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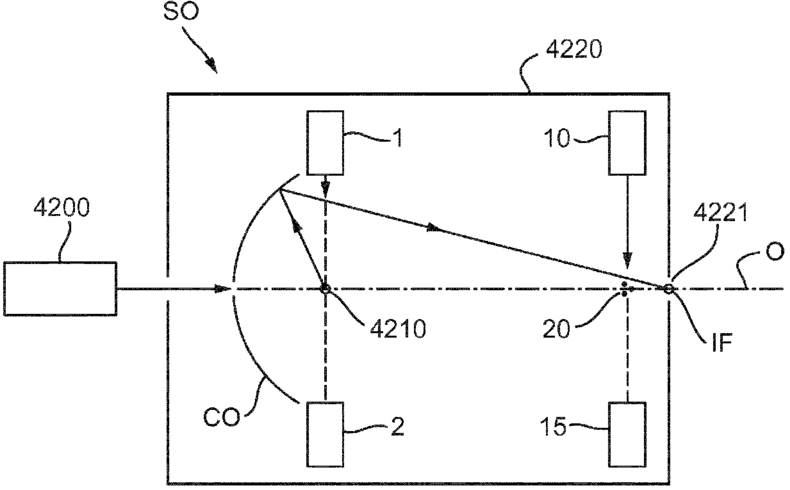
(54) **Title**: RADIATION SOURCE, LITHOGRAPHIC APPARATUS AND DEVICE MANUFACTURING METHOD

Fig. 4



(57) **Abstract**: A radiation source for a lithographic apparatus, in particular a laser-produced plasma source wherein a buffer liquid droplet is provided in a source chamber containing the plasma source. The buffer liquid droplet being evaporated explosively to form a buffer gas within the source chamber. Wherein the buffer gas may deflect physical debris in the source chamber to reduce or prevent physical debris from passing out of an opening in the source chamber into other parts of the lithographic apparatus.

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Radiation Source, Lithographic Apparatus and Device Manufacturing Method

FIELD

[0001] The present invention relates to a radiation source, a lithographic apparatus and a device manufacturing method. In particular, the invention relates to a radiation source using a plasma to generate EUV radiation for a lithographic apparatus.

BACKGROUND

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

[0003] 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

[0004] EUV radiation can be generated by forming a plasma of a suitable material, such that re-combination of free electrons with positive ions in the plasma results in emission of radiation of the desired wavelength. A plasma can be generated by laser irradiation of fuel or electrical discharge. A collector, e.g. in the form of a parabolic mirror, is used to collect the desired radiation and direct it to an intermediate focus in the entrance to an illumination system.

[0005] As well as the desired radiation, a plasma source emits radiation in other wavelengths and also physical debris such as ions, vapor and droplets of the fuel. The physical debris from the source can contaminate the collector, reducing its reflectivity and hence the amount of radiation available for imaging. If the physical debris is permitted to enter the illumination system, which forms the beam of radiation to illuminate the mask, it can cause various undesirable effects, such as contaminating the mirrors of the illumination system. Any such contamination would significantly reduce the transmission of the illumination system, reducing the throughput of the apparatus and the serviceable life of the illumination system.

[0006] Counter-measures are known to prevent debris from the plasma contaminating the collector, entering the illumination system and possibly travelling further into the apparatus which could result in contamination of components (e.g. reflectors and reticles) within the apparatus. One example is to include providing a low-pressure flow of gas such as argon, nitrogen or hydrogen (H_2) around the collector to prevent debris settling thereon. A further example is to include providing a flow of gas such as argon, nitrogen or hydrogen (H_2) at the intermediate focus to prevent or reduce debris particles passing through the intermediate focus to enter the illumination system. A further example is a set of rotating vanes located in the radiation beam between the plasma and the collector on the intermediate focus. The vanes rotate fast enough that the physical debris cannot pass through to the intermediate focus before being swept up by a vane. However, these counter-measures may not be sufficiently effective in some conditions at reducing the accumulation of debris on the collector and/or entering the illumination system. Known methods of supplying buffer gas, for example through the collector may in itself not be sufficient to reduce debris accumulation on the collector to an acceptable level for a high power source and does not sufficiently inhibit transport of debris into the illumination system.

[0007] Therefore, it is desirable to provide a novel approach to preventing or ameliorating the deleterious effects of debris emitted by a plasma.

[0008] According to an aspect of the invention, a radiation source device comprising: a source chamber having an exit aperture; a fuel source unit configured to provide fuel to the source chamber; a fuel excitation unit configured to excite the fuel to form a plasma; a collector configured to collect at least desired radiation emitted by the plasma and to direct the collected radiation along a beam path out of the exit aperture of the source chamber; and a buffer liquid source unit configured to provide a buffer liquid droplet to the source chamber, wherein the radiation source device is configured to excite explosively the buffer liquid droplet to form a buffer gas within the source chamber.

[0009] According to an aspect of the invention, a lithographic tool comprising: a radiation source device according to an aspect of the invention; and an optical system configured to direct radiation emitted by the radiation source device onto an object.

[0010] According to an aspect of the invention, an apparatus comprising: a chamber having an aperture; an optical element configured to direct a radiation beam along a beam path through the aperture; and a buffer liquid source unit configured to provide a buffer liquid droplet to the chamber; wherein the apparatus is configured to excite explosively the buffer liquid droplet to form a buffer gas.

[0011] According to an aspect of the invention, a device manufacturing method comprising: exciting a fuel to form a plasma in a source chamber; collecting radiation emitted by the plasma and directing it into a beam; directing the beam onto a patterning device; directing the beam patterned by the patterning device onto a substrate; supplying a buffer liquid droplet to the source chamber; and explosively exciting the buffer liquid droplet to form a buffer gas within the source chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] 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:

[0013] - Figure 1 depicts a lithographic apparatus used an embodiment of the invention;

[0014] - Figure 2 is a more detailed view of the apparatus of Figure 1;

[0015] - Figure 3 is a more detailed view of the source collector apparatus of the apparatus of Figures 1 and 2;

[0016] - Figure 4 depicts a radiation source device according to an embodiment of the invention;

[0017] - Figure 5 depicts a radiation source device according to an embodiment of the invention;

[0018] - Figure 6 depicts a radiation source device according to an embodiment of the invention;

[0019] - Figure 7 depicts a radiation source device according to an embodiment of the invention;

[0020] - Figure 8 depicts a radiation source device according to an embodiment of the invention; and

[0021] - Figure 9 depicts a radiation source device according to an embodiment of the invention.

DETAILED DESCRIPTION

[0022] 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.

[0023] 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”.

[0024] 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.

[0025] 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.

[0026] 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.

[0027] 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.

[0028] Referring to Figure 1, the illumination system EIL receives an extreme ultraviolet radiation beam from the source collector apparatus SO. Methods to produce EUV radiation include, but are not necessarily limited to, converting a material into a plasma state that has at least one element, e.g., xenon, lithium or tin, with one or more emission lines in the EUV range. In one such method, often termed laser produced plasma ("LPP") the plasma can be produced by irradiating a fuel, such as a droplet, stream or cluster of material having the desired line-emitting element, with a laser beam. The source collector apparatus SO may be part of an EUV radiation system including a laser, not shown in Figure 1, to provide the laser beam exciting the fuel. The resulting plasma emits output radiation, e.g., EUV radiation, which is collected using a radiation collector, disposed in the source collector apparatus. The laser and the source collector apparatus so may be separate entities, for example when a CO_2 laser is used to provide the laser beam for fuel excitation.

[0029] 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. In other cases the source may be an integral part of the source collector apparatus, for example when the source is a discharge-produced plasma EUV generator, often termed as a DPP source.

[0030] The illumination system 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 illumination system EIL may comprise various other components, such as facetted field and pupil mirror devices. The illumination system EIL may be used to condition the radiation beam EB, to have a desired uniformity and intensity distribution in its cross section.

[0031] 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.

[0032] 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.

[0033] Figure 2 shows the EUV apparatus 4100 in more detail, including the source collector apparatus SO, the 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 may be formed by a discharge produced plasma source. EUV radiation may be produced by a gas or vapor, for example Xe gas, Li vapor or Sn vapor in which the plasma 4210 is created to emit radiation in the EUV range of the electromagnetic spectrum. The plasma 4210 is created by, for example, an electrical discharge causing an at least partially ionized plasma. Partial pressures of, for example, 10 Pa of Xe, Li, Sn vapor or any other suitable gas or vapor may be required for efficient generation of the radiation. In an embodiment, a plasma of excited tin (Sn) is provided to produce EUV radiation.

