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(54) Optical System

(57) An optical system arranged to receive a radiation beam. The optical system comprising a reflective element comprising a plurality of reflective regions, wherein different reflective regions are configured to reflect incident radiation in different directions, and wherein the reflective regions are configured such that at a given position of the reflective element the radiation beam is only incident on a subset of the reflective regions and an actuator configured to move the reflective element, relative to the radiation beam, thereby changing the one or more reflective regions on which the radiation beam is incident.

Optical System

FIELD

[0001] The present invention relates to an optical system. In particular, but not exclusively, the optical system may form part of a lithographic system comprising at least one lithographic apparatus.

BACKGROUND

[0002] A lithographic apparatus is a machine constructed to apply a desired pattern onto a substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). A lithographic apparatus may, for example, project a pattern from a patterning device (e.g. a mask) onto a layer of radiation-sensitive material (resist) provided on a substrate.

[0003] The wavelength of radiation used by a lithographic apparatus to project a pattern onto a substrate determines the minimum size of features which can be formed on that substrate. A lithographic apparatus which uses EUV radiation, being electromagnetic radiation having a wavelength within the range 4-20 nm, may be used to form smaller features on a substrate than a conventional lithographic apparatus (which may for example use electromagnetic radiation with a wavelength of 193 nm).

[0004] A lithographic system may include an optical system configured to direct and alter a radiation beam. It is an object of the present invention to obviate or mitigate at least one problem of prior art techniques.

SUMMARY

[0005] According to a first aspect of the invention there is provided an optical system arranged to receive a radiation beam, the optical system comprising a reflective element comprising a plurality of reflective regions, wherein different reflective regions are configured to reflect incident radiation in different directions, and wherein the reflective regions are configured such that at a given position of the reflective element the radiation beam is only incident on a subset of the reflective regions and an actuator configured to move the reflective element, relative to the radiation beam, thereby changing the one or more reflective regions on which the radiation beam is incident.

[0006] Since different reflective regions reflect radiation in different directions, movement of the reflective element, which changes the reflective regions on which radiation is incident, serves to change the directions in which the radiation is reflected. Changing the directions in which radiation is reflected introduces a time variation in the radiation beam which is similar to the effect of increasing the etendue of the radiation beam. The time variation which is introduced in the radiation beam may be particularly advantageous in embodiments in which the radiation beam is provided to a lithographic apparatus.

[0007] An optical system comprising a reflective element and an actuator as specified above may be referred to as a deflecting device.

[0008] The reflective element may include some reflective regions which, when they are in a position to receive radiation, are configured to reflect the radiation in substantially the same direction. However, the reflective element includes a plurality of reflective regions which each reflect radiation in different directions.

[0009] The different directions in which radiation is reflected by the reflective regions may cover an angular range of less than about 1 degree. For example, the angular range may be about 0.5 degrees or less.

[0010] The subset of reflective regions on which the radiation beam is incident may be a single reflective region or may be a plurality of reflective regions. The subset does not include all of the reflective regions. That is, at a given position of the reflective element the radiation beam is not incident on all of the reflective regions.

[0011] The optical system may further comprise an optical element arranged to receive radiation reflected from the reflective element, wherein all of the reflective regions are configured to reflect radiation in a direction which causes it to be received by the optical element.

[0012] The reflective element may be configured such that movement of the reflective element to illuminate different reflective regions causes different portions of the optical element to be illuminated with reflected radiation at different times.

[0013] The different portions of the optical element which are illuminated at different times, may be spread over two perpendicular directions across the optical element.

[0014] The optical system may further comprise one or more focussing elements configured to focus radiation which is reflected from the one or more reflective regions to one or more focal regions which lie in a focal plane.

[0015] The reflective element and the one or more focussing elements may be configured such that movement of the reflective element to change the one or more reflective regions on which the radiation beam is incident, changes the one or more focal regions to which radiation is focussed.

[0016] The one or more focusing elements may be configured to form an image of the radiation beam which is incident on the reflective element substantially in an image plane.

[0017] The one or more focusing elements may be configured such that movement of the reflective element does not substantially change the spatial extent of the radiation in the image plane.

[0018] The reflective element and the actuator may be configured such that the different directions in which radiation is reflected, follows a substantially periodic pattern having a time period which is less than approximately 1 millisecond.

[0019] The time period may be less than about 0.5 milliseconds. For example, the time period may be about 0.25 milliseconds or less.

[0020] The reflective regions may be configured such that at a given position of the reflective element the radiation beam is incident on a plurality of the reflective regions

[0021] Each reflective region may comprise a reflective facet.

[0022] Each reflective facet may be substantially flat.

[0023] Each reflective region may comprise a portion of a continuously undulating surface.

[0024] The actuator may be configured to rotate the reflective element about an axis of rotation.

[0025] The actuator may be configured to rotate the reflective element at a rotational frequency of greater than about 10 Hz. In some embodiments the actuator may be configured to rotate the reflective element at a rotational frequency of greater than about 50 Hz. For example, the rotational frequency may be about 100 Hz or more.

[0026] The reflective element may have an approximately cylindrical shape, the reflective regions being arranged around the circumferential extent of the cylindrical shape and wherein the actuator is configured to rotate the cylindrical shape about a central axis of the cylinder.

[0027] The reflective element may be configured such that the reflective regions fit approximately onto a portion of a paraboloid of revolution, and wherein the actuator is configured to rotate the reflective element about a central axis of the paraboloid.

[0028] The reflective element may be configured such that the reflective regions fit approximately onto a disk-like shape.

[0029] The optical system may further comprise a facetted mirror arranged to receive radiation reflected from the reflective element, the facetted mirror comprising a plurality of reflective facets each arranged to receive a portion of the radiation reflected from the reflective element and reflect the portion in a different direction.

[0030] The reflective facets may comprise curved reflective surfaces.

[0031] For example the reflective facets may comprise concave or convex shaped reflective surfaces. In some embodiments some of the reflective facets may comprise a concave reflective surfaces and some of the reflective facets may comprise convex reflective surfaces.

[0032] The optical system may further comprise one or more focusing elements configured to form an image of the reflective element substantially at the facetted mirror.

[0033] The one or more focusing elements are configured such that movement of the reflective element does not substantially change the spatial extent of the radiation which is incident on the facetted mirror but does change the angular extent of the radiation which is incident on the facetted mirror.

[0034] The optical system may further comprise one or more focusing elements configured to focus the radiation reflected from the reflective facets to a plurality of focal regions which lie in a focal plane, each focal region corresponding to radiation reflected from one or more different reflective facets.

[0035] The one or more focusing elements may be configured such that the focal regions are substantially evenly distributed in the focal plane.

[0036] The one or more focussing elements may be configured such that movement of the reflective element to change the one or more reflective regions on which the radiation beam is incident, results in movement of the plurality of focal regions around the focal plane.

[0037] The one or more focusing elements may be configured to form an image of the radiation beam which is incident on the reflective element in an image plane.

[0038] According to a second aspect of the invention there is provided a radiation system comprising a radiation source configured to emit a main radiation beam, an optical system according to the first aspect and a beam directing apparatus configured to direct at least a portion of the main radiation beam to be incident on a subset of the reflective regions of the reflective element.

[0039] The radiation system may further comprise a beam splitting apparatus configured to split the main radiation beam into a plurality of branch radiation beams, wherein the beam directing apparatus is configured to direct one of the branch radiation beams to be incident on a subset of the reflective regions of the reflective element.

[0040] The radiation source may comprise at least one free electron laser.

[0041] According to a third aspect of the invention there is provided a lithographic system comprising an optical system according to the first aspect or a radiation system according to the second aspect and a lithographic apparatus arranged to receive at least some of the radiation which is reflected from the reflective element.

[0042] According to a fourth aspect of the invention there is provided a method of modifying a radiation beam, the method comprising illuminating a portion of a reflective element with a radiation beam, wherein the reflective element comprises a plurality of reflective regions, wherein different reflective regions are configured to reflect incident radiation in different directions, and wherein only a subset of the reflective regions is illuminated at any given time, and moving the reflective element, relative to the radiation beam, so as to change the one or more reflective regions which are illuminated with the radiation beam.

[0043] Various aspects and features of the invention set out above or below may be combined with various other aspects and features of the invention as will be readily apparent to the skilled person.

BRIEF DESCRIPTION OF THE DRAWINGS

[0044] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings, in which:

- Figure 1 is a schematic illustration of a lithographic system comprising a free electron laser according to an embodiment of the invention;
- Figure 2 is a schematic illustration of a lithographic apparatus that forms part of the lithographic system of Figure 1;
- Figure 3 is a schematic illustration of a free electron laser that forms part of the lithographic system of Figure 1;
- Figure 4 is a schematic illustration of a deflecting device according to an embodiment of the invention;
- Figure 5 is a schematic illustration of a deflecting device according to an alternative embodiment of the invention;
- Figures 6A and 6B are schematic illustrations of a deflecting device according to a further alternative embodiment of the invention;
- Figure 7 is a schematic representation of an optical system according to an embodiment of the invention;
- Figure 8 is a schematic representation of focal regions formed by the optical system of Figure 7;
- Figure 9 is a schematic representation of focal regions formed at different times in the optical system of Figure 7;
- Figure 10 is a schematic representation of an optical system according to an alternative embodiment of the invention;

- Figure 11 is a schematic illustration of a facetted mirror which forms part of the optical system of Figure 10; and
- Figure 12 is a schematic representation of focal regions formed by the optical system of Figure 10.

DETAILED DESCRIPTION

[0045] Figure 1 shows a lithographic system LS according to one embodiment of the invention. The lithographic system LS comprises a radiation source SO, a beam delivery system BDS and a plurality of lithographic apparatus LA_a-LA_n (e.g. eight lithographic apparatus). The radiation source SO is configured to generate an extreme ultraviolet (EUV) radiation beam B (which may be referred to as a main beam). The radiation source SO and the beam delivery system BDS may together be considered to form a radiation system, the radiation system being configured to provide radiation to one or more lithographic apparatus LA_a-LA_n.

[0046] The beam delivery system BDS comprises beam splitting optics and may optionally also comprise beam expanding optics and/or beam shaping optics. The main radiation beam B is split into a plurality of radiation beams B_a-B_n (which may be referred to as branch beams), each of which is directed to a different one of the lithographic apparatus LA_a-LA_n, by the beam delivery system BDS.

[0047] In an embodiment, the branch radiation beams B_a-B_n are each directed through a respective attenuator (not shown in Figure 1). Each attenuator may be arranged to adjust the intensity of a respective branch radiation beam B_a-B_n before the branch radiation beam B_a-B_n passes into its corresponding lithographic apparatus LA_a-LA_n.

[0048] The radiation source SO, beam delivery system BDS and lithographic apparatus LA_a-LA_n may all be constructed and arranged such that they can be isolated from the external environment. A vacuum may be provided in at least part of the radiation source SO, beam delivery system BDS and lithographic apparatuses LA_a-LA_n so as to reduce the absorption of EUV radiation. Different parts of the lithographic system LS may be provided with vacuums at different pressures (i.e. held at different pressures which are below atmospheric pressure).

[0049] Referring to Figure 2, a lithographic apparatus LA_a comprises an illumination system IL, a support structure MT configured to support a patterning device MA (e.g. a mask), a projection system PS and a substrate table WT configured to support a substrate W. The illumination system IL is configured to condition the branch radiation beam B_a that is received by that lithographic apparatus LA_a before it is incident upon the patterning device MA. The projection system PS is configured to project the radiation beam B_a' (now patterned by the patterning device MA) onto the substrate W. The substrate W may include previously formed patterns. Where this is the case, the lithographic apparatus aligns the patterned radiation beam B_a' with a pattern previously formed on the substrate W.

[0050] The branch radiation beam B_a that is received by the lithographic apparatus LA_a passes into the illumination system IL from the beam delivery system BDS though an opening 8 in an enclosing structure of the illumination system IL. Optionally, the branch radiation beam B_a may be focused to form an intermediate focus IF at or near to the opening 8.

[0051] The illumination system IL may include a field facet mirror 10 and a pupil facet mirror 11. The field facet mirror 10 and pupil facet mirror 11 together provide the radiation beam B_a with a desired cross-sectional shape and a desired angular distribution. The radiation beam B_a passes from the illumination system IL and is incident upon the patterning device MA held by the support structure MT. The patterning device MA reflects and patterns the radiation beam to form a patterned beam B_a'. The illumination system IL may include other mirrors or devices in addition to or instead of the field facet mirror 10 and pupil facet mirror 11. The illumination system IL may, for example, include an array of independently moveable mirrors. The independently moveable mirrors may, for example, measure less than 1 mm across. The independently moveable mirrors may, for example, be microelectromechanical systems (MEMS) devices.

