(19) NL Octrooicentrum

(11) **2004706**

(12) A **OCTROOIAANVRAAG**

(21) Aanvraagnummer: **2004706**

(22) Aanvraag ingediend: **12.05.2010**

(51) Int.Cl.:
G03F 7/20 (2006.01) ***H05G 2/00*** (2006.01)

(30) Voorrang:
22.07.2009 US 61/227562

(41) Aanvraag ingeschreven:
25.01.2011

(43) Aanvraag gepubliceerd:
02.02.2011

(71) Aanvrager(s):
ASML Netherlands B.V. te VELDHOVEN.

(72) Uitvinder(s):
Wouter Soer te Nijmegen.
Maarten van Herpen te Heesch.
Kurt Gielissen te Eindhoven.
Martin Jak te Eindhoven.

(74) Gemachtigde:
ir. A.J. Maas te Veldhoven.

(54) **Radiation Source.**

(57) According to a first aspect of the present invention there is provided a radiation source comprising: a radiation emitter for emitting radiation; a collector for collecting radiation emitted by the radiation emitter; and an outlet configured, in use, to introduce a cooled gas into the radiation source. The cooled gas may be arranged to be cooled prior to introduction into the radiation source.

NL A 2004706

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Radiation Source

Field

The present invention relates to a radiation source, and to a lithographic apparatus which is in connection with or comprises such a radiation source.

Background

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.

In order to be able to project ever smaller structures onto substrates, it has been proposed to use extreme ultraviolet (EUV) radiation having a wavelength within the range of 5-20 nm, for example within the range of 13-14 nm. It has further been proposed that radiation with a wavelength of less than 10 nm could be used, for example 6.7 nm or 6.8 nm. In the context of lithography, wavelengths of less than 10 nm are sometimes referred to as 'beyond EUV'.

Extreme ultraviolet radiation and beyond EUV radiation may be produced using a plasma. The plasma may be created for example by directing a laser at particles of a suitable material (e.g. tin), or by directing a laser at a stream of a suitable gas or vapor, such as Xe gas or Li vapor.

Alternatively, the plasma may be created using an electrical discharge. The resulting plasma emits extreme ultraviolet radiation (or beyond EUV radiation), which is collected using a collector such as a normal incidence collector or mirrored grazing incidence collector, which receives the extreme ultraviolet radiation and focuses the radiation into a beam.

In addition to extreme ultraviolet radiation, the plasma produces debris in the form of particles, such as thermalized atoms, ions, nanoclusters, and/or microparticles. The debris is projected, together with the extreme ultraviolet radiation, towards the collector and may cause damage to the collector.

It is desirable to prevent debris from coming into contact with and, for example, coating or damaging the collector. Coating of the collector may, for example, reduce the reflectivity of the collector, reducing the amount of radiation that may be collected and used in the patterning of a substrate.

Debris from plasma–based extreme ultra violet radiation sources is commonly suppressed using a buffer gas. Debris repeatedly collides with constituent parts (e.g. atoms or molecules) of the buffer gas, and these collisions cause the debris to slow down and/or be deflected from their original path. The slowing down and/or deflection of the debris can be used to obviate or mitigate the problem of the debris coming into contact with the collector. After the debris has been slowed down and/or deflected, the debris may be, for example, pumped away (e.g. out of the radiation source) and/or intercepted by a debris trap (for example, a foil trap or the like).

The degree to which the debris is suppressed (i.e. the suppression factor) depends on the number of buffer gas atoms (or, for example, molecules) that debris (for example, a debris atom or the like) encounters on its way through the buffer gas. At constant temperature and volume, the number of buffer gas atoms is proportional to the buffer gas pressure (from the ideal gas law $pV = nRT$). The buffer gas is often characterized in terms of the integrated pressure along the trajectory of the debris. The suppression can be improved by increasing the integrated pressure. Increasing the integrated pressure can be achieved by increasing the pressure, or by increasing the distance over which the pressure is applied. However, both of these solutions are difficult to implement in practice. For instance, the pressure is typically limited by a maximum operating pressure of the radiation source, since too high a pressure inhibits the expansion of the plasma that emits extreme ultra violet radiation. The distance over which the pressure may be applied is limited by the space between the point at which radiation is generated (i.e. the location of the radiation emitter, for example, the plasma) and the collector. Increasing this distance increases the size of the radiation source, which is undesirable.

SUMMARY

It is an object of the present invention to provide a radiation source that solves one or more problems of the prior art, whether identified herein or elsewhere, or which provides an alternative radiation source to those of the prior art.

