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Iwamoto et al.

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(54) **TARGET PRODUCING APPARATUS**

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G03F 7/20 (2006.01)

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CPC ***H05G 2/006*** (2013.01); ***G03F 7/70033*** (2013.01); ***H05G 2/005*** (2013.01)

(58) **Field of Classification Search**
CPC H05G 2/005; H05G 2/006; G03F 7/70033
USPC .... 250/493.1, 503.1, 504 R
See application file for complete search history.

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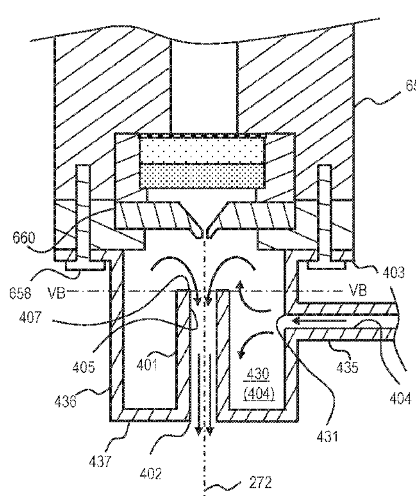
(57) **ABSTRACT**

An aspect of the present disclosure may include a gas lock cover secured to a nozzle holder and provided downstream of a nozzle. The gas lock cover may cover a periphery of an exit of the nozzle and be structured to guide gas supplied from a gas supply unit. The gas lock cover may include a hollow cylindrical part provided downstream of the nozzle and having an exit opening for outputting droplets that are outputted from the nozzle and pass through an internal cavity of the cylindrical part. The gas lock cover may include a channel for transmitting the gas supplied from the gas supply unit, the channel being structured to orient a flow of the transmitted gas so as to flow to the exit opening of the cylindrical part through the internal cavity of the cylindrical part.

3 Claims, 10 Drawing Sheets



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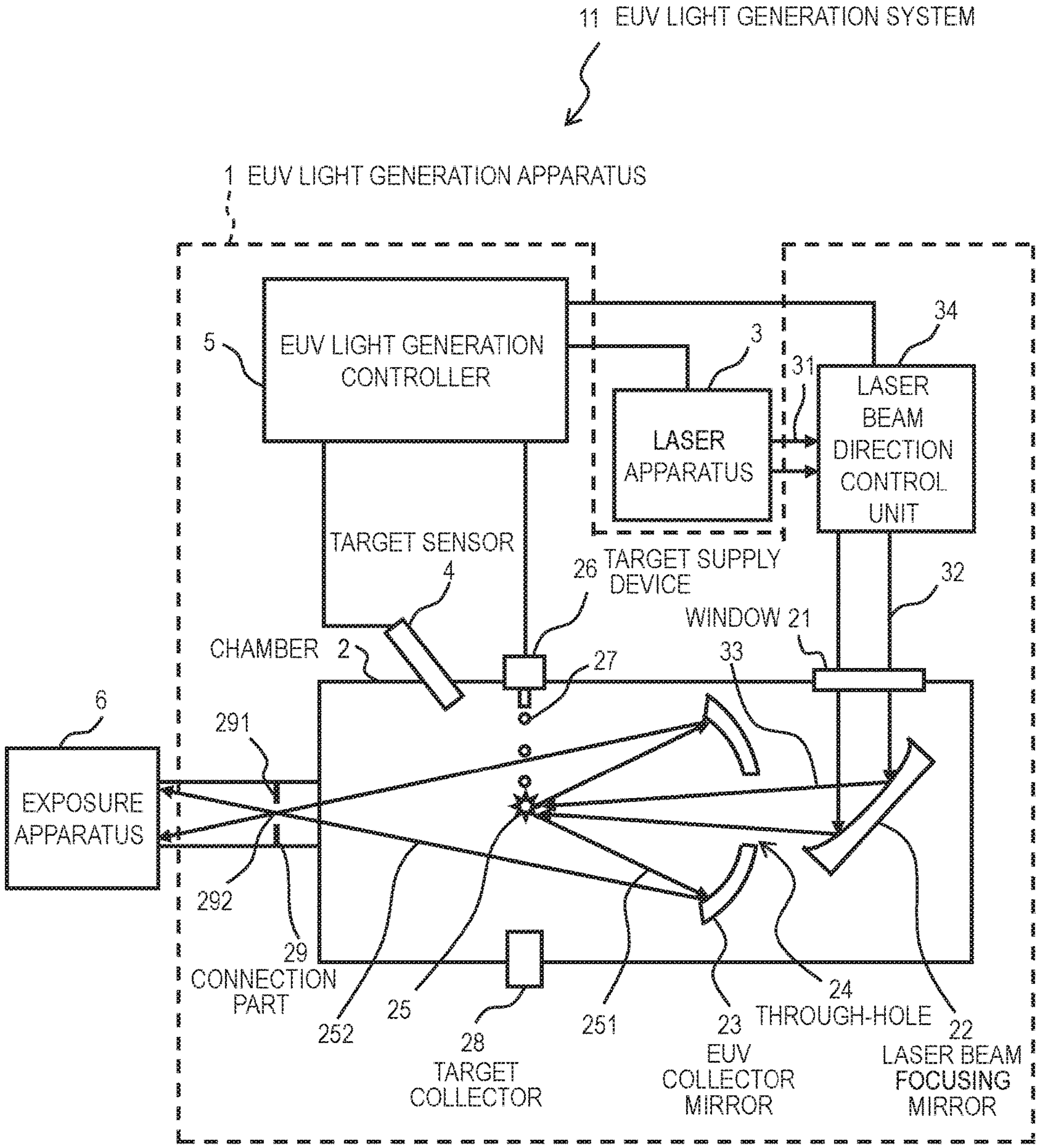
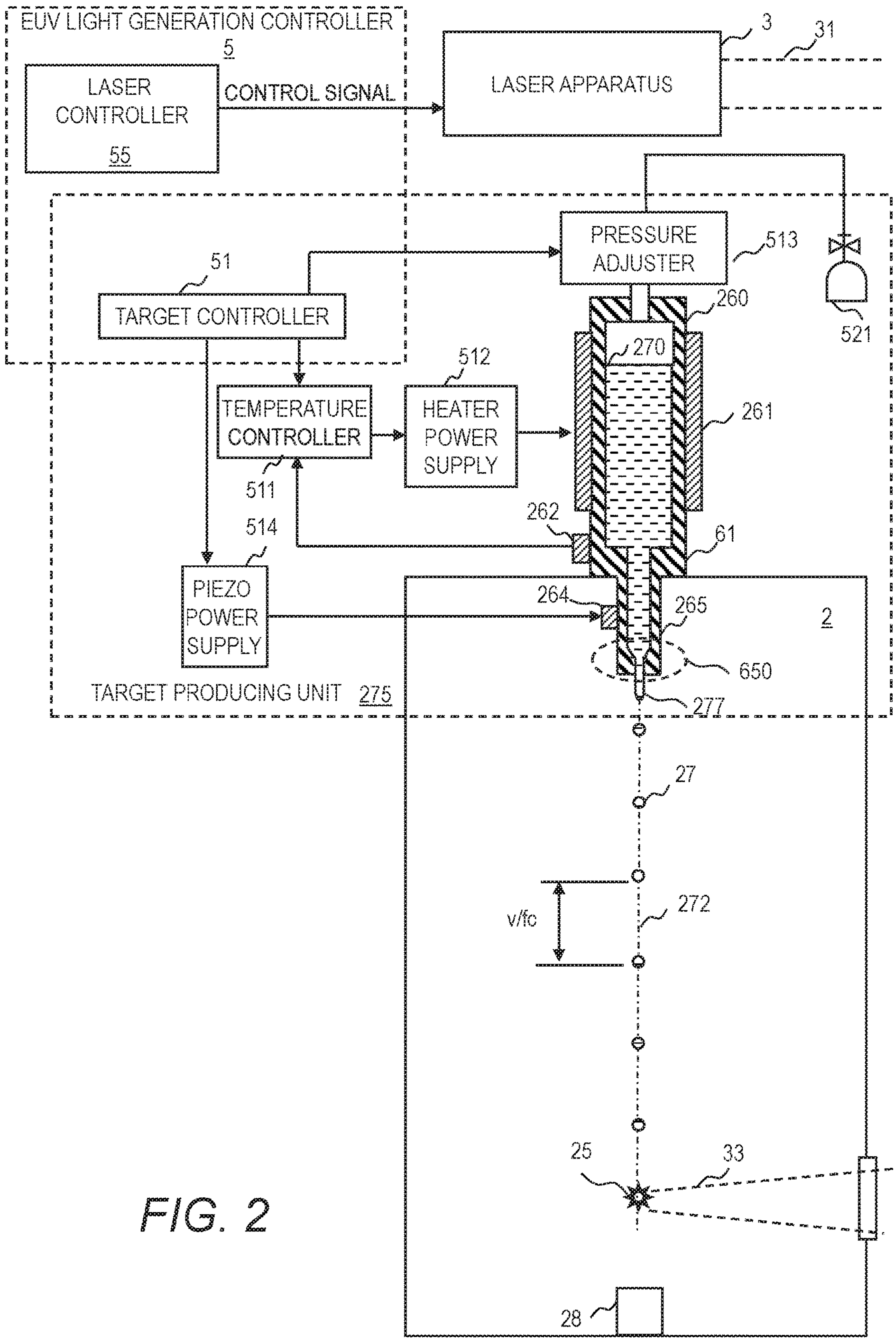
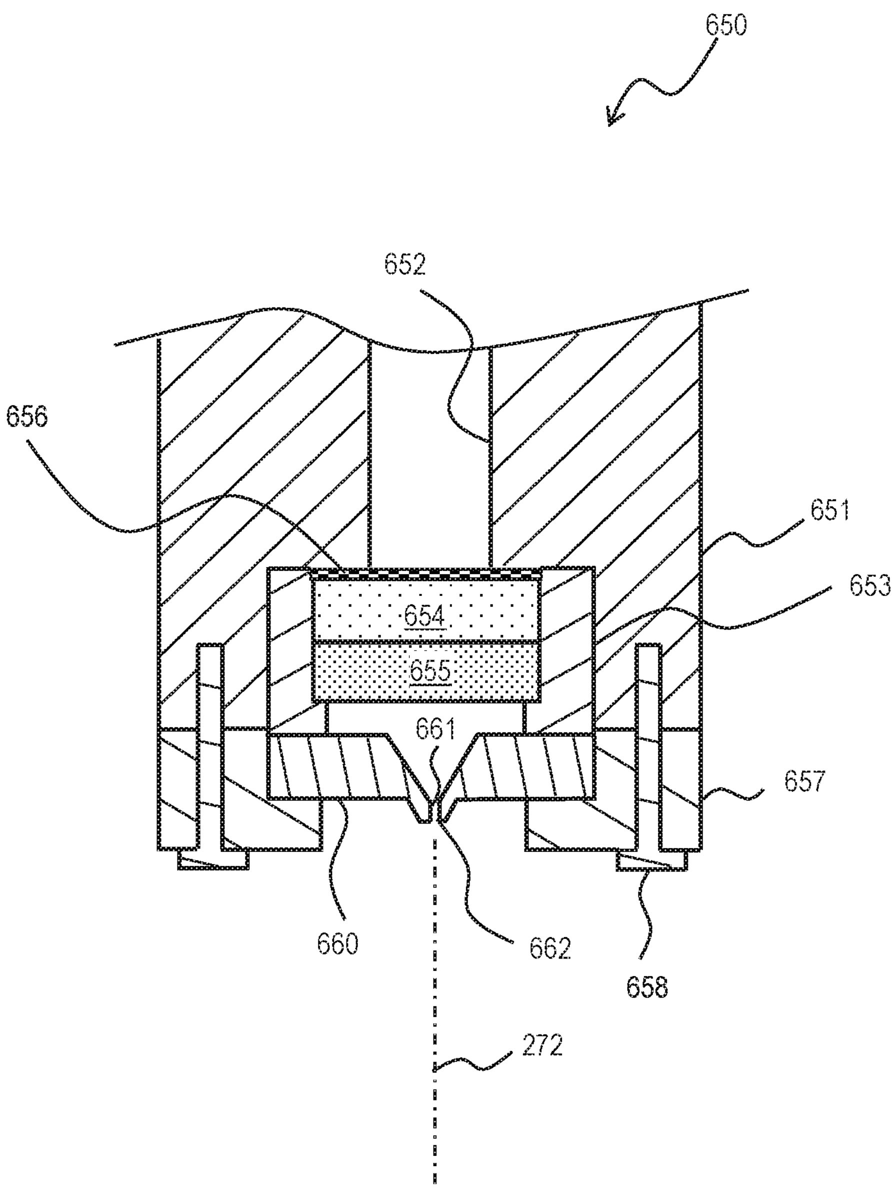

