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(54) VAPORIZER, METHOD, AND ION SOURCE INCLUDING VAPORIZER

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CPC ***H01J 37/08*** (2013.01); ***H01J 37/3171*** (2013.01); ***H01J 37/3244*** (2013.01); ***H01J 37/32467*** (2013.01); ***H01J 37/32522*** (2013.01)

(57) ABSTRACT

A vaporizer includes a crucible in which a solid material is received, the crucible including a reactive gas inlet and a vapor outlet.

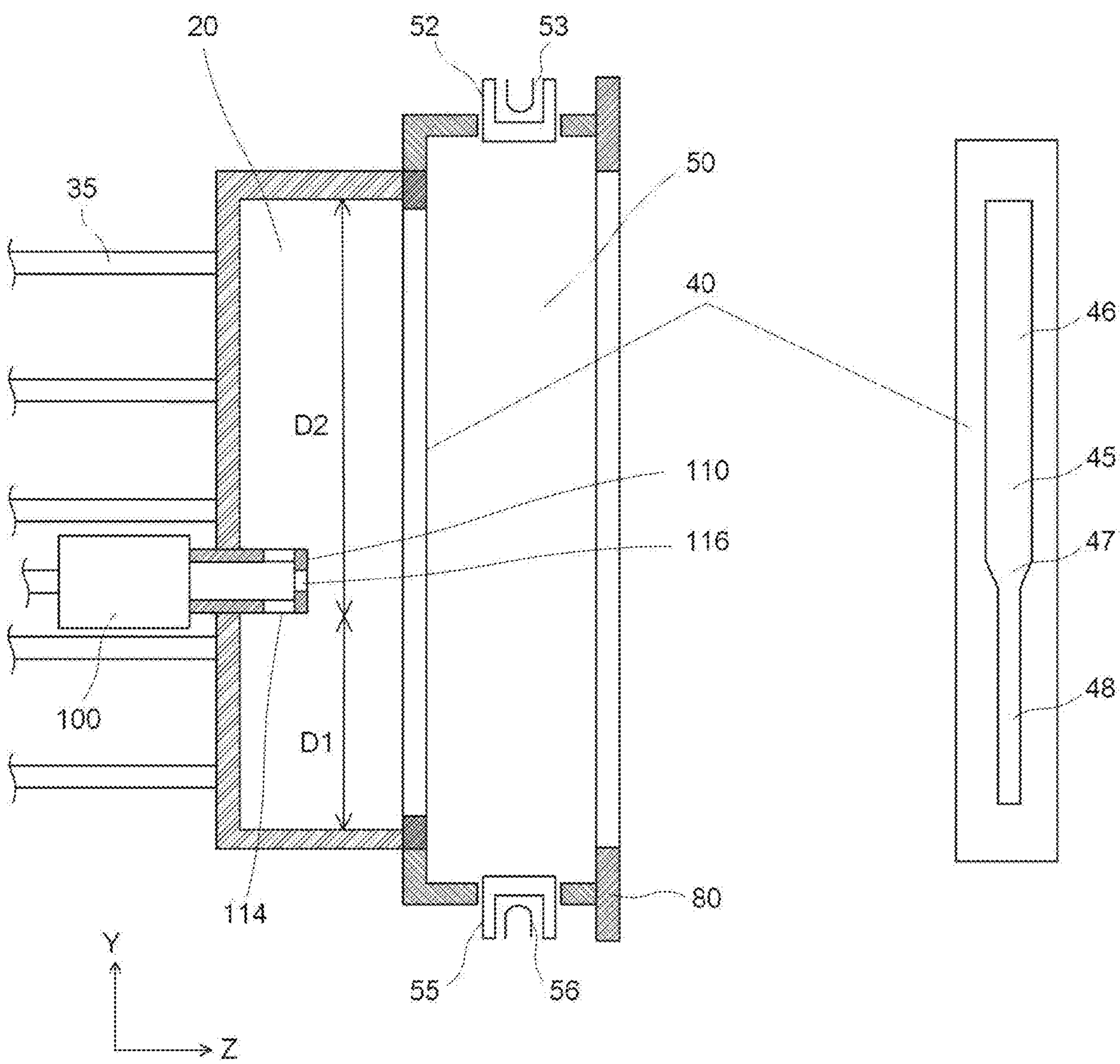

FIG. 1

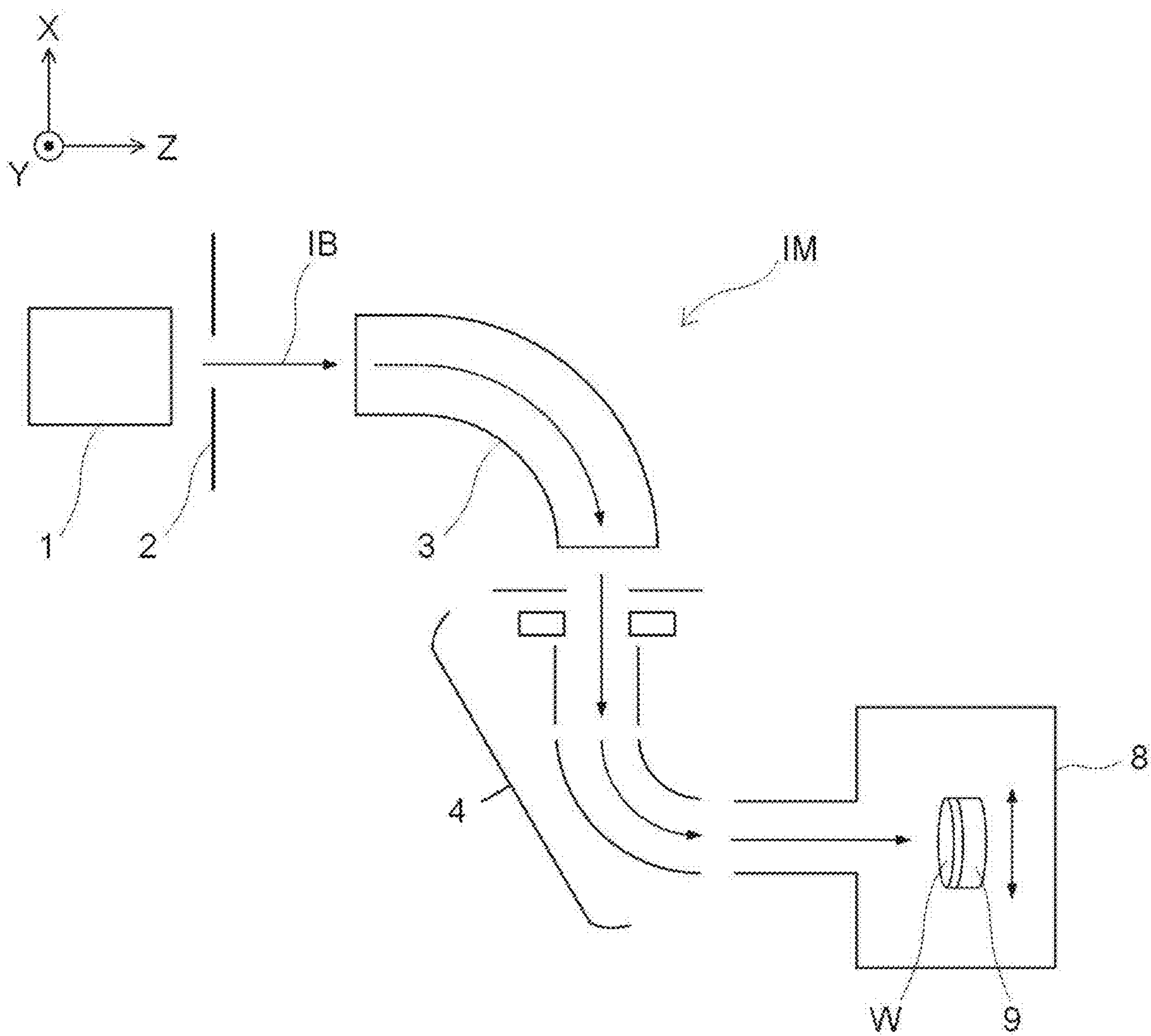

FIG. 2

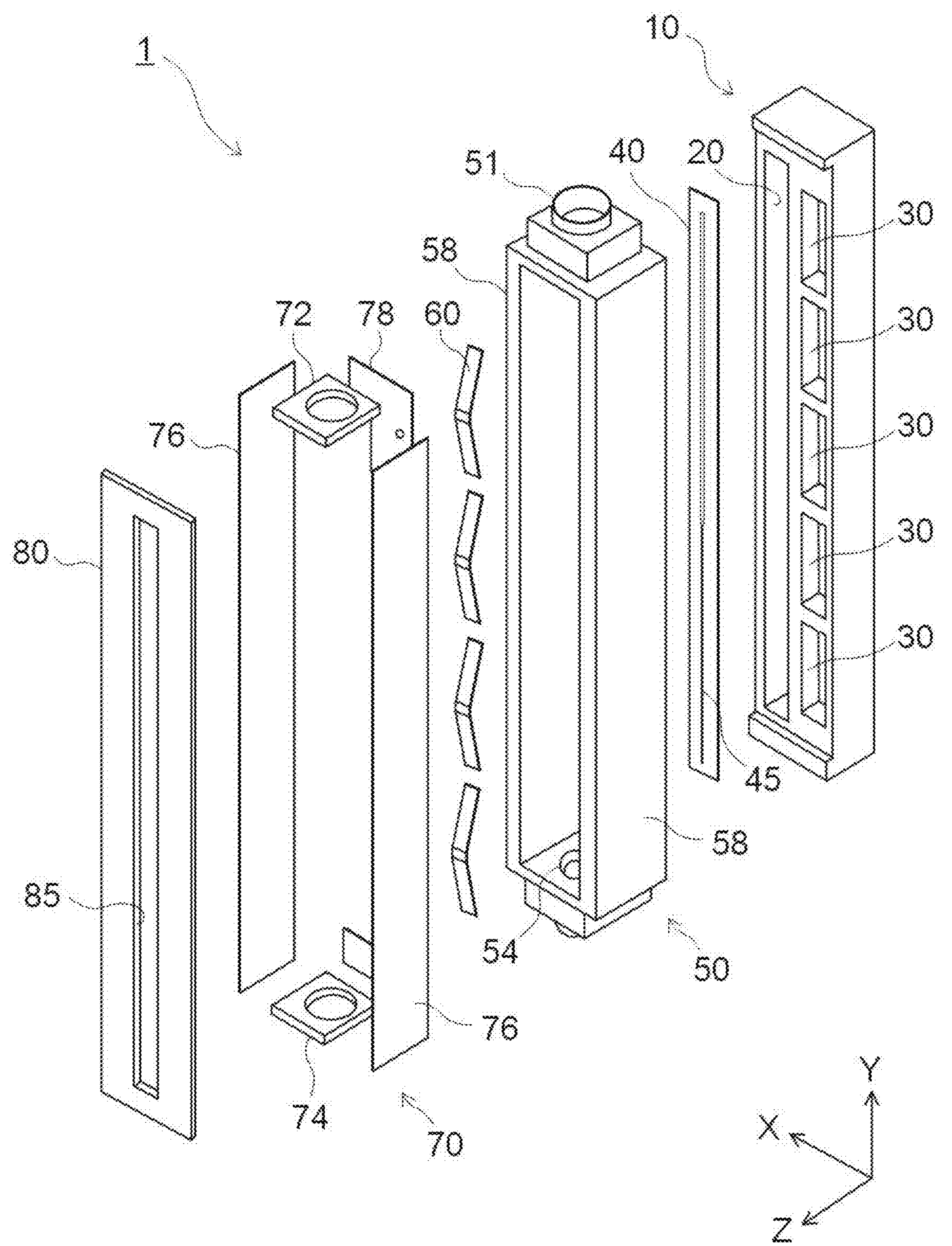
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FIG. 3