According to a first aspect of the present invention there is provided a radiation source comprising: a radiation emitter for emitting radiation; a collector for collecting radiation emitted by the radiation emitter; and an outlet configured, in use, to introduce a cooled gas into the radiation source.

The cooled gas may be arranged to be cooled prior to introduction into the radiation source. The cooled gas may be arranged to be introduced into the radiation source in a compressed state. The gas may be arranged to be introduced in the form of a pressurized liquid which is allowed to evaporate to form the cooled gas. The radiation source may further comprise a nebulizer for nebulizing the liquid.

The outlet may be configured to introduce the cooled gas at a location in-between the radiation emitter and the collector.

The outlet may be configured to introduce the cooled gas at a location in-between the radiation emitter and an exit aperture of the source.

The radiation source may comprise one or more further outlets, each further outlet being arranged to introduce a cooled gas into the radiation source at a different location within the radiation source.

The radiation source may be a plasma-based radiation source, such as a discharge produced plasma radiation source, or a laser produced plasma radiation source.

The collector may be a normal incidence collector or a grazing incidence collector.

The radiation source may be configured to generate radiation having a wavelength of substantially 20 nm or less.

The cooled gas may be arranged to have a temperature below an ambient temperature (e.g. of the environment in which the radiation source is located), or a temperature that is substantially the same as a boiling point of the gas. The cooled gas may be arranged to have that temperature by appropriate cooling, pressurisation or the like.

The cooled gas may be arranged, in use, to serve as one or more of: a buffer gas; a gas for cooling a component of the radiation source; a gas for cleaning a component of the radiation source. The gas may be arranged to perform such a function by, for example, the composition of the gas, or the location of the introduction of the gas into the radiation source.

According to a second aspect of the present invention there is provided a radiation source arrangement comprising: a radiation source according to the first aspect of the present invention; and a source of cooled gas, pressurized gas or liquefied gas in connection with the outlet of the radiation source.

According to a third aspect of the present invention there is provided a lithographic apparatus in connection with, or comprising, a radiation source or radiation source arrangement according to the first and/or second aspect of the present invention.

According to a fourth aspect of the present invention there is provided a method of operating a radiation source or radiation source arrangement any of the first, second or third aspect of the present invention, the method comprising: introducing a cooled gas into the radiation source via an outlet.

BRIEF DESCRIPTION OF THE DRAWINGS

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:

- Figure 1 schematically depicts an embodiment of a lithographic apparatus;

- Figure 2 schematically depicts a detailed schematic illustration of the lithographic apparatus of Figure 1;

- Figure 3 schematically depicts part of a radiation source according to a first embodiment of the invention; and

- Figure 4 schematically depicts part of a radiation source according to a second embodiment of the invention.

<u>DETAILED DESCRIPTION</u>

Figure 1 schematically depicts a lithographic apparatus 1. The apparatus 1 comprises:

- an illumination system (illuminator) IL configured to condition a radiation beam B (e.g. EUV radiation).

- a support structure (e.g. a mask table) MT constructed to support a patterning device (e.g. a mask) MA and connected to a first positioner PM configured to accurately position the patterning device in accordance with certain parameters;

- a substrate table (e.g. a wafer table) WT constructed to hold a substrate (e.g. a resist-coated wafer) W and connected to a second positioner PW configured to accurately position the substrate in accordance with certain parameters; and

- a projection system (e.g. a refractive projection lens system) PS configured to project a pattern imparted to the radiation beam B by patterning device MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

The illumination system may include various types of optical components, such as refractive, reflective, magnetic, electromagnetic, electrostatic or other types of optical components, or any combination thereof, for directing, shaping, or controlling radiation.

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 1, 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.”

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.

Examples of patterning devices include masks and programmable mirror arrays. Masks are well known in lithography, and typically in an EUV radiation (or beyond EUV) lithographic apparatus would be reflective. 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.

The term “projection system” used herein should be broadly interpreted as encompassing any type of projection system. Usually, in a EUV (or beyond EUV) radiation lithographic apparatus the optical elements will be reflective. However, other types of optical element may be used. The optical elements may be in a vacuum. Any use of the term “projection lens” herein may be considered as synonymous with the more general term “projection system”.

As here depicted, the apparatus 1 is of a reflective type (e.g. employing a reflective mask).

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.

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. 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. The source SO and the illuminator IL, together with the beam delivery system if required, may be referred to as a radiation system. In accordance with an embodiment of the present invention, the lithographic apparatus 1 may comprise, or be in connection with, a radiation source or radiation source arrangement according to an embodiment of the present invention, described in detail below.

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

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 been reflected by 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.

