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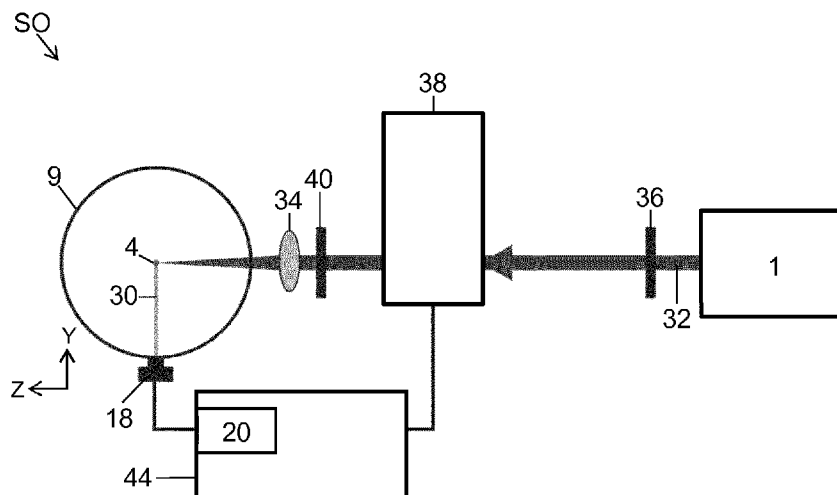


FIG. 3

(57) Abstract: A radiation source (SO) of a laser-produced plasma type is described. The radiation source (SO) comprises a droplet generator (3a) configured to provide a fuel droplet (60). The radiation source (SO) comprises a laser system (1) configured to provide a pre-pulse and a main-pulse. The pre-pulse is operative to condition the fuel droplet (60) for receipt of main pulse. The main pulse is operative to convert the conditioned fuel droplet (60) into plasma. The radiation source (SO) comprises a sensing system (16) configured for sensing a characteristic of an oscillation of a spatial mass distribution of the fuel droplet (60). The radiation source (SO) comprises a control system (44) operative to adjust a polarization of the pre-pulse under control of the sensed characteristic. The polarization of the pre-pulse may affect the spatial mass distribution of the conditioned fuel droplet (60).

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RADIATION SOURCE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of EP application 18159200.7, which was filed on February 28, 2018 and which is incorporated herein in its entirety by reference.

FIELD

[0002] The present invention relates to a radiation source which may, for example but not exclusively, be used for supplying radiation for a lithographic apparatus.

BACKGROUND

[0003] A lithographic apparatus is a machine constructed to apply a desired pattern onto a substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). A lithographic apparatus may, for example, project a pattern at a patterning device (e.g., a mask) onto a layer of radiation-sensitive material (resist) provided on a substrate.

[0004] To project a pattern on a substrate a lithographic apparatus may use electromagnetic radiation. The wavelength of this radiation determines the minimum size of features which can be formed on the substrate. A lithographic apparatus, which uses extreme ultraviolet (EUV) radiation, having a wavelength within the range 4-20 nm, for example 6.7 nm or 13.5 nm, may be used to form smaller features on a substrate than a lithographic apparatus which uses, for example, radiation with a wavelength of 193 nm.

[0005] Some lithographic apparatus may comprise a radiation source of a laser-produced plasma type. This type of radiation source may comprise a droplet generator configured to provide a fuel droplet. The radiation source may be configured to provide a pre-pulse and a main pulse for interacting with the fuel droplet. The pre-pulse may condition the fuel droplet for receipt of main pulse. The main pulse may then convert the conditioned fuel droplet into plasma to generate radiation (e.g. EUV radiation). The generation efficiency of EUV radiation may be dependent on the properties of the conditioned fuel droplet.

SUMMARY

[0006] According to an aspect or embodiment there is provided a radiation source of a laser-produced plasma (LPP) type. The radiation source comprises a droplet generator configured to provide a fuel droplet. The radiation source comprises a laser system configured to provide first laser radiation and second laser radiation to a fuel droplet. The first laser radiation is operative to condition the fuel droplet for receipt of the second laser radiation. The second laser radiation is operative to convert the conditioned fuel droplet into plasma. The radiation source comprises a sensing system configured to sense a characteristic of an oscillation of a spatial mass distribution of the fuel droplet. The radiation

source comprises a control system operative to adjust a polarization of the first laser radiation under control of the sensed characteristic. The first laser radiation may comprise one or more pre-pulses. The second laser radiation may comprise a main pulse.

[0007] The spatial mass distribution of the fuel droplet may oscillate due to several factors. The spatial mass distribution of the fuel droplet may depend on properties of the fuel droplet. Properties such as mass, density, velocity and fuel type may affect the spatial mass distribution of the fuel droplet. The spatial mass distribution of the fuel droplet may also be affected by energy released when the second laser radiation interacts with a preceding fuel droplet. The energy released may be in the form of a shockwave. The energy released may result in the fuel droplet having a spatial mass distribution that is not ideal or undesired. The plasma formation process may be adversely affected if the spatial mass distribution of the conditioned fuel droplet is not ideal or desirable.

[0008] It has been recognized that the polarization of the first laser radiation may affect the spatial mass distribution of the fuel droplet. By controlling the polarization, it may be possible to condition the fuel droplet such that the interaction between the second laser radiation and the conditioned fuel droplet may be optimized or improved. Therefore, an optimum or improved LPP may be produced using the conditioned fuel droplet. For example, the optimum or improved LPP may produce radiation with a higher efficiency compared with if the fuel droplet has not been ideally or not desirably conditioned.

[0009] The sensing system may be configured to sense a geometric projection of the fuel droplet on a plane perpendicular to a propagation axis of the first laser radiation. The sensing system may be configured to sense that the geometric projection has a smaller dimension in a first direction and a larger dimension in a second direction, different from the first direction. In response to the sensed characteristic, the control system may adjust the polarization of the first laser radiation so that the first laser radiation has a first electric field vector of a first magnitude that is parallel to the first direction, and has a second electric field vector of a second magnitude smaller than the first magnitude, the second electric field vector being parallel to the second direction.

[00010] The control system may be operative to adjust a ratio between the first magnitude and the second magnitude in response to the sensed characteristic.

[00011] The control system may be operative to adjust the polarization of the first laser radiation such that the first laser radiation has elliptical polarization with a major axis that is oriented parallel to the first direction.

[00012] The sensing system may comprise a sensor configured for capturing one or more images of the fuel droplet.

[00013] The sensing system may comprise a processor configured for determining, from the one or more images, information representative of the characteristic.

[00014] The processor may be configured to predict, from the information representative of the characteristic, the spatial mass distribution of the fuel droplet when the first laser radiation interacts with the fuel droplet.

[00015] The sensing system may further comprise an illumination system configured for illuminating the fuel droplet with illuminating radiation for obtaining information representative of the characteristic.

[00016] The characteristic may be representative of at least one of: an amplitude, a frequency and a phase of the oscillation of the spatial mass distribution.

[00017] The radiation source may further comprise at least one adjustable polarization element for adjusting the polarization of the first laser radiation.

[00018] The control system may be operative to adjust the at least one adjustable polarization element in response to the sensed characteristic.

[00019] According to an aspect or embodiment there is provided a lithographic system. The lithographic system may comprise a radiation source of any aspect or embodiment described herein. The lithographic system may comprise a lithographic apparatus configured to use radiation provided by the radiation source for imaging a pattern onto a substrate.

