark features, at least one feature comprising a plurality of sub-features. Forming the pattern on the substrate. The sub-features have a smallest pitch equal to a pitch of the product features and when the pattern is formed the outline of the mark features and the product features are formed, but the shape of the sub-features is not formed.

[0008] According to a still further embodiment of the invention there is provided a device manufacturing method comprising the following steps. Projecting a beam of radiation having a pattern onto a substrate, the pattern comprising a product comprising a plurality of product features and a mark comprising plurality of mark features, at least one feature comprising a plurality of sub-features. Forming the pattern on the substrate. The sub-features have a smallest pitch equal to a pitch of the product features and when the pattern is formed the outline of the mark features and the product features are formed, but the shape of the sub-features is not formed.

[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. 1 depicts a lithographic apparatus.

[0012] FIG. 2 depicts a lithographic cell or cluster.

[0013] FIG. 3 depicts a first scatterometer.

[0014] FIG. 4 depicts a second scatterometer.

[0015] FIG. 5 depicts product features and an overlay mark according to an embodiment of the invention.

[0016] FIG. 6 depicts the development of an overlay mark according to an embodiment of the invention.

[0017] 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.

DETAILED DESCRIPTION

[0018] 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.

[0019] 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.

[0020] Embodiments of the invention may be implemented in hardware, firmware, software, or any combination thereof. Embodiments of the invention may also be implemented as instructions stored on a machine-readable medium, which may be read and executed by one or more processors. A machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computing device). For example, a machine-readable medium may include read only memory (ROM); random access memory (RAM); magnetic disk storage media; optical storage media; flash memory devices; electrical, optical, acoustical or other forms of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.), and others. Further, firmware, software, routines, instructions may be described herein as performing certain actions. However, it should be appreciated that such descriptions are merely for convenience and that such actions in fact result from computing devices, processors, controllers, or other devices executing the firmware, software, routines, instructions, etc.

[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] Figure 1 schematically depicts a lithographic apparatus. The apparatus comprises an illumination system (illuminator) IL configured to condition a radiation beam B (e.g., UV radiation or DUV radiation), a support structure (e.g., a mask table) MT constructed to support a patterning device (e.g., a mask) MA and connected to a first positioner PM configured to accurately position the patterning device in accordance with certain parameters, a substrate table (e.g., a wafer table) WT constructed to hold a substrate (e.g., a resist-coated wafer) W and 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) PL configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion C (e.g., comprising one or more dies) of the substrate W.

[0023] 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.

[0024] The support structure supports, i.e., bears the weight of, the patterning device. It 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 support structure can use mechanical, vacuum, electrostatic or other clamping techniques to hold the patterning device. The support structure may be a frame or a table, for example, which may be fixed or movable as required. The support structure may ensure that the patterning device is at a desired position, for example with respect to the projection system. Any use of the terms “reticle” or “mask” herein may be considered synonymous with the more general term “patterning device.”

[0025] 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.

[0026] The patterning device may be transmissive or reflective. Examples of patterning devices include masks, programmable mirror arrays, and programmable LCD panels. Masks are well known in lithography, and include mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. An example of a programmable mirror array employs a matrix arrangement of small mirrors, each of which can be individually tilted so as to reflect an incoming radiation beam in different directions. The tilted mirrors impart a pattern in a radiation beam, which is reflected by the mirror matrix.

[0027] 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”.

[0028] As here depicted, the apparatus is of a transmissive type (e.g., employing a transmissive mask). Alternatively, the apparatus may be of a reflective type (e.g., employing a programmable mirror array of a type as referred to above, or employing a reflective mask).

[0029] The lithographic apparatus may be of a type having two (dual stage) or more substrate tables (and/or two or more mask tables). In such “multiple stage” machines the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposure.

[0030] 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. The term “immersion” as used herein does not mean that a structure, such as a substrate, must be submerged in liquid, but rather only means that liquid is located between the projection system and the substrate during exposure.

[0031] Referring to Figure 1, 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 comprising, 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.

[0032] The illuminator IL may comprise an adjuster AD for adjusting the angular intensity distribution of the radiation beam. Generally, at least the outer and/or inner radial extent (commonly referred to as □-outer and □-inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the illuminator IL may comprise various other components, such as 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.

