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LITHOGRAPHIC SYSTEM, EUV RADIATION SOURCE, LITHOGRAPHIC SCANNING APPARATUS AND CONTROL SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

- 5 [001] This application claims priority of EP application 17161855.6 which was filed on 20 March 2017 and which is incorporated herein in its entirety by reference.

FIELD

- 10 [002] The present invention relates to a lithographic system, an EUV radiation source, a lithographic scanning apparatus and a control system. The invention is particularly applicable to the control of a radiation source apparatus for extreme ultraviolet (EUV) radiation.

BACKGROUND

- 15 [003] A lithographic scanning apparatus is a machine that applies a desired pattern onto a substrate, usually onto a target portion of the substrate. A lithographic scanning 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.

- 25 [004] Lithography is widely recognized as one of the key steps in the manufacture of ICs and other devices and/or structures. However, as the dimensions of features made using lithography become smaller, lithography is becoming a more critical factor for enabling miniature IC or other devices and/or structures to be manufactured.

- [005] A theoretical estimate of the limits of pattern printing can be given by the Rayleigh criterion for resolution as shown in equation (1):

$$CD = k_1 * \frac{\lambda}{NA} \quad (1)$$

- 30 where λ is the wavelength of the radiation used, NA is the numerical aperture of the projection system used to print the pattern, k_1 is a process dependent adjustment factor, also called the Rayleigh constant, and CD is the feature size (or critical dimension) of the printed feature. It follows from equation (1) that reduction of the minimum printable size of features can be obtained in three ways: by shortening the exposure wavelength λ , by increasing the numerical aperture NA or by decreasing the value of k_1 .
- 35

[006] In order to shorten the exposure wavelength and, thus, reduce the minimum printable size, it has been proposed to use an extreme ultraviolet (EUV) radiation source. EUV radiation is electromagnetic radiation having a wavelength within the range of 5-20 nm, for example within the range of 13-14 nm. It has further been proposed that EUV radiation with a wavelength of less than 10 nm could be used, for example within the range of 5-10 nm such as 6.7 nm or 6.8 nm. Possible sources include laser-produced plasma (LPP) sources, although other types of source are possible.

[007] An example of current progress in the development of LPP sources for EUV lithography is described in the paper "High power LPP EUV source system development status" by Benjamin Szu-Min Lin, David Brandt, Nigel Farrar, SPIE Proceedings Vol. 7520, Lithography Asia 2009, December 2009 (SPIE Digital Library reference DOI: 10.1117/12.839488). In a lithographic scanning apparatus, the source apparatus will typically be contained within its own vacuum housing, while a small exit aperture is provided to couple the EUV radiation beam into an optical system where the radiation is to be used.

[008] In order to be useful in high-resolution patterning for lithography, the EUV radiation beam is conditioned to obtain at reticle level desired uniformity of intensity and/or desired angular distribution of intensity. Examples of an illumination system are described in United States Patent Application Publication Nos. US 2005/0274897 (Carl Zeiss/ASML) and US 2011/0063598A (Carl Zeiss), both incorporated herein by reference. The example systems include a 'fly's eye' illuminator which transforms the highly non-uniform intensity profile of the EUV source into a more uniform and controllable source.

[009] For good imaging performance it should also be ensured that the conditioned EUV radiation beam be uniform in intensity, particularly in a non-scanning direction (as explained further below). The known illumination systems include various techniques for uniformity correction, removing residual non-uniformities that are not canceled by the fly's eye illuminator. The known techniques are not necessarily able to correct for all variations in the EUV radiation beam, however. For example, fluctuations in the position of a fuel droplet relative to the timing and place of a laser pulse may cause asymmetry in the radiation beam that are not canceled by the fly's eye illuminator, but which are too rapid to be corrected conveniently by the other uniformity correction mechanisms known to date.

SUMMARY

[0010] Aspects of embodiments of the present invention aim to provide techniques for controlling the intensity and/or uniformity of a conditioned radiation beam passing through an aperture. Embodiments of the invention aim in particular to detect and correct asymmetries in illumination more rapidly and more directly than known techniques.

[0011] The invention relates to a lithographic system comprising: an EUV radiation source, configured for generating EUV radiation; a lithographic scanning apparatus configured for receiving the EUV radiation and for illuminating a pattern using the EUV radiation to image the pattern onto a substrate; and a control system. The EUV radiation source comprises a sensing system configured for providing a sensing signal representative of a spatial intensity distribution of the EUV radiation. The control system is operative to determine a quantity representative of a far-field intensity distribution of the EUV radiation based on the sensing signal and to determine a control signal for control of at least one of the illuminating and the generating, based on the determined quantity.

[0012] The invention also relates to an EUV radiation source configured for use in the lithographic system specified above, wherein the EUV radiation source comprises the control system and wherein the control system is configured to output the control signal to an interface configured for interfacing with the lithographic scanning apparatus.

[0013] The invention also relates to a control system configured for use in the lithographic system specified above, the control system having a first interface configured for receiving the sensing signal and a second interface for providing the control signal.

[0014] The invention further relates to a lithographic scanning apparatus configured for use in the lithographic system specified above and comprising the control system.

[0015] These aspects of the invention and various optional features and implementations thereof will be understood by the skilled reader from the description of examples which follows.

[0016] For completeness, US patent 8,633,881, incorporated herein by reference, discloses a feedback control mechanism. Therein a signal, representative of the uniformity of the EUV radiation received at reticle level of the lithographic scanning apparatus is fed back to the EUV radiation source for control of the EUV radiation produced. The current invention relates to, among other things, a feedforward mechanism wherein sensor signals from the EUV radiation source are sent to the illuminator of the lithographic scanning apparatus.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] 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:

[0018] Figure 1 depicts schematically a lithographic system according to an embodiment of the invention;

[0019] Figure 2 is a more detailed view of the apparatus of Figure 1 and shows a novel monitoring and control system for an EUV radiation source;

[0020] Figure 3 depicts schematically a process of generating EUV radiation as can be applied in an EUV radiation source according to the present invention, as can be applied in a lithographic system according to the present invention;

[0021] Figure 4 depicts schematically a process of generating EUV radiation, whereby a fuel target and the pre-pulse laser are misaligned;

[0022] Figures 5 (a) – (d) schematically depicts cross-sectional views of EUV radiation sources as can be applied in an embodiment of the present invention;

[0023] Figure 6 schematically depicts an illumination slit as can be applied in a lithographic scanning apparatus according to the present invention.

DETAILED DESCRIPTION

[0024] Figure 1 schematically depicts a lithographic system 100 according to an embodiment of the present invention, the lithographic system comprising a lithographic scanning apparatus and an EUV radiation source configured for generating EUV radiation, e.g. an EUV radiation beam. In the embodiment as shown, the EUV radiation source comprises a source collector module SO. In the embodiment as shown, the lithographic scanning apparatus comprises: an illumination system (illuminator) IL configured to condition a radiation beam B (e.g. EUV radiation); a support structure (e.g. a mask table) MT constructed to support a patterning device (e.g. a mask or a reticle) MA and connected to a first positioner PM configured to accurately position the patterning device; 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; and a projection system (e.g. a reflective projection 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.

[0025] The illumination system IL 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.

[0026] The support structure MT holds the patterning device MA in a manner that depends on the orientation of the patterning device, the design of the lithographic scanning 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, 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.

[0027] The term “patterning device” 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. The pattern imparted to the radiation beam may correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit.

[0028] 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.

[0029] The projection system, like 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, as appropriate for the exposure radiation being used, or for other factors such as the use of a vacuum. It may be desired to use a vacuum for EUV radiation since other gases may absorb too much radiation. A vacuum environment may therefore be provided to the whole beam path with the aid of a vacuum wall and vacuum pumps.

[0030] As here depicted, the apparatus is of a reflective type (e.g. employing a reflective mask).

[0031] The lithographic scanning 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.

[0032] Referring to Figure 1, the illuminator IL receives an extreme ultra violet radiation beam from the source collector module SO of the EUV radiation source. Methods to produce EUV light include, but are not necessarily limited to, converting a material into a plasma state that has at least one element, e.g., xenon, lithium or tin, with one or more emission lines in the EUV range. In one such method, often termed laser produced plasma ("LPP") the required plasma can be produced by irradiating a fuel, such as a droplet, stream or cluster of material having the required line-emitting chemical element, with a laser beam. The source collector module SO may be part of an EUV radiation system including a laser, not shown in Figure 1, for providing the laser beam exciting the fuel. The resulting plasma emits output radiation, e.g., EUV radiation, which is collected using a radiation collector, disposed in the source collector module. The laser and the EUV radiation source may be separate entities, for example when a CO₂ laser is used to provide the laser beam for fuel excitation.