[00020] According to an aspect or embodiment there is provided a method. The method comprises providing a fuel droplet. The method comprises using a laser system to provide first laser radiation and second laser radiation. The method comprises sensing, with a sensing system, a characteristic of an oscillation of a spatial mass distribution of the fuel droplet. The method comprises adjusting, with a control system, a polarization of the first laser radiation under control of the sensed characteristic. The method comprises conditioning the fuel droplet, with the first laser radiation, for receipt of the second laser radiation. The method comprises converting, with the second laser radiation, the conditioned fuel droplet into plasma.

[00021] The method may comprise sensing that a geometric projection of the fuel droplet on a plane perpendicular to a propagation axis of the first laser radiation has a smaller dimension in a first direction and a larger dimension in a second direction, different from the first direction. In response to the sensed characteristic, the method may comprise adjusting the polarization of the first laser radiation so that the first laser radiation has a first electric field vector of a first magnitude and being parallel to the first direction, and has a second electric field vector of a second magnitude smaller than the first magnitude, the second electric field vector being parallel to the second direction.

[00022] The method may comprise adjusting a ratio between the first magnitude and the second magnitude in response to the sensed characteristic.

[00023] The method may comprise adjusting the polarization such that the first laser radiation has elliptical polarization with a major axis that is oriented parallel to the first direction.

[00024] The method may comprise capturing one or more images of the fuel droplet. The method may comprise determining, from the one or more images, information representative of the characteristic.

[00025] The method may comprise predicting, from the information representative of the characteristic, the spatial mass distribution of the fuel droplet when the first laser radiation interacts with the fuel droplet.

[00026] The method may comprise illuminating the fuel droplet with illuminating radiation for obtaining information representative of the characteristic.

[00027] The method may comprise adjusting, with at least one adjustable polarization element, the polarization of the first laser radiation.

[00028] The method may comprise adjusting the at least one adjustable polarization element in response to the sensed characteristic.

[00029] The method may comprise providing any radiation source described herein. The method may comprise using radiation provided by the radiation source to image a pattern onto a substrate.

[00030] At least one feature of any aspect or embodiment described herein may replace any corresponding feature of any aspect or embodiment described herein. At least one feature of any aspect or embodiment described herein may be combined with any other aspect or embodiment described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[00031] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings, in which:

- Figure 1 depicts a lithographic system comprising a lithographic apparatus and a radiation source according to an embodiment of the invention;
- Figure 2 is a schematic view of part of the radiation source of Figure 1;
- Figure 3 is a further schematic view of the radiation source of Figure 1; and
- Figure 4 schematically illustrates the effect of polarization control on the spatial mass distribution of fuel droplets used in the radiation source of Figures 1 to 3.

DETAILED DESCRIPTION

[00032] Figure 1 shows a lithographic system comprising a radiation source SO and a lithographic apparatus LA. The radiation source SO is configured to generate an EUV radiation beam B and to supply the EUV radiation beam B to the lithographic apparatus LA. The lithographic apparatus LA comprises an illumination system IL, a support structure MT configured to support a patterning device MA (e.g., a mask), a projection system PS and a substrate table WT configured to support a substrate W.

[00033] The illumination system IL is configured to condition the EUV radiation beam B before the EUV radiation beam B is incident upon the patterning device MA. Thereto, the illumination system IL may include a faceted field mirror device 10 and a faceted pupil mirror device 11. The faceted field mirror device 10 and faceted pupil mirror device 11 together provide the EUV radiation beam B with a desired cross-sectional shape and a desired intensity distribution. The illumination system IL may include other mirrors or devices in addition to, or instead of, the faceted field mirror device 10 and faceted pupil mirror device 11.

[00034] After being thus conditioned, the EUV radiation beam B interacts with the patterning device MA. As a result of this interaction, a patterned EUV radiation beam B' is generated. The projection system PS is configured to project the patterned EUV radiation beam B' onto the substrate W. For that purpose, the projection system PS may comprise a plurality of mirrors 13,14 which are configured to project the patterned EUV radiation beam B' onto the substrate W held by the substrate table WT. The projection system PS may apply a reduction factor to the patterned EUV radiation beam B', thus forming an image with features that are smaller than corresponding features on the patterning device MA. For example, a reduction factor of 4 or 8 may be applied. Although the projection system PS is illustrated as having only two mirrors 13, 14 in Figure 1, the projection system PS may include a different number of mirrors (e.g., six or eight mirrors).

[00035] The substrate W may include previously formed patterns. Where this is the case, the lithographic apparatus LA aligns the image, formed by the patterned EUV radiation beam B', with a pattern previously formed on the substrate W.

[00036] A relative vacuum, i.e. a small amount of gas (e.g. hydrogen) at a pressure well below atmospheric pressure, may be provided in the radiation source SO, in the illumination system IL, and/or in the projection system PS.

[00037] The radiation source SO shown in Figure 1 is, for example, of a type which may be referred to as a laser produced plasma (LPP) source. A laser system 1, which may, for example, include a CO₂ laser, is arranged to deposit energy via a laser beam 2 into a fuel, such as tin (Sn) which is provided from, e.g., a fuel emitter 3. Although tin is referred to in the following description, any suitable fuel may be used. The fuel may, for example, be in liquid form, and may, for example, be a metal or alloy. The fuel emitter 3 may comprise a nozzle configured to direct tin, e.g. in the form of droplets, along a trajectory towards a plasma formation region 4. The laser beam 2 is incident upon a droplet at the plasma formation region 4. The deposition of laser energy into the droplet creates a plasma 7 at the plasma formation region 4. Radiation, including EUV radiation, is emitted from the plasma 7 during de-excitation and recombination of electrons with ions of the plasma.

[00038] In order to condition the fuel droplet for receipt of the laser radiation that generates the plasma, the fuel droplet is first conditioned by one or more laser pulses preceding the main pulse. These conditioning pulses are referred to as pre-pulses. The one or more pre-pulses serve to condition the fuel droplet for receipt of a laser pulse that converts the conditioned fuel droplet into plasma. The laser pulse

that converts the fuel droplet into plasma is referred to as the main pulse. The one or more pre-pulses condition the fuel droplet by means of shaping the fuel droplet, e.g., into the shape of a pancake or into a mist. This conditioning improves the absorption of the electromagnetic radiation of the main pulse. Accordingly, the laser system 1 also includes a pre-pulse laser system, in addition to a main pulse laser system. For example, the pre-pulse laser system comprises a YAG laser configured for producing pre-pulses with a wavelength of about 1 micron, and the main pulse laser comprises a CO₂ laser configured for producing main pulses of about 10 microns. Alternatively, the pre-pulse laser system comprises a YAG laser configured for producing pre-pulses with a wavelength of 1 micron, and the main pulse laser comprises a YAG laser for producing main pulses of about 1 micron. As the invention relates to the pre-pulses, it is to be understood that where reference is made to the laser system 1 below within the context of the polarization, the pre-pulse laser system is meant.

