Level Sensor Arrangement for Lithographic Apparatus and Device Manufacturing Method

Field

[0001] The present invention relates to a lithographic apparatus and a method for manufacturing a device. More particularly, the present invention relates to a level sensor arrangement and a method for level sensing of a substrate.

Background

[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 substrate). 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] European patent application EP-A-1 037 117 discloses an off-axis leveling arrangement in a lithographic projection apparatus. Using this arrangement a height map of a substrate in a lithographic map is determined, by employing a level sensor using grating optics and polychromatic radiation in the wavelength range of 600-1050 nm.

SUMMARY

[0004] It is desirable to provide an improved level sensor arrangement and operation thereof.

[0005] According to an aspect of the invention, there is provided a level sensor arrangement for measuring a position of a surface of a photosensitive layer of a substrate in a lithographic apparatus, comprising a detector unit for measuring radiation reflected from the substrate in operation, characterized by the detector unit being arranged to measure radiation in a wavelength range in which the photosensitive layer to be used for processing the substrate is sensitive

[0006] According to an aspect of the invention, there is provided a lithographic apparatus arranged to measure a position of a surface of a photosensitive layer of a substrate, wherein the lithographic apparatus is arranged to measure the height based on actinic radiation reflected by the substrate.

[0007] According to an aspect of the invention, there is provided a method for measuring a position of a surface of a photosensitive layer of a substrate in a lithographic apparatus, comprising measuring radiation reflected from the substrate in operation, wherein the reflected radiation is in a wavelength range in which in which the photosensitive layer to be used for processing the substrate is sensitive. According to an aspect of the invention, there is provided a device manufacturing method comprising transferring a pattern from a patterning device onto a substrate, comprising measuring a position of a surface of a photosensitive layer of a substrate based on actinic radiation reflected by the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

[0009] - Figure 1 depicts a lithographic apparatus according to an embodiment of the invention;

[0010] - Figure 2 depicts a schematic view of a sensor level arrangement using a projection grating;

[0011] - Figure 3 depicts a schematic cross sectional view of a substrate with a stack of layers including measurement beams of the level sensor arrangement;

[0012] - Figure 4 depicts a schematic view of a sensor level arrangement according to an embodiment of the present invention;

[0013] - Figure 5 depicts a cross sectional view of a part of a detector unit;

[0014] - Figure 6 depicts a cross sectional view of a part of a detector unit according to an embodiment of the present invention;

[0015] - Figure 7a depicts a cross sectional vie of a typical front end stack on a substrate and Figure 7b depicts graphs of the apparent surface depression of the substrate with front end stack as function of angle of incidence for two wavelength ranges; and

[0016] - Figure 8a depicts a cross sectional vie of a typical back end stack on a substrate and Figure 8b depicts graphs of the apparent surface depression of the substrate with back end stack as function of angle of incidence for two wavelength ranges

[0017] In the drawings, like reference numerals indicate like parts.

DETAILED DESCRIPTION

[0018] Figure 1 schematically depicts a lithographic apparatus according to one embodiment of the invention. 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) PS 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.

[0019] 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.

[0020] 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."

[0021] 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.

[0022] 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.

[0023] 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".

[0024] 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).

[0025] 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.

[0026] 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.

[0027] 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.

[0028] 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 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 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.

[0029] 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 PS, which focuses the beam onto a target portion C of the substrate W. With the aid of

the second positioner PW and position sensor IF (e.g. an interferometric device, linear encoder 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.

[0030] The depicted apparatus could be used in at least one of the following modes:

[0031] 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.

[0032] 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 PS. In scan mode, the maximum size of the exposure field limits the width (in the non-scanning direction) of the target portion in a single dynamic exposure, whereas the length of the scanning motion determines the height (in the scanning direction) of the target portion.

[0033] 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.

[0034] Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

[0035] The embodiments of the present invention relate to methods and arrangements for performing a level sensor measurement relating to the substrate in the lithographic apparatus.

