

# **RADIATION SYSTEM AND LITHOGRAPHIC APPARATUS**

## **FIELD**

**[0001]** The present invention relates to a radiation system and a lithographic apparatus that includes a radiation system.

## **BACKGROUND**

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

**[0003]** In addition to EUV radiation, radiation sources used in EUV lithography generate contaminant material that may be harmful for the optics and the working environment in which the lithographic process is carried out. Such is especially the case for EUV sources operating via a plasma produced discharge source, such as a plasma tin source. Such a source typically comprises a pair of electrodes to which a voltage difference can be applied. In addition, a vapor is produced, for example, by a laser beam that is targeted to, for example, one of the electrodes. Accordingly, a discharge will occur between the electrodes, generating a plasma, and which causes a so-called pinch in which EUV radiation is produced. In addition to this radiation, the discharge source typically produces debris particles, among which can be all kinds of microparticles varying in size from atomic to complex particles, which can be both charged and uncharged. It is desired to limit the contamination of the optical system that is arranged to

condition the beams of radiation coming from an EUV source from this debris. Conventional shielding of the optical system primarily includes a system comprising a high number of closely packed foils aligned parallel to the direction of the light generated by the EUV source. A so-called foil trap, for instance, as disclosed in EP1491963, uses a high number of closely packed foils aligned generally parallel to the direction of the light generated by the EUV source. Contaminant debris, such as micro-particles, nano-particles and ions can be trapped in walls provided by the foil plates. Thus, the foil trap functions as a contamination barrier trapping contaminant material from the source. Due to the arrangement of the platelets, the foil trap is transparent for light, but will capture debris either because it is not travelling parallel to the platelets, or because of a randomized motion caused by a buffer gas. It is desirable to improve the shielding of the radiation system, because some (directed, ballistic) particles may still transmit through the foil trap.

## SUMMARY

**[0004]** According to an aspect of the invention there is provided a radiation system for generating a beam of radiation that defines an optical axis. The radiation system includes a plasma produced discharge source constructed and arranged to generate EUV radiation. The discharge source includes a pair of electrodes constructed and arranged to be provided with a voltage difference, and a system constructed and arranged to produce a discharge between the pair of electrodes so as to provide a pinch plasma between the electrodes. The radiation system also includes a debris catching shield constructed and arranged to catch debris from the electrodes, to shield the electrodes from a line of sight provided in a predetermined spherical angle relative the optical axis, and to provide an aperture to a central area between the electrodes in the line of sight.

**[0005]** According to an aspect of the invention, there is provided a lithographic apparatus that includes a radiation system for generating a beam of radiation that defines an optical axis. The radiation system includes a plasma produced discharge source constructed and arranged to generate EUV radiation. The discharge source includes a pair of electrodes constructed and arranged to be provided with a voltage difference, and a system constructed and arranged to produce a discharge between the pair of electrodes so as to provide a pinch plasma between the electrodes. The radiation system also includes a debris catching shield constructed and arranged to catch debris from the electrodes, to shield the electrodes from a line of sight provided in a predetermined spherical angle relative the optical axis, and to provide an aperture

to a central area between the electrodes in the line of sight. The lithographic apparatus also includes a patterning device constructed and arranged to pattern the beam of radiation, and a projection system constructed and arranged to project the patterned beam of radiation onto a substrate.

**[0006]** Other aspects, features, and advantages of the present invention will become apparent from the following detailed description, the accompanying drawings, and the appended claims.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

**[0007]** Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

**[0008]** Figure 1 depicts a lithographic apparatus according to an embodiment of the invention;

**[0009]** Figure 2 depicts a schematic first embodiment of a radiation system of the lithographic apparatus of Figure 1 according to an aspect of the invention;

**[0010]** Figure 3 shows schematically a second embodiment according to an aspect of the invention;

**[0011]** Figure 4 shows a further embodiment according to an aspect of the invention;

**[0012]** Figure 5 shows a modification of the arrangement described with reference to Figure 4;

**[0013]** Figure 6 shows an alternative modification of the arrangement described with reference to Figure 4;

**[0014]** Figure 7 schematically shows a deflection principle of debris from the EUV source;

**[0015]** Figure 8 schematically shows a quadrupole magnet arrangement for providing debris deflection;

**[0016]** Figures 9a-c illustrate a further embodiment of the arrangement of Figure 4;

**[0017]** Figure 10 shows a graph related to a thermal cleaning of the radiation system;

**[0018]** Figure 11 shows an embodiment of the thermal cleaning principle referred with respect to Figure 10;

**[0019]** Figure 12 shows another embodiment of the thermal cleaning principle referred with respect to Figure 10;

**[0020]** Figures 13a-e show embodiments of continuous and droplet fluid jets;

[0021] Figure 14 shows a schematic perspective view of a radiation system according to an embodiment of the invention;

[0022] Figure 15 shows a schematic perspective view of a cross section of the radiation system of Figure 14;

[0023] Figure 16 shows a schematic perspective view of a wiping module of a radiation system according to an aspect of the invention;

[0024] Figure 17 shows a schematic top view of the wiping module of Figure 16;

[0025] Figure 18 shows a schematic cross-sectional side view of the wiping module of Figure 16;

[0026] Figure 19 shows a schematic cross-sectional side view of a wiping module of a radiation system according to another aspect of the invention;

[0027] Figure 20 shows a schematic perspective view of a wiping module of a radiation system according to a further aspect of the invention;

[0028] Figure 21 shows a schematic cross-sectional side view of a radiation system according to an embodiment according to the invention; and

[0029] Figure 22 shows a diagram of collectable optical power as a function of an opening semi-angle of a debris catching shield.

## DETAILED DESCRIPTION

[0030] Figure 1 schematically depicts a lithographic apparatus according to one embodiment of the invention. The apparatus comprises: an illumination system (illuminator) IL configured to condition a radiation beam B (e.g. UV radiation or EUV radiation); a support structure (e.g. a mask table) MT constructed to support a patterning device (e.g. a mask) MA and connected to a first positioner PM configured to accurately position the patterning device in accordance with certain parameters; a substrate table (e.g. a wafer table) WT constructed to hold a substrate (e.g. a resist-coated wafer) W and connected to a second positioner PW configured to accurately position the substrate in accordance with certain parameters; and a projection system (e.g. a refractive or reflective projection lens system) PS configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

[0031] The illumination and projection systems may include various types of optical components, such as refractive, reflective, diffractive or other types of optical components, or any combination thereof, for directing, shaping, or controlling radiation.

**[0032]** The support structure supports, i.e. bears the weight of, the patterning device. It holds the patterning device in a manner that depends on the orientation of the patterning device, the design of the lithographic apparatus, and other conditions, such as for example whether or not the patterning device is held in a vacuum environment. The support structure can use mechanical, vacuum, electrostatic or other clamping techniques to hold the patterning device. The support structure may be a frame or a table, for example, which may be fixed or movable as required. The support structure may ensure that the patterning device is at a desired position, for example with respect to the projection system. Any use of the terms “reticle” or “mask” herein may be considered synonymous with the more general term “patterning device.”

**[0033]** The term “patterning device” used herein should be broadly interpreted as referring to any device that can be used to impart a radiation beam with a pattern in its cross-section such as to create a pattern in a target portion of the substrate. It should be noted that the pattern imparted to the radiation beam may not exactly correspond to the desired pattern in the target portion of the substrate, for example if the pattern includes phase-shifting features or so called assist features. Generally, the pattern imparted to the radiation beam will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit.

