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(71) Applicant: **ASML Netherlands B.V.**
5500 AH Veldhoven (NL)

(72) Inventors:
- **VAN BANNING, Dennis, Herman, Caspar**
  5500 AH Veldhoven (NL)
- **DIRECKS, Daniel, Jozef, Maria**
  5500 AH Veldhoven (NL)
- **WILLEMS, Petrus, Adrianus**
  5500 AH Veldhoven (NL)

(74) Representative: **ASML Netherlands B.V.**
Corporate Intellectual Property
P.O. Box 324
5500 AH Veldhoven (NL)

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Claims 16-18 are deemed to be abandoned due to non-payment of the claims fees (Rule 45(3) EPC).

(54) VESSEL FOR A RADIATION SOURCE

(57) A vessel for an EUV radiation source, the vessel comprising a guide portion for directing fuel debris from a plasma formation region of the radiation source towards a fuel debris removal device, a wall comprising an opening, wherein at least a part of the guide portion is arranged in the opening of the wall so that a gap is defined between the guide portion and the wall; and a gas supply system configured to supply a gas into the gap to control a transfer of heat between the guide portion and the wall.

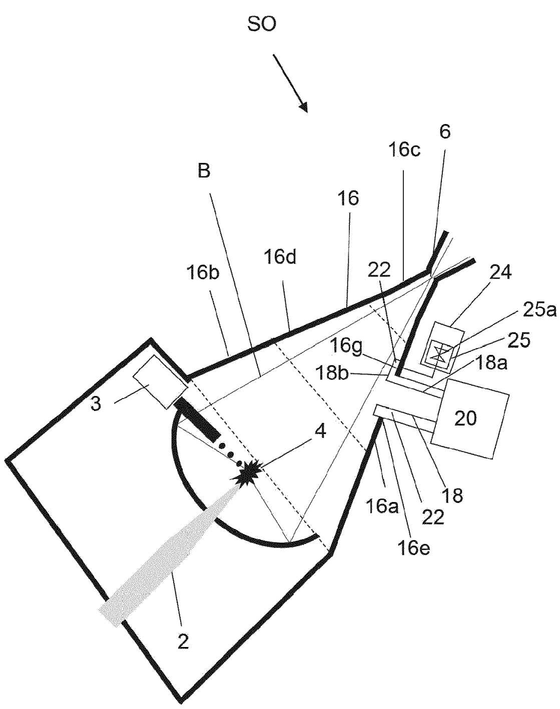

FIG. 2

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Description

FIELD

[0001] The present invention relates to a vessel for a radiation source, such as an extreme ultraviolet (EUV) radiation source, and associated apparatuses and systems.

BACKGROUND

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

[0003] To project a pattern on a substrate a lithographic apparatus may use electromagnetic radiation. The wavelength of this radiation determines the minimum size of features which can be formed on the substrate. A lithographic apparatus, which uses extreme ultraviolet (EUV) radiation, having a wavelength within the range 4-20 nm, for example 6.7 nm or 13.5 nm, may be used to form smaller features on a substrate than a lithographic apparatus which uses, for example, radiation with a wavelength of 193 nm.

[0004] A lithographic system may comprise a radiation source, a beam delivery system and a lithographic apparatus. The beam delivery system may be arranged to deliver EUV radiation from the radiation source to the lithographic apparatus.

[0005] The EUV radiation may be produced using a plasma. The plasma may be created, for example, by directing a laser beam at a fuel in the radiation source. The resulting plasma may emit the EUV radiation. A portion of the fuel may become fuel debris, which may accumulate or be deposited on one or more components of the radiation source.

[0006] The fuel debris deposited on the one or more components of the radiation source may lead to contamination of other components of the radiation source. Such contamination may lead to a decrease in the performance of the radiation source, e.g. the quality or power of the produced EUV radiation, which in turn may lead to degradation of performance of an associated lithographic apparatus. Ultimately, this may lead to significant downtime of the lithographic apparatus whilst components of the radiation source are cleaned or replaced.

SUMMARY

[0007] According to a first aspect of the present invention there is provided a vessel for an EUV radiation source, the vessel comprising a guide portion for directing fuel debris from a plasma formation region of the EUV radiation source towards a fuel debris removal device, a wall comprising an opening, wherein at least a part of the guide portion is arranged in the opening of the wall so that a gap is defined between the guide portion and the wall and a gas supply system configured to supply a gas into the gap to control a transfer of heat between the guide portion and the wall.

[0008] By configuring the gas supply system to supply the gas into the gap, cooling or heating of the guide portion may be controlled and/or improved. For example, it may be desirable to cool the guide portion, when EUV radiation is produced by the EUV radiation source. The gas may be supplied into the gap to allow for cooling of the guide portion, e.g. to below a melting temperature of a fuel that may be used in the EUV radiation source. In use, fuel debris may be deposited on the guide portion. By cooling the guide portion to a temperature below the melting temperature of the fuel, dripping, bubbling and/or spitting of liquid fuel debris may be prevented or reduced. This may result in a decrease of the contamination of one or more components of the EUV radiation source.

[0009] Additionally or alternatively, when EUV radiation is produced by the EUV radiation source, a temperature of the guide portion may increase to about 300°C or larger. This may cause damage and/or corrosion of the guide portion. For example, the guide portion may comprise a metal material or metal alloy material, such as stainless steel. Some metal alloy materials, such as stainless steel, may start to corrode and/or become damaged at a temperature of about 400°C or above. By configuring the gas supply system to supply the gas into the gap, cooling of the guide portion may be controlled and/or improved, e.g. when EUV radiation is produced by the EUV radiation source. This may lead to a reduction in corrosion and/or damage of the guide portion and/or an increase in the lifetime of the guide portion. It may be desirable to heat the guide portion, e.g. when no EUV radiation is produced by the EUV radiation source, e.g. to remove fuel debris from the guide portion.

[0010] The vessel may be or comprise a vacuum vessel, pressure vessel, vacuum chamber or pressure chamber or the like. The vessel may be configured to enclose a vacuum or low pressure environment of the EUV radiation source. The term "low pressure environment" may be considered as an environment comprising a gas at a pressure below atmospheric pressure, e.g. at a pressure between about 100 Pa and 200 Pa.

[0011] The gas supply system may be operable between a first configuration and a second configuration. In the first configuration, the gas supply system may be configured to supply the gas into the gap, e.g. to increase a transfer of heat between the guide portion and the wall. In the second configuration, the gas supply system may be configured to supply no gas into the gap, e.g. to decrease a transfer of heat between the guide portion and the wall. For example, in the second configuration, the gas supply system may be configured to terminate or stop a supply of gas into the gap. By operating the gas supply system between the first configuration and the second configuration a transfer of heat between the guide portion and the wall may be controlled. This may allow for cooling or heating of the guide portion to be controlled and/or improved.

[0012] The gas supply system may be configured to operate in the first configuration, e.g. when EUV radiation is produced by the EUV radiation source. The gas supply system may be configured to operate in the second configuration, e.g. when no EUV radiation is produced by the radiation source. The EUV radiation source may comprise an on state, in which EUV radiation is produced. The EUV radiation source may comprise an off state, in which no EUV radiation is produced. The EUV radiation source may be operative between the on state and the off state.

[0013] When the gas supply system is in the first configuration, a pressure of the gas in the gap may be greater than a pressure of the gas in the gap, when the gas supply system is in the second configuration. When the gas supply system is in the first configuration, the pressure of the gas in the gap may be between about 10 kPa and 20 kPa. When the gas supply system is in the second configuration, the pressure of the gas in the gap may be between about 100 Pa and 200 Pa.

[0014] The gas supply system may be configured to control a pressure of the gas in the gap, e.g. to control the transfer of heat between the guide portion and the wall. The gas supply system may be configured to control the pressure of the gas in the gap based on at least one of: a type of gas and a size of the gap.

[0015] For example in use, the wall may be subjected to a cooling source. For example in use, the guide portion may be subjected to a heating source. The heating source comprises a heating element. The heating element may be configured to heat the guide portion, e.g. when no EUV radiation is produced by the EUV radiation source. The heating element may be comprised in, part of or arranged on the guide portion. The guide portion may be arranged in the vessel so that, for example in use, the guide portion may be subjected to heat generated at the plasma formation region of the EUV radiation source.

[0016] The cooling source may comprise a cooling element. The cooling element may be configured to cool the wall. The cooling element may be comprised in or part of the wall.

[0017] By configuring the gas supply system to supply the gas into the gap, cooling or heating of the guide portion, e.g. by the cooling source or heating source, respectively, may be controlled or adjusted more precisely. This may reduce or avoid the use of heating elements with increased capacity, for example to counteract an increased cooling capacity of the cooling source. For example, an increase of the capacity of the cooling source may be necessary, when the power of the EUV radiation produced by the EUV radiation source is increased. By reducing or avoiding the use of heating elements with an increased capacity, damage or deformation of one or more components of the radiation source, which may be arranged in proximity to the heating elements, may be reduced or avoided.

[0018] The gas may comprise a thermal conductivity at room temperature between about 0.02 W/mK and 0.18 W/mK

[0019] The gas may be selected from at least one of: hydrogen, nitrogen and helium.

[0020] The vessel may comprise at least one restriction element or a plurality of restriction elements for maintaining a pressure of the gas in the gap. The at least one restriction element, some or all of the plurality of restriction elements may be arranged in the gap and/or in or on the wall.

[0021] The vessel may comprise at least one spacing element or a plurality of spacing elements for maintaining a size of the gap. The at least one spacing element or the plurality of spacing elements may be arranged between the guide portion and the wall. For example, the at least one spacing element or the plurality of spacing elements may be arranged on the guide portion, e.g. a portion thereof, and/or the wall.

[0022] The vessel may comprise a plurality of inlets for directing the gas into the gap. The plurality of inlets may be part of, comprised in or arranged in the wall.

[0023] According to a second aspect of the present invention there is provided a vessel for an EUV radiation source, the vessel comprising a vessel module comprising a wall, the wall comprising a first portion and a second portion, wherein a gap is defined between the first portion and the second portion of the wall; and a gas supply system configured to supply a gas into the gap to control a transfer of heat between the first portion and the second portion of the wall.

[0024] By configuring the gas supply system to supply the gas into the gap, cooling or heating of the first portion of the wall may be controlled and/or improved. For example, it may be desirable to cool the first portion of the wall, when EUV radiation is produced by the EUV radiation source. The gas may be supplied into the gap to allow for cooling of the first portion of the wall, e.g. to below a melting temperature of a fuel that may be used in the EUV radiation source. In use, fuel debris may be deposited on the first portion of the wall. By cooling the first portion of the wall to a temperature below the melting temperature of the fuel, dripping, bubbling and/or spitting of liquid fuel debris may be prevented or reduced. This may result in a decrease of the contamination of one or more components of the EUV radiation source. It may be desirable to heat the first portion of the wall, e.g. when no EUV radiation is produced by the EUV radiation source SO, e.g. to remove fuel debris from the first portion of the wall.

[0025] The gas supply system may be operable between a first configuration and a second configuration. In the first configuration, the gas supply system may be configured to supply the gas into the gap, e.g. to increase a transfer of heat between the first portion and the second portion of the wall. In the second configuration, the gas supply system may be configured to supply no gas into the gap, e.g. to decrease a transfer of heat between the first portion and the second portion of the wall. For example, in the second configuration, the gas supply system may be configured terminate or stop a supply of gas into the gap. By operating the gas supply system between the first configuration and the second configuration a transfer of heat between the first portion and the second portion of the wall may be controlled. This may allow for cooling or heating of the first portion of the wall to be controlled and/or improved.

