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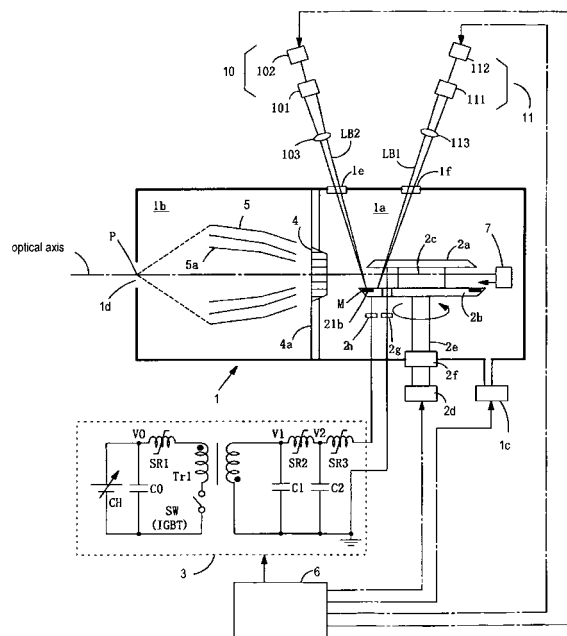
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(54) **Extreme ultraviolet light source device**

(57) The invention relates to an extreme ultraviolet light source device, comprising a pair of discharge electrodes (2a, 2b, 52a, 52b) arranged spaced apart from each other; a pulsed power supply means (3, 53) supplying pulsed power to said discharge electrodes (2a, 2b); a raw material supply means (7) adapted for supplying raw material (M) for generating extreme ultraviolet radiation onto said discharge electrodes (2a, 2b, 52a, 52b); an energy beam emitting means (10, 60) adapted for radiating an energy beam (LB2) to the raw material (M) on said discharge electrodes (2a, 2b, 52a, 52b) to gasify said raw material (M); a means (11, 61, 85, 95, 105) for forming a depression (MA) in the raw material (M) supplied onto said discharge electrodes (2a, 2b, 52a, 52b); and a controller (6, 56). Said controller (6, 56) is adapted to control the depression forming means (11, 61, 85, 95, 105) such that it forms a depression (MA) in the raw material (M) supplied onto the discharge electrodes (2a, 2b, 52a, 52b) before the voltage between the electrodes (2a, 2b, 52a, 52b) increases by means of the supply of pulsed power to the discharge electrodes (2a, 2b, 52a, 52b) by said pulsed power supply means (3, 53), and before the energy beam (LB2) is radiated to the raw material (M) on the electrodes (2a, 2b, 52a, 52b) by said energy beam emitting means (10, 60). The invention also relates to a process for generating EUV radiation.

Fig. 1



Description

[0001] The present invention relates to an extreme ultraviolet light source device (in the following simply referred to as 'EUV light source device') emitting extreme ultraviolet radiation (in the following simply referred to as 'EUV radiation'), and in particular relates to an extreme ultraviolet light source device, which is expected to serve as a light source for the exposure of semiconductor integrated circuits of the next generation.

[0002] With the progressing downsizing and high integration of semiconductor integrated circuits, an improvement of the resolution is desired from lithography tools used for their manufacture. To improve the resolution, it is usual to use light sources for exposure, which emit radiation with a short wavelength. For these light sources for exposure, which emit radiation with a short wavelength, excimer laser devices are used, but with regard to light sources for exposure of the next generation substituting these laser devices, particularly the development of extreme ultraviolet light source devices, which emit extreme ultraviolet radiation with a wavelength of 13.5 nm, is advanced.

[0003] One method to generate extreme ultraviolet radiation is to generate a high temperature plasma by heating and exciting a discharge gas containing an extreme ultraviolet radiation species and to extract the extreme ultraviolet radiation emitted from this plasma.

[0004] For actual developments in this field see, for example, "Actual situation and future prospects of the research regarding EUV (extreme ultraviolet) light sources for lithography", J. Plasma Fusion Res., March 2003, Vol. 79, No. 3, P 219 - 260.

[0005] Extreme ultraviolet light source devices employing such a method are divided broadly according to the method of the generation of the high temperature plasma into an LPP (Laser Produced Plasma) type and a DPP (Discharge Produced Plasma) type.

[0006] LPP type extreme ultraviolet light source devices emit laser light towards a target made of a raw material containing extreme ultraviolet radiation species, generate a high temperature plasma by means of laser ablation, and use the extreme ultraviolet radiation emitted therefrom.

[0007] DPP type extreme ultraviolet light source devices generate a high temperature plasma by means of a discharge by applying a voltage between electrodes supplied with a gas containing an extreme ultraviolet radiation species and use the extreme ultraviolet radiation emitted therefrom. Compared with LPP type extreme ultraviolet light source devices, these DPP type extreme ultraviolet light source devices can downsize the light source device and have the advantage of a low energy consumption of the light source system, and therefore their practical implementation is desired.

[0008] Approximately decavalent Xe (xenon) ions are known as raw material for the generation of the said high temperature plasma, but with regard to materials for the

generation of even stronger extreme ultraviolet radiation, attention is turned to Li (lithium) ions and Sn (tin) ions.

[0009] The extreme ultraviolet radiation conversion efficiency, which is given by the ratio of the electric input necessary to generate a high temperature plasma to the emission intensity of extreme ultraviolet radiation of 13.5 nm, of Sn, for example, is several times higher than that of Xe, because of which it is expected to be a radiation species for obtaining extreme ultraviolet radiation with a large output. As shown in JP-A-2004-279246 and corresponding US 2004/0183038 A1, for example, the development of extreme ultraviolet light source devices using e.g. SnH₄ (stannane) gas as the extreme ultraviolet radiation species is promoted.

[0010] Regarding the above mentioned DPP type, in recent years a method has been disclosed in JP-A-2004-279246 and corresponding US 2004/0183038 A1, wherein solid or liquid Sn or Li having been supplied to electrode surfaces generating a discharge is gasified by means of irradiation with an energy beam such as a laser beam and then a high temperature plasma is generated by means of a discharge.

[0011] FIG. 13 is an illustration to schematically explain the EUV light source device shown in JP-A-2004-279246 and corresponding US 2004/0183038 A1. The EUV light source device is provided with a chamber 1, which is provided with a discharge part 1a containing a pair of disc-shaped discharge electrodes 2a, 2b, an EUV collecting part 1b containing a foil trap 4 and a collecting mirror reflector 5, and a gas exhaust part 1c.

[0012] The pair of disc-shaped discharge electrodes 2a, 2b is arranged in the discharge part 1a.

[0013] The pair of disc-shaped discharge electrodes 2a, 2b is arranged vertically in the plane of the drawing and sandwiches an insulating element 2c.

[0014] The rotating shaft 2e of a motor 2d is attached to the discharge electrode 2b, which is located below in the plane of the drawing. The discharge electrodes 2a, 2b are connected to a pulsed power supply part 3 via wipers 2g, 2h.

[0015] A groove part 21 b is provided at the periphery of the discharge electrode 2b, and in this groove part, a solid raw material M (Li or Sn) for the generation of a high temperature plasma is arranged. The raw material M is supplied to said groove part 21 b from a raw material supply means 7.

[0016] In the above mentioned EUV light source device an energy beam such as a laser beam is radiated via an entrance window 1e from an energy beam emitter 10 provided with an energy beam source 11 and an energy beam source controller 12 towards the raw material for the high temperature plasma located in the groove part 21 b of the discharge electrode 2b, and the solid raw material is gasified between the discharge electrodes 2a and 2b.

[0017] In this state, pulsed power is supplied from the pulsed power supply part 3 between the discharge electrodes 2a and 2b, a discharge is generated between the

edge portion of the discharge electrode 2a and the edge portion of the discharge electrode 2b, and EUV radiation is emitted.

[0018] The emitted EUV radiation is radiated via the foil trap 4 into the EUV collecting part 1b, is collected at a focal point P by means of the collecting mirror reflector 5, and is emitted from an EUV radiation output part 1d.

[0019] The above mentioned EUV light source device has the practical problem that it is not possible to obtain a sufficient output of extreme ultraviolet radiation to be able to form a pattern with a desired line width on a semiconductor substrate.

[0020] The reason for the impossibility to obtain a sufficient output of extreme ultraviolet radiation is not specified, but for example the following is assumed.

[0021] In the known EUV light source devices, a free expansion of the raw material gasified by means of the irradiation with the energy beam occurs. When the raw material expands freely, the density of the gas generated by the gasification of the raw material decreases, and there is a wide spatial dispersion. Therefore, the plasma formed between the pair of electrodes has the tendency to become large.

[0022] When the spatial dispersion of the plasma formed between the electrodes becomes large, the density of the current flowing in the plasma becomes low and the plasma is inhibited from reaching a high temperature condition, the ionisation is inhibited, and also the ion density of the plasma decreases. Further, because of the spatial dispersion becoming large, the self-absorption by the plasma increases.

[0023] The forming of a plasma with a large spatial dispersion by the free expansion of the gasified raw material becomes a main factor for the decrease of the output of the extreme ultraviolet radiation emitted from the plasma.

[0024] As stated above, the known EUV light source devices have the problem that no sufficient extreme ultraviolet radiation output can be obtained.

[0025] The present invention was made in view of the above situation, and the object of the present invention is to provide an EUV light source device, which can, in practice, ensure a sufficient extreme ultraviolet radiation output.

[0026] The object is solved by the extreme ultraviolet light source device as claimed in claim 1 and the process for generating EUV radiation according to claim 6. Preferred embodiments and process variants are described in the respective dependent claims.

[0027] In an extreme ultraviolet light source device, in which an energy beam is radiated to a raw material on electrodes and this raw material is gasified, a high temperature plasma is formed by means of a discharge by a high voltage applied between the electrodes, and extreme ultraviolet radiation emitted therefrom is extracted, the present invention forms a depression in the energy beam irradiation surface of the raw material on the electrodes before the raw material is irradiated with the en-

ergy beam and gasified.

[0028] By means of radiating the energy beam towards said depression, the tendency increases that at the time of the gasification of the raw material the free expansion of the raw material is restricted by the inner wall surface of the depression. Therefore, the density of the gas formed by the gasification of the raw material becomes high and a distribution in a tight space occurs, and therefore, the spatial dispersion of the plasma formed between the pair of discharge electrodes can be rendered smaller than with the known EUV light source devices.

[0029] By means of decreasing the spatial dispersion of the plasma, the density of the electric current running in the plasma can be increased, the plasma can be easily brought to a high temperature condition, and the ion density of the plasma becomes high, and by means of the suppression of the dispersion of the plasma, the self-absorption by the plasma decreases. Therefore it is possible to render the output of the EUV radiation high as compared to the known EUV light source devices.

[0030] Said depression can be formed before the radiation of the energy beam for the gasification of said raw material, e.g. by radiating an energy beam independent of said energy beam to the raw material on said electrodes or by contacting a rod-shaped member with the raw material, for example.

[0031] On the basis of the above, the above mentioned problems are solved by the following.