[00039] The EUV radiation from the plasma is collected and focused by a collector 5. Collector 5 comprises, for example, a near-normal incidence radiation collector 5 (sometimes referred to more generally as a normal-incidence radiation collector). The collector 5 may have a multilayer mirror structure which is arranged to reflect EUV radiation (e.g., EUV radiation having a desired wavelength such as 13.5 nm). The collector 5 may have an ellipsoidal configuration, having two focal points. A first one of the focal points may be at the plasma formation region 4, and a second one of the focal points may be at an intermediate focus 6, as discussed below.

[00040] The laser system 1 may be spatially separated from the radiation source SO. Where this is the case, the laser beam 2 may be passed from the laser system 1 to the radiation source SO with the aid of a beam delivery system (not shown) comprising, for example, suitable directing mirrors and/or a beam expander, and/or other optics. The laser system 1, the radiation source SO and the beam delivery system may together be considered to be a radiation system. In one embodiment, the laser system 1 includes a YAG laser for generating the pre-pulses and a CO₂ laser for generating the main pulses. Different beam delivery systems may be used to deliver the pre-pulses and the main pulses. It will be appreciated that other laser systems could be used to provide the pre-pulses and main pulses. For example, the same type of laser system could be used to provide the main pulses and pre-pulses (e.g. two CO₂ lasers delivering main pulses and pre-pulses at a wavelength of 10 microns, or the two YAG lasers delivering main pulses and pre-pulses, or the like).

[00041] Radiation that is reflected by the collector 5 forms the EUV radiation beam B. The EUV radiation beam B is focused at intermediate focus 6 to form an image at the intermediate focus 6 of the plasma present at the plasma formation region 4. The image at the intermediate focus 6 acts as a virtual radiation source for the illumination system IL. The radiation source SO is arranged such that the intermediate focus 6 is located at or near to an opening 8 in an enclosing structure 9 of the radiation source SO.

[00042] The radiation source SO further comprises a sensor 18 for sensing a spatial mass distribution of a fuel droplet provided by the fuel emitter 3. The radiation source SO further comprises

an element 38, such as a Pockels cell, that is operative to change a polarization of a pre-pulse provided by the laser system 1. The radiation source SO further comprises a control system 44 operative to cause the element 38 to change the polarization of the pre-pulse based on information derived from the spatial mass distribution sensed by the sensor 18. Further details of the sensor 18, element 38 and control system 44 are provided below.

[00043] Figure 2 is a schematic view of part of the radiation source SO comprising the enclosing structure 9. As noted previously, the radiation source SO comprises a fuel emitter 3. In this embodiment, the fuel emitter 3 is in the form of droplet generator 3a configured to provide a stream of fuel droplets. Individual droplets in the stream have been indicated by individual reference numerals 60, 60' and 60''. The fuel droplets follow a trajectory to the plasma formation region 4. The trajectory of the fuel droplets corresponds to an X-direction depicted in Figure 2. Cartesian coordinates are used in Figures 2 and 3 for convenience, and are not intended to imply that the radiation source SO must have a particular orientation. The spatial mass distribution of a fuel droplet may oscillate, i.e., change its shape due to vibration, while moving along the trajectory. Properties of the fuel droplet such as mass, density, velocity and fuel type affect the oscillation of the fuel droplet. When a fuel droplet arrives at the plasma formation region 4, a main pulse is used to convert the fuel droplet into the plasma 7. The spatial mass distribution of the fuel droplet 60' that is approaching the plasma formation region 4 may be affected by, e.g., pressure waves accompanying the energy release during the conversion of a preceding fuel droplet 60'' into plasma. Upon being hit by such pressure wave, the spatial mass distribution of the fuel droplet 60' starts oscillating owing to, among other things, the effects of inertia and the restoring effect of the droplet's surface tension.

[00044] In this embodiment, the fuel droplet 60' which is approaching the plasma formation region 4 is depicted at a moment at which the fuel droplet 60' has a spatial mass distribution that differs from a spherical mass distribution. The plasma formation process may depend on the spatial mass distribution that the fuel droplet 60' assumes when the conditioned fuel droplet 60' arrives at the plasma formation region 4 and is hit by the main pulse. The distance between subsequent ones of the droplets determines if and, if so, how, the pressure waves affect the spatial mass distribution of the approaching droplet that is next to be converted into plasma. This inter-droplet distance, in turn, is determined by the rate at which droplets arrive at the plasma formation region 4 as well as by the speed of the droplets. In one embodiment with a fuel droplet delivery rate of 50 kHz and a fuel droplet velocity of 70 m/s, a droplet-to-droplet spacing of more than 1.5 mm may in some cases ensure that the shockwave dissipates before it reaches the approaching fuel droplet. If the delivery rate increases (and hence the spacing decreases below 1.5 mm), the shockwave may adversely affect the shape of the approaching fuel droplet. However, depending on the strength of the shockwave and the spacing between the fuel droplets, the shockwave may affect the shape of the approaching fuel droplet. Therefore, controlling the polarization of the pre-pulse may help to ensure that the conditioned fuel droplets have an optimum spatial mass distribution for receipt of the main pulse. In the above embodiment, if the droplet-to-

droplet spacing is less than 1.5 mm, controlling the polarization of the pre-pulse may help to ensure the spatial mass distribution of the conditioned fuel droplet is optimum.

[00045] The radiation source SO comprises a sensing system 16 configured to sense a characteristic of an oscillation of a spatial mass distribution of the fuel droplet 60'. The characteristic may be representative of at least one of: an amplitude, a frequency and a phase of the oscillation of the spatial mass distribution. The sensing system 16 comprises a sensor 18 configured for capturing one or more images of the fuel droplet 60'. The sensing system 16 comprises a processor 20 configured for determining, from the one or more images, information representative of the characteristic.

[00046] The sensing system 16 comprises an illumination system 22 configured to illuminate the fuel droplet 60' with illuminating radiation 24 for obtaining information representative of the characteristic. The illuminating radiation 24 is provided, for example, in the form of a sheet 26 of laser radiation for illuminating the fuel droplet 60'. In the embodiment shown, an imaging system 28 is provided for imaging illuminating radiation 30 scattered and/or reflected by fuel droplet 60' onto the sensor 18. Information about the characteristic can be obtained by analyzing a signal generated by the sensor 18. The processor 20 is configured to analyze the signal generated by the sensor 18. This information may be used to predict the spatial mass distribution assumed by the fuel droplet 60' later on, just before the pre-pulse interacts with this fuel droplet 60' at the plasma formation region 4. Alternatively, or in addition, this information about the oscillation of the droplet 60' may be used to predict what spatial mass distribution a specific one of the droplets upstream of the droplet 60', e.g., the droplet 60, will assume when the specific droplet arrives at the plasma formation region 4 just before being hit by the pre-pulse. The laser sheet 26 may have an appropriate laser sheet size such that the oscillation can be detected while the fuel droplet 60' moves through the laser sheet 26. The parameters of the illuminating radiation 24 may be selected to permit detection of the oscillation. The laser sheet 26 may be in the form of a further laser beam with a beam waist that is larger in one direction compared with the beam waist in another, perpendicular direction. In this embodiment, the larger beam waist is oriented to be substantially parallel with the X direction, whereas the smaller beam waist is oriented to be parallel with the Z direction that is perpendicular to the X direction and to the Y direction, see the diagram of Fig.3.