[0033] The radiation beam is passed from the laser to the source collector module with the aid of a beam delivery system comprising, for example, suitable directing mirrors and/or a beam expander.

The source may be an integral part of the source collector module, for example when the source is a discharge produced plasma EUV generator, often termed as a DPP source.

[0034] The illuminator IL may comprise an adjuster 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 a faceted field mirror device and faceted pupil mirror device. The illuminator may be used to condition the radiation beam, to have a desired uniformity and intensity distribution in its cross-section.

[0035] 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. After being reflected from the patterning device (e.g. mask) MA, the radiation beam B passes through the projection system PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioner PW and position sensor PS2 (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 PS1 can be used to accurately position the patterning device (e.g. mask) MA with respect to the path of the radiation beam B. Patterning device (e.g. mask) MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2.

[0036] The depicted apparatus could be used in at least one of the following modes:

1. In step mode, the support structure (e.g. 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.

2. In scan mode, the support structure (e.g. mask table) MT and the substrate table WT are scanned synchronously while a pattern imparted to the radiation beam is projected onto a target portion C (i.e. a single dynamic exposure). The velocity and direction of the substrate table WT relative to the support structure (e.g. mask table) MT may be determined by the (de-)magnification and image reversal characteristics of the projection system PS.

3. In another mode, the support structure (e.g. 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.

[0037] Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed. The embodiments to be illustrated involve scanning, as in the modes 2 and 3 just mentioned.

[0038] Although specific reference may be made in this text to the use of lithographic scanning apparatus in the manufacture of ICs, it should be understood that the lithographic scanning 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.

[0039] Figure 2 shows the system 100 in more detail, including the EUV radiation source comprising the source collector module SO and the lithographic scanning apparatus comprising the illumination system IL, and the projection system PS. The source collector module SO of the EUV radiation source is constructed and arranged such that a vacuum environment can be maintained in an enclosing structure 220 of the source collector module SO. The systems IL and PS are likewise contained within vacuum environments of their own. An EUV radiation emitting plasma 210 may be formed by a laser produced LPP plasma source. The function of source collector module SO is to deliver EUV radiation beam 20 from the plasma 210 such that it is focused in a virtual source point. The virtual source point is commonly referred to as the intermediate focus (IF), and the source collector module is arranged such that the intermediate focus IF is located at or near an aperture 221 in the enclosing structure 220. The virtual source point IF is an image of the radiation emitting plasma 210.

[0040] From the aperture 221 at the intermediate focus IF, the radiation traverses the illumination system IL, which in this example includes a faceted field mirror device 22 and a faceted pupil mirror device 24. These devices form a so-called “fly’s eye” illuminator, which is arranged to provide a desired angular distribution of the radiation beam 21, at the patterning device MA, as well as a desired uniformity of radiation intensity at the patterning device MA. Upon reflection of the beam 21 at the patterning device MA, held by the support structure (mask table) MT, a patterned beam 26 is formed and the patterned beam 26 is imaged by the projection system PS via reflective elements 28, 30 onto a substrate W held by the wafer stage or substrate table WT.

[0041] Each system IL and PS is arranged within its own vacuum or near-vacuum environment, defined by enclosing structures similar to enclosing structure 220. More elements than shown may generally be present in illumination system IL and projection system PS. Further, there may be more mirrors present than those shown in the Figures. For example there may be one to six additional
5 reflective elements present in the illumination system IL and/or the projection system PS, besides those shown in Figure 2. The United States patent application publications referred to above show three additional elements in the illumination system, for example.

[0042] Considering source collector module SO in more detail, laser energy source comprising laser 223 is arranged to deposit laser energy 224 into a fuel, such as xenon (Xe), tin (Sn) or lithium
10 (Li), creating the highly ionized plasma 210 with electron temperatures of several 10's of eV. Higher energy EUV radiation may be generated with other fuel materials, for example, terbium (Tb) or Gadolinium (Gd). The energetic radiation generated during de-excitation and recombination of these ions is emitted from the plasma, collected by a near-normal incidence collector CO and focused on the aperture 221. The plasma 210 and the aperture 221 are located at first and second focal points of
15 collector CO, respectively.

[0043] To deliver the fuel, which for example is liquid tin, a droplet generator 226 is arranged within the enclosure 220, arranged to fire a high frequency stream 228 of droplets towards the desired location of plasma 210. In operation, laser energy 224 is delivered synchronously with the operation of droplet generator 226, to deliver impulses of radiation so as to turn each fuel droplet into plasma
20 210. The frequency of delivery of droplets may be several kilohertz, for example 50 kHz. In practice, laser energy 224 is delivered in at least two pulses: a pre-pulse with limited energy is delivered to the droplet before it reaches the plasma location, in order to vaporize the fuel material into a small cloud, and then a main pulse of laser energy 224 is delivered to the cloud at the desired location, to generate the plasma 210. A trap 230 is provided on the opposite side of the enclosing structure 220, to capture
25 fuel that is not, for whatever reason, turned into plasma.

[0044] Numerous additional components in the source collector module and the lithographic scanning apparatus are present in a typical apparatus, though not illustrated here. These include arrangements for reducing or mitigating the effects of contamination within the enclosed vacuum, for example to prevent deposits of fuel material damaging or impairing the performance of collector CO
30 and other optics. Also, one or more spectral purity filters will be included in the source collector module SO and/or illumination system IL. These filters are configured for eliminating as much as possible radiation of unwanted wavelengths, that is generated by the laser and/or the plasma 210 together with the wanted wavelengths of the EUV radiation. The spectral purity filter(s) may be positioned near the virtual source point, at the collector or at any point between the collector and the
35 virtual source point. The filter can be placed at other locations in the radiation path, for example downstream of the virtual source point IF. Multiple filters can be deployed. The skilled person is

familiar with the need for these measures, and the manner in which they may be implemented, and further detail is not required for the purposes of the present disclosure.

[0045] Referring to laser 223 from Figure 2 in more detail, the laser in the presented embodiment is of the MOPA (Master Oscillator Power Amplifier) type. This type includes a “master” laser or “seed” laser, labeled MO in the diagram, followed by one or more power amplifiers (PA). A beam delivery system 240 is provided to deliver the laser energy 224 into the module SO. In practice, the pre-pulse component of the laser energy may be delivered by a separate laser, not shown separately in the diagram. Laser 223, fuel source (i.e. the droplet generator) 226 and other components may be controlled by a source control module 242.

[0046] The lithographic system according to the present invention further comprises a sensing system 270, as part of the EUV radiation source. In accordance with the present invention, the sensing system 270 is configured to provide a sensing signal 272 representative of a spatial intensity distribution of the EUV radiation to a control system 280. In accordance with the present invention, the sensing signal 272 is representative of the spatial intensity distribution and may refer to, e.g., a direction of the EUV radiation beam that is generated by the EUV radiation source.

[0047] As shown in Figure 2, the sensing signal 272 may be provided to an input 280.1 of the control system 280. In accordance with the present invention, the control system 280 of the lithographic system 100 is configured to provide a control signal 282 for at least one of the EUV radiation source and the lithographic scanning apparatus of the system 100, based on the received sensing signal 272. Such a control signal 282 may e.g. be outputted via an output 280.2 of the control system 280.

[0048] As one of ordinary skill in the art will know, reference axes X, Y and Z may be defined for measuring and describing the geometry and behavior of the system, its various components, and the radiation beams 20, 21, 26. At each part of the system, a local reference frame of X, Y and Z axes may be defined. The Z axis broadly coincides with the direction of the optical axis O at a given point in the system, and is generally normal to the plane of a patterning device (reticle) MA and normal to the plane of substrate W. In the source collector module, the X axis coincides broadly with the direction of fuel stream (228, described below), while the Y axis is orthogonal to that, pointing out of the page as indicated in Figure 2. On the other hand, in the vicinity of the support structure MT that holds the reticle MA, the X axis is generally transverse to a scanning direction aligned with the Y axis. For convenience, in this area of the schematic diagram Figure 2, the X axis points out of the page, again as marked. These designations are conventional in the art and will be adopted herein for convenience. In principle, any reference frame can be chosen to describe the apparatus and its behavior.