[0034] The radiation emitted by the plasma 4210 is passed from a source chamber 4211 into a collector chamber 4212 via an optional gas barrier and/or contaminant trap 4230 (in some cases also referred to as contaminant barrier or foil trap) which is positioned in or behind an opening in source chamber 4211. The contaminant trap 4230 may include a channel structure. Contamination trap 4230 may also include a gas barrier or a combination of a gas barrier and a channel structure. The contaminant trap or contaminant barrier 4230 further indicated herein at least includes a channel structure, as known in the art.

[0035] The collector chamber 4212 may include a radiation collector CO which may be a so-called grazing incidence collector. Radiation collector CO has an upstream radiation collector side 4251 and a downstream radiation collector side 4252. Radiation that traverses collector CO can be reflected by a grating spectral filter 4240 to be focused 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.

[0036] Subsequently the radiation traverses the illumination system EIL, 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.

[0037] More elements than shown may generally be present in illumination system EIL and projection system PS. The grating spectral filter 4240 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.

[0038] Radiation collector CO, as illustrated in Figure 2, is depicted as a nested collector with grazing incidence reflectors 4253, 4254 and 4255, just as an example of a collector (otherwise referred to as a collector mirror or collector optic). The grazing incidence reflectors 4253, 4254 and 4255 are disposed axially symmetric around an optical axis O and a radiation collector CO of this type is preferably used in combination with a discharge produced plasma source, often called a DPP source.

[0039] Alternatively, the source collector apparatus SO may be part of an LPP radiation system as shown in Figure 3. A laser 4200 is arranged to deposit laser energy into a fuel, such as xenon (Xe), tin (Sn) or lithium (Li), creating the highly ionized plasma 4210 with electron temperatures of several 10's of eV. The energetic radiation generated during de-excitation and recombination of these ions is emitted from the plasma, collected by a near normal incidence radiation collector CO and focused onto the opening 4221 in the enclosing structure 4220. The enclosing structure 4220 may also be known as the source chamber.

[0040] In this radiation system, the plasma 4210 emits out of band radiation and physical debris, such as ions and atoms of the fuel and larger droplets as well as other desired EUV radiation. It is necessary to prevent the accumulation of material on the radiation collector CO and also to prevent physical debris exiting the enclosing structure 4220 via the opening 4221 and entering the illumination system EIL. Known proposals include the provision of a low pressure atmosphere of gas within the enclosing structure 4220 that impedes travel of fast debris particles from the source whilst being thin enough to minimize absorption of the desired EUV radiation. This arrangement however, does not provide sufficient protection for sources of increased power which are desirable to increase the throughput of the apparatus. Therefore, an alternative approach is desired.

[0041] Figure 4 depicts a source collector apparatus SO according to an embodiment of the invention including a novel debris mitigation arrangement. The source collector apparatus SO and laser 4200 function as a radiation source device. In the source collector apparatus SO, droplets of a fuel, e.g. Sn (Tin), are emitted by a fuel source unit 1. The fuel source unit 1 may be otherwise referred to as a fuel droplet generator. The droplets of fuel are irradiated by pulses of light from laser 4200 to generate plasma 4210. The laser 4200 functions as a fuel excitation unit. Plasma 4210 emits the desired EUV radiation as well as other radiation (i.e. other wavelengths) and physical debris as discussed above. Any physical debris which passes through the opening 4221 of the enclosing structure 4220 may contaminate other components within the EUV apparatus 4100, for example, components in the illumination system EIL. The enclosing structure 4220 may be otherwise referred to as the source chamber.

[0042] The majority of the fuel material may be collected by fuel droplet catcher 2, but the physical debris emitted in other directions is still sufficient to degrade the lifetime of the collector and to contaminate the illumination system. To mitigate this, the present invention provides a buffer gas within the source collector apparatus SO to deflect physical debris to reduce or prevent physical debris passing through the opening 4221 of the enclosing structure 4220 into the illumination system EIL.

[0043] In the present invention, buffer gas is provided in the source collector apparatus SO. Providing buffer gas at a low density may be beneficial in that it may help avoid or reduce the amount of EUV radiation (i.e. radiation at the desired wavelength) from being absorbed by the buffer gas. However, if the buffer gas is at a low density, this reduces the impact on the physical debris and if the density and/or the velocity of the buffer gas particles are too low, the physical debris may not be effectively stopped, or even deflected, by the buffer gas. Therefore, for impacting the physical debris, it may be advantageous to provide high density, high speed buffer gas.

[0044] To address these issues, in the present invention, a buffer liquid droplet is provided by a buffer liquid source unit 10. The radiation source device is configured to excite explosively the buffer liquid droplet to form the buffer gas. In other words, the buffer liquid droplet is evaporated to form the buffer gas. Ideally, all of the buffer liquid droplets provided are excited to form buffer gas.The buffer liquid source unit 10 may provide a buffer liquid droplet, which means at least one buffer liquid droplet, i.e. a single droplet or multiple buffer liquid droplets.

[0045] In the present invention, energy from radiation present in the enclosing structure 4220 may be used to excite explosively a buffer liquid droplet. As such, a radiation source device of the present device may be configured to excite explosively the buffer liquid droplet to form a buffer gas. As depicted in Figure 4, the buffer liquid droplet may be multiple buffer liquid droplets, i.e. plurality of buffer liquid droplets 20. As mentioned above, the plasma 4210 emits radiation across a range of wavelengths. The desired radiation is EUV radiation, therefore, radiation at different wavelengths, i.e. undesired radiation, is also present in the enclosing structure 4220 due to emissions from the plasma 4210. Additionally, there may be infra-red radiation deriving from the laser 4200 present in the enclosing structure 4220. As well as the desired radiation, the radiation collector CO directs some of the undesired radiation towards the exit aperture 4221. The undesired radiation may be directed towards the plurality of buffer liquid droplets 20 to increase the energy transferred to the plurality of buffer liquid droplets 20 which may explosively evaporate the plurality of buffer liquid droplets 20 to form the buffer gas.

[0046] Additional radiation directing elements, e.g. mirrors and/or diffractive elements, can be provided to direct radiation from the laser 4200 and/or radiation from the plasma 4210 to a predetermined location at which the buffer liquid droplets are excited. Using radiation from the laser 4200 or the plasma 4210 in this way may be advantageous in synchronizing the excitation of the plurality of liquid droplets 20 with the emission of radiation from the plasma 4210.

[0047] In an embodiment as shown in Figure 4, the buffer liquid source unit 10 is arranged to provide the plurality of buffer liquid droplets 20 in the source chamber adjacent to the opening 4221 of the enclosing structure 4220. It may be advantageous to provide the plurality of buffer liquid droplets in this area as the plurality of buffer liquid droplets 20 will then evaporate to form a buffer gas directly in front of the opening 4221, which would increase the effectiveness of the buffer gas at preventing or reducing physical debris going through the opening 4221.

[0048] Additionally or alternatively, in an embodiment the buffer liquid source unit 10 is configured to provide the plurality of buffer liquid droplets 20 at a location where intensity of the local radiation is relatively high compared to other locations in the enclosing structure

4220. For example, the plurality of buffer liquid droplets 20 may be provided near or in the beam path. The plurality of buffer liquid droplets 20 being placed in a location with relatively high intensity of collected radiation means that more energy may be transferred to the plurality of buffer liquid droplets 20 at that location than would be transferred at other locations in the enclosing structure 4220.

[0049] In an embodiment, the formation of the plasma 4210 is cyclical and occurs at a predetermined rate. The predetermined rate may be for example from approximately 40 to 150 kHz, preferably approximately 50 kHz to 100 kHz. Theoretically, it is possible that the predetermined rate could be much higher, for example up to approximately 1.5 MHz. As such, because the EUV radiation is a result of the plasma 4210 formation, the generation of the desired radiation beam is also cyclical and at the predetermined rate. Generally, EUV radiation is generated between approximately 0 nanoseconds (ns) and 150 ns after the plasma 4210 is formed. The generation of the plurality of buffer liquid droplets 20 by the buffer liquid source unit 10 can be provided in synchronization with the formation of plasma 4210. For example, the plurality of buffer liquid droplets 20 may be provided in the enclosing structure 4220 at approximately the predetermined rate. In an embodiment, the plurality of buffer liquid droplets 20 are provided in the enclosing structure 4220 at the predetermined rate, but approximately 0 ns to 200 ns after the formation of the plasma 4210. In an embodiment, the plurality of buffer liquid droplets are exploded to form the buffer gas 0 ns to 300 ns after the plasma is formed, or preferably 0 ns to 200 ns.