The depicted apparatus 1 could be used in at least one of the following modes:

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

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

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.

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

Figure 2 shows the lithographic apparatus 1 of Figure 1 in more detail. Referring to Figure 2, the lithographic apparatus 1 includes a radiation source SO, an illumination optics unit IL, and the projection system PL. The radiation source SO includes a radiation emitter 2 which may comprise a discharge plasma. EUV radiation may be produced by a gas or vapor, such as Xe gas or Li vapor in which a very hot plasma is created to emit radiation in the EUV radiation range of the electromagnetic spectrum. The very hot plasma is created by causing a partially ionized plasma of an electrical discharge to collapse onto an optical axis O. Partial pressures of e.g. 10 Pa of Xe or Li vapor or any other suitable gas or vapor may be required for efficient generation of the radiation. In some embodiments, tin may be used. The radiation emitted by radiation emitter 2 is passed from a source chamber 3 into a collector chamber 4. In another embodiment (not shown), a plasma configured to emit EUV radiation may be created by directing a laser beam at a droplet of fuel, such as a droplet of tin.

The collector chamber 4 includes a debris trap 5 and grazing incidence collector 6 (shown schematically as a rectangle). Radiation allowed to pass through the collector 6 is reflected off a grating spectral filter 7 to be focused in a virtual source point 8 at an aperture in the collector chamber 4. From collector chamber 4, a beam of radiation 9 is reflected in illumination optics unit IL via first and second normal incidence reflectors 10, 11 onto a reticle or mask positioned on reticle or mask table MT. A patterned beam 12 is formed which is imaged in projection optics system PL via first and second reflective elements 13, 14 onto a substrate (not shown) held on a substrate table WT. More elements than shown may generally be present in illumination optics unit IL and projection system PL.

As discussed above, debris generated in a radiation source (e.g a plasma-based radiation source) may be suppressed by the use of a buffer gas. A suppression factor related to the use of the buffer gas can be improved by increasing the integrated pressure of the buffer gas. Such an increase can be achieved by increasing the pressure of the buffer gas, or the distance over which the pressure is applied. However, it is difficult to achieve such an increase in pressure or an increase in distance in practice. In one instance, the pressure is typically limited by a maximum operating pressure of the radiation source, because too high a pressure may inhibit the expansion of the plasma that emits radiation. In another instance, the distance over which the pressure is applied is limited by the space between the radiation emitter (e.g. the plasma or the plasma formation site) and the collector. Increasing this distance increases the size of the radiation source, which is undesirable.

It is therefore desirable to be able to improve debris suppression using a buffer gas, but without increasing the gas pressure of the radiation source or the distance over which the pressure is applied.

In accordance with an embodiment of the present invention, one or more problems of the prior art may be obviated or mitigated by introducing a cooled buffer gas into the radiation source. The cooled buffer gas may be introduced in the radiation source from an outlet. A cooled buffer gas may be a buffer gas having a temperature that is lower than the ambient temperature. For instance, the gas may be cooled to such an extent that the gas is at a temperature which is substantially that of the boiling point of the buffer gas. The buffer gas may be cooled prior to introduction into the radiation source, for example, by a cooling and/or compressing arrangement. Alternatively, the buffer gas may be introduced into the radiation source in a compressed state, and allowed to expand and cool. The compression may be such that the gas is introduced into the radiation source in an initial liquid form or state (which may be pressurised), the liquid then being allowed to expand and evaporate in the radiation source to form the cooled buffer gas.

The use of a cooled buffer gas increases the number of gas atoms for a given pressure and volume (in accordance with the ideal gas law]). By increasing the number of gas atoms for a given pressure and volume, debris suppression is increased while at the same time not affecting the operating pressure of the source, or increasing the distance over which that pressure is applied. An additional benefit associated with the use of a cooled buffer gas is that the cooled buffer gas may be used to cool, or contribute to the cooling of, one of the components of the radiation source (which may include, for example, a collector, a debris suppression arrangement, and the like), thereby allowing the radiation source to run at a higher power within an associated higher output of radiation.

The radiation source may be any radiation source in which a buffer gas (or a gas, in general) is used. For instance, the cooled buffer gas may be introduced into a plasma-based radiation source, which is known to generate debris at the same time as generating radiation. In one example, the radiation source may be a discharge produced plasma (DPP) radiation source. In another example, the radiation source may be a laser produced plasma (LLP) radiation source. The radiation source may be configured to generate radiation having a wavelength of substantially 20nm or less, for which sources debris suppression is highly desirable.