[00047] In an example of a fuel droplet having a diameter of 30 μm , the laser sheet 26 may have a beam width in the Z-direction in the range of 10 μm to 100 μm , but it will be appreciated that different beam widths may be used. This beam width in the Z-direction may be selected to ensure that the whole fuel droplet is illuminated while the fuel droplet passes through the laser sheet 26. In this embodiment, the laser sheet 26 may have a beam width in the X-direction in the range of 50 μm to 1 mm. It will be appreciated that any appropriate beam width may be selected to enable detection of the oscillation while the fuel droplet passes through the laser sheet 26. In this embodiment, the wavelength of the illuminating radiation 24 may be in the UV, visible or near infrared range.

[00048] In one embodiment, the fuel droplet has a natural vibration mode of around 70 kHz. For an example laser sheet 26 with a beam width in the X-direction of 1 mm and a fuel droplet speed of 70 m/s, the fuel droplet may oscillate once while passing through the laser sheet 26. The sensing system 16 may be appropriately configured to sense the characteristic. For example, the sensor 18 may be configured for detecting a plurality of oscillations of the fuel droplet. In one embodiment, a sensor 18 with a sufficiently high frame rate may be provided to capture individual oscillations over one or more captured images. In an example, the oscillation frequency of the fuel droplet is in the order of 70 kHz (e.g. for a 30 μ m diameter Tin fuel droplet). In another embodiment, the sensor 18 may capture one image with the oscillations being detectable across the image, e.g. as a trace of spatial brightness variations.

[00049] Figure 3 is a schematic view of the radiation source SO when viewed along the X direction depicted by Figure 2. The laser system 1 is configured to provide the pre-pulse. The pre-pulse is delivered into the enclosing structure 9 along a laser beam path 32. The pre-pulse is operative to condition a fuel droplet for receipt of the main pulse. The conditioning of the fuel droplet is not depicted in Figure 3. However, the conditioning is described in further detail in relation to Figure 4. In this embodiment, the pre-pulse is focused onto the fuel droplet using a focusing system 34, typically implemented through one or more mirrors.

[00050] In this embodiment, the laser beam path 32 of the pre-pulse comprises a first polarization element 36, a second polarization element 38 and a third polarization element 40. The first polarization element 36 comprises a half-wave plate configured for conditioning the polarization direction of the pre-pulse for receipt by the second polarization element 38. The second polarization element 38 comprises an adjustable polarization element configured for adjusting the polarization of the pre-pulse. In this embodiment, the adjustable polarization element comprises a Pockels cell 38. As known, a Pockels cell is operative to rotate the polarization direction of linearly polarized radiation over an angle determined by the control voltage applied to the Pockels cell. In this embodiment, the Pockels cell 38 receives from the first polarization element 36 the linearly polarized radiation of the pre-pulse. A Pockels cell can produce fast polarization changes in response to being electronically actuated. The radiation source SO comprises a control system 44 configured to electronically actuate the Pockels cell 38 to change the polarization. It will be appreciated that the polarization may be controlled in any appropriate way. For example, the second polarization element may comprise one or more of: a waveplate, a Pockels cell, a Faraday rotator, and the like.

[00051] The control system 44 is operative to adjust the polarization of the pre-pulse under control of the characteristic sensed by the sensing system 16. In this embodiment, the control system 44 is operative to adjust the second polarization element 38 (in this embodiment the Pockels cell) in response to the sensed characteristic. The control system 44 comprises the processor 20. The one or more images produced by the sensor 18 are analyzed by the processor 20 to determine the characteristic of the oscillation of the spatial mass distribution of the fuel droplet traversing the laser sheet 26. Information

representative of the characteristic may be used by the control system 44 to electronically actuate the Pockels cell 38.

[00052] The third polarization element 40 comprises a quarter wave plate. The quarter-wave plate is configured for converting the linearly polarized radiation received from the second polarization element 38 into elliptically polarized radiation. The angle over which the polarization direction of the linearly polarized radiation has been rotated by second polarization element 38, determines the degree of ellipticity and orientation of the ellipse representative of the polarization of the pre-pulse exiting the third polarization element 40. For example, appropriately aligning the quarter wave plate with respect to a linearly polarized pre-pulse may generate circularly or elliptically polarized pre-pulses. One or more of the polarization elements 36, 38, 40 may be adjusted to control the polarization of the pre-pulse. For example, the half-wave plate and/or the quarter-wave plate mentioned above can be rotated about an axis parallel to the propagation direction of the pre-pulse, e.g., for calibration purposes. The control system 44 may be configured to adjust one or more of the polarization elements 36, 38, 40.

[00053] In an embodiment, the Pockels cell 38 may be used to provide fast polarization changes corresponding to the fuel droplet 60 delivery rate, i.e., provide changes on a droplet-to-droplet basis. Therefore, it may not be necessary to make any adjustments to the first or third polarization elements 36, 40 to change the polarization. However, the first and third polarization elements 36, 40 may provide coarse control over the polarization of the pre-pulse if required.

[00054] It will be appreciated that the polarization of the pre-pulse may be varied in any appropriate manner using any number and configuration of polarization elements. For example, only one or two (or any other number of) polarization elements may be needed to adjust the polarization.

[00055] In an embodiment, the pre-pulse may be controlled to have one of: a linear polarization, a circular polarization and an elliptical polarization.

[00056] In some embodiments, the characteristics of the fuel droplets may not substantially change over a period of time during which a plurality of fuel droplets are conditioned by pre-pulses. If each of the fuel droplets is predicted to have the same spatial mass distribution over the period of time, it may not be necessary to adjust the polarization of the pre-pulse. In which case, changing the polarization of the pre-pulse may not be required until it is determined that the polarization of the pre-pulse is no longer optimum for conditioning the fuel droplets. If each of the fuel droplets will have the same spatial mass distribution over the period of time, the polarization of the pre-pulse may be appropriately adjusted so that the fuel droplets are conditioned with pre-pulses of the same polarization. The polarization of the pre-pulses may then be maintained for the period of time. For example, the polarization of the pre-pulses may remain the same until it is determined that the polarization needs to be adjusted to correct for a change in the predicted spatial mass distribution of the fuel droplets.

[00057] However, in some embodiments, the spatial mass distribution may substantially change for each fuel droplet. If the fuel droplets have different spatial mass distributions when hit by their pre-

pulses, then adjusting the polarization of the pre-pulse for conditioning each fuel droplet individually may provide optimum conditioning for each of the fuel droplets.

[00058] The sensing system 16 may be configured to sense the oscillation of the spatial mass distribution of the fuel droplets in order to determine whether there has been a change in behaviour of the fuel droplets compared with the behaviour of fuel droplets in a previous measurement. The sensing system 16 may sense each fuel droplet, for example, to predict the spatial mass distribution of each fuel droplet assumed when being hit by the pre-pulse. Alternatively, the sensing system 16 may not sense the oscillation of each fuel droplet. Instead, the sensing system 16 may be active periodically or over a predetermined time period, for example, to determine if the behaviour predicted on the basis of measurements on fuel droplets generated in a previous time period is still valid for the behaviour of fuel droplets generated during a later time period to have the same spatial mass distribution.