**[0034]** The patterning device may be transmissive or reflective. Examples of patterning devices include masks, programmable mirror arrays, and programmable LCD panels. Masks are well known in lithography, and include mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. An example of a programmable mirror array employs a matrix arrangement of small mirrors, each of which can be individually tilted so as to reflect an incoming radiation beam in different directions. The tilted mirrors impart a pattern in a radiation beam which is reflected by the mirror matrix.

**[0035]** The term “projection system” used herein should be broadly interpreted as encompassing any type of projection system, including refractive, reflective, catadioptric, , or any combination thereof, as appropriate for the exposure radiation being used. Any use of the term “projection lens” herein may be considered as synonymous with the more general term “projection system”.

**[0036]** As here depicted, the apparatus is of a reflective type (e.g. employing a reflective mask). Alternatively, the apparatus may be of a transmissive type (e.g. employing a transmissive mask).

**[0037]** The lithographic apparatus may be of a type having two (dual stage) or more substrate tables (and/or two or more mask tables). In such “multiple stage” machines the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposure.

**[0038]** Referring to Figure 1, the illuminator IL receives a radiation beam from a radiation source SO. The source and the lithographic apparatus may be separate entities, for example when the source is an excimer laser. In such cases, the source is not considered to form part of the lithographic apparatus and the radiation beam is passed from the source SO to the illuminator IL with the aid of a beam delivery system comprising, for example, suitable directing mirrors and/or a beam expander. In other cases the source may be an integral part of the lithographic apparatus, for example when the source is a mercury lamp.

**[0039]** The illuminator IL may comprise an adjuster for adjusting the angular intensity distribution of the radiation beam. Generally, at least the outer and/or inner radial extent (commonly referred to as  $\sigma$ -outer and  $\sigma$ -inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the illuminator IL may comprise various other components, such as an integrator and a condenser. The illuminator may be used to condition the radiation beam, to have a desired uniformity and intensity distribution in its cross-section.

**[0040]** The radiation beam B is incident on the patterning device (e.g., mask MA), which is held on the support structure (e.g., mask table MT), and is patterned by the patterning device. Having traversed the mask MA, the radiation beam B passes through the projection system PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioner PW and position sensor IF2 (e.g. an interferometric device, linear encoder or capacitive sensor), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the radiation beam B. Similarly, the first positioner PM and another position sensor IF1 can be used to accurately position the mask MA with respect to the path of the radiation beam B, e.g. after mechanical retrieval from a mask library, or during a scan. In general, movement of the mask table MT may be realized with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning), which form part of the first positioner PM. Similarly, movement of the substrate table WT may be realized using a long-stroke module and a short-stroke module, which form part of the second positioner PW. In the case of a stepper (as opposed to a scanner) the mask table MT may be connected to a short-stroke actuator only, or may be fixed. Mask MA and substrate W may be

aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2. Although the substrate alignment marks as illustrated occupy dedicated target portions, they may be located in spaces between target portions (these are known as scribe-lane alignment marks). Similarly, in situations in which more than one die is provided on the mask MA, the mask alignment marks may be located between the dies.

**[0041]** The depicted apparatus could be used in at least one of the following modes:

**[0042]** 1. In step mode, the mask table MT and the substrate table WT are kept essentially stationary, while an entire pattern imparted to the radiation beam is projected onto a target portion C at one time (i.e. a single static exposure). The substrate table WT is then shifted in the X and/or Y direction so that a different target portion C can be exposed. In step mode, the maximum size of the exposure field limits the size of the target portion C imaged in a single static exposure.

**[0043]** 2. In scan mode, the mask table MT and the substrate table WT are scanned synchronously while a pattern imparted to the radiation beam is projected onto a target portion C (i.e. a single dynamic exposure). The velocity and direction of the substrate table WT relative to the mask table MT may be determined by the (de-)magnification and image reversal characteristics of the projection system PS. In scan mode, the maximum size of the exposure field limits the width (in the non-scanning direction) of the target portion in a single dynamic exposure, whereas the length of the scanning motion determines the height (in the scanning direction) of the target portion.

**[0044]** 3. In another mode, the mask table MT is kept essentially stationary holding a programmable patterning device, and the substrate table WT is moved or scanned while a pattern imparted to the radiation beam is projected onto a target portion C. In this mode, generally a pulsed radiation source is employed and the programmable patterning device is updated as required after each movement of the substrate table WT or in between successive radiation pulses during a scan. This mode of operation can be readily applied to maskless lithography that utilizes programmable patterning device, such as a programmable mirror array of a type as referred to above.

**[0045]** Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

**[0046]** In Figure 2 a schematic first embodiment is shown of a radiation system according to an aspect of the invention. In particular, there is shown a radiation system 1 for generating a beam of radiation 2 in a radiation space. The radiation space is bounded by a predetermined

spherical angle relative to an optical axis 3. The radiation system 1 includes a plasma produced discharge source 4 for generating EUV radiation. The discharge source includes a pair of electrodes 5 that are constructed and arranged to be provided with a voltage difference, and a system that typically includes a laser 6 for producing a vapor between the pair of electrodes so as to provide a discharge 7 between the electrodes 5. It has been found that debris 8 coming from the radiation system 1 is primarily produced on or near the electrodes 5. These effects also cause a generation of a so-called pinch which develops between the electrodes 5. Typically, the EUV light that is generated is produced by an electron transition in a Tin atom (or another suitable material, for example, Lithium or Xenon), which is ionized multiple times of electrons in the discharge process. It was found that debris particles 8, in particular, ballistic particles of the kind that may contaminate the downstream optics, are mainly produced on or near the electrodes 5 in debris producing zones 9, where the central EUV source light is mainly produced in the pinch zone 10 that is distanced from the debris producing zones 9. Thus, for a plasma produced discharge source 4, the debris producing zones 9 are typically distanced from the EUV radiation producing pinch zone 10. This effect can be utilized by the illustrated embodiment, which according to an aspect of the invention comprises a shield 11 to shield the electrodes 5 from a line of sight provided in a predetermined spherical angle relative the optical axis 3 and to provide an aperture 12 to a central area between the electrodes in the line of sight. Accordingly, debris 8, which is generated in the debris producing zone 9 initially (in the absence of additional electromagnetic fields, however, see the embodiment illustrated in Figure 5 - Figure 7) travels substantially in straight lines from the zone 9. Thus, a shield 11 that shields the electrodes 5 from a line of sight in a predetermined spherical angle around the optical axis 3 is able to trap these debris particles 8, so that in the line of sight a substantial amount of debris 8 is prevented from entering downstream optics (not shown). Additionally, the shield 11 substantially does not shield the radiation coming from the EUV radiation producing pinch zone 10, since it provides an aperture 12 to a central area (conforming to a designated pinch zone 10) between the electrodes 5 in the line of sight, which accordingly can travel into the downstream optics substantially unhindered by the shield 11. In this way, the debris (which comes from the electrodes) may be stopped by the shield, without stopping the EUV radiation. Practically, it is convenient to shield both electrodes, since it is probable that both electrodes generate debris-producing zones that can attribute in debris 8 production.

**[0047]** The shielding effect can be further optimized by placing the shields 11 close enough, preferably, a distance ranging between 0.5 and 25 mm to any of the electrodes, to shield a maximum spherical angle of the debris producing zone 9.