The introduction of cooled buffer gas into the radiation source may be advantageous in comparison with, for example, cooling of the gas within the radiation source itself. If the gas were to be cooled within the radiation source, one or more cooling arrangements would need to be provided within the radiation source. Thus, if the gas were to be cooled within the radiation source, the build cost, size, complexity of design or maintenance costs may increase.

Specific embodiments of the present invention will now be described, by way of example only, with reference to Figures 3 and 4. Principles applicable to both embodiments will be described after the description of the Figures.

Figure 3 schematically depicts a side-on view of a discharge produced plasma (DPP) radiation source. The radiation source comprises a radiation emitter 20 for emitting radiation. The radiation emitter 20 is, in this embodiment, a discharge produced plasma formed by establishing an electrical discharge in or across a fuel (e.g. a gas, vapour or liquid). The radiation emitter 20 emits radiation 22. The radiation 22 may be (or include) extreme ultraviolet radiation, or radiation with a shorter wavelength.

The radiation 22 is collected by a collector 24 which collects the radiation 22 and directs the radiation 22 along an optical axis 26 of the radiation source. The collector 24 comprises a plurality of nested shells 28. At the opening of the shells 28 adjacent to the radiation emitter 20, a debris trap 30 is provided. The debris trap 30 may, for example, comprise one or more magnets or foils 32 which are used to trap debris that enters the collector 24. In other embodiments, the debris trap 30 may be located in-between the radiation emitter 20 and the collector 24, and may not form part of the collector 24.

As well as generating radiation 22, the radiation source also generates debris 34. Debris 34 may be in the form of particles, such as thermalized atoms, ions, nanoclusters, and/or microparticles. The debris is directed toward the collector 24. This debris 34 may be suppressed, and thereby prevented from coming into contact with or entering the collector 24, by the provision of a cooled buffer gas 36. The cooled buffer gas 36 is introduced into the radiation source by outlets 38. The cooled buffer gas 36 is introduced into the radiation source at a location which is in-between the radiation emitter 20 and the collector 24.

Figure 4 schematically depicts a side-on view of a laser produced plasma (LPP) radiation source in accordance with an embodiment of the present invention. The radiation source comprises a radiation emitter 50 for emitting radiation 54. In this embodiment, the radiation emitter is a laser produced plasma formed by directing a laser beam 52 at a fuel droplet, not shown in the Figure (for example, a droplet of tin). The radiation 54 may be (or include) extreme ultraviolet radiation, or radiation with a shorter wavelength.

Radiation 54 emitted by the radiation emitter 50 is collected by a collector 56. The collector 56 is a normal incidence collector 56. The collector 56 is, in this embodiment, provided with an aperture 57 through which the laser beam 52 may be directed. The collector 56 collects radiation 54 and directs the radiation 54 along an optical access 58 of the radiation source.

As well as generating radiation 54, the radiation source may also generate debris 60. Debris 60 may be in the form of particles, such as thermalized atoms, ions, nanoclusters, and/or microparticles. The debris 60 is also directed towards the collector 56. This debris 60 may be suppressed, and thereby prevented from coming into contact with or entering the collector 56, by the provision of a cooled buffer gas 62. The cooled buffer gas 62 is provided at a location which is in between the radiation emitter 50 and the collector 56. The cooled buffer gas 62 may be introduced into the radiation source by outlets 64. The buffer gas 62 may be directed along a collecting surface of the collector 56, or may (in another embodiment, not shown) be directed through one or more apertures of the collector 56.

A debris trap may also be provided. The debris trap may, for example, comprise one or more magnets or foils which are used to trap debris. The debris trap may be located in-between the radiation emitter 50 and the collector 56. Alternatively or additionally, the debris trap may partially surround the radiation emitter 50. Alternatively or additionally, the debris trap may form part of or be attached to the collector 56.

Many features or alternative features of the embodiments of the present invention are not unique to the embodiments shown in Figures 3 and 4, but are generally applicable. Such features and alternatives will now be described.

In one example, the cooled buffer gas may be introduced into the radiation source in a cooled state. For instance, the cooled buffer gas may be cooled prior to introduction into the radiation source by one or more cooling or compression arrangements or the like. For instance, the buffer gas may be arranged to be introduced into the radiation source in a compressed state and allowed to expand and cool in the radiation source. The buffer gas may be introduced into the radiation source in the form of liquid (for example, a pressurised liquid) which is allowed to expand and/or evaporate within the radiation source to thus form the cooled buffer gas. One or more nebulizers may be provided (for example adjacent to, in, or forming part of the outlets) for nebulizing the liquid. The nebulizer may be used to achieve a uniform distribution of a mist of fine droplets of the liquid and enhance the evaporation rate of the liquid.