(1) An extreme ultraviolet light source device, comprising: a pair of discharge electrodes arranged spaced apart from each other; a pulsed power supply means supplying pulsed power to said discharge electrodes; a raw material supply means supplying raw material for emitting extreme ultraviolet radiation onto said discharge electrodes; an energy beam emitting means radiating an energy beam to the raw material on said discharge electrodes to gasify said raw material; a means for forming a depression in the raw material supplied onto said discharge electrodes; and a controller; whereby the controller is adapted to control the depression forming means such that it forms a depression in the raw material supplied onto the discharge electrodes before the voltage between the electrodes increases by means of the supply of pulsed power to the discharge electrodes by said pulsed power supply means, and before the energy beam is radiated to the raw material on the electrodes by said energy beam emitting means.

(2) In the above point (1), the energy beam emitting means gasifying said raw material is also used as an energy beam emitting means for forming said depression, whereby said means radiates an energy beam and forms said depression.

(3) In the above points (1) and (2), the raw material

supply means is provided with containers filled with a melt of said raw material, and each said discharge electrode passes through the raw material melt contained in said containers while being rotated, by means of which the raw material is supplied to the location, where the high temperature plasma is formed.

[0032] By means of the present invention, the following results can be obtained.

(1) As a depression is formed in the raw material on the electrodes before the voltage between the electrodes increases and before the energy beam is radiated to the raw material on the electrodes by said energy beam emitting means, and an energy beam is radiated towards said depression, the spatial dispersion of the plasma generated between the pair of discharge electrodes can be rendered smaller than in the known EUV light source devices. Therefore it is expected that the output of the EUV radiation can be rendered higher as compared to the known EUV light source devices.

(2) As a depression is formed in the raw material on the electrodes and an energy beam is radiated towards said depression and the raw material is gasified, the dispersion of the gasified raw material can be rendered smaller as compared to the case, where the raw material is arranged outside of the electrodes, an energy beam is radiated to said raw material and the gasified raw material is made to arrive at the electrodes. Therefore, the output of the EUV radiation can be rendered higher as compared to an arrangement of the raw material outside of the electrodes.

(3) By using the energy beam emitting means gasifying the raw material also as the energy beam emitting means forming the depression, the construction of the device can be simplified.

[0033] The invention is further described with reference to the enclosed schematic drawings. In the drawings, like reference numbers denote like parts.

FIG. 1 is an illustration schematically showing the configuration of the EUV light source device of a first embodiment of the present invention.

FIG. 2 (a)-(c) are partial explanatory views of the extreme ultraviolet light source device of FIG. 1.

FIG. 3 (a)-(f) is a time chart showing the emission timing of the energy beams, the supply timing of the pulsed power and the

generation of EUV radiation.

FIG. 4

is a view of an exemplary configuration of an EUV light source device being provided with one energy beam emitter.

FIG. 5

is a view (plan view) schematically showing the configuration of the EUV light source device of a second embodiment of the present invention.

FIG. 6

is a view (front view) schematically showing the configuration of the EUV light source device of the second embodiment of the present invention.

FIG. 7

is a partial explanatory view of the EUV light source device of FIG. 5 and FIG. 6.

FIG. 8

is a view showing another example of a depression forming means in the EUV light source device of FIG. 5 and FIG. 6.

FIG. 9

is a view showing another example of a depression forming means in the EUV light source device of FIG. 5 and FIG. 6.

FIG. 10 (a)-(b)

are views showing yet another example of a depression forming means in the EUV light source device of FIG. 5 and FIG. 6.

FIG. 11 (a)-(b)

are explanatory views showing the difference in the state of the generation of the initial discharge plasma for the case in which no depression is formed and the case in which a depression is formed.

FIG. 12 (a)-(b)

are views showing illustrations of the visible light of the laser ablation plasma in case of the absence of a depression and in case of the presence of a depression.

FIG. 13

is a schematic simplified illustration explaining an EUV light source device.

(1) First embodiment

[0034] FIG. 1 is an illustration schematically showing the configuration of the EUV light source device of a first embodiment of the present invention.

[0035] The EUV light source device is provided with a

chamber 1 divided into a discharge part 1a containing discharge electrodes and an EUV collecting part 1b containing a foil trap 4 and a collecting mirror reflector 5, and having an EUV output part 1d to emit EUV radiation towards an exposure device.

[0036] In the chamber 1, a gas exhaust unit 1c is formed to evacuate the discharge part 1a and the EUV collecting part 1b and to provide a vacuum condition in the interior of the chamber 1.

[0037] A pair of disc-shaped discharge electrodes 2a, 2b is arranged oppositely to each other via an insulating element 2c, and the respective centres are arranged coaxially. The perpendicularly lower discharge electrode 2b is attached to a rotating shaft 2e of a motor 2d. The rotating shaft 2e is arranged such that the center of the discharge electrode 2a and the center of the discharge electrode 2b are positioned coaxially with the rotating shaft 2e. The rotating shaft 2e is inserted into the chamber 1 via a mechanical seal 2f. The mechanical seal 2f allows the rotation of the rotating shaft 2e while the reduced-pressure atmosphere within the chamber 1 is maintained.

[0038] Below the discharge electrode 2b, wipers 2g and 2h constructed from carbon brushes, for example, are arranged. The wiper 2g is connected electrically to the discharge electrode 2a via a through hole provided in the discharge electrode 2b. The wiper 2h is connected electrically to the discharge electrode 2b. A pulsed power supply part 3 supplies pulsed power to each discharge electrode 2a, 2b via the wipers 2g, 2h.

[0039] The periphery of the disc-shaped discharge electrodes 2a, 2b is formed in an edge-shape. The discharge electrode 2b is provided with an annular groove part 21b in the vicinity of the edge of the face orthogonal to the rotating shaft 2e, and adjacent to the discharge electrode 2b a raw material supply means 7 for the supply of a raw material M for the generation of a high temperature plasma is arranged. The liquid or solid raw material M for the generation of a high temperature plasma, which is supplied from the raw material supply means 7, is arranged in the interior of said groove part 21b. The raw material M is, for example, tin (Sn) or lithium (Li).

[0040] The radius of the perpendicularly upper discharge electrode 2a is smaller as compared to the radius of the perpendicularly lower discharge electrode 2b. Thereby, the energy beam can be easily radiated towards the raw material M from above.

[0041] The pulsed power supply part 3 supplies energy between the discharge electrodes 2a, 2b, by means of which a discharge is generated between the edge portions of both electrodes. As the discharge electrodes are made from a metal with a high melting point like tungsten, molybdenum or tantalum, they do not melt even when the periphery of the discharge electrodes 2a, 2b reaches a high temperature because of the discharge. The insulating element 2c is made from, e.g., silicon nitride, aluminium nitride or diamond and ensures the insulation between the discharge electrodes 2a and 2b.

[0042] At the chamber 1, an energy beam emitter 10 to emit an energy beam such as a laser beam towards the raw material M to gasify the raw material M is arranged. The energy beam emitter 10 is provided with an energy beam source 101, which radiates an energy beam LB2 towards the raw material M, and an energy beam source controller 102, which controls the operation of the energy beam source 101. The energy beam LB2 radiated from the energy beam source 101 is focused by means of a condenser lens 103, passes through a window 1e, and is radiated towards the raw material M.

[0043] Then, at the chamber 1, an energy beam emitter 11 for forming the depression, which emits an energy beam LB1 independent from the energy beam emitter 10 is provided to form the depression in the surface of the raw material M. The energy beam emitter 11 for forming the depression is provided with an energy beam source 111, which radiates an energy beam LB1 towards the raw material M, and an energy beam source controller 112, which controls the operation of the energy beam source 111. The energy beam LB1 radiated from the energy beam source 111 is focused by means of a condenser lens 113, passes through a window 1f, and is radiated towards the raw material M.

[0044] The radiation of the energy beam LB1 by the energy beam emitter 11 for forming the depression is performed before the radiation of the energy beam LB2 by the energy beam emitter 10, and the energy beam LB2 is radiated to the depression formed by the energy beam LB1. As the discharge electrodes 2a, 2b rotate in the direction of the arrow in this figure, the position of the irradiation with the energy beam LB1 is located before the position of the irradiation with the energy beam LB2 by the energy beam emitter 10, and the formed depression is transported by the rotation of the discharge electrodes 2a, 2b to the position of the irradiation with the energy beam LB2.

[0045] As the rotational speed of the discharge electrodes 2a, 2b is slow with regard to the time from the irradiation with the energy beam LB1 to the irradiation with the energy beam LB2, there is no large difference between the position of the irradiation with the energy beam LB1 and the position of the irradiation with the energy beam LB2. In FIG. 1, the position of the irradiation with the energy beam LB1 and the position of the irradiation with the energy beam LB2 are shown exaggerated.

[0046] For the energy beam sources 101 and 111, for example, a solid-state laser source such as a YAG-laser or a CO₂ laser or an excimer laser source such as an ArF-laser or a KrF-laser can be used. Or for the energy beam sources 101 and 111, an ion beam or an electron beam can be used instead of a laser source. In the following, the energy beam is explained to be a laser beam.

[0047] The pulsed power supply part 3 being the pulsed power supply means applies pulsed power with a short pulse width between the discharge electrode 2a and the discharge electrode 2b via a magnetic pulse compression circuit comprising a capacitor and a magnetic

switch.

[0048] FIG. 1 shows an example for the configuration of the pulsed power generator. The pulsed power generator of FIG. 1 has a two-stage magnetic pulse compression circuit, for which two magnetic switches SR2, SR3 consisting of a saturable reactor are used. The two-stage magnetic pulse compression circuit is constructed by means of a capacitor C1, the first magnetic switch SR2, a capacitor C2 and the second magnetic switch SR3.

[0049] A magnetic switch SR1 is an element for reducing the switching loss at a solid-state switch SW being a semiconductor switching element such as an IGBT, and is also referred to as magnetic assist.

[0050] In the following, the configuration and the operation of the circuit are explained with reference to FIG. 1. First, the charging voltage of a charger CH is set to a certain value and the main capacitor C0 is charged by the charger CH. At this state, the solid-state switch SW such as an IGBT is off.

[0051] When the charging of the main capacitor C0 is finished and the solid-state switch SW has become on, the voltage present at both ends of the solid-state switch SW is mainly present at both ends of the magnetic switch SR1.

[0052] By the time the time integral value of the charge voltage V0 of the main capacitor C0 present at both ends of the magnetic switch SR1 reaches the limiting value specified by the characteristics of the magnetic switch SR1, the magnetic switch SR1 is saturated, the magnetic switch switches on and a current flows in a loop consisting of the main capacitor C0, the magnetic switch SR1, the primary side of a step-up transformer Tr1 and the solid-state switch SW. At the same time, a current flows in a loop consisting of the secondary side of the step-up transformer Tr1 and the capacitor C1 and the electric charge stored in the main capacitor C0 transits and is charged into the capacitor C1.

[0053] Subsequently, by the time the time integral value of the voltage V1 in the capacitor C1 reaches the limiting value specified by the characteristics of the magnetic switch SR2, the magnetic switch SR2 is saturated, the magnetic switch switches on, a current flows in a loop consisting of the capacitor C1, the magnetic switch SR2 and the capacitor C2 and the electric charge stored in the capacitor C1 transits and is charged into the capacitor C2.