[0052] Following redirection (e.g. reflection) from the patterning device MA the patterned radiation beam B_a' enters the projection system PS. The projection system PS comprises a plurality of mirrors 13, 14 which are configured to project the radiation beam B_a' onto a substrate W held by the substrate table WT. The projection system PS may apply a reduction factor to the radiation beam, forming an image with features that are smaller than corresponding features on the patterning device MA. A reduction factor of 4 may, for example, be applied. Although the projection system PS has two mirrors in Figure 2, the projection system may include any number of mirrors (e.g. six mirrors).

[0053] The lithographic apparatus LA_a is operable to impart a radiation beam B_a with a pattern in its cross-section and project the patterned radiation beam onto a target portion of a substrate thereby exposing a target portion of the substrate to the patterned radiation. The lithographic apparatus LA_a may, for example, be used in a scan mode, wherein the support structure MT and the substrate table WT are scanned synchronously while a pattern imparted to the radiation beam B_a' is projected onto a substrate W (i.e. a dynamic exposure). The velocity and direction of the substrate table WT relative to the support structure MT may be determined by the demagnification and image reversal characteristics of the projection system PS.

[0054] Referring again to Figure 1, the radiation source SO is configured to generate an EUV radiation beam B with sufficient power to supply each of the lithographic apparatus LA_a-LA_n. As noted above, the radiation source SO may comprise a free electron laser.

[0055] Figure 3 is a schematic depiction of a free electron laser FEL comprising an injector 21, a linear accelerator 22, a bunch compressor 23, an undulator 24, an electron decelerator 26 and a beam dump 100.

[0056] The injector 21 is arranged to produce a bunched electron beam E and comprises an electron source (for example a thermionic cathode or a photo-cathode) and an accelerating electric field. Electrons in the electron beam E are further accelerated by the linear accelerator 22. In an example, the linear accelerator 22 may comprise a plurality of radio frequency cavities, which are axially spaced along a common axis, and one or more radio frequency power sources, which are operable to control electromagnetic fields along the common axis as bunches of electrons pass between them so as to accelerate each bunch of electrons. The cavities may be superconducting radio frequency cavities. Advantageously, this allows: relatively large electromagnetic fields to be applied at high duty cycles; larger beam apertures, resulting in fewer losses due to wakefields; and for the fraction of radio frequency energy that is transmitted to the beam (as opposed to dissipated through the cavity walls) to be increased. Alternatively, the cavities may be conventionally conducting (i.e. not superconducting), and may be formed from, for example, copper. Other types of linear accelerators may be used such as, for example, laser wake-field accelerators or inverse free electron laser accelerators.

[0057] Optionally, the electron beam E passes through a bunch compressor 23, disposed between the linear accelerator 22 and the undulator 24. The bunch compressor 23 is configured to spatially compress existing bunches of electrons in the electron beam E. One type of bunch compressor 23 comprises a radiation field directed transverse to the electron beam E. An electron in the electron beam E interacts with the radiation and bunches with other electrons nearby. Another type of bunch compressor 23 comprises a magnetic chicane, wherein the length of a path followed by an electron as it passes through the chicane is dependent upon its energy. This type of bunch compressor may be used to compress bunches of electrons which have been accelerated in a linear accelerator 22 by a plurality of resonant cavities.

[0058] The electron beam E then passes through the undulator 24. Generally, the undulator 24 comprises a plurality of modules (not shown). Each module comprises a periodic magnet structure, which is operable to produce a periodic magnetic field and is arranged so as to guide the relativistic electron beam E produced by the injector 21 and linear accelerator 22 along a periodic path within that module. The periodic magnetic field produced by each undulator module causes the electrons to follow an oscillating path about a central axis. As a result, within each undulator module, the electrons radiate electromagnetic radiation generally in the direction of the central axis of that undulator module.

[0059] The path followed by the electrons may be sinusoidal and planar, with the electrons periodically traversing the central axis. Alternatively, the path may be helical, with the electrons rotating about the central axis. The type of oscillating path may affect the polarization of radiation emitted by the free electron laser. For example, a free electron laser which causes the electrons to propagate along a helical path may emit elliptically polarized radiation.

[0060] As electrons move through each undulator module, they interact with the electric field of the radiation, exchanging energy with the radiation. In general the amount of energy exchanged between the electrons and the radiation will oscillate rapidly unless conditions are close to a resonance condition. Under resonance conditions, the interaction between the electrons and the radiation causes the electrons to bunch together into microbunches, modulated at the wavelength of radiation within the undulator, and coherent emission of radiation along the central axis is stimulated. The resonance condition may be given by:

$$\lambda_{em} = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{A}\right), \qquad (1)$$

where λ_{em} is the wavelength of the radiation, λ_u is the undulator period for the undulator module that the electrons are propagating through, γ is the Lorentz factor of the electrons and K is the undulator parameter. A is dependent upon the geometry of the undulator 24: for a helical undulator that produces circularly polarized radiation A=1, for a planar undulator A=2, and for a helical undulator which produces elliptically polarized radiation (that is neither circularly polarized nor linearly polarized) $1<A<2$. In practice, each bunch of electrons will have a spread of energies although this spread may be minimized as far as possible (by producing an electron beam E with low emittance). The undulator parameter K is typically approximately 1 and is given by:

$$K = \frac{q\lambda_u B_0}{2\pi mc}, \qquad (2)$$

where q and m are, respectively, the electric charge and mass of the electrons, B_0 is the amplitude of the periodic magnetic field, and c is the speed of light.

[0061] The resonant wavelength λ_{em} is equal to the first harmonic wavelength spontaneously radiated by electrons moving through each undulator module. The free electron laser FEL may operate in self-amplified spontaneous emission (SASE) mode. Operation in SASE mode may require a low energy spread of the electron bunches in the electron beam E before it enters each undulator module. Alternatively, the free electron laser FEL may comprise a seed radiation source, which may be amplified by stimulated emission within the undulator 24. The free electron laser FEL may operate as a recirculating amplifier free electron laser (RAFEL), wherein a portion of the radiation generated by the free electron laser FEL is used to seed further generation of radiation.

[0062] Electrons moving through the undulator 24 may cause the amplitude of radiation to increase, i.e. the free electron laser FEL may have a non-zero gain. Maximum gain may be achieved when the resonance condition is met or when conditions are close to but slightly off resonance.

[0063] An electron which meets the resonance condition as it enters the undulator 24 will lose (or gain) energy as it emits (or absorbs) radiation, so that the resonance condition is no longer satisfied. Therefore, in some embodiments the undulator 24 may be tapered. That is, the amplitude of the periodic magnetic field and/or the undulator period λ_u may vary along the length of the undulator 24 in order to keep bunches of electrons at or close to resonance as they are guided though the undulator 24. The tapering may be achieved by varying the amplitude of the periodic magnetic field and/or the undulator period λ_u within each undulator module and/or from module to module. Additionally or alternatively tapering may be achieved by varying the helicity of the undulator 24 (by varying the parameter A) within each undulator module and/or from module to module.

[0064] Radiation produced within the undulator 24 is output as a radiation beam B_{FEL}.

[0065] After leaving the undulator 24, the electron beam E is absorbed by a dump 100. The dump 100 may comprise a sufficient quantity of material to absorb the electron beam E. The material may have a threshold energy for induction of radioactivity. Electrons entering the dump 100 with an energy below the threshold energy may produce only gamma ray showers but will not induce any significant level of radioactivity. The material may have a high threshold energy for induction of radioactivity by electron impact. For example, the beam dump may comprise aluminium (Al), which has a threshold energy of around 17 MeV. It may be desirable to reduce the energy of electrons in the electron beam E before they enter the dump 100. This removes, or at least reduces, the need to remove and dispose of radioactive waste from the dump 100. This is advantageous since the removal of radioactive waste requires the free electron laser FEL to be shut down periodically and the disposal of radioactive waste can be costly and can have serious environmental implications.

[0066] The energy of electrons in the electron beam E may be reduced before they enter the dump 100 by directing the electron beam E through a decelerator 26 disposed between the undulator 24 and the beam dump 100.

[0067] In an embodiment the electron beam E which exits the undulator 24 may be decelerated by passing the electrons back through the linear accelerator 22 with a phase difference of 180 degrees relative to the electron beam produced by the injector 21. The RF fields in the linear accelerator therefore serve to decelerate the electrons which are output from the undulator 24 and to accelerate electrons output from the injector 21. As the electrons decelerate in the linear accelerator 22 some of their energy is transferred to the RF fields in the linear accelerator 22. Energy from the decelerating electrons is therefore recovered by the linear accelerator 22 and may be used to accelerate the electron beam E output from the injector 21. Such an arrangement is known as an energy recovery linear accelerator (ERL).

[0068] In some embodiments of a lithographic system LS the radiation source SO may comprise a single free electron laser FEL. In such embodiments the main beam B which is emitted from the radiation source SO may be a laser beam B_{FEL} which is emitted from the free electron laser FEL. In other embodiments, a lithographic system LS may comprise a plurality of free electron lasers. A plurality of laser beams B_{FEL} emitted from the free electron lasers may be combined to form a single main beam B comprising radiation emitted from the plurality of free electron lasers FEL.

[0069] A branch radiation beam (e.g. the branch radiation beam B_a) which is provided to a lithographic apparatus (e.g. the lithographic apparatus LA_a shown in Figure 2) comprises at least a portion of the EUV radiation which is emitted from a free electron laser FEL. A radiation beam which is output from a free electron laser FEL is typically a coherent, well collimated radiation beam having a relatively small etendue. In some embodiments the etendue of a radiation beam which is emitted from a free electron laser FEL may be sufficiently small that the radiation beam is considered to be diffraction limited.

[0070] The etendue of a radiation beam in free space (i.e. a medium with a refractive index of 1) at an infinitesimal surface element dS in an optical system is given by the product of the area of the surface dS, the solid angle dΩ subtended by radiation crossing (or emitted by) the surface element and the cosine of the angle between the normal to the surface element and the direction of the radiation crossing that point. In general, the etendue of a radiation beam at an extended surface S is given by integrating over the solid angle subtended by radiation crossing (or emitted by) each surface element (to account for the fact that light may cross each point on the surface at a range of angles) and integrating over the surface (to sum the contributions from all such surface elements). For a light source operable to produce a well collimated radiation beam, as is produced by a free electron laser FEL, the etendue of the light source may be estimated by the product of the area of the light source and the solid angle into which light is emitted. Further, for such a light source the solid angle into which light is emitted is given by (using small angle approximations) $\pi\theta^2$, where θ is the half divergence of the light source. Therefore the etendue of such a light source is given by $G=\pi A\theta^2$, where A is the area of the light source. A radiation beam which is emitted from a free electron laser FEL may, for example, have a divergence which is less than about 500 µrad (in some embodiments the divergence may be less than about 100 µrad) and may have a diameter of around 50 µm to 100 µm at its beam waist, as it leaves the undulator 24. In an embodiment in which the beam waist diameter is 50 µm and the beam divergence is 100 µrad the etendue of the radiation beam is around 1.5×10^{-11} mm^2.

[0071] In some embodiments a free electron laser FEL may emit a radiation beam which has a Gaussian-like intensity profile. The etendue of a radiation beam having a Gaussian intensity profile is approximately equal to the wavelength of the radiation beam squared. In some embodiments a free electron laser FEL may emit an EUV radiation beam having a wavelength of approximately 13.5 nm and having a Gaussian intensity profile. In such an embodiment the etendue of the radiation beam is approximately 1.8×10^{-16} m^2. In practice the intensity profile of a radiation beam which is emitted from a free electron laser FEL may not be perfectly Gaussian. Consequently the etendue of a radiation beam which is emitted from a free electron laser FEL may in practice be approximately 2 or 3 times greater than the square of the wavelength of the radiation beam.

[0072] The etendue of a radiation beam cannot decrease as it propagates through an optical system. The etendue of a radiation beam may remain constant as it propagates through an optical system in free space and undergoes reflections and refractions. However, as a radiation beam propagates through an optical system which spreads out radiation, for example by scattering and/or diffraction, its etendue will increase. The higher the quality of the optical elements (for example mirrors and lenses) in the optical system, the smaller the increase in etendue will be.