[0036] In a level sensor according to the prior art, the level sensor determines a surface height or surface height profile of a substrate W. A generalized schematic diagram of a level sensor is shown in Fig. 2. Level sensor measurements are performed in all stages of substrate processing, also, when the substrate W already comprises a stack 4 of layers, such as oxide, poly-silicon, dielectric anti-reflective coating (DARC), metal layers (e.g. copper) and resist layers.

[0037] An emitter 6 (e.g. in the form of a light source) emits radiation at a pattern 7 (e.g. a grating having a pitch P of 30 μm), and the so formed radiation beam is projected on the substrate W (or top surface of the stack 4 of layers on the substrate W) using projection optics (e.g. in the form of a lens) 9, with an angle of incidence θ. The radiation used for level sensor measurements in lithographic apparatus has a wavelength range of 600-1050 nm, i.e. a wavelength range for which the resist used in processing of the substrate W is not sensitive. The reflected radiation is again focused using another lens 9 on a reference grating 8. A detector 5 is then used to process the radiation transmitted by the reference grating 8, and the measurement signal is processed to obtain the height of the stack 4 of layers. This level sensor arrangement is based on optical triangulation techniques. The detected height is directly related to the signal strength measured by the detector 5, and has a periodicity dependent on the angle of incidence ($P/2 \sin\theta$).

[0038] In practice the resist and underlying process layers of the stack 4 on the substrate W are (partially) transparent. Light with a specific wavelength reflected from an underlying process layer adds coherently to light reflected from the resist layer and this gives rise to stack interference effects that can lead to large measurement errors that depend on the precise layer thickness. In order to average-out these interference effects a broad wavelength range of about 1 octave is used. This is shown schematically in Fig. 3. An incident beam 11 partially reflects on the surface of stack 4 (comprising a resist layer only in this example) resulting in a reflected beam 12. However, part of the incident beam 11 is refracted into the stack 4, and reflected on the interface between substrate W and stack 4. At the surface of the stack 4 this beam is again refracted and forms a secondary beam 13, parallel to the reflected beam 12. As a result, not the correct height h of the stack 4 is taken into account, but a different value.

[0039] The difference between the measured height and the true resist height is called "Apparent Surface Depression" (ASD). This ASD is minimized by using broadband light with a wavelength range from e.g. 600 – 1050 nm which averages out the detrimental influence of stack interference effects.

[0040] The effect of ASD is corrected with an auxiliary sensor based on pressure or flow measurements between the wafer surface and a nozzle (air gauge), This sensor, however, is slow and it is therefore only used to do incidental calibrations on a few fields on the wafer. Moreover, it is in very close proximity to the substrate surface (≈200 μm) which poses a potential machine safety issue that can only be resolved with costly safety measures. Finally, the use of two sensors further increases cost of goods.

[0041] In an embodiment (as shown in figure 4) of a level sensor arrangement 10 according to an embodiment of the present invention and to be used in a lithographic apparatus as described earlier (in relation to figure 1) a light source 16 is used having a specific light spectrum, which emits radiation towards the substrate W. The radiation from the light source 16 is directed at a projection grating 17 positioned between the light source 16 and substrate W. Using a reflective projection system comprising mirrors 14 and 15 in the embodiment shown, the image formed by the projection grating 17 is projected on the substrate W. The reflected radiation from the substrate W is again optically focused using further reflective elements 14 and 15 to a detector unit 18. The detector unit 18 is e.g. provided with a UV sensor to measure

the radiation reflected from the substrate W and to determine the substrate height (profile) from the reflected radiation in operation.

[0042] According to the present invention embodiments, the effect of ASD is reduced by using a light source 16 emitting a shorter wavelength of the incident beam 11 compared to prior art level sensor arrangements. More specifically, the light source 16 is arranged to emit radiation in a wavelength range in which a resist to be used for processing the substrate W in the lithographic apparatus is sensitive. In other words, the wavelength used in level sensor measurements in a lithographic apparatus is changed to a wavelength for which the resist used in substrate processing is susceptible, also indicated as actinic light (i.e. light radiation effecting chemical changes). Depending on the resist used, this means a measurement wavelength of less than 500nm is implemented. E.g. in one embodiment, the wavelength used is lower than 400nm (UV radiation), e.g. even lower than 300 nm (DUV radiation).