11 EUV LIGHT GENERATION SYSTEM
1 EUV LIGHT GENERATION APPARATUS
5
EUV LIGHT GENERATION CONTROLLER
3
LASER APPARATUS
31
34
LASER BEAM DIRECTION CONTROL UNIT
TARGET SENSOR
4
26
TARGET SUPPLY DEVICE
32
WINDOW 21
CHAMBER 2
27
33
6
EXPOSURE APPARATUS
291
292
29
CONNECTION PART
252
25
28
TARGET COLLECTOR
251
23
EUV COLLECTOR MIRROR
24
THROUGH-HOLE
22
LASER BEAM FOCUSING MIRROR

FIG. 1



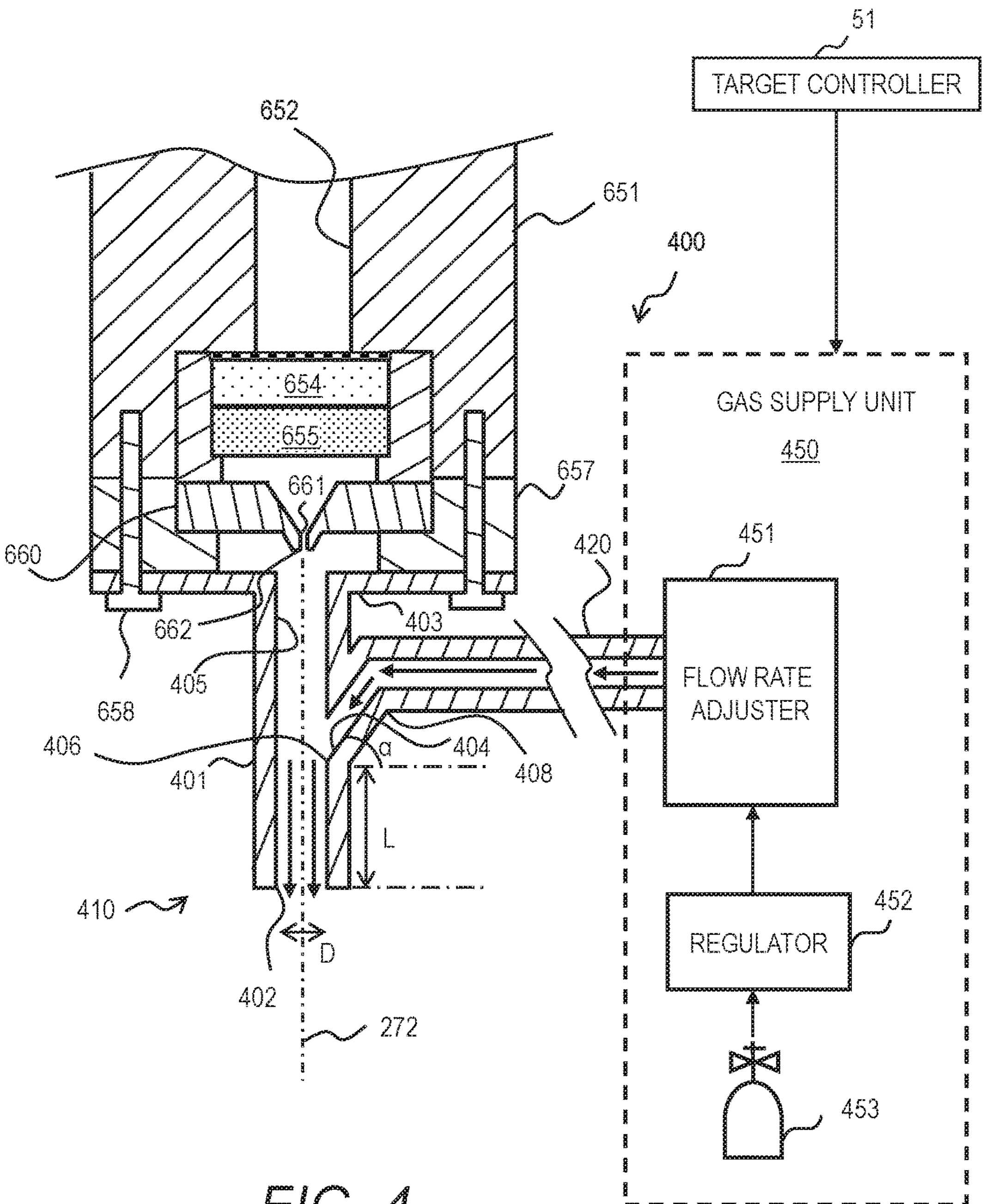
EUV LIGHT GENERATION CONTROLLER
5
LASER CONTROLLER
55
CONTROL SIGNAL
LASER APPARATUS
3
31
PRESSURE ADJUSTER
513
521
51
TARGET CONTROLLER
260
270
TEMPERATURE CONTROLLER
511
512
HEATER POWER SUPPLY
261
262
61
514
PIEZO POWER SUPPLY
264
265
2
650
TARGET PRODUCING UNIT 275
277
27
v/fc
272
25
33
28

FIG. 2



COMPARATIVE EXAMPLE

FIG. 3



51
TARGET CONTROLLER
652
651
400
654
655
GAS SUPPLY UNIT
450
661
657
420
451
660
403
662
FLOW RATE
ADJUSTER
405
658
406
404
α
408
401
L
410
452
REGULATOR
D
402
272
453