**[0048]** To minimize a distance with the electrodes, the heat load will be so high on the shield 11 that it is preferably provided as a fluid jet 13, for example, of molten Tin. Such a jet could have a length of about 75 mm and a thickness of several mm, for example ranging from 0.5 to 3 mm. It is noted that fluid jets are per se known from US 2006-0011864 which discloses electrodes in a plasma discharge source in the form of fluid jets, however, there is not disclosed a shield or at least one fluid jet provided near an electrode of a pair of electrodes. Accordingly, preferably, the debris catching shield 11 is provided, as illustrated, by a pair of fluid jets 13, arranged oppositely and generally parallel to a longitudinal axis of the electrodes 5. It may however, in certain embodiments, be possible to direct the plasma production substantially towards one of the electrodes 5, which one electrode will accordingly be a major contributor in producing debris 8. Such debris may vary in size and travel speed. For instance, one can have micro-particles: these are micron-sized particles with relatively low velocities. In addition, there may be produced nano-particles, which are nanometer-sized particles with typically quite high velocities; atomic debris, which are individual atoms that act as gaseous particles; and ions, which are ionised high-velocity atoms.

**[0049]** It is noted that in one embodiment, the fluid jet 13 may be provided near an electrode of the pair of electrodes without substantially being configured to shield the electrodes from a line of sight provided in a predetermined spherical angle relative the optical axis and to provide an aperture to a central area 10 between the electrodes in the line of sight (unlike the embodiment shown in Figure 2). In such an embodiment, according to another aspect of the invention, the fluid jet 13 may be accelerating the recombination rate of the plasma, which may increase the frequency of the EUV source 4 and accordingly may provide a higher power output of the radiation system. Specifically, the fluid jet 13 may comprise molten Tin, although other materials may be feasible to provide the same recombining effect, including, for example water or a liquid gas, such as liquid nitrogen or liquid argon. An advantage of the latter is that it may evaporate and thus may leave no further traces in the system. Additionally, the fluid is preferably of an electrically conductive material and may be kept at ground potential, although other materials, such as argon and nitrogen may also be used.

**[0050]** The advantage of the fluid jets is that the obstruction is continuously replaced and can thus withstand very high heat loads. However, in other embodiments, it may be possible, to

provide a shield 11 that is positioned at generally the same distance nearby the electrodes 5 as discussed hereabove with reference to Figure 2, but that is not formed by a fluid jet, but by a moving element (not shown), for example, an axially moving metal strip, that moves generally parallel to an electrode longitudinal axis, and which may be cooled by providing coolant in a container, for guiding the moving element there through.

**[0051]** Figure 3 shows schematically an embodiment of the invention, showing a shield in the form of a plurality of fluid jets 13, arranged in radial direction relative from the central area 10 between electrodes 5 in the line of sight. In such an embodiment, the fluid jets 13 are provided adjacent to each other, and may be generally aligned to form a static configuration of generally radially oriented platelets 14, relative to the central area 10. Although within the general context of the invention, preferably, these platelets are oriented to shield the electrodes 5 from a line of sight provided between the platelets 14, this embodiment may also have practical applications with the platelets oriented to include the electrodes 5 in a line of sight provided between the platelets 14. These applications may benefit from the heat load capacity of the shield 11 that is provided by the fluid jets 13. A further advantage is that the jets 13 by nature are not contaminated by debris depositions since they are continuously renewed. This is in contrast with a conventional foil trap solution where solid platelets 14(foils) are used to provide shielding from debris 8. These conventional platelets therefore may suffer from contamination which may hinder a proper transmission of the EUV radiation.

**[0052]** In particular, especially for plasma produced discharge sources 4 operated with Tin plasma, a suitable material for the fluid jets may also be Tin or a compound comprising Tin, such as for example Ga-In-Sn, which may be suitable to have a lower melting point and easier handling properties. Furthermore, although Figure 3 shows an embodiment wherein the jets 13 are dimensioned with a general circular form, other form, including strip forms may be feasible, thus providing a shield 11 comprising platelets 14 in the form of single jets, generally of the form as depicted in Figure 4. A thickness of such liquid foil may be typically 0.5 –1 mm, which is slightly thicker than conventional foil thicknesses that are about 0.1 mm thick. It is noted that thin liquid foils are discussed in T. Inamura, H. Tamura, H. Sakamoto, “Characteristics of Liquid Film and Spray Injected from swirl Coaxial Injector”; Journal of Propulsion and Power 19 (4), 623-639 (2003). In this publication, cone-shaped foils are produced. However, preferably, according to an aspect of the invention, a slit-shaped nozzle is used, in particular, for providing straight-formed jets that are radially oriented relative to a centre zone 10 wherein a pinch can develop. In addition, this static embodiment may be

combined with a rotating foil trap, known per se from EP1491963 and, of course, with other embodiments described in the current document.

**[0053]** Under certain circumstances, fluid jets may not be stable – i.e. they may spontaneously divide into droplets with a diameter approximately equal to the jet diameter. This means that it may only be possible to create continuous jets if the diameter is relatively large ( $> \sim 0.5$  mm). Therefore, it may be advantageous to use jets that intentionally consist of closely spaced droplets that can have a very small and controllable size, with a controllable distance between droplets. The ability to create such stable droplet chains (40  $\mu$ m diameter with about 40  $\mu$ m distance) was presented in the EUVL Sematech conference in Barcelona (Conference 7870, 17 Oct 2006) by David Brandt (session 3-SO-04) for use as a laser target in a LPP EUV source.

**[0054]** The stability of the droplet chains means that different configurations may be employed, depending upon which functional aspects (recombination and/or debris catching) need to be optimized. Figures 13a-e show examples of such configurations. Figure 13a depicts a continuous jet 13 in which the recombination surface is moving in the direction T. Figure 13b depicts a stable train of droplets 113, moving in direction T, which for the purposes of this invention may be considered to be a jet 13. The stability of the droplet chains means that these chains may be positioned adjacent to each other to add an extra degree of flexibility when implementing the invention. Figure 13c shows two adjacent chains of droplets 113, effectively creating a jet 13, extended in one direction compared to the jet 13 of Figure 13b. A disadvantage of a droplet chain is that debris has a possible path to pass through the fluid jet. Figure 13d and Figure 13e show how the droplet chains can be shifted in the direction of movement T with respect to each other to effectively create a virtual continuous jet 13 for debris having a trajectory in the plane of the figure and perpendicular to the direction of movement T of the jet.

**[0055]** Figure 4 in addition shows a further embodiment according to an aspect of the invention, wherein the debris catching shield, herebelow also indicated as a foil trap 15 comprises a static configuration of generally radially oriented platelets 14, relative to the central area 10, wherein the platelets 14 are oriented to shield the electrodes 5 from a line of sight provided between the platelets 14. In this embodiment, at least some of the platelets are of a solid nature, in particular, of foils used in a so called conventional foil trap. It is noted that WO 99/42904 A1 discloses a foil trap of generally the same configuration; however, the publication does not discuss that the platelets 14 are configured to shield the electrodes 5 from

a line of sight provided in a predetermined spherical angle relative the optical axis and to provide an aperture to a central area 10 between the electrodes in the line of sight. In comparison with conventional rotating foil traps of the type as disclosed in EP1491963, this static foil trap configuration may have an advantage in easier cooling properties, since, in an embodiment, this static foil trap configuration can be cooled using static coolant circuits devised on or in proximity of the platelets 14. Since the configuration is static, accordingly, cooling may be much simpler and therefore, the configuration can be easily scaled to higher power levels of the source. In addition, this configuration has as a benefit that it does not require moving parts, which may provide constructional advantages since the required strength and dimensions of the platelets 14 may be of a different order than the rotating conventional construction, which requires complex parts such as air bearings and high tension materials that can withstand centrifugal tension forces applied to the platelets. Thus, according to the proposed embodiment, the radially oriented platelets 14 are aiming at the pinch zone 10 thus substantially unhindering transmittance of EUV-radiation 16. This foil trap 15 will fill up with debris at certain locations so a slow rotation around the optical axis (e.g. once a day) could be useful to make sure no debris will contaminate the next foil trap 15 or other optics. This may be useful, since in a preferred embodiment, the optical axis may be 45 degrees with respect to a level plane. This principle could also be designed in combinations of concentric circles and plates. In addition, the geometry of the depicted embodiment, including static radially oriented platelets 14, may have stacking dimensions that have high gas resistance wherein a distance between the platelets may be in an order of 0.5 –2 mm, preferably about 1 mm. Accordingly, atomic debris may be trapped easier. Also, a high gas resistance may help to allow a lower buffer gas pressure near the pinch zone 10, which may resulting in a higher efficiency EUV power. Typically, such a buffer gas may be Argon gas.