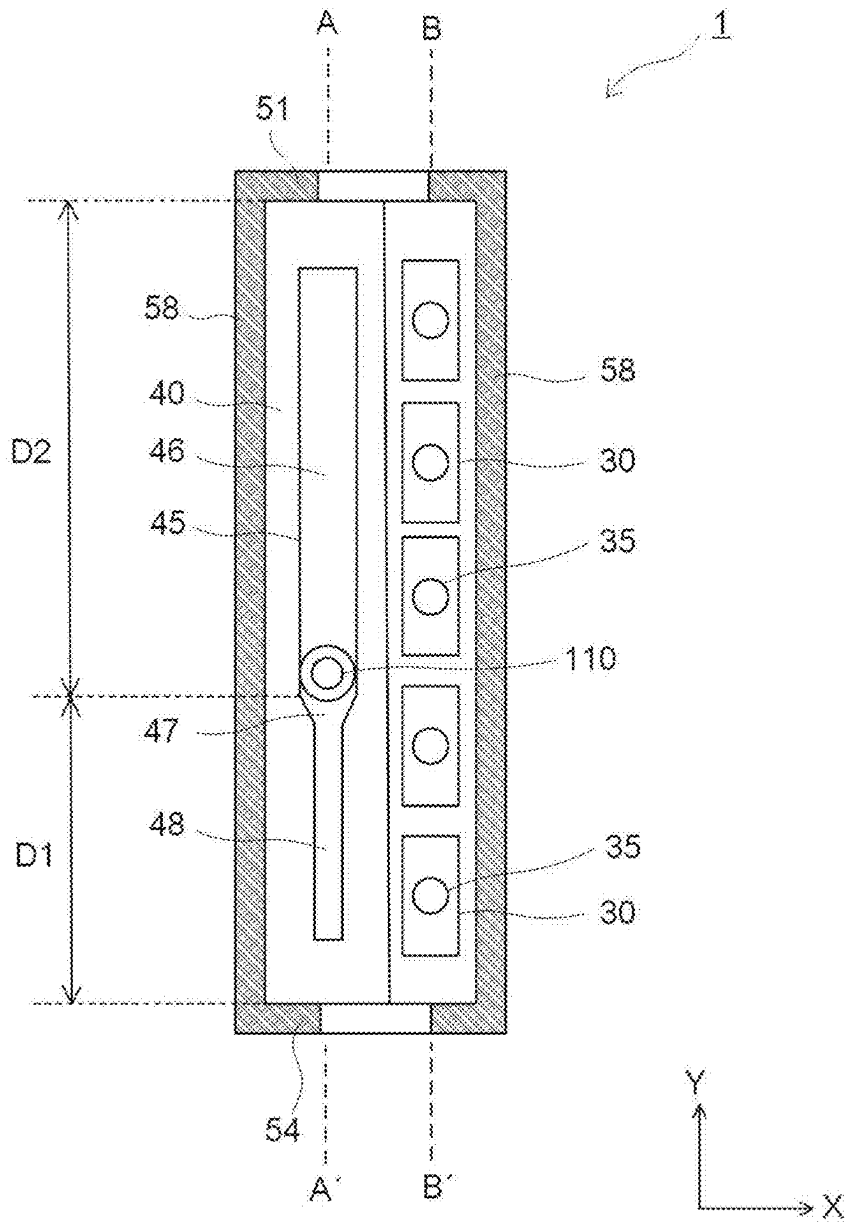

FIG. 4

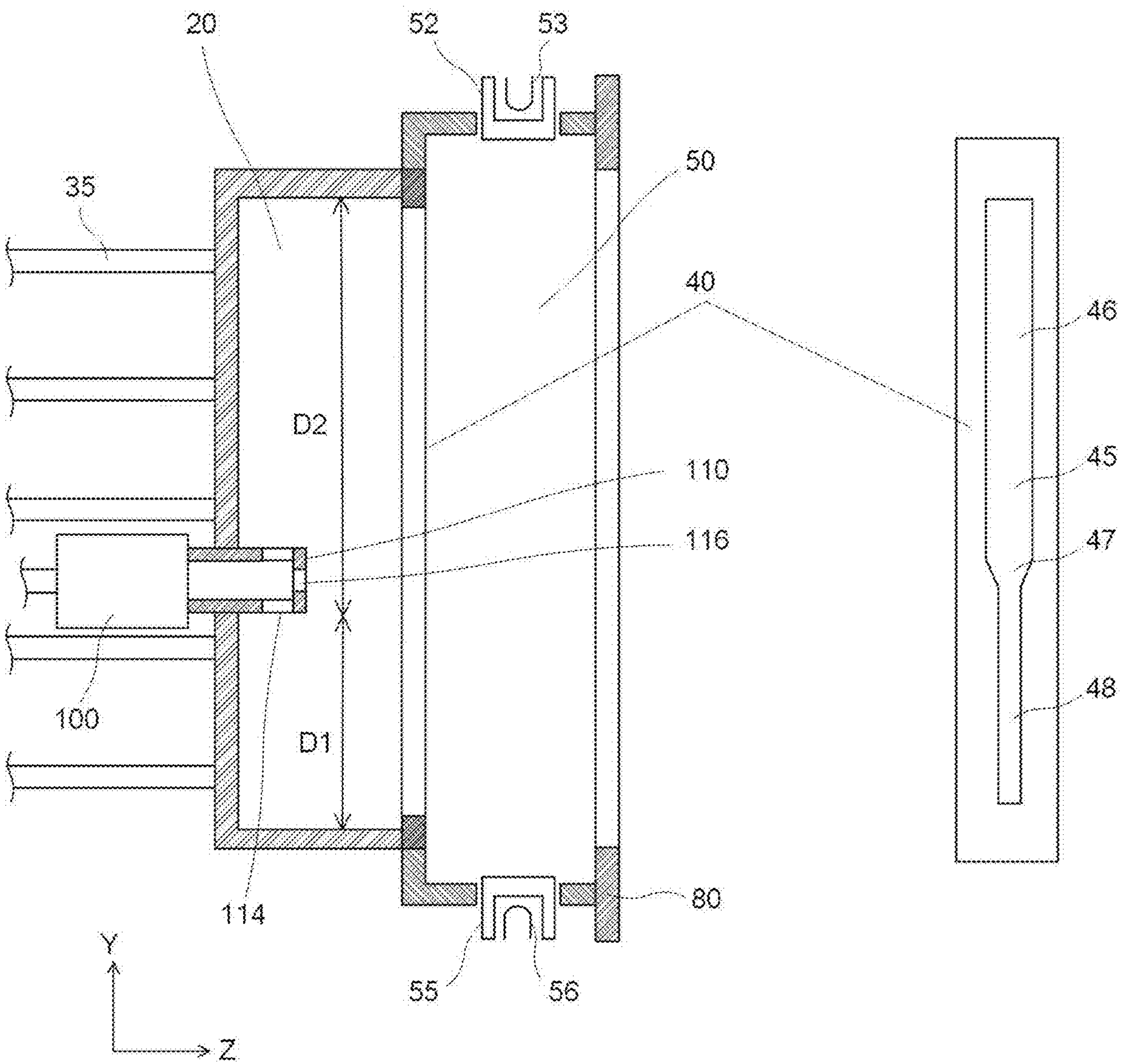

FIG. 5

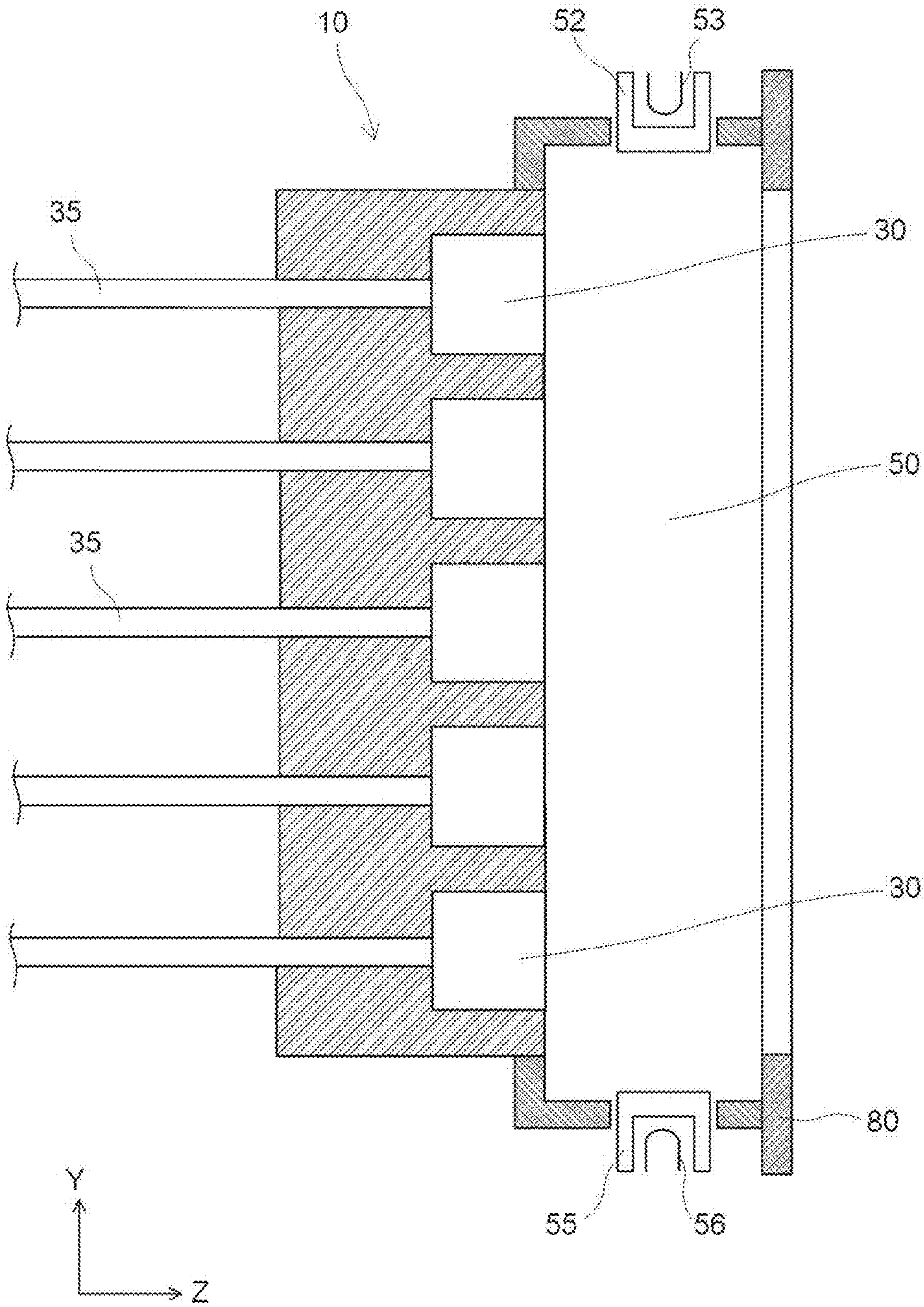

FIG. 6

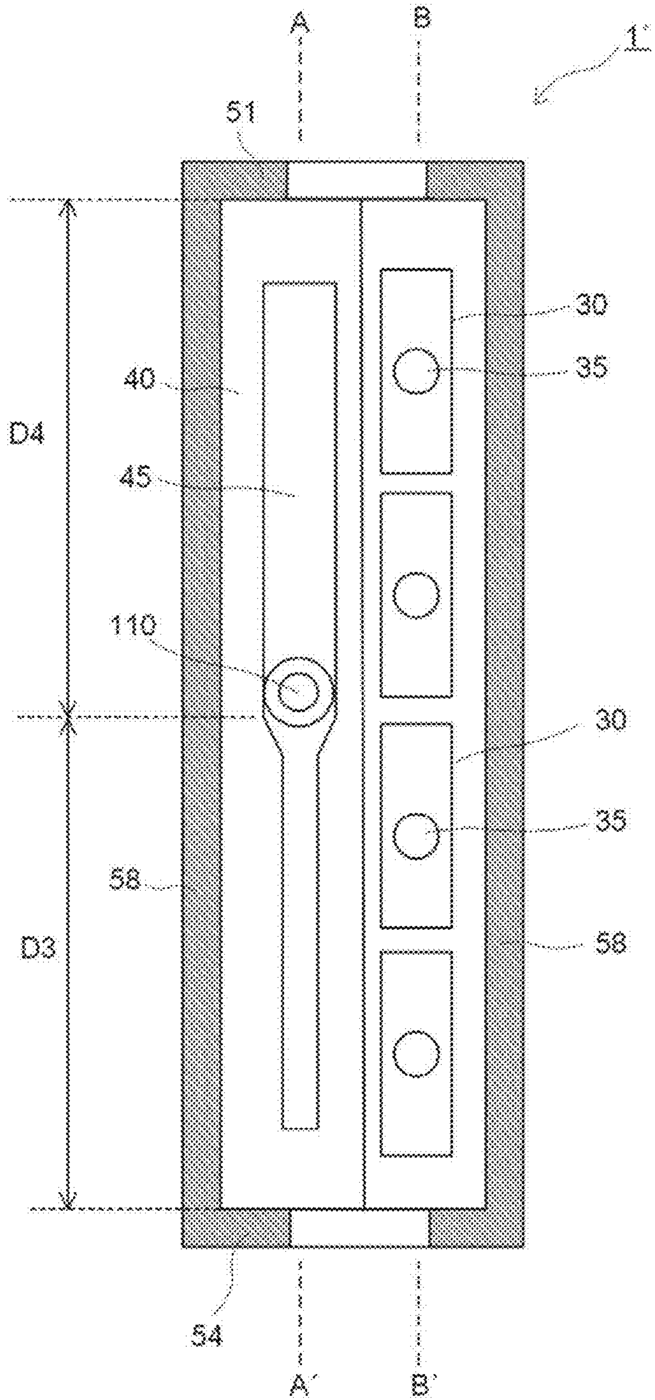

FIG. 7

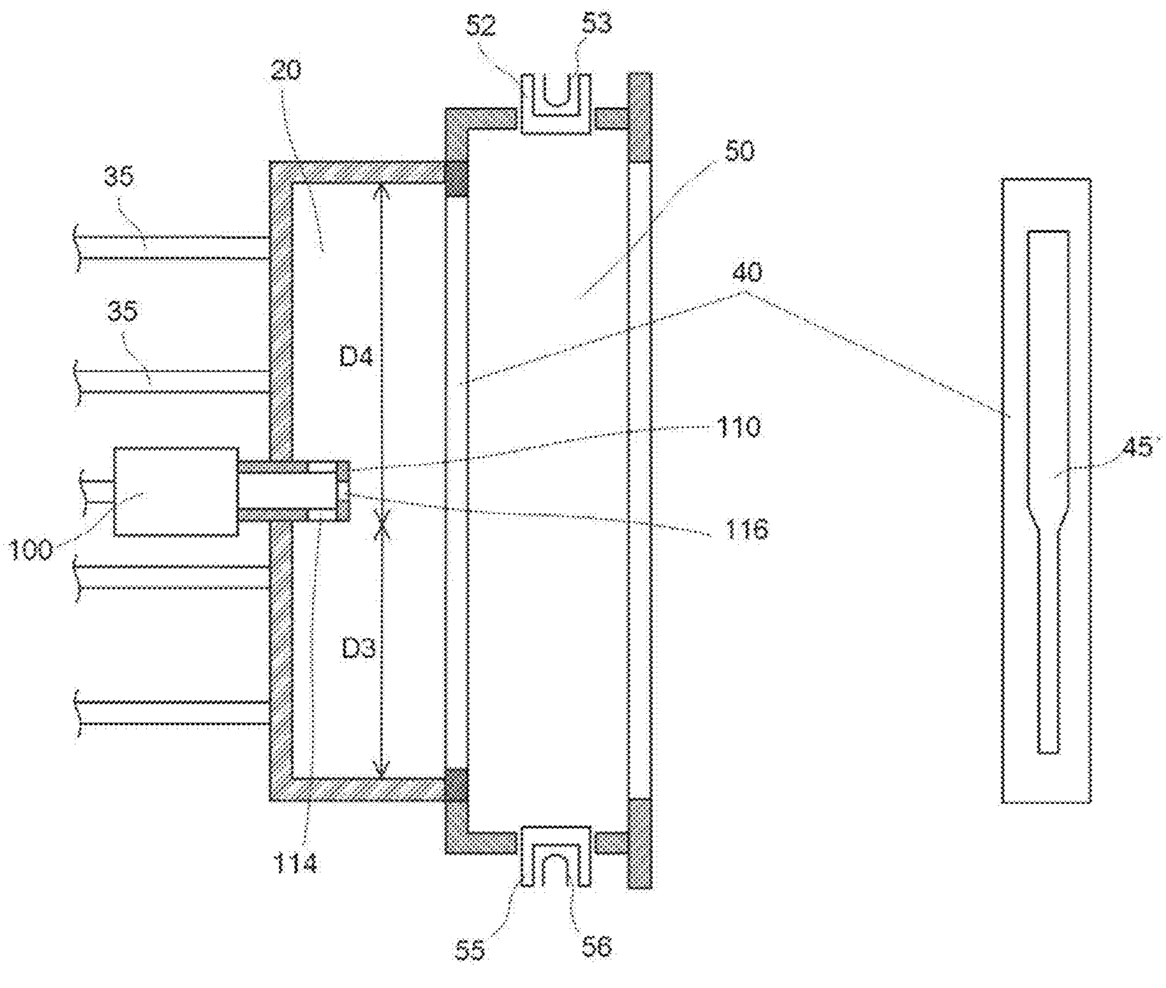

FIG. 8

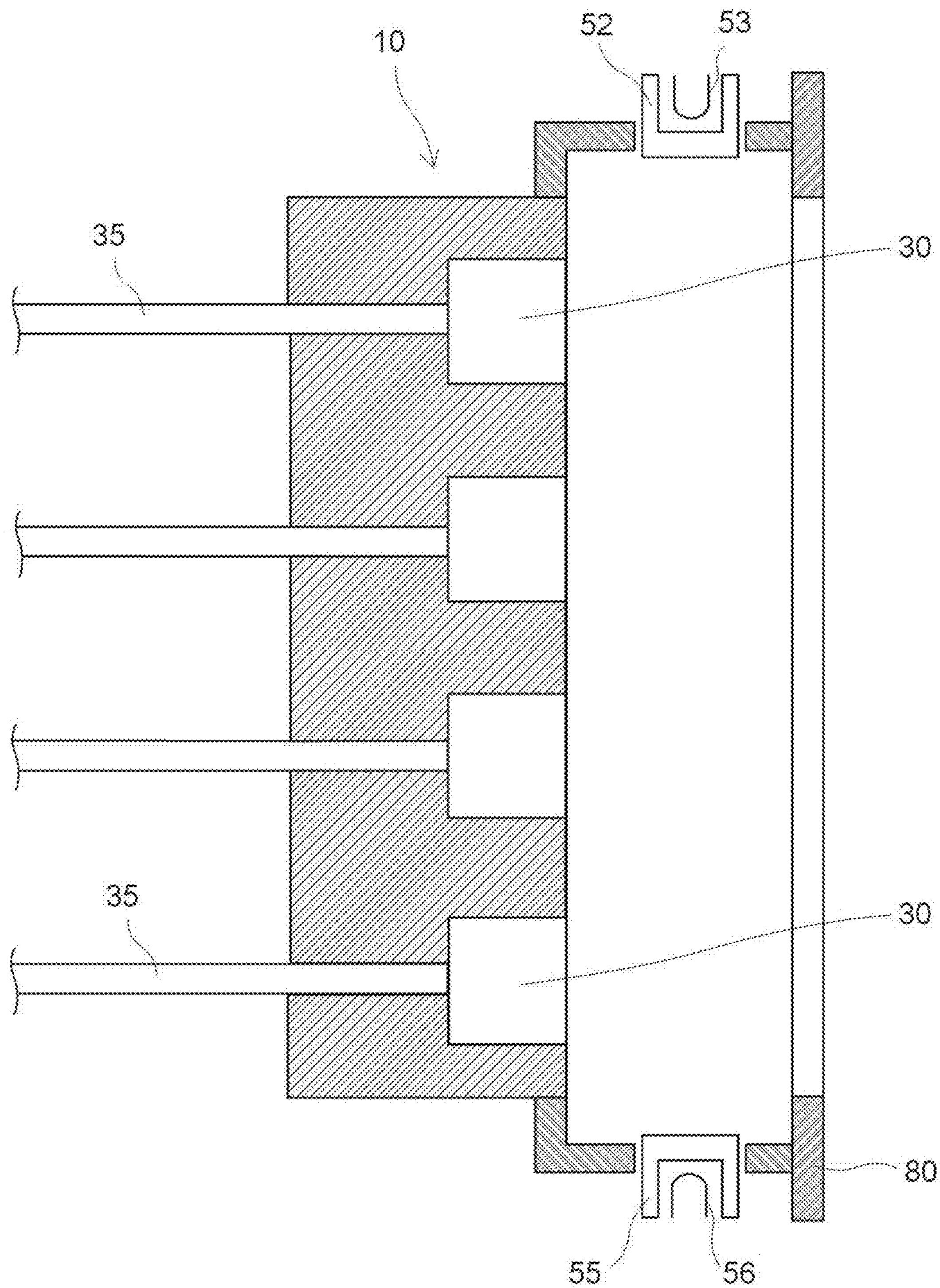

FIG. 9

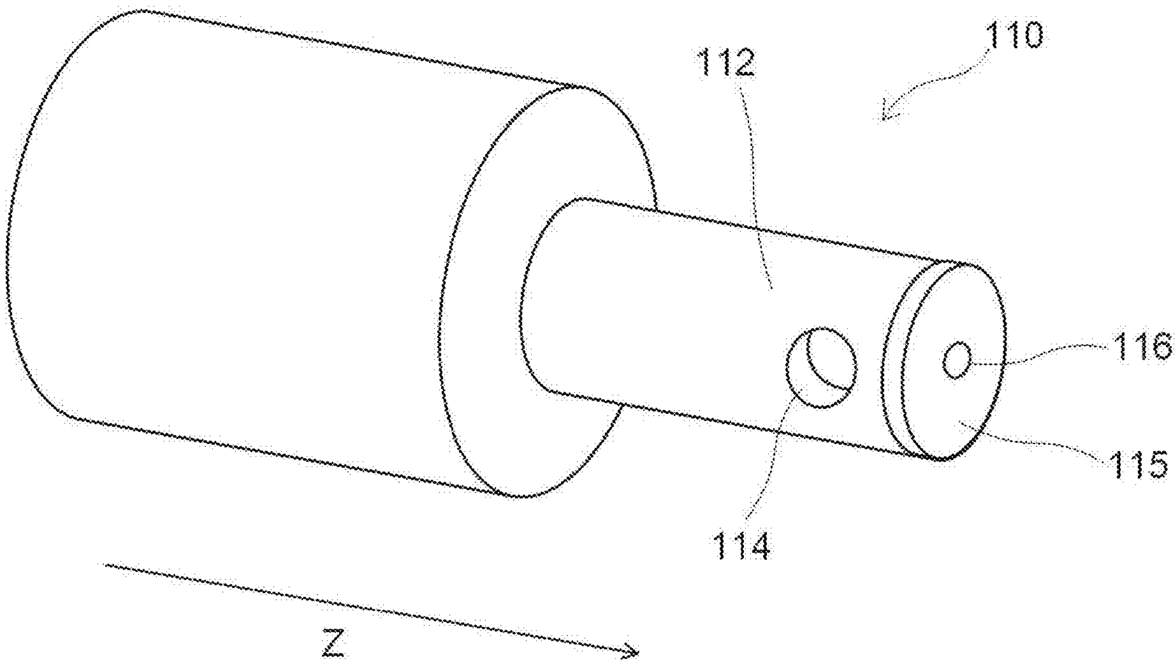

FIG. 10

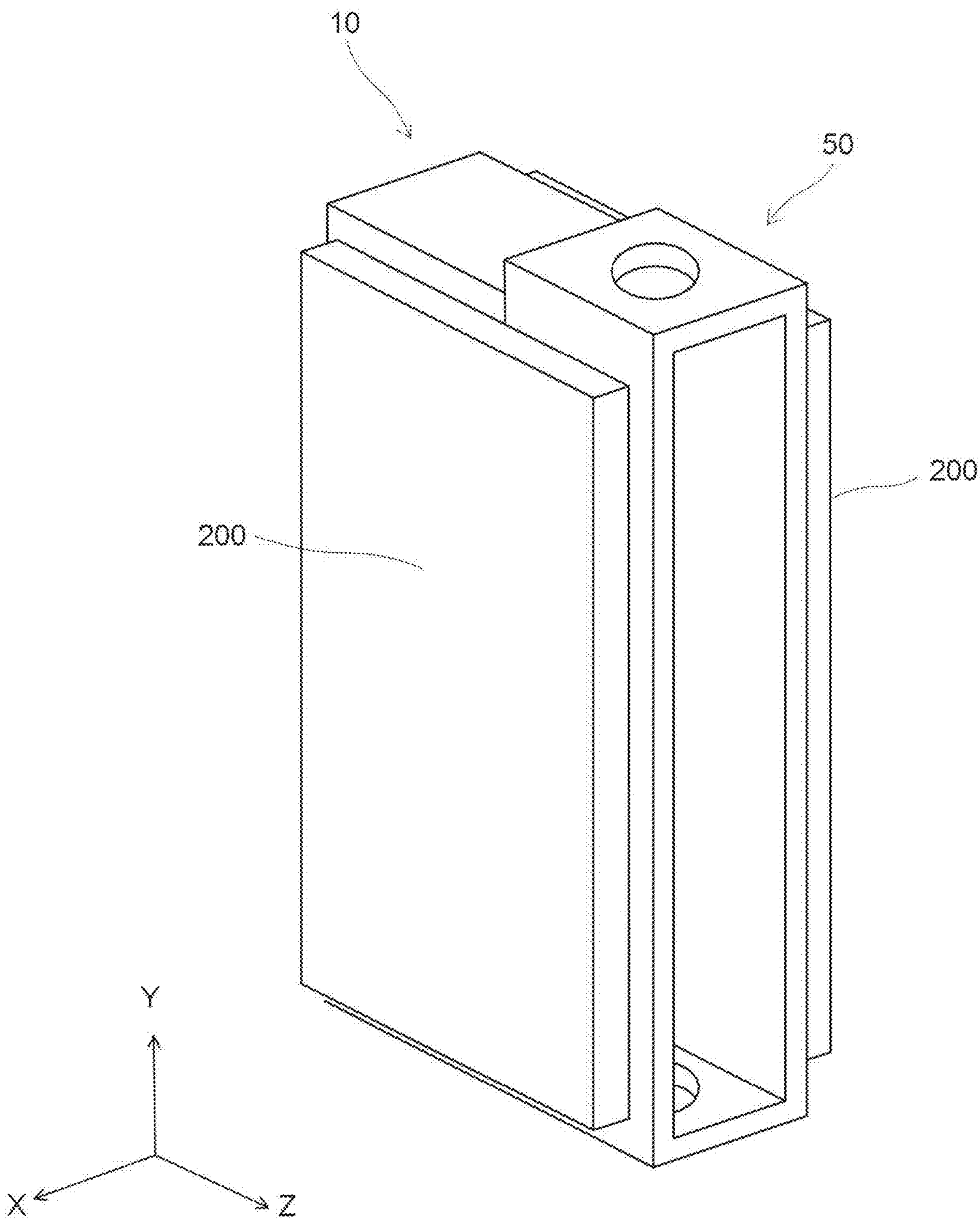

FIG. 11

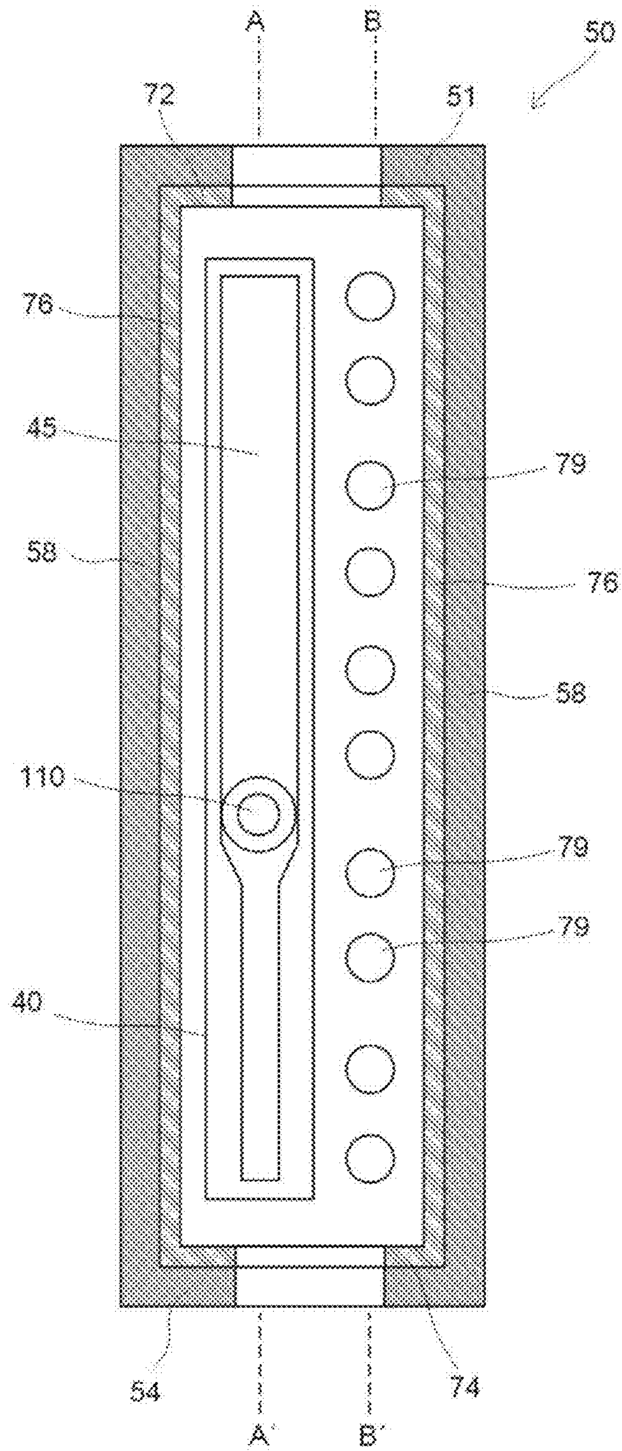

FIG. 12

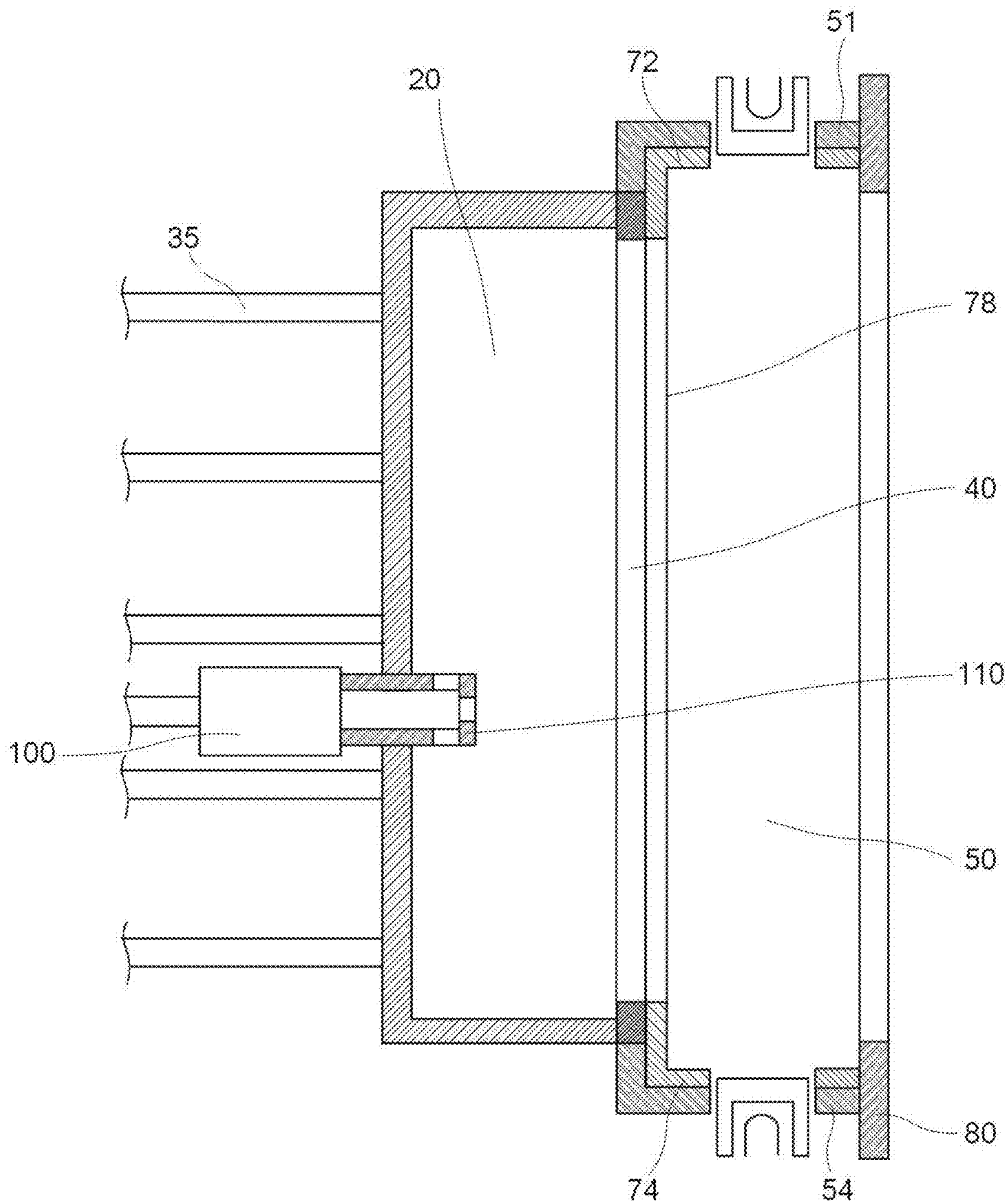

FIG. 13

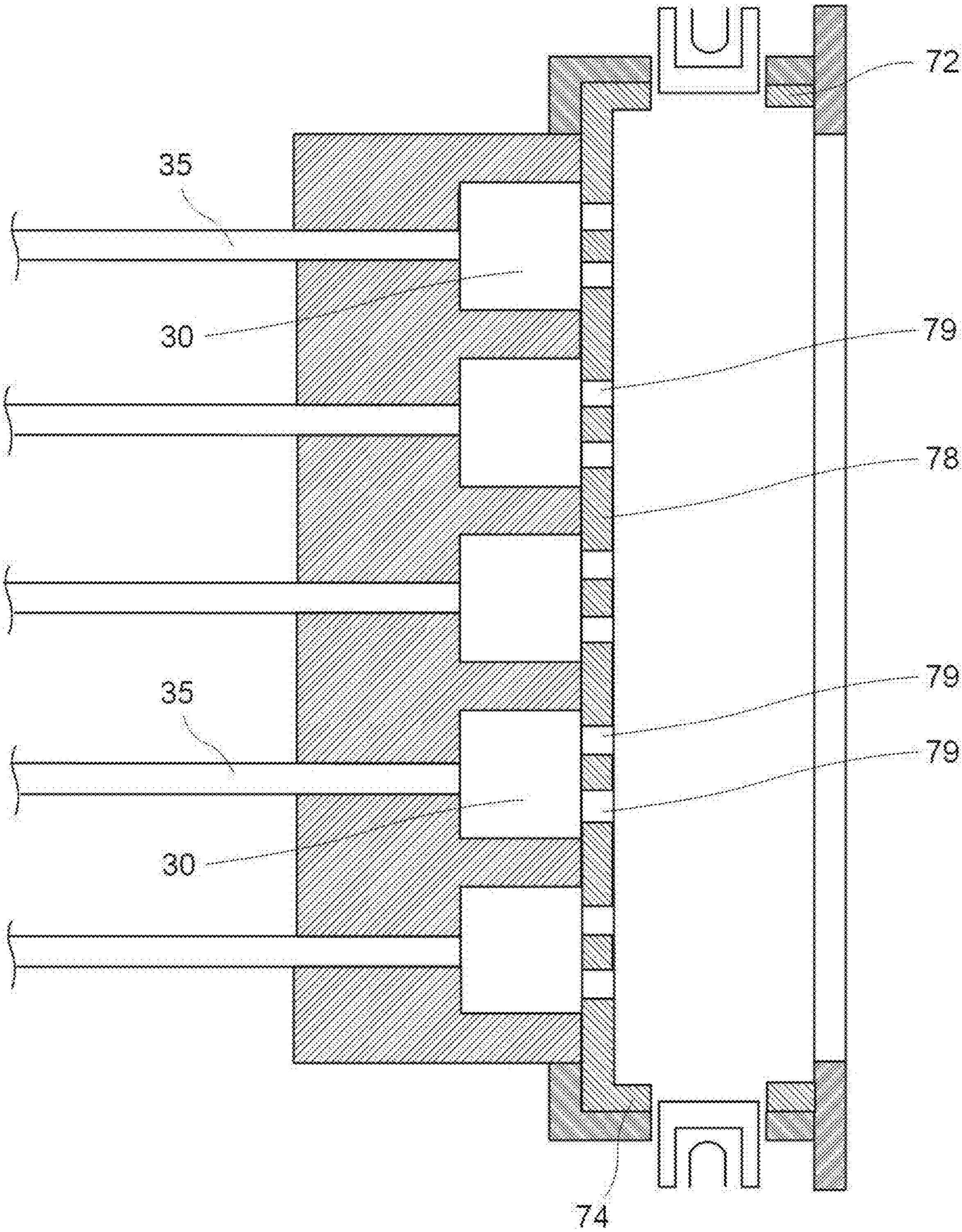

FIG. 14

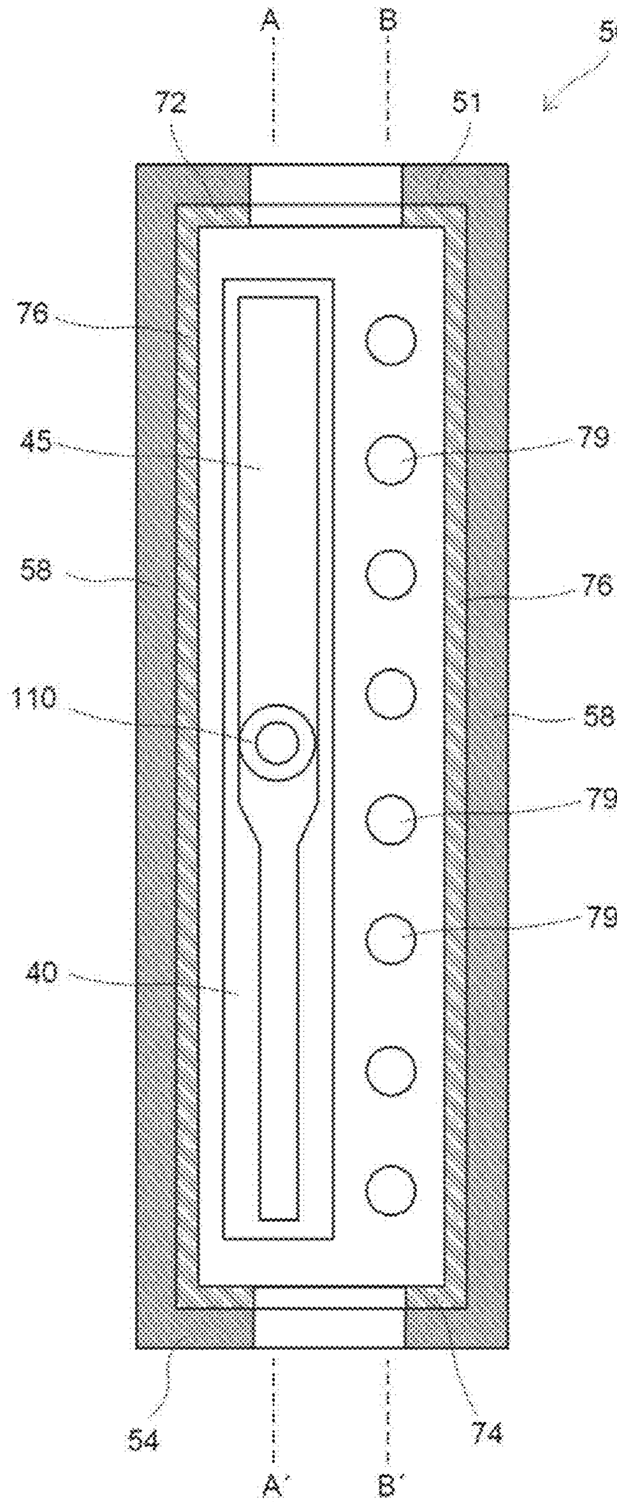

FIG. 15

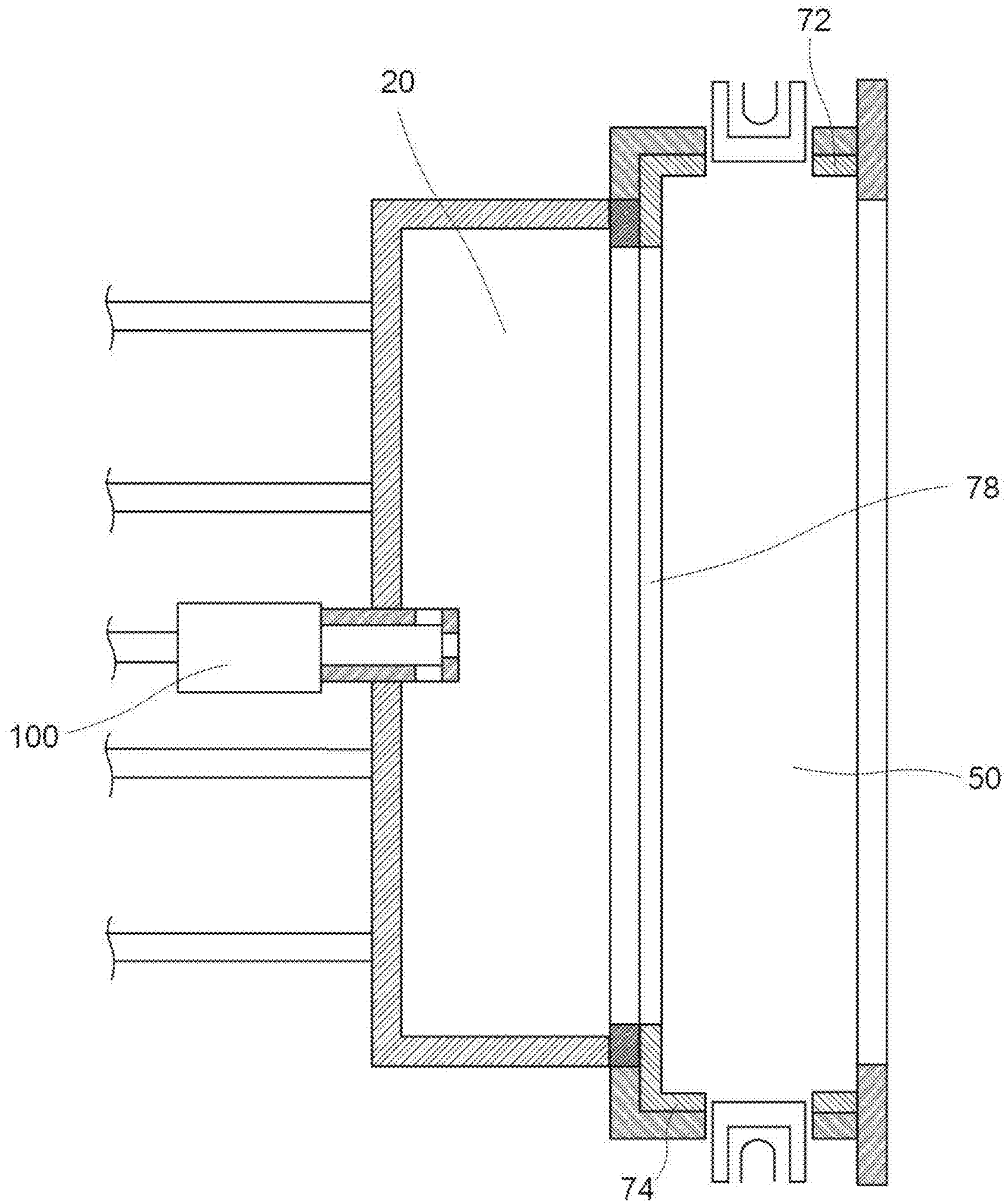

FIG. 16

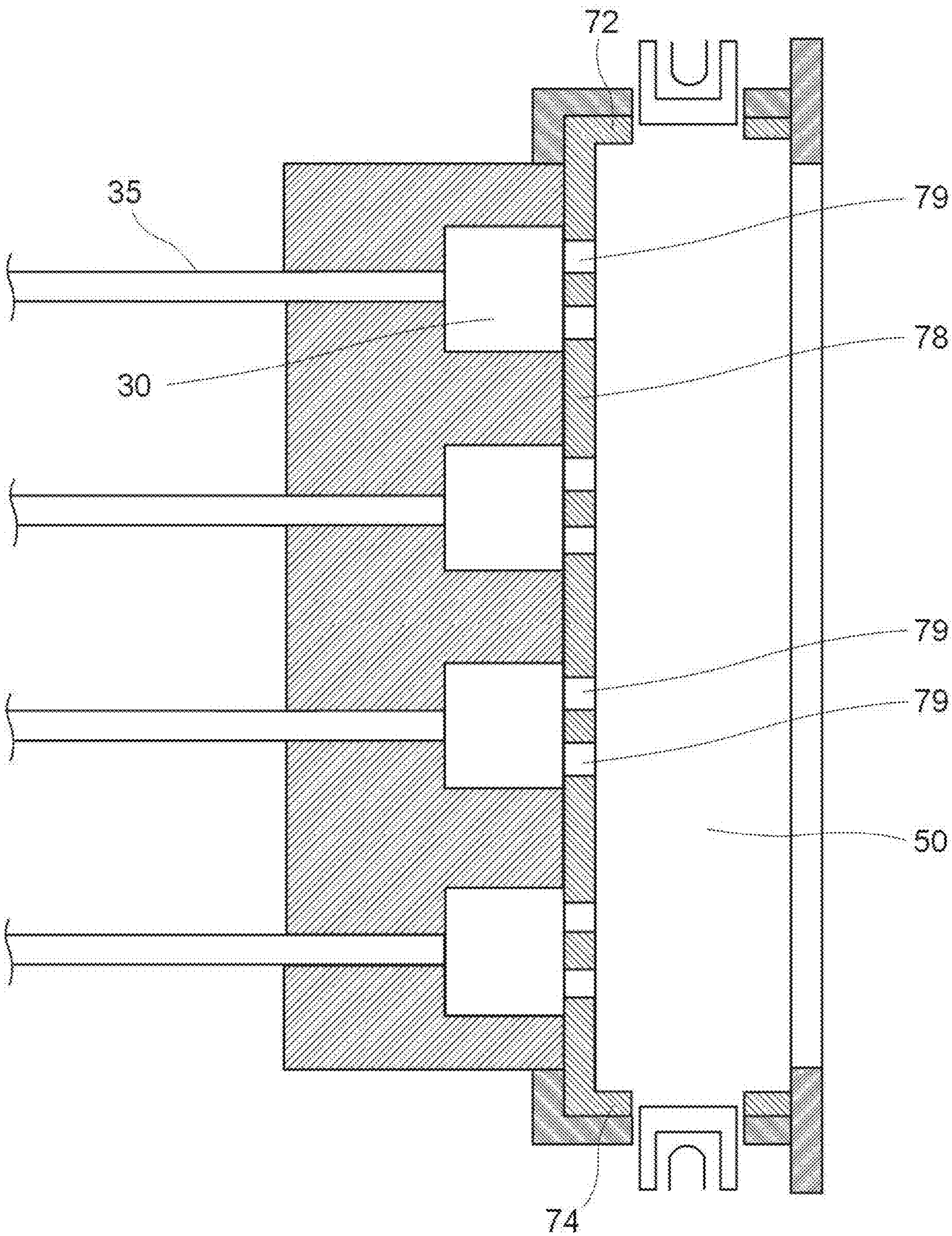

FIG. 17

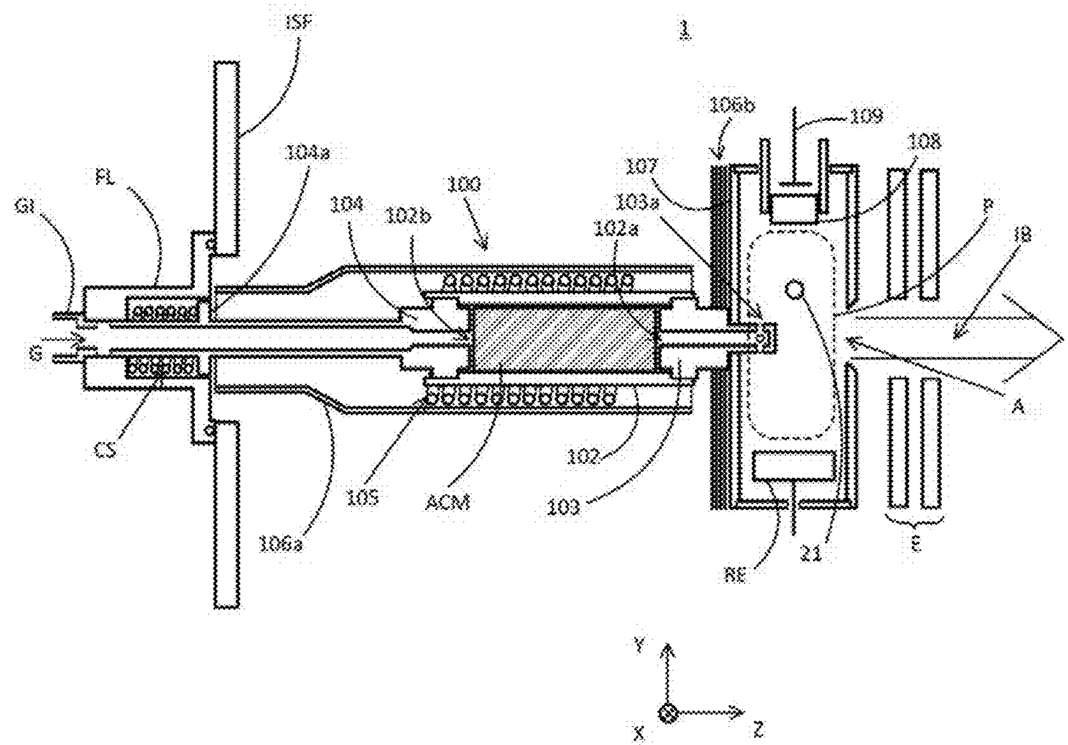
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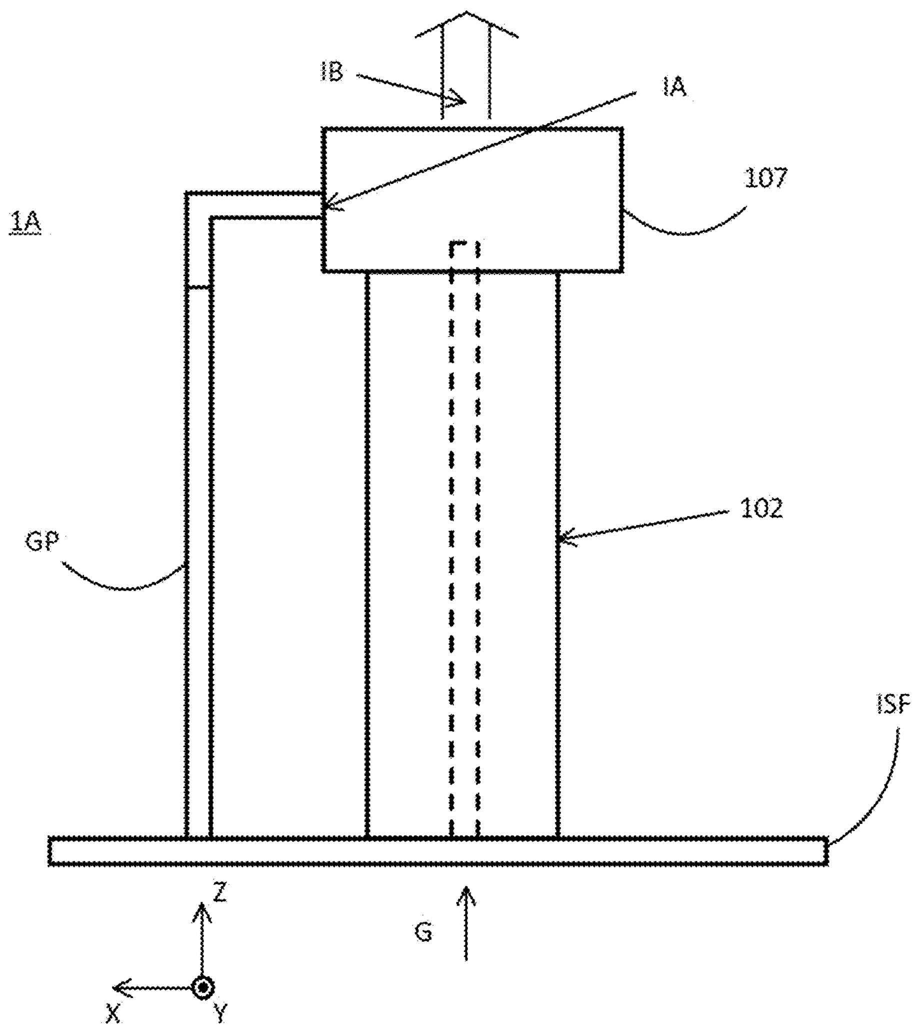
FIG. 18



VAPORIZER, METHOD, AND ION SOURCE INCLUDING VAPORIZER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. application Ser. No. 18/621,274 filed on Mar. 29, 2025 and U.S. application Ser. No. 17/945,705 filed on Sep. 15, 2022, the disclosures of each of which being herein incorporated by reference in their entireties.

BACKGROUND

[0002] The present disclosure relates to an ion source and, in particular, an ion source having a plenum chamber and plenum plate with longitudinal aperture, and an ion implanter having the same.