As discussed above in both described embodiments, the cooled buffer gas may be introduced into the radiation source at a location that is in-between the radiation emitter and the collector. Alternatively or additionally, the outlets (or one or more additional outlets) may be configured to introduce the cooled buffer gas at a location that is in-between the radiator emitter and/or the collector and an exit aperture of the radiation source. An exit aperture may be an aperture through which radiation may pass after being collected by the collector. Cooled buffer gas introduced in-between the radiator emitter and/or the collector and an exit aperture of the radiation source may prevent debris passing into, onto or through further components of the lithographic apparatus, for example, an the illumination system or beam delivery system or the like.

One or more outlets for introducing cool buffer gas into the radiation source may be provided. The outlets may be configured to introduce cooled buffer gas at approximately the same location within the radiation source, or may be configured or arranged to introduce cooled buffer gas into the radiation source at different locations within the radiation source. For example, outlets may be configured to introduce cooled buffer gas between the radiation emitter and the collector, and between the radiation emitter and/or the collector and the exit aperture of the radiation source. The outlets are preferably configured (e.g. positioned, located, or oriented or the like) to provide cooled buffer gas as close as possible to a collecting surface of the collector (to maximise the density of the gas near the collector), but far enough away from the collector surface to reduce or eliminate the possibility of non-evaporated cooled buffer gas (e.g. in the form of a liquid or droplets of liquid) coming into contact with and being deposited on the collector surface. Such deposition might reduce the reflection of radiation from that part of the surface, reducing collection efficiency.

The outlets may be tubes, conduits or apertures in the radiation source. The tubes or conduits may be moveable, such that the location of the introduction of cooled gas can be changed. The outlets may be selectively opened and closed such that the location of the introduction of cooled gas can be changed.

Preferably, the temperature of the cooled buffer gas at the outlet is below ambient (e.g. room temperature). More preferably, the temperature of the buffer gas is substantially the same as (e.g. close to) the boiling point of the buffer gas (for example 87.3K for argon, or 20.3K for hydrogen).

If a refresh rate of the cooled buffer gas (e.g. an introduction rate or flow rate into the radiation source) is sufficiently high, the average temperature of the cooled buffer gas in the radiation source will drop by almost the same amount as (i.e. may drop to being substantially equal to) the temperature of the cooled buffer gas at the outlet of the buffer gas. For example, if a normal average temperature of the buffer gas within the radiation source is 600K, a reduction of the inlet temperature from 293K to approximately 50K may result in the average temperature of the buffer gas dropping to approximately 400K. Thus, the number of gas atoms can be increased by a factor of 1.5 (proportional to the drop in temperature). As a result, debris suppression and source cooling can be improved without affecting the operating pressure of the radiation source.

A radiation source arrangement may be provided. The radiation source arrangement may comprise of a radiation source according to an embodiment of the present invention. Furthermore, the radiation source arrangement may comprise a source of cooled buffer gas, pressurized buffer gas or liquefied buffer gas in connection with the outlet of the radiation source (i.e. the outlet via which the cooled buffer gas is to be introduced into the radiation source). The source of cooled buffer gas, pressurized buffer gas or liquefied buffer gas may be a tank or store or the like, or may be an active arrangement configured to produce or maintain cooled buffer gas, pressurized buffer gas or liquefied buffer gas (e.g. a pump, compressor, refrigeration system or the like). The outlet may be configured to introduce a cooled buffer gas into the radiation source by being in connection with such a source.

A lithographic apparatus (for example the lithographic apparatus described above in the relation to Figure 1 or Figure 2) may comprise, or be in connection with, a radiation source or radiation source arrangement according to any one or more embodiments of the present invention.

In the above embodiments, a cooled buffer gas has been described as being introduced into the radiation source. The cooled gas may alternatively or additionally perform a function other than acting as a buffer. For example, a cooled gas may be introduced to cool one or more components of the radiation source, or to clean one or more components of the radiation source. The cooled gas may thus be arranged, in use, to serve as one or more of: a buffer gas; a gas for cooling a component of the radiation source; a gas for cleaning a component of the radiation source. As discussed above in relation to embodiments wherein the cooled gas served as a cooled buffer gas, the introduction of cooled gas into the radiation source may be advantageous in comparison with, for example, cooling of the gas within the radiation source itself. If the gas were to be cooled within the radiation source, one or more cooling arrangements would need to be provided within the radiation source. Thus, if the gas were to be cooled within the radiation source, the build cost, size, complexity of design or maintenance costs may increase.