[0054] Then, by the time the time integral value of the voltage V2 in the capacitor C2 reaches the limiting value specified by the characteristics of the magnetic switch SR3, the magnetic switch SR3 is saturated, the magnetic switch switches on and a high voltage pulse is applied between the discharge electrode 2a and the discharge electrode 2b.

[0055] By means of setting the inductance of the capacity transition circuit of each stage consisting of the magnetic switch SR2, SR3 and the capacitor C1, C2 such that it becomes lower while transiting to the posterior

stage, a pulse compressing operation is performed such that the pulse width of the current pulse flowing in each stage becomes sequentially narrower and a strong discharge with a short pulse can be effected between the discharge electrode 2a and the discharge electrode 2b. Also the input power to the plasma becomes large.

[0056] A foil trap 4 is fixed by means of a separating wall 4a at the EUV collecting part 1b of the chamber 1. The foil trap 4 prevents that debris generated mainly by the material of the discharge electrodes and the raw material M for the generation of the high temperature plasma scatters towards the collecting mirror reflector 5. The foil trap 4 is provided with a plurality of narrow spaces separated by a plurality of thin plates extending radially.

[0057] The collecting mirror reflector 5, which is arranged in the EUV collecting part 1b is provided with radiation reflecting surfaces 5a to reflect the EUV radiation with a wavelength of 13.5 nm emitted from the high temperature plasma. The collecting mirror reflector 5 comprises a plurality of radiation reflecting surfaces 5a which are arranged nested while not contacting each other. Each radiation reflecting surface 5a is designed for a good reflection of the extreme ultraviolet radiation having an incident angle of 0 to 25 ° by means of a thorough coating of a metal such as Ru (ruthenium), Mo (molybdenum) or Rh (rhodium) onto the radiation reflecting surface of a substrate material with a smooth surface made, for example, from nickel (Ni). Each radiation reflecting surface 5a is configured such that the EUV radiation emitted from the high temperature plasma converges at the focal point P.

[0058] The controller 6 controls the energy beam emitters 10, 11 and the pulsed power supply part 3 with regard to the emission timing of the laser beams radiated from the energy beam emitters 10 and 11 and the timing of the supply of the pulsed power from the pulsed power supply part 3 to the discharge electrodes 2a, 2b as below. That is, before the voltage between the electrodes increases because of the supply of the pulsed power to the discharge electrodes 2a, 2b, and before the energy beam is radiated by the energy beam emitter 10 to the raw material on the electrodes, a laser beam is radiated from the energy beam emitter 11 and a depression is formed in the raw material supplied onto the discharge electrodes.

[0059] FIG. 2 is a partial explanatory view of the extreme ultraviolet light source device of FIG. 1.

FIG. 3 is a time chart showing the emission timing of the energy beams (laser beams), the supply timing of the pulsed power and the generation of EUV radiation, wherein (a) is the emission timing of the first laser beam LB1, (b) is the timing of the switching-on of the switch SW, (c) is the voltage of the capacitor C2, (d) is the emission timing of the second laser beam LB2, (e) is the discharge current flowing between the electrodes, and (f) is the emission timing of the EUV radiation.

[0060] The extreme ultraviolet light source device of FIG. 1 is **characterized in that** a depression is formed

in the surface of the raw material by means of an emission of a laser beam, and in particular, the following operations 1 to 3 are carried out by the controller 6.

<Operation 1 >

[0061] At the time T1, the controller 6 sends a signal to the energy beam source controller 112, and as shown in FIG. 2(a), the first laser beam LB1 is radiated from the energy beam source 111 to the surface of the raw material M supplied onto the discharge electrode 2b (FIG. 3(a)). As shown in FIG. 2(b), the first laser beam is radiated to the surface of the raw material M and a depression MA is formed.

<Operation 2>

[0062] As is shown in FIG. 3, at the time T2 the controller 6 switches the switch SW (IGBT) on (FIG. 3(b)). The time T2 occurs after a specified time has passed from the time T1. When the switch SW is switched on, the voltage between the discharge electrodes 2a, 2b increases after a delay time based on the magnetic switches SR1 to SR3, and after a time Δt_d the voltage of the capacitor C2 reaches a threshold value V_p (FIG. 3(c)). The threshold value V_p is a voltage value in the case that the value of the discharge current flowing at the time of the generation of the discharge becomes higher than a threshold value I_p . The threshold value I_p is the lower limiting value of the discharge current necessary for the production of a high temperature plasma emitting the desired EUV radiation intensity.

<Operation 3>

[0063] If the time from the switching-on of the switch SW to the increase of the voltage of the capacitor C2 is assessed as Δt_d , the controller 6 sends a signal to the energy beam source controller 102 at a time T3 after the time the voltage of the capacitor C2 has reached the threshold value V_p ($T3 \geq T2 + \Delta t_d$), and the second laser beam is radiated from the energy beam source 101. Thereby, as shown in FIG. 2(c), the second laser beam LB2 is radiated to the depression MA formed in the surface of the raw material M in operation 1 and the raw material M is gasified (FIG. 3(d)).

[0064] The raw material M gasified in operation 3 disperses three-dimensionally with a direction perpendicular to the surface of the raw material M as a center and reaches the discharge electrode 2a opposing the discharge electrode 2b, on which the raw material M was arranged. If the time from the emission of the second laser beam to the time that the gasified raw material reaches the discharge electrode 2a is assessed as Δt_i , a discharge is initiated between the edge portions of the peripheries of the discharge electrodes 2a, 2b at a time T4 ($T3 + \Delta t_i$). Thereby, a plasma is generated between the discharge electrodes 2a, 2b. This plasma is heated

by means of the electric current flowing between the discharge electrodes 2a, 2b (FIG. 3(e)).

[0065] When the plasma has been heated by the pulse-shaped discharge current and has reached a high temperature, EUV radiation with a wavelength of 13.5 nm is emitted from this high temperature plasma (FIG. 3(f)).

[0066] In the above discussion the second laser beam is radiated from the energy beam source 101 in operation 3 after the switch SW (IGBT) has been switched on in operation 2, but it is also possible to reverse operation 2 and operation 3 for example in the case of $\Delta t_d < \Delta t_i$, in which the time Δt_d is small because of a small delay of the pulsed power supply part 3 and the time Δt_i until the gasified raw material reaches the discharge electrode 2a is large because of a large spacing between the electrodes.

[0067] As in the EUV light source device of the present invention the second laser beam is radiated to the depression formed in the surface of the raw material M and the raw material is gasified, the intensity of the EUV radiation can be increased. And as, furthermore, the depression is formed in the raw material supplied onto the discharge electrodes by the depression forming means before the voltage between the electrodes increases and before an energy beam is radiated to the raw material on the electrodes by the energy beam emitting means, there is no risk that a discharge is initiated between the discharge electrodes 2a, 2b by the raw material gasified at the time of the forming of the depression. In other words, if the first laser beam for the forming of the depression is radiated to the raw material after the pulsed power has been supplied to the discharge electrodes 2a, 2b, a discharge might be initiated between the discharge electrodes 2a, 2b by the raw material M gasified at the time of the forming of the depression, and it is not possible to initiate the discharge with a proper timing. It is important to proceed as stated above to avoid such a problem.

[0068] In the embodiment of FIG. 1 and FIG. 2, there are provided an energy beam emitter for forming a depression MA in the surface of the raw material M as well as an energy beam emitter for the gasification of the raw material in order to radiate an energy beam to the depression MA formed in the raw material M and to gasify the raw material M. But with the present invention, there is no necessity to implicitly use two or more energy beam emitters. It is, for example, possible to perform the above operations 1 and 3 by using only the energy beam emitter 10.

[0069] FIG. 4 is a view of an exemplary configuration of an extreme ultraviolet light source device being provided with one energy beam emitter. The device shown in FIG. 4 has the same configuration as the device shown in the above FIG. 1, except that only the energy beam emitter 10 is arranged and the energy beam emitter 11 is omitted, and with the exception of the manner of usage of the energy beam emitter 10 also the operations of the device correspond to the device shown in FIG. 1.

[0070] In FIG. 4, in operation 1 the first laser beam is radiated from the energy beam emitter 10 to the surface of the raw material M and the depression is formed. Then operation 2 is performed as mentioned above. Then, in operation 3, at the time T3 after the time the voltage of the capacitor C2 has reached the threshold value Vp, the second laser beam is radiated from the energy beam source 10 to the depression formed in the surface of the raw material M and the raw material M is gasified.

[0071] The gasified raw material reaches the discharge electrode 2a opposing the discharge electrode 2b, a discharge is initiated between the edge portions of the peripheries of the discharge electrodes 2a, 2b, a plasma is formed and EUV radiation is generated.

(2) Second embodiment

[0072] FIG. 5 is a plan view schematically showing the configuration of the EUV light source device of a second embodiment of the present invention, and FIG. 6 is a front view schematically showing the configuration of the EUV light source device of the second embodiment of the present invention.

[0073] The EUV light source device shown in these figures has a chamber 51 being a discharge container. The chamber 51 is divided by means of a separating wall 54 into a discharge space 51a containing a pair of discharge electrodes 52a, 52b and an EUV collecting space 51 b containing a collecting mirror reflector 55, and is provided with an EUV output part 51d to emit EUV radiation towards an exposure device. In the chamber 51, a gas exhaust unit 51c is arranged to provide a vacuum condition in the interior of the chamber.

[0074] In the discharge space 51 a, the pair of independently rotating discharge electrodes 52a, 52b is arranged spaced apart from each other. The discharge electrodes 52a, 52b are heating and excitation means to heat and excite the raw material M. In the EUV condensing space 51 b, the collecting mirror reflector 55 for collecting the EUV radiation emitted from the high temperature plasma formed between the pair of discharge electrodes is arranged.

[0075] The discharge electrodes 52a, 52b are made from a metal with a high melting point such as, for example, molybdenum, tungsten or tantalum, and are arranged opposite to each other in a spaced relationship. One of the discharge electrodes 52a, 52b is a ground side electrode, and the other one is a high voltage side electrode. The discharge electrodes 52a, 52b are preferably arranged such that the imaginary planes containing the surfaces of the respective discharge electrodes intersect. If the discharge electrodes 52a, 52b are arranged in such a way, the major part of the discharge occurs in the portion with the smallest spacing between the edge portions of the peripheries of the discharge electrodes 52a, 52b (discharge region). Therefore, the position of the discharge is stable

[0076] The discharge electrodes 52a, 52b are prefer-

ably arranged such that they approach each other gradually the closer they come to the collecting mirror reflector 55. As with such an arrangement the distance between the discharge region between the pair of discharge electrodes 52a, 52b and the collecting mirror reflector 55 becomes closer, the extreme ultraviolet radiation can be focused with good efficiency.

[0077] The discharge electrodes 52a, 52b of the EUV light source device shown in FIGs. 5 and 6 are disc-shaped and are controlled by a controller 56 such that they rotate independently. As by rotating the discharge electrodes 52a, 52b at the time of the discharge the position of the high temperature plasma changes with each pulse, the thermal stress suffered by the discharge electrodes 52a, 52b becomes small. Therefore, the life cycle of the discharge electrodes 52a, 52b can be extended.

[0078] A rotating shaft 52e of a motor 52d is attached approximately in the center region of each discharge electrode 52a, 52b. Each rotating shaft 52e is inserted into the interior of the chamber 51 via a mechanical seal 52f. The mechanical seal 52f allows the rotation of the rotating shaft 2e while the reduced-pressure atmosphere within the chamber 1 is maintained.