[0033] The radiation beam B is incident on the patterning device (e.g., mask MA), which is held on the support structure (e.g., mask table MT), and is patterned by the patterning device. Having traversed the mask MA, the radiation beam B passes through the projection system PL, 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 WT 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 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. In general, movement of the mask table MT may 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 may 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 may be connected to a short-stroke actuator only, or may be fixed. 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 mask MA, the mask alignment marks may be located between the dies.

[0034] The depicted apparatus could be used in at least one of the following modes:

1. In step mode, the mask table MT and the substrate table WT are kept essentially stationary, while an entire pattern imparted to the radiation beam 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. In step mode, the maximum size of the exposure field limits the size of the target portion C imaged in a single static exposure.

2. In scan mode, the 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 velocity and direction of the substrate table WT relative to the mask table MT may be determined by the (de-)magnification and image reversal characteristics of the projection system PL. 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.

3. In another mode, the mask table MT is kept essentially stationary holding a programmable patterning device, and the substrate table WT is moved or scanned while a pattern imparted to the radiation beam is projected onto a target portion C. In this mode, generally a pulsed radiation source is 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 programmable patterning device, such as a programmable mirror array of a type as referred to above.

[0035] Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

[0036] 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 then 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.

[0037] In order that the substrates that are exposed by the lithographic apparatus are exposed correctly and consistently, it is desirable to inspect exposed substrates to measure properties such as overlay errors between subsequent layers, line thicknesses, critical dimensions (CD), etc. If errors are detected, adjustments may be made to exposures of subsequent substrates, especially if the inspection can be done soon and fast enough that other substrates of the same batch are still to be exposed. Also, already exposed substrates may be stripped and reworked – to improve yield – or discarded – thereby avoiding performing exposures on substrates that are known to be faulty. In a case where only some target portions of a substrate are faulty, further exposures can be performed only on those target portions which are good.

[0038] An inspection apparatus is used to determine the properties of the substrates, and in particular, how the properties of different substrates or different layers of the same substrate vary from layer to layer. The inspection apparatus may be integrated into the lithographic apparatus LA or the lithocell LC or may be a stand-alone device. To enable most rapid measurements, it is desirable that the inspection apparatus measure properties in the exposed resist layer immediately after the exposure. However, the latent image in the resist has a very low contrast – there is only a very small difference in refractive index between the parts of the resist which have been exposed to radiation and those which have not – and not all inspection apparatus have sufficient sensitivity to make useful measurements of the latent image. Therefore measurements may be taken after the post-exposure bake step (PEB) which is customarily the first step carried out on exposed substrates and increases the contrast between exposed and unexposed parts of the resist. At this stage, the image in the resist may be referred to as semi-latent. It is also possible to make measurements of the developed resist image – at which point either the exposed or unexposed parts of the resist have been removed – or after a pattern transfer step such as etching. The latter possibility limits the possibilities for rework of faulty substrates but may still provide useful information.

[0039] Figure 3 depicts a scatterometer SM1 which may be used in the present invention. It comprises a broadband (white light) radiation projector 2 which projects radiation onto a substrate W. The reflected radiation is passed to a spectrometer detector 4, which measures a spectrum 10 (intensity as a function of wavelength) of the specular reflected radiation. From this data, the structure or profile giving rise to the detected spectrum may be reconstructed by processing unit PU, e.g., by Rigorous Coupled Wave Analysis and non-linear regression or by comparison with a library of simulated spectra as shown at the bottom of Figure 3. In general, for the reconstruction the general form of the structure is known and some parameters are assumed from knowledge of the process by which the structure was made, leaving only a few parameters of the structure to be determined from the scatterometry data. Such a scatterometer may be configured as a normal-incidence scatterometer or an oblique-incidence scatterometer.