[0003] Ion sources generate a plasma from which an ion beam is extracted. The extracted ion beam is then directed onto a target, e.g., a wafer, in order to implant various ions into the target to dope the target with the ions.

[0004] The ion beam may be a spot beam or a ribbon ion beam. A spot beam has an elliptical cross-section when the ion beam is cut in a plane perpendicular to a traveling direction of the ion beam. A ribbon beam has a rectangular cross-section (i.e., a vertical length that is greater than a horizontal length) when the ion beam is cut in a plane perpendicular to the traveling direction of the ion beam. In either case, it is advantageous for the ion source to produce a plasma from which a uniform ion beam may be extracted to efficiently implant the ions into the target.

SUMMARY

[0005] It is an aspect to provide a ion source which achieves improved uniformity of the plasma when generating a ribbon ion beam.

[0006] According to an aspect of one or more embodiments, there is provided a vaporizer comprising a crucible in which an solid material is received, the crucible comprising a reactive gas inlet and a vapor outlet.

[0007] According to another aspect of one or more embodiments, there is provided a method for generating a vapor, the method comprising preparing a solid material in a crucible; and introducing a reactive gas into the crucible.

[0008] According to yet another aspect of one or more embodiments, there is provided an ion source comprising a first gas source comprising a first gas that contains a reactive component; a vaporizer comprising a crucible containing a solid material, the crucible comprising a gas inlet communicatively connected to the first gas source, and a vapor outlet; and an arc chamber configured to generate a plasma therein. The vapor outlet of the vaporizer is configured to output a vapor into the arc chamber through a wall of the arc chamber.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The above and/or other aspects will become apparent and more readily appreciated from the following description of various embodiments, taken in conjunction with the accompanying drawings, in which:

[0010] FIG. **1** is a schematic plan view of an example of an ion implanter, according to some embodiments;

[0011] FIG. **2** illustrates an exploded perspective view of an example of a ion source of the ion implanter, according to some embodiments;

[0012] FIGS. **3-5** illustrate a ion source, according to some embodiments, in which FIG. **3** illustrates the ion source when viewed from a Z-axis direction, FIG. **4** illustrates a cross-sectional view of the ion source taken along A-A' in FIG. **3**, and FIG. **5** illustrates a cross-sectional view of the ion source taken along B-B' in FIG. **3**;