[0026] The gas supply system may be configured to operate in the first configuration, e.g. when EUV radiation is produced by the EUV radiation source. The gas supply system may be configured to operate in the second configuration, e.g. when no EUV radiation is produced by the EUV radiation source. The EUV radiation source may comprise an on state, in which EUV radiation is produced. The EUV radiation source may comprise an off state, in which no EUV radiation is produced. The EUV radiation source may be operative between the on state and the off state.

[0027] The gas supply system may be configured to control a pressure of the gas in the gap, e.g. to control the transfer of heat between the first portion and the second portion of the wall. The gas supply system may be configured to control a pressure of the gas in the gap, e.g. based on at least one of: a type of gas and a size of the gap.

[0028] When the gas supply system is in the first configuration, a pressure of the gas in the gap may be greater than a pressure of the gas in the gap, when the gas supply system is in the second configuration. When the gas supply system is in the first configuration, the pressure of the gas in the gap may be between about 10 kPa and 20 kPa. When the gas supply system is in the second configuration, the pressure of the gas in the gap may be between about 100 Pa and 200 Pa.

[0029] For example in use, the first portion of the wall may be subjected to a heating source. The second portion of the wall may be subjected to a cooling source. The heating source comprises a heating element. The heating element may be configured to heat the first portion of the wall, for example when no EUV radiation is produced by the EUV radiation source. The heating element may be part of or comprised in the first portion of the wall. For example, in use, the first portion of the wall may be subjected to heat generated at a plasma formation region of the EUV radiation source. The cooling source may comprise a cooling element. The cooling element may be configured to cool the second portion of the wall. The cooling element may be part of or comprised in the second portion of the wall.

[0030] The gas may comprise a thermal conductivity at room temperature between about 0.02 W/mK and 0.18 W/mK

[0031] The gas may be selected from at least one of: hydrogen, nitrogen and helium.

[0032] The vessel may comprise at least one restriction element or a plurality of restriction elements for maintaining a pressure of the gas in the gap. The at least one restriction element, at least some or all of the plurality of restriction elements may be arranged in the gap and/or on the wall, e.g. the first portion and/or second portion of the wall.

[0033] The vessel may comprise at least one spacing element or a plurality of spacing elements for maintaining a size of the gap. The at least one spacing element or the plurality of spacing elements may be arranged between the first portion and the second portion of the wall. The at least one spacing element, at least some or all of the plurality of spacing elements may be arranged on the first portion and/or the second portion of the wall.

[0034] The vessel may comprise a plurality of inlets for directing the gas into the gap. The plurality of inlets may be arranged in the wall, e.g. the first portion and/or the second portion of the wall.

[0035] The vessel module may be configured for use in proximity to a plasma formation region of the EUV radiation source. For example, the vessel module may be configured to surround the plasma formation region of the EUV radiation source.

[0036] The vessel module may be configured for use in proximity to an intermediate focus of EUV radiation produced by the EUV radiation source.

[0037] The vessel module may comprise a guide portion for directing fuel debris from a plasma formation region of the EUV radiation source towards a fuel debris removal device.

[0038] The vessel module may comprise a reservoir for collecting fuel from at least one component of the EUV radiation source. The vessel module may comprise another reservoir for supplying fuel to at least one component of the EUV radiation source.

[0039] According to a third aspect of the present invention there is provided an EUV radiation source comprising a vessel according to first aspect and/or the second aspect.

[0040] According to a fourth aspect of the present invention there is provided a lithographic system comprising an EUV radiation source according to the third aspect and a lithographic apparatus.

[0041] According to a fifth aspect of the present invention there is provided a guide portion for use in a vessel, the guide portion being configured such that a gap is defined between a wall of the vessel and the guide portion, when at least a part of the guide portion is arranged in an opening of the wall of the vessel.

[0042] The vessel may be or comprise a vessel for an EUV radiation source. For example, when at least the part of the guide portion is arranged in the opening of the wall of the vessel, the guide portion may be configured to direct fuel debris from a plasma formation region of the EUV radiation source towards a fuel debris removal device.

[0043] The guide portion may comprise a first part and a second part. The first part of the guide portion may be configured to be arranged in the opening of the wall of the vessel. The first part of the guide portion may comprise a shape that corresponds to a shape of the opening of the wall of the vessel. The guide portion may be configured such that a size or dimension of the first part of the guide portion is smaller than a size or dimension of the opening of the wall of the vessel. This may allow for the gap to be defined or formed between at least the first part of the guide portion and the opening of the wall of the vessel.

[0044] The guide portion may be configured such that the second part of the guide portion protrudes or extends from the first part of the guide portion. For example, the second part may extend perpendicularly, e.g. substantially perpendicularly, from the first portion. The second part may comprise a shape, e.g. a curved shape, which corresponds to a shape of the wall of the vessel. The guide portion may be configured such that the second part extends parallel, e.g. substantially parallel, to the wall of the vessel, when the part, e.g. the first part, of the guide portion is arranged in the opening of the wall of the vessel. The guide portion may be configured such that the gap is defined or formed between at least the second part of the guide portion and the wall of the vessel, when the part, e.g. the first part, of the guide portion is arranged in the opening of the wall of the vessel.

[0045] Various aspects and features of the invention set out above or below may be combined with various other aspects and features of the invention as will be readily apparent to the skilled person.

BRIEF DESCRIPTION OF THE DRAWINGS

[0046] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings, in which:

- Figure 1 depicts a lithographic system comprising a lithographic apparatus and a radiation source;
- Figure 2 depicts an exemplary vessel for use with the radiation source of Figure 1;
- Figure 3 depicts a cross-sectional view of a part of an exemplary guide portion and wall of the vessel of Figure 2;
- Figure 4 depicts a cross-sectional view of a part of an exemplary guide portion and wall of the vessel of Figure 2;
- Figure 5 depicts a cross-sectional view of a part of an exemplary guide portion and wall of the vessel of Figure 2;
- Figure 6 depicts an exemplary guide portion for use with the vessel of Figure 2;
- Figure 7 depicts an exemplary guide portion for use with the vessel of Figure 2;
- Figure 8 depicts an exemplary vessel module for use in the vessel of Figure 2 with the guide portion removed;
- Figure 9 depicts an exemplary vessel module for use in the vessel of Figure 2 with a part of the guide portion arranged in an opening of the wall;
- Figure 10 depicts a plan view of an exemplary arrangement of a plurality of spacing elements for use in the vessel of Figure 2;
- Figure 11 depicts a cross-sectional view of another exemplary arrangement of the plurality of spacing elements;
- Figure 12 depicts a cross-sectional view of a first part of the guide portion arranged in the opening of the wall of the vessel of Figure 2;
- Figure 13 depicts a part of the cross-sectional view of the first part of the guide portion arranged in the opening of the wall of Figure 12;
- Figure 14 depicts an exemplary vessel module for use in the vessel of the radiation source of Figure 2;
- Figure 15 depicts another exemplary vessel module for use in the vessel of the radiation source of Figure 2; and
- Figure 16 depicts another exemplary vessel module for use in the vessel of the radiation source of Figure 2.

DETAILED DESCRIPTION

[0047] Figure 1 shows a lithographic system comprising a radiation source SO and a lithographic apparatus LA. The radiation source SO is configured to generate an EUV radiation beam B and to supply the EUV radiation beam B to the lithographic apparatus LA. The lithographic apparatus LA comprises an illumination system IL, a support structure MT configured to support a patterning device MA (e.g., a mask), a projection system PS and a substrate table WT configured to support a substrate W.

[0048] The illumination system IL is configured to condition the EUV radiation beam B before the EUV radiation beam B is incident upon the patterning device MA. Thereto, the illumination system IL may include a facetted field mirror device 10 and a facetted pupil mirror device 11. The faceted field mirror device 10 and faceted pupil mirror device 11 together provide the EUV radiation beam B with a desired cross-sectional shape and a desired intensity distribution. The illumination system IL may include other mirrors or devices in addition to, or instead of, the faceted field mirror device 10 and faceted pupil mirror device 11.

[0049] After being thus conditioned, the EUV radiation beam B interacts with the patterning device MA. As a result of this interaction, a patterned EUV radiation beam B' is generated. The projection system PS is configured to project the patterned EUV radiation beam B' onto the substrate W. For that purpose, the projection system PS may comprise a plurality of mirrors 13,14 which are configured to project the patterned EUV radiation beam B' onto the substrate W held by the substrate table WT. The projection system PS may apply a reduction factor to the patterned EUV radiation beam B', thus forming an image with features that are smaller than corresponding features on the patterning device MA. For example, a reduction factor of 4 or 8 may be applied. Although the projection system PS is illustrated as having only two mirrors 13,14 in Figure 1, the projection system PS may include a different number of mirrors (e.g., six or eight mirrors).

[0050] The substrate W may include previously formed patterns. Where this is the case, the lithographic apparatus LA aligns the image, formed by the patterned EUV radiation beam B', with a pattern previously formed on the substrate W.

[0051] A relative vacuum, i.e. a small amount of gas (e.g. hydrogen) at a pressure well below atmospheric pressure, may be provided in the radiation source SO, in the illumination system IL, and/or in the projection system PS.

[0052] The radiation source SO shown in Figure 1 is, for example, of a type which may be referred to as a laser produced plasma (LPP) source. A laser system 1, which may, for example, include a CO_2 laser, is arranged to deposit energy via a laser beam 2 into a fuel, such as tin (Sn), which is provided from, e.g., a fuel emitter 3. Although tin is referred to in the following description, any suitable fuel may be used. The fuel may, for example, be in liquid form, and may, for example, be a metal or alloy. The fuel emitter 3 may comprise a nozzle configured to direct tin, e.g. in the form of droplets, along a trajectory towards a plasma formation region 4. The laser beam 2 is incident upon the tin at the plasma formation region 4. The deposition of laser energy into the tin creates a tin plasma 7 at the plasma formation region 4. Radiation, including EUV radiation, is emitted from the plasma 7 during de-excitation and recombination of electrons with ions of the plasma.

[0053] The EUV radiation from the plasma is collected and focused by a collector 5. Collector 5 comprises, for example, a near-normal incidence radiation collector 5 (sometimes referred to more generally as a normal-incidence radiation collector). The collector 5 may have a multilayer mirror structure which is arranged to reflect EUV radiation (e.g., EUV radiation having a desired wavelength such as 13.5 nm). The collector 5 may have an ellipsoidal configuration, having two focal points. A first one of the focal points may be at the plasma formation region 4, and a second one of the focal points may be at an intermediate focus 6, as discussed below.

[0054] The laser system 1 may be spatially separated from the radiation source SO. Where this is the case, the laser beam 2 may be passed from the laser system 1 to the radiation source SO with the aid of a beam delivery system (not shown) comprising, for example, suitable directing mirrors and/or a beam expander, and/or other optics. The laser system 1, the radiation source SO and the beam delivery system may together be considered to be a radiation system.