[0050] In an embodiment, the plurality of liquid buffer droplets 20 are provided in the enclosing structure 4220 after the collected (desired) radiation has reached the opening 4221, or at least after the collected radiation has passed the location at which the plurality of liquid buffer droplets 20 are provided. This means that the plurality of buffer liquid droplets 20 may be explosively evaporated to form the buffer gas after the collected radiation has passed. This is beneficial as it reduces the amount of EUV radiation absorbed by the plurality of buffer liquid droplets 20. The physical debris will travel at a speed which is lower than the radiation. Therefore, even if the buffer gas if formed after the EUV radiation has passed, most, if not all, of the physical debris would not have reached the location at which the plurality of liquid buffer droplets 20 may be provided before the buffer gas is formed. Therefore, the buffer gas may still be formed in time to reduce or prevent the physical debris from passing through the opening 4221.

[0051] The resulting buffer gas particles may travel at high speeds as described below, which means that the buffer gas particles may be out of the way by the time the next pulse of EUV radiation passes through. This is beneficial as it reduces the amount of EUV radiation absorbed by the buffer gas particles. Providing the plurality of buffer liquid droplets in the enclosing structure 4220 just after the desired radiation reaches the opening 4221 may improve the use of the undesired radiation as described above for exciting the plurality of liquid buffer droplets 20.

[0052] Using radiation already present within the enclosing structure 4220 has the advantage that radiation may be directed to the plurality of buffer liquid droplets 20 at the same time as or immediately after the EUV radiation arrives at the exit aperture 4221. Therefore, using radiation present in the present in the enclosing structure 4220 may synchronize the explosive evaporation of the plurality of buffer liquid droplets 20 with the generation of the desired radiation beam, thus reducing the absorption of the EUV radiation by the plurality of buffer liquid droplets 20 and/or buffer gas.

[0053] The explosive evaporation of each buffer liquid droplet results in buffer gas particles travelling at high speed. The term particles includes molecules, atoms and/or ions. The high speed buffer gas particles collide with debris particles within the enclosing structure 4220. Through impact, the high speed buffer gas particles may alter the velocity (i.e. the speed and/or direction) of debris particles and can therefore deflect debris particles as desired, for example, the debris particles may be deflected in a direction to prevent them passing through the opening 4221.

[0054] The present invention has the advantage that because the buffer gas is formed by rapidly (i.e. explosively) evaporating liquid droplets, the resulting buffer gas particles (e.g. atoms, molecules, ions) have high speed. For example, a buffer gas particle may reach approximately 1000 m/s – 10000 m/s or preferably 5000 m/s – 10000 m/s. Therefore, the buffer gas particles have high kinetic energy because the rapid evaporation will spread out the buffer gas particles at high speed. This means that less buffer gas than may otherwise be required may be used, for example, compared to using a gas lock provided by a flow of gas particles at the intermediate focus. Therefore, less gas may be used overall than corresponding systems in which a buffer gas is supplied directly as a gas. Having less gas in the enclosing structure 4220 may be advantageous as the gas may have a negative effect on components within a lithographic apparatus. The high kinetic energy of the resulting buffer gas particles in the present invention helps to deflect effectively and/or to stop physical debris whilst reducing or minimizing the absorption of EUV radiation by the buffer gas.

[0055] In the above embodiments, the term “explosively evaporate” means to evaporate quickly, i.e. the plurality of buffer liquid droplets 20 are provided with enough energy to rapidly evaporate to form the buffer gas. This is advantageous, as this means that the buffer gas particles travel at high speed as described above. If the buffer gas particles are travelling at high velocity, this means that the particles which impact any physical debris will transfer a greater momentum on the physical debris (proportional to the velocity of the buffer gas particles). Therefore, the higher the velocity, the greater impact the buffer gas particles will have on the velocity of the physical debris.

[0056] In an embodiment, the diameter of each of the plurality of liquid buffer droplets 20 is from approximately 30 microns to approximately 200 microns. More preferably, in an embodiment, the diameter of each of the plurality of liquid buffer droplets 20 is from approximately 30 microns to approximately 100 microns. Smaller droplets require less power to evaporate, and therefore, smaller droplets may be preferable.

[0057] In an embodiment, the liquid used for the plurality of liquid buffer droplets 20 is any liquid which can be used to form a gas, e.g. an inert gas. In an embodiment, the liquid used for the plurality of liquid buffer droplets 20 is liquid hydrogen, liquid helium, liquid argon or liquid nitrogen. Some liquids may be preferable to others, for example, if the liquid is already used in another part of a device, it may be easier to redirect some of the liquid (whether or not it is already in liquid or gas form) for providing the plurality of buffer liquid droplets 20.

[0058] In the above embodiments, the source collector apparatus SO and the laser 4200 act as the radiation source device. However, the radiation source device may be provided by a source collector apparatus SO only, as depicted in Figure 2.

[0059] In the embodiment depicted in Figure 4, the fuel source unit 1 is depicted as inside the enclosing structure 4220. However, the fuel source unit 1 may be located anywhere, for example, inside, outside or as part of the enclosing structure 4220. The fuel source unit 1 should be located to provide droplets of fuel 4210 to the source collector apparatus SO such that it can be used to form a plasma in accordance with the present invention.

[0060] In the embodiment depicted in Figure 4, the fuel droplet catcher 2 is depicted as inside the enclosing structure 4220. However, the fuel droplet catcher 2 may be located anywhere, for example, inside, outside or as part of the enclosing structure 4220. The fuel droplet catcher 2 should be located to catch droplets of fuel 4210 in the source collector apparatus SO.

[0061] In the embodiment depicted in Figure 4, the buffer liquid source unit 10 is depicted as inside the enclosing structure 4220. However, the buffer liquid source unit 10 may be located anywhere, for example, inside, outside or as part of the enclosing structure 4220. The buffer liquid source unit 10 should be located to provide the plurality of buffer liquid droplets 20 to the source collector apparatus SO such that it can be used to form a buffer gas in accordance with the present invention. The buffer liquid source unit 10 may be positioned so as to provide the plurality of buffer liquid droplets 20 with a velocity in a desired direction, e.g. in a preferred direction of travel of the debris particles. For example, the plurality of buffer liquid droplets 20 may have a velocity with a direction generally away from the opening 4221. The buffer liquid source unit 10 may be any source which is capable of providing at least one buffer liquid droplet which can be explosively excited as in the present invention.

[0062] In an embodiment depicted in Figure 4, the source collector apparatus SO may further comprise a buffer liquid droplet catcher 15. The buffer liquid droplet catcher 15 may be located anywhere, for example, inside, outside or as part of the enclosing structure 4220. The buffer liquid droplet catcher 15 should be located to catch any buffer liquid droplets or residue from the buffer liquid droplets which are not explosively excited. The buffer liquid droplet catcher 15 is depicted in Figure 4 but may be present in any of the other embodiments.

[0063] In an embodiment, multiple the buffer liquid source units 10 may be provided. In an embodiment at least one of the buffer liquid source units 10 may be provided to generate the plurality of buffer liquid droplets 20 which have a velocity in a direction away from the opening within the enclosing structure.

[0064] In an embodiment, the radiation source device may further comprise a buffer excitation unit. The buffer excitation unit may be configured to provide additional energy to the plurality of liquid buffer droplets 20 to excite explosively the plurality of buffer liquid droplets 20 to form the buffer gas.

[0065] In an embodiment, as depicted in figure 5, the buffer excitation unit may be a buffer laser 30. The buffer laser 30 may be any laser, e.g. a CO_2 laser or solid-state laser. The buffer laser 30 may use a wavelength specifically selected to improve the amount of energy effectively provided to the plurality of buffer liquid droplets 20. The buffer laser 30 is directed at the plurality of buffer liquid droplets 20 to deposit laser energy into the plurality of buffer liquid droplets 20. The buffer laser 30 is configured to provide enough power to the plurality of liquid buffer droplets 20 to explosively evaporate the plurality of buffer liquid droplets 20.