[0013] FIGS. **6-8** illustrate a ion source, according to some embodiments, in which FIG. **6** illustrates the ion source when viewed from a Z-axis direction, FIG. **7** illustrates a cross-sectional view of the ion source taken along A-A' in FIG. **6**, and FIG. **8** illustrates a cross-sectional view of the ion source taken along B-B' in FIG. **6**;

[0014] FIG. **9** illustrates an example of a nozzle of a vaporizer of the ion source, according to some embodiments.

[0015] FIG. **10** illustrates an example of a heater of the ion source, according to some embodiments;

[0016] FIGS. **11-13** illustrate a liner of the ion source, according to some embodiments, in which FIG. **11** illustrates the liner when the ion source is viewed from a Z-axis direction in FIG. **2**, FIG. **12** illustrates a cross-sectional view of the liner taken along A-A' in FIG. **11**, and FIG. **13** illustrates a cross-sectional view of the liner taken along B-B' in FIG. **11**;

[0017] FIGS. **14-16** illustrate a liner of the ion source, according to some embodiments, in which FIG. **14** illustrates the liner when the ion source is viewed from a Z-axis direction in FIG. **2**, FIG. **15** illustrates a cross-sectional view of the liner taken along A-A' in FIG. **14**, and FIG. **16** illustrates a cross-sectional view of the liner taken along B-B' in FIG. **14**;

[0018] FIG. **17** illustrates an ion source of the ion implanter according to some embodiments; and

[0019] FIG. **18** illustrates an ion source of the ion implanter according to some embodiments.

DETAILED DESCRIPTION

[0020] As used in this specification, a phrase of the form "at least one of A, B, or C" includes within its scope "only A", "only B", "only C", "A and B", "B and C", "A and C" and "A, B, and C".

[0021] In a related art ion source, one or more gases and/or vapors are injected into a plasma chamber of the ion source to generate the plasma inside the plasma chamber. In a related art technology, a plenum is used to generally distribute the gas or vapor throughout an arc chamber. However, the plenum in the related art technology is used to distribute gases or vapor to produce an efficient reaction with a filament, and does not take into account properties of the ion beam. For example, the related art technology does not take into account differences between plasma generated to produce a spot beam verses a ribbon ion beam. In particular, in the case of a ribbon ion beam, it is advantageous for the one or more gases and/or vapors to be uniformly dispersed longitudinally within a plasma chamber so that a plasma density is uniform in a longitudinal direction within the plasma chamber in order to be able to extract a consistent ribbon ion beam to effectively dope the target.