[0055] Radiation that is reflected by the collector 5 forms the EUV radiation beam B. The EUV radiation beam B is focused at intermediate focus 6 to form an image at the intermediate focus 6 of the plasma present at the plasma formation region 4. The image at the intermediate focus 6 acts as a virtual radiation source for the illumination system IL. The radiation source SO is arranged such that the intermediate focus 6 is located at or near to an opening 8 in an enclosing structure 9 of the radiation source SO.

[0056] The radiation source SO may comprise an on state, in which EUV radiation is produced. The radiation source SO may comprise an off state, in which no EUV radiation is produced. The radiation source SO may be operative between the on state and the off state.

[0057] Figure 2 shows an exemplary vessel 16 for use with the radiation source shown in Figure 1. The vessel 16 may be part of or comprised in the radiation source SO. The enclosing structure 9, which is shown in Figure 1, may be defined by or comprised in the vessel 16. The term "vessel" may be considered as encompassing a vacuum vessel, pressure vessel, vacuum chamber or pressure chamber or the like. In other words, the vessel 16 may be considered as providing an enclosure to a vacuum or low pressure environment of the radiation source SO. As described above, a pressure of a gas in the vessel 16 may be below atmospheric pressure. The vessel 16 may be configured to enclose one or more components of the radiation source SO, such as the collector 5 and/or the fuel emitter 3.

[0058] The vessel 16 comprises a guide portion 18 for directing fuel debris from the plasma formation region 4 of the radiation source SO towards a fuel debris removal device 20. Fuel debris may include particulate debris, such as Sn clusters, Sn microparticles, Sn nanoparticles, and/or Sn deposits, molecular and/or atomic debris, such as Sn vapor, SnH_x vapor, Sn atoms, Sn ions, e.g. when tin is used as a fuel. Fuel debris may mix with the gas, e.g. hydrogen, which may be present in the radiation source SO. This fuel debris-gas mixture may be directed towards the debris removal device 20 by the guide portion 18. The fuel debris removal device 20 may be configured to separate the fuel debris, e.g. at least a part thereof, from the gas. The fuel debris removal device 20 may be provided in the form of a scrubber or the like.

[0059] The vessel 16 comprises a wall 16a. The wall 16 may define an inner surface of the vessel 16 or a part thereof. The wall 16a comprises an opening 16e. At least a part of the guide portion 18 is arranged in the opening 16e of the wall 16a so that a gap 22 is defined or formed between the guide portion 18 and the wall 16a. The vessel 16 may comprise a gas supply system 24 for supplying a gas into the gap 22 to control a transfer of heat between the guide portion 18 and the wall 16a. The gas supply system 24 may be part of or comprised in a debris mitigation system (not shown), which may be part of the vessel 16. It will be appreciated that the terms "transfer of heat" may be interchangeably used with the terms "flow of heat."

[0060] At least some of the fuel debris may be deposited on the guide portion 18, e.g. at least a part thereof. For example, when EUV radiation is produced by the radiation source SO, it may be desirable to maintain a temperature of the guide portion 18 below a melting temperature of the fuel. For example, when tin is used as the fuel, it may be desirable to maintain the temperature of the guide portion 18 below 200°C, which is below a melting temperature of tin of about 230°C. This may prevent or reduce contamination of one or more components of the radiation source SO, such as the collector 5. At temperatures above the melting temperature of the fuel, the fuel debris may become liquid and/or drip or be otherwise ejected on one or more components of the radiation source SO. The ejection of the liquid fuel debris may be referred to as spitting. The ejection of the liquid fuel debris may be due to the interaction between hydrogen radicals and the liquid fuel debris. For example, hydrogen (H_2) molecules may split into hydrogen radicals due to their absorption of heat and/or EUV radiation or ion collisions. Expressed differently, under the influence of, for example, the EUV radiation a hydrogen plasma may be formed in the radiation source SO. The hydrogen plasma may contain reactive species (H, H^+, or the like), which may be referred to as hydrogen radicals. The hydrogen radicals may remove, e.g. etch, fuel debris from one or more components of the radiation source, e.g. the collector 5. However, it has been found that some of the hydrogen radicals, such as H^+, may penetrate liquid fuel debris layers and form hydrogen bubbles inside the liquid fuel debris layers. The bubbles may breach the surface and on subsequent collapse of one or more bubbles, fuel debris, e.g. particulate fuel debris, may be ejected or emitted into the radiation source SO. This bubbling or spitting of liquid fuel debris may be considered as a significant cause of contamination of one or more components of the radiation source, such as the collector 5.

[0061] By configuring the gas supply system 24 to supply the gas into the gap 22, cooling or heating of the guide portion 18 may be controlled and/or improved. It may be desirable to cool the guide portion 18, when EUV radiation is produced by the radiation source SO. For example, the gas may be supplied into the gap 22 to allow for cooling of the guide portion 18 to below a melting temperature of the fuel, e.g. tin. This is in turn may decrease contamination of one or more components of the radiation source SO, e.g. by reducing dripping, bubbling and/or spitting of the like of liquid fuel debris. It may be desirable to heat the guide portion 18, when the radiation source is off, e.g. no EUV radiation is produced by the radiation source SO, as will be described below in more detail.

[0062] When EUV radiation is produced by the radiation source SO, a temperature of the guide portion 18 may increase to about 300°C or larger. This may cause damage and/or corrosion of the guide portion 18. For example, the guide portion 18 may comprise a metal material or metal alloy material, such as stainless steel. Some metal alloy materials, such as stainless steel, may start to corrode and/or become damaged at a temperature of about 400°C or above. By configuring the gas supply system 24 to supply the gas into the gap 22, cooling of the guide portion 18 may be controlled and/or improved, e.g. when EUV radiation is produced by the radiation source SO. This may lead to a reduction in corrosion and/or damage of the guide portion 18 and/or an increase in the lifetime of the guide portion 18.

[0063] The gas supply system 24 may be operable between a first configuration and a second configuration. For example, the gas supply system 24 may comprise a mass flow controller 25. The mass flow controller 25 may comprise a controllable valve 25a. The mass flow controller 25 may be configured to operate the valve 25a between an open and a closed state. In the first configuration, the gas supply system 24 may be configured to supply the gas into the gap 22, e.g. to increase a transfer of heat between the guide portion 18 and the wall 16a. In other words, in the first configuration of the gas supply system 24, thermal conduction between the guide portion 18 and the wall 16a may be increased. This may allow for cooling of the guide portion 18, e.g. when EUV radiation is produced by the radiation source SO. In the first configuration of the gas supply device 24, the mass flow controller 25 may be configured to operate the valve 25a in the open state. For example, the mass flow controller 25 may be configured to open the valve 25a so that the gas is supplied to the gap 22 at a target mass flow rate. In this embodiment, the target mass flow rate may be in the region of about 8×10^{-5} kg/s (5 1/min). It will be appreciated that in other embodiments, the target mass flow rate may be between about 8×10^{-5} kg/s (5 l/min) and 0.8 kg/s (50 l/min).

[0064] In the second configuration, the gas supply system 24 may be configured to supply no gas into the gap 22, e.g. to decrease a transfer of heat between the guide portion 18 and the wall 16a. For example, in the second configuration, the gas supply system 24 may be configured to terminate or stop a supply of gas into the gap 22. In the second configuration of the gas supply system 24, thermal conduction between the guide portion 18 and the wall 16a may be decreased, e.g. relative to the thermal conduction between the guide portion 18 and the wall 16a, when the gas supply system 24 is in the first configuration. This may allow for heating of the guide portion 18, e.g. when no EUV radiation is produced by the radiation source SO. In the second configuration of the gas supply device 24, the mass flow controller 25 may be configured to operate the valve in the closed state. The gas supply system 24 may be configured to operate in the first configuration, when EUV radiation is produced by the radiation source SO. The gas supply system 24 may be configured to operate in the second configuration, when no EUV radiation is produced by the radiation source SO.

[0065] The transfer of heat may be expressed by the heat transfer coefficient *h*:

$$h = \frac{q}{\Delta T}$$

where q is the heat flux and ΔT is a difference in temperature.

[0066] The heat transfer coefficient h of the gas in the gap 22 may be dependent on a pressure of the gas in the gap 22. The gas supply system 24 may be configured to control a pressure of the gas in the gap 22 to control the transfer of heat between the guide portion 18 and the wall 16a. For example, the gas supply system 24 may be configured to increase or decrease the pressure of the gas in the gap 22 to increase or decrease the heat transfer coefficient h of the gas in the gap 22. For example, when the gas supply system 24 is in the first configuration, a pressure of the gas in the gap 22 may be greater than a pressure of the gas in the gap 22, when the gas supply system 24 is in the second configuration.

[0067] The gas may comprise a thermal conductivity at room temperature between about 0.02 W/mK and 0.18 W/mK. The gas may comprise an inert gas. The gas may be selected from at least one of hydrogen, nitrogen and helium. In an exemplary embodiment, hydrogen may be used as the gas. As described above, hydrogen may already be used in the radiation source SO. However, it will be appreciated that in other embodiments other gases, such as nitrogen, helium or mixtures thereof may be used.

[0068] In embodiments where hydrogen is used as the gas, a pressure of the gas in the gap 22 may be between about 10 kPa (100 mbar) and 20 kPa (200 mbar), when the gas supply system 24 is in the first configuration. This may result in a heat transfer coefficient h between about 500 W/m^{2}K and 1500 W/m^{2}K. For example, when a size of the gap 22 is about 0.25 mm and a pressure of the gas in the gap 22 is about 15 kPa, the heat transfer coefficient h may be about 750 W/m^{2}K. A decrease in pressure of the gas in the gap 22 may result in a decrease of the thermal heat transfer coefficient h of the gas in the gap 22. When the gas supply system 24 is the second configuration, a pressure of the gas in the gap 22 may be between about 100 Pa (1 mbar) and 200 Pa (2 mbar). This may result in a heat transfer coefficient h between 10 W/m^{2}K and 100 W/m^{2}K. For example, when the size of the gap 22 is about 0.25 mm and a pressure of the gas in the gap 22 is of about 150 Pa (1.5 mbar), the heat transfer coefficient h may be about 85 W/m^{2}K. It will be appreciated that in other embodiments, a pressure of the gas in the gap may be different from the exemplary pressures described above. When the gas supply system 24 is operated in the second configuration, the pressure of the gas in the gap 22 may decrease and/or reach equilibrium with the pressure of the gas in radiation source SO, e.g. the vessel 16. For example, the pressure of the gas in the radiation source SO, e.g. the vessel 16, may be between about 100 Pa (1 mbar) and 200 Pa (2 mbar), such as 150 Pa (1.5 mbar). The guide portion 18 may be arranged in the opening 16e of the wall 16a so that the gap 22 is communicably coupled with an interior of the radiation source SO, e.g. an interior of radiation source SO, e.g. the vessel 16. For example, the guide portion 18 may be arranged in the opening 16e of the wall 16a so that some of the gas in the gap 22 may be allowed to leak or flow into the vessel 16. In other words, the guide portion 18 may be arranged in the opening 16e of the wall 16a so that some gas exchange between the gap 22 and the vessel 16 is allowed. This may allow for the pressure of the gas in the gap 22 to decrease and/or reach an equilibrium with the pressure of the gas in radiation source SO, e.g. the vessel 16, e.g. when the gas supply system 24 is in the second configuration. The gas supply system 24 may be configured to control a pressure of the gas in the gap 22, e.g. based on a type of gas and/or a size of the gap. For example, a gas other than hydrogen may have a different thermal conductivity, which may require a different pressure of the gas in the gap to result in a desired heat transfer coefficient. However, a pressure of a gas other than hydrogen may be selected to be similar or the same as that described above, e.g. when the gas supply system is in the first or second configuration, in order to avoid varying the pressure of the gas in the radiation source, e.g. the vessel. Additionally or alternatively, the heat transfer coefficient h of the gas in the gap 22 may depend on the size of the gap 22. As such, when the size of the gap is varied, a heat transfer coefficient h of the gas in the gap 22 may be varied too. The size of the gap 22 may be in between about 0.1mm and 1mm, such as about 0.25mm. For example, when the pressure of the gas in the gap 22 is in the region of about 15 kPa, the heat transfer coefficient h may vary between about 1700 W/m^{2}K and 195 W/m^{2}K for a size of the gap 22 varying between about 0.1mm and 1mm.

