(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
18 June 2015 (18.06.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/086232 A1

(51) International Patent Classification:
G03F 7/20 (2006.01) *H05G 2/00* (2006.01)

(21) International Application Number:
PCT/EP2014/073992

(22) International Filing Date:
7 November 2014 (07.11.2014)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
13196309.2 9 December 2013 (09.12.2013) EP

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

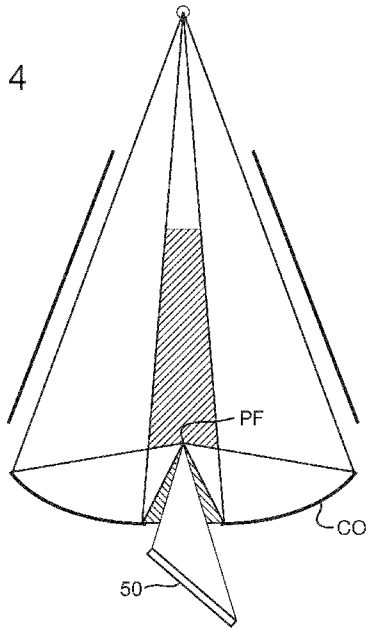
Published:

— *with international search report (Art. 21(3))*

WO 2015/086232 A1

(54) Title: RADIATION SOURCE DEVICE, LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD

Fig. 4



(57) Abstract: A radiation source, e.g. for EUV for use in a lithographic apparatus, generates radiation by illuminating droplets of fuel with first radiation to form a plasma and collects second radiation omitted by the plasma using a collector (CO). The collector has an aperture and the fuel passes along a vertical trajectory through that aperture before being irradiated by the first radiation. In an embodiment the first radiation is directed along a beam, the final part of which is coincident with the final part of the trajectory of the fuel droplets. In an embodiment a gas flow is arranged coincident with the fuel trajectory and/or the beam of first radiation.

Radiation Source Device, Lithographic Apparatus and Device Manufacturing Method

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of European patent application 13196309.2, which was filed on 9 December 2013, and which is incorporated herein in its entirety by reference.

FIELD

[0002] The present invention relates to a radiation source device, a lithographic apparatus and a device manufacturing method. In particular, the invention relates to radiation sources for generating EUV radiation for lithographic apparatus.

BACKGROUND

[0003] A lithographic apparatus is a machine that applies a desired pattern onto a substrate, usually onto a target portion of the substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In that instance, a patterning device, which is alternatively referred to as a mask or a reticle, may be used to generate a circuit pattern to be formed on an individual layer of the IC. This pattern can be transferred onto a target portion (e.g. comprising part of, one, or several dies) on a substrate (e.g. a silicon wafer). Transfer of the pattern is typically via imaging onto a layer of radiation-sensitive material (resist) provided on the substrate. In general, a single substrate will contain a network of adjacent target portions that are successively patterned. Known lithographic apparatus include so-called steppers, in which each target portion is irradiated by exposing an entire pattern onto the target portion at one time, and so-called scanners, in which each target portion is irradiated by scanning the pattern through a radiation beam in a given direction (the "scanning"-direction) while synchronously scanning the substrate parallel or anti-parallel to this direction.

[0004] In order to reduce the size of the features of the circuit pattern, it is necessary to reduce the wavelength of the imaging radiation. To this end, lithographic apparatus using EUV radiation, e.g. having a wavelength in the range of from about 5 nm to 20 nm, are under development. EUV radiation is strongly absorbed by almost all materials, therefore the

optical systems and mask must be reflective and the apparatus kept under a low pressure or vacuum.

SUMMARY

[0005] Generation of EUV radiation of sufficient intensity and spectral purity for use in a lithographic apparatus is difficult. Possible sources include synchrotrons, free electron lasers and plasma sources of various types. Currently, the most promising source type is the laser-produced plasma source. In such a source, a small quantity of a fuel, e.g. a droplet of liquid tin, is irradiated with a powerful laser so that it forms a plasma. When free electrons in the plasma recombine with the tin ions, radiation at 13.5 nm wavelength is emitted. Although functioning tin-based LPP sources have been developed, they present various issues, in particular relating to the large amounts of debris generated which contaminates the source module and can also migrate into other parts of the lithographic apparatus. Further, there are difficulties in accurately targeting the laser on the droplets, with significant pulse-to-pulse variations in the source position and output power. Generation of sufficient power in the desired wavelength is also a major concern, given the significant losses that occur at each reflection of the EUV beam.

[0006] Therefore, it is desirable to provide an improved source for EUV radiation which avoids or ameliorates at least some of the above problems.

[0007] According to an aspect of the invention, there is provided a radiation source comprising:

a fuel dispenser, such as a droplet generator, for emitting fuel along a fuel trajectory;

a beam guiding system for directing first radiation in a first beam to a first focal point located on the fuel trajectory, whereby fuel at the focal point is excited into a plasma that emits second radiation; and

a collector arranged to collect the second radiation and direct it in a second beam to a second focal point;

wherein the fuel trajectory is substantially parallel to the first beam.

The fuel trajectory may be vertically upward. The fuel dispenser may be a droplet generator arranged to generate droplets of molten tin.

[0008] The second beam may be substantially parallel to the first beam. The radiation source may include a debris trap located behind the first focal point as seen from the collector and a drain arranged to remove debris from the debris trap. Alternatively or additionally, the radiation source may include a debris trap located behind the first focal point as seen from the

collector and a gas supply device arranged to supply a gas to a chamber including the collector and a gas exhaust device arranged to remove gas from the debris trap. The gas supply device may include a nozzle member around the aperture and at least one nozzle aperture arranged to emit gas toward the first focal point. The nozzle member may be mounted on the collector.

[0009] In an embodiment the radiation source may include a heat store member located on the fuel trajectory past the first focal point. The heat store member may be located within a debris trap. The radiation source may include a temperature control system arranged to control the temperature of the heat store member to be higher than a melting point of the fuel. The radiation source may include a wall provided on the collector around the aperture therein and extending toward the first focal point.

[0010] According to an aspect of the invention, there is provided a radiation source comprising:

a fuel dispenser for emitting fuel along a fuel trajectory;

a beam guiding system for directing first radiation to a first focal point located on the fuel trajectory, whereby fuel at the focal point is excited into a plasma that emits second radiation; and

a collector arranged to collect the second radiation and direct it to a second focal point;

wherein the collector has an aperture through which the first beam is directed and a conical wall surrounding the aperture and extending towards the first focal point.

[0011] According to an aspect of the invention, there is provided a radiation source comprising:

a fuel dispenser for emitting fuel along a fuel trajectory;

a beam guiding system for directing first radiation to a first focal point located on the fuel trajectory, whereby fuel at the focal point is excited into a plasma that emits second radiation; and

a collector arranged to collect the second radiation and direct it to a second focal point;

wherein the fuel trajectory is vertical and passes through an aperture in the collector.

[0012] According to an aspect of the invention, there is provided a lithographic apparatus comprising:

a radiation source as described above;

an illuminator arranged to direct the second radiation onto a patterning device;

a support table arranged to support a patterning device; and

a projection system arranged to project radiation patterned by the patterning device onto a substrate.

[0013] According to an aspect of the invention, there is provided a device manufacturing method comprising:

emitting fuel on a fuel trajectory;

irradiating the fuel with first radiation in a first beam so as to excite the fuel into a plasma;

collecting radiation emitted by the plasma into a second beam using a collector;

directing the collected radiation to illuminate a patterning device; and

projecting radiation pattern by the patterning device onto a substrate; wherein the fuel trajectory is substantially parallel to the first beam.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

[0015] - Figure 1 depicts a lithographic apparatus used in an embodiment of the invention;

[0016] - Figure 2 is a more detailed view of the main optical path of the apparatus of Figure 1;

[0017] - Figures 3A and B depict principal components of the source collector apparatus of the apparatus of Figures 1 and 2;

[0018] - Figure 4 depicts the beam path of EUV radiation in the source collector apparatus of the apparatus of Figures 3A and B;

[0019] - Figures 5A and B depict principal components of another source collector apparatus according to an embodiment of the invention;

[0020] - Figure 6 depicts gas flow in the source collector apparatus of Figures 5A and B;

[0021] - Figure 7 depicts principal components of another source collector apparatus according to an embodiment of the invention;

[0022] - Figure 8A and B depict principal components of another source collector apparatus according to an embodiment of the invention;;

[0023] - Figure 9 is an enlarged depiction of part of the source collector apparatus of Figures 8A and B;

[0024] - Figure 10 depicts gas flow in a source collector apparatus of an embodiment of the invention;

[0025] - Figure 11 depicts the effect of gas flow in a source collector apparatus of an embodiment of the invention on fuel droplets;

[0026] - Figure 12 depicts a nozzle unit of a source collector apparatus of an embodiment of the invention; and

[0027] - Figure 13 depicts gas flow in a source collector apparatus using the nozzle unit of Figure 12.

DETAILED DESCRIPTION

[0028] Figure 1 schematically depicts an EUV lithographic apparatus 4100 including a source collector apparatus SO. The apparatus comprises:

- an illumination system (illuminator) EIL configured to condition a radiation beam EB (e.g. EUV radiation);
- a support structure (e.g. a mask table) MT constructed to support a patterning device (e.g. a mask or a reticle) MA and connected to a first positioner PM configured to accurately position the patterning device;
- a substrate table (e.g. a wafer table) WT constructed to hold a substrate (e.g. a resist-coated wafer) W and connected to a second positioner PW configured to accurately position the substrate; and
- a projection system (e.g. a reflective projection system) PS configured to project a pattern imparted to the radiation beam EB by patterning device MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

[0029] The support structure MT holds the patterning device. The support structure MT holds the patterning device in a manner that depends on the orientation of the patterning device, the design of the lithographic apparatus, and other conditions, such as for example whether or not the patterning device is held in a vacuum environment. The support structure MT can use mechanical, vacuum, electrostatic or other clamping techniques to hold the patterning device. The support structure MT may be a frame or a table, for example, which may be fixed or movable as required. The support structure MT may ensure that the patterning device is at a desired position, for example with respect to the projection system. Any use of the terms “reticle” or “mask” herein may be considered synonymous with the more general term “patterning device”.