[0022] FIG. **1** is a schematic plan view of an example of an ion implanter IM, according to some embodiments. The ion implanter IM illustrates an example of a use case of the ion source. The ion implanter IM is only an example and, in some embodiments, the ion source may be used in any device requiring ion generation.

[0023] In an embodiment, the ion implanter IM may include a ion source **1**, one or more extraction electrodes **2**, a mass analyzer **3**, an E-bend device **4**, a process chamber **8**, and a wafer holder **9**. However, these components are only an example and, in some embodiments, a greater or lesser number of components may be included in the ion implanter IM.

[0024] In an embodiment, the ion source **1** may be an indirect hot cathode (IHC) ion source. However, embodiments are not limited thereto and, in some embodiments, other types of ion source may be used. In the description that follows, the ion source **1** is described under the assumption that ion source **1** is an IHC ion source. The ion source **1** generates plasma, which is a source of an ion beam IB. The one or more extraction electrodes **2** extract the ion beam IB from the plasma generated in the ion source **1**. In some embodiments, the one or more extraction electrodes **2** may include a plurality of extraction electrodes **2**.

[0025] The ion beam IB extracted from the extraction electrode **2** contains a plurality of ions. The mass analyzer **3**, which is an electromagnet, selects the ions according to their mass to extract desired ions from the ion beam IB. The E-bend device **4** accelerates or decelerates and bends the ion beam IB including ions selected by mass analyzer **3** to convert the ion beam IB into an ion beam IB having a desired energy.

[0026] The ion beam IB having the desired energy is then irradiated onto a wafer W that is held by a wafer holder **9**. By moving the wafer holder **9** (and thus the wafer W) across the ion beam IB, an ion implantation process may be carried out on the wafer W.

[0027] The wafer W held by the wafer holder **9** is placed in the process chamber **8**. A drive device (not illustrated) is connected to the wafer holder **9**. The drive device may adjust a posture of the wafer holder **9** with respect to the ion beam IB to adjust an irradiation angle of the ion beam IB with respect to the wafer W.

[0028] The XYZ axes shown in FIG. **1** are drawn such that the Z axis is parallel to the traveling direction of the ion beam IB; the X and Y axes are mutually orthogonal to the Z axis. The direction of each of the XYZ axes for any individual component varies according to an orientation of a component with respect to the ion beam being transported as illustrated in FIG. **1**.

[0029] FIG. **2** illustrates an exploded perspective view of an example of a ion source of the ion implanter, according to some embodiments.

[0030] In an embodiment, the ion source **1** may include a plenum **10** and an ionization chamber **50**. The plenum **10** may include a plenum chamber **20**, a plurality of gas feed chambers **30**, and a plenum plate **40**. The plenum chamber **20** is rectangular, having a long side in a vertical direction (e.g., a Y-axis direction) and a short side in a horizontal direction (e.g., a X-axis direction). In other words, the plenum chamber **20** may be a longitudinal chamber having a width in the X-axis direction and height in the Y-axis direction that is greater than the width. In an embodiment, the plenum chamber **20** includes a plurality of walls that, along with the plenum plate **40**, define the plenum chamber **20**. In an embodiment, the plenum chamber **20** has an opening in a distal side thereof and the opening is covered by the plenum plate **40**. The plenum plate **40** has a slit **45** therein. The slit **45** is long in the vertical direction (e.g., the Y-axis direction) and narrow in the horizontal direction (e.g., the X-axis direction) and thus forms a longitudinal aperture in the plenum plate **40**. Examples of the slit **45** are described in more detail below.

[0031] The plurality of gas feed chambers **30** are formed adjacent to the plenum chamber **20**. In an embodiment, the plurality of gas feed chambers **30** are spaced apart from each other in the vertical direction (e.g., the Y-axis direction). In an embodiment, each of the gas feed chambers **30** may be generally rectangular, having a long side in a vertical direction (e.g., a Y-axis direction) and a short side in a horizontal direction (e.g., a X-axis direction). Each of the gas feed chambers **30** may have an opening in a distal end thereof, similar to the plenum chamber **20**. In an embodiment, a surface in which the openings of the plurality of gas feed chambers **30** may be formed may be coplanar with the plenum plate **40**. In an embodiment, a surface in which the openings of the plurality of gas feed chambers **30** are provided may be coplanar with a surface in which the opening of the plenum chamber **20** is provided.

[0032] The embodiment of FIG. **2** shows the plenum **10** as formed from a single block. However, in some embodiments, the plenum **10** may be formed in two separate blocks and the two separate blocks may be fixed together. In other words, the plenum chamber **20** may be formed in a first block and the plurality of gas feed chambers **30** may be formed in a second block, and the first and second blocks may be secured together side-by-side. However, it is advantageous to form the plenum **10** from a single block in terms of decreased manufacturing cost and decreased complexity.

[0033] In an embodiment, each of the plenum **10** and the plenum plate **40** may be made of carbon. However, this is only an example and, in other embodiments, each of the plenum **10** and the plenum plate **40** may be made of graphite or other materials.

[0034] In an embodiment, the ionization chamber **50** may include a top wall **51** including a top hole for receiving a cathode **52** and a filament **53** (see FIG. **4**), a bottom wall **54** including a bottom hole for receiving a cathode **55** and a filament **56** (see FIG. **4**), and two side walls **58** that connect the top wall to the bottom wall. The front and the back of the ionization chamber **50** in a third direction (e.g., a Z-axis direction), which is a traveling direction of an ion beam that is extracted from the ion source **1**, are open. The ionization chamber **50** is rectangular, having a long side in a vertical direction (e.g., a Y-axis direction) and a short side in a horizontal direction (e.g., a X-axis direction). In other words, similar to the plenum chamber **20**, the ionization chamber **50** may be a longitudinal chamber having a width in the X-axis direction and height in the Y-axis direction that is greater than the width. It is noted that the cathode **52** and the filament **53** are described as being received in the top hole of the ionization chamber **50** and the cathode **55** and filament **56** are described as being received in the bottom hole of the ionization chamber **50** in FIG. **1**. However, this is only an example and, in some embodiments, the positions of the cathode **52** and the filament **53**, and the cathode **55** and the filament **56** may be changed.

[0035] The ionization chamber **50** is secured to the plenum **10** at a proximal end of the ionization chamber **50** and a distal end of the ionization chamber **50** is covered by an extraction plate **80**. In other words, the back of the ionization chamber **50** is secured to the plenum **10** such that an interior of the plenum chamber **20** is in fluid communication with an interior of the ionization chamber **50** and such that an interior of each of the plurality of gas feed chambers **30** is in fluid communication with the interior of the ionization chamber **50**. The front of the ionization chamber **50** is covered by the extraction plate **80**. The extraction plate **80** has an extraction aperture **85** therein. The extraction aperture **85** is long in the vertical direction (e.g., the Y-axis direction) and narrow in the horizontal direction (e.g., the X-axis direction) and thus forms a longitudinal aperture in the extraction plate **80**. In an embodiment, the extraction aperture **85** has a uniform width along the vertical direction (e.g., Y-axis direction) thereof.

[0036] In some embodiments, interior walls of the ionization chamber **50** may be covered by a liner **70**. In some embodiments, the liner **70** may include a plurality of liners. The plurality of liners may include a top liner **72**, a bottom liner **74**, and two side wall liners **76**, which correspond respectively to the top wall **51**, bottom wall **54**, and two side walls **58** of the ionization chamber **50**, and a rear liner **78**. The rear liner **78** is formed with an opening corresponding to the slit **45** in the plenum plate **40** and openings corresponding to the plurality of gas feed chambers **30**. In some embodiments, the plurality of liners may further include a front liner that is formed with an opening corresponding to the extraction aperture **85** in the extraction plate **80**. Examples of the liner **70** will be described in more detail below.

[0037] In an embodiment, the liner **70** may be held in place by a spring **60**. In an embodiment, the spring **60** may include a plurality of leaf springs as illustrated in the example of FIG. **1**. However, this is only an example and, in some embodiments, the spring **60** may include a plurality of coil springs.

[0038] In some embodiments, the liner **70** may be omitted.

[0039] In use, the plenum chamber **20** receives a vapor from a single point source and provides a space for the vapor to spread out evenly along the height of the ion source **1**. In other words, the vapor may broaden and diverge in a longitudinal direction (e.g., a Y-axis direction) within the plenum chamber **20**. The plenum plate **40** restricts the flow of vapor from the single point source. The shape of the slit **45** is a longitudinal aperture and is used to produce vertical uniformity of the flow of the vapor into the ionization chamber **50**. Each of the plurality of gas feed chambers **30** receives a gas from one or more of a plurality of gas feed lines **35** (not illustrated in FIG. **2**) and allows the received gas to spread out before entering the ionization chamber **50**. In the ionization chamber **50**, a plasma based on the vapor and the gases is generated and the ion beam IB is extracted by the extraction electrodes **2** outside the extraction plate **80** of the ionization chamber **50**. The liner **70** prevents sputtering of a plasma generated in the ionization chamber **50** onto the walls of the ionization chamber **50**, and thus may increase the time needed between cleanings of the ionization chamber **50**, thus saving maintenance costs. In some embodiments, the liner **70** may prevent reaction of the plasma with the walls of the ionization chamber **50**.

[0040] FIGS. **3-5** illustrate the ion source **1**, according to some embodiments, in which FIG. **3** illustrates the ion source **1** when viewed from a Z-axis direction with the extraction plate **80** removed, FIG. **4** illustrates a cross-sectional view of the ion source **1** taken along A-A' in FIG. **3**, and FIG. **5** illustrates a cross-sectional view of the ion source **1** taken along B-B' in FIG. **3**. In FIGS. **3-5**, like reference designators represent like components in FIG. **2** that have like structure and functions, and therefore a repeated description thereof is omitted for conciseness.

[0041] As illustrated in FIGS. **3-5**, in an embodiment, the plenum **10** includes the plurality of gas feed chambers **30**, each having a corresponding gas feed line **35**. In other words, the plurality of gas feed lines **35** feed gases respectively into corresponding ones of the plurality of gas feed chambers **30**. The gas feed lines **35** feed various gases into the ionization chamber **50** for generating the plasma in the ionization chamber **50**. For example, in some embodiments, the gases may include tungsten fluoride (WF_6), hydrogen (H_2) co-gas, boron trifluoride (BF_3), arsine (AsH_3), phosphine (PH_3), a noble gas such as Argon, Helium and Xenon and/or chlorine (Cl_2), etc. However, these are only examples and, in some embodiments, any gas suitable for generating plasma may be used.

[0042] In an embodiment, the ion source **1** includes a vaporizer **100** for generating the vapor, and a nozzle **110** for introducing the vapor into the plenum chamber **20**. The vaporizer **100** may be, for example, a vaporizer as described in U.S. application Ser. No. 18/585,499, filed Feb. 23, 2024, and titled "VAPORIZER AND ION SOURCE"; U.S. patent application Ser. No. 17/714,491, filed Apr. 6, 2022, now U.S. Pat. No. 12,112,915 for "VAPORIZER, ION SOURCE AND METHOD FOR GENERATING ALUMINUM-CONTAINING VAPOR"; or U.S. patent application Ser. No. 17/945,705, filed Sep. 15, 2022, now U.S. Patent Application Publication No. 2024/0098869 for "VAPORIZER, ION SOURCE AND METHOD FOR GENERATING ALUMINUM-CONTAINING VAPOR", the entire contents of each of these U.S. patent applications being herein incorporated by reference in their entireties. In some embodiments, the vaporizer **100** may generate the vapor from a solid raw material. For example, in some embodiments, the solid raw material may be aluminum (Al). However, this is only an example and, in some embodiments, other solid raw materials may be used depending on the vapor used to generate the plasma for extracting the ion beam. In some embodiments, the vaporizer **100** may generate the vapor from antinomy (Sb), sulfur(S) containing compounds, InI_3, $InCl_3$, WCl_4, Al_2O_3, $AlCl_3$, Ti (Titanium), Ni (Nickel), or molybdenum disulfide (MoS2) alone or in combination with one or more gasses. However, these are only examples and, in some embodiments, the vaporizer **100** may generate the vapor from other materials and/or gasses.