FIG. 4

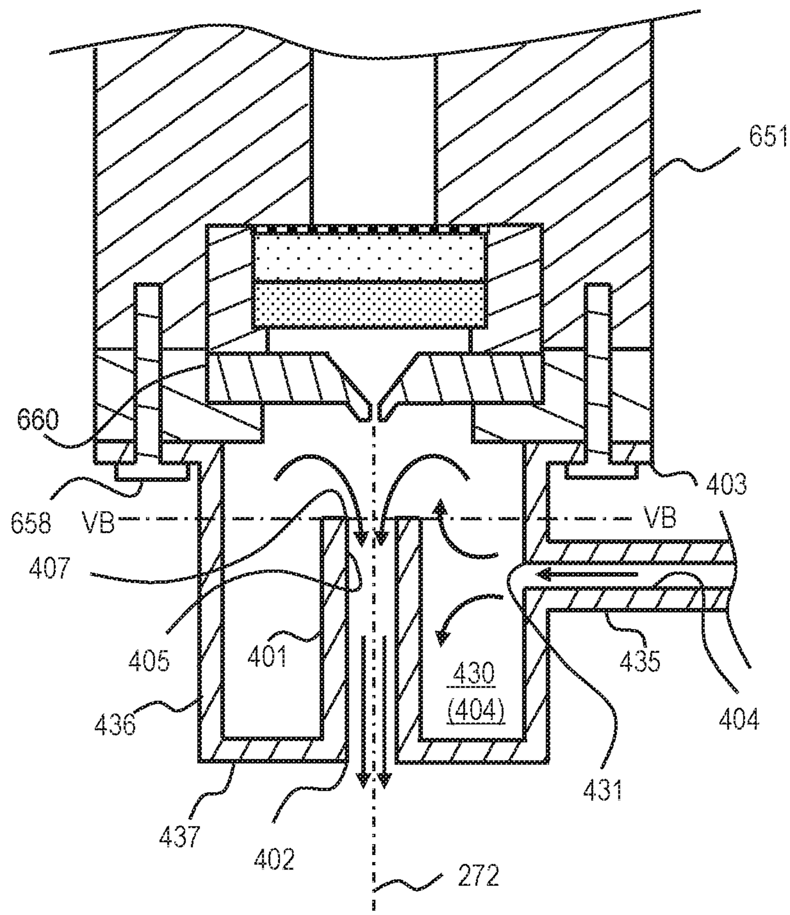

651
660
403
658
VB
VB
407
405
401
430
(404)
435
404
436
431
437
402
272

FIG. 5A

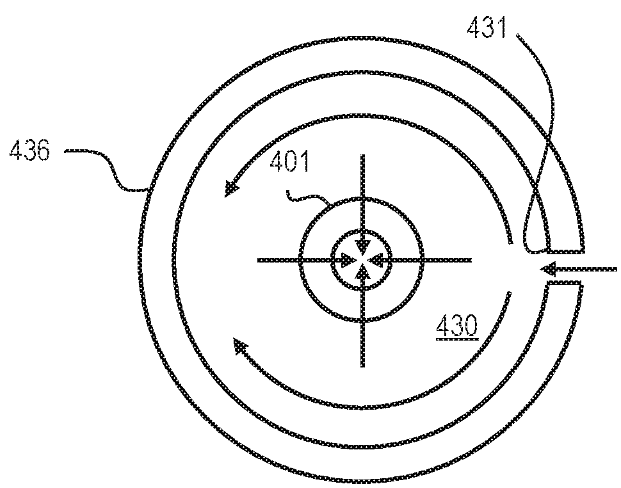
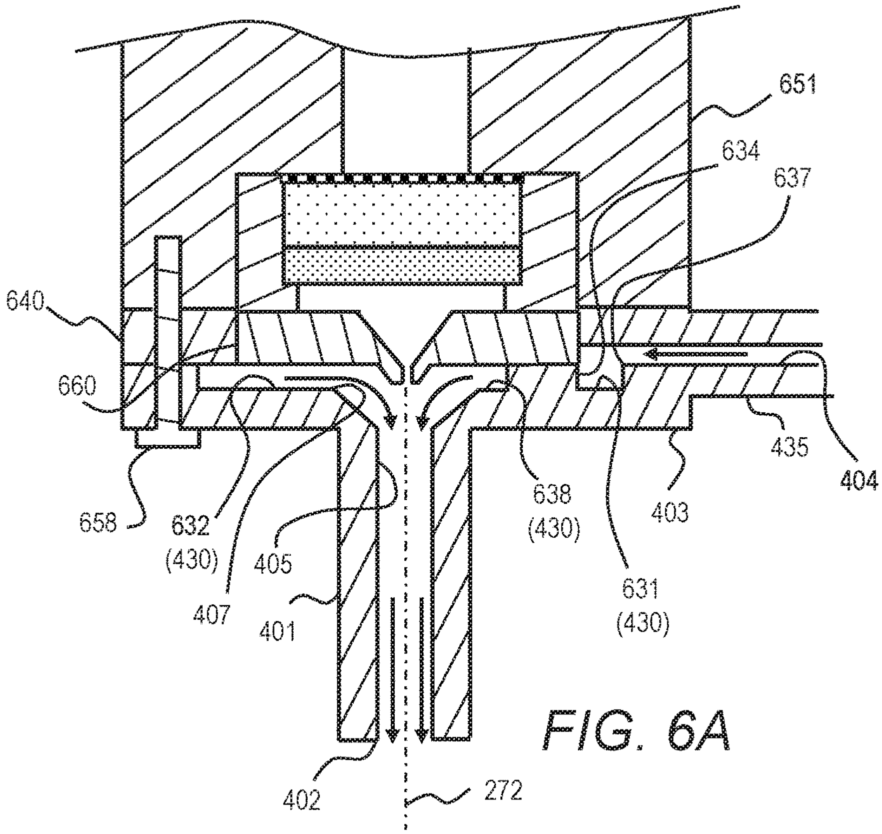
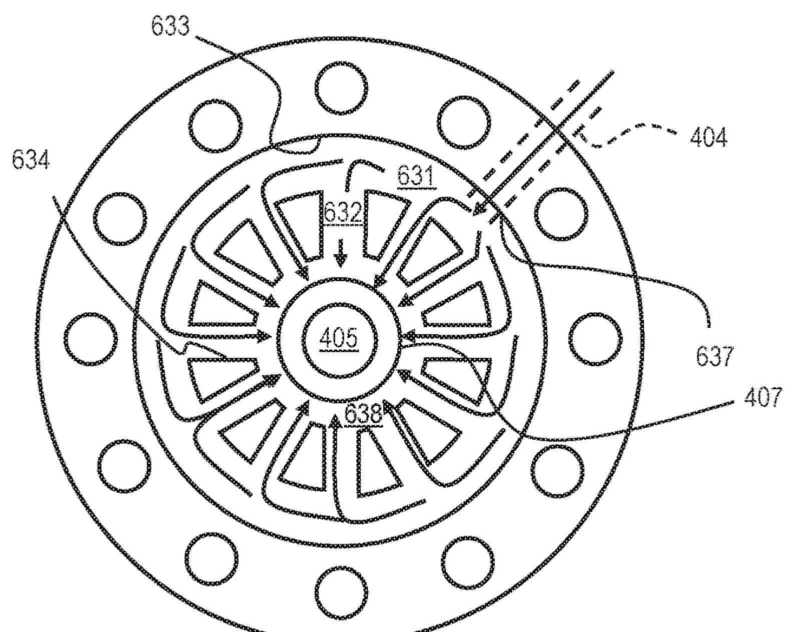

431
436
401
430

FIG. 5B



651
634
637
640
660
435
404
658
632 (430)
405
407
401
638 (430)
403
631 (430)
402
272