[0049] Referring in a little more detail to the illumination system, faceted field mirror device 22 comprises an array of individual facets, so that the EUV radiation beam 20 is divided into a number of

subsidiary beams (sub beams), of which one is labeled 260 in the diagram. Each sub beam is directed towards an individual facet on the faceted pupil mirror device 24. The facets of pupil mirror device 24 are arranged to direct their individual sub beams onto a target which is a slit-shaped area of patterning device MA. The division into sub beams 260 and the combination into a single beam 21 are designed to create highly uniform illumination over the slit area, if the illumination arriving from the source collector module is highly non-uniform in its angular distribution. As is also known, the facets of the devices 22 and/or 24 may be steerable and/or maskable or otherwise controllable, in order to implement different illumination modes.

The conditioned EUV radiation beam 21 is delivered to patterning device MA through a conditioning and masking module 262. This module includes a masking unit, also referred to as the reticle mask (REMA) which may have movable blades defining the extent of an illumination slit in X and Y directions. Typically, the illumination slit as applied in EUV-type lithographic scanning apparatuses may be curved.

In front of the REMA may also be an illumination uniformity correction module (UNICOM).

[0050] To expose a target portion C on substrate W, pulses of radiation are generated while substrate table WT and mask table MT perform synchronized movements 266, 268 to scan the pattern on patterning device MA through the slit of illumination.

[0051] Examples of illumination systems including REMA and UNICOM functions are described in United States Patent Application Publication Nos. 2005/0274897A1 and 2011/0063598A, both incorporated herein by reference.

[0052] Many measures are applied in the source controller 242. Such measures include monitoring to ensure that the virtual source point IF is aligned with the aperture 221 that forms the exit of the source collector module SO. In systems based on LPP sources, control of alignment is generally achieved by controlling the location of the plasma 210, rather than by moving the collector optic CO. The collector optic, the exit aperture 221 and the illuminator IL are aligned accurately during a set-up process, so that aperture 221 is located at the second focal point of the collector optic CO. However, the exact location of the virtual source point IF formed by the EUV radiation at the exit of the source SO depends on the exact location of the plasma 210, relative to the first focal point of the collector optic CO. To fix this location accurately enough to maintain sufficient alignment generally requires active monitoring and control.

[0053] For this purpose, source control module (controller) 242 in this example controls the location of the plasma 210 (the source of the EUV radiation), by controlling the injection of the fuel and/or, for example, the timing of energizing pulses from laser. In a typical example, energizing pulses of laser radiation 224 are delivered at a rate of 50 kHz (period 20 μ s), and in bursts lasting anything from, say, 20 ms to 20 seconds. The duration of each main laser pulse may be around 1 μ s, while the resulting EUV radiation pulse may last around 2 μ s. By appropriate control, it is maintained

that the EUV radiation beam is focused by collector CO precisely on the aperture 221. If this is not achieved, all or part of the beam will impinge upon surrounding material of the enclosing structure.

[0054] The source control module 242 is supplied with monitoring data from one or more arrays of sensors (not shown) which provide a first feedback path for information as to the location of the plasma. The sensors may be of various types, for example as described in Unites States Patent Application Publication No. 2005/0274897A1, mentioned above. The sensors may be located at more than one position along the radiation beam path. They may, for example, be located around and/or behind the field mirror device 22. The sensor signals just described can be used for control of the optical systems of the illuminator IL and projection system PS. They can also be used, via feedback path, to assist the control module 242 of the source collector module SO to adjust the intensity and position of the EUV plasma source 210. The sensor signals can be processed for example to determine the observed location of the virtual source IF, and this is extrapolated to determine, indirectly, the position of the EUV plasma source. If the virtual source location drifts, as indicated by the sensor signals, corrections are applied by control module 242 to re-center the beam in the aperture 221.

[0055] Rather than rely entirely on the signals from the illuminator sensors, additional sensors and feedback paths may generally be provided in the source collector module SO itself, to provide for more rapid, direct and/or self-contained control of the radiation source. Such sensors may include one or more cameras, for example, monitoring the location of the plasma. In this way the location beam 20 is maintained in the aperture 221, and damage to the equipment is avoided, and efficient use of the radiation is maintained.

[0056] In order to ensure that the substrate W is provided with the appropriate dosage of radiation, it is important to ensure that the illumination across the illumination slit has an overall intensity as desired, in addition to having a desired uniformity across the illumination slit. In order to realize this, in accordance with the present invention, the EUV source further comprises a sensing system 270 preferably comprising a plurality of sensors 270.1, 270.2 that are arranged in the source enclosure 220. In accordance with the present invention, the plurality of sensors as applied is sensitive to EUV radiation. Examples of such sensors are EUV photodiodes.

[0057] In accordance with the present invention, the sensors 270.1, 270.2 of the sensing system 270 are arranged in such manner that, based on measurement signals of the sensors, a direction of the EUV radiation beam as generated may be determined.

[0058] It has been observed by the inventors that the direction of the EUV radiation beam as generated by the EUV source may deviate from the desired direction, i.e., along the optical axis O as shown in Figure 2. In particular, it has been observed that such a deviation or tilt may be caused by a misalignment of the laser pulse, either the pre-pulse or the main pulse, with the fuel target. Figure 3 illustrates schematically the process of generating the EUV-emitting plasma, and a resulting EUV radiation beam 20, in case of an accurate alignment of the laser pulses and the fuel target. In Figure 3,

the X, Y and Z axis as applied in the EUV source are defined, whereby the Z-axis corresponds to the optical axis O of the EUV collector module SO. By convention, the X axis is aligned with the stream of fuel droplets, with the droplets travelling in the positive X direction, as shown. The Y-axis is perpendicular to the X-axis and the Z-axis. The origin where the X-, Y- and Z-axes intersect is located at the focal point FP of collector CO. As known, this origin is the ideal location for the plasma. As schematically shown in Figure 3, in order to generate the plasma at the desired location, laser pulses are fired as follows. The stream of fuel droplets arrives at the origin along the X axis, from the negative X direction. A droplet is at the location where it will be impinged by the pre-pulse of laser radiation. The energy of this pre-pulse is sufficient to vaporize the fuel contained in the droplet, so that it forms a cloud of fuel material which continues to travel towards the origin FP. In Figure 3, the cloud of fuel material arrives perfectly centred at the origin FP, where it is impinged by the main laser radiation pulse and forms the plasma emitting the EUV radiation beam. In Figure 3, the lines may e.g. indicate the contours of the radiation beam that will end up at the faceted field mirror device. Reference number represents the cross section of the EUV radiation beam, at some distance from collector CO. The location may be in a plane in front of or behind the virtual source point IF, and it is assumed here for the sake of clarity that it is located in the illumination module (behind IF), for example in the plane of the faceted field mirror device. The beam may be inverted, magnified, etc., according to the geometry of the optical system, and according to the location of the plane in which cross section is located. In relation to the cross section, curve represents an intensity profile of the EUV radiation across the beam.

[0059] Figure 4 schematically shows the generation of an EUV radiation beam, in case of misalignment of a pre-pulse laser beam with a fuel target. In Figure 4, corresponding reference numbers refer to corresponding features as shown in Figure 3. Compared to the EUV generation process depicted in Figure 3, the pre-pulse laser beam in Figure 4 is assumed to be misaligned with the target droplet, causing the cloud of fuel material to be somewhat tilted. In the arrangement as shown, the cloud of fuel material can be considered to be tilted about the Y-axis that is perpendicular to the XZ-plane of the drawing. When such a tilted cloud of fuel material is subsequently hit by the main laser radiation pulse, it forms the plasma emitting the EUV radiation beam. Due to the tilt of the cloud of fuel material, the plasma may emit the EUV radiation beam in a direction that deviates from the desired direction, i.e. deviates from the direction of the optical axis O (or: the Z-direction). Note that the dotted lines indicate the position of the EUV radiation beam in the nominal or desired situation, i.e. the situation as depicted in Figure 3. Due to the tilt of the cloud of fuel material, the resulting EUV radiation beam may be considered to be tilted as well, e.g. about an axis parallel to the Y-axis and through the intermediate focal point IF, as indicated by the arrow. It may further be noted that the intensity distribution of the generated EUV radiation beam, e.g. across a cross-section, may still be substantially

uniform. However, due to the deviating direction of the generated beam 20, the intensity distribution as received by the faceted field mirror device 22 may no longer be uniform or as expected.

[0060] As illustrated in Figure 4, a mismatch between a pre-pulse 304 and a target droplet may cause a tilt of the generated EUV radiation beam 20. As a result, the intensity distribution as received by the various optical components downstream of the EUV radiation source may change. Within the meaning of the present invention, the intensity distribution as perceived downstream of the EUV radiation source, e.g. by the optical elements of the illuminator or the patterning device or the projection optics, may be referred to as the far-field intensity distribution. As will be clear to the skilled person, this far-field intensity distribution will displace due to a tilt of the EUV radiation beam 20. As a result, the far-field intensity distribution as received, e.g. by the field mirror device 22 may have a different intensity and/or distribution compared to the nominal situation.