[0066] In an embodiment, the buffer laser 30 may be arranged to provide a few watts of energy directed at a buffer liquid droplet 20 inside the enclosing structure 4220. In an embodiment, the buffer laser provides a beam of radiation having a power from approximately 2 W to approximately 10 W to the buffer liquid droplet . In an embodiment, the buffer laser provides approximately 2 W to approximately 8 W to the buffer liquid droplet . In an embodiment, the buffer laser provides approximately 3 W to approximately 6 W to the buffer liquid droplet. In an embodiment, a plurality of buffer liquid droplets 20 is provided, and the buffer laser 30 is configured to provide more power to adequately evaporate the plurality of buffer liquid droplets 20. For a plurality of buffer liquid droplets 20, the buffer laser 30 may provide up to approximately 5-10 kW. The amount of power provided by the buffer laser 30 may be variable depending on the number, size and frequency at which the buffer liquid droplets are provided by the buffer liquid source unit 10.

[0067] In the embodiment depicted in Figure 5, the buffer excitation unit 30 is depicted as inside the enclosing structure 4220. However, the buffer excitation unit 30 may be located anywhere, for example, inside, outside or as part of the enclosing structure 4220. The buffer excitation unit 30 should be located to explosively excite the plurality of buffer liquid droplets 20 in accordance with the present invention. Although the buffer excitation unit 30 is depicted as in line with buffer liquid source unit 10, the buffer excitation unit 30 may be located at any location and angle relative to the buffer liquid source unit 10, for example the buffer excitation unit 30 may be located substantially parallel to the optical axis O. The buffer excitation unit 30 may be located so as to excite explosively and efficiently the plurality of buffer liquid droplets 20.

[0068] In any of the above embodiments in which a buffer laser 30 is used to deposit energy on the plurality of buffer liquid droplets 20, the laser energy will be more effectively transferred to the plurality of buffer liquid droplets 20 if the buffer laser 30 is aimed accurately at the plurality of buffer liquid droplets 20. Known methods and metrology devices, such as cameras and sensors, for aiming lasers in lithographic apparatus may be used to aim and control the buffer laser 30.

[0069] In an embodiment, the buffer liquid source unit 10 may be provided within a channel 90 in the enclosing structure 4220. The channel 90 may be used to control the direction of the plurality of buffer liquid droplets 20 and/or the buffer gas particles entering the enclosing structure 4220. The channel 90 may otherwise be referred to as a nozzle. An example embodiment depicting a channel 90 is shown in Figure 6. As depicted in Figure 6, the buffer liquid source generator 10 may be located in the channel 90 to provide the plurality of buffer liquid droplets 20 into the enclosing structure 4220 in a direction generally away from the opening 4221. In an embodiment, as depicted in Figure 6, the radiation source device may comprise a buffer excitation unit, for example a buffer laser 30 may be located and directed so as to explosively evaporate the plurality of buffer liquid droplets 20 in the channel 90. Alternatively, in an embodiment, the buffer laser 30 may be located and directed so as to explosively evaporate the plurality of buffer liquid droplets 20 outside the channel 90, but still within the enclosing structure 4220. Figure 6 provides an example of resulting direction of movement of the buffer gas particles, as indicated by the arrows A. Although the embodiment of figure 6 shows a buffer laser 30, the above embodiments described in relation to Figure 6 do not require a buffer laser 30, or even a buffer excitation unit, as this feature is optional.

[0070] In an embodiment, the plurality of buffer liquid droplets 20 may be preheated. For example, the plurality of liquid droplets 20 may be preheated by the liquid buffer source unit 10.

[0071] As described in further detail below, a heated member (similar to heated member 40 in further embodiments) may be optionally provided in the channel 90, for example to form the walls of the channel 90. In other words, the channel itself may also be heated by various direct or indirect (induction) contact with thermal devices. As described below, the heated member (not shown in Figure 6) may be used to impart energy to the plurality of buffer liquid droplets 20 and/or the particles of the buffer gas, by transferring heat energy when in contact with plurality of buffer gas liquid droplets 20 or particles of the buffer gas. This may be done in addition to, or instead of, other methods of transferring energy to the plurality of buffer gas liquid droplets 20 as described. Multiple channels 90 may be used to provide the plurality of liquid buffer droplets 20 to the enclosing structure 4220.

[0072] In an embodiment, a buffer gas reflector 60 may be placed in the enclosing structure. As can be seen in the example embodiment in Figure 7, the buffer gas reflector 60 is a physical barrier. Figure 7 is an enlarged view of the opening 4221 compared to the previous figures. In an embodiment, the reflector 60 is arranged to deflect debris particles in the enclosing structure 4220 away from the opening 4221. As depicted in Figure 7, the reflector 60 may be arranged to alter the trajectory of buffer gas particles to redirect them away from the opening 4221. This is shown in Figure 7, wherein arrows A depict the velocity of buffer gas particles after at least one of the plurality of buffer liquid droplets 20 have explosively evaporated, and arrows B depict the velocity of buffer gas particles after bouncing off the reflector 60. (Arrows A and B are used to indicate exemplary directions of buffer gas particles and are not intended to indicate relative speeds of these particles.) It is advantageous to direct the buffer gas particles in this way, i.e. to deflect the buffer gas particles in a direction away from the opening 4221, as this increases the probability of impacting physical debris travelling towards the opening 4221, and increases the impact that a buffer gas particle may have on physical debris. Additionally, physical debris may be stopped or deflected by the reflector 60. Additionally, the reflector 70 may direct radiation towards the plurality of liquid buffer gas droplets 20, i.e. radiation may be reflected off the reflector 70 towards the plurality of buffer liquid droplets 20. The reflector 70 may be rectangular or square shaped. The reflector 70 may have at least one curved surface, for example the reflector 70 may be a sphere or have at least one concave or convex surface.

[0073] The reflector 60 may be placed in or near the opening 4221. The reflector may be placed near to a location at which the plurality of liquid buffer droplets 20 are expected to explode. The reflector may be placed in a position so as to reduce or avoid negatively affecting EUV radiation from passing through the opening 4221 into the illuminator system EIL. For example, the reflector 60 may be located in a dark cone (depicted as within dashed lines 50 in Figure 7), which is a portion within the enclosing structure 4220 which is already dark due to an entrance hole in the collector CO (for example, which may be used to allow the laser 4200 to direct the laser through the collector CO at the plasma 4210 in the enclosing structure 4220).

[0074] In an embodiment, a debris trap 80 is provided in the enclosing structure 4220. The debris trap 80 may be used to collect deflected physical debris. The debris trap 80 allows physical debris to be collected more easily and therefore, may make it easier to remove physical debris from the enclosing structure. An exemplary embodiment is depicted in Figure 8 wherein a debris trap 80 is shown at the edge of the enclosing structure 4220, near the opening 4221. Figure 8 depicts the possible use of a debris trap 80 with an embodiment described above in relation to Figure 6.

[0075] As depicted in Figure 8, the buffer gas particles may move in the direction of arrows A. The direction of travel of the physical debris 70 (as shown by arrows C in Figure 8) may be altered as buffer gas particles, for example moving in direction A, impact the physical debris 70. Therefore, the buffer gas deflects the physical debris 70, and in this instance, deflects the physical debris towards the debris trap 80. The debris trap 80 may be placed anywhere inside and/or forming an edge of the enclosing structure 4220. It may be advantageous to provide the debris trap adjacent to the opening 4221 such that only a small deviation of physical debris 70 is required to prevent the physical debris to exiting the enclosing structure 4220 via the opening 4221. Multiple debris traps may be placed throughout the enclosing structure 4220. Although the embodiment of figure 8 shows a buffer laser 30, the above embodiments described in relation to Figure 8 do not require a buffer laser 30, or even a buffer excitation unit, as this feature is optional.

[0076] In an embodiment, the radiation source device is configured to provide a high power pulsed electromagnetic field through which the plurality of buffer liquid droplets 20 may pass through. The high power pulsed electromagnetic field may be configured to excite explosively the plurality of buffer liquid droplets 20. The high power pulsed electromagnetic field may be inside or at an entrance to the enclosing structure 4220, such that the plurality of buffer liquid droplets are explosively excited to form the buffer gas within the enclosing structure 4220. The high power pulsed electromagnetic field may be used in addition to, or instead of, the other methods of transferring energy to the plurality of buffer gas liquid droplets 20 as described.