FIG. 6A



633
404
634
631
632
405
638
637
407

FIG. 6B

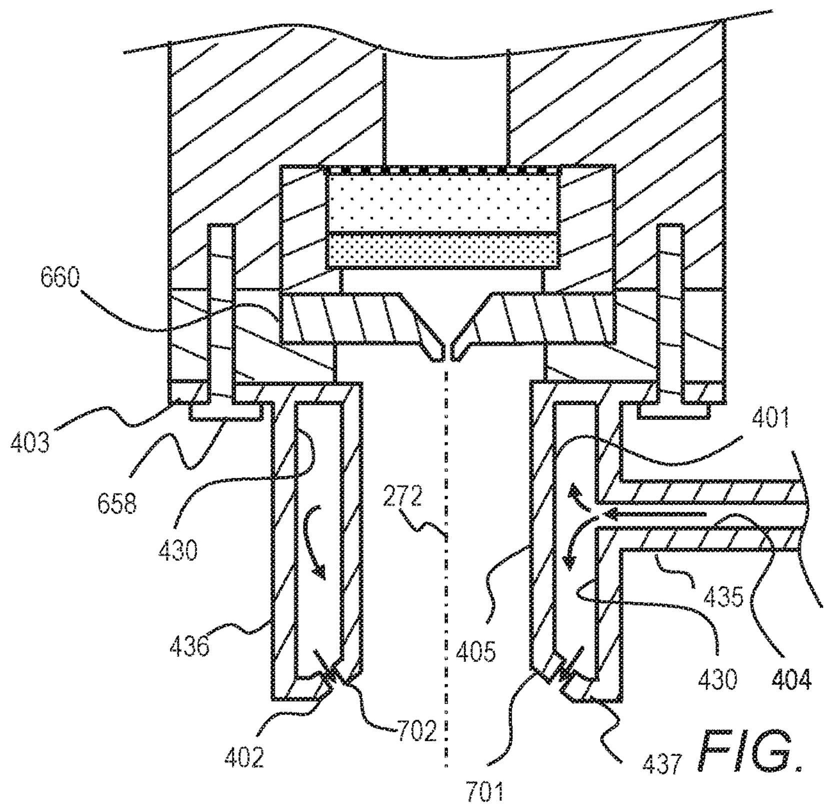


FIG. 7A

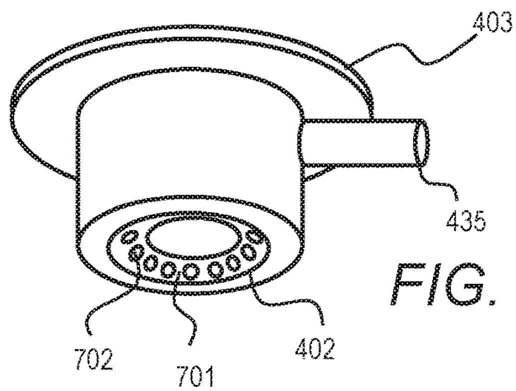


FIG. 7B

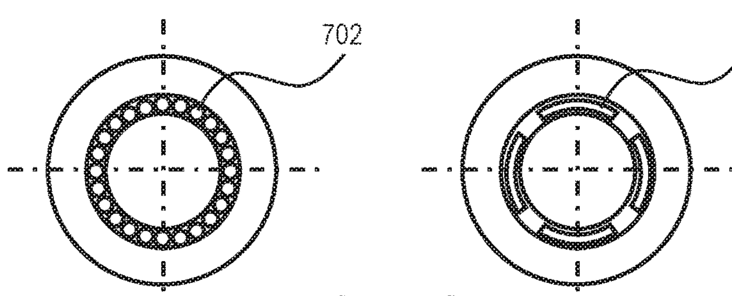


FIG. 7C

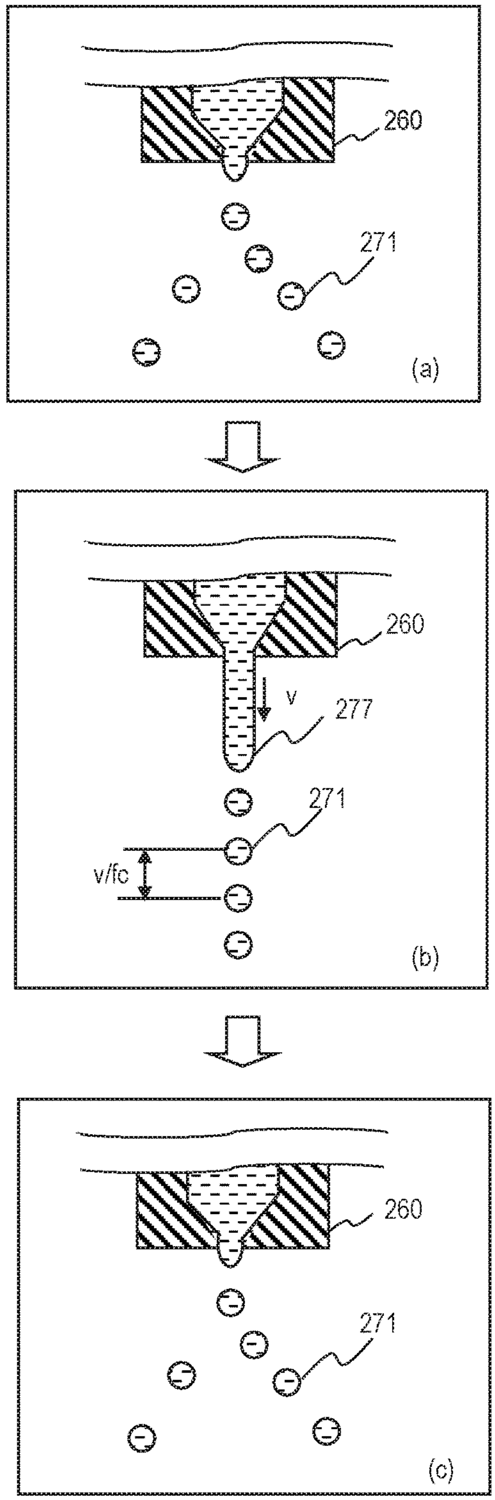


FIG. 8

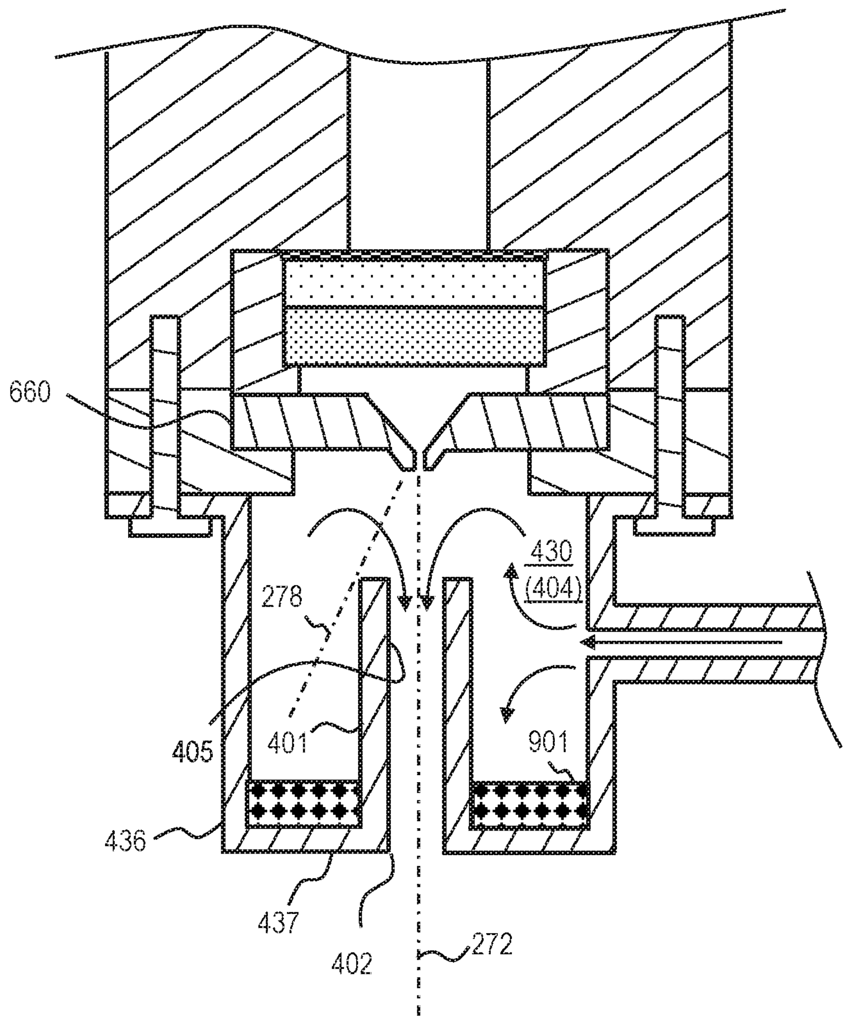


FIG. 9

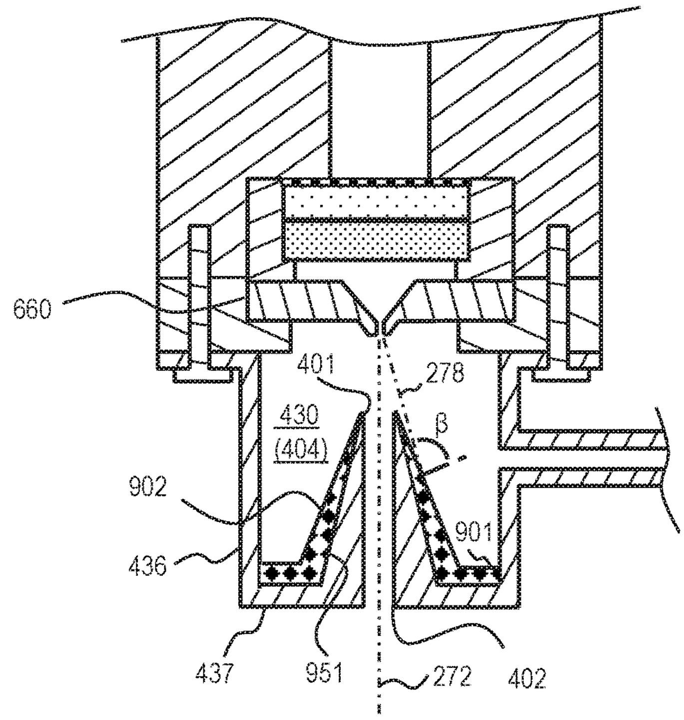

660
401
278
430
(404)
β
902
901
436
437
951
272
402

FIG. 10

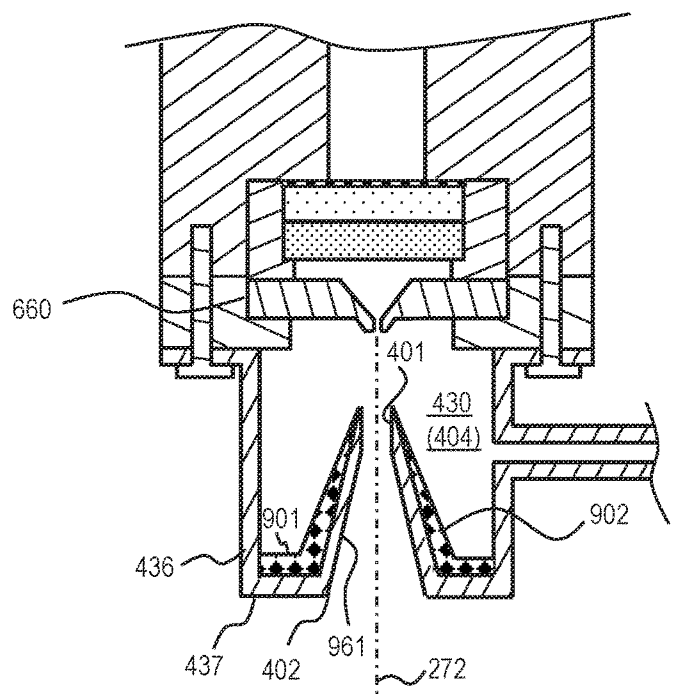

660
401
430
(404)
901
902
436
437
402
961
272

FIG. 11

TARGET PRODUCING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application is a continuation application of International Application No. PCT/JP2014/084337 filed on Dec. 25, 2014, which claims priority from International Application No. PCT/JP2013/084933 filed on Dec. 26, 2013, the content of which is hereby incorporated by reference into this application.

BACKGROUND

1. Technical Field

The present disclosure relates to a target producing apparatus to be used in an extreme ultraviolet light generation apparatus.

2. Related Art

In recent years, semiconductor production processes have become capable of producing semiconductor devices with increasingly fine feature sizes, as photolithography has been making rapid progress toward finer fabrication. In the next generation of semiconductor production processes, microfabrication with feature sizes at 70 nm to 45 nm, and further, microfabrication with feature sizes of 32 nm or less will be required. In order to meet the demand for microfabrication with feature sizes of 32 nm or less, for example, an exposure apparatus is needed in which a system for generating extreme ultraviolet (EUV) light at a wavelength of approximately 13 nm is combined with a reduced projection reflective optical system.

Three kinds of systems for generating EUV light are known in general, which include a Laser Produced Plasma (LPP) type system in which plasma is generated by irradiating a target material with a laser beam, a Discharge Produced Plasma (DPP) type system in which plasma is generated by electric discharge, and a Synchrotron Radiation (SR) type system in which orbital radiation is used to generate plasma.

SUMMARY

An example of the present disclosure may be a target producing apparatus to be used in an extreme ultraviolet light generation apparatus capable of generating extreme ultraviolet light by irradiating droplets in a plasma generation region with a laser beam. The target producing apparatus may include: a tank capable of containing a droplet material; a heater capable of heating the tank to melt the droplet material; a nozzle provided at a distal end of the tank and being capable of outputting droplets toward the plasma generation region; a nozzle holder holding the nozzle on the tank; a gas supply unit capable of supplying a gas; and a gas lock cover secured to the nozzle holder and provided downstream of the nozzle. The gas lock cover may cover a periphery of an exit of the nozzle and be structured to guide the gas supplied from the gas supply unit. The gas lock cover may include: a hollow cylindrical part provided downstream of the nozzle and having an exit opening for outputting droplets that are outputted from the nozzle and pass through an internal cavity of the cylindrical part; and a channel for transmitting the gas supplied from the gas supply unit. The channel may be structured to orient a flow of the transmitted gas so as to flow to the exit opening of the cylindrical part through the internal cavity of the cylindrical part.

Another example of the present disclosure may be a target producing apparatus to be used in an extreme ultraviolet light generation apparatus capable of generating extreme ultraviolet light by irradiating droplets in a plasma generation region with a laser beam. The target producing apparatus may include: a tank capable of containing a melted droplet material; a nozzle provided at a distal end of the tank and being capable of outputting droplets toward the plasma generation region; a nozzle holder holding the nozzle on the tank; a gas supply unit capable of supplying a gas; a gas lock cover secured to the nozzle holder and provided downstream of the nozzle. The gas lock cover may be structured to guide the gas supplied from the gas supply unit. The gas lock cover may include: a hollow cylindrical part provided downstream of the nozzle and having an exit opening for outputting droplets that are outputted from the nozzle and pass through an internal cavity of the cylindrical part; and a channel for transmitting the gas supplied from the gas supply unit. The channel may be structured to orient a flow of the transmitted gas so as to flow to the exit opening of the cylindrical part through the internal cavity of the cylindrical part. The channel may include a buffer space that joins the internal cavity of the cylindrical part and is structured to diffuse the gas flow entering the buffer space into different directions to guide the gas into the internal cavity of the cylindrical part.