**[0056]** In addition to the thermal cleaning techniques illustrated with reference to the Figure 10 –Figure 12 presented herebelow, the platelets 14 may provided as a material of porous characteristics for removing the debris from the platelets through capillary action. For instance, by using foil material with porous characteristics (e.g. sintered materials) Tin can be taken out of the optical path and drained (or buffered in an exchangeable element). Accordingly, lifetime of the debris suppression system may be increased and downtime due to foil trap cleaning may be minimized.

**[0057]** In addition to the above-discussed cleaning technique, the radiation system may comprise an excitator 17 (see Figure 4) for removing the debris from the platelets 14 through

mechanical excitation of the platelets 14. For example, by rotating the module fast enough (~2000-3000 RPM as an indication) on a temporarily basis, the tin may be spun of the relevant foils, and may be caught by a getter 18. In an embodiment, the revolution axis is the optical axis, but other axes of revolution may also be possible. A combination of rotation and vibration is also an option. Accordingly, the excitator may comprise a centrifuge for removing the debris from the platelets through centrifugal action and advantageously a getter 18 for catching debris 8 removed from the platelets.

**[0058]** Also, the foil could be externally excited (longitudinal waves) so a flow of tin in a predefined direction may be present. Also (directional) accelerations/vibrations can be used to give excitation profile(s) (pending between stick/slip effect of the droplets) to the entire module instead of each separate foil.

**[0059]** Figure 5 discloses a further embodiment of the arrangement described with reference to Figure 4. In this embodiment, a deflecting electromagnetic field unit 19 is disposed between the electrodes 5 and a shield, in this embodiment illustrated as foil trap 15. By applying an electromagnetic field, charged debris particles 8 traveling from the debris producing zones 9 can be deflected, which accordingly can be used to virtually expand the distance between the EUV radiation producing pinch zone 10 and the debris producing zones 9 as will be made even more clear with reference to Figure 7. In Figure 5, the deflecting field is produced by a pair of electrodes 20 arranged oppositely to the optical axis. Accordingly, a static electric field is generated according to which the electrically charged particles can be deflected.

**[0060]** In Figure 6, in contrast to the embodiment depicted in Figure 5, or in addition to it, the electromagnetic deflecting field is provided as a static magnetic field 21, due to magnet elements 26 (see Figure 8) arranged around the optic axis 3. For a front view of this configuration, see Figure 8. Although various static field configurations are feasible, an optimally defined field is provided as a quadrupole field, arranged for deflecting substantially all electrically charged particles 8 traveling generally in a direction towards the optical system (not shown), towards a plane 22 oriented along the radially oriented platelets 14 and generally parallel to a length axis of the electrodes 5. Preferably, as is also shown in the Figure, this plane 22 is provided along the optical axis 3. However, it may be possible to select another region that is more off axis to deflect the particles thereto. Accordingly, charged debris particles can be deflected more easily towards the platelets 14 of the foil trap 15, which virtually increases the distance between the electrodes 5. Consequently, fewer platelets 14 may be needed to

achieve a given extent of debris suppression. Accordingly, a typical distance may range between 0.5 and 3 mm, preferably about 2 mm. This significantly increases the optical transmission of the foil trap.

**[0061]** The principle of operation in Figure 6 is as follows. The rectangle 10 indicates an acceptance width of the foil trap in the absence of a magnetic field and is accordingly generally corresponding to a zone 10 from where EUV radiation is produced. However, particles 8 generated near the edges of the zone 10 (accordingly, produced from a debris producing zone 9) may travel unhindered through the shield, in this embodiment illustrated as foil trap 15, without being intercepted, as illustrated by the trajectory 23.

**[0062]** By applying a magnetic field of the type as indicated (with a conventional arrow indication), such debris particles 8 are deflected towards the optical axis 3. For example, the particle with trajectory 23 may be deflected to follow the solid line 24 and no longer be transmitted through the foil trap 15. This is because on entrance of the foil trap, the particle appears to originate from a point outside the acceptance width 10 as indicated by the other dashed line 25. In other words, the application of the magnetic field effectively narrows down an effective acceptance width of the shield, which width defines a zone from where debris particles could enter the system unhindered. Accordingly, for a given dimensioning of the acceptance width, the optical transmission may be improved by reducing the number of platelets 11 and applying a magnetic field.

**[0063]** A typical distance for the acceptance width of the foil trap in the absence of a magnetic field may be ranging from about 0.5 to about 2 mm, preferably about 1 mm. For typical foil trap dimensions (inner radius 30 mm, relative to a central zone 10, outer radius 139 mm), this leads to a foil trap with 137 foils having an optical transmission of approximately 63%. As the Figure shows, in a preferred embodiment, the distance  $d$ ,  $d'$  between the platelets 14 may vary, wherein typically a distance  $d$  towards the optical axis 3 may increase relative to distances  $d'$  away from the optical axis 3.

**[0064]** Figure 7 shows how the source of the particles, that is, the debris producing zone 9 can be virtually shifted over a distance  $d$  to a virtual debris producing zone 9' by applying the magnetic field. Accordingly, an effective acceptance width may be reduced.

**[0065]** In the presence of a magnetic field  $\mathbf{B}$ , a particle with charge  $q$  and velocity  $\mathbf{v}$  experiences a Lorentz force given by

**[0066]** 
$$\mathbf{F} = q\mathbf{v} \times \mathbf{B} \quad (1)$$

[0067] Consequently, if the direction of the magnetic field is perpendicular to the velocity, the particle follows a circular trajectory with radius  $R$  equal to

$$R = \frac{mv}{qB} \quad (2)$$

[0068] In the present embodiment, the angular deflection  $\alpha$  due to the magnetic field depends on the distance over which the field is applied, which is approximately equal to the inner radius of the foil trap  $r_0$ . The deflection angle is given by  $\sin \alpha = r_0/R$  as shown in Figure 3. The apparent point of departure of the particle is accordingly displaced over a distance  $d$  given by

$$d = r_0 \sin \alpha - R(1 - \cos \alpha) \quad (3)$$

which for small values of  $\alpha$  reduces to

$$d = \frac{r_0^2}{2R} \quad (4)$$

[0069] By substituting Eq. (2), the following expression relating the displacement  $d$  to the characteristic parameters  $q$ ,  $m$  and  $v$  of the debris particles is obtained:

$$d = \frac{qBr_0^2}{2mv} \quad (5)$$

[0070] Using permanent magnets or electromagnets, a magnetic field of the order of 1 T can fairly easily be achieved. When a magnetic field is applied so that the displacement  $d$  is equal to 0.5 mm for a certain type of debris, the acceptance width for that debris accordingly effectively decreases by a factor of 2 compared to the earlier mentioned value of 1 mm acceptance width. One can therefore construct a foil trap that has an acceptance width of 2 mm and still obtain the same extent of debris mitigation. Such a foil trap may have only 69 foils and an optical transmission of 70%. Thus, the optical transmission is significantly improved by applying a magnetic field.