Although the above description of embodiments of the invention relates to a radiation source which generates EUV radiation, the invention may also be embodied in a radiation source which generates ‘beyond EUV’ radiation, that is radiation with a wavelength of, for example, less than 10 nm. Beyond EUV radiation may for example have a wavelength of 6.7 nm or 6.8 nm. A radiation source which generates beyond EUV radiation may operate in the same manner as the radiation sources described above.

The description above is 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. A radiation source comprising:
a radiation emitter for emitting radiation;
a collector for collecting radiation emitted by the radiation emitter; and
an outlet configured, in use, to introduce a cooled gas into the radiation source.

2. The radiation source of clause 1, wherein the cooled gas is arranged to be cooled prior to introduction into the radiation source.

3. The radiation source of clause 1, wherein the cooled gas is arranged to be introduced into the radiation source in a compressed state.

4. The radiation source of clause 3, wherein the gas is arranged to be introduced in the form of a pressurized liquid which is allowed to evaporate to form the cooled gas.

5. The radiation source of clause 3 or clause 4, further comprising a nebulizer for nebulizing the liquid.

6. The radiation source of any preceding clause, wherein the outlet is configured to introduce the cooled gas at a location in-between the radiation emitter and the collector.

7. The radiation source of any of clauses 1 to 5, wherein the outlet is configured to introduce the cooled gas at a location in-between the radiation emitter and an exit aperture of the source.

8. The radiation source of any preceding clause, further comprising one or more further outlets, each further outlet being arranged to introduce a cooled gas into the radiation source at a different location within the radiation source.

9. The radiation source of any preceding clause, wherein the cooled gas is arranged to have a temperature below an ambient temperature, or a temperature that is substantially the same as a boiling point of the gas.

10. The radiation source of any preceding clause, wherein the cooled gas is arranged, in use, to serve as one or more of:

a buffer gas;

a gas for cooling a component of the radiation source;

a gas for cleaning a component of the radiation source.

11. A radiation source arrangement comprising:

a radiation source of any preceding clause; and

a source of cooled gas, pressurized gas or liquefied gas in connection with the outlet.

12. A lithographic apparatus in connection with, or comprising, a radiation source or radiation source arrangement as clauseed in any preceding clause.

13. A method of operating a radiation source or radiation source arrangement of any preceding clause, the method comprising:

introducing a cooled gas into the radiation source via the outlet of the radiation source.

14. The method of clause 13, wherein the cooled gas is introduced to suppress debris or to cool a part of the radiation source.

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.

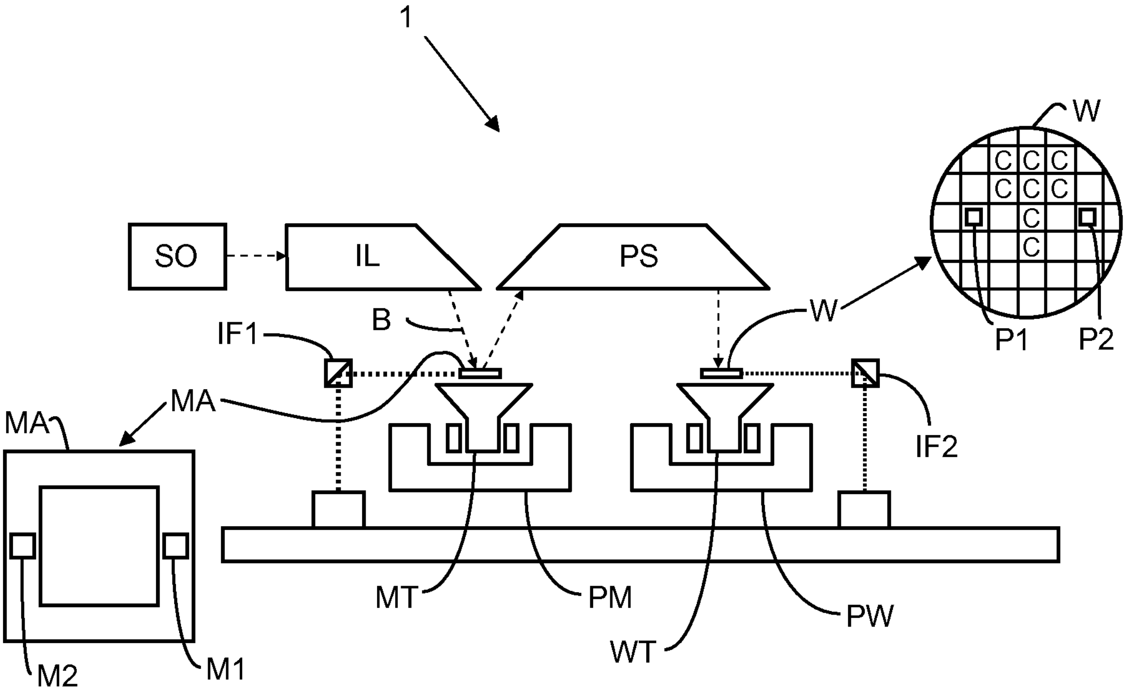
1
SO
IL
PS
W
C C C
C C C
C
C
P1
P2
B
W
IF1
MA
MA
IF2
MT
PM
WT
PW
M2
M1