[0073] The optical elements which form the optical path of a branch radiation beam B_a from a free electron laser FEL to a lithographic apparatus LA_a are typically of a high quality such that they result in only relatively small increases in the etendue. If the branch radiation beam B_a only passes via optical elements which do not significantly increase the etendue of the branch radiation beam B_a then the etendue of the branch radiation beam B_a which is focused at the intermediate focus IF will be relatively small and the branch radiation beam B_a will be focused to a small point at the intermediate focus IF. As was described above with reference to Figure 2, the branch radiation beam B_a which is focused at the intermediate focus IF enters the illumination system IL of the lithographic apparatus LA_a and is incident on a field facet mirror 10 and a pupil facet mirror 11. The field facet mirror 10 and the pupil facet mirror 11 each comprise a plurality of reflective facets which each reflect a portion of the branch radiation beam B_a. The portions of the branch radiation beam B_a which are reflected at the field facets and pupil facets may be referred to as sub-beams.

[0074] The field facets which form the field facet mirror 10 may focus the sub-beams which are received by the field facets onto the pupil facets which form the pupil facet mirror 11. The spot size of each sub-beam which is incident on a pupil facet of the pupil facet mirror 11 depends in part on the etendue of the branch radiation beam B_a. A branch radiation beam B_a having a small etendue may cause the spot sizes of the sub-beams of the branch radiation beam B_a which are incident on the pupil facets to be relatively small. A small spot size on a pupil facet causes the sub-beam to be incident on a pupil facet with a relatively high irradiance. A high irradiance on a pupil facet may damage the pupil facet.

[0075] It may therefore be desirable to increase the spot sizes of the sub-beams which are incident on the pupil facets so as to decrease the irradiance on the pupil facets and reduce any damage to the pupil facets. The spot sizes of the sub-beams which are incident on the pupil facets may be increased by increasing the etendue of the branch radiation beam B_a.

[0076] Providing a lithographic apparatus LA_a with a branch radiation beam B_a, which has a relatively small etendue, may additionally or alternatively cause one or more other problems in the lithographic apparatus LA_a. For example, a small etendue branch radiation beam B_a may mean that the patterned radiation beam B_a' which is incident on the substrate W is highly sensitive to defects in the optical path of the branch radiation beam B_a. For example, scratches, dust or other defects present on optical elements (e.g. mirrors) with which the branch radiation beam B_a interacts, may be imaged onto a substrate W by a small etendue branch radiation beam B_a.

[0077] For a small etendue branch radiation beam B_a, radiation which is received at a given point on a substrate W may be considered to have originated from a discrete number N of point sources in an illumination pupil of a projection system PS. The N points in the illumination pupil translate to N discrete rays which illuminate the point on the substrate W from N different angles. A defect, such as a scratch on a mirror in the projection system PS may obscure one or more of the N rays of radiation and thus the point on the substrate will be illuminated from less than N different angles. Consequently the defect will deteriorate the imaging performance at some locations on the substrate W. Increasing the etendue of a branch radiation beam B_a may reduce this deterioration of the imaging performance.

[0078] For the reasons which have been described above it may be desirable to increase the etendue of a branch radiation beam B_a which is provided to a lithographic apparatus LA_a. One approach to increasing the etendue of a branch radiation beam B_a is to provide a static optical component which serves to apply an alteration to the branch radiation beam B_a which is constant over time. Embodiments, which are contemplated herein apply a dynamic alteration to a branch radiation beam B_a which varies over time. Such embodiments may not serve to change the instantaneous etendue of a branch radiation beam B_a but may introduce a time dependent variation in the branch radiation beam B_a, which has a similar effect to increasing the etendue.

[0079] Figure 4 is a schematic illustration of a deflecting device 100 according to an embodiment of the invention. The deflecting device 100 comprises a reflective element 101 and an actuator 103. The deflecting device 100 is arranged to receive a branch radiation beam B_a. The reflective element 101 comprises a plurality of reflective regions 105. The reflective regions 105 are configured to reflect radiation which is incident upon them in different directions. That is, a first reflective region 105a is configured to reflect radiation in a different direction to a second reflective region 105b.

[0080] In the embodiment which is shown in Figure 4, each reflective region comprises a reflective facet. References herein to reflective facets are intended to refer to reflective surfaces which are arranged such that boundaries between adjacent reflective facets are discontinuous. For example, in the embodiment which is shown in Figure 4, the reflective facets each comprise a substantially flat reflective surface. The flat surfaces of adjacent facets are orientated differently to each other such that different reflective facets reflect radiation in different directions. Consequently the boundaries between adjacent facets are discontinuous and formed as a sharp edge.

[0081] In some embodiments, reflective facets may comprise reflective surfaces which are not flat. In such embodiments the reflective facets will still be arranged such that boundaries between adjacent facets are discontinuous. In some embodiments, the reflective regions 105 may not comprise reflective facets. In such embodiments, the reflective regions 105 may comprise portions of a continuously undulating reflective surface. The reflective regions 105 may therefore be arranged such that the boundaries between adjacent reflective regions 105 are continuous.

[0082] In the embodiment of Figure 4, the reflective element 101 has an approximately cylindrical shape and the reflective regions 105 are arranged around the circumferential extent of the cylindrical shape. The cylindrical shape of the reflective element has a central axis which coincides with the axis 107. The actuator 103 is therefore configured to rotate the cylindrical shape about the central axis of the cylindrical shape.

[0083] Whilst the reflective element 101 is described as having an approximately cylindrical shape, the arrangement of the reflective facets having different orientations around the approximately cylindrical shape, means that the precise shape of the reflective element 105 deviates from a perfect cylinder. Reference to a cylindrical shape is therefore merely intended to describe the general arrangement of the reflective regions 105 and is not intended to describe the precise shape of the reflective element 105.

[0084] At a given position of the reflective element 101 relative to the branch radiation beam B_a, the branch radiation beam B_a is only incident on a subset of the reflective regions 105. For example, at a given position of the reflective element 101, the branch radiation beam B_a may only be incident on a single reflective region. In some embodiments, at a given position of the reflective element 101, the branch radiation beam B_a may be incident on a plurality of reflective regions 105. For example, the branch radiation beam B_a may be incident on two reflective regions, three reflective regions or more than three reflective regions. In some embodiments, the branch radiation beam B_a may be incident on five or more reflective regions 105 at once.

[0085] Reference herein to a subset of reflective regions 105 is intended to mean one or more reflective regions 105 but not all of the reflective regions 105. That is, when a branch radiation beam B_a is incident on a subset of reflective regions 105, at least one of the reflective regions 105 receives radiation from the branch radiation beam B_a and at least one of the reflective regions 105 does not receive radiation from the branch radiation beam B_a.

[0086] The actuator 103 is configured to move the reflective element 101, relative to the branch radiation beam B_a so as to change the one or more reflective regions 105 on which radiation is incident. In the embodiment which is shown in Figure 4, the actuator 103 is configured to rotate the reflective element 101 about a central axis 107. Rotation of the reflective element 101 about the axis 107, changes the reflective regions 107 which lie in the beam path of the branch radiation beam B_a. Since different reflective regions 105 reflect radiation in different directions, movement of the reflective element 101, which changes the reflective regions 105 on which radiation is incident, serves to change the directions in which radiation is reflected. This can be seen in Figure 4 in which illuminated beam spot regions 111 of a far field plane 109 situated downstream of the reflective element 101, are shown.

[0087] Each of the beam spot regions 111 which are shown in Figure 4 represents a region of the far field plane 109 which is illuminated when the branch radiation beam B_a is incident on one of the reflective regions 105. At a given position of the reflective element 101 one or more beam spot regions 111 may be illuminated in the far field plane 109. For example, when the reflective element 101 is in a position in which the first reflective region 105a and the second reflective region 105b both receive radiation from the branch radiation beam B_a, first and second beam spot regions 111a, 111b are illuminated in the far field plane 109.

[0088] As the reflective element 101 is rotated about the axis 107, different reflective regions 105 will be moved into and out of the path of the branch radiation beam B_a. Movement of the reflective element 101 therefore causes different portions (e.g. different beam spot regions 111) of the far filed plane 109 to be illuminated at different times. In Figure 4, x and y-axes are shown in the far field plane 109. The x and y directions are perpendicular to each other and lie in the far field plane 109. The reflective regions 105 are configured such that the different portions of the far field plane 109 which are illuminated at different times are spread over two perpendicular directions in the far field plane 109. This can be seen in Figure 4 by the beam spot regions 111 which are spread in both the x and y directions.

[0089] Figure 5 is a schematic illustration of a deflecting device 1100 according to an alternative embodiment of the invention. The deflecting device 1100 which is shown in Figure 5 is similar to the deflecting device 100 which is shown in Figure 4. Features in Figure 5 which correspond with features in Figure 4 are denoted with the same reference numerals with the addition of 1000.

[0090] The deflecting device 1100 comprises a reflective element 1101 comprising a plurality of reflective regions 1105 in the form of reflective facets. The deflecting device 1100 further comprises an actuator 1103 configured to rotate the reflective element 1101 about an axis 1107. Similarly to the embodiment shown in Figure 4, different reflective regions 1105 of the reflective element 1101 are configured to reflect radiation incident upon them, in different directions.

[0091] At a given position of the reflective element 1101 relative to a branch radiation beam B_a, the branch radiation beam B_a is only incident on a subset of the reflective regions 1105. Rotation of the reflective element 1101 changes the one or more reflective regions 1105 on which radiation is incident. Since different reflective regions 1105 reflect radiation in different directions, rotation of the reflective element 1101, which changes the reflective regions 1105 on which radiation is incident, serves to change the directions in which radiation is reflected.

Consequently different portions (represented by different beam spot regions 1111) of a far field plane 1109 are illuminated at different times.

[0092] The embodiment which is shown in Figure 5 differs from that shown in Figure 4 in that the reflective element 1101 shown in Figure 5 does not have an approximately cylindrical shape. In the embodiment of Figure 5, the reflective element 1101 is configured such that the reflective regions 1105 fit approximately onto a portion of a paraboloid of revolution 1113. The paraboloid of revolution 1113 has a central axis which coincides with the axis 1107. The actuator 1103 is therefore configured to rotate the reflective element substantially about the central axis of the reflective element 1101. The axis 1107 may be substantially parallel with the direction of propagation of the branch radiation beam B_a prior to the branch radiation beam B_a being incident on the reflective element 1101.

[0093] Whilst the reflective regions 1105 are described as fitting approximately onto a paraboloid of revolution 1113, the arrangement of the reflective facets having different orientations around the paraboloid 1113, means that the precise shape of the reflective element 1105 deviates from a perfect paraboloid. Reference to the reflective regions fitting a paraboloid of revolution is therefore merely intended to describe the general arrangement of the reflective regions 1105 and is not intended to describe the precise shape of the reflective element 1105.

[0094] Arranging the reflective regions 1105 around a paraboloid of revolution 1113 (as shown in Figure 5) may allow the reflective regions 1105 to be configured such that the different directions in which radiation is reflected covers a greater angular range (for example, when compared to the embodiment of Figure 4). In particular, there may be greater freedom in the orientation of the reflective regions 1105 with respect to the axis 1107 which may allow radiation to be reflected to a greater range of positions on the y-axis which is shown in the far field plane 1109.

[0095] Figures 6A and 6B are schematic illustrations of a deflecting device 2100 according to a further alternative embodiment of the invention. Figure 6A is a top down view of the deflecting device 2100 and Figure 6B is a side cross-section through the deflecting device 2100. The deflecting device 2100 which is shown in Figures 6A and 6B is similar to the deflecting devices 100, 1100 shown in Figures 4 and 5 respectively. Features in Figures 6A and 6B which correspond with features in Figures 4 and 5 are denoted with the same reference numerals with the addition of 2000 with respect to Figure 4 and the addition of 1000 with respect to Figure 5.

[0096] The deflecting device 2100 comprises a reflective element 2101 and an actuator 2103 (visible only in Figure 6B). The reflective element 2101 comprises a plurality of reflective regions 2105 in the form of reflective facets. The actuator 2103 is configured to rotate the reflective element 2101 about an axis 2107. Similarly to the embodiments shown in Figures 4 and 5, different reflective regions 2105 of the reflective element 2101 are configured to reflect radiation incident upon them, in different directions.