[0040] Another scatterometer SM2 that may be used with the present invention is shown in Figure 4. In this device, the radiation emitted by radiation source 2 is focused using lens system 12 through interference filter 13 and polarizer 17, reflected by partially reflected surface 16 and is focused onto substrate W via a microscope objective lens 15, which has a high numerical aperture (NA), preferably at least 0.9 and more preferably at least 0.95. Immersion scatterometers may even have lenses with numerical apertures over 1. The reflected radiation then transmits through partially reflective surface 16 into a detector 18 in order to have the scatter spectrum detected. The detector may be located in the back-projected pupil plane 11, which is at the focal length of the lens system 15, however the pupil plane may instead be re-imaged with auxiliary optics (not shown) onto the detector. The pupil plane is the plane in which the radial position of radiation defines the angle of incidence and the angular position defines azimuth angle of the radiation. The detector is preferably a two-dimensional detector so that a two-dimensional angular scatter spectrum of a substrate target 30 can be measured. The detector 18 may be, for example, an array of CCD or CMOS sensors, and may use an integration time of, for example, 40 milliseconds per frame.

[0041] A reference beam is often used for example to measure the intensity of the incident radiation. To do this, when the radiation beam is incident on the beam splitter 16 part of it is transmitted through the beam splitter as a reference beam towards a reference mirror 14. The reference beam is then projected onto a different part of the same detector 18.

[0042] A set of interference filters 13 is available to select a wavelength of interest in the range of, say, 405 - 790 nm or even lower, such as 200 - 300 nm. The interference filter may be tunable rather than comprising a set of different filters. A grating could be used instead of interference filters.

[0043] The detector 18 may measure the intensity of scattered light at a single wavelength (or narrow wavelength range), the intensity separately at multiple wavelengths or integrated over a wavelength range. Furthermore, the detector may separately measure the intensity of transverse magnetic- and transverse electric-polarized light and/or the phase difference between the transverse magnetic- and transverse electric-polarized light.

[0044] Using a broadband light source (i.e., one with a wide range of light frequencies or wavelengths – and therefore of colors) is possible, which gives a large etendue, allowing the mixing of multiple wavelengths. The plurality of wavelengths in the broadband preferably each has a bandwidth of.□ and a spacing of at least 2.□ (i.e., twice the bandwidth). Several "sources" of radiation can be different portions of an extended radiation source which have been split using fiber bundles. In this way, angle resolved scatter spectra can be measured at multiple wavelengths in parallel. A 3-D spectrum (wavelength and two different angles) can be measured, which contains more information than a 2-D spectrum. This allows more information to be measured which increases metrology process robustness. This is described in more detail in EP1,628,164A, which is incorporated by reference herein in its entirety.

[0045] The target 30 on substrate W may be a grating, which is printed such that after development, the bars are formed of solid resist lines. 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. 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.

[0046] A pattern to be exposed on a substrate W comprises product features 40 and overlay mark features 45. The product features have a smallest pitch of the order of tens of nanometers, in particular 80nm. The overlay mark features are significantly larger, of the order of several microns, as depicted in Figure 5 (although this figure is not to scale). However, according to an embodiment of the invention an overlay mark has sub-features 46, which have a smallest pitch equal to the smallest pitch of the product features 40, as shown in Figure 6. As can be seen, although the pitch of the product features and the sub-features are the same, the critical dimension of the sub-features is larger. Because the product features 40 and the sub-features 46 have the same pitch when the patterned projection beam is projected through the projection system it has the same sensitivity to aberrations and other distortions as the product features.

[0047] The patterned projection beam exposes a radiation sensitive material on the substrate which is then developed. During development the outline of the product features is revealed. However, due to their larger critical dimension the sub-features merge into a single (large) overlay feature. The features, including the overlay feature are then etched into the substrate and the use of larger scale features in an overlay feature results in structures which have a high contrast when measured. The overlay feature can then be used in a scatterometer to determine overlay error with respect to another overlay feature.

[0048] The smallest pitch of the sub-features should be of a similar order to the smallest pitch of the product features. The skilled person will understand that although the smallest pitch should be as close as possible and approximately equal they need not be identical.

[0049] Preferably every overlay feature on every feature of the substrate should have sub-features with a smallest pitch approximately equal to the smallest pitch of the product features of the layer concerned.

[0050] This invention has been described in relation to the use of overlay marks. However, the same design can be used for overlay marks, which would have similar sub-features.

[0051] 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.

[0052] 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.

[0053] 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.

[0054] 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.

[0055] 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 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.

Conclusion

[0056] 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 the appended claims in any way.

[0057] 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 functions and relationships thereof are appropriately performed.

[0058] 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, 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. 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 the skilled artisan in light of the teachings and guidance.