[0077] In the above embodiments, the buffer liquid source unit 10 is arranged to provide the plurality of buffer liquid droplets 20 adjacent to the opening 4221. However, the plurality of buffer liquid droplets 20 may be provided at any location in or on the enclosing chamber 4220. For example, in an embodiment, the plurality of liquid buffer droplets 20 can be provided through apertures in the collector CO (not shown) and/or around the edges of the collector CO.

[0078] In any of the embodiments, the plurality of liquid buffer droplets 20 may be replaced with a single droplet. The buffer liquid source unit 10 may be configured to provide multiple buffer liquid droplets at a set rate, i.e. by providing a buffer liquid droplet in pulses. The set rate may be the same as the predetermined rate. Alternatively, the set rate is different from the predetermined rate. Each pulse may only include one droplet. Alternatively, each pulse may include more than one droplet, i.e. each pulse may include a plurality of buffer liquid droplets 20. The number of droplets provided by the buffer liquid source unit 10 in each pulse may be variable, i.e. different numbers of droplets may be provided in each different pulse. Additionally or alternatively, the rate at which the pulse of a single (and/or a plurality of buffer liquid droplets 20) is provided by the buffer liquid source unit 10 may be variable.

[0079] In an embodiment, the buffer liquid source unit 10 is configured to provide the plurality of buffer liquid source droplets 20 as a spray, for example, as a small cluster of buffer liquid source droplets provided simultaneously.

[0080] In an embodiment, multiple buffer liquid source units 10 may be provided. For example, a ring of buffer liquid source unit 10 may be provided around the opening 4221. If multiple buffer liquid source units are provided, they may provide droplets with the same number of droplets per pulse as each other and/or at the same rate as each other. Alternatively, if multiple buffer liquid source units are provided, they may provide droplets with a different number of droplets per pulse as each other and/or at a different rate as each other.

[0081] A heated member 40 may be provided with any of the above embodiments, for example the heated member 40 may be provided instead of, or in addition to, the buffer laser 30 in any of the above embodiments, i.e. a heated member may function as a buffer excitement unit. An example of the heated member 40 is shown in figure 9 as a cone shaped member around the collected radiation beam. The cone shape heated member 40 allows the buffer liquid source unit 10 to provide the plurality of buffer liquid droplets 20 to a location in the enclosing structure 4220, for example, near the optical axis O in front of the opening 4221 as shown in Figure 9. The heated member is provided around the collected radiation beam as shown in figure 9, such that when each of the plurality of liquid buffer droplets 20 make contact with the heated member, enough energy is imparted to each droplet to explosively evaporate the droplet to form buffer gas particles moving at high speed. The heated member 40 may be any shape. A heated member 40 could be used to form the reflector 60 described above. As previously mentioned, a heated member 40 could be used to form the walls of a channel 90 as described above or may form part of the enclosing structure 4220. The heated member can take the form of a cone or shroud, possibly with vanes.

[0082] The use of the plurality of buffer liquid droplets 20 in the above described embodiments may be used in any part of an apparatus, for example, in which it may be beneficial to provide a buffer gas and where physical debris is present. In an embodiment, the above principles may be used in an apparatus comprising a chamber having an aperture, an optical element configured to direct a radiation beam along a beam path through the exit aperture, and a buffer liquid source unit configured to provide a plurality of buffer liquid droplets to the chamber; wherein the apparatus is configured to excite explosively the plurality of buffer liquid droplets to form a buffer gas. A buffer excitation unit, a channel, a reflector and/or a debris trap as described in any of the above embodiments may be used in the apparatus described here. For example, the apparatus may be the illumination system EIL, wherein an opening through which the beam is directed may be the same, or aligned with, an exit aperture from the source collector apparatus SO. As such, the apparatus may be configured to explosively evaporate the plurality of buffer liquid droplets to form the buffer gas adjacent to the opening of the apparatus to prevent debris particles from traveling towards components within the illumination system EIL.

[0083] The buffer liquid source unit 10 can be used in combination with any other methods and/or devices for ameliorating or preventing debris from passing into the opening 4221. For example, in an embodiment a fan unit (not shown) may be provided outside the radiation beam to create a flow in the buffer gas sufficient to mitigate the deleterious effects of debris on the collector and illumination system. Additionally or alternatively, at least one fan unit may be placed inside the radiation beam path, for example, a rotating foil trap and/or a static foil trap. Additionally or alternatively, in a further embodiment multiple non-concentric fan units (not shown) may be arranged around the collected radiation beam. Additionally or alternatively, a dynamic gas lock (not shown) may be provided close to the opening 4221. A dynamic gas lock comprises gas outlets provided in or near the opening 4221 and gas inlets to provide a flow of buffer gas, such as hydrogen or an inert gas, in the opposite direction to the propagation of the projection beam PB.

[0084] Embodiments of the present invention can be employed with any form of plasma based source using a fuel selected from the group consisting of Sn, Li, Gd, Tb and mixtures or combinations thereof. A fan unit as described above can also be employed in another module of the apparatus, such as the illumination system or projection system, in order to locally control or remove contamination.

[0085] 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.

[0086] 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.

[0087] Although specific reference may be made in this text to embodiments of the invention in the context of a lithographic apparatus, embodiments of the invention may be used in other apparatus. Embodiments of the invention may form part of a mask inspection apparatus, a metrology apparatus, or any apparatus that measures or processes an object such as a wafer (or other substrate) or mask (or other patterning device). These apparatus may be generally referred to as lithographic tools. Such a lithographic tool may use vacuum conditions, below atmospheric pressure conditions or ambient (non-vacuum) conditions. 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, in an embodiment, a device manufacturing method comprising: exciting a fuel to form a plasma in a source chamber; collecting radiation emitted by the plasma and directing it into a beam; directing the beam onto a patterning device; directing the beam patterned by the patterning device onto a substrate; supplying a plurality of buffer liquid droplets to the source chamber; and explosively exciting the plurality of buffer liquid droplets to form a buffer gas within the source chamber. The method may be used in combination with any of the above-mentioned embodiments.

[0088] 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.

[0089] 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.

[0090] 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 device comprising:

a source chamber having an exit aperture;

a fuel source unit configured to provide fuel to the source chamber;

a fuel excitation unit configured to excite the fuel to form a plasma;

a collector configured to collect at least desired radiation emitted by the plasma and to direct the collected radiation along a beam path out of the exit aperture of the source chamber; and

a buffer liquid source unit configured to provide a buffer liquid droplet to the source chamber, wherein

the radiation source device is configured to excite explosively the buffer liquid droplet to form a buffer gas within the source chamber.

2. The radiation source device according to claim 1, wherein the buffer liquid source unit is configured to provide the buffer liquid droplet at a location where the local radiation intensity is high compared to other locations in the source chamber.

3. The radiation source device according to either of claims 1 or 2, further comprising a buffer excitation unit, wherein the buffer excitation unit is configured to excite explosively the buffer liquid droplet to form the buffer gas within the source chamber.

4. The radiation source device according to any of the previous claims, wherein the plasma is formed at a predetermined rate and the buffer liquid droplet is exploded to form the buffer gas 0 ns to 300 ns after the plasma has been formed.

5. The radiation source device according to any of the previous claims, wherein the plasma is formed at a predetermined rate and the liquid source unit is configured to provide multiple buffer liquid droplets at substantially the same rate as the predetermined rate.

6. The radiation source device according to either claim 4 or claim 5, wherein the predetermined rate is approximately 40 to 150 kHz, preferably approximately 50 kHz to 100 kHz.

7. The radiation source device according to any of the previous claims, wherein the buffer liquid droplet is liquid hydrogen, helium, nitrogen, or argon.

8. The radiation source device according to any of the previous claims, wherein the diameter of each buffer liquid droplet is from approximately 30 microns to approximately 200 microns.

9. The radiation source device according to any of claims 3-8, wherein the buffer excitation unit comprises a laser.

10. The radiation source device according to any of claims 3-9, wherein the buffer excitation unit comprises a heated member.