[0043] There are a number of reasons why a shorter wavelength improves process robustness. The refractive index of resist increases towards shorter wavelengths. This increases the reflectance at the resist-air interface and as a result less light penetrates the resist. Averaging of thin-film interference effects improves at shorter wavelengths for today's thin films. When copper (Cu) is used in the back-end advantage can be taken of the characteristic that copper has a significantly lower reflectance at shorter wavelengths. Furthermore, many modern process layers like poly-Si and a-C hardmask become opaque in the UV regime so the level sensor will "see" less of the underlying stack. For this effect, reference is made to the article 'Refractive Index Measurements of Photoresist and Antireflective Coatings with Variable Angle Spectroscopic Ellipsometry' by R.A. Synowicki et al, SPIE Vol. 3332, pp384-390. In this article it is described that SiON, which is a known in-organic anti-reflection material used for coating substrates, is transparent at visible light wavelengths (k=0), but starts absorbing light energy at wavelengths of 400nm and below.

[0044] At first sight the idea of using UV light in the level sensor measurement arrangement sounds totally unacceptable since there is this "holy" rule that the substrate should never be exposed with measurement light. However, when you look at the system requirements it turns out that leveling measurements can be done with very low light levels that are well below the normally used exposure energies. I.e. in a further embodiment, a dose (or energy level) of the radiation emitted towards the substrate W (as used for level sensor measurement) is below a predefined level, i.e. below a set threshold value, e.g. less than $0.1 mJ/cm^2$.

According to a further embodiment of the present invention, the level sensor measurement is executed in a lithographic apparatus as described above (with reference to Fig. 1), using a predefined level which is dependent on a stray light level allowed to exit the projection system PS. The threshold value of $0.1 mJ/cm^2$ as mentioned before is deduced from a practical implementations of a lithography apparatus, wherein the projection system PS is allowed to have that level of stray light (about 1%) impinging on the substrate W during exposure with a mask pattern.

[0045] Another way to approach the setting of a threshold value is by starting from what energy is required to be able to provide a robust and repeatable measurement. The number of photons needed to achieve a reproducibility σ_h is approximately:

$$N_{ph} \cong \frac{P^2}{16\sigma_h^2}$$

In case the parameters are chosen as $\sigma_h = 1$ nm and P=30μm, this value becomes $N_{ph} \approx 6\times10^7$. Assuming a photo detector efficiency of 10 %, a detection optics efficiency of 75 %, and a resist reflection (i.e. specular reflection) of 20 %, which are conservative values, the number of photons incident on resist would be $N_{photons} = 4\times10^9$. With a mean energy per photon of 6.6×10^{-19} J and an illuminated area of 2.5×2.5 mm^2 this would require an energy density incident on the substrate of $\approx4\times10^{-5}$ mJ/cm^2. This is orders of magnitude below the UV stray light requirement in imaging (≈0.1 mJ/cm^2).

[0046] Even when the energy dose of the measurement light transmitted by the level sensor arrangement 10 exceeds the predefined threshold value, it is possible to use this technique by a small change to the subsequent exposure step of the lithographic apparatus as described above (with reference to Fig. 1). In this embodiment, the illumination system IL is further arranged to apply an exposure level offset in case the level sensor arrangement has applied radiation with a dose (or energy level) above the predefined threshold value. In other words, the level sensor arrangement in the lithographic apparatus is operated with a dose (or energy level) of the measurement radiation above the threshold value on a substrate W, after which a dose correction is applied in a subsequent exposure step of that substrate W. In this way the exposure with measurement light by the level sensor arrangement introduces a predictable CD offset across the substrate W that can be corrected with a small dose reduction during the actual exposure.