[0030] The term "patterning device" used herein should be broadly interpreted as referring to any device that can be used to impart a radiation beam with a pattern in its cross-section such as to create a pattern in a target portion of the substrate. It should be noted that the pattern imparted to the radiation beam may not exactly correspond to the desired pattern in the target portion of the substrate, for example if the pattern includes phase-shifting features or so called assist features. Generally, the pattern imparted to the radiation beam will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit.

[0031] Examples of patterning devices include masks and programmable mirror arrays. Masks are well known in lithography, and include mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as various hybrid mask types. An example of a programmable mirror array employs a matrix arrangement of small mirrors, each of which can be individually tilted so as to reflect an incoming radiation beam in different directions. The tilted mirrors impart a pattern in a radiation beam which is reflected by the mirror matrix.

[0032] The lithographic apparatus may be of a type having two or more substrate support structures, such as substrate stages or substrate tables, and/or two or more support structures for patterning devices. In an apparatus with multiple substrate stages, all the substrate stages can be equivalent and interchangeable. In an embodiment, at least one of the multiple substrate stages is particularly adapted for exposure steps and at least one of the multiple substrate stages is particularly adapted for measurement or preparatory steps. In an embodiment of the invention one or more of the multiple substrate stages is replaced by a measurement stage. A measurement stage includes at least a part of one or more sensor systems such as a sensor detector and/or target of the sensor system but does not support a substrate. The measurement stage is positionable in the projection beam in place of a substrate stage or a support structure for a patterning device. In such apparatus the additional stages may be used in parallel, or preparatory steps may be carried out on one or more stages while one or more other stages are being used for exposure.

[0033] In an EUV lithographic apparatus, it is desirable to use a vacuum or low pressure environment since gases can absorb too much radiation. A vacuum environment can therefore be provided to the whole beam path with the aid of a vacuum wall and one or more vacuum pumps.

[0034] Referring to Figure 1, the EUV illuminator EIL receives an extreme ultraviolet radiation beam from the source collector apparatus SO. The source collector apparatus SO is described in more detail below. In outline, a material (which may be referred to as the fuel)

that has at least one element, e.g., xenon (Xe), lithium (Li) or tin (Sn), with one or more emission lines in the EUV range is converted into a plasma state. This is achieved by irradiating a droplet, stream or cluster of the fuel with a laser beam. The resulting plasma emits output radiation, e.g., EUV radiation, which is collected using a radiation collector, disposed in the source collector apparatus.

[0035] Different arrangements of the parts of the radiation system are possible. For example, the laser and the source collector apparatus may be separate entities, for example when a CO_2 laser is used to provide the laser beam for fuel excitation. In such cases, the laser is not considered to form part of the lithographic apparatus and the radiation beam is passed from the laser to the source collector apparatus with the aid of a beam delivery system comprising, for example, suitable directing mirrors and/or a beam expander.

[0036] The EUV illuminator EIL may comprise an adjuster to adjust the angular intensity distribution of the radiation beam EB. Generally, at least the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the EUV illuminator EIL may comprise various other components, such as facetted field and pupil mirror devices. The EUV illuminator EIL may be used to condition the radiation beam EB, to have a desired uniformity and intensity distribution in its cross section.

[0037] The radiation beam EB is incident on the patterning device (e.g., mask) MA, which is held on the support structure (e.g., mask table) MT, and is patterned by the patterning device. After being reflected from the patterning device (e.g. mask) MA, the radiation beam EB passes through the projection system PS, which focuses the beam onto a target portion C of the substrate W. With the aid of the second positioner PW and position sensor PS2 (e.g. an interferometric device, linear encoder or capacitive sensor), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the radiation beam EB. Similarly, the first positioner PM and another position sensor PS1 can be used to accurately position the patterning device (e.g. mask) MA with respect to the path of the radiation beam EB. Patterning device (e.g. mask) MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2.

[0038] The depicted apparatus could be used in at least one of the following modes:

[0039] 1. In step mode, the support structure MT and the substrate table WT are kept essentially stationary, while an entire pattern imparted to the radiation beam is projected onto a target portion C at one time (i.e. a single static exposure). The substrate table WT is then shifted in the X and/or Y direction so that a different target portion C can be exposed. In step

mode, the maximum size of the exposure field limits the size of the target portion C imaged in a single static exposure.

[0040] 2. In scan mode, the support structure MT and the substrate table WT are scanned synchronously while a pattern imparted to the radiation beam is projected onto a target portion C (i.e. a single dynamic exposure). The velocity and direction of the substrate table WT relative to the support structure MT may be determined by the (de-)magnification and image reversal characteristics of the projection system PS. In scan mode, the maximum size of the exposure field limits the width (in the non-scanning direction) of the target portion in a single dynamic exposure, whereas the length of the scanning motion determines the height (in the scanning direction) of the target portion.

[0041] 3. In another mode, the support structure MT is kept essentially stationary holding a programmable patterning device, and the substrate table WT is moved or scanned while a pattern imparted to the radiation beam is projected onto a target portion C. In this mode, generally a pulsed radiation source is employed and the programmable patterning device is updated as required after each movement of the substrate table WT or in between successive radiation pulses during a scan. This mode of operation can be readily applied to maskless lithography that utilizes programmable patterning device, such as a programmable mirror array of a type as referred to above.

[0042] Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

[0043] A control system (not shown) controls the overall operations of the lithographic apparatus and in particular performs an optimization process described further below. The control system can be embodied as a suitably-programmed general purpose computer comprising a central processing unit and volatile and non-volatile storage. Optionally, the control system may further comprise one or more input and output devices such as a keyboard and screen, one or more network connections and/or one or more interfaces to the various parts of the lithographic apparatus. It will be appreciated that a one-to-one relationship between controlling computer and lithographic apparatus is not necessary. In an embodiment of the invention one computer can control multiple lithographic apparatuses. In an embodiment of the invention, multiple networked computers can be used to control one lithographic apparatus. The control system may also be configured to control one or more associated process devices and substrate handling devices in a lithocell or cluster of which the lithographic apparatus forms a part. The control system can also be configured to be

subordinate to a supervisory control system of a lithocell or cluster and/or an overall control system of a fab.

[0044] Figure 2 shows the optical path and related components of EUV apparatus 4100 in more detail, including the source collector apparatus SO, the EUV illumination system EIL, and the projection system PS. The source collector apparatus SO is constructed and arranged such that a vacuum environment can be maintained in an enclosing structure 4220 of the source collector apparatus SO. An EUV radiation emitting plasma 4210, e.g. of excited tin (Sn), is generated by laser irradiation to produce EUV radiation.

[0045] A radiation collector CO collects EUV radiation emitted by the plasma 4210 and focuses it in a virtual source point IF. The virtual source point IF is commonly referred to as the intermediate focus, and the source collector apparatus is arranged such that the intermediate focus IF is located at or near an opening 4221 in the enclosing structure 4220. The virtual source point IF is an image of the radiation emitting plasma 4210.

[0046] Subsequently the radiation traverses the illumination system IL, which may include a facetted field mirror device 422 and a facetted pupil mirror device 424 arranged to provide a desired angular distribution of the radiation beam 421, at the patterning device MA, as well as a desired uniformity of radiation intensity at the patterning device MA. Upon reflection of the beam of radiation 421 at the patterning device MA, held by the support structure MT, a patterned beam 426 is formed and the patterned beam 426 is imaged by the projection system PS via reflective elements 428, 430 onto a substrate W held by the substrate stage or substrate table WT.

[0047] More elements than shown may generally be present in illumination optics unit IL and projection system PS. A spectral filter (not shown) may optionally be present, depending upon the type of lithographic apparatus. There may be more mirrors present than those shown in the Figures, for example there may be from 1 to 6 additional reflective elements present in the projection system PS than shown in Figure 2.

[0048] In a known radiation source, droplets of molten tin as a fuel are emitted in a horizontal, or near horizontal, trajectory that passes through the primary focus of a reflective collector. A high powered laser beam is directed through a centrally located aperture in the collector and focused on the primary focus. The laser is pulsed and the pulse timing is controlled so that a pulse is directed at each droplet of fuel as it arrives at the primary focus. This causes the fuel to form a plasma which emits a UV radiation that is collected by the collector and directed into an apparatus where it is to be used, e.g. a lithographic apparatus.

[0049] A large amount of debris is generated and measures must be taken to prevent the debris entering other parts of the apparatus and contaminating the collector, which reduces its reflectivity and the efficiency of the source. Various arrangements, e.g. using static or rotating vanes, have been developed for minimizing migration of debris into other parts of the apparatus but these quickly become contaminated and absorb significant amounts of the useful radiation.

[0050] Other contamination mitigation strategies include the provision of a buffer gas, e.g. hydrogen, which serves to slow down the movement of debris and also chemically clean contaminated surfaces. However, flows of the buffer gas can deflect the droplets of fuel on their trajectory to the primary focus, making targeting the droplets with the first radiation difficult and causing positional instability in the radiation source. A shroud can be provided to shield part of the droplet trajectory from the effects of the buffer gas. However, the shroud cannot protect the entire trajectory and obstructs part of the beam of useful radiation. As well as the contamination issues with existing source designs and their limited lifetime, it would be greatly desirable to increase the power of the beam of useful radiation in order to improve throughput of a lithographic apparatus.