[0097] In the embodiment which is shown in Figures 6A and 6B the reflective element 2105 is in the form of a disk-like structure, on which the reflective regions 2105 approximately fit. The reflective regions 2105 are each situated at substantially the same radial distance from an axis 2107 about which the reflective element 2105 is rotated by the actuator 2103.

[0098] At a given position of the reflective element 2101 relative to a branch radiation beam B_a, the branch radiation beam B_a is only incident on a subset of the reflective regions 2105. Rotation of the reflective element 2101 changes the one or more reflective regions 2105 on which radiation is incident. Since different reflective regions 2105 reflect radiation in different directions, rotation of the reflective element 2101, which changes the reflective regions 2105 on which radiation is incident, serves to change the directions in which radiation is reflected. Consequently different portions of a far field plane (not shown in Figures 6A and 6B) are illuminated at different times.

[0099] In the embodiment of Figures 6A and 6B, the reflective regions 2105 lie approximately in a plane which is defined by the disk-like structure on which the reflective regions 2105 approximately fit. In such an embodiment, the angular deflection of the branch radiation beam B_a may be smaller than the angular deflection which is caused by the embodiments shown in Figures 4 and 5 and in which the reflective regions 105, 1105 do not lie approximately in a plane.

[00100] Several embodiments of deflecting devices 100, 1100, 2100 have been described above with reference to Figures 4, 5, 6A and 6B. In each of these embodiments, reflective regions 105, 1105, 2105 are provided in the form of reflective facets. In alternative embodiments, the reflective regions 105, 1105, 2105 may comprise portions of a continuously undulating reflective surface. In such embodiments, the portions of a far field plane which are illuminated with reflected radiation may change continuously with time. This contrasts with the discontinuous transitions from one beam spot region to another which was described above for example with reference to Figure 4.

[00101] The actuators 103, 1103, 2103 which form part of the deflecting devices 100, 1100, 2100 shown in Figures 4, 5, 6A and 6B may take any suitable form. For example, the actuators 103, 1103, 2103 may comprise electric motors.

[00102] Whilst specific embodiments of deflecting devices have been described above, alternative embodiments of deflecting devices according to the invention may take different forms to those described and depicted herein. In general a deflecting device according to the invention comprises a reflective element comprising a plurality of reflective regions and an actuator configured to move the reflective element. Different reflective regions are configured to reflect incident radiation in different directions. The reflective regions are configured such that at a given position of the reflective element, a radiation beam is only incident on a subset of the reflective regions. Movement of the reflective element, by the actuator and relative to the radiation beam, changes the one or more reflective regions on which the radiation beam is incident. Consequently, the directions in which radiation is reflected changes with the movement of the reflective element.

[00103] Figure 7 is a schematic representation of an optical system which includes an embodiment of a deflecting device as described above. The representation which is shown in Figure 7 is a representation of the path of rays of radiation which form a branch radiation beam B_a. The branch radiation beam B_a is shown on a z-axis and a y-axis. The z direction represents the direction along which the branch radiation beam B_a generally propagates through the optical system. Since the branch radiation beam B_a undergoes multiple reflections during its optical path through the optical system, the direction in which the branch radiation beam B_a propagates changes through the optical system. The z-direction which is shown in Figure 7 is considered to change with the propagation direction of the branch radiation beam B_a such that it always follows the branch radiation beam B_a. Consequently, the branch radiation beam B_a is shown in Figure 7 as propagating generally in a single direction and the optical components represented in Figure 7 appear as transmissive optical components. However, it will be appreciated that in practice the optical components may be realized as reflective components and the direction in which the branch radiation beam B_a propagates may change along its optical path. The representation which is shown in Figure 7 may be referred to as a paraxial approximation.

[00104] The branch radiation beam B_a is incident on a deflecting device 100. In Figure 7, the deflecting device 100 is denoted with the same reference numeral as the deflecting device 100 which is shown in Figure 4. However, the deflecting device of Figure 7 may take any suitable form. For example, the deflecting device of Figure 7 may be the deflecting device 1100 which is shown in Figure 5, or may be the deflecting device 2100 which is shown in Figures 6A and 6B. Alternatively the deflecting device of Figure 7 may be another embodiment of a deflecting device which is not specifically described herein.

[00105] As was described above with reference to the embodiments of Figures 4, 5, 6A and 6B, the direction in which radiation is reflected from the deflecting device 100 varies with time. Figure 7 shows three alternative directions in which the branch radiation beam B_a may be reflected from the deflecting device 100. The three alternative directions are represented by a first set of rays 121a shown with dotted lines, a second set of rays 121b shown with dashed lines and a third set of rays 121c shown with solid lines. The first set of rays 121a and the third set of rays 121c may represent the angular extremes of the different directions in which radiation is reflected by the deflecting device 100. The different directions in which radiation is reflected by the deflecting device 100 covers an angular range α. In some embodiments, the angular range may be less than about 10 degrees. In some embodiments the angular range may be less than about 5 degrees, may be less than about 2 degrees and may in some embodiments be less than about 1 degree. For example, the angular range α may be about 0.5 degrees. The angular range may be greater than about 0.1 degrees. In some embodiments the angular range may be greater than about 0.5 degrees. The angular range α which is shown in Figure 7 represents the spread of different directions as displayed on a y-axis. The spread of different directions as displayed on an x-axis (where the x-axis is perpendicular to both the y and z-axes) may have a similar angular range α to that described above and shown in Figure 7.

[00106] The etendue of a radiation beam may be estimated by the product of the area of the light source and the solid angle into which light is emitted. An important property of a branch radiation beam B_a which is output from a deflecting device may therefore be the product of diameter of the branch radiation beam B_a and the angular range α over which it is deflected. The diameter of a branch radiation beam B_a which is incident on a deflecting device may, in some embodiments, be greater than about 5 mm. The diameter of a branch radiation beam B_a which is incident on a deflecting device may, in some embodiments, be less than about 30 mm. In some embodiments, the product of the beam diameter and the angular range α may be greater than about 0.2 mm radians. The product of the beam diameter and the angular range α may be less than about 5 mm radians.

[00107] Radiation which is reflected in different directions by the deflecting device 100 is received by an optical element 125. The reflective regions which form part of the deflecting device 100 are configured such that all of the reflective regions reflect radiation in a direction which causes it to be received by the optical element 125. The optical element 125 may be a focusing element 125 and may be referred to as a first focusing element 125. The first focusing element 125 of Figure 7, functions as a relay optic which is configured to provide an inverted image of the branch radiation beam B_a, which is output from the deflecting device 100, on a second focusing element 127.

[00108] A third focusing element 129 receives radiation from the second focusing element 127. The second and third focusing elements 127, 129 are together configured to focus the branch radiation beam B_a such that it passes through an intermediate focus region IF. As was described above with reference to Figure 2, the intermediate focus region IF may be located at or near to an opening 8 in an enclosing structure of a lithographic apparatus LA_a (not shown in Figure 7). The branch radiation beam B_a enters the lithographic apparatus LA_a through the opening 8 in the enclosing structure.

[00109] The rays 121a, 121b, 121c of radiation in the vicinity of the intermediate focus region IF are shown in more detail in an inset portion 133 of Figure 7. Figure 8 is a schematic representation of radiation at the intermediate focus region IF. As can be seen in Figure 8, the radiation is focused to three focal regions 1121a, 1121b and 1121c in the intermediate focus region IF. The x-y plane which is shown in Figure 8 and in which radiation is focused to the focal regions 1121a, 1121b, 1121c may be referred to as a focal plane. A first focal region 1121a is the region to which the first set of rays 121a is focused. The second focal region 1121b is the region to which the second set of rays 121b is focused. The third focal region 1121c is the region to which the third set of rays 121c is focused.

[00110] The three focal regions 1121a, 1121b, 1121c correspond to regions of the focal plane to which radiation is focused when radiation is reflected in different directions by the deflecting device 100. For example, the different focal regions 1121a, 1121b, 1121c may correspond to different regions of the focal plane to which radiation is focused when radiation is reflected by different reflective regions of a reflective element, which forms part of the deflecting device 100.

[00111] The focal regions to which radiation is focused depends on the reflective regions (of the deflecting device 100) from which radiation is reflected. That is, movement of the reflective element, which changes the reflective regions from which radiation is reflected, changes the one one or more focal regions to which radiation is focused. Whilst three focal regions 1121a, 1121b, 1121c are shown in the focal plane of Figure 8, movement of the reflective element (of the deflecting device 100) may cause radiation to be focused to other focal regions in the focal plane. For example, radiation may also be focused to focal regions which have different positions in the x-direction.

[00112] Whilst the focal regions 1121a, 1121b, 1121c which are shown in Figure 8 are separated from each other, some focal regions, which represent radiation reflected from different reflective regions, may overlap with each other at the intermediate focus region IF.

[00113] Figure 9 is a schematic illustration of the distribution of a plurality of focal regions 1121 in the focal plane. The focal regions 1121 represent different regions of the focal plane which may be illuminated at different times. For example, as the reflective element of the deflecting device 100 is moved, the focal regions 1121 which are illuminated may change. As is shown in Figure 9, some of the focal regions 1121 overlap with each other in the focal plane.

[00114] Referring again to Figure 7, the radiation which passes through the intermediate focus region IF is incident on an image plane 131. The image plane 131 may, for example, be a plane in which a field facet mirror 10 of a lithographic apparatus LA_a (as shown in Figure 2) is situated. The focusing elements 125, 127, 129 may be configured to form an image of the branch radiation beam B_a which is incident on the reflective element (of the deflecting device 100) substantially in the image plane 131. In particular, the focusing elements 125, 127, 129 may be configured such that the spatial extent of radiation in the image plane 131 is not strongly dependent on the direction in which radiation is reflected at the deflecting device 100.

[00115] This is, in particular, advantageous in an embodiment in which a field facet mirror 10 is situated in the image plane 131. The field facet mirror 10 comprises a plurality of reflective facets, which are arranged to direct radiation onto a particular portion of a pupil facet mirror 11. The field facet mirror 10 and pupil facet mirror 11 together provide the radiation incident on the patterning device MA with a desired cross-sectional shape and a desired angular distribution. A change in the spatial extent of the radiation which is incident on the field facet mirror 10, may change the facets (of the field facet mirror 10) on which radiation is incident and may therefore change the portions of the pupil facet mirror 11 to which radiation is directed. Consequently, the cross-sectional shape and/or the desired angular distribution of radiation which is incident on the pattering device MA may change. It is desirable for the cross-sectional shape and the desired angular distribution of radiation which is incident on the pattering device MA to remain substantially constant with time. As was described above, this may advantageously be achieved by forming an image of the branch radiation beam B_a which is incident on the deflecting device 100, at an image plane 131 in which the field facet mirror 10 is situated.

[00116] The focusing elements 125, 127, 129 may take any suitable form. The focusing elements 125, 127, 129 may, for example, comprise curved reflective surfaces arranged to receive the radiation beam. The reflective surfaces may be arranged to receive radiation at grazing incidence angles. For example, the reflective surfaces may receive radiation at grazing incidence angles of less than about 5°, for example, around 2° or even less, for example around 1°.

[00117] Whilst a specific embodiment is shown in Figure 7 and is described above as comprising a first focussing element 125, a second focusing element 127 and a third focussing element 129, in general any form of one or more focussing elements may be used. For example, in some embodiments more than or fewer than three focussing elements may be used. The one or more focussing elements may be configured to image angular variations introduced by a deflecting device 100 into positional variations in an intermediate focus region IF. The one or more focussing elements may be configured to image the cross-section of a branch radiation beam $B_{a,}$ which is incident on the deflecting device 100 onto an image plane 131.

[00118] Whilst, the focussing elements 125, 127, 129 may be configured such that the spatial extent of radiation incident on the field facet mirror 10 remains substantially constant, the spatial extent of radiation at other positions in the lithographic apparatus LA_a may vary. For example, the position of radiation which is incident on reflective facets of the pupil facet mirror 11 may vary with time as the direction in which radiation is reflected from the deflecting device 10 changes. The reflective facets, of the pupil facet mirror 11, which receive radiation may remain substantially the same. However, the position of the radiation on each reflective facet may change with time.

[00119] Changing the position at which radiation is incident on a reflective facet advantageously reduces the heat load on portions of the facet which receive radiation (when compared to the position of the incident radiation on the facet being constant). Damage which is caused to the reflective facet by the radiation may therefore be reduced or eliminated, by moving the radiation around the reflective facet.