[0047] In an even further embodiment, the level sensor arrangement 10 is arranged to provide a predictable distribution of the photon energy of the measurement light across the substrate W, e.g. a homogeneous distribution. When the actual distribution of measurement energy is known, it is then possible to apply a very simple dose reduction during actual exposure of the substrate W, depending on the distribution of energy during level sensor measurement.

[0048] In one specific embodiment, a light source 16 is used which has specific characteristics which make it suitable for use in the present level sensor arrangement. A deuterium source 16 has a wavelength spectrum from about 200-400nm, wherein the spectral irradiance is higher for the shorter wavelength range. It is therefore particularly suited for obtaining an improved level sensor arrangement where the stack 4 of layers has little or no influence on the height measurement, due to the lower sensitivity for layer interference at lower wavelengths.

[0049] The detector unit 18 is in a further embodiment provided with matched elements, such as radiation detectors 35, 36 (see also the description with reference to Fig. 6 below). Matched detectors 35, 36 have a sensitivity profile as function of wavelength which substantially inversely matches the energy profile as function of wavelength in the light source. In other words, the detection characteristic in the wavelength range as used is complementary to that of light source 16.

[0050] Alternatively or in addition, other (optical) elements of the detector unit 18, such as mirror reflectance or transmission through illumination fibers may be adapted to obtain the matched characteristics. E.g. when using a deuterium source which has a higher energy in the lower wavelengths, the detector unit 18 (or more specific the radiation detectors 35, 36) is chosen to be more sensitive in the higher portion of the wavelength range used. Using these types of matching it is possible to provide a level sensor arrangement 10 with a substantially flat system response as function of wavelength.

[0051] Known level sensor arrangements project a grating on the substrate W at an oblique angle θ, as shown in the embodiments of both Fig. 1 and Fig 4. The reflected image is projected on a detection grating (e.g. reference grating 8 in Fig. 1). A vertical displacement Z of the substrate W shifts the grating image over the detection grating which results in an intensity variation of the light that is transmitted by the grating. This intensity variation is proportional to the Z-displacement but the intensity also varies due to light source intensity variations or

substrate (specular) reflection variations. In order to eliminate these variations a differential detection scheme is used. In such a known detection set-up of a detector unit 5, a combination of a polarizer 21 and shear plate 22 (e.g. in the form of a Wollaston prism) produces two laterally sheared grating images ('e' and 'o') from the reflected beam 20 on a reference grating 23, as shown schematically in Fig. 5. The 'e' and 'o' images that are transmitted by the reference grating 23 are detected by two detectors (respectively, 25 and 26) and processed in processing unit 27 to yield a normalized height signal h.

[0052] This known set up of the detector unit 5 has a number of disadvantages. Polarization optics (such as polarizer 21) are expensive and the price rapidly increases for larger sizes. This increases cost of goods the level sensor is scaled up to a larger Field of View. The Wollaston prism/shear plate 22 is chromatic which produces a λ-dependant shift. This shift results in a color-dependant height error. This is probably acceptable at longer wavelengths where dispersion of the Wollaston prism 22 is low but this shift rapidly increases towards the UV wavelengths.

[0053] According to an embodiment of the present invention a relatively shallow ruled grating 31 with a triangular grating profile is used instead of using an amplitude transmission grating. Such a set-up of the detector unit 18 according to an embodiment is shown schematically in Fig. 6. The detector unit 18 as shown comprises a ruled grating 31 which acts as a phase grating. The pitch P of the ruled grating 31 is larger than the wavelength of the radiation emitted by the light source 16. The pitch P is e.g. equal to the period of the image of the projection grating 17 (see Fig. 4), e.g. 30 μm. In Fig. 6 a transmission grating 31 is shown, but as an alternative a ruled reflection grating is useable. For a transmission grating 31, a suitable material would be MgF, which is sufficiently transparent at the used wavelengths (at more than 120 nm).