[0061] In accordance with the present invention, measures are taken to detect that the actual direction of the EUV radiation beam 20 deviates from the desired or nominal direction. In particular, the sensing system 270 as applied in the EUV source is configured to generate measurement signals indicative of a tilt of the EUV radiation beam 20.

[0062] In this respect, it can be pointed out that, depending on the orientation of the mismatch between the pre-pulse and the target droplet, the cloud of fuel material 310 may be tilted about the X-axis, or the Y-axis or a combination thereof.

[0063] Figures 5(a) to 5(d) schematically depict different cross-section views of a source collector module SO of an EUV radiation source, which can be applied in a lithographic system according to the present invention, indicating possible arrangements of the sensing system 270. Figure 5 (a) schematically shows an XZ-view of the EUV radiation source module SO, Figure 5 (b) schematically shows a YZ-view of the EUV radiation source module SO and Figure 5 (c) schematically shows an XY-view of the EUV radiation source module SO. In the Figures 5 (a) to 5 (c), CO denotes the collector, 220 denotes the enclosure of the radiation source module SO, 226 denotes a droplet generator, e.g. generating a stream of tin droplets 228, and 230 denotes a trap to capture any fuel that is not transformed into plasma.

[0064] In Figure 5 (a), three EUV radiation beams 20.1, 20.2 and 20.3 are schematically shown, beam 20.1 having a nominal or expected direction relative to the optical axis (Z-axis), beams 20.2 and 20.3 being tilted about the Y-axis. In Figure 5 (b), three EUV radiation beams 20.1, 20.4 and 20.5 are schematically shown, beam 20.1 having a nominal or expected direction relative to the optical axis (Z-axis), beams 20.4 and 20.5 being tilted about the X-axis. Note that a tilt of the beam about the X-axis results in a displacement in the Y-direction of the location where the beam intersects with a virtual plane perpendicular to the Z-axis. Similarly, a tilt of the beam about the Y-axis results in a displacement in the X-direction of the location where the beam intersects with a virtual plane perpendicular to the Z-axis.

[0065] In the embodiment of the EUV radiation source SO as shown in Figures 5 (a)-(c), the sensing system comprises four EUV sensors 270.1, 270.2, 270.3 and 270.4. In the embodiment as shown, sensors 270.1 and 270.2 are arranged on opposite sides of the YZ-plane. By such an arrangement, a tilt of the EUV radiation beam about the Y-axis, such a tilt e.g. being illustrated by the radiation beams 20.2, 20.3 as shown in Figure 5 (a), may be detected since, due to the tilt, the sensors 270.1 and 270.2 will observe a different amount of EUV radiation. Further, as shown in Figures 5 (b) and 5 (c), sensors 270.3 and 270.4 are arranged on opposite sides of the XZ-plane. By such an arrangement, a tilt of the EUV radiation beam about the X-axis, such a tilt e.g. being illustrated by the radiation beams 20.4, 20.5 as shown in Figure 5 (b) may be detected in a similar manner. In accordance with the present invention, a combination of two sensor signals that enables to determine a tilt of the EUV radiation beam is referred to as a bi-sensor signal. In an embodiment, such a combination of two sensor signals may e.g. be the difference between the two sensor signals. In particular, the difference between the measurements of two sensors arranged on opposite sides of a plane may be considered indicative for a tilt of an EUV radiation beam out of said plane. As such, the difference between the signals of the sensors 270.1 and 270.2 may be referred to as the bisensorX signal, whereas the combination of the signals of the sensors 270.3 and 270.4 may be referred to as the bisensorY signal. As such, in the embodiment described, the sensing system may be configured to output a first sensing signal representative of a tilt about a first axis and a second sensing signal representative of a tilt about a second axis. In such embodiment, the first axis, e.g. the Y-axis as shown in Figures 3-5, may be selected such that a tilt about said axis has a corresponding displacement of the far-field intensity distribution along a scanning direction, e.g. indicated by reference number 268 in Figure 2, while the second axis, e.g. the X-axis as shown in Figures 3-5, may be selected such that a tilt about said axis has a corresponding displacement of the far-field intensity distribution along a non-scanning direction, e.g. indicated as the X-axis in Figure 2. In accordance with the present invention, the control system applied in the lithographic system is configured to determine a quantity representative of a far-field intensity distribution of the EUV radiation based on the sensing signal generated by the sensing system. As an example of such quantity, the position or displacement of the far-field intensity distribution may be mentioned. As will be apparent from Figures 3-5, the position or displacement, i.e. a deviation of the position relative to a nominal or expected position, of the far-field intensity distribution may also be characterized by the tilt of the EUV radiation beam. Based on the determined quantity, the control system is further configured to determine a control signal for control of at least one of the illuminating and the generating, based on the determined quantity representative of the far-field intensity distribution. In this respect, illuminating may refer to the illumination process as performed by the lithographic scanning apparatus, whereas generating may refer to the process of generating the EUV radiation or radiation beam, as performed by the EUV radiation source.

[0066] It may further be noted that a signal representative of a tilt about a particular axis, e.g. the X-axis or the Y-axis may also be derived from more than two sensor signals, when available.

[0067] Figure 5 (d) illustrates such an embodiment. Figure 5 (d) schematically shows view in the X-Y plane of a source collector module SO of an EUV radiation source including a sensing system 270 comprising four EUV sensors 270.1, 270.2, 270.3 and 270.4. Compared to the embodiment shown in Figure 5 (c), the position of the EUV sensors is different; compared to the arrangement of Figure 5 (c), one can consider the positions of the sensors, in the example shown, to be rotated about 45° counterclockwise relative to the embodiment of Figure 5 (c). More generally, the four EUV sensors 270.1, 270.2, 270.3 and 270.4 may occupy other angular positions in the X-Y plane and need not be positioned at equal angular distances from one another. As a result, one can now consider that sensor pair 270.3, 270.1 and sensor pair 270.2, 270.4 are arranged on opposite sides of the XZ-plane while sensor pair 270.3, 270.2 and sensor pair 270.1, 270.4 are arranged on opposite sides of the YZ-plane. As such, a difference between the intensities measured by the sensors 270.3, 270.1 and the sensors 270.2, 270.4 may be indicative for a tilt of the EUV radiation beam about the Y-axis whereas a difference between the intensities measured by the sensors 270.3, 270.2 and the sensors 270.1, 270.4 may be indicative for a tilt of the EUV radiation beam about the X-axis. As an example, the tilt about the Y-axis (Y_{tilt}) and the tilt about the X-axis (X_{tilt}) may be described as:

$$Y_{tilt} \sim S1 + S3 - S2 - S4;$$

(2)

$$X_{tilt} \sim S2 + S3 - S1 - S4.$$

wherein:

S1 = the measurement signal of sensor 270.1;

S2 = the measurement signal of sensor 270.2;

S3 = the measurement signal of sensor 270.3;

S4 = the measurement signal of sensor 270.4;

[0068] In such an embodiment, the sensor signals S1-S4 are all used in the calculations of both the X_{tilt} and the Y_{tilt} .

[0069] With respect to the arrangement as shown in Figure 5 (d), it may be pointed out that signals indicative of the X-tilt and of the Y-tilt could also be obtained with only three sensors. Assuming that sensor 270.4 would be omitted, one could describe the tilt about the Y-axis (Y_{tilt}) and the tilt about the X-axis (X_{tilt}) by:

$$Y_{tilt} \sim S3 - S2$$

(3)

$$X_{\text{tilt}} \sim S3 - S1.$$

[0070] In such arrangement, sensors 270.3 and 270.2 form a pair of sensors to determine Y_{tilt} ,
5 whereas sensors 270.3 and 270.1 form a pair of sensors to determine X_{tilt} .

[0071] As a result of the tilt of the EUV radiation beam, it has been observed that the intensity
distribution across the illumination slit, i.e. the intensity distribution as applied to the patterning
device MA during scanning, may deviate from the desired distribution. In particular, it has been
observed that a tilt of the EUV radiation beam in the direction of the X-axis may result in a non-
10 uniformity along the illumination slit in the non-scanning direction, i.e. the X-direction as indicated in
Figure 2 near the patterning device MA, whereas a tilt of the EUV radiation beam in the Y-direction
may cause an error in the assessment of the intensity of the radiation beam.