[00059] The processor 20 may be configured to predict, using the sensed characteristic of the oscillation of the spatial mass distribution of a fuel droplet, the spatial mass distribution of the fuel droplet at the plasma formation region 4. The processor 20 may compare the predicted spatial mass distribution with an ideal or desired spatial mass distribution for the fuel droplet. The processor 20 may be configured to determine the difference between the predicted spatial mass distribution and the ideal or desired spatial mass distribution. If the difference is equal to or above a threshold, the processor 20 may be configured to determine the polarization of the pre-pulse that would result in the difference being below the threshold. Alternatively or additionally, the processor 20 may cause the control system 44 to set at least one of the polarization elements 36, 38, 40 such that the polarization of the pre-pulse may result in the difference being below the threshold. It will be appreciated that the processor 20 may be configured in any appropriate way to determine the predicted spatial mass distribution and to determine a polarization to apply to the pre-pulse.

[00060] The polarization of the pre-pulse may be used to affect the spatial mass distribution of the fuel droplet at the plasma formation region 4. By controlling the polarization, it may be possible to condition the fuel droplet such that the interaction between the main pulse and the conditioned fuel droplet may be optimized or improved. Therefore, an optimum or improved LPP may be produced using the conditioned fuel droplet. For example, the optimum or improved LPP may produce radiation with a higher efficiency compared with if the fuel droplet has not been ideally or desirably conditioned.

[00061] Figure 4 schematically illustrates the effect of polarization control on the spatial mass distribution of the fuel droplet 60". The first column 46 of Figure 4 depicts examples of the fuel droplet 60" spatial mass distributions. The second column 48 of Figure 4 depicts the polarization of the pre-pulse used to condition the fuel droplet 60". The conditioning by the pre-pulse causes the fuel droplet 60" to expand. The third column 50 of Figure 4 depicts the expanded spatial mass distribution of fuel droplet 60" after being conditioned (ready for being converted into plasma by the main pulse).

[00062] In row A and column 46 of Figure 4, the fuel droplet 60" has a symmetric spatial mass distribution. This is the spatial mass distribution of the fuel droplet 60" when a pre-pulse is incident

upon the fuel droplet 60'' as depicted by Figure 2. Column 46 therefore refers to the predicted spatial mass distribution of the fuel droplet 60'' when the pre-pulse interacts with the fuel droplet 60''. In this embodiment, a geometric projection of the fuel droplet 60'' on a plane perpendicular to a propagation axis of the pre-pulse has the same dimension in a first direction 52 and a second direction 54. The propagation axis corresponds to the laser beam path 32 of Figure 3. Thus, the view of the fuel droplet 60'' in Figure 4 corresponds to the X-Y plane in Figures 2 to 3. The symmetry of the fuel droplet 60'' has a corresponding effect on the sensed characteristic by the sensing system 16.

[00063] As depicted by column 48, a circularly polarized pre-pulse is used to condition the fuel droplet 60''. As depicted by column 50, the spatial mass distribution of the fuel droplet 60'' remains symmetrical after being expanded. It will be appreciated that the position of the fuel droplet 60'' before being conditioned (see column 46) is slightly different to the position of the fuel droplet 60'' after being conditioned (see column 50) for receipt of the main laser pulse. The respective positioning of the fuel droplet 60'' before and after conditioning depends on its velocity. However, Figure 2 does not depict this difference in positioning of the fuel droplet 60'' before and after conditioning.

[00064] In this embodiment, the pre-pulse and main pulse interact with the fuel droplet 60'' at approximately the same position. As the fuel droplet 60'' moves, the pre-pulse and main pulse interact with the fuel droplet 60'' at different times. Thus, the interaction at different times means that the pre-pulse and main pulse interact with the fuel droplet 60'' at slightly different positions with respect to the center of the fuel droplet 60''. In this embodiment, the pre-pulse and main pulse each have approximately the same focal point. In other embodiments, the pre-pulse and main pulse may be delivered to the fuel droplet 60'' at different positions (i.e. the laser pre-pulse and laser main pulse may have spaced apart focal points).

[00065] The circularly polarized pre-pulse is defined by having a first electric field vector along a first direction 52 and a second electric field vector along a second direction 54. The first and second electric field vectors have an equal magnitude for circular polarization. The first and second directions 52, 54 are perpendicular to each other. The interaction between the circularly polarized pre-pulse and the fuel droplet 60'' may result in the fuel droplet expanding at an equal rate in both the first and second directions 52, 54. For an initially spherical fuel droplet 60'', a circularly polarized pre-pulse may cause the fuel droplet to expand to have a spherical spatial mass distribution. A circularly polarized pre-pulse may be provided if the sensing system 16 predicts that the fuel droplet 60'' will have a spherical spatial mass distribution when the pre-pulse is incident upon with the fuel droplet. An optimum or improved LPP may be produced using the symmetric conditioned fuel droplet 60''.

[00066] In row B of Figure 4, the fuel droplet 60'' has an ellipsoidal spatial mass distribution when the pre-pulse is incident upon the fuel droplet 60''. In this embodiment, a geometric projection of the fuel droplet 60'' on a plane perpendicular to a propagation axis of the pre-pulse has a smaller dimension in a first direction 52 and a larger dimension in a second direction 54. The propagation axis corresponds

to the laser beam path 32 of Figure 3. Thus, the view of the fuel droplet 60'' in Figure 4 corresponds to the X-Y plane in Figures 2 to 3.

[00067] As illustrated in row B of Fig.4, the mass of the fuel droplet 60'' is spatially distributed over a larger distance along the second direction 54 than the first direction 54. The ellipsoidal shape of the fuel droplet 60'' has a corresponding effect on the sensed characteristic by the sensing system 16. In this embodiment, a circularly polarized pre-pulse is used to condition the fuel droplet 60''. However, the interaction between the pre-pulse and the fuel droplet 60'' may result in the fuel droplet 60'' expanding at different rates in the first and second directions 52, 54. The mass along the second direction 54 has a greater resistance to movement than the mass along the first direction 52 due to inertia. Upon being conditioned, the fuel droplet 60'' expands at a faster rate along the first direction 52 compared with the expansion rate along the second direction 54. As a result, the conditioned fuel droplet 60'' has a larger dimension in the first direction 52 and a smaller dimension in the second direction 54. The conditioned fuel droplet 60'' may be regarded as being not ideal or not desirable due to having a spatial mass distribution deviating from a spheroidal distribution. The plasma formation process may be adversely affected if the spatial mass distribution of the conditioned fuel droplet 60'' is not ideal or not desirable.

[00068] In one embodiment, the fuel droplet 60'' is conditioned by a picosecond or low nanosecond (e.g. 5 ns or shorter) pre-pulse of 1 micron. It will be appreciated that other pulse durations may be used (e.g. femtosecond, and the like or other wavelengths). The resulting expansion of the fuel droplet 60'' is understood to be caused by a shockwave that produces an expanding cavity in the center of the fuel droplet 60''. In the case of a spherical fuel droplet 60'', the expansion of the cavity may be isotropic in the plane orthogonal to the laser beam path 32. In contrast, the cavitation induced in a non-spherical fuel droplet 60'' may result in a non-isotropic expansion in the plane orthogonal to the laser beam path 32. The cavity expansion in the non-spherical fuel droplet 60'' is thought to cause the fuel droplet 60'' to expand at a faster rate in a direction in which the fuel droplet 60'' has a lower inertial mass. In the embodiment of row B, the fuel droplet 60'' expands with a greater velocity along the first direction 52 than the second direction 54 due to the difference in the inertial mass along the first and second directions 52, 54.