[0069] Referring to Figure 2, the vessel 16 may be provided in the form of a modular vessel. For example, the vessel 16 may comprise three modules 16b, 16d, 16c. A first module 16b of the vessel 16 may be arranged in proximity to the plasma formation region 4. The first module 16b of the vessel 16 may be arranged to surround the plasma formation region 4. A second module 16c of the vessel 16 may be arranged in proximity to the intermediate focus 6. A third module 16d of the vessel 16 may be arranged between the first and second modules 16b, 16c of the vessel 16. The wall 16a may be comprised in the third module 16d of the vessel 16. Each of the first, second and third modules 16b, 16c, 16d of the vessel 16 may comprise a truncated conical shape. It will be appreciate that the modules of the vessel disclosed herein are not limited to having a truncated conical shape. For example, in other embodiments, the modules of the vessel may each comprise cylindrical or polyhedral shape or the like. Additionally or alternatively, it will be appreciated that the vessel disclosed herein is not limited to having three modules. For example, in other embodiments, the vessel may have more or less than three modules. It will be appreciated that the guide portion 18 may be or define another module of the vessel 16.

[0070] Figure 3 shows a cross-sectional view of a part of the guide portion 18 and the wall 16a. As can be seen in Figure 3, the gap 22 is defined between the guide portion 18 and the wall 16a. For example, in use, the wall 16a may be subjected to a cooling source. The vessel 16 may comprise a plurality of cooling elements 26, five of which are shown in Figure 3. The cooling elements 26 may be part of or comprised in the cooling source. It will be appreciated that in other embodiments, the vessel may comprise more or less than five cooling elements. The cooling elements 26 may be part of or comprised in the wall 16a of the vessel 16. The cooling source may be configured to cool the wall 16a of the vessel 16. The cooling source may be configured to cool the wall 16a to a temperature below 150°C. For example, the cooling source may be configured to cool the wall 16a to a temperature in the region of about 40°C to 60°C, such as about 50°C. The cooling elements 26 may be provided in the form of coolant channels. The cooling elements 26 may be configured for transporting a coolant, such as a coolant fluid or gas. For example, the coolant may comprise water. The wall 16a may comprise a metal material or metal alloy material. The metal material or metal alloy material may be selected to have a thermal conductivity of about 200 W/mK or greater at room temperature, e.g. to allow for sufficient cooling by the cooling source. In this embodiment, the metal material or metal alloy material may comprise aluminium.

[0071] For example, in use, the guide portion 18 may be subjected to a heating source. The guide portion 18 may be arranged in the vessel 16 so that, for example in use, the guide portion 18 is subjected to heat generated at the plasma formation region 4 of the radiation source SO. The heat generated at the plasma formation region 4 of the radiation source SO is indicated by the arrows in Figure 3. This heat may result in an increase of the temperature of the guide portion 18, e.g. to above the melting temperature of the fuel. This may in turn result in dripping, spitting and/or bubbling of fuel debris deposited on the guide portion 18, which may cause contamination of one or more components of the radiation source SO, such as the collector 5. As described above, when EUV radiation is produced by the radiation source SO, the gas supply system 24 may be operated in the first configuration. The gas supply system 24 may supply the gas into the gap 22, e.g. to increase the transfer of heat between the guide portion 18 and the wall 16a. Expressed differently, by supplying the gas in the gap 22, heat may be transferred from the guide portion 18 to the wall 16a. This may lead a decrease of a temperature of the guide portion 18. In examples, where the heat generated at the plasma formation region 4 is in the region of about 2 kW, the pressure of the gas in the gap 22 may be between about 10 kPa and 20 kPa. This pressure of the gas in the gap 22 may result in a heat transfer coefficient h between about 500 W/m^{2}K and 1500 W/m^{2}K between the guide portion 18 and the wall 16a, as described above. As such, a temperature of the guide portion 18 may be decreased to below 150°C, such as between about 70 °C and 120°C. By reducing a temperature of the guide portion 18 to below 150°C, dripping, spitting and/or bubbling of fuel debris deposited on the guide portion 18 may be reduced or prevented. This may lead to a reduction in the contamination of other components of the radiation source SO, such as the collector 5. Additionally or alternatively, by reducing a temperature of the guide portion 18 to below 150°C, damage, degradation and/or corrosion of the guide portion 18 may be reduced.

[0072] The heating source may comprise a plurality of heating elements 28, six of which are shown in Figure 3. The heating elements 28 may be part of or comprised in the guide portion 18. It will be appreciated that in other embodiments, the guide portion may comprise more or less than six heating elements. The heating elements 28 may be configured to heat the guide portion 18, e.g. when no EUV radiation is produced by the radiation source SO. The heating elements 28 may be configured to heat the guide portion 18 during maintenance operations of the radiation source SO, e.g. to allow removal of fuel debris from the guide portion 18 and/or other components of the radiation source SO. The heating source may be configured to heat the guide portion 18 to a temperature greater than a melting temperature of the fuel. In embodiments, where tin is used as the fuel, the heating source may be configured to heat the guide portion 18 to a temperature above 230°C. This may allow for removal of fuel debris from the guide portion 18. As described above, the gas supply system 24 may be configured to operate in the second configuration, e.g. when no EUV radiation is produced by the radiation source SO. In the second configuration, the gas supply system 24 may supply no gas to the gap 22, e.g. to decrease the transfer of heat between the guide portion 18 and the wall 16a. In such examples, a pressure of the gas in the gap 22 may be between about 100 Pa and 200 Pa, which may result in a heat transfer coefficient h between about 10 W/m^{2}K and 100 W/m^{2}K. As such, heat transfer between the guide portion 18 and the wall 16a may be reduced, e.g. to allow the heating elements 28 to heat the guide portion 18 to a temperature above the melting temperature of the fuel. For example, when a power of about 2 kW is applied to the heating elements 28, a temperature of the guide portion 18 may be increased to between about 270°C and 330°C. This may allow for removal of fuel debris from the guide portion 18, e.g. during maintenance operations of the radiation source SO. For example, the fuel debris may become liquid and drip-off from the guide portion 18 or parts thereof. The liquid fuel debris may be collected in a reservoir, such as a fuel reservoir.

[0073] By configuring the gas supply system 24 to supply the gas into the gap 22, cooling or heating of the guide portion 18 may be controlled or adjusted more precisely. This may reduce or avoid the use of heating elements with increased capacity, for example to counteract an increased cooling capacity of the cooling source, e.g. the cooling elements. For example, an increase of the capacity of the cooling source may be necessary, when the power of the EUV radiation produced by the radiation source SO is increased. By reducing or avoiding the use of heating elements with an increased capacity, damage or deformation of one or more components of the radiation source, which may be arranged in proximity to the heating elements, may be reduced or avoided.

[0074] Figure 4 shows another cross-sectional view of a part of the guide portion 18 and the wall 16a. The embodiment shown in Figure 4 is similar to that described above in relation to Figure 3. As such, any features described above in relation to Figure 3 may also apply to the embodiment shown in Figure 4. In Figure 4, the cooling elements 26 have been omitted for the sake of clarity. However, it will be appreciated that in the embodiment shown in Figure 4, the vessel 16 may comprise the cooling elements 26, as described above.

[0075] The vessel 16 may comprises at least one restriction element or a plurality of restriction elements 30 for maintaining a pressure of the gas in the gap 22. For example, the restriction element(s) 30 may be configured to reduce a flow of gas in and/or along the gap 22, e.g. into the radiation source SO, to maintain the pressure in the gap 22. The restriction element(s) 30 may be configured to create a pressure differential between the pressure of the gas in the gap 22 and the pressure of the gas in the radiation source SO, e.g. the vessel 16, for example, when the gas supply system 24 is in the first configuration. The restriction element(s) 30 may be provided in the form of a plurality of restriction elements. In the embodiment shown in Figure 4, the restriction element(s) 30 are arranged in the gap 22. It will be appreciated that in other embodiments, the restriction elements may be arranged in or on other parts of the vessel, such as in the wall.

[0076] In this embodiment, the restriction element 30 may be provided in the form of a corrugated structure 30a. The corrugated structure 30a may be formed from a metal or metal alloy, such as stainless steel. The corrugated structure 30 may comprise a plurality of troughs 30b and peaks 30c. The corrugated structure 30a, may be configured to reduce a flow of the gas 32 along the gap 22, e.g. in a direction parallel, e.g. substantially parallel, to the wall 16a. For example, the corrugated structure 30a may be configured so that a flow of gas 32 between the troughs 30b and the peaks is reduced. However, the corrugated structure 30a may be configured so that some gas may flow between the troughs 30b and peaks 30c, e.g. adjacent troughs 30b and peaks 30c. This may prevent a pressure built-up or pressure drop in one or more of the troughs 30b and/or peaks 30c of the corrugated structure 30a. For example, a size of the through 30b and peaks 30c may be smaller than a size of the gap 22. A gap 31a may be defined between the corrugated structure 30, e.g. the troughs 30b thereof, and the guide portion 18 and/or a gap 31b may be formed between the corrugated structure 30a, e.g. the peaks 30c thereof, and the wall 16a.

[0077] Figure 5 shows another cross-sectional view of a part of the guide portion 18 and the wall 16a. The embodiment shown in Figure 5 is similar to the embodiments described above in relation to Figures 3 and 4. As such, any features described above in relation to Figures 3 and 4 may also apply to the embodiment shown in Figure 5. In Figure 5, the cooling elements 26 have been omitted for the sake of clarity. However, it will be appreciated that in the embodiment shown in Figure 5, the vessel 16 may comprise the cooling elements 26, as described above.

[0078] Referring to Figure 5, the vessel 16 may comprise a plurality of inlets 34, five of which are shown in Figure 5, for directing the gas into the gap 22. It will be appreciated that in other embodiments, the vessel may comprise more or less than five inlets. The inlets 34 may be arranged in the wall 16a. The inlets 34 may be provided in the form of nozzles, which may be arranged to direct the flow of gas 32 into the gap 22. Although the inlets 34 are only shown in the embodiment shown in Figure 5, it will be appreciated that any of the features of the inlets 34 may also apply to the embodiments described above.