[0072] With respect to the latter, it can be pointed out that, in known apparatuses, an energy
sensor is applied to determine the intensity of the EUV radiation that is applied onto the patterning
15 device or mask MA. In the embodiment shown in Figure 2, reference number 264 is used to indicate
such an energy sensor. Such an energy sensor 264 may e.g. be incorporated in the conditioning and
masking module 262 and may be arranged somewhere along a boundary of the illumination slit or
aperture through which the conditioned EUV radiation beam protrudes. The shape of the illumination
slit or aperture may be realized by means of a plurality of blades (REMA) as indicated above.

[0073] Figure 6 schematically shows the contour of an illumination slit 600 as may be applied in
a lithographic scanning apparatus according to the present invention. Figure 6 further shows an energy
sensor 610 arranged along a boundary 600 of the illumination slit 600. The sensor 610 may e.g. be
mounted in front of the illumination slit 600, in order to capture EUV radiation from the EUV
radiation beam that has been conditioned by the illuminator IL. As will be appreciated by the skilled
25 person, the conditioning of the EUV radiation beam as generated by the EUV radiation source, e.g.
beam 20 as schematically shown in Figure 2, should be such that across the illumination slit 600, the
illumination should be as uniform as possible. Outside the slit however, as will be understood, the
intensity will gradually decrease, both in the X-direction and in the Y-direction. As such, the intensity
as measured at the location of the energy sensor 610 will in general be somewhat lower than the actual
30 intensity in the slit.

[0074] In order to determine the correlation between the intensity as measured by the sensor 610
and the actual intensity inside the slit, one would need to know the actual intensity in the illumination
slit. It may be cumbersome to measure this intensity.

[0075] However, it may be more feasible to determine a correlation between the intensity
35 measurement as performed by the sensor 610 located at a boundary of the illumination slit and an
energy sensor located on the substrate table, i.e. an energy sensor receiving the conditioned EUV

radiation beam after having passed through the projection system PS. Such a correlation may e.g. be determined by means of a calibration test. In case one could determine a one-to-one relationship between the intensity as measured by the sensor 610 provided at the boundary of the illumination slit and an intensity as measured by a sensor provided on the substrate table, this would provide useful data to control the lithographic system in order to apply the appropriate dose of EUV illumination on the substrate.

[0076] It has been observed by the inventors that this one-to-one relationship is not constant; in particular, it has been observed that the ratio of intensity as measured at substrate level to the intensity as measured by the sensor arranged near the illumination slit varies depending on the direction of the EUV radiation beam, or more specifically, on the position of the far-field intensity distribution as perceived by the sensor 610 arranged near the illumination slit.

[0077] In this respect, it should be pointed out that one could assume there to be a fixed correlation or relationship between the measured intensity by the sensor at or near the boundary of the illumination slit and the actual intensity in the illumination slit, provided that the EUV radiation beam has propagated along the optical axis O. However, as will be understood by the skilled person, in case the EUV radiation beam gets somewhat tilted, the correlation between the measured intensity and the intensity across the slit may be different or may vary. As a result, the correlation between the measured intensity and the intensity at the substrate table level would be different as well. In particular, in case the EUV radiation beam as generated by the EUV radiation source got tilted about the Y-axis, the Y-axis as defined in Figures 3-5, this would result in a shift of the far-field intensity distribution along the Y-axis shown in Figure 6. Note that the Y-axis of the reference system of the EUV source SO is shown as being parallel to the X-axis at the masking stage MT in Figure 2. This could e.g. result in a situation whereby, in case of an upward displacement of the far-field intensity distribution, the intensity as sensed by the sensor 610 would be higher, whereas the intensity across the slit would actually become lower. Note that, as a consequence, the intensity as perceived by a sensor at the substrate table level would be lower as well.

[0078] In a similar manner, a tilt of the EUV radiation beam about the X-axis of the EUV source SO as shown in Figures 3-5, will affect the intensity distribution of the EUV radiation in the illumination slit (along the X-direction at the mask stage MT), and thus the intensity distribution of the EUV radiation at the substrate table level. In order to avoid or mitigate this effect, it is proposed, in an embodiment of the present invention, to take account of a detected tilt of the EUV radiation beam, whereby the detection of the tilt is based on measurements performed by the sensing system that is provided within the EUV radiation source, e.g. in the source collector module SO shown in Figure 2.

[0079] In an embodiment, a linear model is used to correlate an intensity I_{slit_sensor} as measured by a sensor near the illumination slit to an intensity $I_{substrate_sensor}$ measured by a sensor arranged on the substrate table:

$$5 \quad \frac{I_{substrate_sensor}}{I_{slit_sensor}} = C \cdot (1 + c_x \cdot bisensorX + c_y \cdot bisensorY) \quad (4)$$

wherein:

C = the ratio of the measured intensities in case there is no tilt of the EUV radiation beam;

$bisensorX$ = the differential signal of two sensors arranged to detect a tilt in the X-direction as a result of the beam of EUV radiation having rotated about the Y-axis of the EUV radiation source;

10 $bisensorY$ = the differential signal of two sensors arranged to detect a tilt in the Y-direction as a result of the beam of EUV radiation having rotated about the X-axis of the EUV radiation source; and
 c_x and c_y are weight coefficients.

[0080] In an embodiment, the ratio C and the weight coefficients c_x and c_y may be determined by fitting measurements of the intensities I_{slit_sensor} , $I_{substrate_sensor}$ and the tilts, represented by the signals $bisensorX$ and $bisensorY$, to equation (4). Note that the values of the weight coefficients c_x and c_y may also depend on the illumination mode selected. Moreover, a spatially non-uniform degradation of the collector mirror CO may also affect these values. Accordingly, it may be preferred to calibrate the weight coefficients c_x and c_y periodically and per illumination mode.

[0081] Once the coefficients C , c_x and c_y are determined, the intensity at substrate level
 20 $I_{substrate}$ during an exposure process of the substrate may be calculated based on the intensity I_{slit} measured by the sensor 610 near the illumination slit using:

$$I_{substrate} = I_{slit} \cdot C \cdot (1 + c_x \cdot bisensorX + c_y \cdot bisensorY) \quad (5)$$

25 **[0082]** Based on this calculated intensity as received by the substrate during the exposure process, operational parameters of both the EUV radiation source and of the lithographic scanning apparatus may be controlled to ensure that the proper illumination dose is applied to the substrate.

[0083] Upon review of equation (5), one may consider that the intensity $I_{substrate}$ during expose is in fact calculated using a corrected or adjusted value for the measured intensity I_{slit} , the
 30 corrected or adjusted value $I_{slit_corrected}$ being expressed by:

$$I_{slit_corrected} = I_{slit} \cdot (1 + c_x \cdot bisensorX + c_y \cdot bisensorY) \quad (6)$$

The intensity $I_{substrate}$ thus being expressed by:

$$I_substrate = I_slit_corrected \cdot C \quad (7)$$

[0084] In an embodiment of the present invention, the one or more sensing signals as received from the sensing system of the EUV radiation source may thus be applied to correct a measured intensity value measured by a sensor arranged along a boundary of the illumination slit. Using this corrected measurement value, a more accurate prediction of the intensity of the radiation as received by the substrate during the exposure process can be realized. As a result, the illumination dose as received by the substrate can be more accurately controlled.

[0085] In an embodiment of the present invention, a sensing signal as received from the sensing system of the EUV radiation source is used to adjust an element or component of the conditioning and masking module 262. In particular, in an embodiment of the present invention, the control system 280 of the lithographic system according to the present invention is configured to control the uniformity correction module (UNICOM) of the conditioning and masking module 262, based on the sensing signal 272 as received from the sensing system 270, see Figure 2. Such a uniformity correction module may e.g. comprises a plurality of blades or vanes that can be partially inserted in the EUV radiation beam, thereby 'trimming' the radiation beam, so as to improve the uniformity.

[0086] According to an aspect of the present invention, there is provided an EUV radiation source for use in the lithographic system according to the present invention, the EUV radiation source comprising the control system and wherein control system is configured to output the control signal to an interface configured for interfacing with the lithographic scanning apparatus. In such an embodiment, the control system may be incorporated in the control unit 242 of the EUV radiation source as schematically shown in Figure 2. Alternatively, the control system may be separate from the control unit 242 as shown. The control system of the EUV radiation source according to the present invention may be configured to determine a control signal for control of the lithographic scanning apparatus and output this control signal to an interface for interfacing with the lithographic scanning apparatus. In an embodiment, the lithographic scanning apparatus may e.g. use the control signal to control the illuminating process as performed. Such control may e.g. include adjusting of a uniformity correction module or a correction of an energy sensor value or an adjustment of the scanning process performed by the lithographic scanning apparatus.

[0087] According to yet another aspect of the present invention, there is provided control system configured for use in the lithographic system according to the present invention, the control system having a first interface configured for receiving the sensing signal and a second interface for providing the control signal.