[00069] In row C of Figure 4, the fuel droplet 60'' has a non-spherical spatial mass distribution when the pre-pulse is incident upon the fuel droplet 60''. In this embodiment, the sensing system 16 senses a characteristic of an oscillation of the spatial mass distribution of the fuel droplet 60' (depicted by Figure 2). The processor 20 then predicts the spatial mass distribution of the fuel droplet 60'' at the time when the pre-pulse is incident upon the fuel droplet 60''. In response to the sensed characteristic, the control system 44 adjusts the polarization of the pre-pulse. The polarization of the pre-pulse is determined based on the predicted spatial mass distribution of the fuel droplet 60'' when the pre-pulse is incident upon the fuel droplet 60''.

[00070] Column 48, row C of Figure 4 depicts the polarization of the pre-pulse as comprising a combination of circular polarization and linear polarization. The combination may be regarded as being an elliptical polarization. The pre-pulse comprises a first electric field vector of a first magnitude that is parallel to the first direction 52. The pre-pulse comprises a second electric field vector of a second magnitude, smaller than the first magnitude, and parallel to the second direction 54. The control system 44 is operative to adjust a ratio between the first magnitude and the second magnitude in response to the sensed characteristic. The ratio may be adjusted by varying the polarization of the pre-pulse by the Pockels cell 38 depicted by Figure 3. In this embodiment, the ratio between the first and second magnitude is selected such that the pre-pulse has an elliptical polarization with a major axis that is oriented parallel to the first direction 52.

[00071] It is believed that the electric field vector of the pre-pulse constrains the expansion rate of the fuel droplet 60'' in the direction parallel to the electric field vector with the largest magnitude. By aligning the electric field vector with the largest magnitude to be parallel with the direction corresponding to the smaller dimension of the fuel droplet 60'', the electric field acts to constrain the expansion rate of the fuel droplet 60'' in that direction. Constraining the expansion rate using polarization control may offset the expansion rate that depends on the inertial mass for a certain direction. In the embodiment depicted by row C, the elliptically polarized pre-pulse has a first electric field vector with a larger magnitude than that of the second electric field vector. The first electric field vector is aligned to be parallel with the first direction 52.

[00072] The ratio between the first and second electric field vectors may affect the rate of expansion of the fuel droplet in the first and second directions 52, 54. The larger magnitude of the first electric field vector may constrain the rate of expansion in the first direction 52. In contrast, the relatively smaller magnitude of the second electric field vector may not constrain the rate of expansion to the same extent in the second direction 54. The predicted spatial mass distribution of the fuel droplet 60'' may be used to determine the ratio between the magnitudes of the first and second electric field vectors. For a spherical spatial mass distribution, the magnitudes of the first and second electric field vectors may be selected to be equal. Accordingly, the pre-pulse may have a circular polarization, as depicted by row A. For a non-spherical spatial mass distribution, the magnitudes of the first and second electric field vectors may be selected according to the magnitudes of the different dimensions of the fuel droplet 60''. The pre-pulse may have an elliptical polarization with its major axis selected to be parallel to the first direction 52, as depicted by row C.

[00073] To further illustrate the effect of polarization of the pre-pulse on the spatial mass distribution of the conditioned fuel droplet 60'', the interaction between a linearly polarized pre-pulse and a spherical fuel droplet 60'' (as depicted by column 46, row A) is described. In the embodiment depicted by row D, the pre-pulse has a linear polarization with a first electric field vector aligned to be parallel with the first direction 52. In other words, the second electric field vector aligned with the second direction 54 effectively has zero magnitude or a much smaller magnitude than the first electric

field vector. The fuel droplet 60'' has a spherical spatial mass distribution when the pre-pulse is incident upon it. The first electric field vector of the pre-pulse constrains the expansion in the first direction 52. However, the fuel droplet 60'' expands at a greater rate in the second direction 54. Accordingly, the fuel droplet 60'' expands to have an ellipsoidal spatial mass distribution when conditioned.

5 [00074] Therefore, the control system 44 may determine the appropriate polarization for the pre-pulse based on the predicted spatial mass distribution of the fuel droplet 60'' when the pre-pulse is incident upon the fuel droplet and conditions the fuel droplet 60''.

10 [00075] In one embodiment, the sensing system 16 may be used to determine the characteristic to calibrate the control system 44. The characteristic refers to the amplitude, frequency and/or phase of the oscillation of the fuel droplet 60. The frequency and phase of the oscillation is dependent on the configuration of the droplet generator 3a and physical properties of the fuel droplets 60. Other factors may also affect the frequency and phase of the oscillation. However, the amplitude of the oscillation may be particularly affected by the energy released by the plasma 7. The characteristic (e.g. the amplitude, frequency and/or phase) is determined by the spatial mass distribution of the fuel droplet 60' sensed by the sensing system 16 (as depicted by Figure 2). The characteristic is then used to predict the spatial mass distribution of the fuel droplet 60'' when the pre-pulse interacts with the fuel droplet 60''. Each of the fuel droplets may be assumed to have the same characteristic such that each fuel droplet is assumed to have the same spatial mass distribution upon interacting with the pre-pulse. The control system 44 may then adjust the polarization such that each pre-pulse has the same polarization for conditioning the fuel droplets. Therefore, in one embodiment, the control system 44 may not need to continually adjust the polarization of the pre-pulse for each fuel droplet individually.

20 [00076] In another embodiment, the sensing system 16 may provide information regarding the characteristic (e.g. the amplitude, frequency and/or phase of the oscillation as explained above) for each fuel droplet. The information may be processed by the processor 20 to predict the spatial mass distribution for each fuel droplet when the pre-pulse is incident upon that fuel droplet. The control system 44 may then adjust the Pockels cell 38 to control the polarization of the pre-pulse for conditioning each fuel droplet. The control system 44 may therefore be able to provide an ideal or optimally polarized pre-pulse to condition each fuel droplet such that the interaction between the main pulse and the conditioned fuel droplet may be optimized or improved. If the energy released by the plasma formation process varies such that the characteristic changes for each fuel droplet individually, providing a different polarization for each pre-pulse may appropriately control the fuel droplet conditioning process.

30 [00077] It will be appreciated that the sensing system 16 may take any appropriate form. In the depicted embodiments, the sensing system 16 comprises an illumination system 24 for producing a laser sheet 26. It will be appreciated that any appropriate laser sheet dimensions may be used. In another embodiment, an alternative sensing system 16 may be provided. For example, the sensing system 16

may comprise a shadowgraphy system configured for sensing the characteristic using a shadow projected by an illuminated fuel droplet.

[00078] It will be appreciated that the laser system 1 may be configured in any appropriate way. The laser system 1 may be configured to provide first and second laser radiation having any appropriate wavelength, number of pulses, pulse duration, pulse energy, and the like. In one embodiment, the pre-pulse has a wavelength of 1 micron, a pulse duration of 15 ps, a pulse energy of 4 mJ, a beam width of greater than 30 μm (e.g. for 30 μm diameter fuel droplets 60). In another embodiment, the wavelength of the pre-pulse may be around 10 μm .

[00079] Although specific reference may be made in this text to the use of lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications. Possible other applications include the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, flat-panel displays, liquid-crystal displays (LCDs), thin-film magnetic heads, etc.