[0079] In this embodiment, the restriction elements 30 may be provided in the form of a plurality of outlets 30d. The outlets 30d may be part of the wall 16a. The outlets 30d may be configured to restrict the flow of gas 32 from the gap 22, e.g. to maintain a pressure in the gap 22. For example, the outlets 30c may be provided in the form of slits or orifice or the like. A size of each outlet 30d may be selected so that the flow of gas 32 from the gap 22 through the outlets 30d is restricted or reduced. The outlets 30d may each comprise a sealing element (not shown), such a leaking sealing element or O-ring or the like. The outlets 30d may each comprise the sealing element to reduce or restrict the flow of gas 32 from the gap 22 through the outlets 30d. This may allow for a pressure of the gas in the gap 22 to be maintained. It will appreciated that the outlets 30d may be used in addition or alternatively to the corrugated structure 30a. Although in the above description the restriction element(s) are described as being provided in the form of a corrugated structure and/or outlets, it will be appreciated that in other embodiments another structure or element may be used to maintain the pressure of the gas in the gap.

[0080] Figures 6 and 7 show an exemplary guide portion 18 for use with the vessel 16. The guide portion 18 may comprise a first part 18a and a second part 18b. The first part 18a of the guide portion 18 may be configured to be arranged in the opening 16e of the wall 16a. The first part 18a of the guide portion 18 may be provided in the form of a tubular portion or conduit. The first part 18a of the guide portion 18 may comprise a shape that corresponds to a shape of the opening 16e of the wall 16a. For example, the first part 18a may comprise a round shape, such as a shape having a circular cross-section, e.g. substantially circular cross-section, or elliptical cross-section, e.g. substantially elliptical cross-section, or the like. A size or dimension, such as a radius and/or circumference, of the first part 18a of the guide portion 18 may be smaller than a size or dimension, such as a radius and/or circumference, of the opening 16e of the wall 16a of the vessel 16. This may allow for the gap 22 to be defined or formed between at least the first part 18a of the guide portion and the opening 16e of the wall 16a of the vessel 16.

[0081] The first part 18a of the guide portion 18 may be configured for connection to another conduit (not shown), which may be configured to connect the guide portion 18 to the fuel debris removal device 20.

[0082] The second part 18b of the guide portion 18 may protrude or extend from the first part 18a of the guide portion 18. For example, the second part 18b of the guide portion 18 may extend perpendicularly, e.g. substantially perpendicularly, from the first part 18a of the guide portion 18. The second part 18b of the guide portion 18 may comprise a curved shape, which may correspond, e.g. substantially correspond, to a shape of the wall 16a. For example, when the first part 18a the guide portion 18 is arranged in the opening 16e of the wall 16a, the second part 18b of the guide portion 18 may extend parallel, e.g. substantially parallel, to the wall 16a of the vessel 16, as for example shown in Figure 2.

[0083] The heating elements 28 are schematically indicated by the blocks in Figures 6 and 7. Although two blocks 28 are shown in Figures 6 and 7, it will be appreciated that each block may be indicative of one or more heating elements 28. The heating elements 28 may be arranged on the guide portion 18, e.g. so that the heating elements 28 are located in the gap 22, when the first part 18a of the guide portion 18 is arranged in the opening 16e of the wall 16a. For example, the heating elements 28 may be arranged on a surface 18c of the guide portion 18. The gap 22 may be defined between the surface 18c of the guide portion 18 and the wall 16a, when the first part 18a of the guide portion 18 is arranged in the opening 16e. The heating elements 28 may be arranged on the surface 18c of the guide portion 18 so as to uniformly heat the guide portion 18, for example during maintenance operations of the heating source SO.

[0084] Figures 8 and 9 show an exemplary vessel module for use in the vessel 16 of the radiation source SO shown in Figure 2. The vessel module shown in each of Figure 8 and 9 may be provided in the form of the third vessel module 16d, as described above in relation to Figure 2. Figure 8 shows the third vessel module 16d with the guide portion 18 removed. Figure 9 shows the third vessel module 16d with the first part 18a of the guide portion 18 arranged in the opening 16e of the wall 16a.

[0085] The third vessel module 16d may comprise an enclosing structure 36. The enclosing structure 36 may be configured to surround the wall 16a of the third vessel module 16d. The enclosing structure 36 may form an outer surface of the third vessel module 16d. The enclosing structure 36 may comprise an opening 36a. A size and/or shape of the opening 36a of the enclosing structure 36 may correspond to a size and/or shape of the opening 16e in the wall 16a.

[0086] Referring to Figure 8, the opening 16e of the wall 16a may comprise a round shape. For example, the opening 16e may comprise a circular cross-section, e.g. substantially circular cross-section, or elliptical cross-section, e.g. substantially elliptical cross-section, or the like.

[0087] When the first part 18a of the guide portion 18 is arranged in the opening 16e of the wall 16a, the gap 22 may be defined between the first part 18a of the guide portion 18 and a periphery 16f of the opening 16e in the wall 16a. The gap 22 may extend between first part 18a of the guide portion 18 and the opening 36a of the enclosing structure 36, e.g. a periphery thereof. The gap 22 may also be defined between the second part 18b of the guide portion 18 and the wall 16a, e.g. a part 16g of the wall 16a, which can be best seen in Figure 2. The gap 22 may extend between the second part 18b of the guide portion 18 and the wall 16a, e.g. the part 16g thereof.

[0088] Referring to Figure 9, when the first part 18a of the guide portion 18 is arranged in the opening 16e of the wall 16a, the first part 18a of the guide portion 18 may protrude from the wall 16a in an outward direction. The first part 18a of the guide portion 18 may also protrude from the enclosing structure 36 in the outward direction. This may facilitate connection of the guide portion 18 to the other conduit and/or the fuel debris removal device 20.

[0089] Figure 10 shows a plan view of an exemplary arrangement 42 of a plurality of spacing elements 40 for use in the vessel 16. The plurality of spacing elements 40 may be part of or comprised in the vessel 16. The plurality of spacing elements 40 may be configured for maintaining a size of the gap 22. For example, the spacing elements 40 may be configured to control the size of the gap 22. The spacing elements 40 be configured to determine a tolerance of the size of the gap 22, e.g. during manufacture of the guide portion 18 and/or the third vessel module 16. As described above, the size of the gap 22 may be between about 0.1mm and 1mm, such as about 0.25mm. For example, the spacing elements 40 may be part of the wall 16a. Alternatively or additionally, the spacing elements 40 may be part of the guide portion 18.

[0090] Referring to Figure 10, the arrangement 42 of the spacing elements 40 may be arranged on the wall 16a, e.g. opposite to the second part 18b of the guide portion 18. For example, the arrangement 42 of the spacing elements 40 may be arranged on the part 16g of the wall 16a, which may be opposite to the second part 18b of the guide portion 18, when the first part 18a of the guide portion 18 is arranged in the opening 16e of the wall 16a, as shown in Figure 2. The spacing elements 40 may be arranged on the wall 16a to extend into the gap 22 and to face the second part 18b of the guide portion 18. The arrangement 42 of the spacing elements 40 may comprise the inlets 34 and the outlets 30d, as described above. The inlets 34 may be arranged between at least two of the spacing elements 40. For example, the inlets 34 may be equidistantly arranged between the spacing elements 40. It will be appreciated that in other embodiments, the inlets may be differently arranged. The outlets 30d may be arranged so as to surround the spacing elements 40 and the inlets 34. For example, the outlets 30d may be arranged on a periphery 42a of the arrangement 42. However, it will be appreciated that in other embodiments, the outlets may be differently arranged.

[0091] Figure 11 shows a cross-sectional view of another exemplary arrangement 44 of the spacing elements 40. The arrangement 44 shown in Figure 11 may comprise any of the features of the arrangement 42 shown in Figure 10. However, it will be appreciated that the arrangement 44 of the spacing elements 40 shown in Figure 11 may find applicability on a different part of the wall 16a. For example, the spacing elements 40 may be arranged between the first part 18a of the guide portion 18 and the opening 16e of the wall 16a. The spacing elements 40 may be arranged on the periphery 16f of the opening 16e. The spacing elements 40 may be arranged on the wall 16a, e.g. on the periphery 16f of the opening 16e, e.g. so as to extend towards an interior or centre of the opening 16e, as will be described below. It will be appreciated that in other embodiments, the spacing elements may additionally or alternatively be arranged on the guide portion.

[0092] In the exemplary embodiments shown in Figures 10 and 11, each spacing element 40 may be provided in the form of a round or semi-round structure, such as a burl. However, it will be appreciated that in other embodiments, each spacing element may have a different shape. The size G of the gap 22 is indicated in Figure 11. A height H of each spacing element 40 may be determined by one or more manufacturing tolerances of the size G of the gap 22. However, it will be appreciated that the height H of each spacing element 40 may correspond to a minimum of the allowed size G of the gap 22. Although a plurality of spacing elements are described above, it will be appreciated that in other embodiments, the vessel may comprise single or at least one spacing element.

[0093] The vessel 16 may comprise a fastening element 46 for fastening the guide portion 18 to the wall 16a. The fastening element 46 may be configured for detachably fastening the guide portion 18 to the vessel 16, e.g. the wall 16a. For example, the fastening element 46 may be provided in the form of a bolt and nut arrangement or a bolt and bolt-hole arrangement or the like. Although only one fastening element 46 is shown in Figure 11, it will be appreciated that the vessel may comprise more than one fastening element for fastening the guide portion to the vessel, e.g. the wall.

[0094] Figure 12 shows a cross-sectional view of the first part 18a of the guide portion 18 arranged in the opening 16e of the wall 16a. The first part 18a of the guide portion 18 may be concentrically arranged in the opening 16e of the wall 16a. In the exemplary embodiment shown in Figure 12, three inlets 34 are provided in the wall 16a.

[0095] Figure 13 shows a part of the cross-sectional view of the first part 18a of the guide portion 18 arranged in the opening 16e of the wall 16a shown in Figure 12. The spacing elements 40 may be arranged between the first part 18a of the guide portion 18a and the opening 16e of the wall 16a. By arranging the spacing elements 40 between the first part 18a of the guide portion 18 and the opening 16e of the wall 16a, the spacing elements 40 may apply a tension or pre-tension on the first part 18a of the guide portion 18 and/or prevent expansion of at least the first part 18a of the guide portion 18, in use.

[0096] The spacing elements 40 may be arranged between the first part 18a of the guide portion 18a and the opening 16e of the wall 16a, e.g. so as to extend towards a centre of the opening 16e. The spacing elements 40 may be circumferentially arranged on the periphery 16f of the opening 16e of the wall 16a. It will be appreciated that in other embodiments, the spacing elements may additionally or alternatively be arranged on the guide portion, e.g. the first part and/or second part thereof.

[0097] Figure 14 shows an exemplary vessel module 48 for use in a vessel, such as the vessel 16 of the radiation source SO shown in Figure 2. The vessel module 48 may be provided in the form of the third vessel module 16d, described above. As such, any features described above in relation to the third vessel module 16d may also apply to the vessel module 48 shown in Figure 14.

[0098] The vessel module 48 comprise a wall 50 comprising a first portion 50a and a second portion 50b. The first portion 50a of the wall 50 may be provided in the form of an inner wall of the vessel module 48. The second portion 50b may be provided in the form of an outer wall of the vessel module 48. A gap 52 is defined between the first portion 50a and the second portion 50b of the wall 50. In the exemplary embodiment shown in Figure 14, the vessel module 48 comprises the guide portion 18 for directing fuel debris from the plasma formation region 4 of the radiation source SO towards the fuel debris removal device 20, as described above. However, it will be appreciated that in other embodiments the vessel module may not comprise the guide portion. The wall 50 may comprise an opening 50c. At least a part of the guide portion 18 is arranged in the opening 50c of the wall, e.g. so that the gap 52 extends between the guide portion 18, the first portion 50a and the second portion 50b of the wall 50. The second portion 50b of the wall 50 may comprise any features of the wall 16a described above.