[0079] A foil trap 54 and the collecting mirror reflector 55 shown in FIG. 5 and FIG. 6 each have the same configuration as the foil trap 4 and the collecting mirror reflector 5 of the EUV light source device of the first embodiment. The foil trap 54 is fixed by means of a separating wall 54a at the EUV collecting part 51 b of the chamber 51. The collecting mirror reflector 55 comprises a plurality of radiation reflecting surfaces 55a which are arranged nested while not contacting each other.

[0080] The EUV light source device shown in FIGs. 5 and 6 is provided with containers 57a, 57b filled with a melt of the raw material M. The raw material M is a melt of a conducting substance, for example a melt of tin. The discharge electrodes 52a, 52b are arranged such that they pass through the melt of the raw material M filled into the respective containers 57a, 57b. That is, at the time of the discharge the discharge electrodes 52a, 52b are rotated and immersed in the raw material M filled into the respective containers 57a, 57b, and the raw material M is applied onto the surfaces of the electrodes. Although not shown in the figures, the containers 57a, 57b are provided with a temperature regulating means to maintain the molten state of the raw material M.

[0081] The containers 57a, 57b are connected electrically to a pulsed power supply part 53. The containers 57a, 57b are connected electrically to the pulsed power supply part 53 via energy lead-in parts 58a, 58b. The energy lead-in parts 58a, 58b are provided with insulating properties and maintain the reduced-pressure atmosphere within the chamber 51. The pulsed power supply part 53 applies pulsed power to the discharge electrodes 52a, 52b via the melt of the raw material M filled into each container 57a, 57b.

[0082] The EUV light source device of FIG. 5 and FIG. 6 is provided with an energy beam emitter 60 radiating

an energy beam to the raw material M generating the high temperature plasma and to a specified location of the discharge region. The energy beam emitter 60 comprises an energy beam source 601 and an energy beam source controller 602 controlling the operation of the energy beam source 601. A laser beam radiated from the energy beam source 601 is focused by means of a condenser lens 603, passes through a window part 51e, and is radiated towards the periphery of the discharge electrode 52a. The raw material M is gasified by the laser beam between the discharge electrodes 52a and 52b.

[0083] At the chamber 51, an energy beam emitter 61 for forming a depression, which radiates an energy beam independent of the energy beam emitter 60, is arranged to form a depression in the surface of the raw material M. The energy beam emitter 61 for forming a depression comprises an energy beam source 611 radiating an energy beam towards the raw material M and an energy beam source controller 612 controlling the operation of the energy beam source 611. The laser beam radiated from the energy beam source 611 is focused by means of a condenser lens 613, passes through a window part 51f, and is radiated towards the raw material M.

[0084] The energy beam sources 601, 611 are for example solid-state laser sources such as YAG-lasers or CO₂ lasers or excimer laser sources such as ArF-lasers or KrF-lasers. Or for the energy beam sources 601, 611, an ion beam or an electron beam can be used instead of a laser source.

[0085] Similar to the extreme ultraviolet light source device of FIG. 1, the pulsed power supply part 53 has a two-stage magnetic pulse compression circuit which uses two magnetic switches SR2, SR3 consisting of a saturable reactor. The two-stage magnetic pulse compression circuit is formed by a capacitor C1, the first magnetic switch SR2, a capacitor C2 and the second magnetic switch SR3.

[0086] The controller 56 controls the energy beam emitters 60, 61 and the pulsed power supply part 53 with regard to the emission timing of the laser beams radiated from the energy beam emitters 60 and 61 and the timing of the supply of the pulsed power from the pulsed power supply part 53 to the discharge electrodes 52a, 52b such that the above mentioned operations 1 to 3 are carried out according to the following order. That is, as mentioned above, a laser beam is radiated from the energy beam emitter 61 and a depression is formed in the raw material supplied onto the discharge electrodes before the voltage between the electrodes increases and before an energy beam is radiated from the energy beam emitter 60 to the raw material on the electrodes.

[0087] FIG. 7 is a partial explanatory view of the EUV light source device of FIG. 5 and FIG. 6. By using FIG. 7, the above mentioned operations 1 to 3 are explained concretely.

[0088] The discharge electrode 52a passes through the melt of the raw material M filled into the container 57a, by means of which raw material M is applied onto

the peripheral portion of the discharge electrode 52a. The raw material M applied onto the peripheral portion of the discharge electrode 52a becomes solid.

5 <Operation 1 >

[0089] As shown in FIG. 7, the first laser beam radiated from the energy beam source 611 is radiated towards the energy beam irradiation surface of the raw material M applied onto the peripheral portion of the discharge electrode 52a. The first laser beam forms a depression MA in the energy beam irradiation surface of the irradiated raw material M.

15 <Operation 2>

[0090] The switch SW of the pulsed power supply part is switched on as shown in the time chart (b) of the above mentioned FIG. 3.

20 <Operation 3>

[0091] After the voltage of the capacitor C2 has exceeded a threshold value Vp as shown in the time charts (c) and (d) of the above mentioned FIG. 3, the second laser beam radiated from the energy beam source 601 is radiated to the depression MA of the raw material M. The raw material gasified in operation 3 reaches the discharge electrode 52b arranged opposite to the discharge electrode 52a, as was mentioned above, a discharge is initiated between the edge portions of the peripheries of the discharge electrodes 52a, 52b, a plasma is heated and reaches a high temperature, and EUV radiation with a wavelength of 13.5 nm is emitted from this high temperature plasma.

[0092] As shown in FIG. 7, the area of the raw material M reached by the second laser beam radiated from the energy beam source 601 is separated from the area of the raw material M reached by the first laser beam radiated from the energy beam source 611. The reason is that, as also the depression MA formed in the raw material M applied onto the peripheral portion of the discharge electrode 52a moves in the peripheral direction according to the rotation of the discharge electrode 52a with a specified speed in the peripheral direction, the laser beam radiated from the energy beam source 611 is radiated to the depression MA formed in the raw material M applied onto the discharge electrode 52a. As the speed of the rotation of the discharge electrodes 52a, 52b is slow with regard to the time from the emission of the first laser beam to the emission of the second laser beam, there is actually no large difference between the irradiation position of the first laser beam and the irradiation position of the second laser beam, but in FIG. 7 the irradiation positions of the first and second laser beams LB1, LB2 are shown with an exaggerated separation.

[0093] To form the depression MA in the surface of the raw material M, the extreme ultraviolet light source device

of the above FIGs. 5 to 7 is provided with the energy beam emitter 61 for forming a depression, which emits an energy beam independently of the energy beam emitter 60. But as mentioned above, it is not implicitly necessary that the extreme ultraviolet light source device of the present invention is provided with two energy beam emitters. It is also possible to carry out the operation to form the depression MA in the surface of the raw material M (the above mentioned operation 1) and the operation to radiate an energy beam to the depression MA (the above mentioned operation 3) only by means of the energy beam emitter 60.

[0094] FIG. 8 is a partial explanatory view regarding another example of a depression forming means in the EUV light source device of FIG. 5 and FIG. 6.

[0095] In the EUV light source device shown in FIG. 8, the discharge electrode 52a is rotated and passes through the melt of the raw material M filled into the container 57a, and the raw material M adheres to the peripheral portion of the discharge electrode 57a in a solid state.

[0096] The depression forming means 85 consists of a rod-shaped element made from metal, which is fixed by a suitable means. The tip part contacting the raw material M adhered to the peripheral portion of the discharge electrode 52a has a sharp-edged projection part 86. The depression forming means 85 is controlled by the controller 56 shown in FIG. 5 such that it reciprocates in a direction perpendicular to the tangential direction of the discharge electrode 52a. That is, the depression forming means 85 alternately repeats an operation in which the projection part 86 is brought into contact with the raw material M adhered to the peripheral portion of the discharge electrode 52a and an operation in which the projection part 86 is withdrawn from the raw material M adhered to the peripheral portion of the discharge electrode 52a.

[0097] In the EUV light source device of FIG. 8, the above mentioned operations 1 to 3 are carried out by the controller 56 provided in the extreme ultraviolet light source device of FIGs. 5 and 6 concretely as follows:

<Operation 1 >

[0098] The controller 56 drives the depression forming means 85, advances the projection part 86 to the rotating discharge electrode 52a and brings the projection part 86 into contact with the surface of the raw material M adhered to the peripheral portion of the discharge electrode 52a. In the surface of the raw material M, a plurality of hole-shaped depressions MA is formed, which are separated from each other in the circumferential direction of the discharge electrode 52a.

<Operation 2>

[0099] The switch SW of the pulsed power supply means 3 is switched on as shown in the time chart (b) of the above mentioned FIG. 3.

<Operation 3>

[0100] After the voltage of the capacitor C2 has exceeded the threshold value V_p as shown in the time charts (c) and (d) of the above mentioned FIG. 3, the controller 56 sends a signal to the energy beam source controller 602, whereby the energy beam source 601 is driven and the second laser beam is radiated to the depressions MA in the raw material M.

[0101] The raw material gasified in operation 3 reaches the discharge electrode 52b being arranged, as mentioned above, opposite to the discharge electrode 52a, a discharge is initiated between the edge portions of the peripheries of the discharge electrodes 52a, 52b, the plasma is heated and reaches a high temperature, and EUV radiation with a wavelength of 13.5 nm is emitted from this high temperature plasma.

[0102] FIG. 9 is a partial explanatory view regarding another example of a depression forming means in the EUV light source device of FIG. 5 and FIG. 6.

[0103] In the EUV light source device of FIG. 9, the discharge electrode 52a is rotated by the controller 56 and passes through the melt of the raw material M filled into the container 57a, and the raw material M adheres to the peripheral portion of the discharge electrode 57a in a solid state.

[0104] As shown in FIG. 9, the depression forming means 95 consists of a rod-shaped element made from metal, which is fixed by a suitable means, and has a tip part 96 contacting the raw material M adhered to the peripheral portion of the discharge electrode 52a.

[0105] In the EUV light source device of FIG. 9, the above mentioned operations 1 to 3 are carried out by the controller 56 provided in the extreme ultraviolet light source device of FIGs. 5 and 6 concretely as follows:

<Operation 1>

[0106] The controller 56 drives the depression forming means 95, advances the projection part 96 to the rotating discharge electrode 52a and brings the projection part 96 into contact with the raw material M adhered to the peripheral portion of the discharge electrode 52a. In the surface of the raw material M, a groove-shaped depression MA is formed, which extends in the circumferential direction of the discharge electrode 52a.

<Operation 2>

[0107] The switch SW of the pulsed power supply means 3 is switched on as shown in the time chart (b) of the above mentioned FIG. 3.

<Operation 3>

[0108] After the voltage of the capacitor C2 has exceeded the threshold value V_p as shown in the time charts (c) and (d) of the above mentioned FIG. 3, the

controller 56 sends a signal to the energy beam source controller 602, whereby the energy beam source 601 is driven and the second laser beam is radiated to the depression MA in the raw material M.