[00080] Where the context allows, embodiments of the invention may be implemented in hardware, firmware, software, or any combination thereof. Embodiments of the invention may also be implemented as instructions stored on a machine-readable medium, which may be read and executed by one or more processors. A machine-readable medium may include any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computing device). For example, a machine-readable medium may include read only memory (ROM); random access memory (RAM); magnetic storage media; optical storage media; flash memory devices; electrical, optical, acoustical or other forms of propagated signals (e.g. carrier waves, infrared signals, digital signals, etc.), and others. Further, firmware, software, routines, instructions may be described herein as performing certain actions. However, it should be appreciated that such descriptions are merely for convenience and that such actions in fact result from computing devices, processors, controllers, or other devices executing the firmware, software, routines, instructions, etc. and in doing that may cause actuators or other devices to interact with the physical world.

[00081] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. The descriptions above are intended to be illustrative, not limiting. Thus it will be apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the claims set out below.

CLAIMS

1. A radiation source of a laser-produced plasma type, comprising:
a droplet generator configured to provide a fuel droplet;
5 a laser system configured to provide first laser radiation and second laser radiation, wherein the first laser radiation is operative to condition the fuel droplet for receipt of the second laser radiation, and wherein the second laser radiation is operative to convert the conditioned fuel droplet into plasma;
a sensing system configured to sense a characteristic of an oscillation of a spatial mass distribution of the fuel droplet; and
10 a control system operative to adjust a polarization of the first laser radiation under control of the sensed characteristic.
2. The radiation source of claim 1, wherein:
the sensing system is configured to sense a geometric projection of the fuel droplet on a plane
15 perpendicular to a propagation axis of the first laser radiation has a smaller dimension in a first direction and a larger dimension in a second direction, different from the first direction; and
in response to the sensed characteristic, the control system adjusts the polarization of the first laser radiation so that the first laser radiation has a first electric field vector of a first magnitude and being parallel to the first direction, and has a second electric field vector of a second magnitude smaller
20 than the first magnitude, the second electric field vector being parallel to the second direction.
3. The radiation source of claim 2, wherein the control system is operative to adjust a ratio between the first magnitude and the second magnitude in response to the sensed characteristic.
- 25 4. The radiation source of claim 2 or 3, wherein the control system is operative to adjust the polarization such that the first laser radiation has elliptical polarization with a major axis that is oriented parallel to the first direction.
5. The radiation source of any one of claims 1 to 4, wherein the sensing system comprises:
30 a sensor configured for capturing one or more images of the fuel droplet; and
a processor configured for determining, from the one or more images, information representative of the characteristic.
6. The radiation source of claim 5, wherein the processor is configured to predict, from the
35 information representative of the characteristic, the spatial mass distribution of the fuel droplet when the first laser radiation interacts with the fuel droplet.

7. The apparatus of any one of claims 1 to 6, wherein the sensing system further comprises an illumination system configured for illuminating the fuel droplet with illuminating radiation for obtaining information representative of the characteristic.

8. The radiation source of any one of claims 1 to 7, wherein the characteristic is representative of at least one of: an amplitude, a frequency and a phase of the oscillation of the spatial mass distribution.

9. The radiation source of any one of claims 1 to 8, further comprising at least one adjustable polarization element for adjusting the polarization of the first laser radiation.

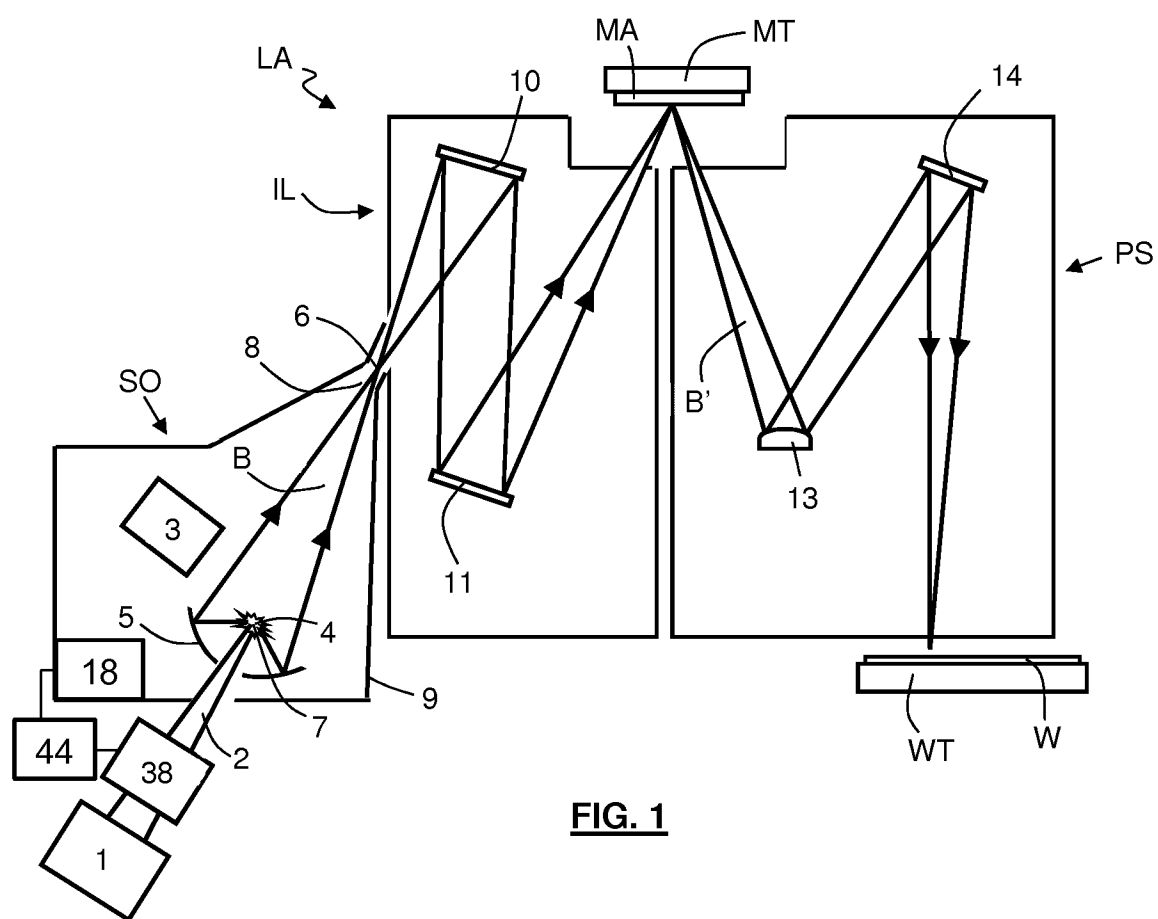
10. The radiation source of claim 9, wherein the control system is operative to adjust the at least one adjustable polarization element in response to the sensed characteristic.

11. A lithographic system comprising:
a radiation source of any one of claims 1 to 10; and
a lithographic apparatus configured to use radiation provided by the radiation source for imaging a pattern onto a substrate.

12. A method, comprising:
providing a fuel droplet;
using a laser system to provide first laser radiation and second laser radiation;
sensing, with a sensing system, a characteristic of an oscillation of a spatial mass distribution of the fuel droplet; and
adjusting, with a control system, a polarization of the first laser radiation under control of the sensed characteristic;
conditioning the fuel droplet, with the first laser radiation, for receipt of the second laser radiation; and
converting, with the second laser radiation, the conditioned fuel droplet into plasma.