[0099] The vessel module 48 may be configured for connection to the gas supply system 24. In this embodiment, the gas supply system 24 may be configured to supply a gas into the gap 52 to control a transfer of heat between the first portion 50a and the second portion 50b of the wall 50. The gas supply system 24 shown in Figure 14 may comprise any of the features of the gas supply system, described above. It will be appreciated that in other embodiments, the gas supply system may be part of or comprised in the vessel module.

[0100] As described above, the gas supply system 24 may be operable between the first configuration and the second configuration. The gas supply system 24 may comprise the mass flow controller 25. The mass flow controller 25 may comprise the controllable valve 25a. The mass flow controller 25 may be configured to operate the valve 25a between the open and the closed state. In the first configuration, the gas supply system 24 may be configured to supply the gas into the gap 52, for example to increase a transfer of heat between the first portion 50a and the second portion 50b of the wall 50. In other words, in the first configuration of the gas supply system 24, thermal conduction between the first portion 50a and the second portion 50b of the wall 50 may be increased. In the first configuration of the gas supply device 24, the mass flow controller 25 may be configured to operate the valve in the open state. For example, the mass flow controller 25 may be configured to open the valve 25a so that gas is supplied to the gap 52 at a target mass flow rate.

[0101] In the second configuration, the gas supply system 24 may be configured to terminate a supply of gas into the gap 52, for example to decrease a flow of heat between the first portion 50a and the second portion 50b of the wall 50. Expressed differently, in the second configuration, the gas supply system 24 may be configured to supply no gas into the gap 52. In the second configuration of the gas supply system 24, thermal conduction between the first portion 50a and the second portion 50b may be decreased, for example relative to the thermal conduction between the first portion 50a and the second portion 50b of the wall 50, when the gas supply system 24 is in the first configuration. In the second configuration of the gas supply device 24, the mass flow controller 25 may be configured to operate the valve in the closed state. The gas supply system 24 may be operated in the first configuration, when EUV radiation is produced by the radiation source SO. The gas supply system 24 may be operated in the second configuration, when no EUV radiation is produced by the radiation source SO.

[0102] The heat transfer coefficient of the gas in the gap 52 may be dependent on a pressure of the gas in the gap 52. The gas supply system 24 may be configured to control a pressure of the gas in the gap 52 to control the transfer of heat between the first portion 50a and the second portion 50b of the wall. For example, the gas supply system 24 may be configured to increase or decrease the pressure of the gas in the gap 52 to increase or decrease the heat transfer coefficient h of the gas in the gap 52. For example, when the gas supply system 24 is in the first configuration, a pressure of the gas in the gap 52 may be greater than a pressure of the gas in the gap 52, when the gas supply system 24 is in the second configuration. For example, when the gas supply system 24 is in the first configuration, the pressure of the gas in the gap 52 may be between about 10 kPa and 20 kPa. For example, when the gas supply system 24 is in the second configuration, the pressure of the gas in the gap 52 may be between about 100 Pa and 200 Pa. A pressure of the gas in the gap 52 may depend on the size of the gap 52 and/or the type of gas. The gas may comprise a thermal conductivity at room temperature between about 0.02 W/mK and 0.18 W/mK. The gas may comprise an inert gas. The gas may be selected from at least one of hydrogen, nitrogen and helium. In an exemplary embodiment, hydrogen may be used as the gas. As described above, hydrogen may already be used in the radiation source SO. However, it will be appreciated that in other embodiments another gas, such as nitrogen, helium or mixtures thereof may be used.

[0103] As described above, for example, in use, the wall 50 may be subjected to a cooling source. The vessel module 48 may comprise a plurality of cooling elements. The cooling elements may be part of or comprised in the cooling source. The cooling elements may be part of or comprised in the second portion 50b of the wall 50. The cooling elements of the vessel module 48 may comprise any of the features of the cooling elements 26 described above.

[0104] For example, in use, the first portion 50a of the wall 50 may be subjected to a heating source. For example, in use, the first portion 50a of the wall 50 may be subjected to heat generated at the plasma formation region 4 of the radiation source SO. This heat may result in an increase of the temperature of first portion 50a of the wall 50 to above the melting temperature of the fuel. As described above, this may in turn result in dripping, spitting and/or bubbling of fuel debris deposited on the first portion 50a of the wall 50, which may cause contamination of one or more components of the radiation source SO, such as the collector 5. As described above, when the radiation source is on, the gas supply system 24 may be operated in the first configuration. The gas supply system 24 may supply the gas into the gap 52, e.g. to increase the transfer of heat between the first portion 50a and the second portion 50b of the wall 50. Expressed differently, by supplying the gas in the gap 22, heat may be transferred from the first portion 50a to the second portion 50b of the wall 50. This may lead a decrease of a temperature first portion 50a of the wall 50, for example to below the melting temperature of the fuel. By reducing the temperature of the first portion 50a of the wall to below the melting temperature of the fuel, dripping, spitting and/or bubbling of fuel debris deposited on the first portion 50a of the wall may be reduced or prevented. This may lead to a reduction in the contamination of other components of the radiation source SO, such as the collector 5.

[0105] The heating source may comprise the heating elements 28. The heating elements 28 may be part of or comprised in first portion 50a of the wall 50. The heating elements 28 may be configured to heat the first portion 50a of the wall 50, for example when no EUV radiation is produced by the radiation source SO. The heating elements 28 may heat the guide portion 18 during maintenance operations of the radiation source SO, e.g. to allow removal of fuel debris from the first portion 50a of the wall and/or other components of the radiation source SO. The heating elements 28 may be configured to heat the first portion 50a of the wall 50 to a temperature greater than a melting temperature of the fuel. In embodiments, where tin is used as the fuel, the heating source may be configured to heat the first portion 50a of the wall to a temperature above 230°C. This may allow for removal of fuel debris from the first portion 50a of the wall 50. As described above, the gas supply system 24 may be configured to operate in the second configuration, when no EUV radiation is produced by the radiation source SO. In the second configuration, the gas supply system 24 may supply no gas to the gap 52, e.g. to decrease a transfer of heat between the first portion 50a and the second portion 50b of the wall 50. This may allow the heating element 28 to heat the first portion 50a of the wall 50 to a temperature above the melting temperature of the fuel. This in turn may allow for removal of fuel debris from the first portion 50a of the wall 50, e.g. during maintenance operations of the radiation source SO. For example, the fuel debris may become liquid and drip-off from the first portion 50 of the wall or parts thereof. The liquid fuel debris may be collected in a reservoir, such as a fuel reservoir.

[0106] It will be appreciated that the vessel module 48 may comprise any of the features of the restriction elements, inlets and/or spacing elements, as described above. For example, the restriction elements may be arranged in the gap 52 and/or in the second portion 50b of the wall 50. The inlets may be arranged in the second portion 50b of the wall 50. The spacing elements may be arranged on the first portion 50a and/or the second portion 50b of the wall 50, e.g. such that the spacing elements extend into the gap 52, as described above.

[0107] Although in vessel module 48 has been described herein as being provided in the form of the third vessel module 16d, it will be appreciated that in other embodiments, the vessel module may be provided in the form of the first module 16b or the second module 16c.

[0108] Figure 15 shows another exemplary vessel module 48 for use in a vessel of the radiation source SO. In the embodiment shown in Figure 15, the vessel module 48 is provided in the form of the first vessel module 16b described above.

[0109] Figure 16 shows another exemplary vessel module 48 for use in a vessel of the radiation source SO. In the embodiment shown in Figure 16, the vessel module 48 is provided in the form of the second vessel module 16c described above.

[0110] It will be appreciated that each of the first, second and third vessel modules 16b, 16c, 16d of the vessel 16, as shown in Figure 2, may comprise the feature of the vessel module 48. In some embodiments, the gaps the modules may be in communication with each other. Expressed differently, the vessel 16, e.g. the first, second and/or third vessel modules 16b, 16c, 16d, may be configured such that gas exchange between the gap 52 of one of the first, second and third vessel modules 16b, 16c, 16d and the gap 52 of at least one other the first, second and third vessel modules 16b, 16c, 16d is allowed. In other embodiments, the vessel 16, e.g. the first, second and/or third vessel modules 16b, 16c, 16d, may be configured such that gas exchange between the gap of one of the first, second and third vessel modules 16b, 16c, 16d and the gap of at least one other the first, second and third vessel modules 16b, 16c, 16d is prevented. The first, second and/or third vessel modules 16b, 16c, 16d may be configured such that gas exchange between the gap 52 of at least one of the first, second and third vessel modules 16b, 16c, 16d and the radiation source SO, e.g. the vessel 16, may be allowed, e.g. to decrease a pressure in the gap 52, when the gas supply system 24 is in the second configuration.

[0111] Although in the above description the vessel module 48 may be provided in the form of the first, second and/or third vessel module 16b, 16c, 16d, it will be appreciated that the present disclosure is not limited to this. For example, it will be appreciated that in other embodiments, the vessel module may be provided in the form of a reservoir for supplying fuel to the radiation source. The vessel module may be provided in the form of another reservoir for collecting fuel from the radiation source.

[0112] Although in the above description the gas supply system is operated in the first configuration, when radiation is produced by the radiation source, it will be appreciated that in other embodiments, the gas supply system may additionally or alternatively be operated in the first configuration, when no radiation is produced by the radiation source. Additionally or alternatively, the gas supply system may be operated in the second configuration, when radiation is produced by the radiation source.

[0113] Although in the above description hydrogen is used as the gas. It will be appreciated that in other embodiments, a gas other than hydrogen may be used. For example, in other embodiments, the gas may comprise helium, nitrogen or a mixture thereof. In such other embodiments, a pressure of the gas in the gap may be similar to, the same as or different from the exemplary pressure(s) disclosed herein, e.g. when the gas supply system is in the first or second configuration.

[0114] 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. Possible other applications include the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, flat-panel displays, liquid-crystal displays (LCDs), thin-film magnetic heads, etc.

[0115] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The descriptions above are intended to be illustrative, not limiting. Thus it will be apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the claims set out below.

Claims

1. A vessel for an EUV radiation source, the vessel comprising:

a guide portion for directing fuel debris from a plasma formation region of the EUV radiation source towards a fuel debris removal device;
a wall comprising an opening, wherein at least a part of the guide portion is arranged in the opening of the wall so that a gap is defined between the guide portion and the wall; and
a gas supply system configured to supply a gas into the gap to control a transfer of heat between the guide portion and the wall.

2. The vessel of claim 1, wherein the gas supply system is operable between a first configuration and a second configuration, wherein in the first configuration, the gas supply system is configured to supply the gas into the gap to increase a transfer of heat between the guide portion and the wall and wherein in the second configuration, the gas supply system is configured to supply no gas into the gap to decrease a transfer of heat between the guide portion and the wall.

3. The vessel of claim 2, wherein the gas supply system is configured to operate in the first configuration, when EUV radiation is produced by the EUV radiation source and wherein the gas supply system is configured to operate in the second configuration, when no EUV radiation is produced by the EUV radiation source.