BRIEF DESCRIPTION OF THE DRAWINGS

Hereinafter, selected embodiments of the present disclosure will be described with reference to the accompanying drawings.

FIG. **1** schematically illustrates an exemplary configuration of an LPP type EUV light generation system.

FIG. **2** schematically illustrates a configuration of a part of the EUV light generation system including a target producing apparatus.

FIG. **3** illustrates a comparative example of the configuration of the tip of a projection of a tank.

FIG. **4** schematically illustrates a configuration of a part of the target producing apparatus in Embodiment 1.

FIG. **5**A schematically illustrates a configuration example of a gas lock cover in Embodiment 2.

FIG. **5**B schematically illustrates a configuration example of a gas lock cover in Embodiment 2.

FIG. **6**A schematically illustrates a configuration example of a gas lock cover in Embodiment 3.

FIG. **6**B schematically illustrates a configuration example of a gas lock cover in Embodiment 3.

FIG. **7**A schematically illustrates a configuration example of a gas lock cover in Embodiment 4.

FIG. **7**B schematically illustrates a configuration example of a gas lock cover in Embodiment 4.

FIG. **7**C schematically illustrates a configuration example of a gas lock cover in Embodiment 4.

FIG. **8** schematically illustrates states of droplets outputted from a droplet supply device.

FIG. **9** schematically illustrates a configuration example of a gas lock cover in Embodiment 5.

FIG. **10** schematically illustrates a configuration example of a gas lock cover in Embodiment 6.

FIG. **11** schematically illustrates a configuration example of a gas lock cover in Embodiment 6.

DETAILED DESCRIPTION

<Contents>

Hereinafter, selected embodiments of the present disclosure will be described in detail with reference to the accompanying drawings. The embodiments to be described below are merely illustrative in nature and do not limit the scope of the present disclosure. Further, the configuration(s) and operation(s) described in each embodiment are not all essential in implementing the present disclosure. Note that like elements are referenced by like reference numerals and characters, and duplicate descriptions thereof will be omitted herein.

1. Overview

In an LPP type EUV light generation system, a target producing apparatus may output droplets of a target material from a nozzle into a chamber. The target producing apparatus may be controlled so that the droplets will reach a plasma generation region in the chamber at desired intervals.

The LPP type EUV light generation system may generate EUV light by irradiating targets with a pulse laser beam to change the targets into plasma. The LPP type EUV light generation system for an exposure apparatus may generate laser beam pulses at a high cyclic frequency of 50 to 100 kHz or higher to irradiate targets.

The targets, typically made of tin, irradiated with a pulse laser beam may diffuse because of the shock caused by the inflation pressure of the plasma when the targets change into plasma to generate EUV light. The targets not irradiated with the pulse laser beam may diffuse in being collected into a target collector. The diffuse target material (also referred to as droplet material) may become fine contaminant or debris and spread within the chamber. The spreading debris may reach the nozzle bore of the target supply device.

In an aspect of the present disclosure, the target producing apparatus may include a gas lock cover that covers the periphery of the nozzle exit and directs the gas supplied from a gas supply unit to keep the debris away from the nozzle exit with the gas flow. The gas lock cover may include a cylindrical part and a channel. The cylindrical part may be disposed downstream of the nozzle, be hollow, and have an exit opening. The droplets outputted from the nozzle may pass through the internal cavity of the cylindrical part and go out from the exit opening. The gas supplied from the gas supply unit may pass through the channel. The channel may orient the flow of the gas that is transmitted through the channel to go through the internal cavity of the cylindrical part to the exit opening of the cylindrical part.

This aspect of the present disclosure may prevent the debris from adhering to the nozzle using the gas flow. The debris may cause fluctuations in the trajectories of droplets.

In another aspect of the present disclosure, the target producing apparatus may include a gas lock cover disposed downstream of the nozzle. The gas lock cover may direct the gas supplied from the gas supply unit to keep the debris away from the nozzle exit. The gas lock cover may include a cylindrical part and a channel. The cylindrical part may be disposed downstream of the nozzle, be hollow, and have an exit opening. The droplets outputted from the nozzle may pass through the internal cavity of the cylindrical part and go out from the exit opening. The gas supplied from the gas supply unit may pass through the channel. The channel may orient the flow of the gas that has passed through the channel to go through the internal cavity of the cylindrical part to the exit opening of the cylindrical part. The channel may include a buffer space joined to the internal cavity of the cylindrical part to diffuse the gas flow that has entered the buffer space in different directions in directing the gas flow into the internal cavity of the cylindrical part.

This other aspect of the present disclosure may prevent the debris to cause fluctuations in the trajectories of droplets from adhering to the nozzle using a gas flow and further, prevent fluctuations in the trajectories of the droplets caused by the gas flow.

2. Terms

Terms used in the present disclosure will be described hereinafter. A "gas lock device" is a device to prevent debris from adhering to a specific region with a gas flow. A "nozzle bore" is a bore formed in a nozzle to output a droplet material therethrough. A "nozzle exit" is an opening at the distal end of the nozzle bore.

"Debris" is a substance including the target material supplied into the chamber but not changed to plasma as well as ionic and neutral particles emitted from plasma and may adhere to the nozzle to disturb precise supply of droplets. "Outputting a droplet from the nozzle or nozzle bore" includes an action that the droplet passes through the nozzle bore and in addition, an action that a droplet is produced and outputted from the jet outputted from the nozzle exit.

3. Overview of EUV Light Generation System

3.1 Configuration

FIG. **1** schematically illustrates an exemplary configuration of an LPP type EUV light generation system. An EUV light generation apparatus **1** may be used with at least one laser apparatus **3**. Hereinafter, a system that includes the EUV light generation apparatus **1** and the laser apparatus **3** may be referred to as an EUV light generation system **11**. As shown in FIG. **1** and described in detail below, the EUV light generation system **11** may include a chamber **2** and a target supply device **26**.

The chamber **2** may be sealed airtight. The target supply device **26** may be mounted onto the chamber **2**, for example, to penetrate a wall of the chamber **2**. A target material to be supplied by the target supply device **26** may include, but is not limited to, tin, terbium, gadolinium, lithium, xenon, or any combination thereof.

The chamber **2** may have at least one through-hole formed in its wall, a window **21** may be installed in the through-hole, and the pulse laser beam **32** from the laser apparatus **3** may travel through the window **21**. An EUV collector mirror **23** having a spheroidal surface may, for example, be provided in the chamber **2**. The EUV collector mirror **23** may have a first focus and a second focus.

The EUV collector mirror **23** may have a multi-layered reflective film including alternately laminated molybdenum layers and silicon layers formed on the surface thereof. The EUV collector mirror **23** is preferably positioned such that the first focus lies in a plasma generation region **25** and the second focus lies in an intermediate focus (IF) region **292**. The EUV collector mirror **23** may have a through-hole **24** formed at the center thereof and a pulse laser beam **33** may travel through the through-hole **24**.

The EUV light generation apparatus **1** may include an EUV light generation controller **5** and a target sensor **4**. The target sensor **4** may have an imaging function and detect at least one of the presence, trajectory, position, and speed of a target **27**.

Further, the EUV light generation system **11** may include a connection part **29** for allowing the interior of the chamber **2** to be in communication with the interior of the exposure apparatus **6**. A wall **291** having an aperture may be provided in the connection part **29**. The wall **291** may be positioned such that the second focus of the EUV collector mirror **23** lies in the aperture.

The EUV light generation apparatus **1** may also include a laser beam direction control unit **34**, a laser beam focusing mirror **22**, and a target collector **28** for collecting targets **27**. The laser beam direction control unit **34** may include an optical element for defining the direction and an actuator for adjusting the position, the orientation or posture, and the like of the optical element.

3.2 Operation

With reference to FIG. **1**, a pulse laser beam **31** outputted from the laser apparatus **3** may pass through the laser beam direction control unit **34** and, as the pulse laser beam **32**, travel through the window **21** and enter the chamber **2**. The pulse laser beam **32** may travel inside the chamber **2** along at least one beam path, be reflected by the laser beam focusing mirror **22**, and strike at least one target **27** as a pulse laser beam **33**.

The target supply device **26** may be configured to output the target(s) **27** toward the plasma generation region **25** in the chamber **2**. The target **27** may be irradiated with at least one pulse of the pulse laser beam **33**. Upon being irradiated with the pulse laser beam, the target **27** may be turned into plasma, and rays of light **251** may be emitted from the plasma.

The EUV light **252** included in the light **251** may be reflected selectively by the EUV collector mirror **23**. EUV light **252** reflected by the EUV collector mirror **23** may be focused at the intermediate focus region **292** and be outputted to the exposure apparatus **6**. Here, the target **27** may be irradiated with multiple pulses included in the pulse laser beam **33**.

The EUV light generation controller **5** may be configured to integrally control the EUV light generation system **11**. The EUV light generation controller **5** may be configured to process image data of the target **27** captured by the target sensor **4**. Further, the EUV light generation controller **5** may be configured to control: the timing when the target **27** is outputted and the direction into which the target **27** is outputted, for example.

Furthermore, the EUV light generation controller **5** may be configured to control at least one of: the timing when the laser apparatus **3** oscillates, the direction in which the pulse laser beam **33** travels, and the position at which the pulse laser beam **33** is focused. It will be appreciated that the various controls mentioned above are merely examples, and other controls may be added as necessary.

4. EUV Light Generation System Including Target Producing Apparatus

4.1 Configuration

FIG. **2** schematically illustrates a configuration of a part of the EUV light generation system **11** including a target producing apparatus **275**. The EUV light generation controller **5** may include a target controller **51** and a laser controller **55**. The target controller **51** may control the operation of the other components in the target producing apparatus **275**. The laser controller **55** may control the operation of the laser apparatus **3**.

The target producing apparatus **275** may include the target controller **51**, a temperature controller **511**, a heater power supply **512**, a pressure adjuster **513**, a piezo power supply **514**, a droplet supply device **260**, and an inert gas source **521**.

The droplet supply device **260** may be mounted on the chamber **2**. The droplet supply device **260** may include a tank **61**, a heater **261**, a temperature sensor **262**, and a piezoelectric element **264**. The tank **61** may have a smaller-diameter projection **265** at the distal end thereof.