FIG 1

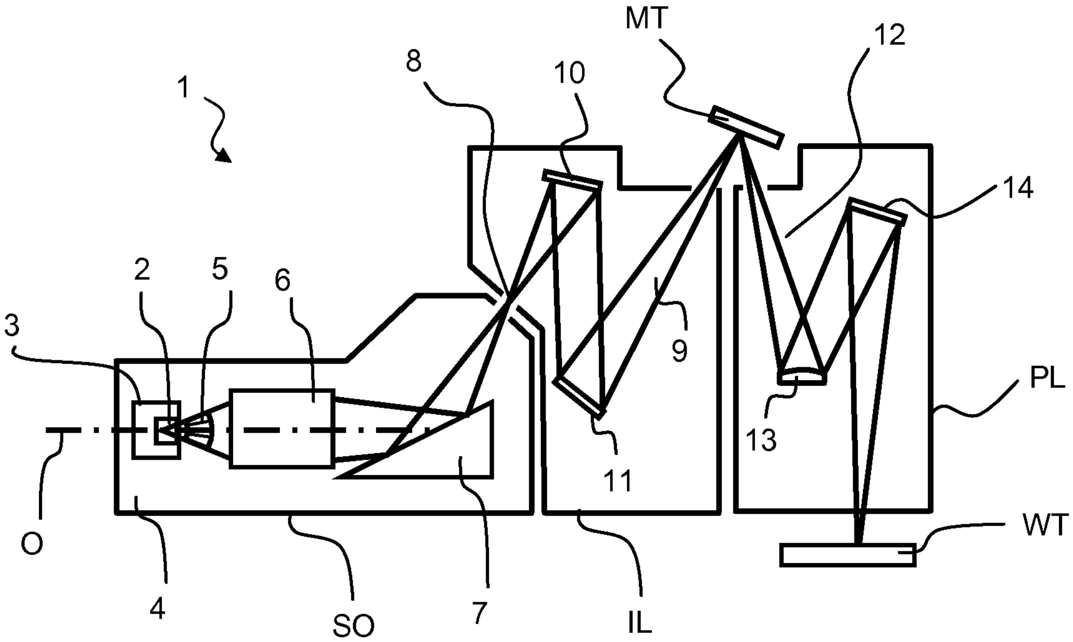
MT
12
1
8
10
14
2
5
6
3
9
PL
11
13
O
4
SO
7
IL
WT