[0059] 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 following claims and their equivalents.

WHAT IS CLAIMED IS:

1. A method of measuring a characteristic, the method comprising:

   (a) projecting a beam of radiation having a pattern onto a substrate, the pattern comprising a product comprising a plurality of product features and a mark comprising plurality of mark features, at least one feature comprising a plurality of sub-features;

   (b) forming the pattern on the substrate;

   (c) projecting a beam of radiation onto the pattern

   (d) detecting a diffraction pattern from the pattern;

   (e) determining the overlay error between the pattern and an underlying pattern based on the diffraction pattern;

   wherein the sub-features have a pitch substantially equal to a pitch of the product features and when the pattern is formed the outline of the mark features and the product features are formed, but the shape of the sub-features is not formed.

2. A method according to claim 1 wherein forming the pattern on the substrate comprises etching the pattern into the substrate.

3. A method according to claim 1 wherein forming the pattern on the substrate comprises forming the pattern in a radiation sensitive layer on the substrate.

4. A method according to claim 3 wherein forming the pattern on the substrate comprises developing the radiation sensitive layer on the substrate.

5. A method according to claim 1 wherein the product features have a plurality of pitches.

6. A method according to claim 5 wherein the sub-features have a pitch substantially equal to the smallest pitch of the product features.

7. A method according to claim 1 wherein the pitch of the sub-features and the product features is 80-100nm.

8. A method of measuring a characteristic, the method comprising:

   (a) projecting a beam of radiation having a pattern onto a substrate, the pattern comprising a product comprising a plurality of product features and a mark comprising plurality of mark features, at least one feature comprising a plurality of sub-features;

   (b) forming the pattern on the substrate,

   wherein the sub-features have a smallest pitch equal to a pitch of the product features and when the pattern is formed the outline of the mark features and the product features are formed, but the shape of the sub-features is not formed.

9. A device manufacturing method comprising:

   (a) projecting a beam of radiation having a pattern onto a substrate, the pattern comprising a product comprising a plurality of product features and a mark comprising plurality of mark features, at least one feature comprising a plurality of sub-features;

   (b) forming the pattern on the substrate,

   wherein the sub-features have a smallest pitch equal to a pitch of the product features and when the pattern is formed the outline of the mark features and the product features are formed, but the shape of the sub-features is not formed.

10. A method comprising:

projecting a beam of radiation having a pattern onto a substrate, the pattern comprising a product comprising a plurality of product features and a mark comprising plurality of mark features, at least one feature comprising a plurality of sub-features;

forming the pattern on the substrate;

projecting a beam of radiation onto the pattern

detecting a diffraction pattern from the pattern;

determining overlay error between the pattern and an underlying pattern based on the diffraction pattern;

wherein the sub-features have a pitch substantially equal to a pitch of the product features and, if the pattern is formed, the outline of the mark features and the product features are formed, but the shape of the sub-features is not formed.

11. The method according to claim 10, wherein forming the pattern on the substrate comprises etching the pattern into the substrate.

12. The method according to claim 10, wherein forming the pattern on the substrate comprises forming the pattern in a radiation sensitive layer on the substrate.

13. The method according to claim 12, wherein forming the pattern on the substrate comprises developing the radiation sensitive layer on the substrate.

14. The method according to claim 10, wherein the product features have a plurality of pitches.

15. The method according to claim 14, wherein the sub-features have a pitch substantially equal to the smallest pitch of the product features.

16. The method according to claim 10, wherein the pitch of the sub-features and the product features is about 80-100nm.

17. A method comprising:

projecting a beam of radiation having a pattern onto a substrate, the pattern comprising a product comprising a plurality of product features and a mark comprising plurality of mark features, at least one feature comprising a plurality of sub-features;

forming the pattern on the substrate,

wherein the sub-features have a smallest pitch equal to a pitch of the product features and, if the pattern is formed, the outline of the mark features and the product features are formed, but the shape of the sub-features is not formed.

18. A device manufacturing method comprising:

projecting a beam of radiation having a pattern onto a substrate, the pattern comprising a product comprising a plurality of product features and a mark comprising plurality of mark features, at least one feature comprising a plurality of sub-features;

forming the pattern on the substrate,

wherein the sub-features have a smallest pitch equal to a pitch of the product features and, if the pattern is formed, the outline of the mark features and the product features are formed, but the shape of the sub-features is not formed.