[0054] The triangular grating profile of the ruled grating 31 acts as a series of wedges 31a, 31b, which redirects the light beam 20 according to the well known Snell's law. The image that is on a positive wedge 31a is redirected in an upward direction ('u') and the image that is on a negative wedge 31b is redirected in a down ward direction ('d'). If the image is exactly centered on the ruled grating 31 then the 'u' and 'd' images have equal intensity and the output 'h' of a processing unit 37 connected to two detectors 35, 36 will be zero. If the substrate height changes then the image of the projection grating 31 will also shift and this will result in an unbalance between the 'u' and 'd' signals.

[0055] The angle between the 'u' and 'd' beams should be more than the divergence of the image that is incident on the projection grating 17. Moreover, the ruled grating 31 introduces additional divergence of the light due to the wavelength dependant refraction (only in case of a transmission grating) and due to diffraction that occurs at the finite size of the wedges. The divergence caused by diffraction is roughly given by $2\lambda/P$. The total extra divergence is small (of the order of 0.1 radians) and is acceptable in a practical design. It should also be note that the diffraction-induced additional divergence is also found in the current polarization-based detection branch (as shown in Fig. 5).

[0056] The detector unit 18 embodiment of Fig. 6 provides a number of advantages. E.g. the current embodiment has low cost compared to the state of the art solutions. Especially in the UV region, polarizers 21 and shear plates 22 are very expensive. Furthermore, the detector unit 18 has no wavelength dependent height offset. Also, it can be easily scaled in size for a large-field level sensor.

[0057] Also, the new set-up is very light efficient. No light is blocked since a phase grating 31 is used rather than an amplitude grating 8. As a result more photons are available for the measurement. This embodiment of the detector unit 18 is particularly suitable for the UV level sensor embodiments described above. However, it may also be of interest for state of the art level sensors using visible light wavelengths as a cost-of-goods reduction.

[0058] Ruled gratings 31 are known as such and used in e.g. spectroscopy. For many applications ruled gratings 1 are made with a blaze angle. In the present embodiments the blaze is not needed or equal to zero, i.e. the positive and negative wedges 31a, 31b are at the same angle to the normal of ruled grating 31.

[0059] Simulations have been performed, were a level sensor arrangement has been used in one occasion with a wavelength range of 500-1000nm, and another occasion (using the above described embodiments) with a wavelength range of 200-400nm. The apparent surface depression (ASD) was determined as function of the incidence angle θ (indicated as angle of incidence or AOI in Fig. 7b and 8b).

[0060] In a first simulation, typical for a front end stack 4 of layers on a substrate W, a stack 4 on a substrate W was used comprising (in order from bottom to top: a 50nm oxide layer 4a, a 70 nm poly-silicon layer 4b, a 40 nm dielectric anti-reflective coating (DARC) layer 4c and an 80 nm resist layer 4d (see Fig. 7a). The resulting ASD's are much better for the low wavelength range. This is clearly visible in the graph of Fig. 7b.

[0061] In a second simulation, typical for a back end stack 4 of layers on a substrate W, a stack 4 on a substrate W was used comprising (in order from bottom to top: a 50nm oxide layer 4a, a 70 nm copper layer 4e, a 40 nm dielectric anti-reflective coating (DARC) layer 4c and an 80 nm resist layer 4d (see Fig. 8a). The resulting ASD's are again much better for the low wavelength range measurements. This is clearly visible in the graph of Fig. 8b.

[0062] In an embodiment that may usefully be combined with any of the foregoing described embodiments, actinic light from the light source 16 is prevented from impinging on the substrate W during alignment scans, or indeed during any time period in which level sensing is not required or useful. This result may be achieved as illustrated in Fig. 9 by way of the incorporation of a shutter 19 that is controllably closed as desired. As will be appreciated, the shutter 19 need not be in located upstream from the projection grating 17, but may be placed anywhere convenient within the optical path between the light source 16 and the substrate W. However, placing the shutter close to the light source may reduce the potential problem of reflected stray light and heating of the optical path. In another approach, a controller C is provided that is operable to shut off the light source during times that it is not in use. This approach, while mechanically simpler than a shutter, has the potential drawback that system stability may be impacted due to the required switching.

[0063] 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 "substrate" 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.

[0064] 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. The patterning device is moved out of the resist leaving a pattern in it after the resist is cured.