FIG. 2

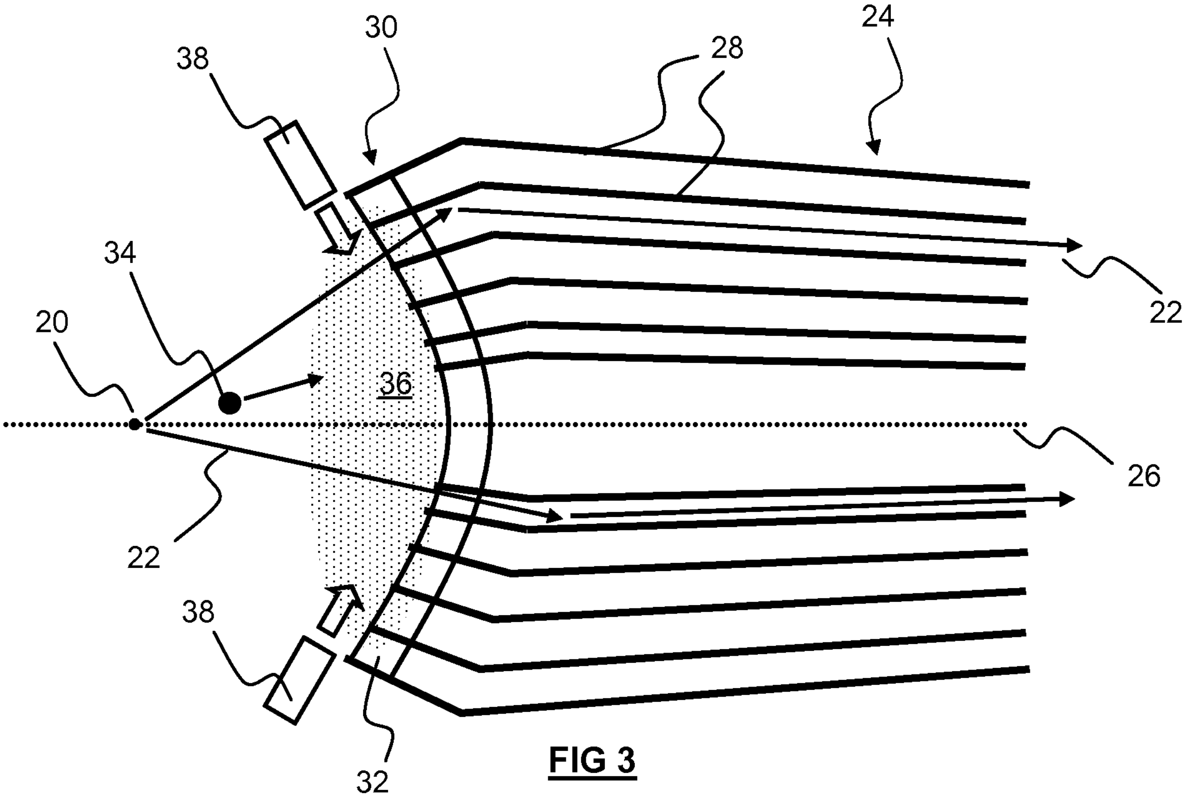

FIG 3

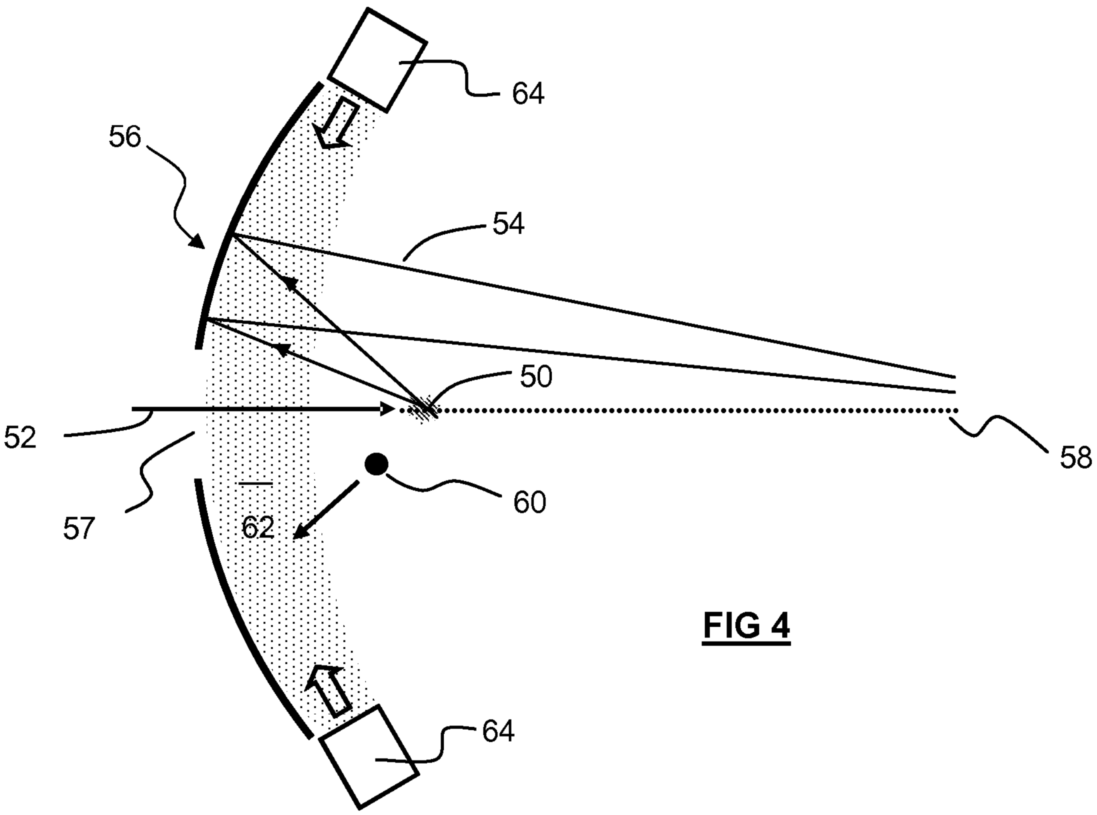

FIG 4