[0051] A first embodiment of the invention is a radiation source comprising:

a fuel dispenser for emitting fuel along a fuel trajectory;

a beam guiding system for directing first radiation in a first beam to a first focal point located on the fuel trajectory, whereby fuel at the focal point is excited into a plasma that emits second radiation; and

a collector arranged to collect the second radiation and direct it in a second beam to a second focal point;

wherein the fuel trajectory is substantially parallel to the first beam.

[0052] By making the fuel trajectory substantially parallel to the first beam, the accuracy of targeting fuel droplets can be improved and the configuration of the source can be improved. For example, it becomes possible to locate a debris mitigation device behind the first focal point, close to the point of generation of the debris.

[0053] A second embodiment is based on the first embodiment and the beam guiding system is arranged to direct the first radiation to converge on the first focal point and an end part of the fuel trajectory is within the first beam. This arrangement is particularly convenient to improve targeting accuracy and allows the fuel to be preheated by the first beam before reaching the first focal point.

[0054] A third embodiment is based on the second embodiment and the end part of the fuel trajectory is substantially collinear with an optical axis of the first beam. This arrangement is most preferred to improve targeting accuracy.

[0055] A fourth embodiment is based on any of the first to third embodiments and the fuel trajectory and the first radiation pass through an aperture in the collector. The use of a single aperture to pass both the fuel and the first radiation through the collector maximizes the area of the reflector available for collecting useful radiation.

[0056] A fifth embodiment is based on the fifth embodiment and the beam guiding system comprises a mirror oriented obliquely to the fuel trajectory and the fuel trajectory passes through a second aperture in the mirror. With this arrangement, the first radiation can easily be coupled onto the fuel trajectory to be collinear therewith.

[0057] A sixth embodiment is based on any of the first to fifth embodiments and wherein the second beam is substantially parallel to the first beam. By having the first and second beam parallel to each other as well as to the fuel trajectory, the radiation source can be arranged to maximize the collection of desired radiation and coupling of that radiation into the second (output) beam.

[0058] A seventh embodiment is based on any of the first to sixth embodiments and further comprises a debris trap located behind the first focal point as seen from the collector. Because the debris trap is located behind the primary focus, the momentum of the fuel carries the debris into the trap. The debris trap can be located very close to the primary focus so that there is little time for the debris to disperse before entering the debris trap. The amount of debris in the apparatus is thereby reduced at the very outset.

[0059] A eighth embodiment is based on the seventh embodiment and the debris trap is located substantially within a volume not traversed by second radiation directed by the collector to the second focal point. This location of the debris trap ensures that it does not obstruct any useful radiation and thereby does not reduce the effective source power. The aperture in the collector necessarily creates a shadow cone in the second radiation collected by the collector in which the debris trap can be placed.

[0060] A ninth embodiment is based on the eighth embodiment and the debris trap is elongate and has a longitudinal axis, the longitudinal axis substantially lying on an optical axis of the second beam. With such an arrangement, the debris trap can be located so as to minimize the obstruction of desired radiation in the second beam.

[0061] A tenth embodiment of the invention is based on the eighth or ninth embodiment and further comprises a drain arranged to remove debris from the debris trap. The fuel debris in

the debris trap can be removed simply on a continuous basis via the drain without needing down time to empty the debris trap.

[0062] An eleventh embodiment of the invention is based on any of the first to tenth embodiments and further comprises a gas supply device arranged to supply a gas to a chamber including the collector and a gas exhaust device arranged to remove gas from the debris trap. A gas, such as a buffer gas, can assist in reducing movement of debris into other parts of the source or a connected apparatus and/or can assist in cleaning any contamination of surfaces thereof. By supplying the gas to a chamber including the collector and removing it from the debris trap, a flow of gas into the debris trap is created which increases the amount of debris captured by the trap.

[0063] A twelfth embodiment is based on the eleventh embodiment and the gas supply device is arranged to supply gas to a space behind the collector viewed from the first focal point so that a gas flow through the aperture is established in use. The gas flow through the aperture, i.e. parallel to or collinear with the trajectory, helps to maintain the fuel on course and avoids buffeting thereof that might cause it to deviate from the desired trajectory.

[0064] A thirteenth embodiment is based on the eleventh or twelfth embodiment and the gas supply device includes a nozzle member around the aperture and having at least one nozzle aperture arranged to emit gas toward the first focal point. The gas emitted toward the first focal point creates a stream of gas that further assists in ensuring the fuel does not deviate from the desired trajectory and can even redirect fuel that has deviated to the correct trajectory.

[0065] A fourteenth embodiment is based on the thirteenth embodiment and the nozzle member has a plurality of nozzle apertures each arranged to emit a gas stream directed to a respective point adjacent the first focal point whereby a vortex flow of gas surrounding the first focal point can be established. The vortex flow is particularly effective in ensuring the correct trajectory for the fuel and for conveying debris into the debris trap.

[0066] A fifteenth embodiment is based on the thirteenth or fourteenth embodiment and the nozzle member is mounted to the collector.

[0067] A sixteenth embodiment is based on any of the preceding embodiments and further comprises a heat store member located on the fuel trajectory past the first focal point. The heat source member can heat approaching fuel droplets, causing them to expand and thereby provide a larger target of the first radiation. Alternatively a fuel droplet can be shaped on contact with the heat store member to maximize the are irradiated by the first radiation. The heat store member can avoid the need for a pre-pulse to expand a fuel droplet.

[0068] An eighteenth embodiment is based on the sixteenth embodiment and the heat store member is located within a debris trap. Locating the heat store member in the debris trap avoids obstructing useful radiation ad increase the collection of debris in the trap.

[0069] A fifteenth eighteenth embodiment is based on the sixteenth or seventeenth embodiment and further comprises a temperature control system arranged to control the temperature of the heat store member to be higher than a melting point of the fuel. The temperature control system can heat or cool the heat store member to ensure it is at the correct temperature for effective operation.

[0070] A nineteenth embodiment is based on any one of the preceding embodiments and further comprises a wall provided on the collector around the aperture therein and extending toward the first focal point. The wall serves to assist in isolating a chamber behind the collector from a chamber in front of the collector and is useful to further control debris migration.

[0071] A twentieth embodiment is based on any one of the preceding embodiments and the fuel trajectory is vertically upward. An upward fuel trajectory enable the output beam of the radiation source to be directed upward which can be convenient for arrangement of an apparatus to which the output beam is supplied.

[0072] A twenty-first embodiment is based on any one of the preceding embodiments and the fuel dispenser is a droplet generator.

[0073] A twenty-second embodiment is based on any one of the preceding embodiments and the droplet generator is arranged to generate droplets of molten tin.

[0074] A twenty-third embodiment of the invention is a radiation source comprising:

a fuel dispenser for emitting fuel along a fuel trajectory;

a beam guiding system for directing first radiation to a first focal point located on the fuel trajectory, whereby fuel at the focal point is excited into a plasma that emits second radiation; and

a collector arranged to collect the second radiation and direct it to a second focal point;

wherein the collector has an aperture through which the first beam is directed and a conical wall surrounding the aperture and extending towards the first focal point.

[0075] The conical wall around the aperture helps to separate the space behind the collector from the space in front of the collector and so helps to control the migration of debris in the source.

[0076] A twenty fourth embodiment of the invention is a radiation source comprising:

a fuel dispenser for emitting fuel along a fuel trajectory;

a beam guiding system for directing first radiation to a first focal point located on the fuel trajectory, whereby fuel at the focal point is excited into a plasma that emits second radiation; and

a collector arranged to collect the second radiation and direct it to a second focal point;

wherein the fuel trajectory is vertical and passes through an aperture in the collector.

[0077] By providing a vertical fuel trajectory, the accuracy of the delivery of fuel to the first focal point (primary focus) can be improved, as deviations due to gravity and gas flows are reduced.

[0078] A twenty-fifth embodiment is a lithographic apparatus comprising:

a radiation source according to any one of the preceding embodiments;

an illuminator arranged to direct the second radiation onto a patterning device;

a support table arranged to support a patterning device; and

a projection system arranged to project radiation patterned by the patterning device onto a substrate.

[0079] A twenty-sixth embodiment is a device manufacturing method comprising:

emitting fuel on a vertical trajectory;

irradiating the fuel with first radiation so as to excite the fuel into a plasma;

collecting radiation emitted by the plasma using a collector having an aperture through which the fuel trajectory passes;

directing the collected radiation to illuminate a patterning device; and

projecting radiation pattern by the patterning device onto a substrate.

[0080] An exemplary embodiment of the present invention will now be described in more detail. Figures 3A and 3B show the principal components of the source collector apparatus SO in more detail. A droplet generator 10 emits droplets of fuel (e.g. molten tin) on a trajectory 11. Trajectory 11 is desirably vertical or near vertical (e.g. within 10 degrees of vertical, more desirably within 5 degrees of vertical). In an embodiment the droplets move upwardly, i.e. against the force of gravity G, along trajectory 11. Upward movement of the droplets enables the source collector apparatus SO to be more conveniently arranged for the remainder of the lithographic apparatus. In an embodiment of the apparatus the droplets move downwardly, i.e. with the force of gravity. Downward movement can allow the droplets to be emitted at a lower initial velocity and can improve collection of debris as discussed further below. The droplets are emitted at an initial velocity in the range of 10 ms^{-1}

to 200 ms^{-1}, desirably in the range of from about 30 ms^{-1} to about 150 ms^{-1}. Each droplet desirably has a diameter in the range of from 10 μm to 50 μm, desirably about 30 μm. Suitable droplet generators are known in the art and can readily be adapted to emit droplets on the desired trajectory.