[0109] The raw material gasified in operation 3 reaches the discharge electrode 52b being arranged, as mentioned above, opposite to the discharge electrode 52a, a discharge is initiated between the edge portions of the peripheries of the discharge electrodes 52a, 52b, a plasma is heated and reaches a high temperature, and EUV radiation with a wavelength of 13.5 nm is emitted from this high temperature plasma.

[0110] FIG. 10 is a partial explanatory view regarding another example of a depression forming means in the EUV light source device of FIG. 5 and FIG. 6. FIG. 10(b) shows a cross-section of the discharge electrode 52a.

[0111] In the EUV light source device of FIG. 10, a groove 521 a is formed along the whole circumference of the edge portion of the discharge electrode 52a, and the device is provided with a depression forming means 105 having a projection part 106 contacting the raw material M adhered along the groove 521 a of the discharge electrode. The depression forming means 105 is immovable with regard to the discharge electrode 52a rotating in the circumferential direction.

[0112] In the EUV light source device of FIG. 10, the above mentioned operations 1 to 3 are carried out by the controller 56 provided in the extreme ultraviolet light source device of FIGs. 5 and 6 concretely as follows:

<Operation 1 >

[0113] The controller 56 drives the depression forming means 105, advances the projection part 106 to the rotating discharge electrode 52a and brings the projection part 106 into contact with the raw material M adhered along the groove 521a of the discharge electrode 52a. In the surface of the raw material M, a belt-shaped depression MA is formed, which extends in the circumferential direction of the discharge electrode 52a.

<Operation 2>

[0114] The switch SW of the pulsed power supply means 3 is switched on as shown in the time chart (b) of the above mentioned FIG. 3.

<Operation 3>

[0115] After the voltage of the capacitor C2 has exceeded the threshold value V_p according to the time charts (c) and (d) of the above mentioned FIG. 3, the controller 56 sends a signal to the energy beam source controller 602, whereby the energy beam source 601 is driven and the second laser beam is radiated to the depression MA in the raw material M. The raw material gasified in operation 3 reaches the discharge electrode 52b being arranged, as mentioned above, opposite to the dis-

charge electrode 52a, a discharge is initiated between the edge portions of the peripheries of the discharge electrodes 52a, 52b, the plasma is heated and reaches a high temperature, and EUV radiation with a wavelength of 13.5 nm is emitted from this high temperature plasma.

[0116] Also in the above mentioned second embodiment it is possible as mentioned above to reverse operation 2 and operation 3 for example in the case of $\Delta t_d < \Delta t_i$, in which the time Δt_d is small because of a small delay of the pulsed power supply part 3 and the time Δt_i until the gasified raw material reaches the discharge electrode 2a is large because of a large spacing between the electrodes.

[0117] As in the above mentioned first embodiment and second embodiment of the EUV light source device of the present invention a depression is formed in the energy beam irradiation surface of the raw material and an energy beam is radiated towards said depression, the output of the EUV radiation can be rendered large as compared to the known EUV light source devices. The reason for this is assumed to be as follows. The explanation will be made with reference to FIGs. 11 and 12.

[0118] FIG. 11 is an explanatory view showing the difference in the state of the generation of the initial discharge plasma for the case, in which no depression is formed in the energy beam irradiation surface of the raw material (FIG. 11(a)), and the case, in which a depression is formed (FIG. 11(b)).

[0119] When no depression is formed in the energy beam irradiation surface of the raw material as shown in FIG. 11(a), the initial discharge plasma disperses at the time of the radiation of the laser beam to the raw material M and the density of the generated plasma decreases. Therefore, it is assumed that the amount of the plasma contributing to the generation of EUV radiation is low even if the plasma is heated by the discharge, and only weak EUV radiation is obtained. If, on the other hand, as shown in FIG. 11(b), a depression is formed in the energy beam irradiation surface of the raw material, the free expansion of the raw material at the time of the irradiation with the energy beam and the gasification of the raw material is restricted by the inner wall surfaces of the depression. Therefore, the dispersion in the lateral direction decreases and the ability for orientation increases. Thus, the density of the gas generated by the gasification of the raw material becomes high and a narrow spatial dispersion occurs so that the spatial distribution of the plasma generated between the pair of discharge electrodes can be rendered lower than in the case of the known EUV light source devices. As the density of the current flowing in the plasma can be rendered large by rendering the spatial dispersion of the plasma generated between the discharge electrodes small, the plasma can be easily brought into a high temperature condition, the ionisation is promoted and the ion density of the plasma becomes high. By means of restricting the dispersion of the plasma, the self absorption by the plasma is reduced. Therefore, the output of EUV radiation can be rendered higher than

with the known EUV light source devices.

[0120] FIG. 12 is a view showing illustrations of the visible light of the laser ablation plasma in case of the absence of a depression and in case of the presence of a depression. In case of the absence of a depression, the plasma disperses spatially as shown in FIG. 12(a), but by means of the provision of a depression the dispersion of the plasma can be rendered small as shown in FIG. 12(b), and the density of the current flowing in the plasma can be rendered large.

Claims

1. An extreme ultraviolet light source device, comprising:

a pair of discharge electrodes (2a, 2b, 52a, 52b) arranged spaced apart from each other;
 a pulsed power supply means (3, 53) supplying pulsed power to said discharge electrodes (2a, 2b);
 a raw material supply means (7) adapted for supplying raw material (M) for generating extreme ultraviolet radiation onto said discharge electrodes (2a, 2b, 52a, 52b);
 an energy beam emitting means (10, 60) adapted for radiating an energy beam (LB2) to the raw material (M) on said discharge electrodes (2a, 2b, 52a, 52b) to gasify said raw material (M);
 a means (11, 61, 85, 95, 105) for forming a depression (MA) in the raw material (M) supplied onto said discharge electrodes (2a, 2b, 52a, 52b); and
 a controller (6, 56);

characterized in that

said controller (6, 56) is adapted to control the depression forming means (11, 61, 85, 95, 105) such that it forms a depression (MA) in the raw material (M) supplied onto the discharge electrodes (2a, 2b, 52a, 52b) before the voltage between the electrodes (2a, 2b, 52a, 52b) increases by means of the supply of pulsed power to the discharge electrodes (2a, 2b, 52a, 52b) by said pulsed power supply means (3, 53), and before the energy beam (LB2) is radiated to the raw material (M) on the electrodes (2a, 2b, 52a, 52b) by said energy beam emitting means (10, 60).

2. The extreme ultraviolet light source device according to claim 1, **characterized in that** said depression forming means (11, 61) is a means radiating an energy beam (LB1), preferably a means emitting one of a laser beam, an electron beam and an ion beam.
3. The extreme ultraviolet light source device according to claim 2, **characterized in that** said energy beam

emitting means (10, 60) gasifying said raw material serves also as said depression forming means (11, 61).

4. The extreme ultraviolet light source device according to claim 1, **characterized in that** said depression forming means (85, 95, 105) is provided with a tip part (86, 96, 106) for mechanically forming a depression (MA) in the raw material (M).
5. The extreme ultraviolet light source device according to claim 1, **characterized in that** said raw material supply means (7, 57) is provided with containers (57a, 57b) filled with a melt of said raw material (M); and each said discharge electrodes (2a, 2b, 52a, 52b) passes through the raw material melt contained in said containers while being rotated.
6. A process for generating extreme ultraviolet radiation using an extreme ultraviolet light source device of any one of claims 1 to 5, **characterized in that** said depression forming means (11, 61, 85, 95, 105) forms a depression (MA) in the raw material (M) supplied onto the discharge electrodes (2a, 2b, 52a, 52b) before said pulsed power supply means (3, 53) supplies pulsed power to the discharge electrodes (2a, 2b, 52a, 52b) such that the voltage between the electrodes (2a, 2b, 52a, 52b) increases, and before said energy beam emitting means (10, 60) radiates an energy beam (LB2) to the raw material (M) on the electrodes (2a, 2b, 52a, 52b) to gasify said raw material (M).
7. The process according to claim 6, **characterized in that** said energy beam emitting means (10, 60) radiates an energy beam (LB2), preferably one of a laser beam, an electron beam and an ion beam, onto said raw material (M).
8. The process according to claim 6 or 7, **characterized in that** said depression forming means (11, 61) radiates an energy beam (LB1), preferably one of a laser beam, an electron beam and an ion beam, onto said raw material (M).
9. The process according to claim 6 or 7, **characterized in that** said depression (MA) is formed by pressing a tip part (86, 96, 106) of said depression forming means (85, 95, 105) into the raw material (M).
10. The process according to any one of claims 6 to 9, **characterized in that** said discharge electrodes (2a, 2b, 52a, 52b) are rotated such that their edges dip into a melt of said raw material (M) which is filled into containers (57a, 57b) of the raw material supply means (7, 57).

Fig. 1

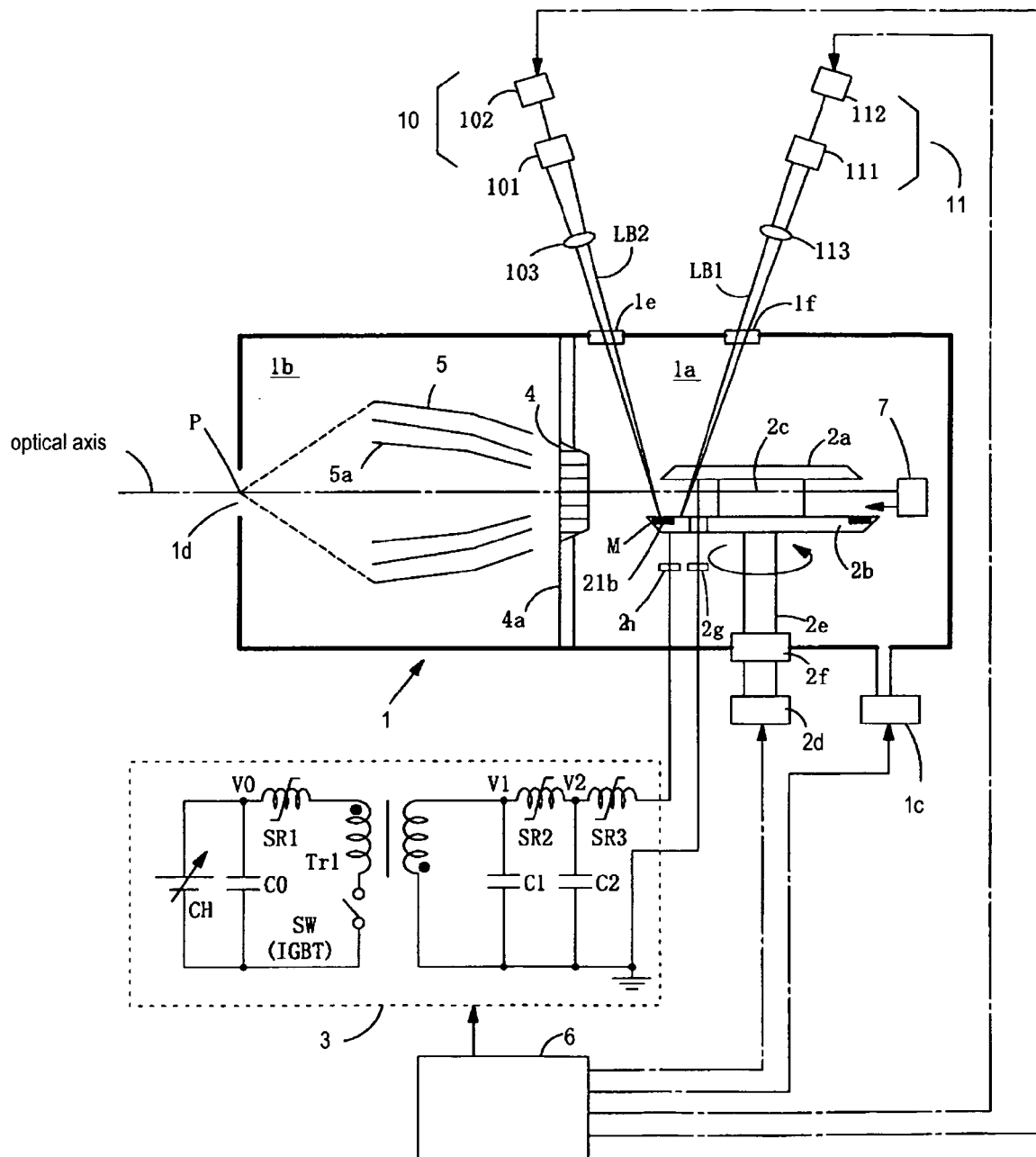


Fig. 2 (a)