[0088] According to yet another aspect of the present invention, there is provided a lithographic scanning apparatus configured for use in the lithographic system according to the present invention, comprising the control system. In an embodiment, such a lithographic scanning apparatus may e.g. be

configured to interface with an interface configured to interface with the EUV radiation source, thus enabling the control system to receive the sensing signal from the interface and enabling the control system to determine the control signal.

[0089] While specific embodiments of the invention have been described above, it will be

5 appreciated that the invention may be practiced otherwise than as described. The behavior of the apparatus may be defined in large part by a computer program containing one or more sequences of machine-readable instructions for implementing certain steps of 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. The descriptions above are intended to be illustrative, not limiting. Thus it
10 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.

WHAT IS CLAIMED IS:

1. A lithographic system comprising:
an EUV radiation source, configured for generating EUV radiation;
5 a lithographic scanning apparatus configured for receiving the EUV radiation and for illuminating a pattern using the EUV radiation to image the pattern onto a substrate; and
a control system,
wherein:
the EUV radiation source comprises a sensing system configured to provide a sensing signal
10 representative of a spatial intensity distribution of the EUV radiation;
the control system is operative to determine a quantity representative of a far-field intensity distribution of the EUV radiation based on the sensing signal and to determine a control signal for control of at least one of the illuminating and the generating, based on the determined quantity.
- 15 2. The lithographic system according to claim 1, wherein the EUV radiation source comprises a source collector module configured for generating an EUV radiation beam along an optical axis and wherein the control system is operative to determine a displacement of the far-field intensity distribution of the EUV radiation beam and determine the control signal based on the displacement.
- 20 3. The lithographic system according to claim 1, wherein the EUV radiation source comprises a source collector module configured for generating an EUV radiation beam along an optical axis and wherein the control system is operative to determine a direction of the EUV radiation beam and determine the control signal based on the direction of the EUV radiation beam.
- 25 4. The lithographic system according to claim 2 or 3, wherein the control system is operative to determine a tilt of the EUV radiation beam about an axis substantially perpendicular to the optical axis.
5. The lithographic system according to claim 2, 3 or 3, wherein the sensing system is
30 configured to provide a first sensing signal representative of a tilt of the EUV radiation beam about a first axis substantially perpendicular to the optical axis and a second sensing signal representative of a tilt about a second axis substantially perpendicular to both the optical axis and the first axis.
6. The lithographic system according to claim 5, wherein the tilt about the first axis results in a
35 displacement of the far-field intensity distribution along a scanning direction of the lithographic scanning apparatus and wherein the tilt about the second axis results in a displacement of the far-field intensity distribution along a non-scanning direction of the lithographic scanning apparatus.

7. The lithographic system according to claim 5 or 6, wherein the sensing system comprises a first pair of sensors for generating the first sensing signal, a first sensor of the first pair of sensors and a second sensor of the first pair of sensors being arranged on opposite sides of a first plane, the first
5 plane containing the optical axis and being parallel to the first axis, and wherein the sensing system comprises a second pair of sensors for generating the second sensing signal, a first sensor of the second pair of sensors and a second sensor of the second pair of sensors being arranged on opposite sides of a second plane, the second plane containing the optical axis and being parallel to the second axis.

10 8. The lithographic system according to any of the preceding claims, wherein the lithographic scanning apparatus comprises an energy sensor configured to measure an intensity of the EUV radiation adjacent an illumination slit of the lithographic scanning apparatus, and wherein the control system is configured to:

- 15 - receive an energy sensor signal representative of the measured intensity from the energy sensor, and
- determine a value for the intensity of the EUV radiation in the illumination slit, based on the energy sensor signal and the sensing signal.

20 9. The lithographic system according to any of the preceding claims, wherein the lithographic scanning apparatus further comprises a uniformity correction module configured for adjusting an intensity distribution of the EUV radiation and wherein the control signal is configured to control the uniformity correction module.

25 10. The lithographic system according to any of the preceding claims, wherein the sensing system comprises a plurality of sensors such as EUV photodiodes.

11. The lithographic system according to claim 10, wherein the EUV radiation source comprises a vessel, the plurality of sensors being mounted to the vessel.

30 12. The lithographic system according to claim 10 or 11, wherein the EUV sensors are mounted in a plane substantially perpendicular to the optical axis of the EUV source.

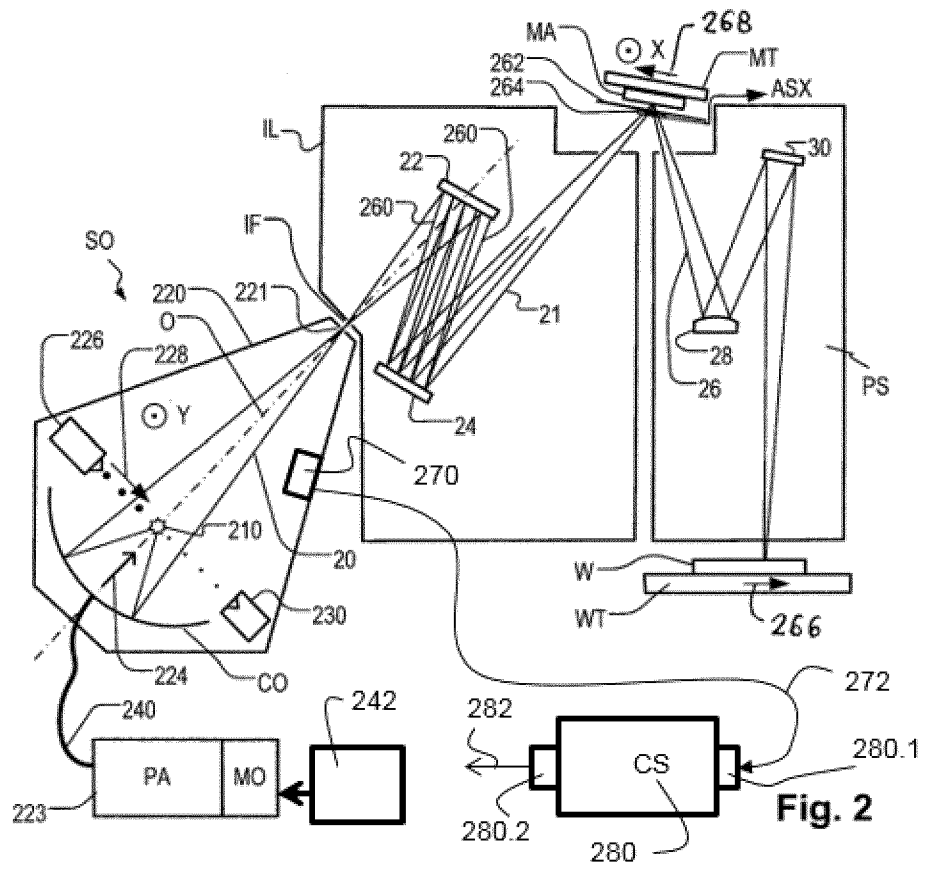
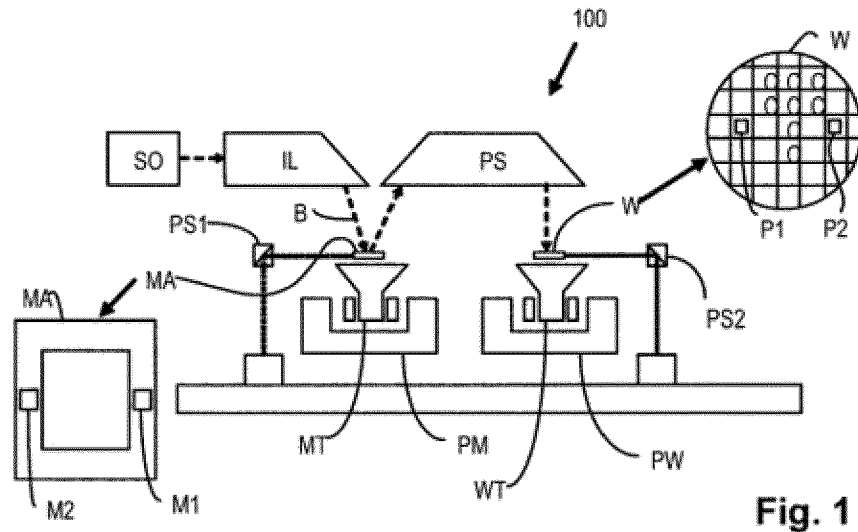
13. An EUV radiation source for use in a lithographic system according to any of the preceding
35 claims, the EUV radiation source comprising the control system and wherein control system is configured to output the control signal to an interface configured for interfacing with the lithographic scanning apparatus.