11. The radiation source device according to any of the previous claims, wherein the buffer liquid source unit is arranged to provide the buffer liquid droplet in the source chamber adjacent to the exit aperture of the source chamber.

12. The radiation source device according to any of the previous claims, wherein the liquid source device is arranged to provide the buffer liquid droplet at a velocity having a direction which is away from the exit aperture.

13. The radiation source device according to any of the previous claims, further comprising a reflector located adjacent to the exit aperture, the reflector being arranged to reflect the buffer gas particles away from the exit aperture.

14. The radiation source device according to any of the previous claims, wherein the source chamber further comprises a debris trap.

15. The radiation source device according to any of the previous claims, wherein the collector is configured to direct the radiation to an intermediate focus near the exit aperture.

16. A lithographic tool comprising:

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

an optical system configured to direct radiation emitted by the radiation source device onto an object.

17. The lithographic tool according to claim 16, wherein the optical system comprises an illumination system arranged to direct radiation emitted by the radiation source device onto a patterning device, and the lithographic tool further comprises:

a support system arranged to support a patterning device;

a projection system arranged to direct radiation patterned by the patterning device onto a substrate; and

a substrate holder arranged to support a substrate.

18. An apparatus comprising:

a chamber having an aperture;

an optical element configured to direct a radiation beam along a beam path through the aperture; and

a buffer liquid source unit configured to provide a buffer liquid droplet to the chamber; wherein

the apparatus is configured to excite explosively the buffer liquid droplet to form a buffer gas.

19. A device manufacturing method comprising:

exciting a fuel to form a plasma in a source chamber;

collecting radiation emitted by the plasma and directing it into a beam;

directing the beam onto a patterning device;

directing the beam patterned by the patterning device onto a substrate;

supplying a buffer liquid droplet to the source chamber; and

explosively exciting the buffer liquid droplet to form a buffer gas within the source chamber.

Fig. 1

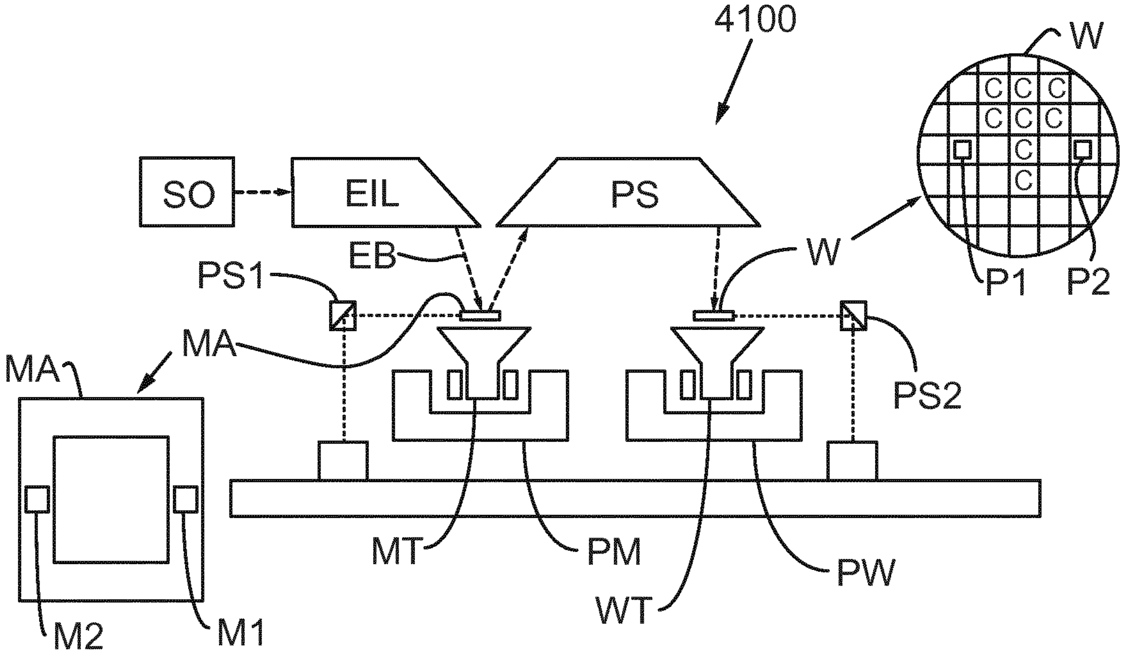
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Fig. 2

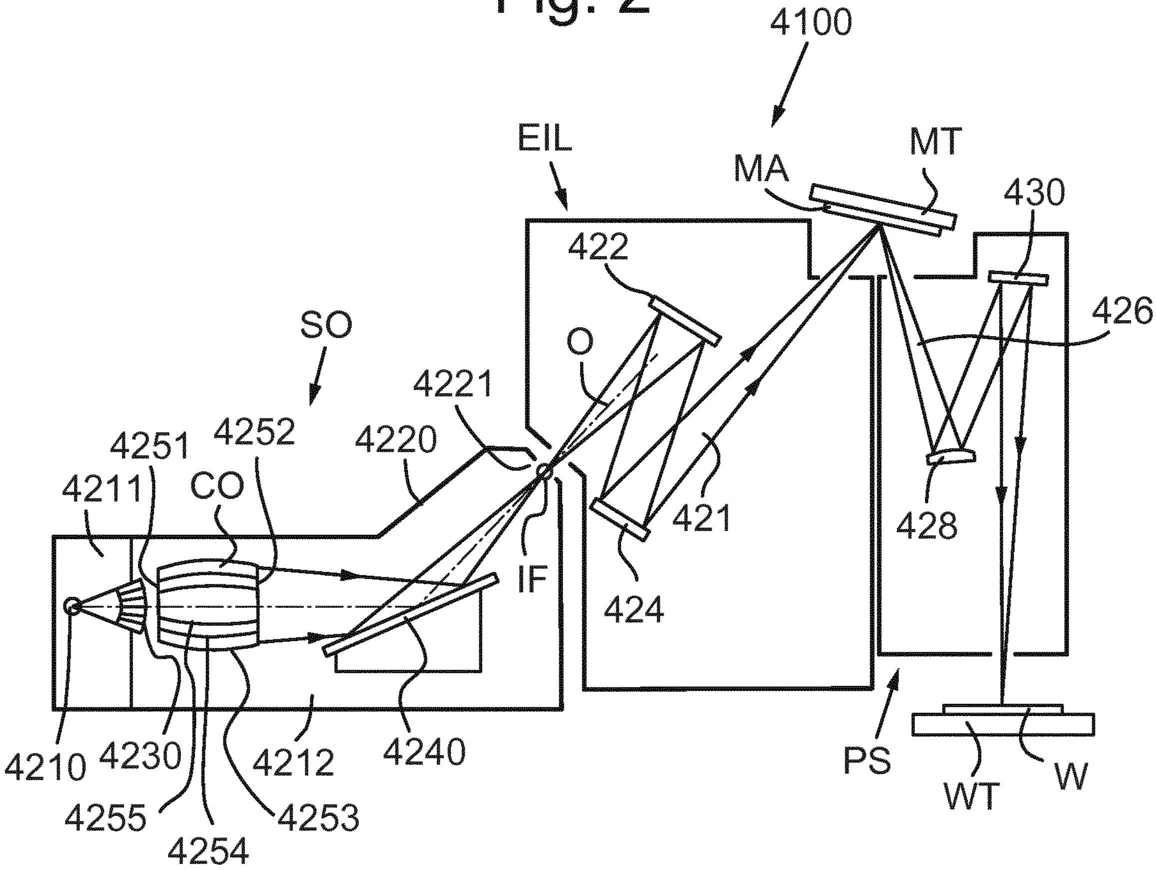
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Fig. 3