13. The method of claim 12, comprising:
sensing that a geometric projection of the fuel droplet on a plane perpendicular to a propagation axis of the first laser radiation has a smaller dimension in a first direction and a larger dimension in a second direction, different from the first direction; and
in response to the sensed characteristic, adjusting the polarization of the first laser radiation so that the first laser radiation has a first electric field vector of a first magnitude and being parallel to the first direction, and has a second electric field vector of a second magnitude smaller than the first magnitude, the second electric field vector being parallel to the second direction.

14. The method of claim 13, comprising adjusting a ratio between the first magnitude and the second magnitude in response to the sensed characteristic.
- 5 15. The method of claim 13 or 14, comprising adjusting the polarization such that the first laser radiation has elliptical polarization with a major axis that is oriented parallel to the first direction.
- 10 16. The method of any one of claims 12 to 15, comprising:
capturing one or more images of the fuel droplet; and
determining, from the one or more images, information representative of the characteristic.
- 15 17. The method of claim 16, comprising predicting, from the information representative of the characteristic, the spatial mass distribution of the fuel droplet when the first laser radiation interacts with the fuel droplet.
18. The method of any one of claims 12 to 17, comprising illuminating the fuel droplet with illuminating radiation for obtaining information representative of the characteristic.
- 20 19. The method of any one of claims 12 to 18, comprising adjusting, with at least one adjustable polarization element, the polarization of the first laser radiation.
20. The method of claim 19, comprising adjusting the at least one adjustable polarization element in response to the sensed characteristic.
- 25 21. The method of any one of claims 12 to 20, comprising
providing the radiation source of any one of claims 1 to 10; and
using radiation provided by the radiation source to image a pattern onto a substrate.



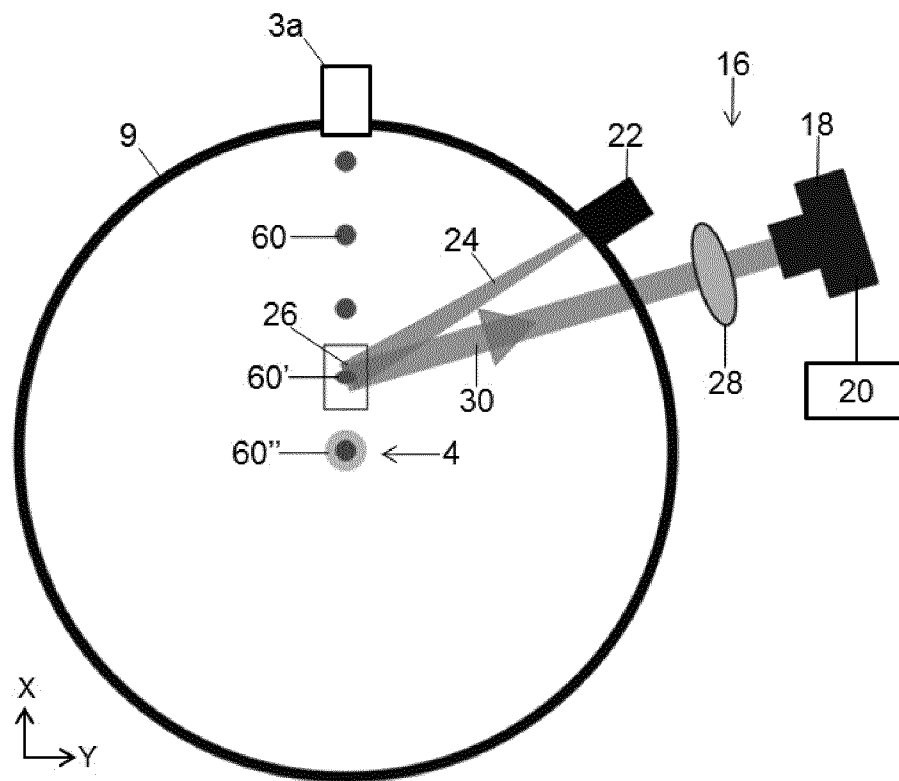


FIG. 2

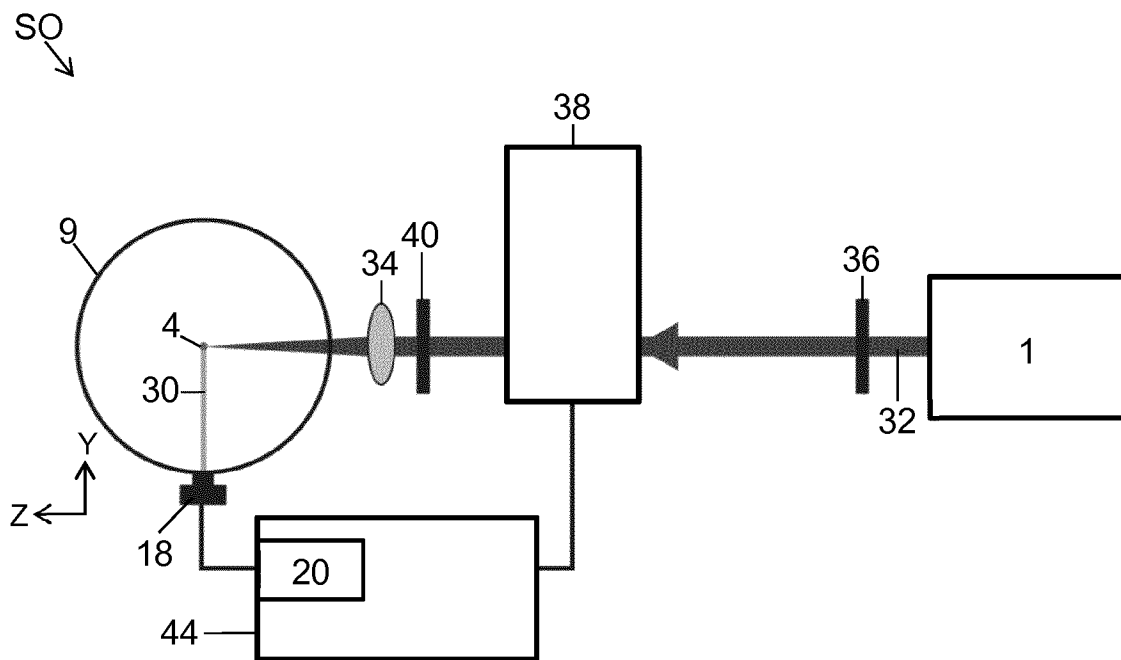


FIG. 3

	46	48	50
A			
B			
C			
D			

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/051950

A. CLASSIFICATION OF SUBJECT MATTER
INV. 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)
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.
A	US 2017/280545 A1 (TOMITA KENTARO [JP] ET AL) 28 September 2017 (2017-09-28) paragraphs [0100], [0145] - [0147]; claim 5; figures -----	1-21
A	WO 2016/146400 A1 (ASML NETHERLANDS BV [NL]) 22 September 2016 (2016-09-22) abstract; claims; figures -----	1,12
A	WO 2017/216847 A1 (GIGAPHOTON INC [JP]) 21 December 2017 (2017-12-21) claims 8,13; figure 1 -----	1,12



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"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

4 April 2019

Date of mailing of the international search report

15/04/2019

Name and mailing address of the ISA/

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Authorized officer

Smith, Christopher

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2019/051950

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