[0071] Figure 8 shows a front view, seen along the optic axis, of the electrodes 5 and a quadrupole magnet configuration of magnets 26. In this configuration, the North-South lines of opposing magnets 26 are oriented alternating and generally parallel to the longitudinal axis of the electrodes 5. Accordingly, a magnetic field may be produced that follows the orientation depicted in Figure 6, that is, with a general direction of the magnetic field on either sides of the optic axis 3 in a plane generally parallel to the length axis of the electrodes, to deflect the particles inwards towards a plane 22 coaxial with the optic axis 3. Accordingly, for typical configurations, positively charged particles are focused to a vertical plane (by focusing in the

horizontal direction and spreading in the vertical direction). Alternatively, a similar (but less well-defined) deflecting field may be obtained by placing two identical magnetic poles on opposite sides of the optical axis.

[0072] Figure 14 shows a schematic perspective view of a further embodiment of a radiation system 1 according to an aspect of the invention. The radiation system 1 is arranged for generating a beam of radiation in a radiation space. Figure 15 shows a schematic perspective view of a cross section of the radiation system 1 of Figure 14. Similar to the radiation system shown in Figure 2, the radiation system 1 shown in Figures 14 and 15 comprises a plasma produced discharge source for generating EUV radiation. The discharge source includes a pair of electrodes 5 that are constructed and arranged to be provided with a voltage difference, and a system that typically includes a laser for producing a vapor between the pair of electrodes 5 so as to provide a discharge between the electrodes. Further, the electrodes 5 define a discharge axis 40 interconnecting said electrodes 5. The discharge axis 40 traverses the central area between the electrodes. The radiation space is substantially bounded between two mutually reversely oriented cones 41, 42 relative to the discharge axis 40, the cones 41, 42 having their apex 43 substantially in the central area between the electrodes 5. The two cones 41, 42 have a diabolo type appearance. The radiation system 1 further comprises a debris catching shield constructed and arranged to catch debris from said electrodes 5 from a line of sight provided in the radiation space 44 bounded between the two cones 41, 42, and to provide an aperture to the central area between the electrodes in said line of sight. The debris catching shield extends circumferentially around the discharge axis 40 over at least 180°, preferably over at least 270°. By arranging the shield such that the shield surrounds the discharge axis 40 over at least 180° the effective optical output of the plasma source is relatively high. A beam of radiation generated by the plasma source and passing the debris catching shield has a larger spherical extension compared with the embodiment of the radiation system shown in Figure 2. As a consequence, the performance of the plasma source output that can be collected for further processing, increases with respect to the radiation system shown in Figure 2. Further, by extending the debris catching shield circumferentially around the discharge axis 40 up to 360° an optimal effective optical output is obtained. In one embodiment, the shield extends over a circumferential range of approximately 270° to approximately 360°, a space near the discharge axis is available, e.g. for inspection purposes and/or for arranging devices, such as a system for producing the vapor between the pair of electrodes and/or a cooling structure.

**[0073]** The debris catching shield of the radiation system 1 in Figure 14 includes a ring shaped or ring section shaped structure that is substantially rotationally symmetric with respect to the discharge axis 40. As a consequence, debris suppression can be obtained along radial directions in a substantial circumferential range around the discharge axis 40, viz. in a circumferential range of at least 180° around the discharge axis 40. The debris catching shield comprises a static configuration of generally radially oriented platelets, relative to the discharge axis 40, wherein the platelets are oriented to shield the electrodes from a line of sight provided between the platelets. It appears that good debris suppression can be obtained along directions having an angle of at least 45° with respect to the discharge axis 40. Platelets of the debris catching shield have concentric conical surfaces and/or comprise at least one planar section.

**[0074]** In a preferred embodiment, the platelets, also called foils, have concentric conical surfaces aligned with respect to the discharge axis 40, with their apex at the central area along the discharge axis. In another embodiment, the foils can be composed of a multiple number of planar sections, the foil being aligned with respect to the discharge axis. For example, each foil may have, in cross-sections thereof, a hexagonal or octagonal shape.

**[0075]** Figure 9 shows a further embodiment of the static configuration of generally radially oriented platelets 14 described with reference to Figure 4. In this embodiment, instead of solid monolithic platelets 14, in at least some of the platelets 14, traverses 27 are provided oriented generally transverse to the platelets 14. This embodiment may provide thermal isolation to the further downstream platelets 14, as seen from the EUV source 4. In addition to it, possibly by applying fluid jets as shown in Figure 3, preferably on a proximal side of the platelets 14 relative to the EUV source 4, the heat load to the platelets 14 can be further managed. In addition, a gas 28 can be guided through the traverses 27 of the platelets 14, which may be used for cleaning purposes of the platelets 14, for example, a hydrogen radical gas. Accordingly, the platelets 14 can be cleaned to prevent debris depositing on the platelets 14, thereby preventing a situation in which EUV light will no longer be able to pass through the platelets. Preferably, the foil trap may be cleaned without having to take the foil trap out of the system. The principle of additional traverses in the shown foil trap embodiment could also be used for other types of foil traps, in particular, in non-static foil traps.

**[0076]** In addition to, or alternatively, the traverses may be used as a buffer gas to provide a buffer gas zone within a zone inside the platelets, in order to be able to further trap, for example, neutral nanoparticles which may diffuse through the platelets 14 and may cause

contamination of the optical system provided downstream (not shown). Figure 9 A shows a side view of an embodiment with traverses 27, which may be provided with alternating use of wires 29 and platelet parts 30.

**[0077]** Figure 9B shows an embodiment with only wires 29; to provide a configuration similar to the fluid jet configuration depicted in Figure 3. Figure 9C in addition shows a top view generally seen along an axis parallel to the length axis of the electrodes 5, of the platelet embodiment depicted in Figure 9 A. The more open structure of Figure 9B has an advantage when integrating foil trap cleaning based on hydrogen radicals, because it becomes easier to bring the reactive H radicals to the surface of the foils, and it becomes easier to transport the reaction products out of the foil trap 15. However, the drawback is that the flow resistance of the foil trap 15 becomes lower, which may make it more difficult to achieve a high buffer gas pressure. Therefore one needs to optimize the amount of openings in the platelets. The preferred embodiment therefore is in most cases a partially open foil structure, as shown in Figure 9A. Furthermore, in a preferred embodiment H cleaning is integrated with the wired structures shown in the figures by providing an electric current supply 31, which is connected to at least some of the wires 29 of a platelet 14. At least some of the wires 29 in the platelet are now interconnected in order to allow a current to run through several wires 29 simultaneously. With a high enough current (for example, 20 A for a 0.4 mm thick wire), the wires will form a filament that will reach temperatures of about 2000 °C where typically H<sub>2</sub> molecules will dissociate, generating H radicals. These H radicals can then react with Sn to form gaseous SnH<sub>4</sub>, which is pumped out of the system. In order to add H<sub>2</sub> to the system, the embodiment therefore further comprises a H<sub>2</sub> gas inlet 32 and the embodiment comprises a vacuum pump 33 to remove gas from the system (as shown in Figure 9C).