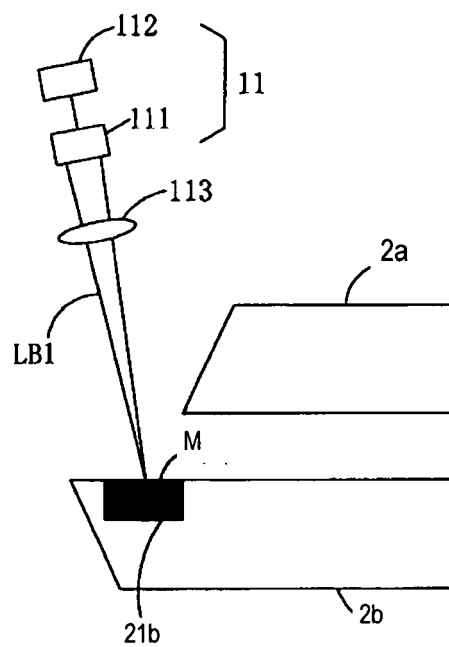


Fig. 2 (b)

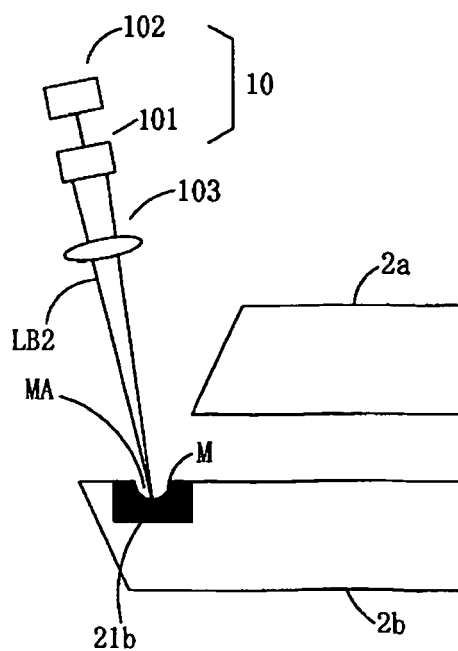
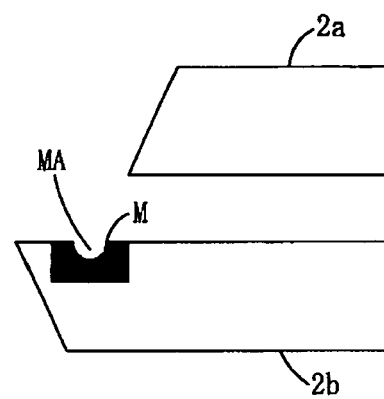


Fig. 2 (c)