Fig. 1

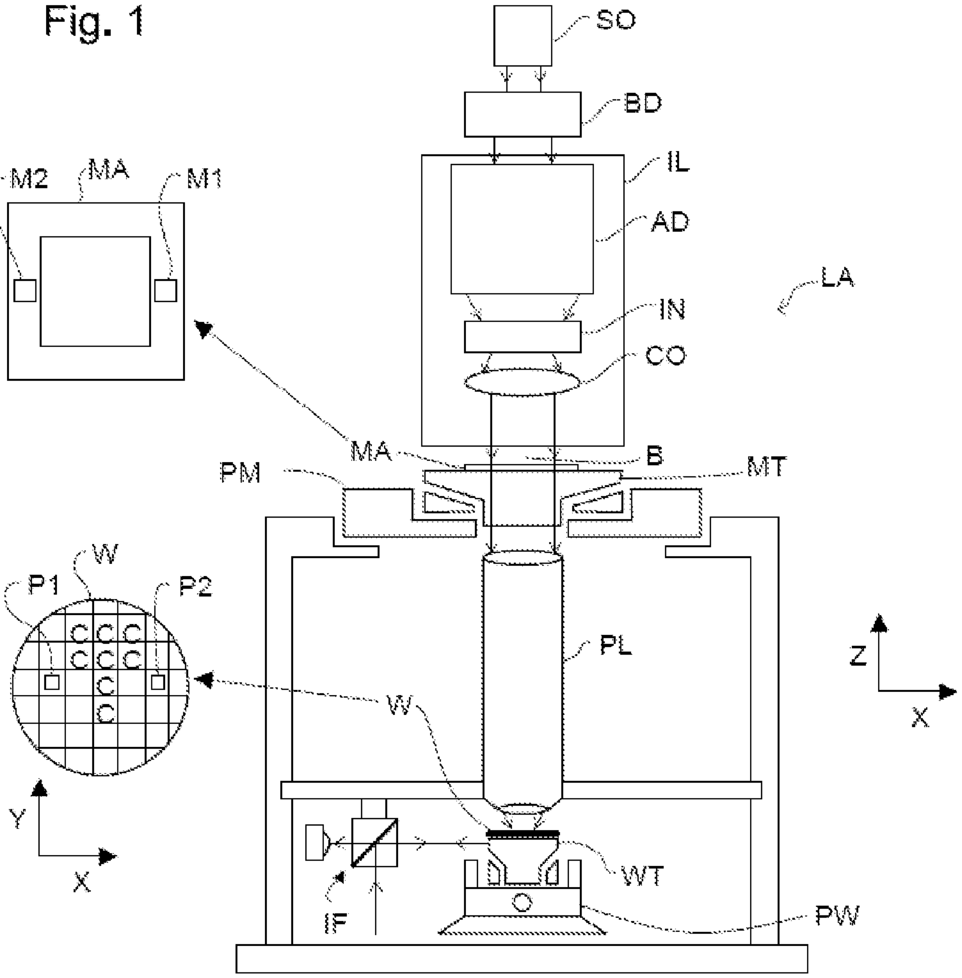

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Fig. 2

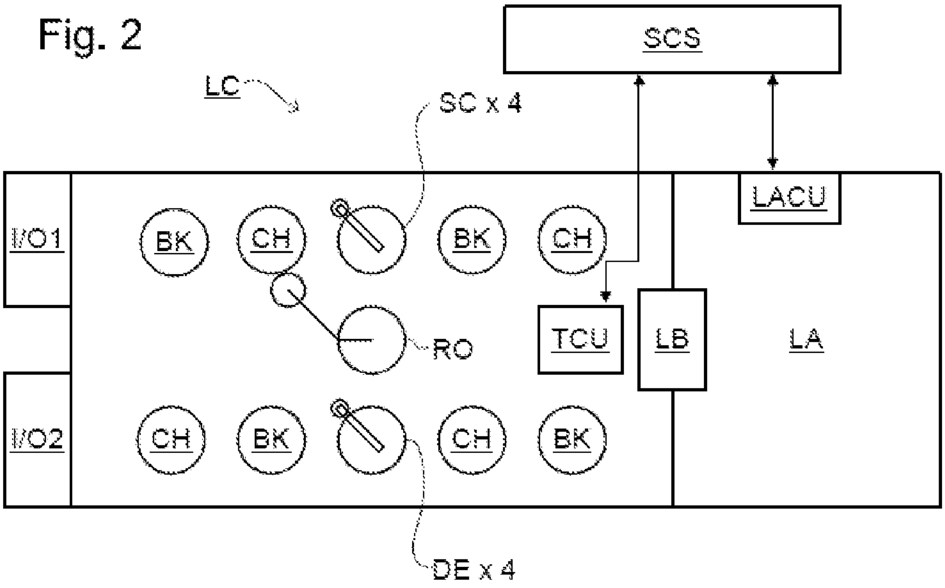
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Fig. 3