**[0078]** Alternatively, it is possible to remove debris from the capture shield using evaporation. Figure 10 schematically indicates a comparison between removal rates by evaporation for lithium and tin. Along the horizontal axis is plotted the temperature, in degree Celsius. Along the vertical axis is plotted the removal rate (nm/hr). In particular Figure 10 shows a graph of a calculation that was performed to calculate the removal rate of tin and lithium, for temperatures in a range of 200 - 800 °C. In addition, for tin a removal rate of about 0.1 nm/hour was calculated for a temperature of about 900 K, and a rate of about 1E5 nm/hour for a temperature of about 1400 K, with an almost exponential increase. Thus, in a range between these temperature values, by providing a heating system (which may be EUV source 4) the debris catching shield, in particular a foil trap 15 of the kind as shown in Figure 4 may be selectively heated to elevate a temperature of the debris shield to a temperature for evaporating debris from the debris catching shield. In addition a gas supply system is provided which may in use serve for providing a buffer gas flow between the platelets, and

which may off line be used for cleaning purposes, in particular, for providing a gas flow to evacuate evaporated debris from the debris catching shield. A particular preferable elevation temperature of the debris catching shield for a tin plasma source may be at least 900 K for offline cleaning purposes. Accordingly an alternative may be provided for chemically reactive cleaning, which may be harmful to the optics system. For a temperature of the platelets 14 of 940 K (667 C) a Tin evaporation of 0.4 nm/hour may be achievable.

**[0079]** Advantageously, a lithium plasma source is used since lithium has a significantly higher vapor pressure than tin (about 9 orders of magnitude) and as a consequence also a significantly higher removal rate (removal rate of 0.4 nm/hr requires temperature of only 550 K (277 C). This allows applying evaporative cleaning of lithium-contaminated surfaces at significantly lower temperatures than evaporative cleaning of tin-contaminated surfaces; evaporative cleaning of collector shells contaminated with lithium is feasible.

**[0080]** Figure 11 shows a general schematic illustration of the cleaning principle explained hereabove with reference to Figure 10. In particular, a platelet 14 is heated, so that debris 8 deposited thereon will be evaporated. By providing a gas flow 34 along the platelet 14, the evaporated debris, for example, tin vapor 35, will be carried away from the platelet, through which the platelet can be cleaned. Although Figure 11 has been explained with reference to a gas flow along a platelet 14 of a foil trap, the cleaning principle can be used generally, to clean EUV mirror surfaces in particular, of downstream optical elements such as a collector element.

**[0081]** In Figure 11, the object to be cleaned (a platelet 14 or mirror optic) is heated while a gas is flowing over the mirror in order to transport the tin vapor away from the mirror. Heating can be done with a heating device, but it is also possible to temporarily reduce active cooling of the object, and use the heat generated by the EUV source.

**[0082]** In Figure 12 this technique is used for the collector 36 of an EUV lithography setup. In this embodiment the collector shells are heated one-by-one, in order to evaporate the tin from the reflective side of the collector shell, and to deposit the tin vapor on the backside of the collector shell below. When a collector shell 37 is heated, it will typically evaporate tin on both sides of the shells. This means that also the backside of the shell will evaporate tin and deposit this on the reflective surface of the collector shell above. To prevent this it is preferable to heat the center shell first, and then continue with the next shell, etc. Thus by cleaning the collector shells in the right order and controlling the temperature of the collector shell at the same time, it is possible to minimize (re)deposition on the reflective surface.

**[0083]** Figure 16 shows a schematic perspective view of a wiping module 60 of a radiation system according to an aspect of the invention. The wiping module 60 is provided with a multiple number of substantially parallel oriented wiping elements 61 that are movable along respective platelet surfaces 62 of a debris catching shield. Figures 17 and 18 show further schematic views of the wiping module 60, in a top view and a cross-sectional side view, respectively. A single frame supports the wiping elements 61. In particular, the wiping module is implemented as a comb-like structure wherein the individual wiping elements 61 form the fingers of the comb. The width of the wiping elements 61 are chosen such that the elements 61 fill an intermediate space 63 between adjacent platelet surfaces. As consequence, platelet surfaces arranged opposite to each other can be wiped simultaneously by performing one or more movements of the wiping module 60 with respect to the surfaces to be cleaned. A local wiping element width  $W$  substantially equals the intermediate space 63 distance between two adjacent platelet surfaces. It is noted that in another embodiment according to an aspect of the invention, the wiping elements are not oriented substantially parallel, but otherwise, e.g. mutually deviating arranged for following a surface shape of a platelet to be cleaned.

**[0084]** By moving the wiping module 60 along a moving path of a wiping element 61 with respect to a platelet surface 62 contamination particles, such as Sn contamination, is swept and/or pushed away from the platelet surface 62. As the spacings between platelets of the debris catching shield, also called foil trap, can be small, contamination particles might quickly fill said intermediate spacings, thereby strongly reducing a transmittance of the foil trap. This is especially the case with foil traps that are directly exposed to micro particle debris emitted by an EUV source, such as described referring to Figures 14 and 15. Thus, by applying the wiping module 60, contamination particles can be removed from the platelet surfaces, thereby improving the transmittance of the foil trap.

**[0085]** As the wiping elements 61 are substantially parallel oriented, similarly oriented platelet surfaces can be cleaned. Further, instead of using a single frame for supporting the wiping elements, multiple supporting elements can be used for supporting the wiping elements. It is also possible to mutually interconnect ends of the finger-like wiping elements, thereby obtaining a plate-like structure having slots for receiving the platelets.

**[0086]** It is noted in this context that during use of the wiping module, the wiping elements move with respect to the platelet surfaces, meaning that the wiping elements move, or the platelets, or both such that a net relative movement results. Along a moving path of the wiping elements with respect to the platelet surfaces, the intermediate spacing distance between two

opposite platelet surfaces remains substantially constant, thereby maintaining an efficient wiping operation. In an alternative embodiment, the distance between the opposite platelet surfaces along said path varies, e.g. for providing locally a low sweep resistance for the movement of the wiping elements.

**[0087]** The wiping elements 61 are arranged for performing a translation and/or swiveling movement with respect to the respective platelet surfaces 62. In the embodiment shown in Figures 16-18, the wiping elements 61 perform a translation, i.e. the elements 61 move in a moving direction M, substantially transversely with respect to the plane wherein the wiping elements extend. The platelets 62 are substantially planar. Further, the platelet structure of the debris catching shield, the foil trap, is substantially invariant in the moving direction M, thereby allowing an efficient cleaning operation of the wiping module 60. The moving direction M is substantially transverse with respect to both a discharge axis and an optical axis of the source.

**[0088]** Viewed from the discharge 7 between the electrodes of the source, the platelets 62 extend substantially between a fixed radial inner distance and a fixed radial outer distance, see e.g. Figure 18. As can be deduced from the figures, some space is to be reserved for accommodating the wiping module 60 between the source and a collector, especially when the wiping elements 61 are at end positions of the moving path, in Figure 18 at an uppermost and lowermost position.

**[0089]** Depending on an accumulation rate of contamination particles, e.g. Sn, the wiping module 60 can be moved along the platelet surfaces of the foil trap at a specific time interval, e.g. once every 5 minutes. This can be done online during operation of the source. However, a significant amount of radiation can be blocked during a wiping action and it may be necessary to compensate this loss of illumination with a longer illumination time, e.g. using a feedback system with a dose sensor. In a non-operational state of the wiping module 60, in a stationary position, the wiping module is preferably placed outside a collection angle of the source, in order to counteract any radiation blocking. As an example, the wiping module can in the non-operational state be placed in an uppermost or lower position. Alternatively, the wiping module may be placed on the optical axis, the position as shown in Figure 18, so that it is optimally aligned with source radiation paths, so that optical losses are relatively small.