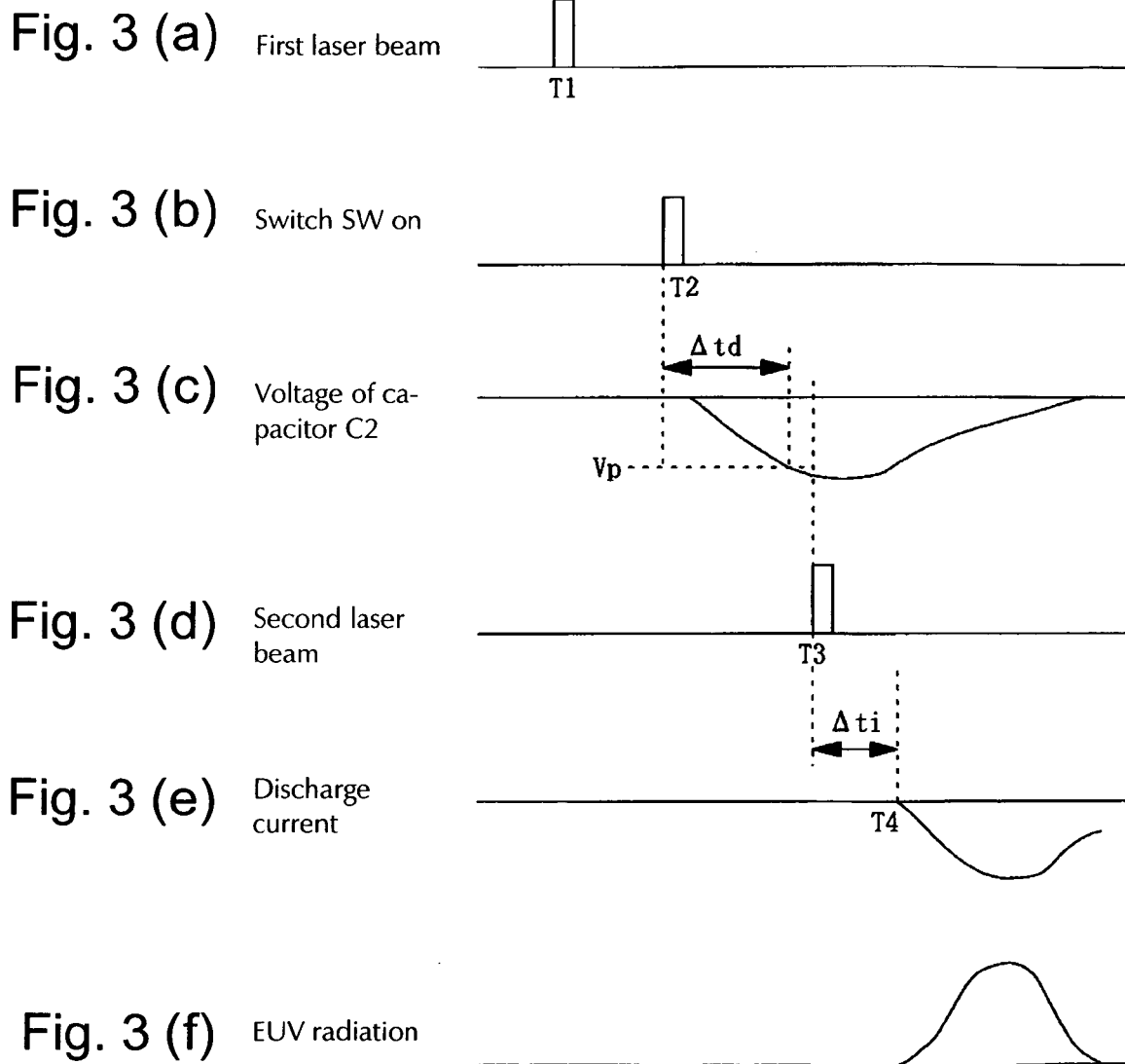


Fig. 4

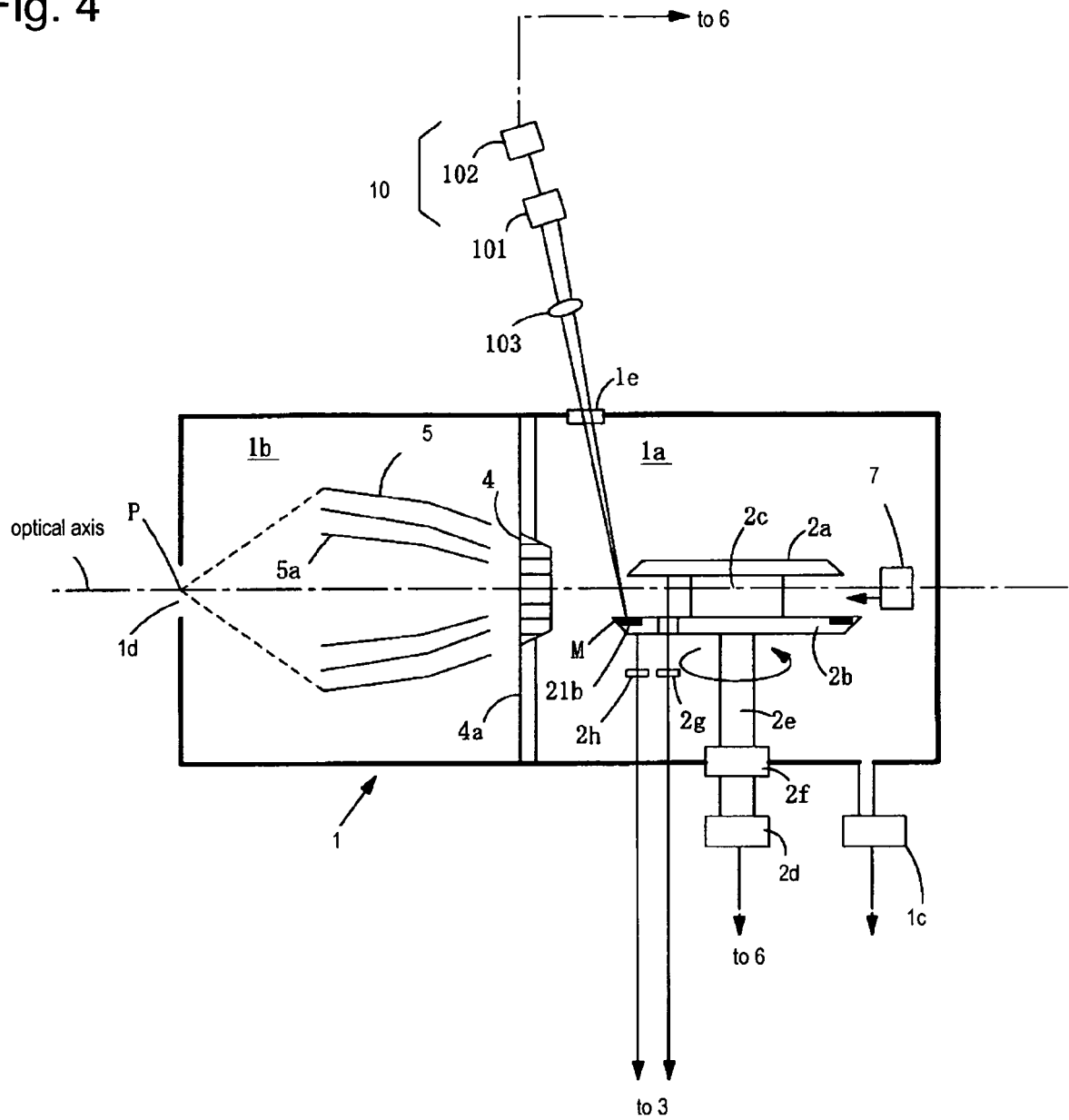


Fig. 5

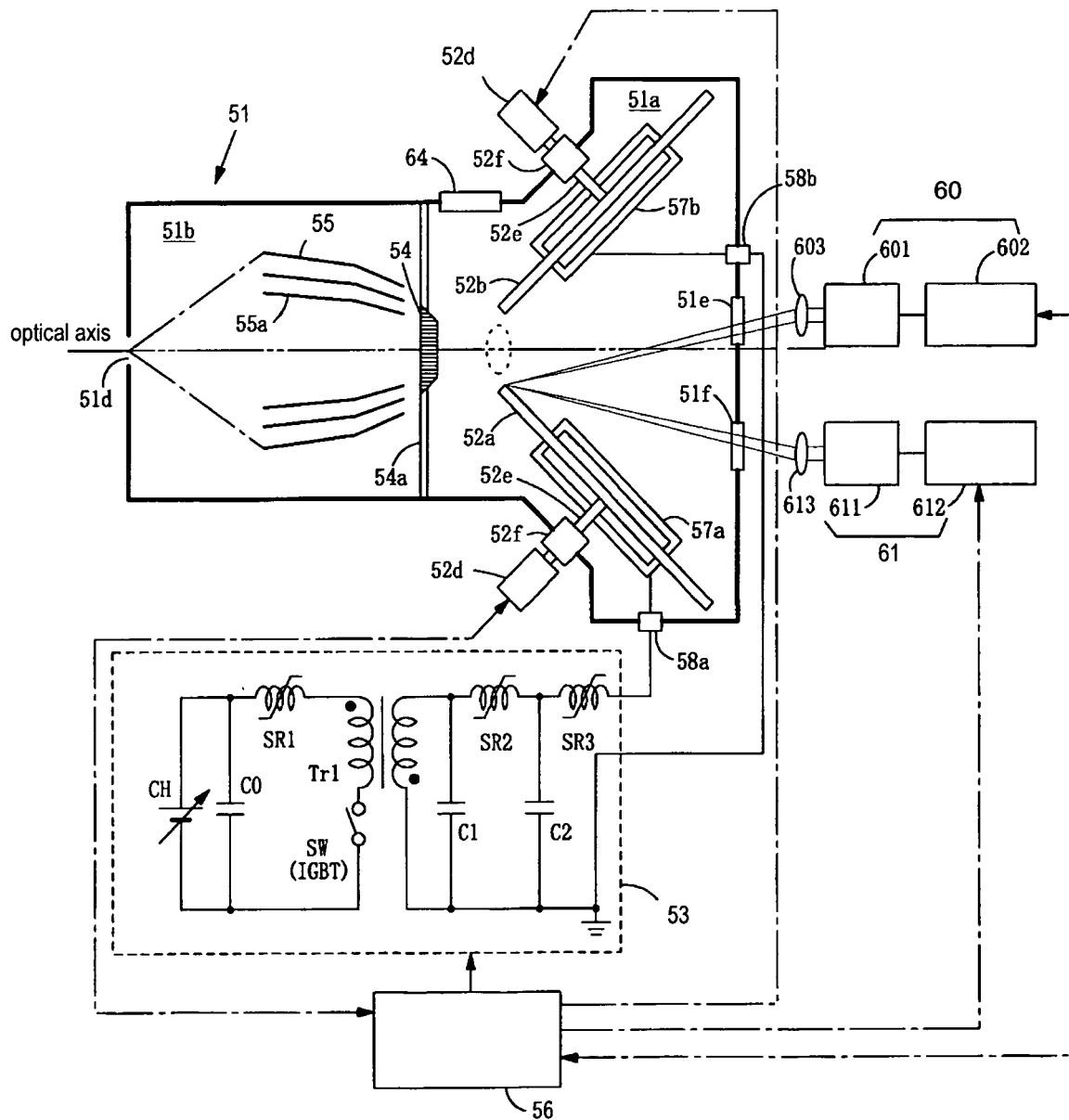


Fig. 6

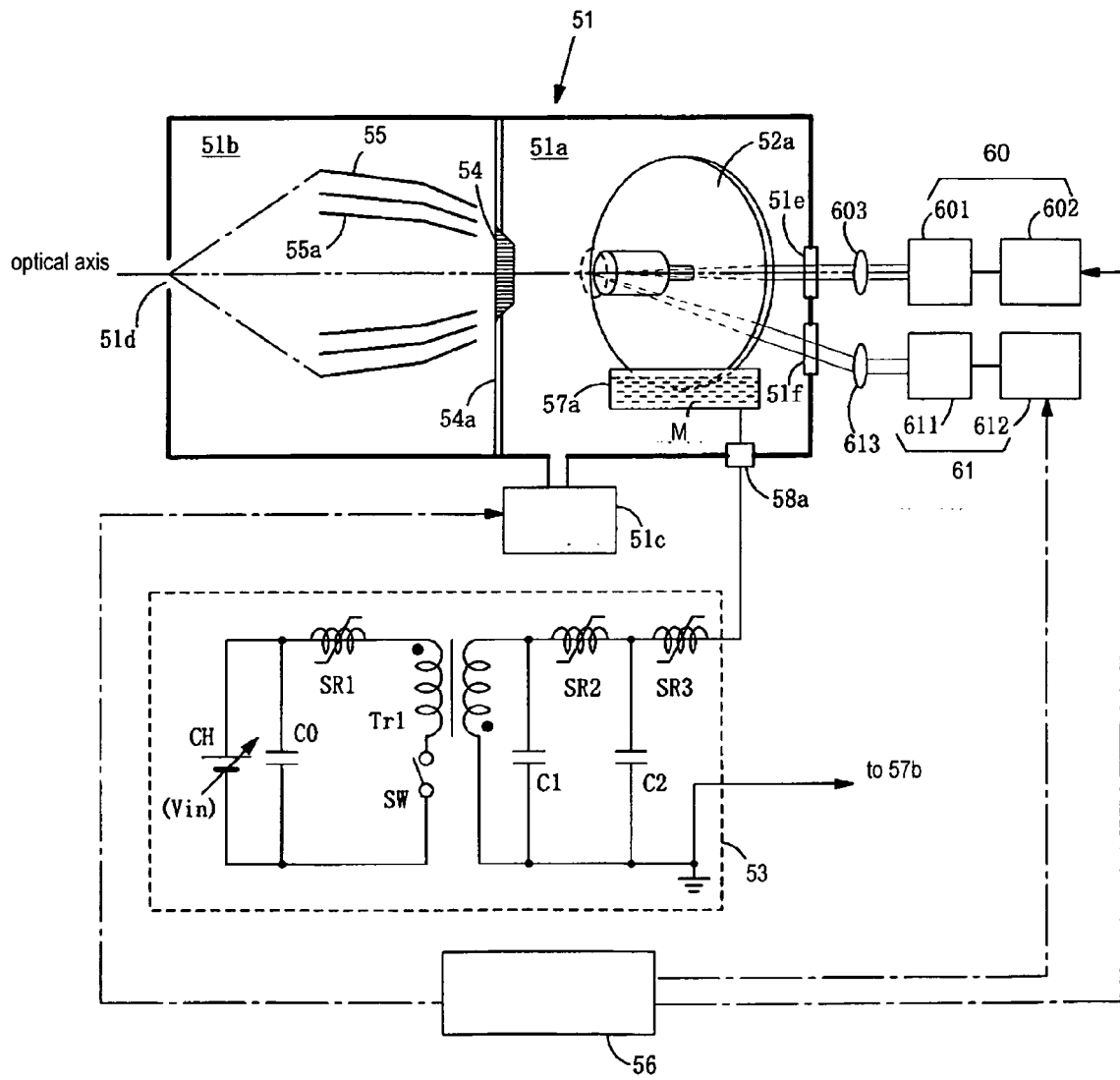


Fig. 7

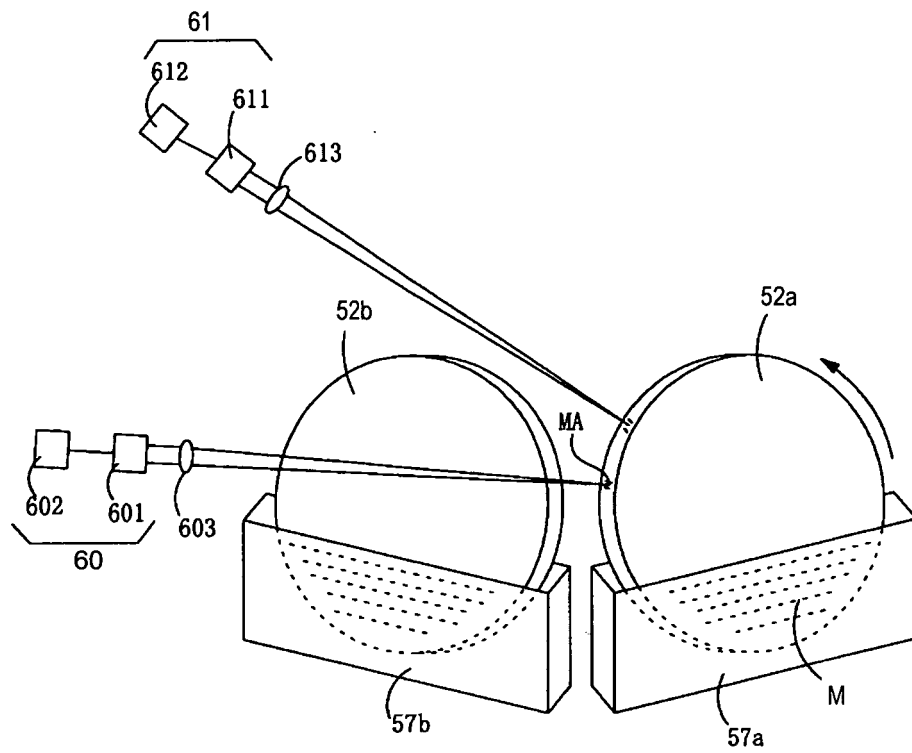


Fig. 8

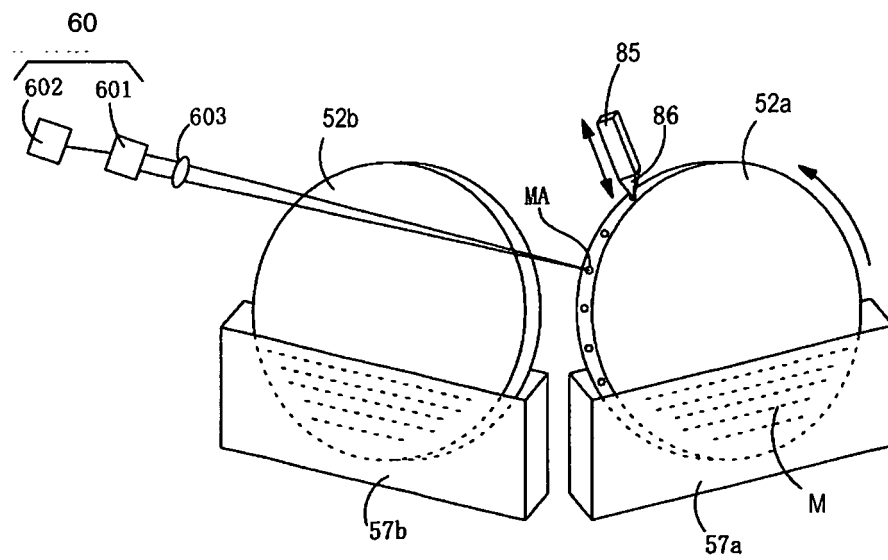


Fig. 9

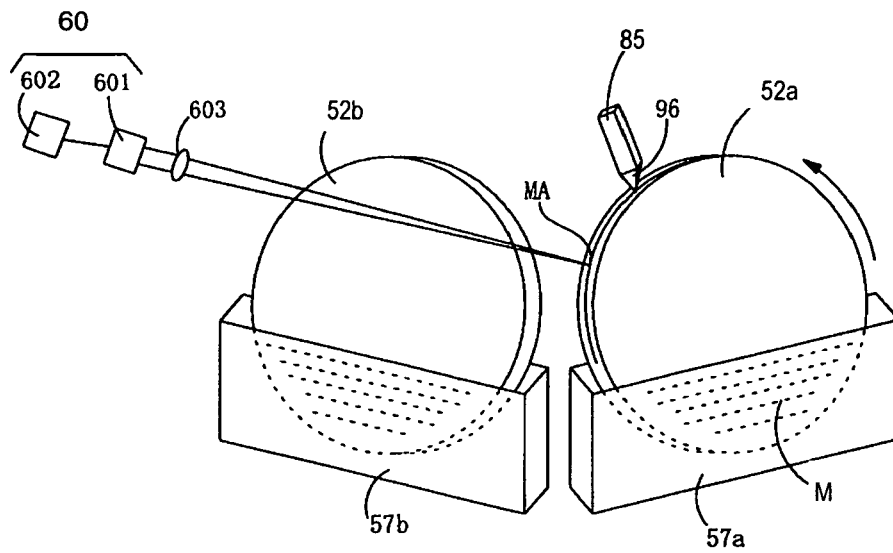


Fig. 12(a)

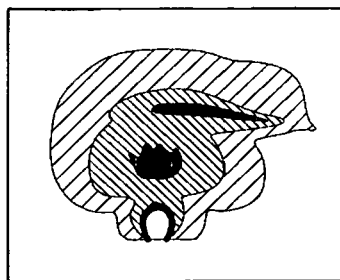


Fig. 12(b)

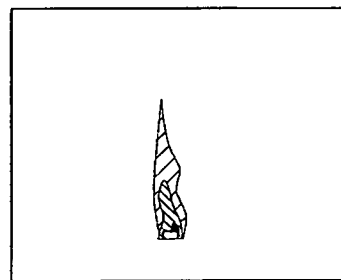


Fig. 10(a)