[0081] Trajectory 11 of the fuel droplets passes through an aperture 31 in collector CO to reach a first focal point PF, sometimes referred to as a primary focus. At the primary focus PF the fuel droplets are irradiated by first radiation, e.g. light emitted by a CO_2 excimer laser (not shown in Figure 3A). A mirror 50 directs a convergent beam of the first radiation so that it converges at the primary focus PF. Mirror 50 can be flat with other optical elements provided to create the converging beam or can have an optical power to assist in converging the first radiation. An aperture 51 is provided in mirror 50 for the droplets of fuel to pass through. Trajectory 11 can be located so that it passes to the side of mirror 50 or through a notch in the edge of mirror 50. The first radiation is generated by a pulsed source. Arrangements to ensure that pulses of the first radiation occur at the appropriate timing to be coincident with arrival of a droplet at the primary focus are known.

[0082] Droplets of the fuel irradiated at the primary focus by the first radiation receive sufficient energy to be excited into a plasma state. The plasma state then emits radiation through recombination of electrons and ions, including EUV radiation at a desired wavelength. The EUV radiation is emitted in all directions. A part of the emitted radiation is collected by collector CO, which in an embodiment is a near normal reflector formed by a multilayer stack acting as a distributed Bragg reflector provided on a suitably curved substrate. The radiation collected by collector CO is directed to a second focal point, referred to as the intermediate focus IF.

[0083] Beyond the primary focus along the trajectory 11, a debris trap 20 is provided. Debris trap 20 has an opening 21 adjacent the prime focus. The plasma generated by irradiation of fuel droplet generates a large amount of physical debris in the form of free electrons, ions, neutral atoms and larger particles of the fuel material which have either re-condensed after emission of EUV or were not fully ionized. This expanding cloud of debris retains overall the momentum of the original fuel droplet and the majority of the debris enters the debris trap 20. The debris condenses within the debris trap, e.g. on the internal walls thereof, and runs down towards the base. A wall is provided around aperture 21 to prevent condensed debris exiting aperture 21. A drain 22 is provided at the lower end of debris trap 20 to conduct away condensed debris. To assist draining of debris the interior of debris trap 20 and drain 22 are maintained at a temperature above the melting point of the fuel. In an

embodiment this can be achieved through the heat input from the first radiation. In an embodiment heaters, e.g. electric heaters, are provided to maintain the interior of debris trap 20 and drain 22 at the necessary temperature.

[0084] It is desirable that the debris trap not obstruct or obstruct as little as possible of the EUV radiation collected by collector CO and directed to intermediate focus IF. To this end, the debris trap 20 is located substantially within a space in the center of the cone of the second radiation that is in effect in the shadow of the aperture 31 in collector CO. The shadow is shown by hatching in Figure 4. In an embodiment, the debris trap 20 has the form of a cone, e.g. a truncated cone, that tapers towards the intermediate focus IF. In an embodiment, the debris trap is elongate and has a longitudinal axis which is collinear with the optical axis of the collector CO and the beam of EUV radiation directed to the intermediate focus IF.

[0085] The drain 22 crosses the path of radiation collected by the collector and directed to the intermediate focus and therefore it is desirable that its width in a plane perpendicular to the optical axis of the second radiation is as small as possible. In an embodiment, the drain 22 additionally functions to support debris trap 20. In an embodiment an additional support for debris trap 20 is provided in the shadow of drain 22.

[0086] A conical wall 30 is provided around the aperture 31 and projects towards the primary focus PF. Conical wall 30 tapers towards primary focus PF and in an embodiment its thickness also reduces towards primary focus PF. Conical wall 30 functions to assist in separating the space above the collector in which the plasma is formed from the space below or behind the collector CO. It therefore serves to reduce migration of debris to the chamber behind collector CO and reduces contamination of mirror 50 and other components. The space behind collector CO can be referred to as the source chamber and the space above collector CO can be regarded as the collector chamber. Desirably, to minimize contamination outside the collector chamber these two chambers are isolated from each other as far as possible. Since the plasma occupies only a small volume, e.g. having a diameter of about 100 μm or less than 200 μm, when emitting EUV, only a narrow annular gap between conical wall 30 and debris trap 20 is necessary to allow the EUV radiation to reach the collector CO. Desirably the gap between conical wall 30 and debris trap 20 is as small as possible without obstructing useful EUV radiation in order to minimize the amount of debris and unwanted radiation that reaches other parts of the apparatus. Conical wall 30 can be implemented in a radiation source having a different arrangement than described herein. Conical wall 30 is useful independently of other features of the present invention.

[0087] Figures 5A, 5B and 6 illustrate a second embodiment of the source collector apparatus of the present invention. Parts of the second embodiment that are the same as or correspond to parts of the first embodiment are identified with like references. Only aspects of the second embodiment which differ from the first embodiment are described below.

[0088] In the second embodiment, a gas is supplied to the source chamber and/or the collector chamber to assist in mitigation of the transport of debris and/or cleaning of contaminated surfaces such as the reflective surface of collector CO. The gas can be hydrogen (especially if a cleaning function is desired), helium, argon or another inert gas. Hydrogen can be provided in the form of H_2 gas which is converted to H radicals by the first and second radiation. Figure 5A shows gas supply 60 supplying gas to the source chamber and gas supply 61 supplying gas to the collector chamber. In an embodiment, a single gas supply supplies gas to only one of the two chambers. In an embodiment, a single gas supply supplies a gas to both of the gas chambers.

[0089] An exhaust duct 23 is provided to remove gas from the interior of the debris trap 20. Desirably exhaust duct 23 is provided substantially in the shadow of drain 22. Exhaust duct 23 can additionally function to support or assist in support of, debris trap 20. In an embodiment exhaust duct 23 and drain 22 are combined. In an embodiment, drain 22 and exhaust 23 are oriented vertically to assist in draining fuel debris from the debris trap.

[0090] Gas can be supplied to one or both chambers in a total amount in the range of from 10 to 250 standard liters per minute (sL/min), desirably less than 100 sL/m, more desirably less than 50 sL/min. A suitable rate of gas supply is determined by the desired gas flow rate to be achieved in the opening to the debris trap and the size of that opening. Gas is exhausted through exhaust duct 23 at substantially the same rate as it is supplied so that the gas pressure in the collector chamber is maintained in the range of from about 100 Pa to about 200 Pa. The above figures are particularly suitable where the gas is hydrogen, different values may be appropriate for other gasses.

[0091] The gas supply and exhaust arrangements of the second embodiment result in gas flows as indicated in Figure 6. A gas flow 62 passes along trajectory 11 from the source chamber to the collector chamber through the interior of conical wall 30. The gas passes the primary focus and enters debris trap 20 from which it is exhausted via exhaust duct 23. Gas supplied to the collector chamber circulates around the reflective face of collector CO and forms a gas flow 63 that enters debris trap 20 through the annular gap between conical wall 30 and debris trap 20. In an embodiment of the invention, the gas flow rates and the geometry of the apparatus are arranged such that the gas flow velocity in gas flow 62 and/or

gas flow 63 is greater than 50 ms^{-1}, desirably greater than 75 ms^{-1}, desirably greater than 100 ms^{-1}. The gas flows into debris trap 20 serve to assist in collection of debris from the plasma and substantially reduces the amount of debris that enters the collector chamber. Gas flow 62 can be generated by a pressure difference between the source chamber and the collector chamber or debris trap or by entrainment with gas flowing into the debris trap from the collector chamber or a combination of both effects.

[0092] Figure 7 depicts a third embodiment of the present invention. Parts of the third embodiment that are the same as or correspond to parts of the first and second embodiment are indicated by the same references. Only differences are described below.

[0093] The third embodiment is tilted so as to provide an output beam at an angle to the vertical. This can provide advantages in layout of the rest of the apparatus. Although the rest of the source collector apparatus is tilted as compared to the first and second embodiment, the trajectory 11 remains vertical. A small aperture 12 is provided in collector CO for the fuel to pass through. This aperture need only be very small and does not significantly reduce the radiation collected into the output beam. If necessary, a part of conical wall 30 can be cut away near debris trap 20.

[0094] Figures 8A, 8B and 9 depict a fourth embodiment of the present invention. Parts of the fourth embodiment that are the same as or correspond to parts of the previous embodiments are identified with like references. Only differences are described below.

[0095] In the fourth embodiment, a heat storage element 70 is provided within the debris trap 20. Heat storage element 70 has a tip portion 71 close to the entrance to the debris trap 20 and the primary focus PF. In an embodiment, tip 71 is placed at the primary focus. Tip 71 of the heat storage element 70 is heated by the first radiation and desirably reaches a heat substantially in excess of the melting point of the fuel. In an embodiment, an additional heating mechanism, e.g. an electric heater is provided to heat the heat storage element 70 to the desired temperature. Even if the heat delivered by the first radiation is sufficient to maintain the heat store member at the correct temperature during steady state operation, a heater can be useful to bring the heat store member to the correct temperature quickly at start up. In an embodiment of the invention a droplet 13 of fuel approaching heat storage element tip 71 is heated.

[0096] Several mechanisms can be employed to heat the approaching droplet 13. One mechanism is sputtering or spitting of particles 14 from fuel accumulating on tip 71 from previous droplets. In the case of tin as the fuel and hydrogen gas as the buffer gas it has been found that hydrogen induces bubbling within fuel condensed on tip 71 and hot particles are

emitted when those bubbles burst. Another mechanism for heating approaching fuel droplets 13 is infrared radiation emitted by tip 71. Heating fuel droplets 13 as they approach the primary focus has the effect of causing the droplet to expand, potentially into a mist. An expanded droplet forms a larger target for the pulse of the first radiation, increasing energy transfer into the fuel and thereby increasing efficiency. The pre-heating of droplets 13 in an embodiment of the invention can avoid the need for a pre-pulse to heat and shape the droplets prior to the main plasma forming pulse as has been used in some prior designs.

[0097] Another mechanism for pre-heating fuel droplets 13 in an embodiment of the invention is partial absorption of first radiation from pulses aimed at earlier droplets in the droplet train. For the most part of the trajectory 11, droplets 13 of fuel are within the shadow of the aperture in mirror 50 through which the trajectory 11 passes. However, by appropriate selection of the rate of convergence of the first radiation it can be arranged that approaching fuel droplets 13 are partially within converging beam 51 in advance of reaching the primary focus and are therefore partially irradiated by pulses aimed at droplets further ahead in the pulse train.