A part of the tank **61** may be fit in a through-hole formed in a wall of the chamber **2** and the projection **265** of the tank **61** may be located inside the chamber **2**. The projection **265** may have a nozzle bore to eject the melted droplet material **270**. The material of droplets may be referred to as droplet material. The heater **261** and the temperature sensor **262** may be anchored on the outside of the tank **61**. The piezoelectric element **264** may be anchored on the outside of the projection **265**.

4.2 Operation

The droplet supply device **260** may store the droplet material **270** in the tank **61** in a melted state with the heater **261**. The target material may be tin, for example. The target controller **51** may control the temperature of the heater **261** to change the tin in the tank **61** into a liquid state by controlling the heater power supply **512** with the temperature controller **511**. As a result, the tin stored in the tank **61** may be melted.

The target controller **51** may control the piezo power supply **514** to send an electric signal to the piezoelectric element **264** at such a frequency to produce droplets from the liquid tin ejected from the projection **265**.

The pressure adjuster **513** may adjust the pressure of the inert gas to be supplied from the inert gas source **521** to the tank **61**. The target controller **51** may control the pressure in the tank **61** with the pressure adjuster **513**. The pressure adjuster **513** may adjust the pressure in the tank **61** to a predetermined value so that the droplets **27** will reach the plasma generation region **25** at a predetermined speed in a designed trajectory **272** in accordance with instructions from the target controller **51**.

The predetermined speed may be, for example, 60 m/s to 110 m/s. The predetermined pressure in the tank **61** may be, for example, 10 MPa to 20 MPa. As a result, a jet **277** of the droplet material may be ejected from the hole of the projection **265** at the predetermined speed.

The target controller **51** may send an electric signal at a carrier frequency fc to the piezo power supply **514** to oscillate the piezoelectric element **264** at the carrier frequency fc. The projection **265** may oscillate with the oscillation of the piezoelectric element **264** at the carrier frequency fc. The carrier frequency fc may be, for example, 1500 kHz.

The oscillation of the projection **265** at the carrier frequency fc may cause the jet **277** to oscillate at the carrier frequency fc. As a result, droplets **27** may be produced from the jet **277** at the carrier frequency fc.

The outputted droplets **27** may have diameters of 20 μm to 30 μm. The laser controller **55** may control the laser apparatus **3** to irradiate the plasma generation region **25** with a pulse laser beam **33** in synchronous with arrival of droplets **27** at the plasma generation region **25**. As a result, the target droplets **27** may turn into plasma to generate EUV light.

The droplets **27** not irradiated with the pulse laser beam **33** may pass through the plasma generation region **25** and enter the target collector **28** to be stored in the state of liquid tin.

4.3 Comparative Example of Configuration of Tip of Droplet Supply Device

FIG. **3** illustrates a comparative example of the configuration of the tip **650** of the projection **265** of the tank **61** in FIG. **2**. The tip **650** may include an output tube **651** of the tank **61** and a nozzle **660** held at the distal end of the output tube **651**. The output tube **651** may have a channel **652** in which the pressurized droplet material **270** flows. The inner diameter of the channel **652** may be smaller than the inner diameter of the body of the tank **61** containing the droplet material **270**.

Stacked filters **654** and **655** may be provided upstream of the nozzle **660**. A filter holder **653** holding the filters **654** and **655** may be fitted in the output tube **651**. A shim **656** may be provided upstream of the filters **654** and **655** to adjust the pressure to the filters **654** and **655**.

The filters **654** and **655** may remove impurities in the droplet material **270** flowing in the channel **652**. The filters **654** and **655** may have different densities. The number of filters may depend on the design. The filters may be omitted.

A nozzle holder **657** may hold the nozzle **660** and fix the nozzle **660** to the output tube **651**. The nozzle holder **657** may be secured to the output tube **651** with one or more bolts **658**.

The nozzle **660** may have a nozzle bore **661** to output the droplet material **270**. The nozzle bore **661** may have an exit opening (nozzle exit) **662** of the nozzle **660** at the distal end thereof. As described above, the jet **277** of the droplet material may be outputted from the nozzle exit **662**.

4.4 Issues

When a droplet **27** irradiated with a pulse laser beam **33** changes to plasma to generate EUV light, the droplet **27** may diffuse because of the shock of the inflation pressure of the plasma. A droplet **27** not irradiated with the pulse laser beam **33** may diffuse when being collected into the target collector **28**. The diffused droplet material may become fine contaminant or debris and spread within the chamber **2**. The spreading debris may adhere to the nozzle bore **661** of the nozzle **660** and its periphery. The debris adhered to the nozzle **660** may disturb stable production of droplets.

5. Embodiments

5.1 Embodiment 1: Target Producing Apparatus Including Gas Lock Device Configuration

FIG. **4** schematically illustrates a configuration of a part of the target producing apparatus **275** in the present embodiment. The target producing apparatus **275** may include a gas lock device **400** for preventing debris from adhering to the nozzle bore **661** and the periphery of the nozzle exit **662** of the nozzle **660**. The gas lock device **400** may prevent debris from adhering to the nozzle bore **661** and the periphery of the nozzle exit **662** by keeping the debris away from the nozzle exit **662** with a gas flow.

The gas lock device **400** may be provided downstream of the nozzle **660** and include a gas lock cover **410** for covering the periphery of the nozzle exit **662** and a gas supply unit **450** for supplying lock gas to the gas lock cover **410**. The gas supply unit **450** and the gas lock cover **410** may be connected by a relay tube **420**.

The gas supply unit **450** may include a flow rate adjuster **451**, a regulator **452**, and a gas source **453**. The flow rate adjuster **451** may adjust the flow rate of the lock gas supplied from the gas source **453** to the gas lock cover **410** through the relay tube **420**. The regulator **452** may adjust the gas pressure of the gas supplied from gas source **453**. The target controller **51** may control the flow rate adjuster **451** and the regulator **452** to control the flow rate and the pressure of the lock gas to be supplied to the gas lock cover **410**.

The gas supply unit **450** may supply a lock gas, which may be an active gas that reacts to the droplet material to generate a substance that becomes a gas at room temperature. If the droplet material is Sn, the gas to be supplied may be a gas including H_2. Sn and H_2 react to generate SnH_4, which is gaseous at room temperature. Instead of the reactive gas, the gas supply unit **450** may supply an inert gas such as a noble gas.

The gas lock cover **410** may include parts of a cylinder **401**, a support **403** for supporting the cylinder **401** at an upstream of the cylinder **401**, and a channel **404** for directing the lock gas to the inside (cylinder internal cavity) **405** of the cylinder **401**. The channel **404** may be defined in a tube **408**. The tube **408** may connect with the gas supply unit **450** via the relay tube **420**.

The gas lock cover **410** may be disposed downstream of the nozzle **660** and cover the periphery of the nozzle exit **662** to direct the lock gas so that the lock gas flow will keep the debris away from the nozzle exit **662**.

The support **403** may be secured tight to the nozzle holder **657** with bolts **658**. The support **403** may be planar and surround the entire circumference of the nozzle exit **662**. An O-ring may be sandwiched between the support **403** and the nozzle holder **657** for sealing.

The cylinder **401** may be disposed and fixed downstream of the nozzle exit **662** and extend toward the plasma generation region **25**. The designed droplet trajectory **272** may run through the cylinder internal cavity **405**. The nozzle exit **662** may be on the extension of the central axis of the cylinder **401**; the central axis of the cylinder **401** may correspond to the designed droplet trajectory **272**. The cylinder **401** may have an exit opening (cylinder exit) **402** to output droplets. The portion including the nozzle exit **662** may be exposed to the interior of the chamber **2** only at the cylinder exit **402** of the gas lock cover **410**.

The material of the cylinder **401** may be a substance that hardly reacts to the droplet material, for example, Mo. Alternatively, the surface of the cylinder **401** may be coated with a substance that hardly reacts to the droplet material.

The channel **404** may join the cylinder internal cavity **405** at the side of the cylinder **401**. A lock gas entrance **406** is formed in the side wall of the cylinder internal cavity **405** and the channel **404** may be connected with the cylinder internal cavity **405** at the lock gas entrance **406**. The entry angle α of the channel **404** to the designed droplet trajectory **272** at the lock gas entrance **406** may be larger than 0°.

The entry angle α may be 45° or more and more particularly, 60° or more. The entry angle α may be defined between the central axis of the channel **404** and the designed droplet trajectory **272** at the lock gas entrance **406**.

The lock gas supplied from the gas supply unit **450** may pass through the channel **404**. The channel **404** may orient the flow of the lock gas so that the lock gas that has passed through the channel **404** will flow from the cylinder internal cavity **405** to the cylinder exit **402**.

The cross-section of the cylinder internal cavity **405** is not limited to a circle, but may be a polygon. The inner wall of the cylinder **401** may have a smooth surface. This structure may prevent fluctuation of the droplet trajectory caused by turbulence of the lock gas flow.

The inner diameter D of the cylinder **401** and the length L from the lock gas entrance **406** to the cylinder exit **402** may be designed to achieve the gas lock function required to prevent adhesion of debris to the nozzle **660** and to reduce the flow rate of the lock gas. In addition, the inner diameter D of the cylinder **401** and the length L from the lock gas entrance **406** to the cylinder exit **402** may be designed to prevent droplets from adhering to the cylinder internal cavity **405** because of the fluctuation of the trajectory. For example, the inner diameter D may be determined to be 3 mm or more, and the length L may be determined to be 4 mm or more.

Operation

To start supplying targets, the target controller **51** may control the flow rate adjuster **451** to supply lock gas including H_2 to the cylinder internal cavity **405**. The flow rate of the lock gas may be 42 sccm or more, for example.

The lock gas supplied from the gas supply unit **450** may pass through the relay tube **420** and the channel **404** of the gas lock cover **410** to enter the cylinder internal cavity **405**. The lock gas that enters the cylinder internal cavity **405** from the channel **404** via the lock gas entrance **406** may flow to the cylinder exit **402**. In this way, the gas lock cover **410** may generate a lock gas flow directed from the cylinder exit **402** toward the plasma generation region **25**.

The droplets outputted from the nozzle **660** may pass through the cylinder internal cavity **405** and be outputted from cylinder exit **402** toward the plasma generation region **25**. The angle of the gas flow entering the cylinder internal cavity **405** may depend on the angle of the channel **404** at the lock gas entrance **406**. The entry angle of the lock gas flow entering the cylinder internal cavity **405** with respect to the trajectory of the droplets may be larger than 0°, and particularly, 45° or more, and further, 60° or more. This structure may reduce the effects of the lock gas flow on the droplet trajectory.