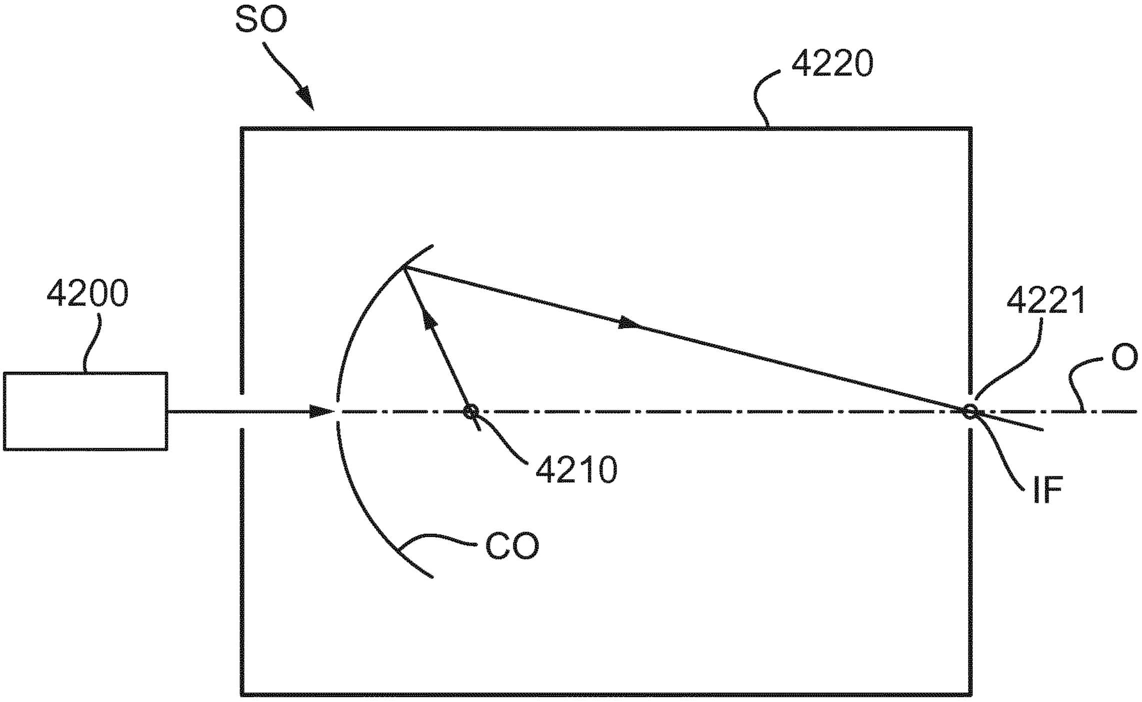
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Fig. 4

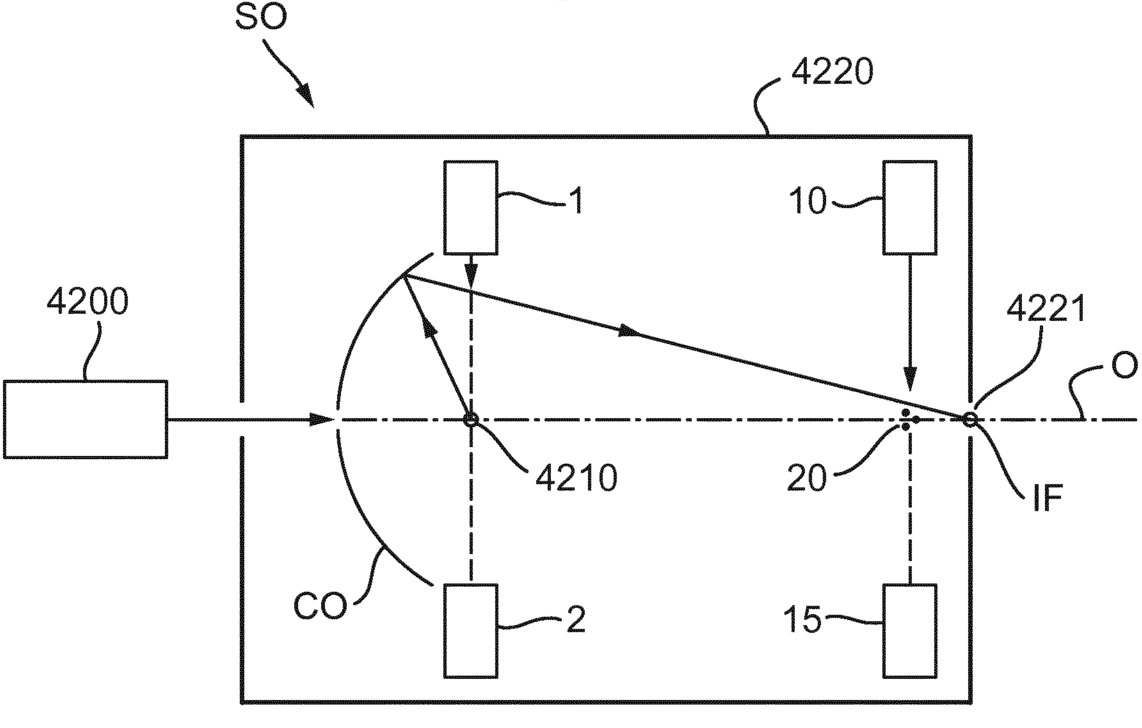
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Fig. 5