[0098] Tip 71 of heat storage electrode 70 is illustrated as having a conical shape at its lower end. Other shapes are possible, including cones with more than one cone angle, cones with flattened points (truncated cones), dome shapes of various types including shapes with different radii of curvature, concave shapes whether inverted cones or curved, flat tops, knurled cups.

[0099] In a variation of the fourth embodiment, the heat storage element 70 is maintained at a lower temperature, e.g. at or slightly above the melting point of the fuel. A cooling system (not shown in the Figure) can be provided to maintain the desired temperature. In an embodiment, the cooling system for the heat storage element 70 circulates a cooling medium, e.g. water, through conduit within or in thermal contact with heat storage element 70. The cooling medium can be supplied to the heat storage element 70 and removed therefrom by conduits located within exhaust duct 23 or in the shadow thereof. In this variation of the fourth embodiment, the heat storage element 70 does not function to heat approaching debris particles 13 but rather presents a shape that causes the debris particle to flatten into a disc or pancake shape in the surface of the heat storage element. This again serves to present a larger target to the first radiation so as to increase energy absorption.

[00100] In either variation of the fourth embodiment, the heat storage element can serve to increase the effective size of the fuel droplet by a factor of 2 or 3 or more. In an embodiment,

an initial droplet of 30 μm diameter has its cross section in a plane perpendicular to the optical axis of the first radiation increased to 100 μm or more.

[00101] In a fifth embodiment of the invention depicted in Figures 10 to 13, the conical wall 30 is modified to provide an additional gas flow for controlling the trajectory of fuel droplets and the movement of plasma debris. As shown in Figure 10 a nozzle member 80 replaces or is incorporated in the conical wall 30. Nozzle member 80 is supplied with buffer gas and has at least one nozzle aperture arranged to create a gas flow 65 directed toward primary focus PF. As shown in Figure 11 gas flow 65 can correct the trajectory of a droplet 13 that has deviated from the optimal trajectory and deliver it to the primary focus or onto tip 71 of the heat storage element 70. It will be appreciated that the nozzle member 80 can be employed in any of the above described embodiments.

[00102] A variation of the nozzle member is shown in Figures 12 and 13. Nozzle member 81 comprises a conical ring having a plurality of apertures 82 spaced around its upper surface. Nozzles 82 are arranged to generate respective gas jets 66 that are aimed not exactly at the primary focus PF but at respective points slightly to one side of it and arranged in a ring around the primary focus. The gas jets 66 are oblique to the optical axis of the first radiation. As shown in Figure 13 this sets up a vortex flow around the primary focus which serves both to direct fuel droplets toward the primary focus and debris into the debris trap 20 (not shown). A vortex flow can be used alternatively or in addition elsewhere in the radiation source, e.g. in gas flow 63 to protect the collector, and can be established by suitably directed nozzles and/or vanes. For example, tangentially directed nozzles can be provided around the perimeter of the collector and supplied with buffer gas.

[00103] As will be appreciated, any of the above described features can be used with any other feature and it is not only those combinations explicitly described which are covered in this application.

[00104] A radiation source according to the invention can be used for other purposes than lithography and with other apparatus that a lithographic apparatus. For example a radiation source according to the invention can be used as an illumination source for a metrology or inspection apparatus.

[00105] 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 in manufacturing components with microscale, or even nanoscale features, such as the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, flat-panel displays, liquid-crystal

displays (LCDs), thin-film magnetic heads, etc.. In the context of such alternative applications, any use of the terms "wafer" or "die" herein may be considered as synonymous with the more general terms "substrate" or "target portion", respectively. The substrate referred to herein may be processed, before or after exposure, in for example a track (a tool that typically applies a layer of resist to a substrate and develops the exposed resist), a metrology tool and/or an inspection tool. Where applicable, the disclosure herein may be applied to such and other substrate processing tools. Further, the substrate may be processed more than once, for example in order to create a multi-layer IC, so that the term substrate used herein may also refer to a substrate that already contains multiple processed layers.

[00106] While specific embodiments of the invention have been described above, it will be appreciated that the invention, at least in the form of a method of operation of an apparatus as herein described, may be practiced otherwise than as described. For example, the embodiments of the invention, at least in the form of a method of operation of an apparatus, may take the form of one or more computer programs containing one or more sequences of machine-readable instructions describing a method of operating an apparatus as discussed above, or a data storage medium (e.g. semiconductor memory, magnetic or optical disk) having such a computer program stored therein. Further, the machine readable instruction may be embodied in two or more computer programs. The two or more computer programs may be stored on one or more different memories and/or data storage media.

[00107] Any controllers described herein may each or in combination be operable when the one or more computer programs are read by one or more computer processors located within at least one component of the lithographic apparatus. The controllers may each or in combination have any suitable configuration for receiving, processing and sending signals. One or more processors are configured to communicate with at least one of the controllers. For example, each controller may include one or more processors for executing the computer programs that include machine-readable instructions for the methods of operating an apparatus as described above. The controllers may include data storage media for storing such computer programs, and/or hardware to receive such media. So the controller(s) may operate according to the machine readable instructions of one or more computer programs.

[00108] An embodiment of the invention may be applied to substrates with a width (e.g., diameter) of 300 mm or 450 mm or any other size.

[00109] 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 radiation source comprising:

a fuel dispenser for emitting fuel along a fuel trajectory;

a beam guiding system for directing first radiation in a first beam to a first focal point located on the fuel trajectory, whereby fuel at the focal point is excited into a plasma that emits second radiation; and

a collector arranged to collect the second radiation and direct it in a second beam to a second focal point;

wherein the fuel trajectory is substantially parallel to the first beam.

2. A radiation source according to claim 1, wherein the beam guiding system is arranged to direct the first radiation to converge on the first focal point and an end part of the fuel trajectory is within the first beam.

3. A radiation source according to claim 2, wherein the end part of the fuel trajectory is substantially collinear with an optical axis of the first beam.

4. A radiation source according to any one of the preceding claims, wherein the fuel trajectory and the first radiation pass through an aperture in the collector.

5. A radiation source according to claim 4, wherein the beam guiding system comprises a mirror oriented obliquely to the fuel trajectory and the fuel trajectory passes through a second aperture in the mirror.

6. A radiation source according to any one of the preceding claims, further comprising a debris trap located behind the first focal point as seen from the collector.

7. A radiation source according to claim 6, wherein the debris trap is located substantially within a volume not traversed by second radiation directed by the collector to the second focal point.

8. A radiation source according to claim 7 wherein the debris trap is elongate and has a longitudinal axis, the longitudinal axis substantially lying on an optical axis of the second beam.

9. A radiation source according to any one of claims 6, 7 or 8, further comprising a gas supply device arranged to supply a gas to a chamber including the collector and a gas exhaust device arranged to remove gas from the debris trap, wherein the gas supply device is arranged to supply gas to a space behind the collector viewed from the first focal point so that a gas flow through the aperture is established in use.

10. A radiation source according to any one of claims 6, 7, or 8, further comprising a gas supply device arranged to supply a gas to a chamber including the collector and a gas exhaust device arranged to remove gas from the debris trap, wherein the gas supply device includes a nozzle member around the aperture and having at least one nozzle aperture arranged to emit gas toward the first focal point.

11. A radiation source according to claim 10, wherein the nozzle member has a plurality of nozzle apertures each arranged to emit a gas stream directed to a respective point adjacent the first focal point whereby a vortex flow of gas surrounding the first focal point can be established.

12. A radiation source comprising:

a fuel dispenser for emitting fuel along a fuel trajectory;

a beam guiding system for directing first radiation to a first focal point located on the fuel trajectory, whereby fuel at the focal point is excited into a plasma that emits second radiation; and

a collector arranged to collect the second radiation and direct it to a second focal point;

wherein the collector has an aperture through which the first beam is directed and a conical wall surrounding the aperture and extending towards the first focal point.

13. A radiation source comprising:

a fuel dispenser for emitting fuel along a fuel trajectory;

a beam guiding system for directing first radiation to a first focal point located on the fuel trajectory, whereby fuel at the focal point is excited into a plasma that emits second radiation; and

a collector arranged to collect the second radiation and direct it to a second focal point;

wherein the fuel trajectory is vertical and passes through an aperture in the collector.

14. A lithographic apparatus comprising:

a radiation source according to any one of the preceding claims;

an illuminator arranged to direct the second radiation onto a patterning device;

a support table arranged to support a patterning device; and

a projection system arranged to project radiation patterned by the patterning device onto a substrate.

15. A device manufacturing method comprising:

emitting fuel on a fuel trajectory;

irradiating the fuel with first radiation in a first beam so as to excite the fuel into a plasma;

collecting radiation emitted by the plasma into a second beam using a collector;

directing the collected radiation to illuminate a patterning device; and

projecting radiation pattern by the patterning device onto a substrate; wherein the fuel trajectory is substantially parallel to the first beam.