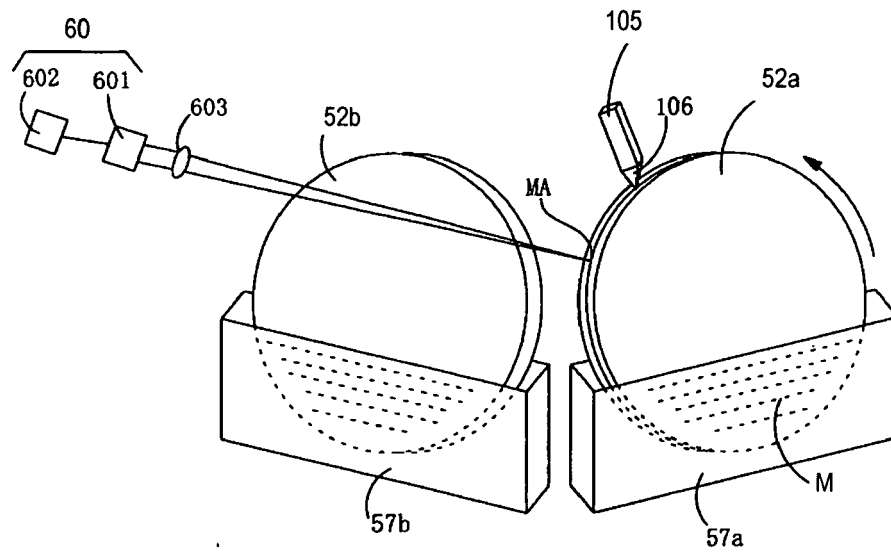


Fig. 10(b)

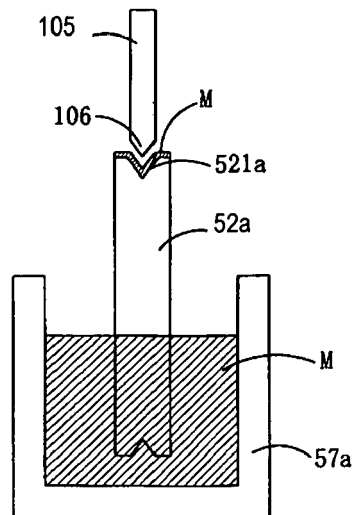


Fig. 11(a)

Fig. 11(b)

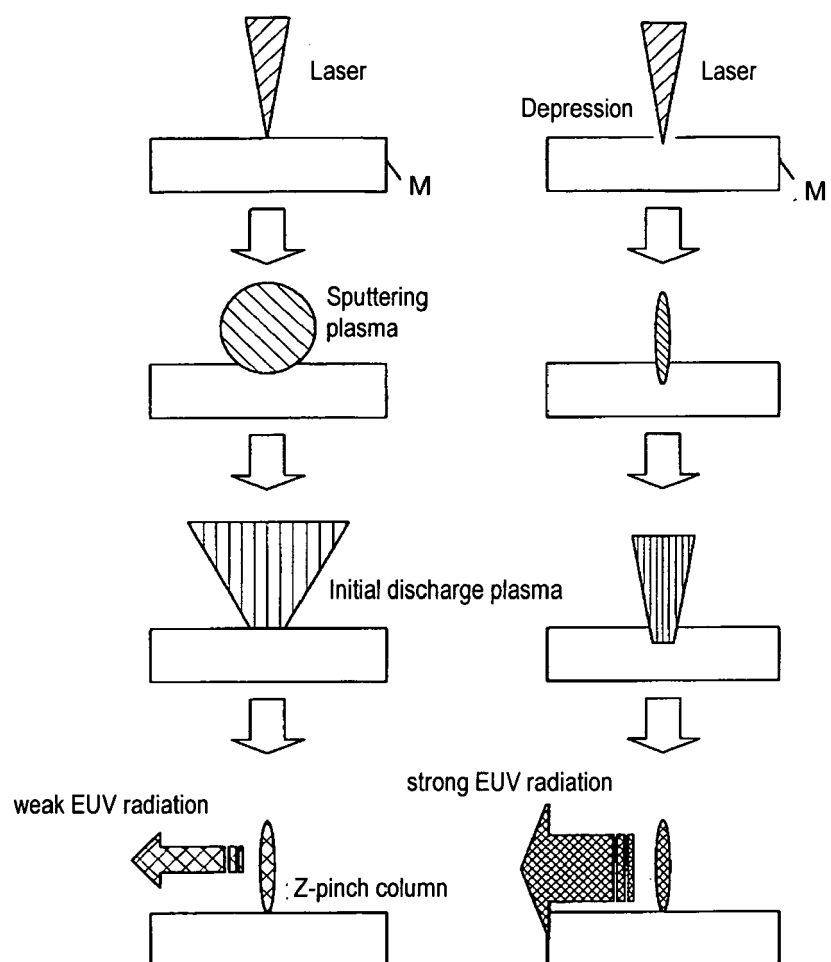
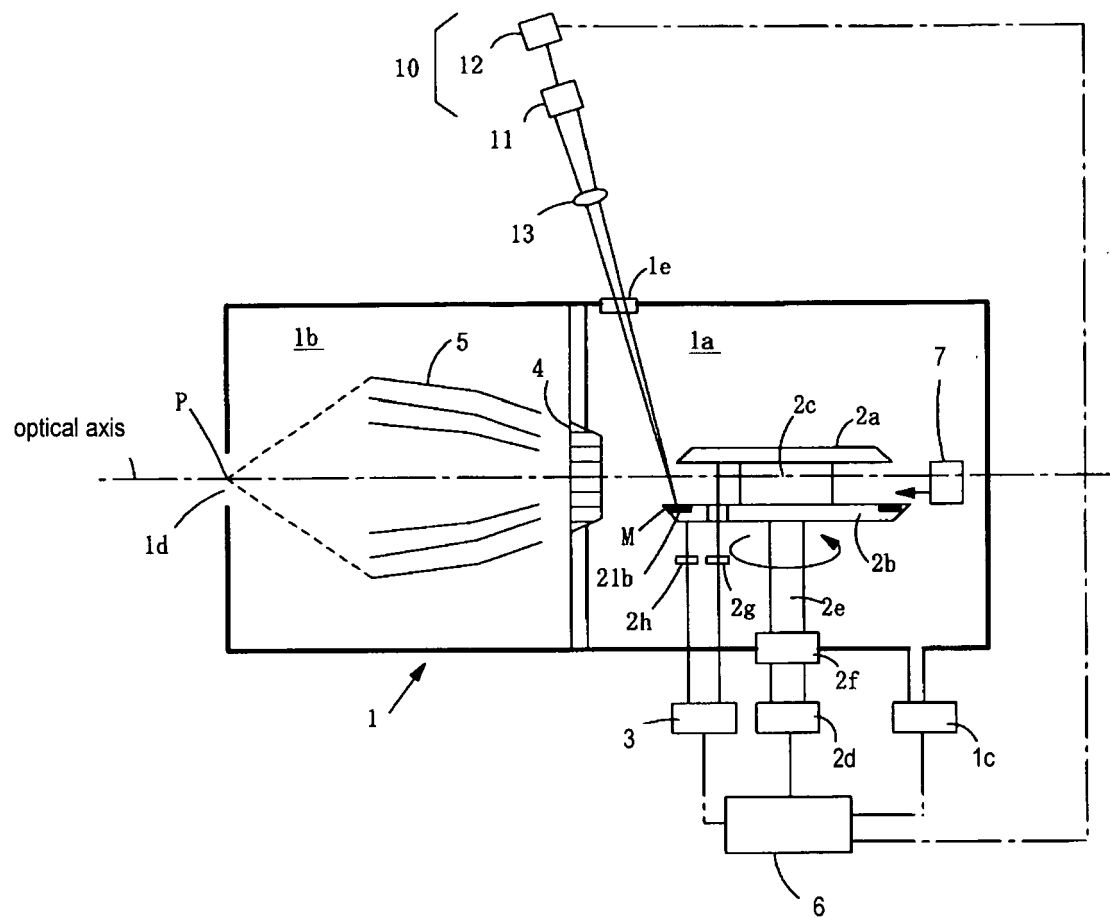


Fig. 13 (Prior Art)



REFERENCES CITED IN THE DESCRIPTION

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- US 20040183038 A1 [0009] [0010] [0011]

Non-patent literature cited in the description

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