4. The vessel of any one of claim 2 or 3, wherein when the gas supply system is in the first configuration, a pressure of the gas in the gap is greater than a pressure of the gas in the gap, when the gas supply system is in the second configuration.

5. The vessel of claim 4, wherein when the gas supply system is in the first configuration, the pressure of the gas in the gap is between about 10 kPa and 20 kPa and wherein when the gas supply system is in the second configuration, the pressure of the gas in the gap is between about 100 Pa and 200 Pa.

6. The vessel of any preceding claim, wherein the gas supply system is configured to control a pressure of the gas in the gap to control the transfer of heat between the guide portion and the wall, the gas supply system being configured to control the pressure of the gas in the gap based on at least one of: a type of gas and a size of the gap.

7. The vessel of any preceding claim, wherein in use, the wall is subjected to a cooling source and the guide portion is subjected to a heating source.

8. The vessel of claim 7, wherein the heating source comprises a heating element configured to heat the guide portion, when no EUV radiation is produced by the EUV radiation source, the heating element being part of the guide portion.

9. The vessel of claim 7 or 8, wherein the guide portion is arranged in the vessel so that in use, the guide portion is subjected to heat generated at the plasma formation region of the EUV radiation source.

10. The vessel of any one of claims 7 to 9, wherein the cooling source comprises a cooling element configured to cool the wall, the cooling element being part of the wall.

11. The vessel of any preceding claim, wherein the gas comprises a thermal conductivity at room temperature between about 0.02 W/mK and 0.18 W/mK

12. The vessel of any preceding claim, wherein the gas is selected from at least one of: hydrogen, nitrogen and helium.

13. The vessel of any preceding claim, wherein the vessel comprises at least one restriction element or a plurality of restriction elements for maintaining a pressure of the gas in the gap, at least some of the plurality of restriction elements being arranged in the gap and/or in the wall.

14. The vessel of any preceding claim, wherein the vessel comprises a plurality of spacing elements for maintaining a size of the gap, the plurality of spacing elements being arranged between the guide portion and the wall.

15. The vessel of any preceding claim, wherein the vessel comprises a plurality of inlets for directing the gas into the gap, the plurality of inlets being arranged in the wall.

16. An EUV radiation source comprising a vessel according to any preceding claim.

17. A lithographic system comprising an EUV radiation source according to claim 16 and a lithographic apparatus.

18. A guide portion for use in a vessel, the guide portion being configured such that a gap is defined between a wall of the vessel and the guide portion, when at least a part of the guide portion is arranged in an opening of the wall of the vessel.