If debris scatters within the chamber **2**, the lock gas flow passing through the cylinder internal cavity **405** and outputted from the cylinder exit **402** may reduce the momentum of the debris flying toward the nozzle **660**. If the droplet material is Sn, part of the debris exposed to the lock gas flow may react to H_2 to become SnH_4 gas.

Effects

The gas lock device **400** may reduce the contaminant adhered to the nozzle **660**, so that the nozzle **660** may stably output the droplet material for a long term. As a result, the EUV light generation system **11** may stably generate EUV light.

Structure of Cylinder

The structure of the cylinder **401** is described. The Peclet number of the cylinder **401** is expressed as the following formula (1). With increase in Peclet number, the effect of the gas lock function may increase.

$$Pe = vL/D_f \quad (1)$$

Pe: Peclet number

v: Speed of lock gas flow inside the cylinder (m/s)

Df: Diffusion factor of debris in the lock gas (m^2/s)

L: Length from the cylinder exit to the lock gas entrance (m)

If the cylinder has a right circular cylindrical shape, the Peclet number may be expressed as the following formula (2):

$$Pe = \left(\frac{Q}{P}\frac{4}{\pi D^2}\right)L/D_f \quad (2)$$

Q: Flow rate of lock gas that passes through the cylinder internal cavity per pressure ($Pa \cdot m^3/s$)

P: Pressure in the cylinder internal cavity (Pa)

D: Inner diameter of the cylinder (m)

Substituting 4 mm for L, 3 mm for D, and 8 $Pa \cdot m^2/s$ for the product P·Df of the pressure by the diffusion factor in the formula (2), if the minimum required Peclet number is 5, the required flow rate is 42 sscm or more. If the minimum required Peclet number is 10, the required flow rate is 85 sscm or more. If the minimum required Peclet number is 20, the required flow rate is 168 sscm or more.

The rate R of preventing contamination of debris is "the mass of debris in use of gas lock/the mass of debris not in use of gas lock" and may be expressed as the following formula (3).

$$R = \mathrm{EXP}(Pe) \quad (3)$$

Formula (3) teaches that increasing the Peclet number may prevent debris from reaching the nozzle **660** more effectively. Formula (2) may derive the following factors to increase the Peclet number:

(a) to increase the flow rate Q of the lock gas,

(b) to increase the length L from the lock gas entrance to the cylinder exit, and

(c) to reduce the inner diameter D of the cylinder.

However, the length of the cylinder **401** may have a limitation. For example, if the cylinder **401** is too long, the cylinder **401** may overlap with the optical path of the EUV light to block the EUV light. If the flow rate Q of the lock gas is increased or the inner diameter D of the cylinder **401** is reduced, the droplet trajectory may be largely fluctuated because of the effects of the lock gas flow.

Accordingly, a structure for reducing the fluctuation in droplet trajectory caused by the lock gas flow may be demanded. In the present embodiment, the entry angle α of the channel **404** to the designed droplet trajectory **272** may be larger than 0°, and particularly, 45° or more, and further, 60° or more. Such a structure may reduce the fluctuation in droplet trajectory caused by the lock gas flow.

5.2 Embodiment 2: Gas Lock Device with Buffer Space (1) Configuration

The present embodiment provides a configuration example of a gas lock device **400** for reducing the fluctuation in droplet trajectory caused by the lock gas flow. FIGS. **5**A and **5**B schematically illustrate a configuration example of a gas lock cover **410** in the present embodiment. FIG. **5**B shows a cross-section along the line VB-VB in FIG. **5**A.

The gas lock cover **410** may have a buffer space **430** in the channel **404** for the lock gas. The buffer space **430** may be formed in the channel **404** between the tube **435** and the cylinder internal cavity **405**. The buffer space **430** may be formed to surround the outer wall of the cylinder **401**. In FIG. **5**A, the channel **404** may include the space in the tube **435** and the buffer space **430**.

The buffer space **430** may be configured as a space between the walls **436** and **437** surrounding the cylinder **401** and the cylinder **401**. The wall **436** may be parallel to the outer wall of the cylinder **401**. The wall **437** may connect the wall **436** and the cylinder exit **402**. The wall **436** may be continued to the support **403**.

The droplet entrance **407** of the cylinder **401** may be exposed to the buffer space **430**. The buffer space **430** may join the cylinder internal cavity **405** via the droplet entrance **407**.

The tube **435** may be connected at the lock gas entrance **431** formed in the wall **436**. The lock gas entrance **431** to the buffer space **430** may face the outer wall of the cylinder **401**. The lock gas entrance **431** may be located between the droplet entrance **407** and the nozzle exit **402** in the direction along the designed droplet trajectory **272**.

Operation

The lock gas supplied from the gas supply unit **450** may flow through the channel **404** in the tube **435** and enter the buffer space **430** from the lock gas entrance **431**. As illustrated in FIGS. **5**A and **5**B, the buffer space **430** may diffuse the incoming lock gas flow into different directions to guide the gas to the cylinder internal cavity **405**. The lock gas that has entered the buffer space **430** may diffuse in the circumferential directions and the axial directions of the cylinder **401**. The speed of the lock gas flow may decrease in the buffer space **430**.

The lock gas flow diffused in the buffer space **430** may enter the cylinder internal cavity **405** through the droplet entrance **407** from various different directions. As illustrated in FIGS. **5**A and **5**B, the lock gas may enter the cylinder internal cavity **405** from any directions of the droplet entrance **407**.

Effects

The buffer space **430** may prevent the lock gas coming from the tube **435** from directly blowing the droplets. Since the buffer space **430** may diffuse the incoming gas flow into different directions to guide the gas into the cylinder internal cavity **405**, the lock gas may enter the cylinder internal cavity **405** from many different directions. The speed of the lock gas flow in each direction may decrease. Furthermore, the lock gas may enter the cylinder internal cavity **405** from the opposite direction. As a result, fluctuation in droplet trajectory may be prevented.

5.3 Embodiment 3: Gas Lock Device with Buffer Space (2) Configuration

The present embodiment provides a configuration example of a gas lock device **400** for reducing the fluctuation in droplet trajectory caused by the lock gas flow. FIGS. **6**A and **6**B schematically illustrate a configuration example of the gas lock cover **410** in the present embodiment. FIG. **6**B illustrates a face of a support **403** being opposed to the nozzle. The support **403** is a component of the gas lock cover **410**.

The gas lock cover **410** may have a buffer space **430** in the channel **404** for the lock gas. The gas lock cover **410** may include an input-side part **640**, a support **403**, and a cylinder **401**. The support **403** may have a function of a nozzle holder to support the nozzle **660** and fix the nozzle **660** to the tank **61**.

The buffer space **430** may be formed in the channel **404** between the input-side part **640** and the support **403**. In FIG. **6**A, the channel **404** may include the space in the tube **435** and the buffer space **430**. The buffer space **430** may include an outer annular space **631** and an inner annular space **638** formed to surround the cylinder internal cavity **405** as seen in the direction of outputting droplets. The centers of the outer annular space **631** and the inner annular space **638** may match the center of the cylinder internal cavity **405** or the designed droplet trajectory **272**.

The outer annular space **631** may be a space defined between a plurality of islands **634** disposed in a circle and the outer wall **633**. The inner annular space **638** may be a space between the plurality of islands **634** and the droplet entrance **407** of the cylinder **401**. Each of the plurality of islands **634** may contact with the nozzle **660** to support the nozzle **660** and in addition, to regulate the flow of the lock gas.

The buffer space **430** may further include a radial space **632** between the outer annular space **631** and the inner annular space **638**. The radial space **632** may be formed between each two of multiple islands **634** disposed in a circle. The radial space **632** may connect the outer annular space **631** and the cylinder internal cavity **405** via the inner annular space **638**. The inner annular space **638** may be omitted.

The radial space **632** may be configured with a plurality of space pairs; the spaces of each pair are opposed to each other with respect to the center of the cylinder internal cavity **405**. The radial space **632** may be composed of spaces having the identical shapes or spaces having different shapes. The radial space **632** may be symmetric about the center of the cylinder internal cavity **405** or the designed droplet trajectory **272**.

The cylinder **401** may have an inner wall tapered from the input end. The droplet entrance **407** of the cylinder **401** may be exposed to the buffer space **430**. The buffer space **430** may join the cylinder internal cavity **405** via the droplet entrance **407**.

The tube **435** may join the outer annular space **631** at the lock gas entrance **637**. The lock gas entrance **637** to the outer annular space **631** may face the outer end face of one island **634**.

Operation

The lock gas supplied from the gas supply unit **450** may flow through the channel **404** in the tube **435** and enter the buffer space **430** from the lock gas entrance **637**. As illustrated in FIGS. **6**A and **6**B, the buffer space **430** may diffuse the incoming lock gas flow into different directions to guide the gas to the cylinder internal cavity **405**. The speed of the lock gas flow may decrease in the buffer space **430**.

Specifically, the lock gas that has entered the buffer space **430** through the lock gas entrance **637** may flow in the outer annular space **631** in both circumferential directions. Furthermore, the lock gas may flow through the radial space **632** to reach the droplet entrance **407** of the cylinder **401**. The lock gas may enter the cylinder internal cavity **405** from radial directions.

Effects

The outer annular space **631** and the radial space **632** may prevent the lock gas entering from the tube **435** from directly blowing the droplets. Since the outer annular space **631** and the radial space **632** may diffuse the incoming gas flow into different directions to guide the gas into the cylinder internal cavity **405**, the lock gas may enter the cylinder internal cavity **405** from many different directions.

The speed of the lock gas flow in each direction may decrease. Furthermore, the lock gas may enter the cylinder internal cavity **405** from the opposite direction. As a result, fluctuation in droplet trajectory may be prevented. The radial space **632** may control the directions of the lock gas to enter the cylinder internal cavity **405** more reliably.

5.4 Embodiment 4: Gas Lock Device with Buffer Space (3)

The present embodiment provides a configuration example of a gas lock device **400** for reducing the fluctuation in droplet trajectory caused by the lock gas flow. Hereinafter, differences from Embodiment 2 are mainly described. FIGS. 7A to 7C schematically illustrate a configuration example of the gas lock cover **410** in the present embodiment. FIG. 7B is a perspective view of the gas lock cover **410** and FIG. 7C provides configuration examples of the output end face of the gas lock cover **410**.