14. A control system configured for use in the lithographic system of claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12, having a first interface configured for receiving the sensing signal and a second interface for providing the control signal.

5

15. A lithographic scanning apparatus configured for use in the lithographic system of claim 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12, comprising the control system.

16. The lithographic scanning apparatus according to claim 15, wherein the control system is
10 configured to receive the sensing signal from an interface configured for interfacing with the EUV radiation source.



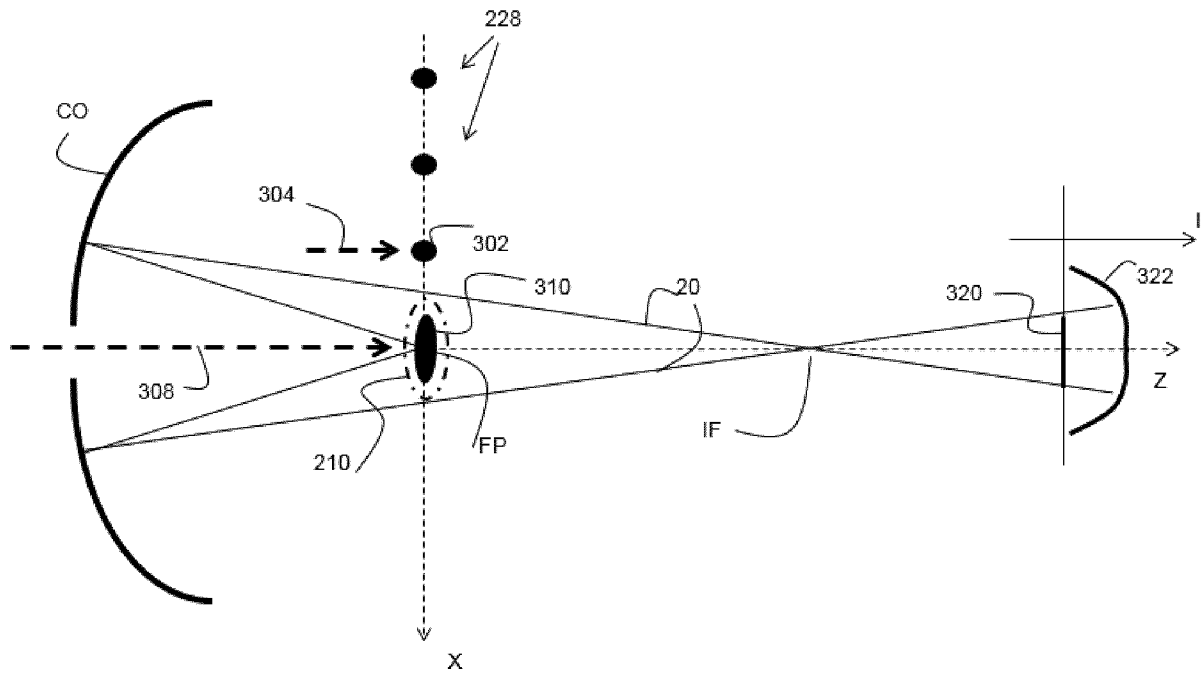


Figure 3

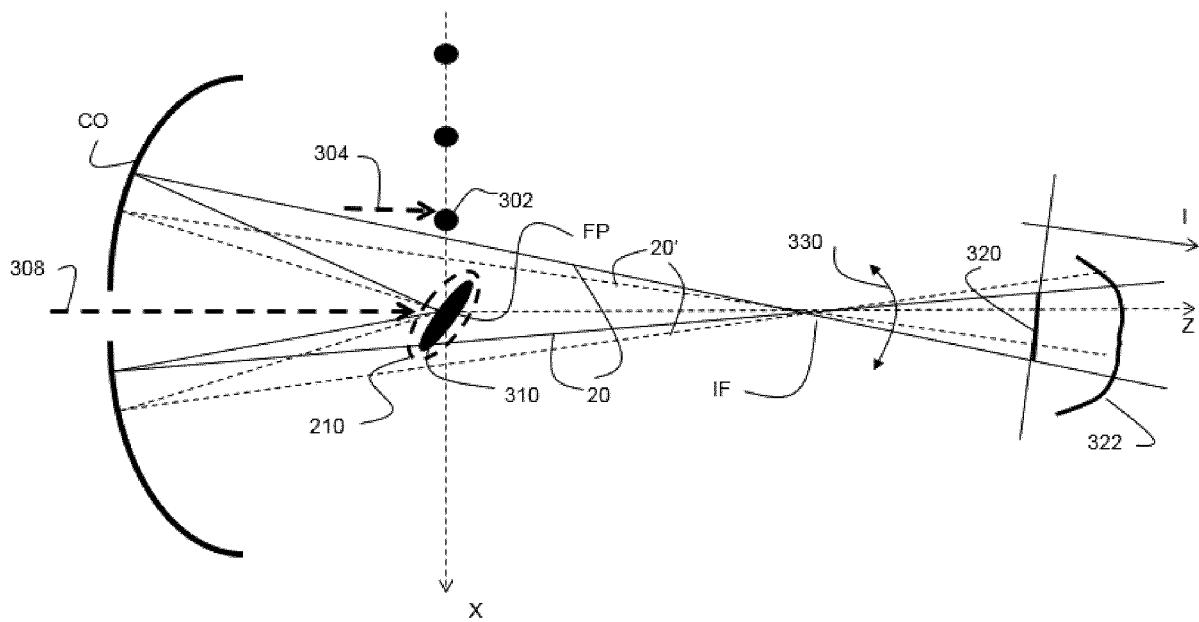


Figure 4

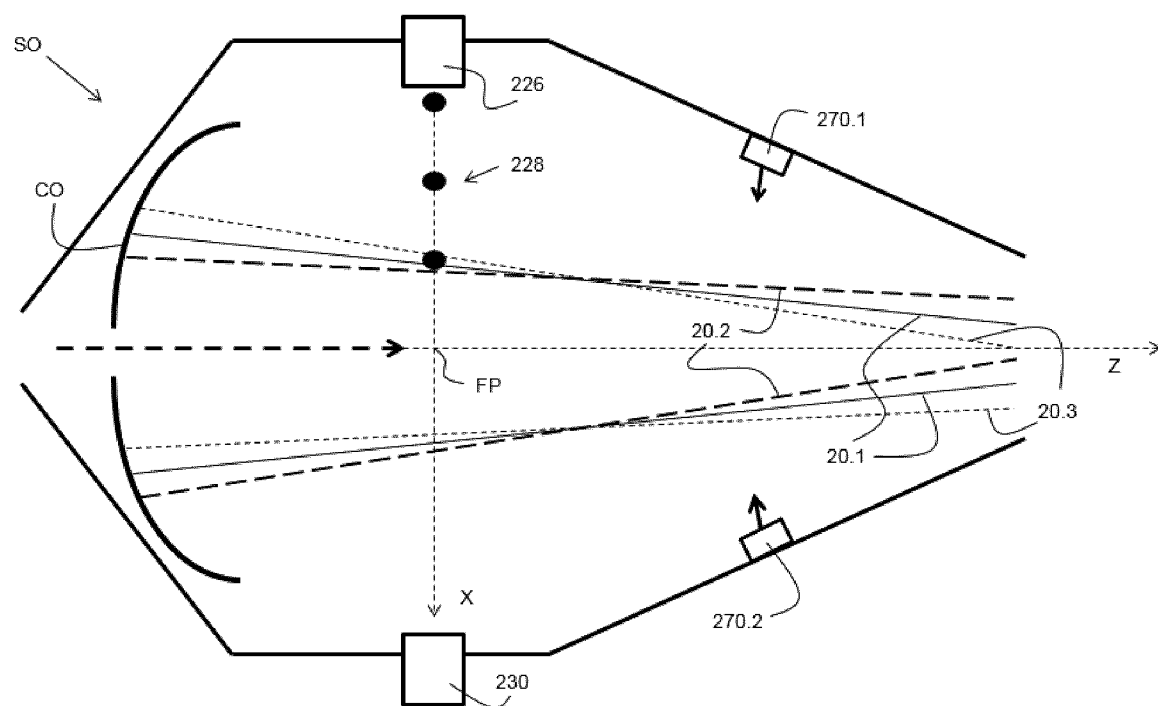


Figure 5 (a)