[0065] 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.

[0066] 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.

[0067] 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.

[0068] The descriptions above are intended to be illustrative, not limiting. Thus, it will be apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the claims set out below.

CLAIMS

1. A level sensor arrangement for measuring a position of a surface of a photosensitive layer of a substrate in a lithographic apparatus, comprising

- a radiation detector for measuring radiation reflected from the substrate in operation, wherein the radiation detector is arranged to measure radiation in a wavelength range in which the photosensitive layer to be used for processing the substrate is sensitive.

2. The level sensor arrangement of claim 1, comprising

- a light source for emitting radiation in the wavelength range towards the substrate and
- a substrate support for supporting the substrate and positioning the surface in a position wherein the radiation of the light source is specularly reflected by the substrate to the detector

3. The level sensor arrangement of claim 2, wherein the light source is a deuterium light source.

4. The level sensor arrangement of claim 1, 2 or 3, wherein the wavelength range comprises radiation of less than 400nm.

5. The level sensor arrangement of any one of claims 1-4, wherein a dose of radiation received at the surface of the substrate is below a predetermined level.

6. The level sensor arrangement of claim 5, wherein the predetermined level is 1 x 10^{-8} J/m2.

7. The level sensor arrangement of any one of claims 1-6, wherein the detector unit comprises a ruled grating having a pitch which is larger than the wavelength of the radiation emitted by the light source.

8. The level sensor arrangement of claim 7, further comprising a projection grating positioned in between the light source and the substrate, wherein the pitch of the ruled grating is equal to the pitch of the projection grating.

9. The level sensor arrangement of any one of claims 1-8, wherein the detector unit comprises elements having a sensitivity profile as function of wavelength which substantially inversely matches the spectral irradiance profile as function of wavelength of the light source.

10. The level sensor arrangement of any one of claims 2-9, further comprising a shutter, operable to block light from the light source from impinging on the substrate.

11. The level sensor arrangement of any one of claims 2-9, further comprising a controller, operable to turn off the light source.

12. A lithographic apparatus arranged to measure a position of a surface of a photosensitive layer of a substrate, wherein the lithographic apparatus is arranged to measure the height based on actinic radiation reflected by the substrate.

13. The lithographic apparatus of claim 12, wherein the lithographic apparatus comprises a level sensor arrangement according to any one of claims 1-11.

14. The lithographic apparatus of claim 12 or 13, wherein the lithographic apparatus further comprises a projection system configured to project a patterned radiation beam of exposure radiation onto a target portion of the substrate, wherein a dose of radiation received at the surface of the substrate is below a predetermined level, and the predetermined level is dependent on a stray light level allowed to exit the projection system.

15. The lithographic apparatus of claim 12, 13 or 14, comprising an illumination system configured to condition a radiation beam of exposure radiation, wherein the illumination system is further arranged to apply an exposure level offset to correct for the dose of radiation applied by the level sensor arrangement.

16. A method for measuring a position of a surface of a photosensitive layer of a substrate in a lithographic apparatus, comprising measuring radiation reflected from the substrate in operation,

wherein the reflected radiation is in a wavelength range in which in which the photosensitive layer to be used for processing the substrate is sensitive.

17. A method of measuring a position of a surface of a photosensitive layer on a substrate in a lithographic apparatus, the lithographic apparatus being operable to project a radiation beam onto the photosensitive layer, the photosensitive layer comprising a material sensitive to radiation in a range of wavelengths, the range of wavelengths including a wavelength of the radiation beam, the method comprising:

reflecting a measurement beam of radiation having a wavelength within the range of wavelengths to which the material of the photosensitive layer is sensitive from the surface of the photosensitive layer;

receiving the reflected measurement beam; and

determining, based on the reflected measurement beam, a position of the surface of the photosensitive layer.

18. A device manufacturing method comprising transferring a pattern from a patterning device onto a substrate, comprising measuring a position of a surface of a photosensitive layer of a substrate based on actinic radiation reflected by the substrate.