The input end of the cylinder **401** may be joined with the support **403**. The output end of the cylinder **401** may have a reverse-tapered face **701** that expands outward as the output end gets closer to the plasma generation region **25**. The reverse-tapered face **701** may be of the wall of the cylinder internal cavity **405**. The reverse-tapered face **701** may have a plurality of lock gas outlets **702**.

The plurality of lock gas outlets **702** may be disposed symmetrically about the center of the cylinder **401** or the designed droplet trajectory **272**. Each lock gas outlet **702** may be opposed to a lock gas outlet **702**.

The number and the shape of the lock gas outlets **702** may depend on the design. For example, the shape of each lock gas outlet **702** may be a circle or an arc slit as illustrated in FIG. 7C. The circular lock gas outlets **702** may have a diameter of 10 to 100 μm, for example.

The lock gas in the buffer space **430** may spout from the lock gas outlet **702**. The spouting direction of the lock gas may have a component heading toward the designed droplet trajectory **272** and a component in the output direction of droplets. Each lock gas outlet **702** may be provided with an opposed lock gas outlet **702** to reduce the fluctuation in droplet trajectory caused by the lock gas flow.

5.5 Embodiment 5: Gas Lock Device with Buffer Space (4) (with Damper Member)

FIG. **8** schematically illustrates states of droplets outputted from the droplet supply device **260**. FIG. **8**(*a*) schematically illustrates the state of droplets **271** immediately after start of ejection of the droplet material from the droplet supply device **260**. FIG. **8**(*b*) schematically illustrates the state when the droplet supply device **260** steadily ejects a jet **277** and droplets **271**.

FIG. **8**(*c*) schematically illustrates the state of droplets **271** immediately before stop of ejection of the droplet material from the droplet supply device **260**. The operating status of the droplet supply device **260** may change in the order of FIG. **8**(*a*), FIG. **8**(*b*), and FIG. **8**(*c*).

The pressure applied to the droplet material in the tank **61** may be low immediately after the start and immediately before the stop of ejection of the droplet material from the droplet supply device **260**. Accordingly, the trajectories of the droplets **271** may become unstable immediately after the start and immediately before the stop of ejection of the droplet material.

When the trajectories of droplets **271** are unstable, the droplets **271** may bounce off the wall forming the buffer space and as a result, may adhere to the nozzle **660**. To reduce the momentums of the droplets **271** outputted obliquely with respect to the designed droplet trajectory **272** and to prevent the droplets **271** from adhering to the nozzle **660**, the buffer space may be provided with a damper member therein.

FIG. **9** schematically illustrates a configuration example of the gas lock cover **410** in the present embodiment. Hereinafter, differences from Embodiment 2 are mainly described. The gas lock cover **410** may have a damper member **901** in the buffer space **430**. For example, as illustrated in FIG. **9**, the gas lock cover **410** may have a dumper member **901** on the bottom of the buffer space **430**. The dumber member **901** may be provided at a different place. The damper member **901** may attenuate the impact of the droplet **271** that hits the damper member **901**; the droplet **271** that hits the damper member **901** may adhere to the damper member **901**.

The damper member **901** may be formed of a graphite felt made of carbon fiber, for example. The graphite felt includes three-dimensionally tangled carbon fiber in mesh; when a droplet hits the damper member **901**, the damper member **901** may absorb the impact. As a result, the damper member **901** may prevent the droplet from bouncing off.

The damper member **901** may be made of a porous ceramic material (inclusive of glass material) or a foam metal. The material of the damper member **901** may be a porous material made of silicon carbide, silicon nitride, aluminum oxide, zirconium oxide, silicon oxide, or a silicon oxide glass including aluminum oxide, or otherwise, a foam metal made of nickel or aluminum. The damper member **901** may be a woven textile of quartz glass fiber.

The walls **436** and **437** defining the buffer space **430** may be heated by the heat conducted from the heater **261** provided for the tank **61**. Likewise, the damper member **901** may be heated by the heat conducted from the heater **261**. The walls **436** and **437** defining the buffer space **430** may be provided with a heater to heat the damper member **901**.

The material of the damper member **901** may be selected from the materials that have contact angles with melted tin being the droplet material is not more than 90°. For example, the material of the damper member **901** may be selected from aluminum, copper, silicon, nickel, titan, and molybdenum.

For example, in the case where the damper member **901** is made of a foam metal of nickel or aluminum, the damper member **901** may melt the droplets adhered thereto and store them in the foam metal. This configuration may prevent deposition of the droplets outputted in a tilted trajectory on the surface of the damper member **901**, preventing reduction in impact absorption effect.

5.6 Embodiment 6: Gas Lock Device with Buffer Space (5) (with Tilted Damper Member)

FIG. **10** schematically illustrates a configuration example of the gas lock cover **410** in the present embodiment.

Hereinafter, differences from Embodiment 5 are mainly described. As illustrated in FIG. **10**, the gas lock cover **410** may have a damper member **902** on the outer wall **951** of the cylinder **401**. The outer diameter of the cylinder **401** may increase in the output direction. Likewise, the outer diameter of the damper member **902** on the outer wall **951** of the cylinder **401** may increase in the output direction.

Regarding the trajectory **278** of a droplet off the designed droplet trajectory **272**, the entry angle β of the droplet to the damper member **902** on the outer wall **951** of the cylinder **401** may be 0° or more; the entry angle β may increase depending on the shape of the damper member **902**. A larger entry angle β of a droplet to the damper member **902** may prevent the droplet from bouncing off the damper member **901** toward the nozzle **660**.

FIG. **11** schematically illustrates another configuration example of the gas lock cover **410** in the present embodiment. As illustrated in FIG. **11**, the diameter of the cylinder internal cavity **405** may increase in the droplet output direction. That is to say, the inner wall **961** of the cylinder **401** may be slanted with respect to the designed droplet trajectory **272** and the distance between the designed droplet trajectory **272** and the inner wall **961** may increase as getting closer to the plasma generation region **25**.

When droplets are not outputted normally but outputted slightly obliquely to the designed droplet trajectory **272**, the droplets may adhere to the inner wall **906** of the cylinder **401**. The adhered droplets may react to H_2 to generate SnH_4, be deposited onto the cylinder internal cavity **405** heated by the heat conductance, and block the designed droplet trajectory **272**.

Increasing the inner diameter of the cylinder **401** on the downstream side may reduce the adhesion of droplets outputted slightly obliquely to the designed droplet trajectory **272** to the inner wall **961** of the cylindrical part. In the configuration of FIG. **11**, the damper members **901** and **902** may be omitted. The cylinder **401** may have a uniform outer diameter and an inner diameter increasing on the downstream side.

As set forth above, the present invention has been described with reference to embodiments. The foregoing description is merely provided for the purpose of exemplification but not limitation. Accordingly, it is obvious for a person skilled in the art that the embodiments in this disclosure may be modified within the scope of the appended claims.

A part of the configuration of an embodiment may be replaced with a configuration of another embodiment. A configuration of an embodiment may be incorporated to a configuration of another embodiment. A part of the configuration of each embodiment may be removed, added to a different configuration, or replaced by a different configuration.

The terms used in this specification and the appended claims should be interpreted as "non-limiting". For example, the terms "include" and "be included" should be interpreted as "including the stated elements but not limited to the stated elements". The term "have" should be interpreted as "having the stated elements but not limited to the stated elements". Further, the modifier "one (a/an)" should be interpreted as "at least one" or "one or more."

What is claimed is:

1. A target producing apparatus, to be used in an extreme ultraviolet light generation apparatus capable of generating extreme ultraviolet light by irradiating droplets in a plasma generation region with a laser beam, the target producing apparatus comprising:

a tank capable of containing a melted droplet material;

a nozzle provided at a distal end of the tank and being capable of outputting droplets toward the plasma generation region;

a nozzle holder holding the nozzle on the tank;

a gas supply unit capable of supplying a gas;

a gas lock cover secured to the nozzle holder and provided downstream of the nozzle, the gas lock cover being structured to guide the gas supplied from the gas supply unit,

wherein the gas lock cover includes:

a hollow cylindrical part provided downstream of the nozzle and having an exit opening for outputting droplets that are outputted from the nozzle and pass through an internal cavity of the cylindrical part; and

a channel for transmitting the gas supplied from the gas supply unit, the channel being structured to orient a flow of the transmitted gas so as to flow to the exit opening of the cylindrical part through the internal cavity of the cylindrical part,

wherein the channel includes a buffer space that joins the internal cavity of the cylindrical part and is structured to diffuse the gas flow entering the buffer space into different directions to guide the gas into the internal cavity of the cylindrical part,

wherein the cylindrical part has a reverse-tapered wall expanding outward at an output end, and

wherein the reverse-tapered wall has a plurality of ejection outlets structured to join the buffer space and to eject the gas.

2. A target producing apparatus, to be used in an extreme ultraviolet light generation apparatus capable of generating extreme ultraviolet light by irradiating droplets in a plasma generation region with a laser beam, the target producing apparatus comprising:

a tank capable of containing a melted droplet material;

a nozzle provided at a distal end of the tank and being capable of outputting droplets toward the plasma generation region;

a nozzle holder holding the nozzle on the tank;

a gas supply unit capable of supplying a gas;

a gas lock cover secured to the nozzle holder and provided downstream of the nozzle, the gas lock cover being structured to guide the gas supplied from the gas supply unit,

wherein the gas lock cover includes:

a hollow cylindrical part provided downstream of the nozzle and having an exit opening for outputting droplets that are outputted from the nozzle and pass through an internal cavity of the cylindrical part; and

a channel for transmitting the gas supplied from the gas supply unit, the channel being structured to orient a flow of the transmitted gas so as to flow to the exit opening of the cylindrical part through the internal cavity of the cylindrical part,

wherein the channel includes a buffer space that joins the internal cavity of the cylindrical part and is structured to diffuse the gas flow entering the buffer space into different directions to guide the gas into the internal cavity of the cylindrical part, and

wherein a damper member is provided in the buffer space, the damper member being capable of attenuating impacts of droplets that hit the damper member and catching the droplets that hit the damper member.

3. The target producing apparatus according to claim **2**, wherein the damper member is provided on an outer wall of the cylindrical part and an outer diameter of the damper member increases in a direction of outputting the droplets.

* * * * *