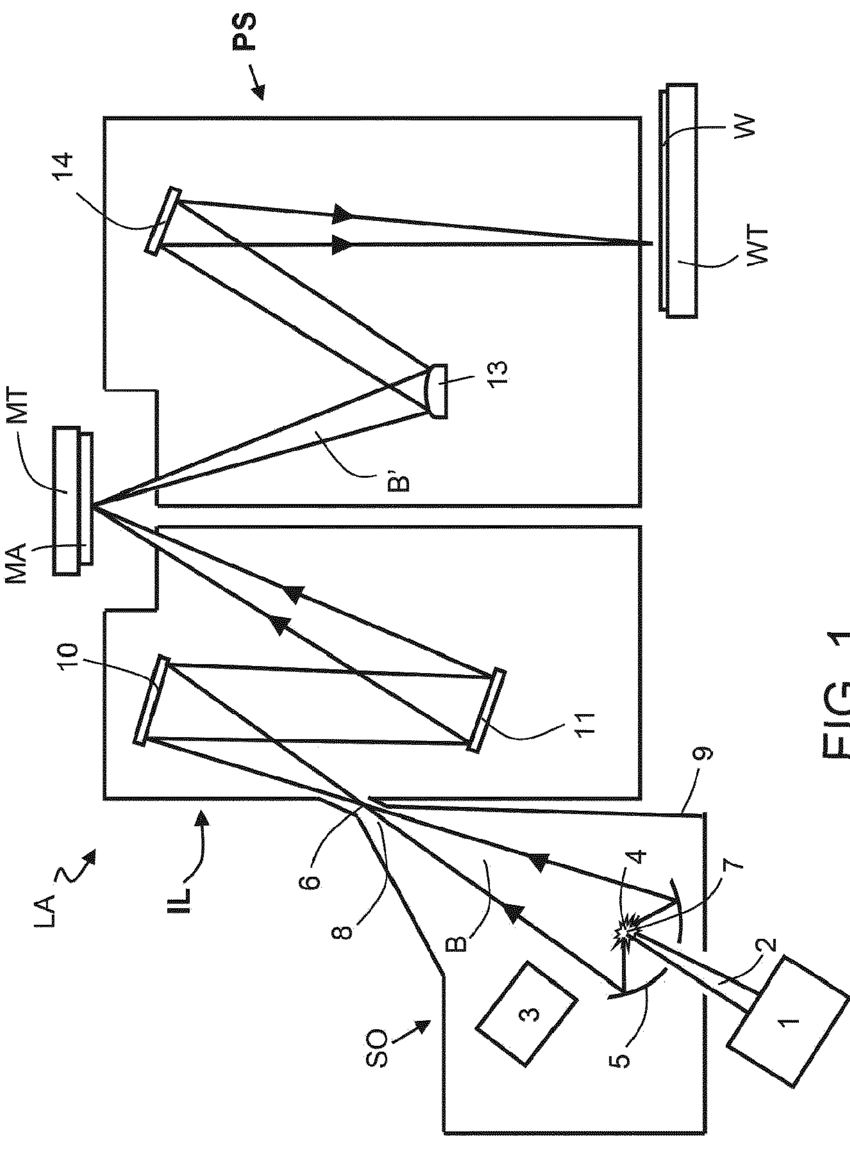

FIG. 1

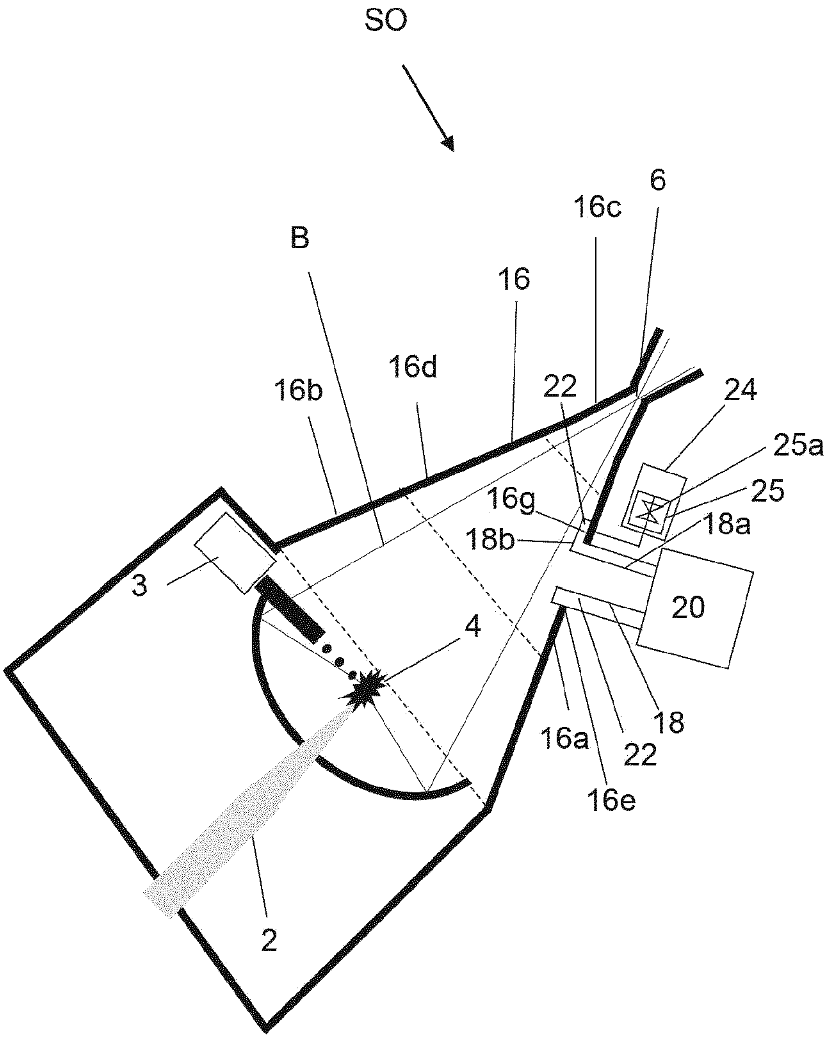

FIG. 2

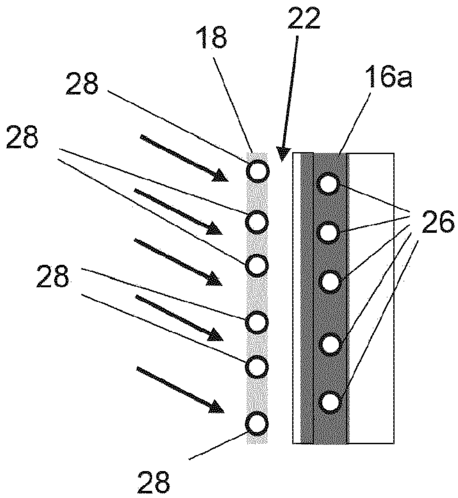

FIG. 3

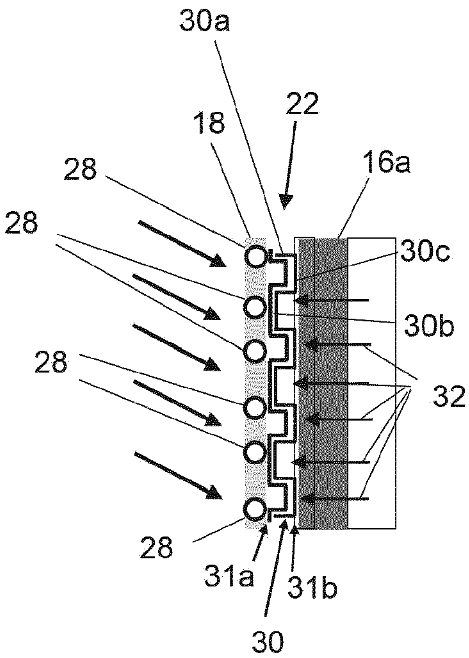

FIG. 4

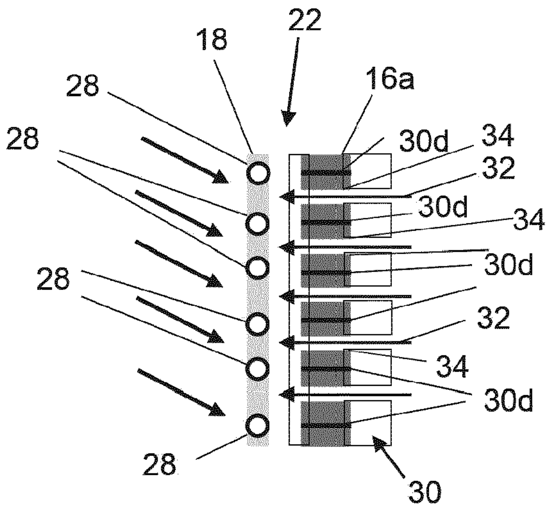

FIG. 5

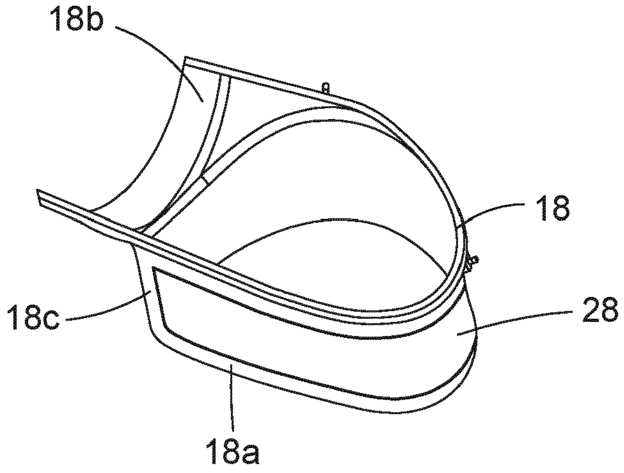

FIG. 6

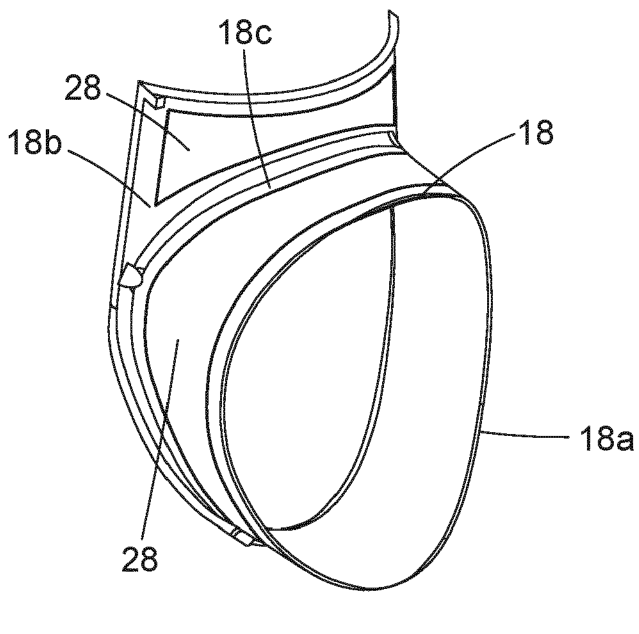

FIG. 7

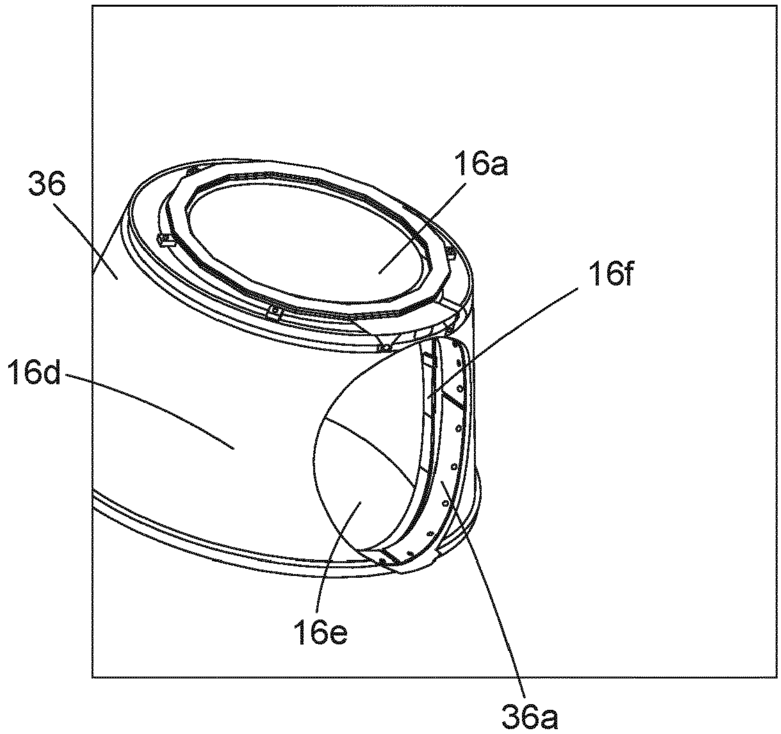

FIG. 8

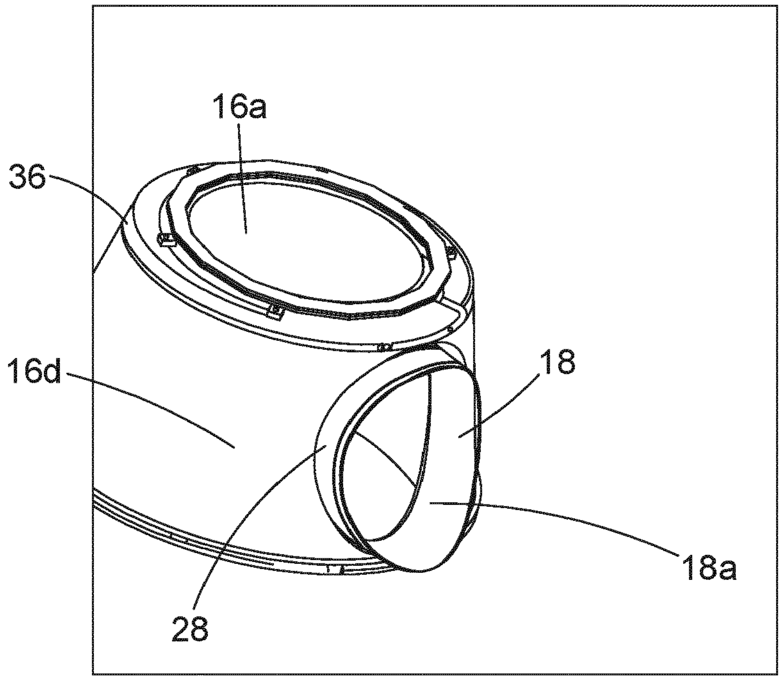

FIG. 9

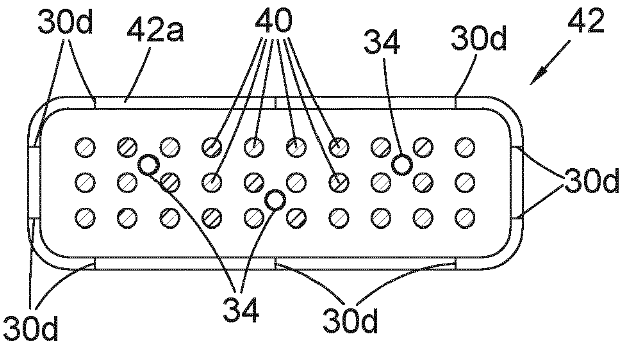

FIG. 10

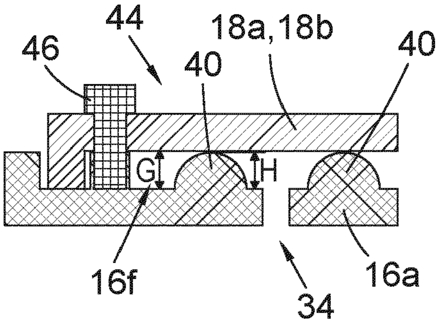

FIG. 11

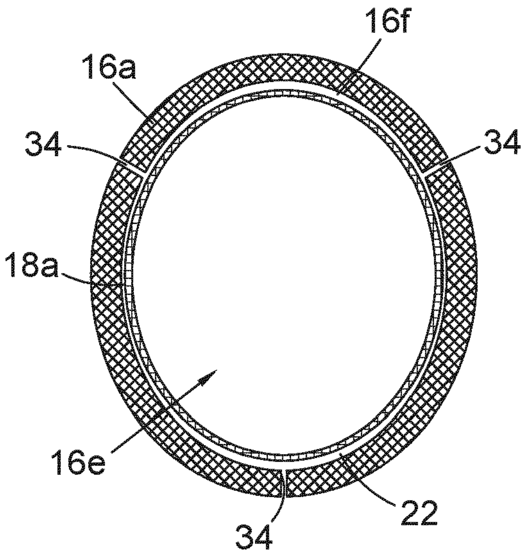

FIG. 12

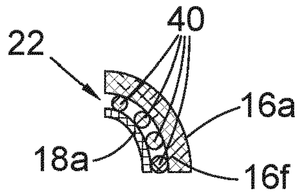

FIG. 13

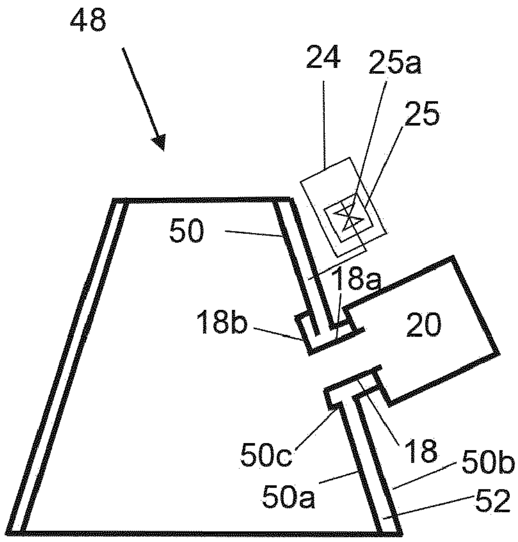

FIG. 14

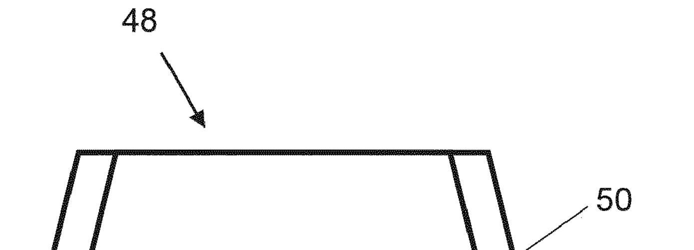

FIG. 15

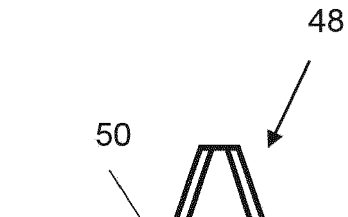

FIG. 16

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EUROPEAN SEARCH REPORT

Application Number
EP 21 21 7092

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2018/127565 A2 (ASML NETHERLANDS BV [NL]) 12 July 2018 (2018-07-12) * paragraph [0243]; claims; figures * -----	1-3,6-15	INV. H05G2/00
X	US 10 379 443 B2 (ASML NETHERLANDS BV [NL]) 13 August 2019 (2019-08-13) * column 12, line 50 - column 13, line 3; figures * -----	1	
A	US 2020/124976 A1 (PATEL HRISHIKESH [NL] ET AL) 23 April 2020 (2020-04-23) * claim 1; figures * -----	1-15	
			TECHNICAL FIELDS SEARCHED (IPC)
			H05G

The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
Munich	19 September 2022	Smith, Christopher

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
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T : theory or principle underlying the invention
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D : document cited in the application
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EPO FORM 1503 03.82 (P04C01)

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Application Number
EP 21 21 7092

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☒ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

☐ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 21 21 7092

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

19-09-2022

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