Fig. 1

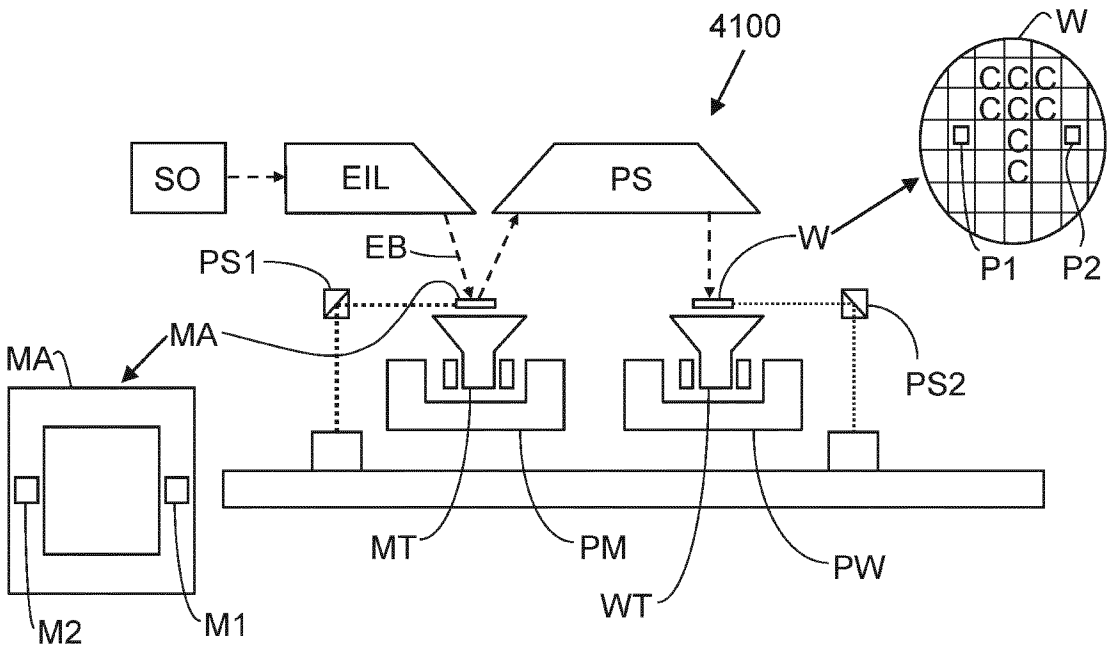


Fig. 2

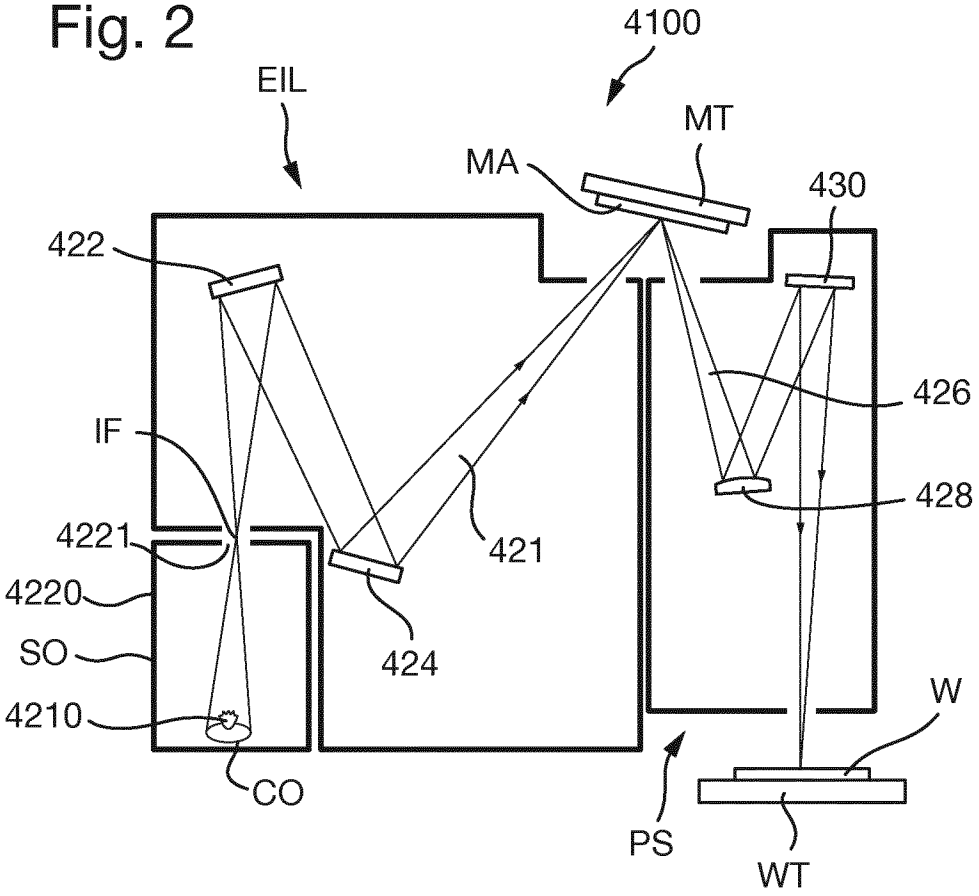


Fig. 3A

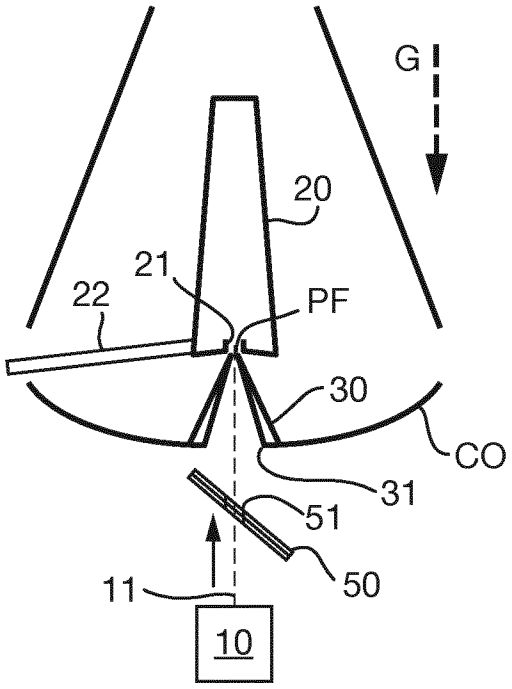


Fig. 3B

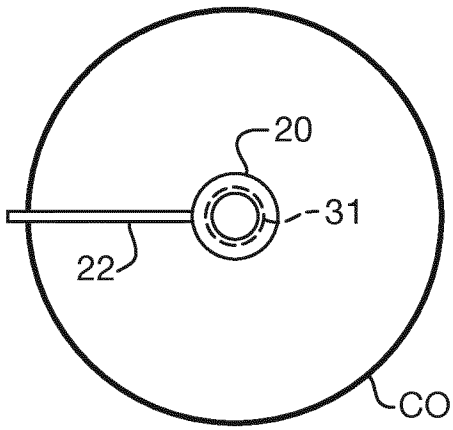


Fig. 4

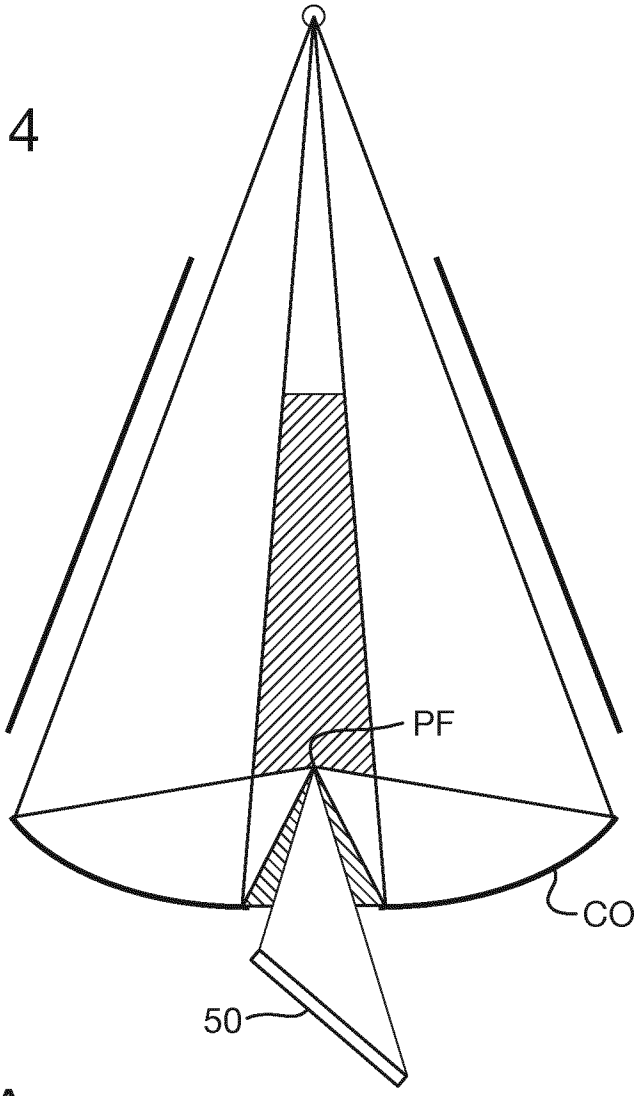


Fig. 5A

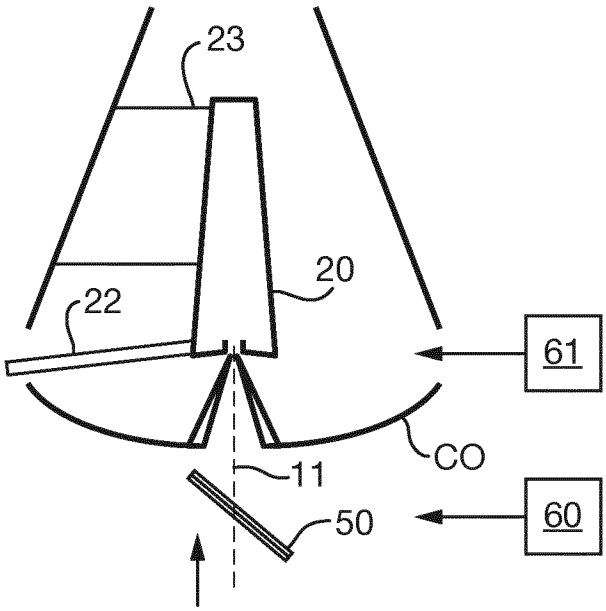


Fig. 5B

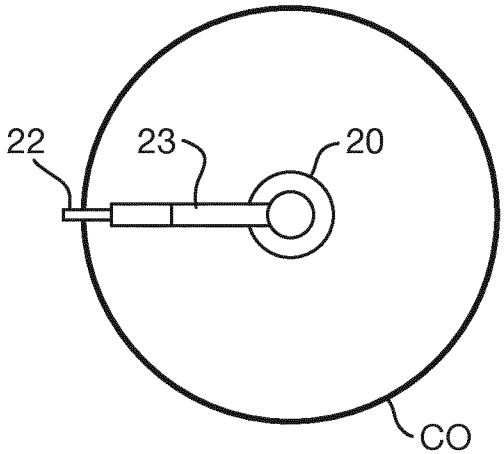


Fig. 6

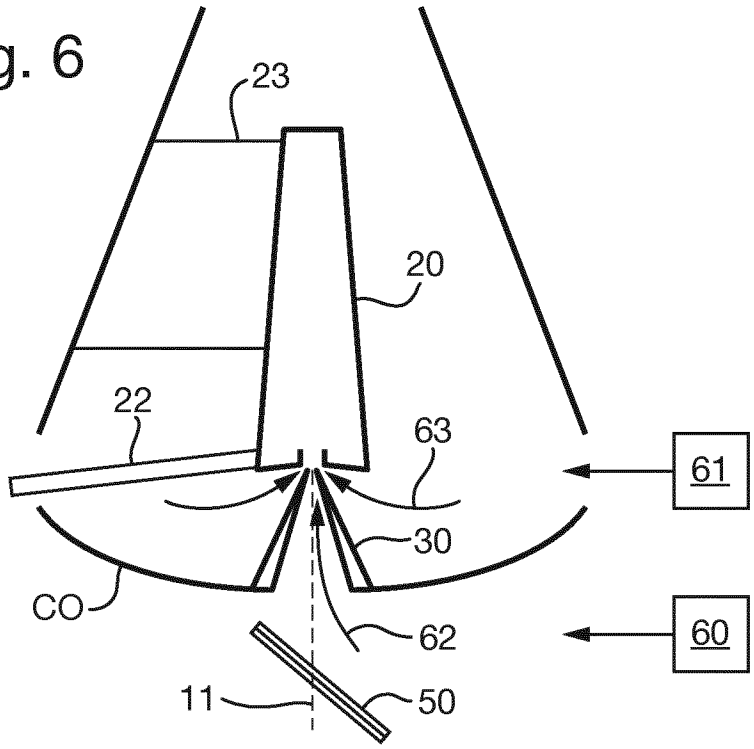


Fig. 7

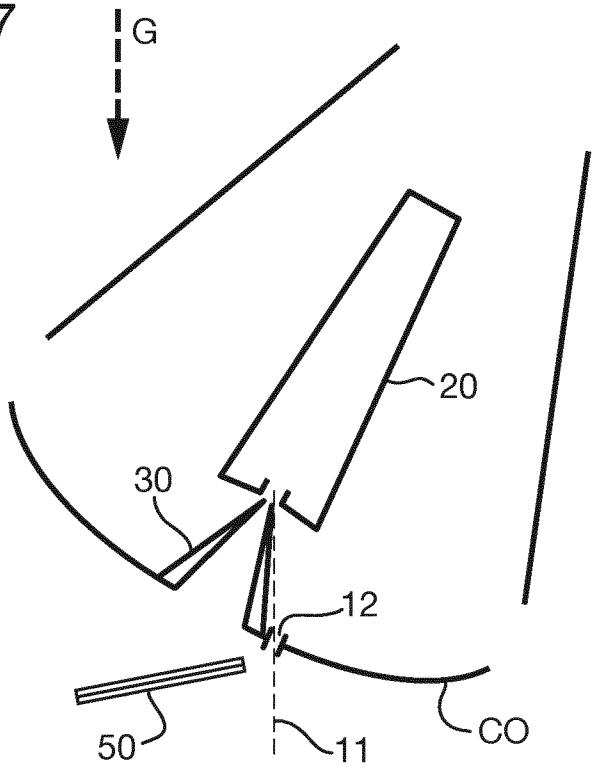


Fig. 8A

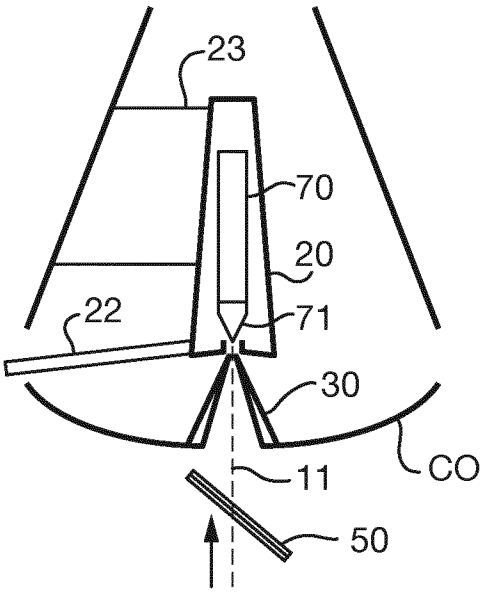


Fig. 8B

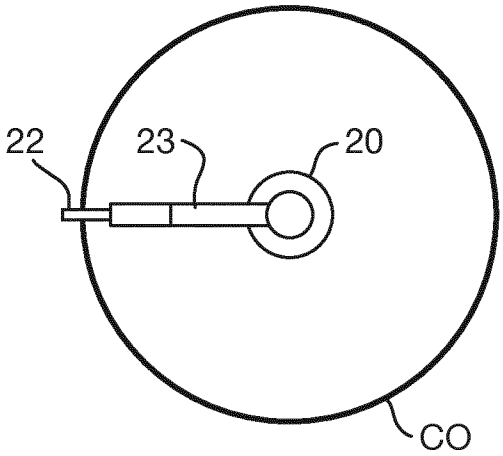


Fig. 9

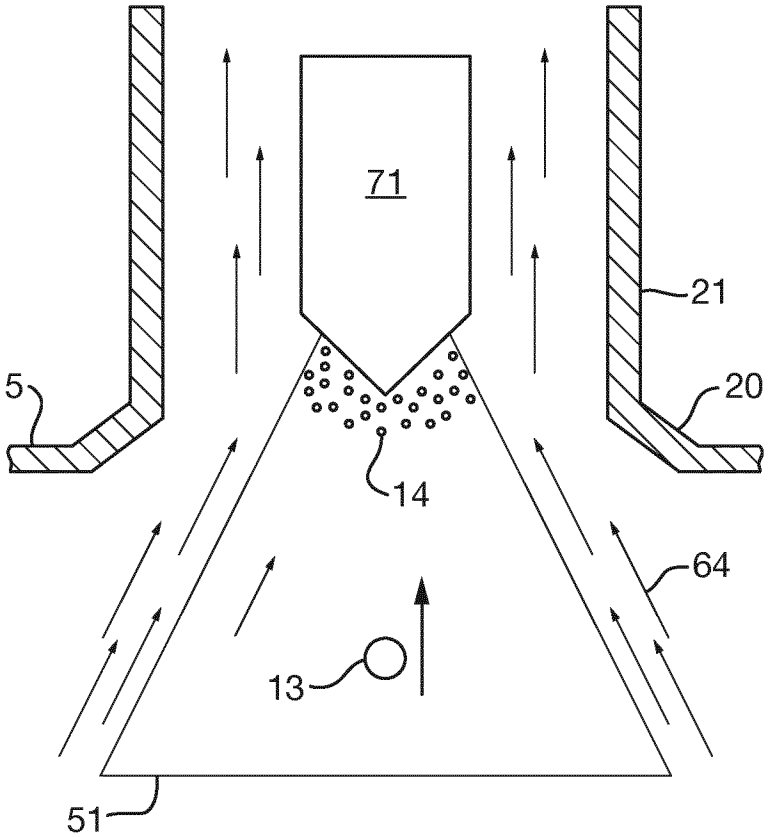


Fig. 10

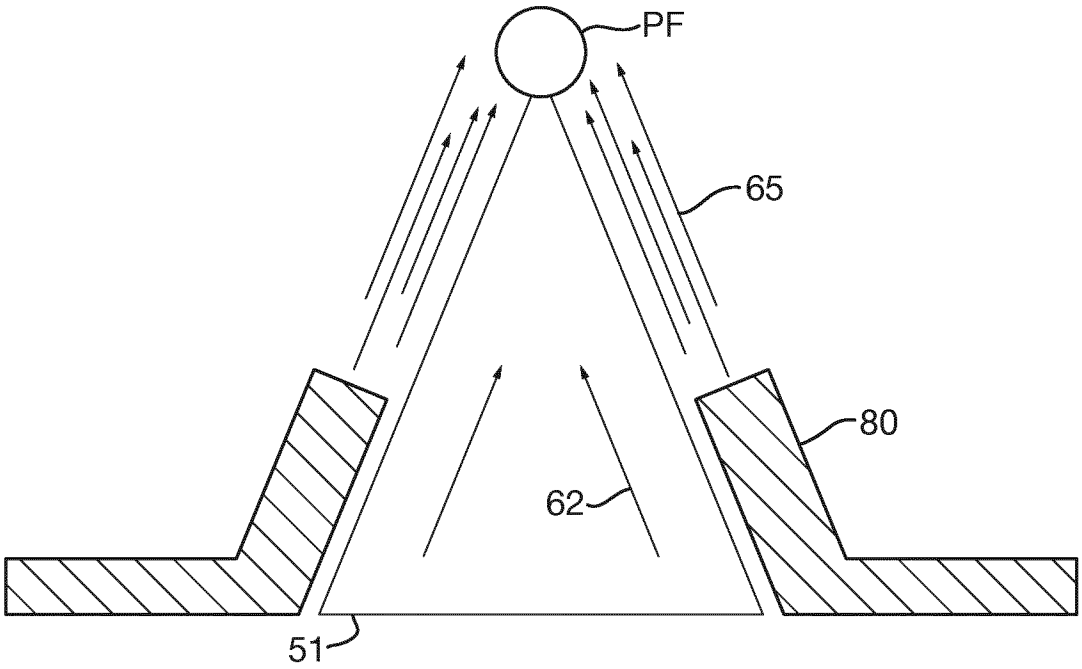


Fig. 11

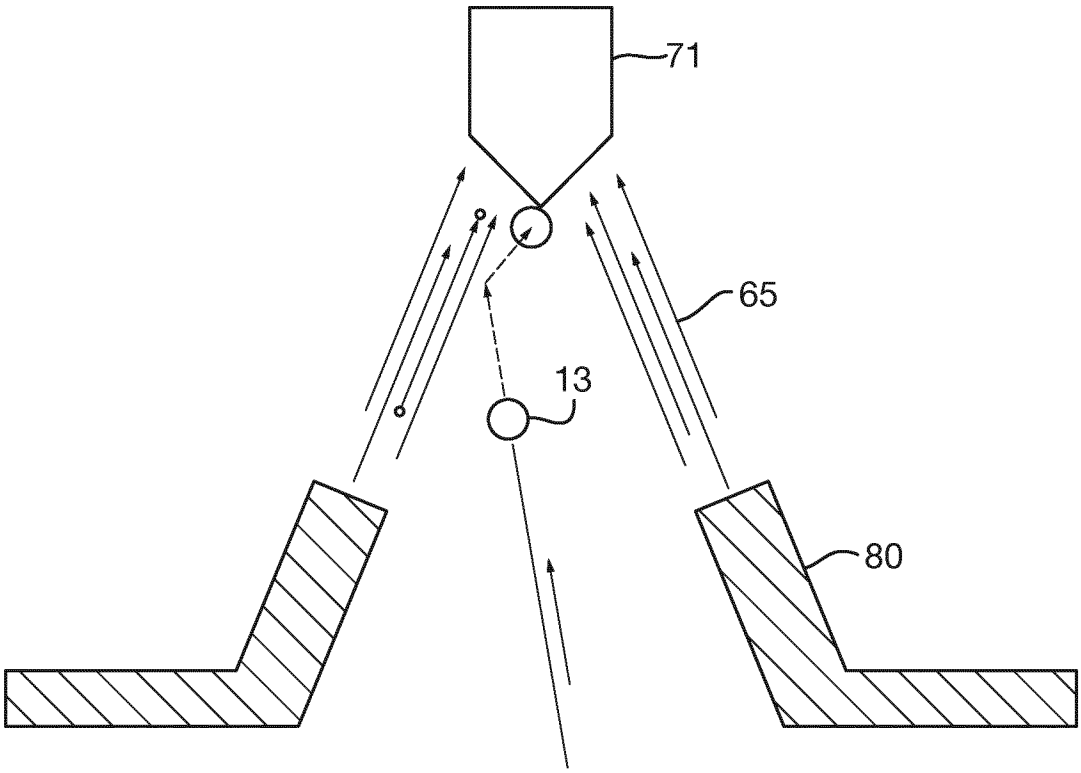


Fig. 12

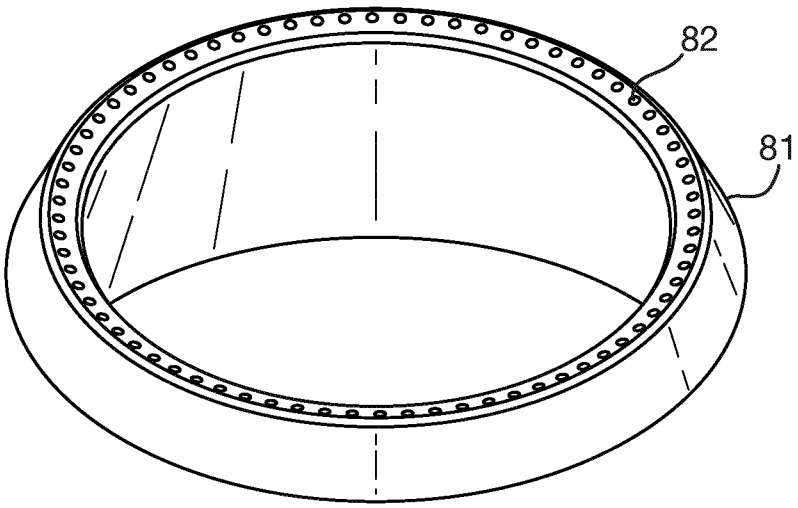
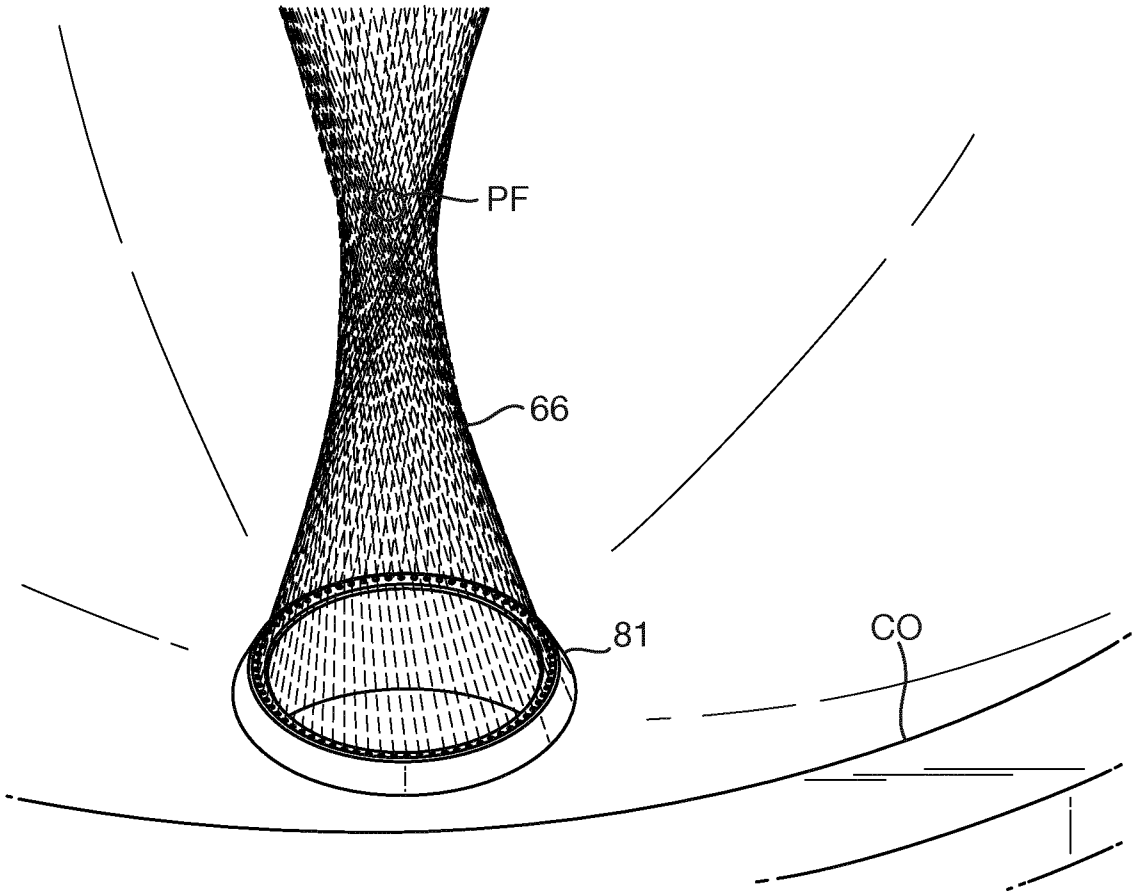


Fig. 13



INTERNATIONAL SEARCH REPORT

International application No.
PCT/EP2014/073992

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☒ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/073992