[00120] Changing the direction of reflection from the deflecting device 100 with time, also advantageously reduces the sensitivity of the patterned radiation beam B_a' which is incident on the substrate W, to defects in the optical path of the branch radiation beam B_a. For example, if an optical component (e.g. a mirror) includes a scratch then if the direction of propagation of radiation remains constant then the scratch may be undesirably imaged onto the substrate W. When the direction of propagation of radiation is altered with time (by the deflecting device 100) then the effect of the scratch may be blurred across different portions of the substrate W and may have little or no effect on the pattern which is transferred to the substrate W. Similarly the effect of other defects (e.g. dust) on the pattern which is transferred to the substrate W may be advantageously reduced by the deflecting device 100.

[00121] As was described above, a high etendue branch radiation beam B_a may have the effect that N point sources in an illumination pupil of the projection system result in N discrete rays being incident on a point on the substrate W. The deflecting device 100 serves to move the point sources around the illumination pupil with time such that over a period of time a point on the substrate W sees disk-like sources in the illumination pupil as opposed to point sources.

Consequently any deterioration in imaging performance which results from defects in the optical path of the branch radiation beam B_a will be reduced by the deflecting device 100.

[00122] In a lithographic apparatus LA_a, a given point on the substrate W may be exposed to radiation for a given amount of time, which may be referred to as an exposure time. For example, in a scan mode, a slit of patterned radiation may be scanned relative to the substrate W. The exposure period may be equal to the time taken for the slit of patterned radiation to be scanned over a single point on the substrate W. The exposure period may be of the order of a few milliseconds. For example, in some embodiments the exposure period may be approximately 1 millisecond.

[00123] It is desirable that the changes in the direction of propagation of the branch radiation beam B_a, caused by the deflecting device 10, have little or no effect on the total amount of radiation which is received at each point on the substrate W. The changes in the direction of propagation of the branch radiation beam B_a, may affect the amount of radiation which is received by a given point on the substrate W at different times within an exposure period. However, it is desirable that the total amount of radiation which is received by each point on the substrate W remains substantially unaffected.

[00124] This may be achieved by ensuring that changes to the direction of propagation of the branch radiation beam B_a are performed with a time period which is less than the exposure period. For example, the deflecting device 100 may be configured such that the different directions in which radiation is reflected by the deflecting device 100 follows a substantially periodic pattern having a time period which is less than the exposure period. The different directions in which radiation is reflected by the deflecting device 100 following a periodic pattern is not a functional requirement of a deflecting device but may be the case in some practical implementations. The time period of the substantially periodic pattern may be referred to as a directional period. The directional period may be less than about 1 millisecond. In some embodiments the directional period may be less than about 0.5 milliseconds, for example, about 0.2 milliseconds or less.

[00125] In an embodiment in which the directional period of the periodic pattern is about 0.2 milliseconds, the frequency with which the direction of propagation is varied is about 5 kHz. The frequency with which the direction of propagation is varied may be referred to as a directional frequency. In some embodiments the frequency with which the reflective element of a deflecting device is moved may be less than the directional frequency. For example, in embodiments in which a reflective element is rotated by an actuator (e.g. the embodiments shown in Figures 4, 5, 6A and 6B), the rotational frequency of the reflective element may be less than the directional frequency. The reflective regions which extend around the reflective element may therefore correspond to more than one directional period. For example, the reflective regions may correspond to 10 or more directional periods. In some embodiments the reflections regions may correspond to 50 or more directional periods.

[00126] In some embodiments a reflective element may comprise a plurality of reflective regions which are arranged roughly around a circle. For example, the embodiments which are shown in Figures 4, 5, 6A and 6B may all be considered to be embodiments in which the reflective regions 105, 1105, 2105 are arranged roughly around a circle. The circle may have a diameter of approximately 0.5 meters. The reflective regions which extend around the circle may correspond to approximately 50 directional periods. In such an embodiment, each directional period may cover approximately 31 mm of the circumference of the circle. Each region of the circumference which makes up a directional period may comprise reflective regions which are each configured to reflect radiation in different directions. In some embodiments a directional period may include more than about 10 reflective regions. Some embodiments may include, for example, more than about 20 reflective regions. The reflective regions which form the entire reflective element may include reflective regions which are configured to reflect radiation in the same direction. However, each directional period may only include reflective regions which are each configured to reflect radiation in different directions.

[00127] A reflective element may be rotated by an actuator at a rotational frequency which is greater than about 10 Hz. For example, the rotational frequency may be about 100 Hz or more. In some embodiments, the rotational frequency with which a reflective element is rotated may be about 100 Hz and the reflective regions of the reflective element may correspond to approximately 50 directional periods. In such an embodiment, the directional frequency is about 5 kHz and the directional period is about 0.2 milliseconds.

[00128] In addition to the advantageous effects described above, a deflecting device as described herein may also serve to advantageously reduce the effect of interference patterns in a lithographic apparatus. A radiation beam which is emitted from a free electron laser FEL is typically a coherent radiation beam. When a spatially coherent radiation beam is reflected (for example at one or more of the reflective elements which form part of an optical system) then small path length differences may be introduced between different portions of the radiation beam, thereby introducing phase differences between different portions of the radiation beam. Phase differences between different portions of the radiation beam may cause different portions of the radiation beam to interfere with each, thereby forming interference patterns. For example, interference between different portions of a radiation beam may lead to the occurrence of a so called speckle pattern. In a lithographic apparatus a radiation beam exhibiting a speckle pattern may disadvantageously cause different portions of a substrate W to be exposed to different doses of radiation. It may therefore be desirable to reduce any disadvantageous effects which result from interference between different portions of a branch radiation beam B_a.

[00129] A deflecting device, as described herein, serves to change the direction of propagation of a branch radiation beam B_a with time. Any speckle patterns which occur in the branch radiation beam B_a will therefore also change with time. As was described above, the directional period may be less than the exposure period. Consequently a speckle pattern in the branch radiation beam B_a will change on a shorter time scale than the exposure period. The speckle pattern will therefore have little or no effect on the amount of radiation to which a given point on the substrate W is exposed.

[00130] Figure 10 is a schematic representation of a portion of an alternative embodiment of an optical system. The components which are shown in Figure 10 are similar to those which are shown in Figure 7. Components in Figure 10 which correspond to the components which are shown in Figure 7 are denoted with the same reference numerals and will not described in detail with reference to Figure 10. The embodiment of Figure 10 includes an extra component in the form of a facetted mirror 126. The facetted mirror is shown in more detail in Figure 11 which is a schematic illustration of a perspective view of the facetted mirror 126.

[00131] The facetted mirror 126 comprises a plurality of reflective facets 141. The reflective facets 126 are arranged to receive a portion of a branch radiation beam B_a and reflect the respective portions so as to form a plurality of sub-beams (not shown individually in Figure 11). The reflective facets 141 may comprise curved reflective surfaces such that the reflective facets have a focusing power. In some embodiments, the reflective facets 141 may comprise a concave reflective surface such that the reflective facets 141 have a positive focusing power. Alternatively the reflective facets 141 may comprise a convex reflective surface such that the reflective facets 141 have a negative focusing power.

[00132] In some embodiments, some of the reflective facets 141 may comprise concave reflective surfaces (having a positive focusing power) and some of the reflective facets 141 may comprise convex reflective facets 141 (having a negative focusing power). For example, in an embodiment the reflective facets 141 may alternate between concave and convex reflective surfaces.

[00133] Reflective facets 141 which comprise a curved reflective surface (e.g. a concave or convex reflective surface) serve to alter the angular distribution of rays of radiation.

[00134] Whilst the facetted mirror 126 which is shown in Figure 11 comprises nine reflective facets 141, in other embodiments the facetted mirror 126 may comprise more or fewer than nine reflective facets 141.

[00135] The reflective facets 141 are configured such that the sub-beams reflected from the facets 141 are focused to different focal regions which lie in a focal plane at the intermediate focus region IF. Figure 12 is a schematic illustration of radiation in the focal plane at the intermediate focus region IF. The second and third focusing elements 127, 129 are configured to focus the sub-beams reflected from the facetted mirror 126 to form a plurality of focus regions 143. Each focus region 143 represents a single sub-beam which is reflected from a single reflective facet 141 of the facetted mirror 126. The focus regions 143 are substantially evenly distributed in the focal plane of Figure 12.

[00136] The sub-beams which form the focus regions 143 diverge as they propagate away from the intermediate focus region IF such that the sub-beams overlap with each other in the image plane 131, which is shown in Figure 10. As viewed from the image plane 131, the focus regions 143 are equivalent to evenly distributed point sources of radiation. As radiation from the focus regions 143 overlap they form a high etendue radiation beam. The facetted mirror 126 therefore serves to increase the etendue of the branch radiation beam B_a. As was described in detail above, increasing the etendue of a radiation beam which is provided to a lithographic apparatus LA_a has a number of advantageous effects. For example, increasing the etendue serves to increase the spot size of radiation incident on facets of a pupil facet mirror 11 and reduces or prevents imaging problems in the lithographic apparatus LA_a.

[00137] The focus regions 143 which are shown in Figure 12 represent an instantaneous snap-shot of radiation which is reflected from a single reflective region of a deflecting device. That is, the focus regions 143 shown in Figure 12 result from a single position of a reflective element, which forms part of the deflecting device 100 and radiation being incident on only a single reflective region of the reflective element. Movement of the reflective element causes the direction of propagation of radiation which is incident on the facetted mirror 126 to vary with time. This is shown in Figure 10 with a first group of rays 121a shown with dotted lines and a second group of rays 121b shown with solid lines. The first group of rays 121a represent reflection from a first reflective region of the deflecting device 100 and the second group of rays 121b represent reflection from a second reflective region of the deflecting device 100. Since the reflective regions from which radiation is reflected changes with time, the first and second groups of rays 121a, 121b may represent radiation at different times.

[00138] A change in the direction of propagation of radiation which is incident on the facetted mirror 126 serves to change the position of the focus regions 143 in the focal plane. Movement of the reflective element (of the deflecting device 100) therefore results in movement of the focal regions 143 around the focal plane. In some embodiments, radiation may be incident on more than one reflective region of the reflective element at a given time. In such an embodiment two or more sets of focus regions 143, corresponding to those shown in Figure 12, may be present in the focal plane at a given time.

[00139] The first focusing element 125 (which may be referred to as a relay optic) is configured to form an image of the branch radiation beam B_a which is incident on the deflecting device 100 on the facetted mirror 126. As is shown in Figure 10, the image may be inverted relative to the radiation which is incident on the deflecting device 100. The first focusing element 125 is configured such that movement of the reflective element (of the deflecting device 100) does not substantially change the spatial extent of the radiation which is incident on the facetted mirror 126 but does change the angular extent of the radiation which is incident on the facetted mirror. The same reflective facets 141 are therefore illuminated with radiation at different times but the angles from which the facets 141 are illuminated changes with time.

[00140] The first 125, second 127 and third focusing elements 129 are configured such that the angular variations which are introduced by the deflecting device 100 cause positional variations in the image plane 131. In some embodiments it is desirable to provide radiation in the image plane 131 which has a relatively smooth intensity profile. The focusing elements 125, 126, 127 are configured to image the angular variations introduced by the facetted mirror 126 onto the image plane 131. The facetted mirror 126 may be configured such that the radiation which is incident on the image plane 131 has a smooth spatial intensity profile (i.e. it does not include any substantial discontinuities in intensity). In such an embodiment, positional variations at the deflecting device 100 and at the facetted mirror 126 are imaged into positional variations in the intermediate focus region IF.

[00141] Whilst a specific embodiment is shown in Figure 10 and is described above as comprising three focusing elements 125, 127, 129, in general any arrangement of one or more focusing elements may be used. In some embodiments more than or fewer than three focusing elements may be used. One or more focusing elements may be configured to image positional variations at the deflecting device 100 and the facetted mirror 126 into positional variations in an intermediate focus region IF (as was described above with reference to Figure 10).

[00142] In the embodiment which is shown in Figure 10, a deflecting device 100 is used in conjunction with a facetted mirror 126. As was described in detail above, the deflecting device

100 serves to overcome many of the problems associated with a low etendue branch radiation beam. Since the facetted mirror 126 serves to increase the etendue of the branch radiation beam B_a, in embodiments in which a facetted mirror 126 is included some of the effects of the deflecting device 100 may be less advantageous (when compared to embodiments in which no facetted mirror 126 is included). For this reason, in embodiments which include a facetted mirror 126, the deflecting device 100 may be configured to reflect radiation over a smaller angular range α (not labelled in Figure 10) than in embodiments which do not include a facetted mirror 126. For example, the angular range α which is introduced by a deflecting device when used in conjunction with a facetted mirror 126 may be less than about a degree. In some embodiments the angular range α may be about 0.5 degrees or less.