**[0090]** In an embodiment according to an aspect of the invention, the wiping module further comprises one or more wipers 64 that are positioned to clean the wiping elements 61 from contamination particles that are collected during a wiping movement. Preferably, the

wiping module also comprises a collection base 65 to collect the contamination particles that are removed from the wiping elements. As shown in Figure 18, the wipers 64 can be positioned to clean the wiping elements when the module is in its uppermost position or in its lowermost position. Alternatively, the wipers can also be positioned for cleaning the wiping elements in either the uppermost position or lowermost position. In the embodiment shown in Figure 18, the wipers 64 perform a movement along the surface of the wiping elements 61. By collecting the contamination particles in the one or more collection bases 65, the particles such as Sn, can be removed, e.g. for re-use. In another embodiment according to the invention, the wiping elements 61 are arranged for moving along a stationary wiper 64, see e.g. Figure 19 showing a schematic cross-section view of a wiping module embodiment. Specifically, the wiper might comprises two wiper sections placed opposite with respect to each other and defining a receiving opening for receiving the wiping elements 61. In further embodiments according to an aspect of the invention, the wiping elements are cleaned otherwise, e.g. by using a hydrogen or halogen cleaning or evaporation process.

**[0091]** Figure 20 shows a schematic perspective view of a wiping module 60 of a radiation system according to a further aspect of the invention. Here, the platelets 14 of the foil trap are curved, in particular the platelets have concentric conical surfaces aligned with respect to a discharge axis of the source as explained referring to Figure 14. The apex of the platelets are located substantially at a central area along the discharge axis. In the embodiment shown in Figure 20, the wiping elements 61 of the wiping module 60 are arranged for performing a swiveling movement with respect to the respective platelet surfaces. The swiveling axis of the swiveling movement substantially coincides with the discharge axis of the EUV source. Since the spacing between the platelets is substantially invariant under swiveling with respect to the discharge axis, an effective and efficient wiping operation can be performed. In radiation system shown in Figure 20 a more compact construction is obtained. In particular, no substantial additional space is required for the wiping module in a non-operational state. Further, the wiping elements block merely a minimum amount of radiation during operation as the wiping elements are always aligned with the central area between the electrodes. In addition, the cleaning process at extreme positions of the wiping elements becomes easier.

**[0092]** According to a further aspect of the invention, the surface of the wiping elements is treated for enhancing its wetting properties, e.g. by reduction of oxides or by applying a coating.

**[0093]** It is noted that the described wiping module variants can also be applied in combination with other debris catching shield types. As an example, such a wiping module can be applied in combination with a debris catching shield that extends circumferentially around the discharge axis over at least 180°, preferably over at least 270°, optionally over 360°. In such an embodiment, the debris catching shield can be rotated with respect to the discharge axis, thereby performing a cleaning action by means of a stationary wiping module. Therefore, according to an aspect of the invention, a radiation system is provided for generating a beam of radiation in a radiation space, the radiation system comprising a plasma produced discharge source constructed and arranged to generate extreme ultraviolet radiation, the discharge source comprising a pair of electrodes constructed and arranged to be provided with a voltage difference, and a system constructed and arranged to produce a discharge between said pair of electrodes so as to provide a pinch plasma between said electrodes, a debris catching shield comprising platelets constructed and arranged to catch debris from said electrodes, and a wiping module provided with a multiple number of substantially parallel oriented wiping elements movable along respective surfaces of said platelets. In a preferred embodiment according to an aspect of the invention, the intermediate distance between platelet surfaces is substantially invariant along a moving path of a wiping element with respect to a platelet surface to be cleaned.

**[0094]** Figure 21 shows a schematic cross-sectional side view of a radiation system according to an embodiment according to the invention. The radiation system 1 comprises a plasma produced discharge source and a debris catching shield as explained referring to Figures 14 and 15. The source includes a pair of electrodes 5 between which electrodes a discharge 7 is generated during operation of the radiation system 1. In a radiation space that is bounded between two mutually reversely oriented cones, a beam of radiation generated passing through a debris catching shield having a static configuration of generally radially oriented platelets 14. In the shown embodiment, the platelets 14 form a ring-shaped foil trap. Further, the system 1 comprises a collector configuration for modifying a generated beam of radiation, wherein the collector configuration substantially surrounds the plasma produced discharge source in a circumferential direction around the discharge axis. The collector configuration comprises a normal incidence reflector 44 that extends circumferentially substantially around the plasma source. In Figure 21, an upper cross section 44a and a lower cross section 44b of the reflector 44 is shown. The reflector 44 is arranged for reflecting the beam of radiation passed through the foil trap. In the shown embodiment, the reflector 44 is provided with an elliptic

reflector surface so that the beam 46a, 46b incident upon the reflector surface is transformed into a converging beam 48a, 48b propagating towards an intermediate focus point 50. It is noted that the collector configuration can be arranged to extend over a reduced circumferential range, e.g. over a circumferential range of approximately  $270^\circ$  with respect to the plasma source, in particular if the debris catching shield also does not entirely enclose the discharge axis 40 in the circumferential orientation. Further, instead of applying a single normal incidence collector, a grazing incidence collector, or a combination of a normal incidence collector and a grazing incidence collector might be applied.

**[0095]** In addition, it is noted that a collector configuration substantially surrounding a plasma produced discharge source can not only be applied in combination with a radiation system according to the invention having a debris catching shield constructed and arranged to catch debris from electrodes of a plasma source, to shield said electrodes from a line of sight provided in the radiation space, and to provide an aperture to a central area between said electrodes in said line of sight, but also in combination with other radiation systems, e.g. provided with a rotating foil trap configuration. Therefore, according to an aspect of the invention, a radiation system is provided for generating a beam of radiation in a radiation space, the radiation system comprising a plasma produced discharge source constructed and arranged to generate extreme ultraviolet radiation, the discharge source comprising a pair of electrodes constructed and arranged to be provided with a voltage difference, and a system constructed and arranged to produce a discharge between said pair of electrodes so as to provide a pinch plasma between said electrodes, and a collector configuration for modifying a generated beam of radiation, wherein the collector configuration substantially surrounds the plasma produced discharge source in a circumferential direction around discharge axis interconnecting said electrodes. In a preferred embodiment according to the invention, the collector configuration extends circumferentially around the discharge axis over at least  $180^\circ$ , preferably over at least  $270^\circ$ , optionally over  $360^\circ$ . In a further preferred embodiment according to the invention, the collector configuration is substantially rotationally symmetric with respect to the discharge axis between the electrodes.

**[0096]** Figure 22 shows a diagram of collectable optical power as a function of an opening semi-angle of a debris catching shield. An amount of effective, collectable optical power transmitted through the debris catching shield can be calculated by subtracting the solid angle allocated to the cones 41, 42 in Figure 14 from a total of  $4\pi$ . The solid angle subtended by a

single cone of opening semi-angle  $\alpha$  is given by  $2\pi (1 - \cos \alpha)$ . Hence, the total solid angle that can be collected is given by:

$$\Omega = 4\pi - 4\pi(1 - \cos \alpha) = 4\pi \cos \alpha = 4\pi \sin \theta \quad (6)$$

where  $\theta$  is the opening semi-angle of the foil trap. For example, a foil trap with  $\theta = 45^\circ$  covers 71% of the total solid angle of  $4\pi$ .

**[0097]** The amount of power that is actually transmitted through the debris catching shield can be calculated by integrating the transmittance of the debris catching shield over the covered solid angle. The transmittance of the debris catching shield increases with  $\theta$  due to the increasingly dense spacing between the foils.