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03F7/20 H05G2/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G03F H05G

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011/309260 A1 (NISHISAKA TOSHIHIRO [JP] ET AL) 22 December 2011 (2011-12-22)	13
A	paragraph [0035] - paragraph [0041]; figures 1,2 paragraph [0059] - paragraph [0062]; figures 12,13,19	1-11,15

Y	US 2010/051832 A1 (NISHISAKA TOSHIHIRO [JP] ET AL) 4 March 2010 (2010-03-04) paragraph [0077] - paragraph [0078]; figure 6B paragraph [0144] - paragraph [0147]; figure 31	13

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
15 January 2015	27/01/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	van Toledo, Wiebo

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/073992

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/025557 A1 (ASML NETHERLANDS BV [NL]; VAN EMPEL TJARKO ADRIAAN RUDOLF [NL]; BANINE) 26 February 2009 (2009-02-26) paragraph [0020] - paragraph [0047]; figures 1-4	12,14
X	US 2010/327192 A1 (FOMENKOV IGOR V [US] ET AL) 30 December 2010 (2010-12-30) paragraph [0083] - paragraph [0090]; figure 6 paragraph [0097] - paragraph [0103]; figure 9 paragraph [0003]	12,14
A	US 2002/014599 A1 (RAUCH JOHN E [US] ET AL) 7 February 2002 (2002-02-07) paragraph [0062] - paragraph [0064]; figure 2E	1,15

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2014/073992

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		US 2002014599 A1	07-02-2002
		WO 0199143 A1	27-12-2001

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-15

   EUV radiation source comprising a collector, fuel supply and laser beam supply system

1.1. claims: 1-11, 13, 15(completely); 14(partially)

   EUV radiation source comprising a collector, and accurate fuel and laser beam supply system

1.2. claims: 12(completely); 14(partially)

   EUV radiation source comprising debris mitigating system