[00143] The inclusion of a deflecting device 100, even when a facetted mirror 126, is used offers a particular advantage in that the deflecting device 100 reduces the effects of interference patterns (e.g. a speckle pattern) in a lithographic apparatus LA_a. In the absence of a deflecting device 100, a speckle pattern may occur in the branch radiation beam B_a, which may disadvantageously affect the pattern which is imaged on to a substrate W. The deflecting device 100 ensures that any speckle pattern varies on a short enough time scale that it has little or no effect on the pattern which is imaged on to a substrate W.

[00144] It will be appreciated that a deflecting device 100 and a facetted mirror 126 may overcome similar problems in a lithographic system LS. Whilst, a facetted mirror 126 advantageously increases the etendue of a radiation beam, a facetted mirror 126 which has desired etendue increasing properties, may be difficult and expensive to manufacture. Embodiments which do not include a facetted mirror 126 may therefore offer cost savings when compared to embodiments which do include a facetted mirror 126.

[00145] The term “optical system” has been used above to refer to a combination of a deflecting device and one or more other optical components (e.g. one or more focusing elements and/or a facetted mirror). However, it should be understood that an optical system need not necessarily include components other than a deflecting device. A deflecting device alone may therefore be considered to be an embodiment of an optical system.

[00146] In the embodiments which have been described above, a deflecting device is arranged to alter the direction of propagation of a branch radiation beam B_a with time. A lithographic system LS may include a plurality of deflecting devices. For example, a lithographic system may include a deflecting device positioned in the optical path of each branch radiation beam.

[00147] Alternatively a deflecting device as described herein may be arranged to receive a radiation beam other than a branch radiation beam B_a. For example, a deflecting device may be arranged to receive and reflect a main radiation beam B prior to the main radiation beam B being provided to a beam splitting apparatus. However, a deflecting device serves to increase an angular range over which a radiation beam propagates. Increasing the angular range serves to increase the surface area on optical elements downstream of the deflecting device, on which radiation is incident. It will be appreciated that the surface area on optical elements downstream of the deflecting device, on which radiation is incident increases with distance from the deflecting device. In order to direct a radiation beam which is output from a deflecting device over long distances, the size of optical elements which direct the radiation beam may be increased (relative to an arrangement without a deflecting device) and/or the distance between optical elements may be decreased. Increasing the size of the optical elements may increase the expense of the optical elements. Decreasing the distance between optical elements may increase the number of optical elements which are positioned in the optical path of the radiation beam. Increasing the number of optical elements will both increase the total expense of the optical elements and increase the amount of radiation which is lost from the radiation beam due to absorption at the optical elements.

[00148] It may therefore be desirable to position a deflecting device relatively close to a lithographic apparatus, in order to limit the distance over which a radiation beam, output from the deflecting device, is transported prior to being provided to a lithographic apparatus. Embodiments in which deflecting devices are positioned in the optical paths of a plurality of branch radiation beams (and therefore relatively close to the lithographic apparatuses) may therefore be preferable to embodiments in which a deflecting device is positioned in the optical path of a main radiation beam B (prior to the main radiation beam being split into a plurality of branch radiation beams).

[00149] Whilst embodiments of a radiation source SO have been described and depicted as comprising a free electron laser FEL, a radiation source SO may include a source of radiation other than a free electron laser FEL.

[00150] It should be appreciated that a radiation source which comprises a free electron laser FEL may comprise any number of free electron lasers FEL. For example, a radiation source may comprise more than one free electron laser FEL. For example, two free electron lasers may be arranged to provide EUV radiation to a plurality of lithographic apparatus. This is to allow for some redundancy. This may allow one free electron laser to be used when the other free electron laser is being repaired or undergoing maintenance.

[00151] A lithographic system LS may comprise any number of lithographic apparatus. The number of lithographic apparatus which form a lithographic system LS may, for example, depend on the amount of radiation which is output from a radiation source SO and on the amount of radiation which is lost in a beam delivery system BDS. The number of lithographic apparatus which form a lithographic system LS may additionally or alternatively depend on the layout of a lithographic system LS and/or the layout of a plurality of lithographic systems LS.

[00152] Embodiments of a lithographic system LS may also include one or more mask inspection apparatus MIA and/or one or more Aerial Inspection Measurement Systems (AIMS). In some embodiments, the lithographic system LS may comprise a plurality of mask inspection apparatuses to allow for some redundancy. This may allow one mask inspection apparatus to be used when another mask inspection apparatus is being repaired or undergoing maintenance. Thus, one mask inspection apparatus is always available for use. A mask inspection apparatus may use a lower power radiation beam than a lithographic apparatus. Further, it will be appreciated that radiation generated using a free electron laser FEL of the type described herein may be used for applications other than lithography or lithography related applications.

[00153] It will be further appreciated that a free electron laser comprising an undulator as described above may be used as a radiation source for a number of uses, including, but not limited to, lithography.

[00154] The term “EUV radiation” may be considered to encompass electromagnetic radiation having a wavelength within the range of 4-20 nm, for example within the range of 13-14 nm. EUV radiation may have a wavelength of less than 10 nm, for example within the range of 4-10 nm such as 6.7 nm or 6.8 nm.

[00155] The lithographic apparatus which have been described herein may be used in the manufacture of ICs. Alternatively, the lithographic apparatuses described herein may have other applications. Possible other applications include 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.

[00156] Different embodiments may be combined with each other. Features of embodiments may be combined with features of other embodiments.

While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The 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 clauses set out below. Other aspects of the invention are set-out as in the following numbered clauses.

1. An optical system arranged to receive a radiation beam, the optical system comprising:

a reflective element comprising a plurality of reflective regions, wherein different reflective regions are configured to reflect incident radiation in different directions, and wherein the reflective regions are configured such that at a given position of the reflective element the radiation beam is only incident on a subset of the reflective regions; and

an actuator configured to move the reflective element, relative to the radiation beam, thereby changing the one or more reflective regions on which the radiation beam is incident.

2. The optical system of clause 1, further comprising an optical element arranged to receive radiation reflected from the reflective element, wherein all of the reflective regions are configured to reflect radiation in a direction which causes it to be received by the optical element.

3. The optical system of clause 2, wherein the reflective element is configured such that movement of the reflective element to illuminate different reflective regions causes different portions of the optical element to be illuminated with reflected radiation at different times.

4. The optical system of clause 3, wherein the different portions of the optical element which are illuminated at different times, are spread over two perpendicular directions across the optical element.

5. The optical system of any preceding clause, further comprising one or more focussing elements configured to focus radiation which is reflected from the one or more reflective regions to one or more focal regions which lie in a focal plane.

6. The optical system of clause 5, wherein the reflective element and the one or more focussing elements are configured such that movement of the reflective element to change the one or more reflective regions on which the radiation beam is incident, changes the one or more focal regions to which radiation is focussed.

7. The optical system of clause 5 or 6, wherein the one or more focusing elements are configured to form an image of the radiation beam which is incident on the reflective element substantially in an image plane.

8. The optical system of clause 7, wherein the one or more focusing elements are configured such that movement of the reflective element does not substantially change the spatial extent of the radiation in the image plane.

9. The optical system of any preceding clause, wherein the reflective element and the actuator are configured such that the different directions in which radiation is reflected, follows a substantially periodic pattern having a time period which is less than approximately 1 millisecond.

10. The optical system of any preceding clause, wherein the reflective regions are configured such that at a given position of the reflective element the radiation beam is incident on a plurality of the reflective regions

11. The optical system of any preceding clause, wherein each reflective region comprises a reflective facet.

12. The optical system of clause 11, wherein each reflective facet is substantially flat.

13. The optical system of any of clauses 1-10, wherein each reflective region comprises a portion of a continuously undulating surface.

14. The optical system of any preceding clause, wherein the actuator is configured to rotate the reflective element about an axis of rotation.

15. The optical system of clause 14, wherein the reflective element has an approximately cylindrical shape, the reflective regions being arranged around the circumferential extent of the cylindrical shape and wherein the actuator is configured to rotate the cylindrical shape about a central axis of the cylinder.

16. The optical system of clause 14, wherein the reflective element is configured such that the reflective regions fit approximately onto a portion of a paraboloid of revolution, and wherein the actuator is configured to rotate the reflective element about a central axis of the paraboloid.

17. The optical system of clause 14, wherein the reflective element is configured such that the reflective regions fit approximately onto a disk-like shape.

18. The optical system of any preceding clause, further comprising a facetted mirror arranged to receive radiation reflected from the reflective element, the facetted mirror comprising:

a plurality of reflective facets each arranged to receive a portion of the radiation reflected from the reflective element and reflect the portion in a different direction.

19. The optical system of clause 18, wherein the reflective facets comprise curved reflective surfaces.

20. The optical system of clause 18 or 19, further comprising one or more focusing elements configured to form an image of the reflective element substantially at the facetted mirror.

21. The optical system of clause 20, wherein the one or more focusing elements are configured such that movement of the reflective element does not substantially change the spatial extent of the radiation which is incident on the facetted mirror but does change the angular extent of the radiation which is incident on the facetted mirror.

22. The optical system of any of clauses 18-21, further comprising one or more focusing elements configured to focus the radiation reflected from the reflective facets to a plurality of focal regions which lie in a focal plane, each focal region corresponding to radiation reflected from one or more different reflective facets.

23. The optical system of clause 22, wherein the one or more focusing elements are configured such that the focal regions are substantially evenly distributed in the focal plane.

24. The optical system of clause 22 or 23, wherein the one or more focussing elements are configured such that movement of the reflective element to change the one or more reflective

regions on which the radiation beam is incident, results in movement of the plurality of focal regions around the focal plane.

25. The optical system of any of clauses 22-24, wherein the one or more focusing elements are configured to form an image of the radiation beam which is incident on the reflective element in an image plane.

26. A radiation system comprising:

a radiation source configured to emit a main radiation beam;

an optical system according to any of clauses 1-25; and

a beam directing apparatus configured to direct at least a portion of the main radiation beam to be incident on a subset of the reflective regions of the reflective element.

27. The radiation system of clause 26, further comprising a beam splitting apparatus configured to split the main radiation beam into a plurality of branch radiation beams, wherein the beam directing apparatus is configured to direct one of the branch radiation beams to be incident on a subset of the reflective regions of the reflective element.

28. The radiation system of clause 26 or 27, wherein the radiation source comprises at least one free electron laser.

29. A lithographic system comprising:

an optical system according to any of clauses 1-25 or a radiation system according to any of clauses 26-28; and

a lithographic apparatus arranged to receive at least some of the radiation which is reflected from the reflective element.

30. A method of modifying a radiation beam, the method comprising:

illuminating a portion of a reflective element with a radiation beam, wherein the reflective element comprises a plurality of reflective regions, wherein different reflective regions are configured to reflect incident radiation in different directions, and wherein only a subset of the reflective regions is illuminated at any given time; and

moving the reflective element, relative to the radiation beam, so as to change the one or more reflective regions which are illuminated with the radiation beam.

CONCLUSIE

1. Een lithografieinrichting omvattende:

een belichtinginrichting ingericht voor het leveren van een stralingsbundel;

een drager geconstrueerd voor het dragen van een patroneerinrichting, welke patroneerinrichting in staat is een patroon aan te brengen in een doorsnede van de stralingsbundel ter vorming van een gepatroneerde stralingsbundel;

een substraattafel geconstrueerd om een substraat te dragen; en

een projectieinrichting ingericht voor het projecteren van de gepatroneerde stralingsbundel op een doelgebied van het substraat, met het kenmerk, dat de substraattafel is ingericht voor het positioneren van het doelgebied van het substraat in een brandpuntsvlak van de projectieinrichting.