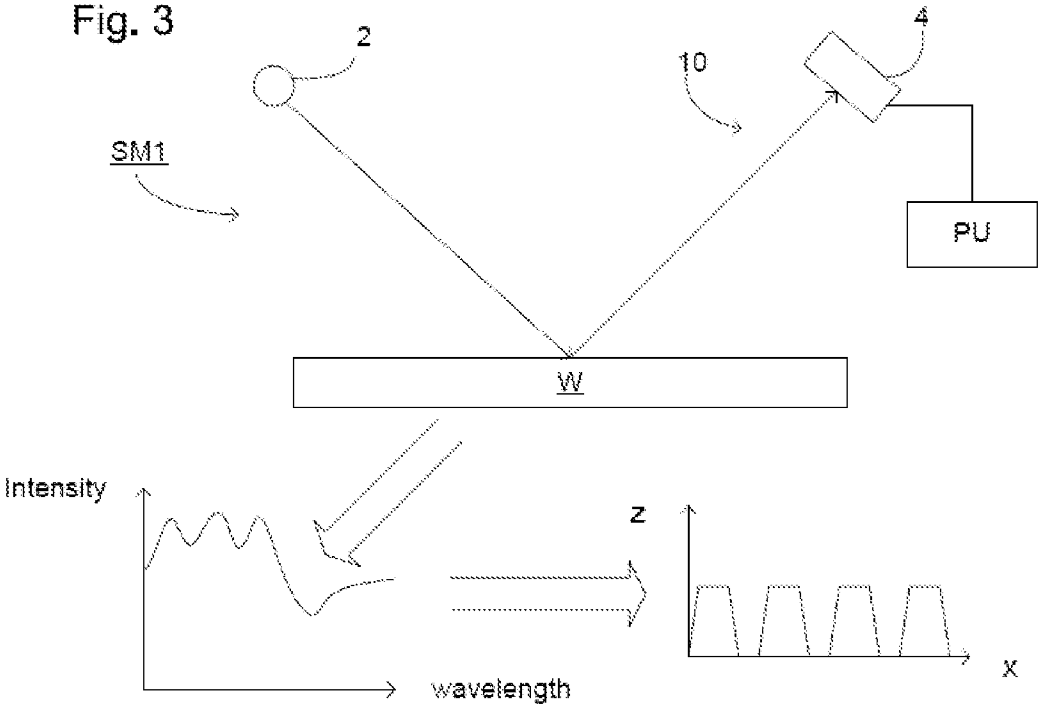
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Fig. 4