**[0098]** Figure 22 shows a diagram of collectable optical power as a function of an opening semi-angle of a debris catching shield. The diagram shows a first curve 80 representing the collectable solid angle as a function of the semi-angle of the shield according to equation 6, assuming that optical power is emitted in  $4\pi$  and that no losses occur in passing the shield. Further, the diagram shows a second curve 81 wherein optical losses have been incorporated according to parameters of a typical foil trap shield. From the diagram, it can be deduced that, as an example, using a foil trap with  $\theta = 45^\circ$ , 45% of the radiation emitted in  $4\pi$  can be collected after the foil trap. The diagram further shows a third and fourth curve 82, 83 representing a collectable power without and with losses in the foil trap, respectively, in a typical radiation system as shown in Figure 5, assuming a typical collection with respect to the optical axis of a beam of radiation. As can be seen from the diagram, the amount of optical power that can be collected using a typical ring-shaped foil trap with  $\theta = 45^\circ$  is about four times higher than the collectable power in the typical radiation system collecting a beam of radiation using a foil trap as e.g. shown in Figure 5.

**[0099]** Although specific reference may be made in this text to the use of lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications, such as the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, flat-panel displays, liquid-crystal displays (LCDs), thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms “wafer” or “die” herein may be considered as synonymous with the more general terms “substrate” or “target portion”, respectively. The substrate referred to herein may be processed, before or after exposure, in for example a track (a tool that typically applies a layer of resist to a substrate and develops the exposed resist), a metrology tool and/or an inspection tool. Where applicable, the

disclosure herein may be applied to such and other substrate processing tools. Further, the substrate may be processed more than once, for example in order to create a multi-layer IC, so that the term substrate used herein may also refer to a substrate that already contains multiple processed layers.

**[00100]** The term “lens”, where the context allows, may refer to any one or combination of various types of optical components, including refractive, reflective, magnetic, electromagnetic and electrostatic optical components.

**[00101]** The descriptions above are intended to be illustrative, not limiting. Thus, it will be apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the claims set out below.

## What is claimed is:

1. A radiation system for generating a beam of radiation defining an optical axis, the radiation system comprising:
  - a plasma produced discharge source constructed and arranged to generate extreme ultraviolet radiation, the discharge source comprising a pair of electrodes constructed and arranged to be provided with a voltage difference, and a system constructed and arranged to produce a discharge between said pair of electrodes so as to provide a pinch plasma between said electrodes; and
  - a debris catching shield constructed and arranged to catch debris produced on or near said electrodes in debris producing zones, to shield said electrodes from a line of sight provided in a predetermined spherical angle relative the optical axis, and to provide an aperture to a central area between said electrodes in said line of sight.
2. A radiation system according to claim 1, wherein the debris catching shield comprises at least one fluid jet.
3. A radiation system according to claim 2, wherein the fluid jet comprises molten tin or a tin compound.
4. A radiation system according to claim 3, wherein the tin compound comprises Ga—In—Sn.
5. A radiation system according to claim 1, wherein the debris catching shield is provided by a pair of fluid jets, arranged oppositely and generally parallel to a longitudinal axis of the electrodes.
6. A radiation system according to claim 2, wherein the debris catching shield comprises a plurality of fluid jets, arranged in radial direction relative from the central area.
7. A radiation system according to claim 6, wherein said plurality of fluid jets are provided adjacent to each other.
8. A radiation system according to claim 1, wherein the debris catching shield is provided at a distance from the electrodes ranging between about 0.5 mm and about 25 mm.
9. A radiation system according to claim 1, wherein the debris catching shield is provided by a moving element that moves generally parallel to an electrode longitudinal axis.
10. A radiation system according to claim 9, wherein a container is provided for containing a coolant, for guiding said moving element therethrough.
11. A radiation system according to claim 1, wherein the debris catching shield comprises a static configuration of generally radially oriented platelets, relative to said central area, wherein the platelets are oriented to shield the electrodes from a line of sight provided between said platelets.

12. A radiation system according to claim 11, wherein a distance between the platelets is increased relative to distances away from the optical axis.
13. A radiation system according to claim 11, wherein a distance between the platelets ranges between about 0.5 mm and about 3 mm.
14. A radiation system according to claim 11, further comprising an electromagnetic deflecting field unit disposed for applying an electromagnetic deflecting field between the electrodes and the shield.
15. A radiation system according to claim 14, wherein said electromagnetic deflecting field unit provides a static magnetic field.
16. A radiation system according to claim 15, wherein said magnetic field is provided as a quadrupole field, arranged for deflecting positive particles towards a plane oriented along said radially oriented platelets.
17. A radiation system according to claim 16, wherein said plane is provided along the optic axis.
18. A radiation system according to claim 11, further comprising a hydrogen radical supply system for guiding hydrogen radicals through said platelets.
19. A radiation system according to claim 11, wherein at least some of the platelets are provided with traverses oriented generally transverse to said platelets.
20. A radiation system according to claim 19, further wherein said traverses are provided with wires.
21. A radiation system according to claim 19 further comprising a hydrogen radical supply system for guiding hydrogen radicals through said traverses.
22. A radiation system according to claim 11 wherein at least some of the platelets are provided by a fluid jet.
23. A radiation system according to claim 22, wherein the fluid jet comprises molten tin or a tin compound.
24. A radiation system according to claim 23, wherein the tin compound comprises Ga—In—Sn.
25. A radiation system according to claim 1, further comprising a heating system that can be selectively heated for elevating a temperature of said debris catching shield to a temperature for evaporating said debris from said debris catching shield; and a gas supply system for providing a gas flow to evacuate said evaporated debris from said debris catching shield.
26. A radiation source according to claim 25, wherein said elevation temperature is at least 900° C. to remove tin debris.
27. A radiation source according to claim 25, wherein said elevation temperature is at least 270° C. to remove lithium debris.

28. A radiation system according to claim 1, wherein said plasma source comprises tin, lithium, or xenon.
29. A radiation system according to claim 11, wherein the platelets are provided as a material of porous characteristics for removing said debris from said platelets through capillary action.
30. A radiation system according to claim 11, further comprising an excitator for removing said debris from said platelets through mechanical excitation of said platelets.
31. A radiation system according to claim 30, wherein said excitator comprises a vibrator for providing vibrations to said platelets.
32. A radiation system according to claim 30, wherein said excitator comprises a centrifuge for removing said debris from said platelets through centrifugal action.
33. A radiation system according to claim 30, further comprising a getter for catching debris removed from said platelets.
34. A radiation system according to claim 1, wherein the system that is constructed and arranged to produce a discharge between said pair of electrodes comprises a laser.
35. A lithographic apparatus comprising:
- a radiation system constructed and arranged to generate a beam of radiation defining an optical axis, the radiation system comprising:
    - a plasma produced discharge source constructed and arranged to generate extreme ultraviolet radiation, the discharge source comprising a pair of electrodes constructed and arranged to be provided with a voltage difference, and a system constructed and arranged to produce a discharge between said pair of electrodes so as to provide a pinch plasma between said electrodes; and
    - a debris catching shield constructed and arranged to catch debris produced on or near said electrodes in debris producing zones, to shield said electrodes from a line of sight provided in a predetermined spherical angle relative the optical axis, and to provide an aperture to a central area between said electrodes in said line of sight;
    - a patterning device constructed and arranged to pattern the beam of radiation; and
    - a projection system constructed and arranged to project the patterned beam of radiation onto a substrate.