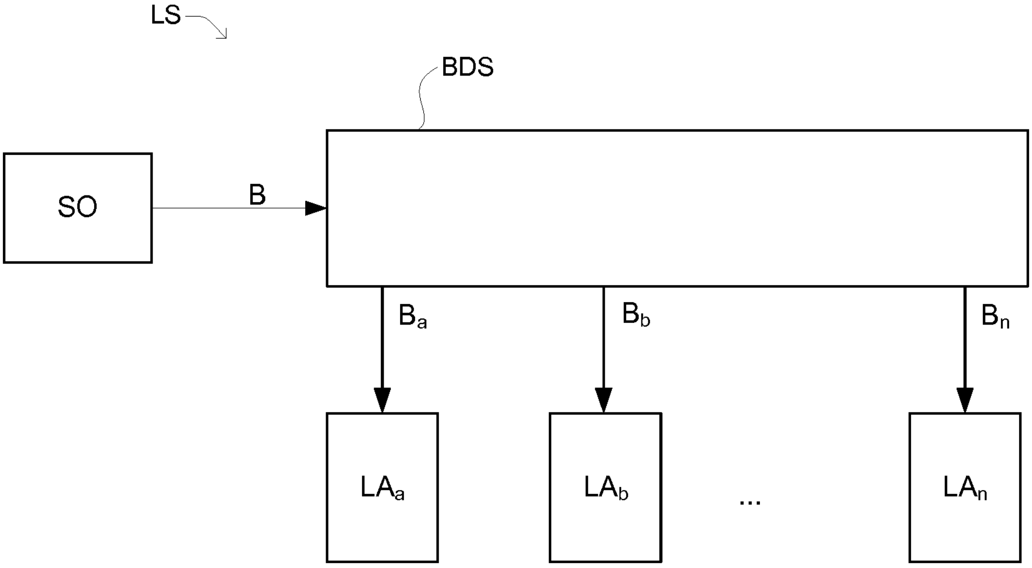
LS
BDS
SO
B
B_a
B_b
B_n
LA_a
LA_b
...
LA_n

FIG. 1

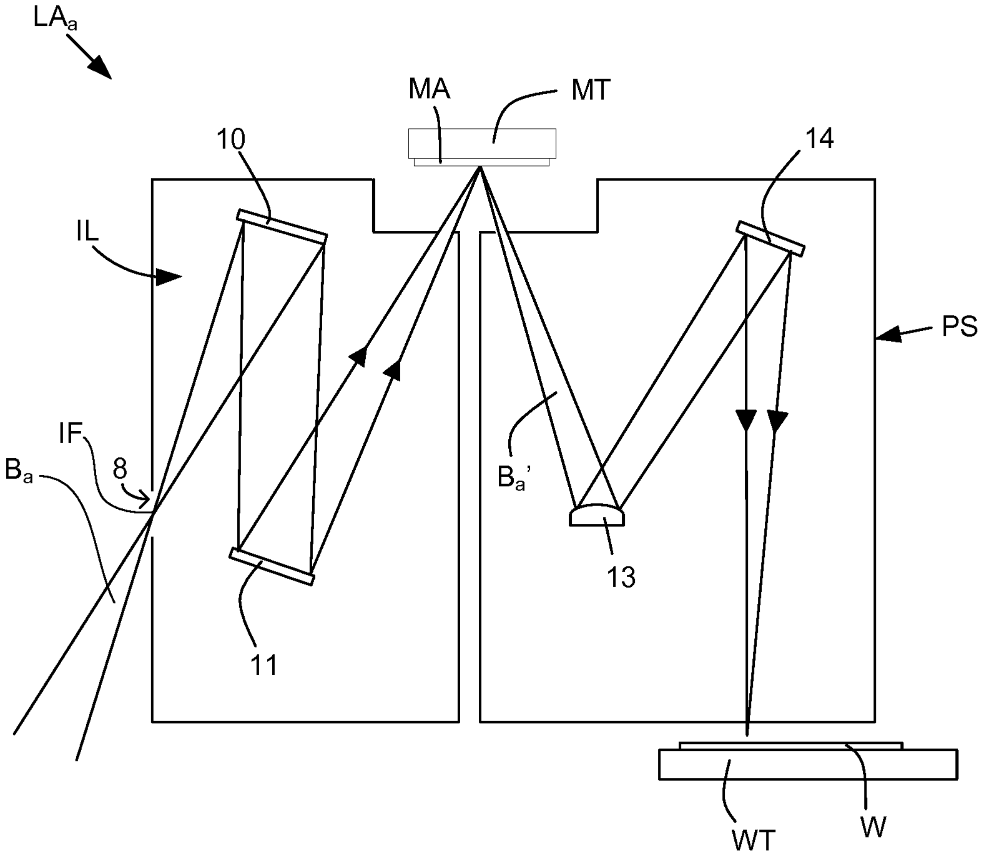
LA_a
MA
MT
10
14
IL
PS
IF
8
B_a
B_a'
13
11
WT
W

FIG. 2

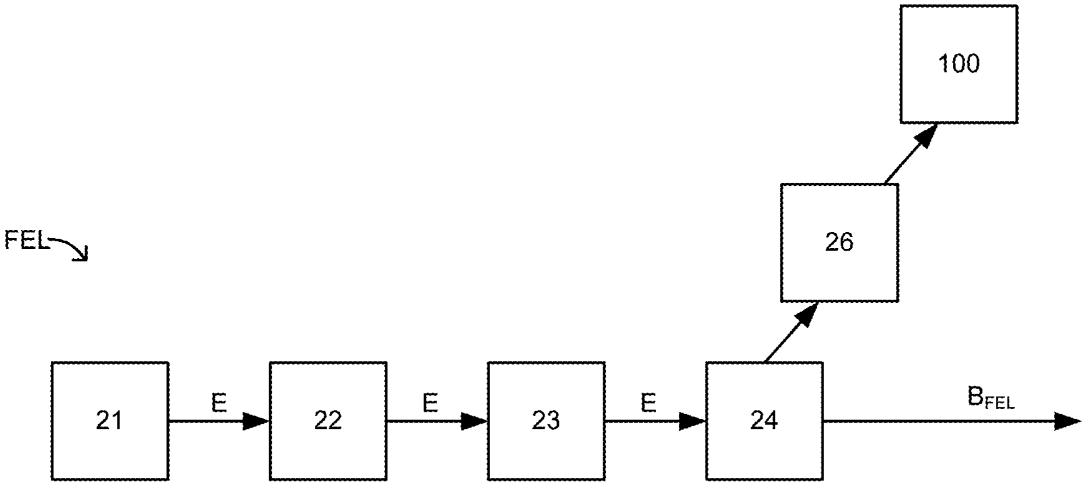
FEL
21
E
22
E
23
E
24
B_{FEL}
26
100

FIG. 3

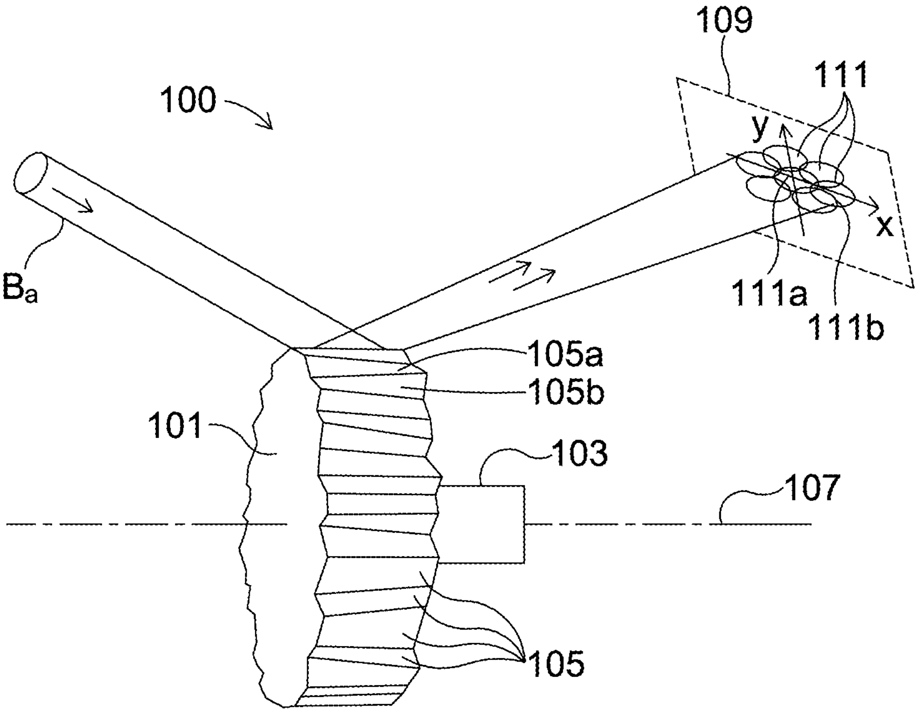
109
111
100
y
x
B_a
111a
111b
105a
105b
101
103
107
105

FIG. 4

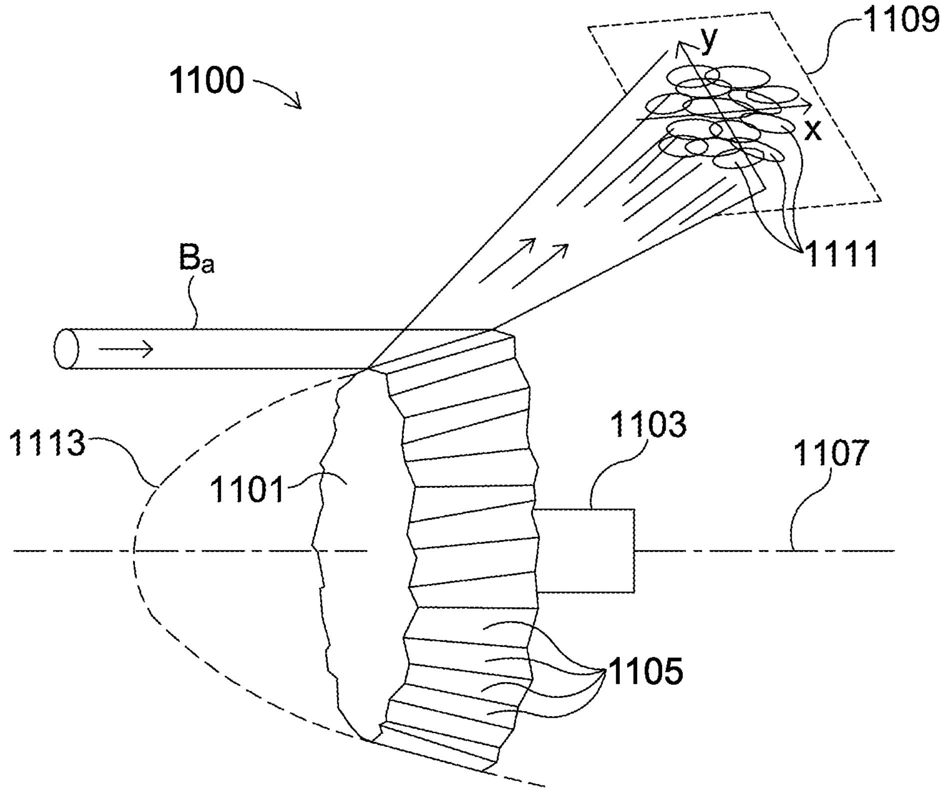
1100
1109
y
x
1111
Ba
1113
1101
1103
1107
1105