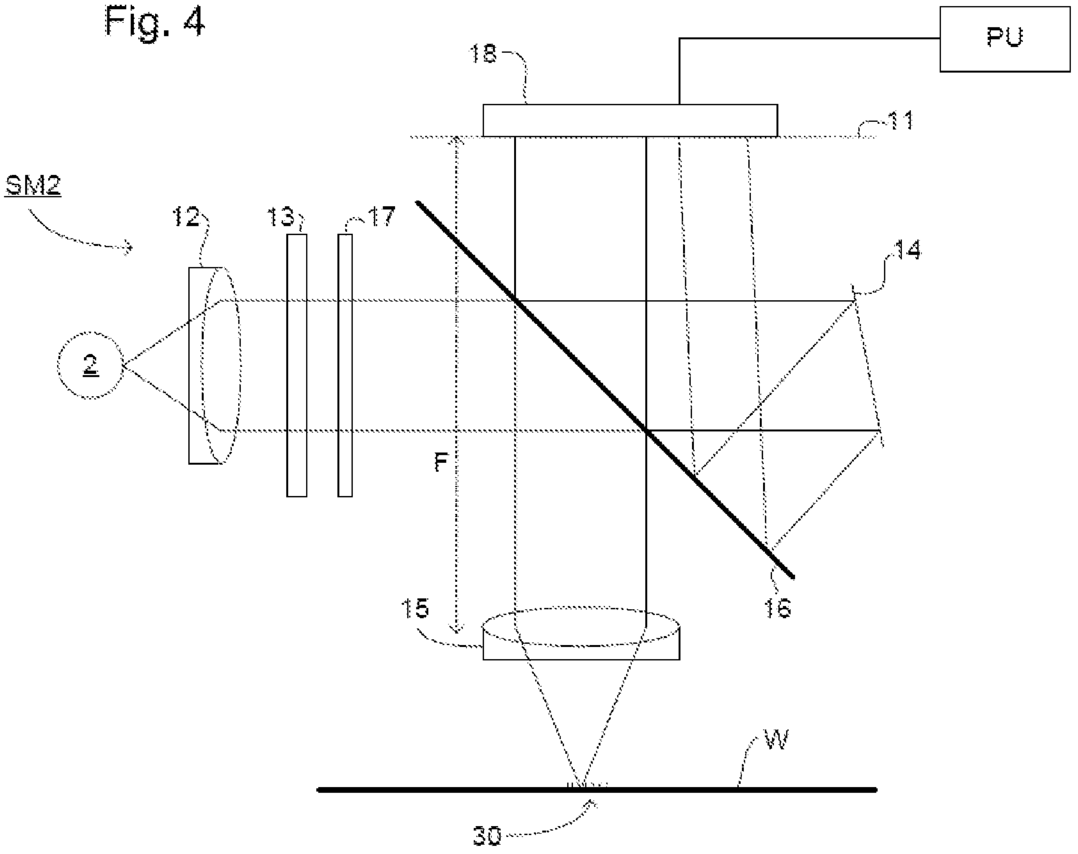
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Fig. 5

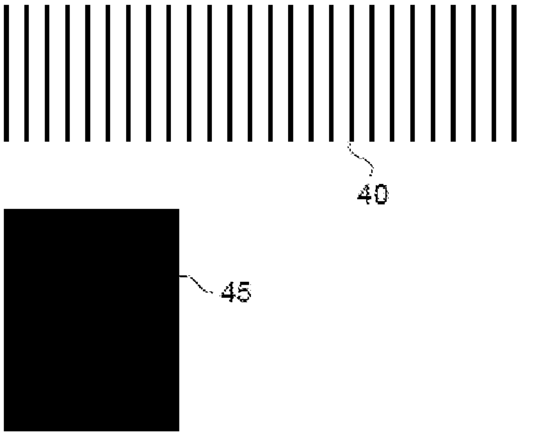
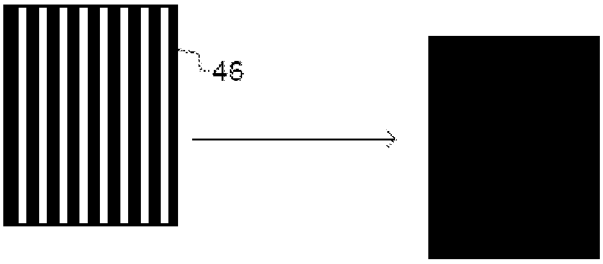


Fig. 6



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2010/059698

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

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

B. FIELDS SEARCHED

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

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

Electronic data base consulted during the international search (name of data base and, where practical, 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 6 636 312 B1 (HSIN CHIH-HSING [TW] ET AL) 21 October 2003 (2003-10-21) the whole document column 1, line 12 - line 16 column 2, line 56 - column 4, line 6 figures 1, 3A, 3B, 4 -----	1-18

☐ 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 document 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 5 October 2010	Date of mailing of the international search report 13/10/2010
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 Heryet, Chris

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2010/059698

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6636312 B1	21-10-2003	TW 434686 B	16-05-2001