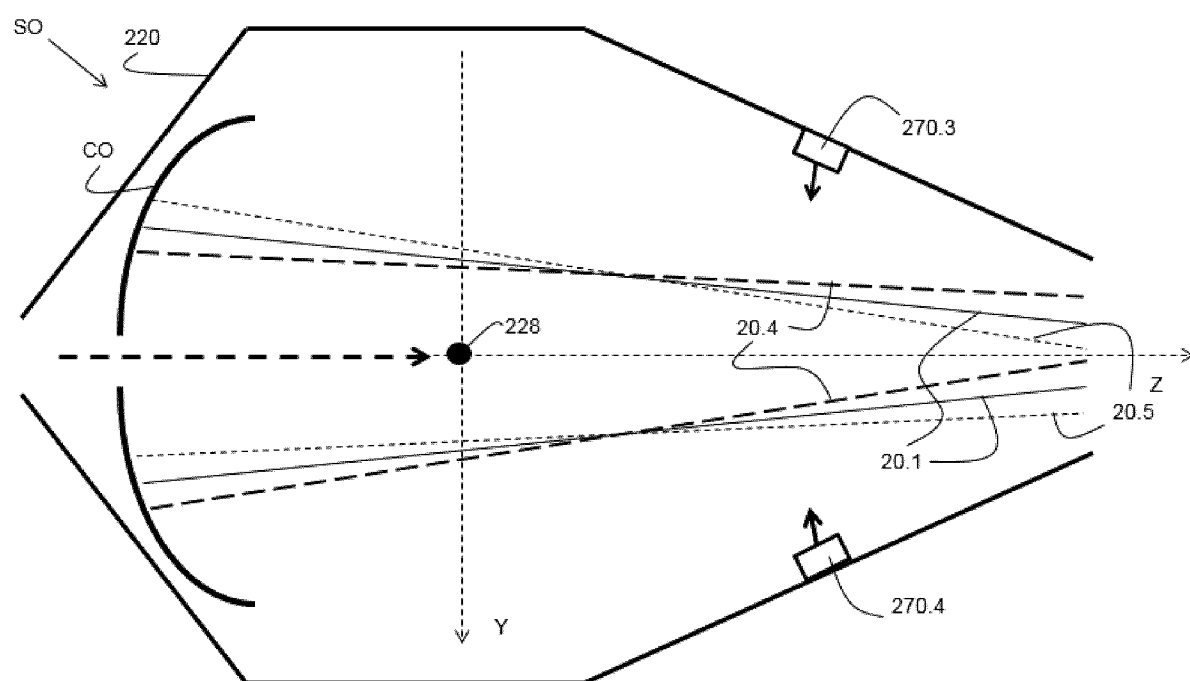


Figure 5 (b)

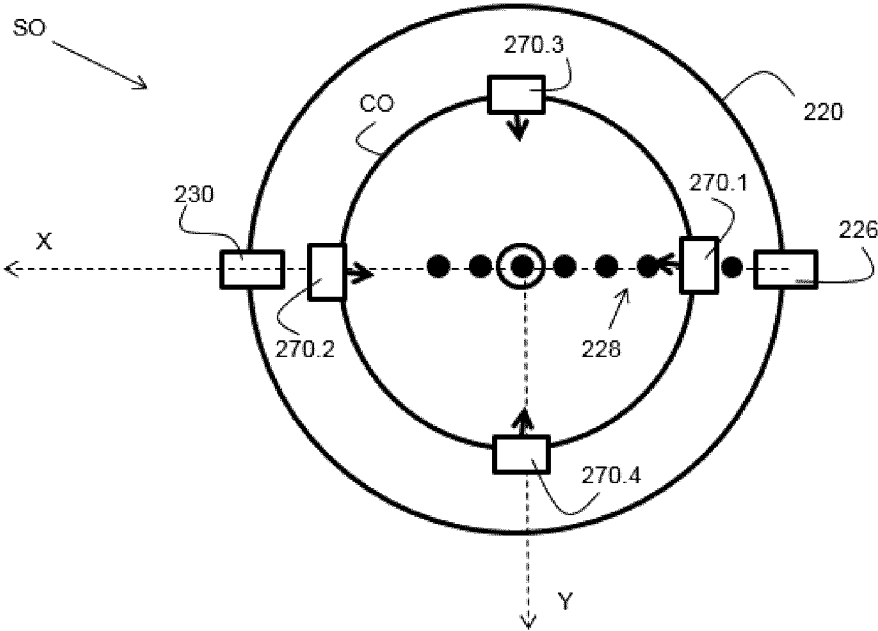


Figure 5 (c)

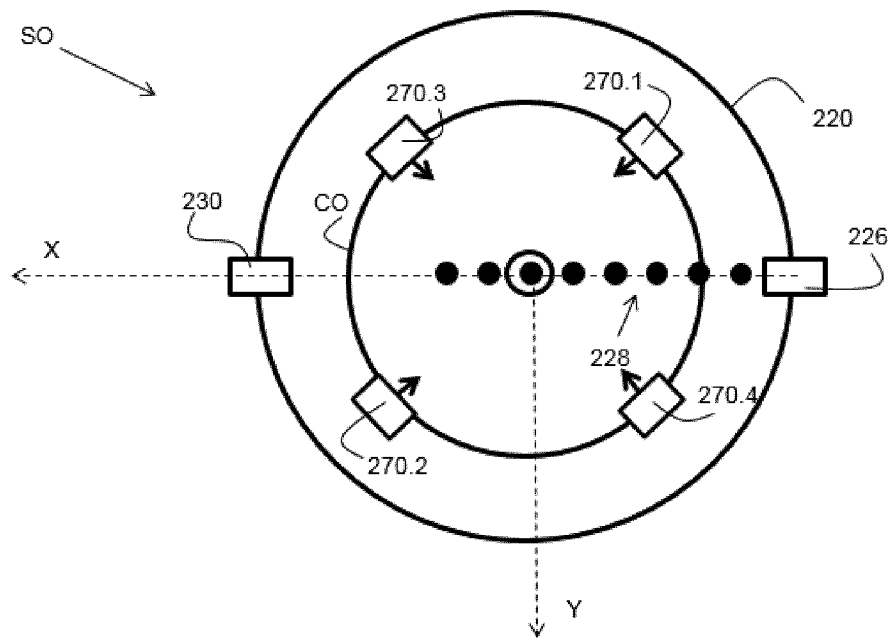


Figure 5 (d)

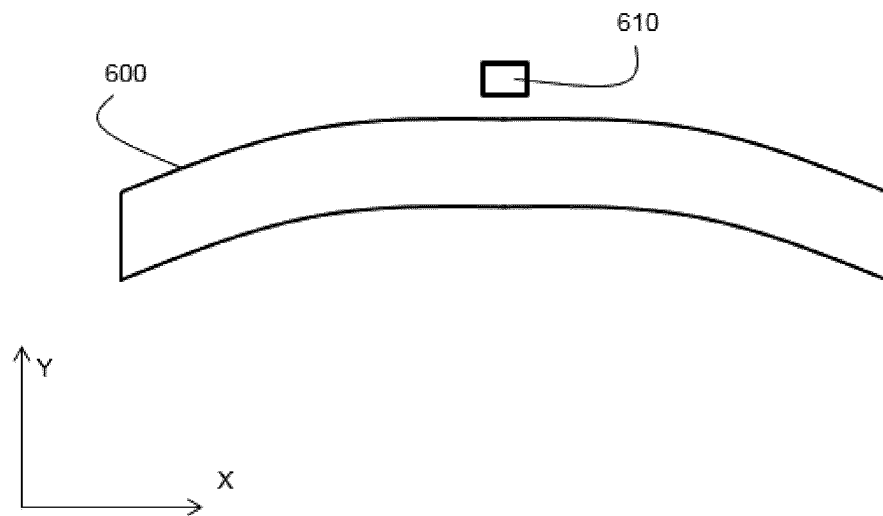


Figure 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/054326

A. CLASSIFICATION OF SUBJECT MATTER

INV. G03F7/20 H05G2/00 G01J1/42
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 H05G G01J

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2012/248327 A1 (BOLSHUKHIN DENIS [DE] ET AL) 4 October 2012 (2012-10-04) abstract figure 1 paragraphs [0002], [0045], [0047], [0051], [0052], [0063], [0089] - [0098] -----	1-8,10, 13-16 9,11,12
X A	US 2010/123086 A1 (YAMATANI DAIKI [JP]) 20 May 2010 (2010-05-20) abstract figure 1 paragraphs [0002], [0049], [0065], [0078] - [0080] ----- -/--	1,8-16 2-7



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

29 May 2018

Date of mailing of the international search report

13/06/2018

Name and mailing address of the ISA/

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Authorized officer

Andersen, Ole

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2018/054326

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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