FIG. 5

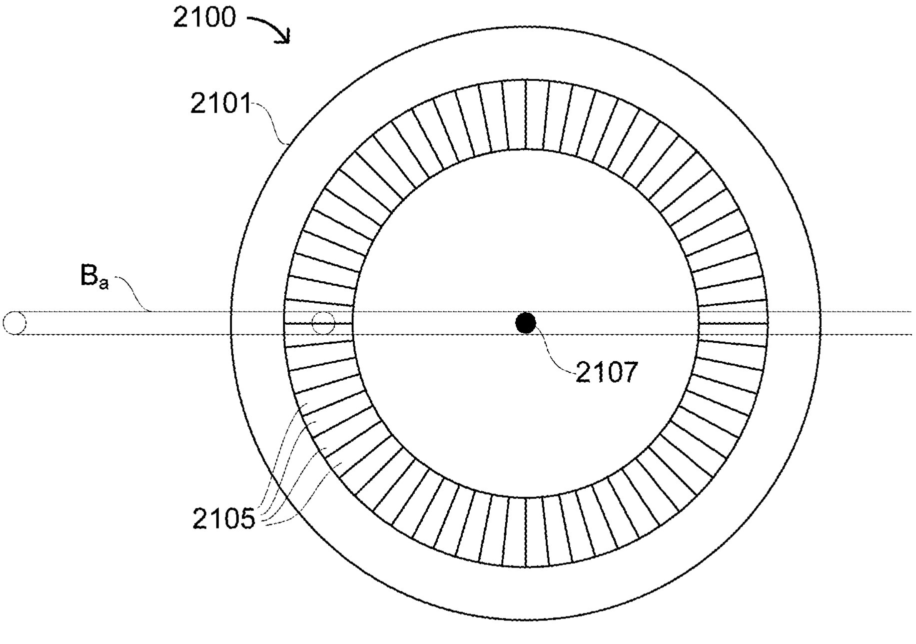
2100
2101
Ba
2107
2105

FIG. 6A

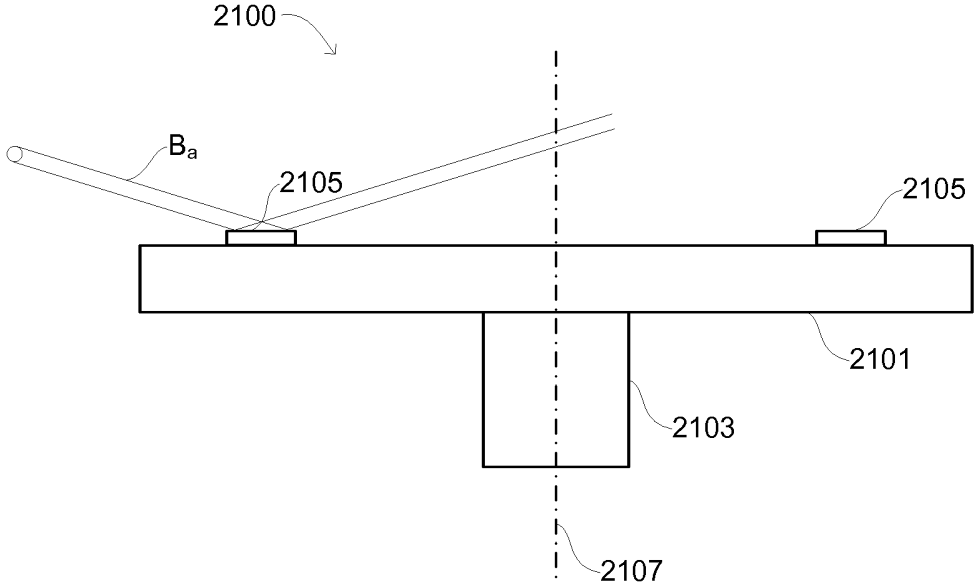
2100
B_a
2105
2105
2101
2103
2107

FIG. 6B

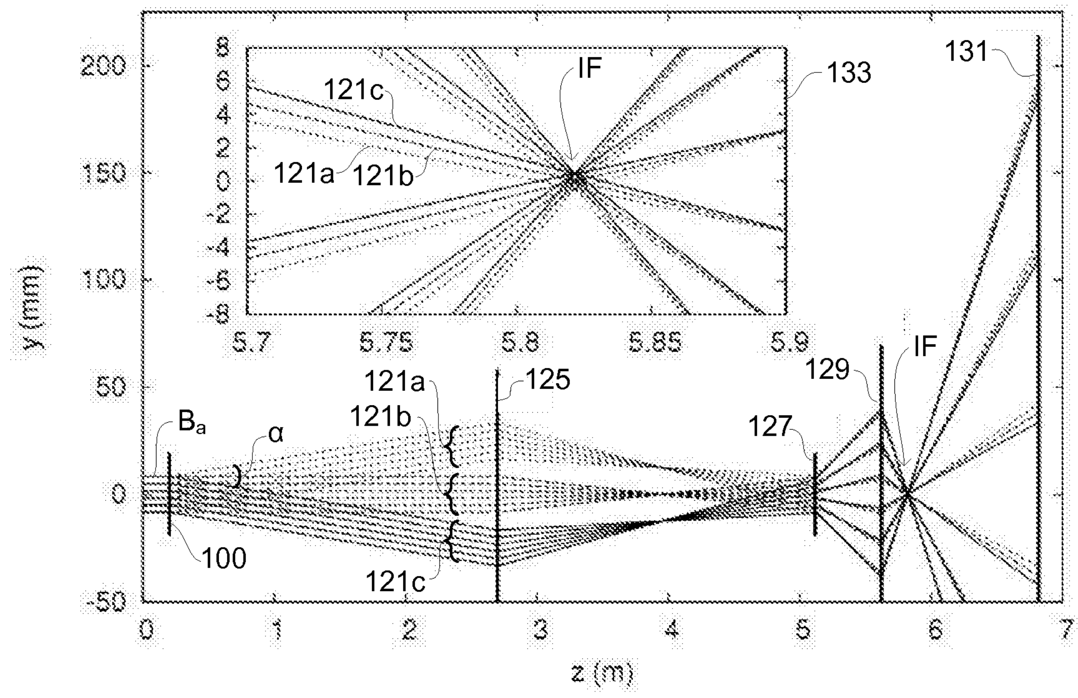
y (mm)
200
150
100
50
0
-50
z (m)
0
1
2
3
4
5
6
7
8
6
4
2
0
-2
-4
-6
-8
5.7
5.75
5.8
5.85
5.9
121c
IF
133
121a
121b
131
121a
125
121b
B_a
α
127
129
IF
100
121c

FIG. 7

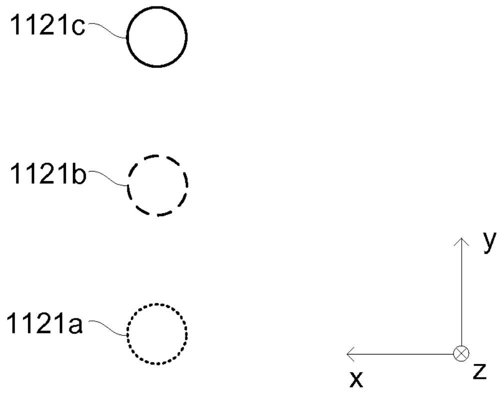

FIG. 8

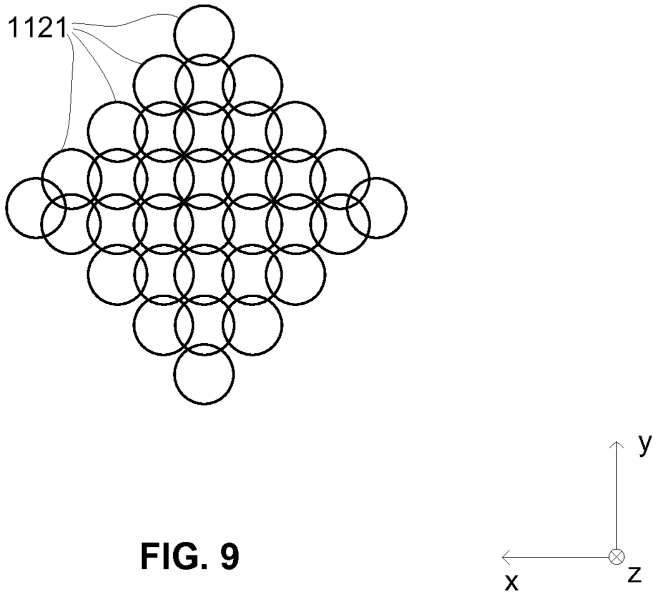

FIG. 9

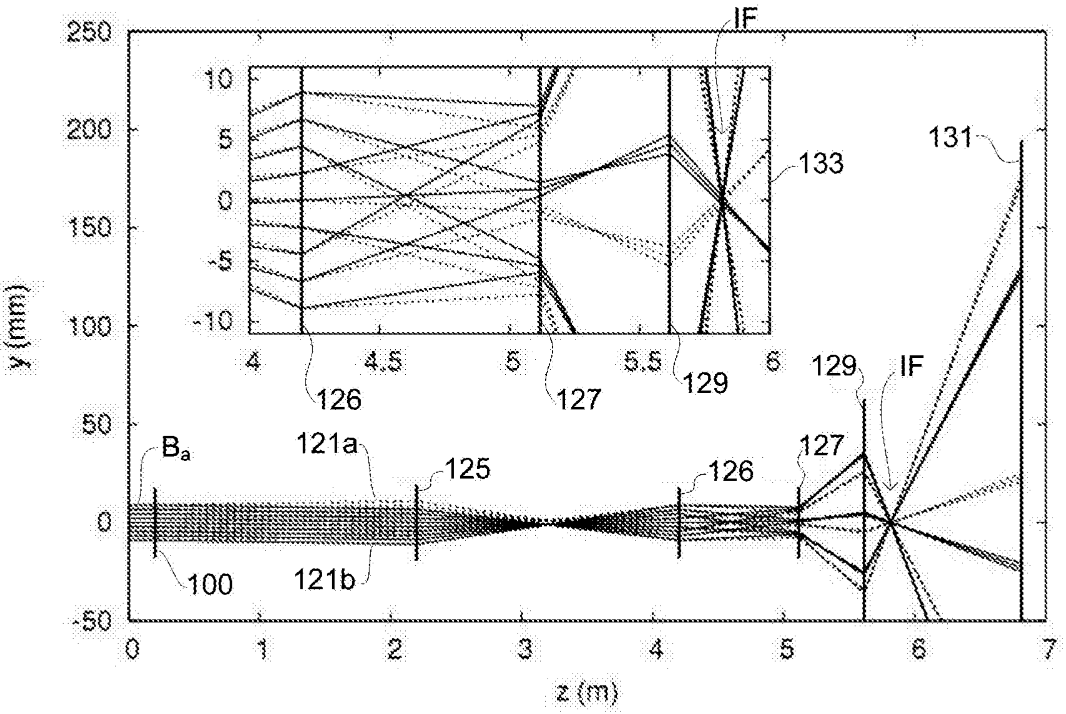
y (mm)
z (m)
250
200
150
100
50
0
-50
0
1
2
3
4
5
6
7
10
5
0
-5
-10
4
4.5
5
5.5
6
IF
133
131
126
127
129
129
IF
Ba
121a
125
126
127
100
121b

FIG. 10

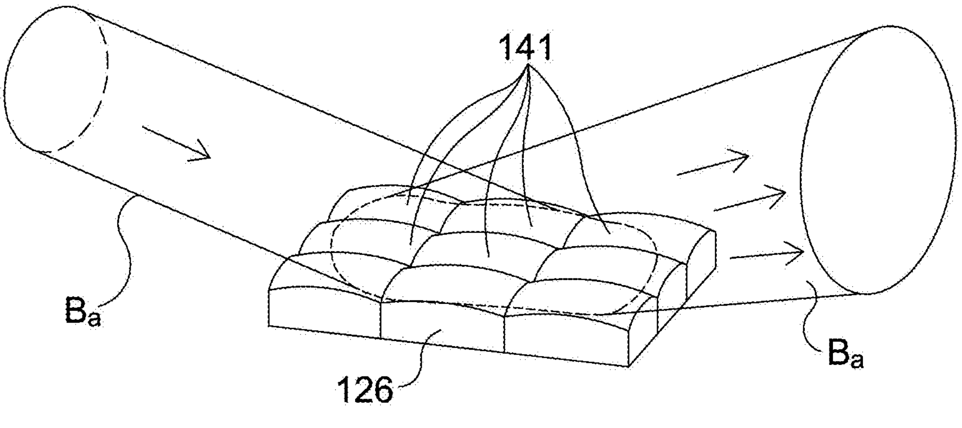
141
Ba
126
Ba

FIG. 11

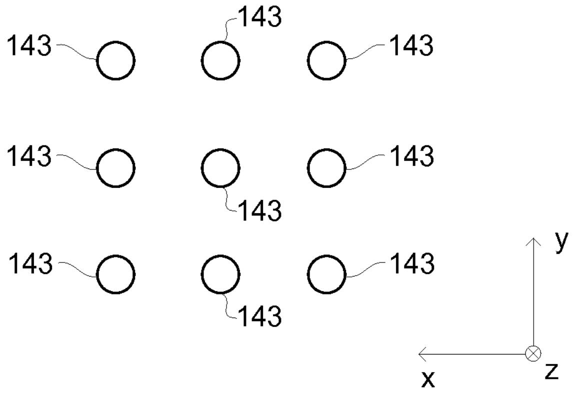

FIG. 12

ABSTRACT

An optical system arranged to receive a radiation beam. The optical system comprising a reflective element comprising a plurality of reflective regions, wherein different reflective regions are configured to reflect incident radiation in different directions, and wherein the reflective regions are configured such that at a given position of the reflective element the radiation beam is only incident on a subset of the reflective regions and an actuator configured to move the reflective element, relative to the radiation beam, thereby changing the one or more reflective regions on which the radiation beam is incident.