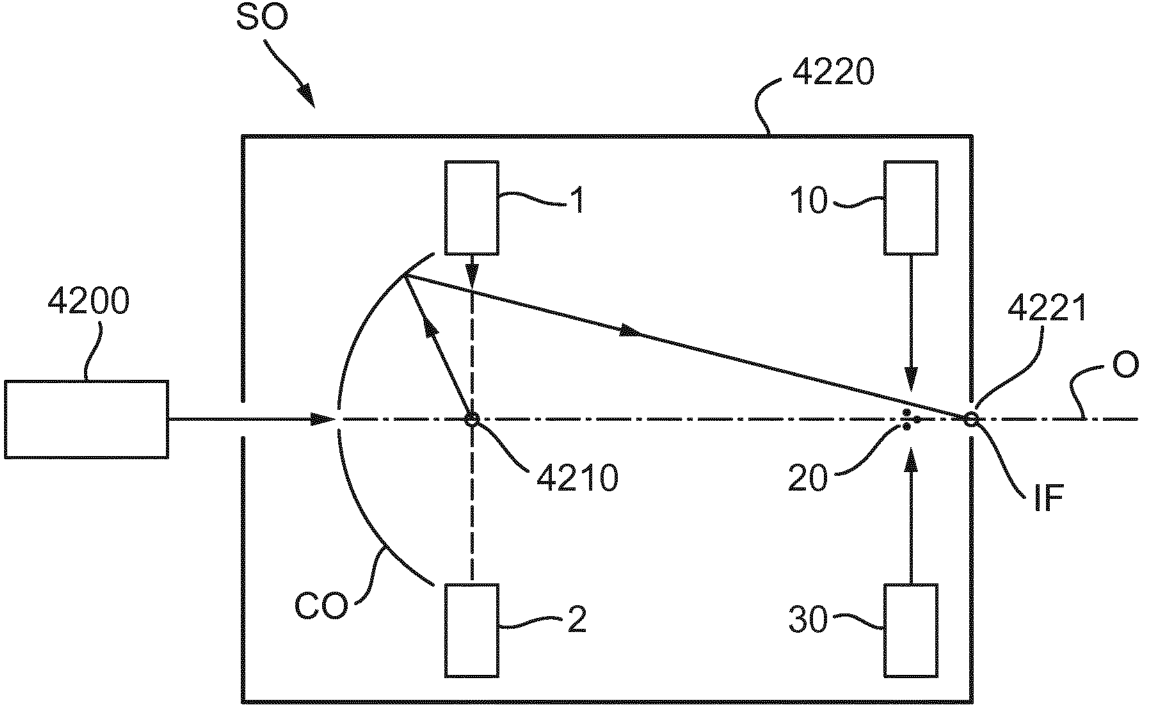

Fig. 6

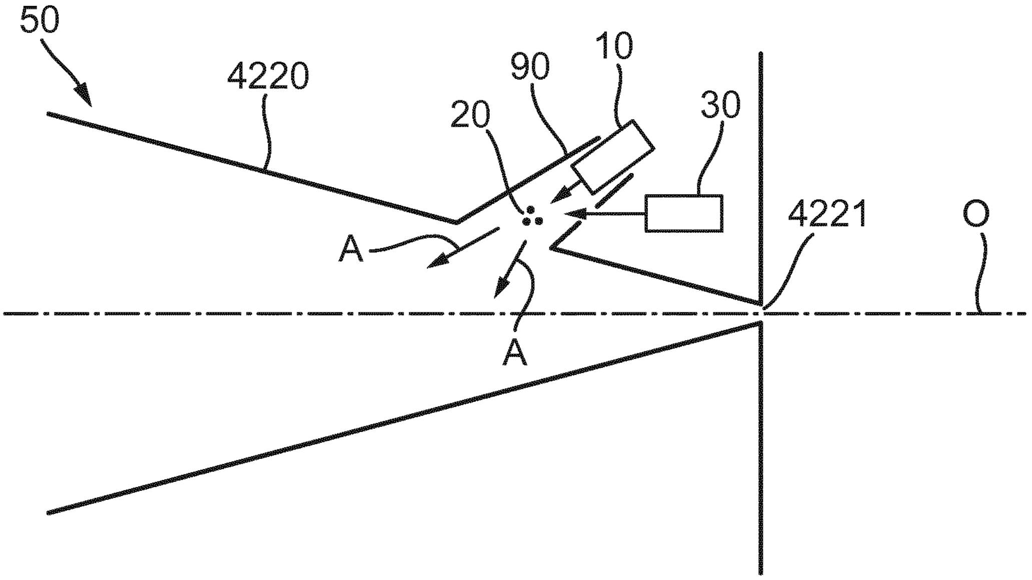

Fig. 7

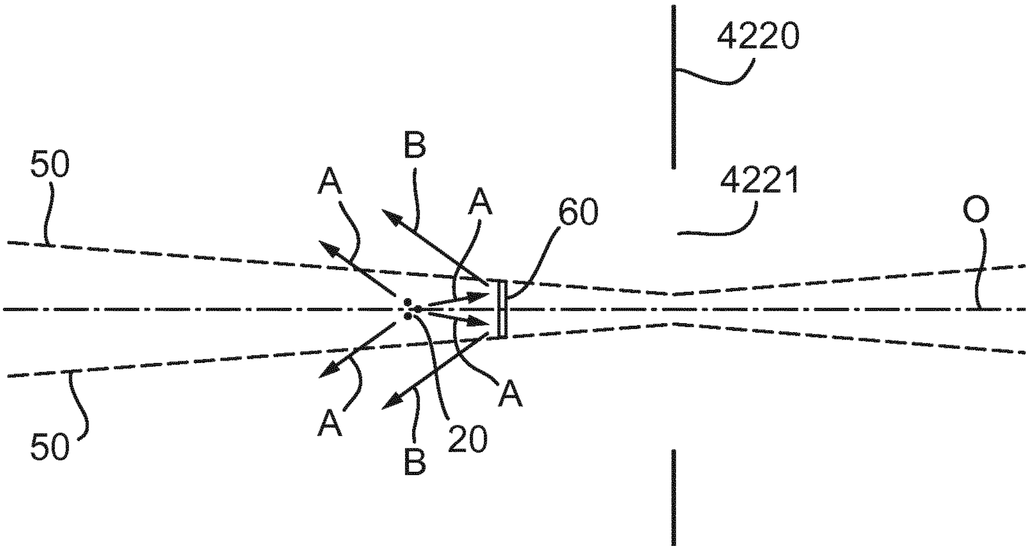

Fig. 8

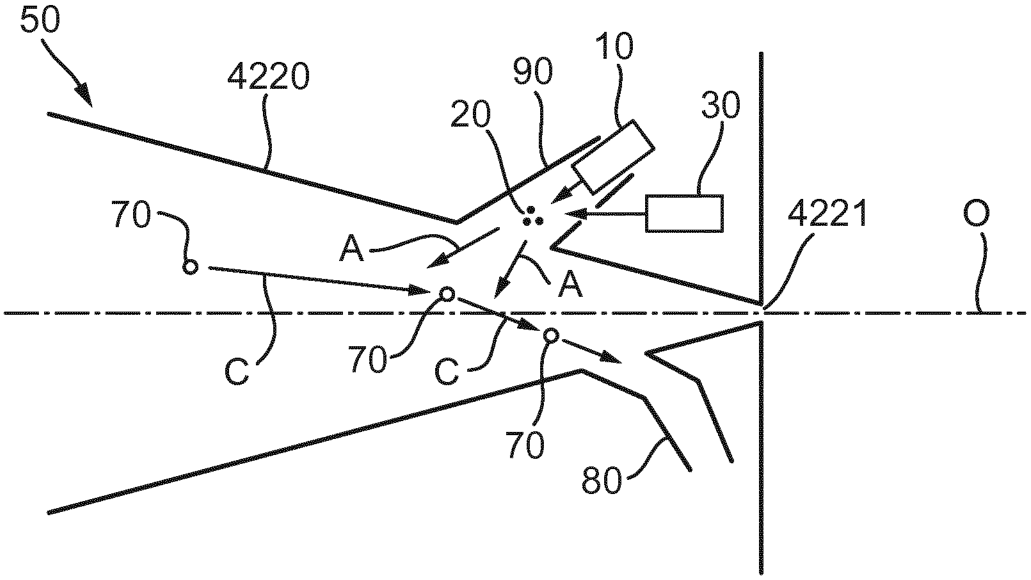
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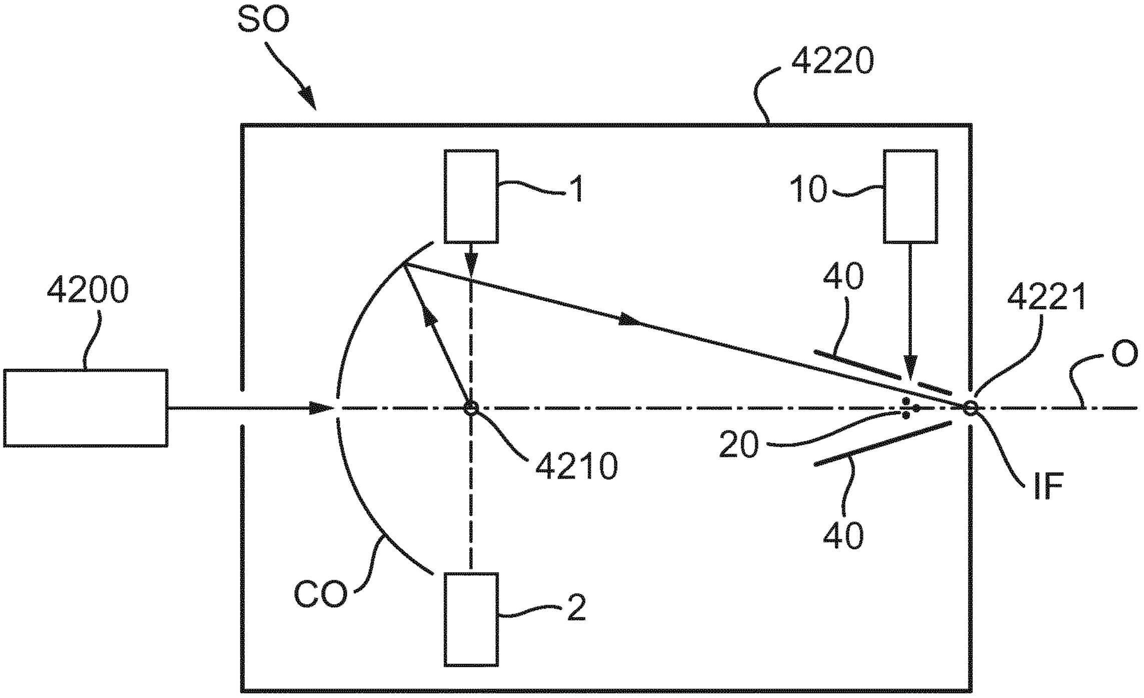
Fig. 9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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/057341

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, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	EP 1 367 866 A1 (NORTHROP GRUMMAN SPACE TECHNOL [US]) 3 December 2003 (2003-12-03) paragraphs [0004], [0010], [0015] - [0022]; claims 1, 2; figures 1, 2	1-3,5, 18,19 4,6,8-17 7
Y	US 2009/250639 A1 (BANINE VADIM YEVGENYEVICH [NL] ET AL) 8 October 2009 (2009-10-08) paragraphs [0005], [0033] - [0038], [0041] - [0051]; figures 2a, 2b	4,6,8-17

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 7 July 2016	Date of mailing of the international search report 14/07/2016
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Eisner, Klaus

3

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/057341

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 1367866 A1	03-12-2003	DE 60310807 T2	25-10-2007
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US 2009250639 A1	08-10-2009	US 2009250639 A1	08-10-2009
		US 2010253928 A1	07-10-2010