[0043] For example, the vaporizer **100** may be included in the ion source **1** as illustrated in FIG. **17**. A plasma P may be generated based on an aluminum-containing vapor in an arc chamber **107**. An ion beam IB containing aluminum ions is extracted by extraction electrodes E through an aperture A of the arc chamber **107**. While two extraction electrodes E having an aperture respectively are illustrated in FIG. **17**, the number of extraction electrodes E is exemplary. In some embodiments, the number of extraction electrodes may be more or less than two. Generally, the number of the extraction electrodes may be changed depending on a configuration of the ion source. The vaporizer **100** may be equipped with a crucible **102** in which an aluminum-containing material ACM is placed.

[0044] The crucible **102** illustrated in FIG. **17** is a cylindrical member that is longer in one direction. For example, as shown in FIG. **17**, an axis of the crucible **102** may extend along a longitudinal direction (e.g., the Z-axis direction in FIG. **17**). One end of the crucible **102** in the longitudinal direction has a vapor outlet **102***a* for supplying aluminum-containing vapor to the arc chamber **107**, and the other end of the crucible **102** in the longitudinal direction has a gas inlet **102***b* to deliver a chlorine containing gas into the crucible **102**. In some embodiments, the chlorine containing gas may be, for example, a chlorine gas (Cl_2) or hydrogen chloride gas (HCl).

[0045] In some embodiments, a first nozzle **103** and a second nozzle **104** may be removably attached to the crucible **102**. The first nozzle **103** and the second nozzle **104** are respectively a roughly elongated cylindrical member. In some embodiments, the first nozzle **103**, the second nozzle **104**, and the crucible **102** may be made of graphite. However, graphite is only an example and, in some embodiments, another material may be used. The second nozzle **104** includes a portion located on the opposite end of the crucible **102** from the first nozzle **103**, and a long cylindrical portion that extends in the −Z axis direction to the end of the ion source **1**. Various methods (e.g., fitting and/or screwing) may be used to attach the first nozzle **103** and the second nozzle **104** to the crucible **102**. The first and second nozzles **103** and **104** are used to extend a vapor outlet **102***a* and a gas inlet **102***b* of the crucible **102**.

[0046] In FIG. **17**, arrow G denotes a flow of a supply of chlorine containing gas. The chlorine containing gas passes through the second nozzle **104**, the crucible **102**, and the first nozzle **103** and into the arc chamber **107**, in that order. In the crucible **102**, the chlorine containing gas reacts with the aluminum-containing material ACM that is heated to a high temperature to generate aluminum-containing vapor including aluminum chloride ($AlCl_3$) and other aluminum particles. The aluminum-containing vapor and chlorine containing gas are fed from crucible **102** to arc chamber **107** through the first nozzle **103**.

[0047] In some embodiments, the aluminum-containing material ACM may be in the form of a powder, pellets, and/or a block. In the case in which the aluminum-containing material ACM is provided in the form of a block, the aluminum-containing material ACM may have a plurality of pores so that a chemical reaction with the chlorine containing gas may be increased, since the chemical reaction depends on a size of a contact area between the chlorine containing gas and the aluminum. In some embodiments, the aluminum-containing material ACM may be, for example, pure aluminum, aluminum nitride, or aluminum oxide, or other aluminum containing materials including a powder.

[0048] In some embodiments, the aluminum-containing material ACM may be pure aluminum. Pure aluminum increases an aluminum ratio of the aluminum-containing vapor, and also increases an ion beam current of the ion beam extracted from the ion source IS. However, embodiments are not limited to pure aluminum, and in some embodiments, aluminum nitride, aluminum oxide and/or other solid aluminum containing materials may be used.

[0049] The supply of chlorine containing gas G to the second nozzle **104** may be done through a gas source inlet GI fitted inside of the second nozzle **104**, as shown in FIG. **17**. For example, in some embodiments, the chlorine containing gas G may be supplied from a gas source configured to supply the chlorine containing gas. The specific configuration of the gas source is not particularly limited as long as the gas source is capable of supplying a chlorine containing gas to the gas source inlet GI. In some embodiments, the crucible **102**, the first nozzle **103**, the second nozzle **104** and other components that serve as flow paths for chlorine containing gas may be made of corrosion-resistant carbon materials.

[0050] The end portion **103***a* of the first nozzle **103**, opposite from an end of the first nozzle **103** attached to the crucible **102**, protrudes into the arc chamber **107**. The end portion **103***a* has holes for vapor supply in four orthogonal directions so that aluminum-containing vapor may be diffused and supplied in multiple directions inside of the arc chamber **107**.

[0051] A coil heater **105** with a thermocouple is wound around a periphery of crucible **102**. The aluminum-containing material ACM is heated to a high temperature by the heater **105** and reacts with the chlorine containing gas to generate the aluminum-containing vapor. A first heat shield **106***a* is placed around a periphery of the heater **105** to block heat radiation from the heater **105**.

[0052] During operation, as the coil heater **105** heats the crucible **102** and thus the aluminum-containing material ACM within the crucible **102**, the temperature within the crucible **102** may vary from an ion source end of the crucible **102** (i.e., an end at which the second nozzle **104** is provided) to an opposite end of the crucible **102** (i.e., an end at which the first nozzle **103** is provided) due, at least in part, to heat that is generated by the arc chamber **107** and transferred to an end of the crucible **102** near the arc chamber **107**. For example, in some cases, the temperature difference may be about 125 degrees C. The variance of the temperature from one end of the crucible **102** to the other end of the crucible **102** causes the vapor supply from the vaporizer **100** to the arc chamber **107** to become unstable. In some embodiments, the temperature may be controlled by a thermocouple installed at an end of the coil heater **105**. However, even with crucible temperature control based on a temperature measured by the thermocouple, the crucible temperature control is not concise due to the large temperature difference from one end of the crucible **102** to the other end of the crucible **102** as discussed above. Therefore, it becomes difficult to achieve a stable vapor supply from the vaporizer **101** to the arc chamber **107**.

[0053] Accordingly, in some embodiments, the ion source **1** may be provided with a second heat shield **106***b* as illustrated in FIG. **1**. The second heat shield **106***b* may be provided between the crucible **102** and a side wall of the arc chamber **107** that faces the crucible **102**, and may extend radially outward from the first nozzle **103** and parallel to the side wall of the arc chamber **107**. In some embodiments, the second heat shield **106***b* may be secured by screws or other fittings. The second heat shield **106***b* may function to prevent heat from the arc chamber **107** from heating the end of the crucible **102** that is near the arc chamber **107**.

[0054] In some embodiments, the second nozzle **104** may have a large diameter section **104***a*. In some embodiments, a flange FL may be provided to attach the vaporizer **100** to an ion source flange ISF. A coil spring CS may be provided between the flange FL and the large diameter section **104***a* of the second nozzle **104**. The coil spring CS forces vaporizer **100** against a side wall of the arc chamber **107** to prevent aluminum-containing vapor and/or chlorine containing gas from leaking out between the first nozzle **103** and the arc chamber **107**. In some embodiments, one or more gaskets (not shown) may also be provided between the vaporizer **100** and the side wall of the arc chamber **107** to prevent gas leakage between the first nozzle **103** and the arc chamber **107**, and/or one or more gaskets (not shown) may be provided between the vaporizer **100** and the second heat shield **106***b* to prevent gas leakage between the vaporizer **100** and the second heat shield **106***b*. In some embodiments, a damper, for example, a spring clip in the form of a snap ring, may be attached to the first nozzle **103** in order to avoid excess pressure by the elastic force of the coil spring CS. In still other embodiments, a damper, for example, a spring clip, may be provided between the large diameter section **104***a* of the second nozzle **104** and the inner wall of the heat shield **106***a* in order to prevent the excess pressure by the elastic force of the coil spring CS. In some embodiments, one or all of one or more gaskets, a snap ring, and/or a spring clip may be provided. It is noted that the gaskets, snap ring and spring clip are only examples and, in other embodiments, different or additional structures may be used. The ion source flange ISF also indirectly supports the arc chamber **107** and other components around the arc chamber **107** such as the filament **109** and the cathode **108** by supporting parts not shown in FIG. **17**. In some embodiments, a reflecting electrode RE may be positioned opposite the cathode **108** to repel electrons from the cathode **108**. An external electromagnet, which is not shown in FIG. **17**, may generate a magnetic field along a direction connecting the cathode **108** and the reflecting electrode RE.

[0055] In some embodiments, the aluminum-containing material ACM may substantially fill the interior of the crucible **102** and chlorine containing gas may move through the crucible **102** through the powder or the pellets, or in the case of an aluminum block, through the pores in the block of the aluminum-containing material ACM. Thus, the chlorine containing gas may escape through the aluminum and be reduced.

[0056] In other embodiments, the aluminum-containing material may fill only a portion of the interior of the crucible **102**. For example, in some embodiments, a top edge of the aluminum-containing material ACM may coincide with a bottom edge of the vapor outlet **102***a*. In some embodiments, the aluminum-containing material ACM may be a semi-circular material in cross section, and a top edge of the aluminum-containing material ACM may coincide with a bottom edge of the gas inlet **102***b*. With this configuration, the chlorine containing gas may flow along the surface of the aluminum-containing material ACM rather than through pores in the aluminum-containing material ACM or between pellets of the aluminum-containing material ACM, allowing the chlorine containing gas to flow more freely to react with the aluminum-containing material ACM. That is, with a configuration in which the aluminum-containing material ACM is provided in a semi-circular cross-section, a reaction between chlorine containing gas and the aluminum-containing material ACM may be accelerated. As example of an aluminum-containing material ACM that is provided in a semi-circular cross-section is illustrated in U.S. application Ser. No. 17/714,491, filed Apr. 6, 2022, now U.S. Pat. No. 12,112,915 for "VAPORIZER, ION SOURCE AND METHOD FOR GENERATING ALUMINUM-CONTAINING VAPOR", the entire contents of which being herein incorporated by reference. During operation of the ion source IS, a temperature of the extraction electrodes E becomes around 400-500 Celsius. There are no deposits formed on a surface of the extraction electrodes E, based on aluminum chloride which is main ingredient of aluminum-containing vapor, because the boiling point of aluminum chloride included in aluminum-containing vapor is around 180 Celsius. Therefore, in the ion source **1** according to various embodiments described above, the insulation issue with the extraction electrodes E becoming insulated over time and requiring cleaning is avoided. That is, with ion source IS according to various embodiments, it is not necessary to use hydrogen gas in a method such as the "H_2 Co-gas" method to avoid the insulation issue of the extraction electrodes E becoming insulated over time as in the related art.

[0057] The above description is provided using an example of an IHC ion source. However, an IHC source is only one example embodiment and, in other embodiments, other types of ion sources such as a Bernas ion source and a Radio frequency inductively coupled plasma ion source, etc. may be used as the ion source IS.

[0058] Ion species other than aluminum ions may also be used. The chlorine containing gas flow path in the vaporizer **100** may be used for supplying other gas species (PH_3, PF_3, BF_3 and N_2, etc.). However, a reaction product generated by the reaction between the aluminum-containing solid material ACM in the crucible **102** and other gas species and other reaction products generated by the reaction between a residual gas and/or a residual vapor in the chlorine containing gas flow path and other gas species may cause unexpected discharge or other disadvantages.

[0059] Therefore, it is advantageous to separate a flow path for other gas species from the chlorine containing gas flow path.

[0060] FIG. **18** is a schematic plan view of another example of an ion source, according to various embodiments. In FIG. **18**, like reference numbers refer to like elements and a repeated description thereof is omitted for conciseness. As illustrated in FIG. **18**, an ion source **1**A includes the arc chamber **107** and a crucible **102**. The arc chamber **107** is provided with an inlet aperture IA on a side wall of the arc chamber **107** to which an L-shaped gas piping GP is connected to supply other gas species into the arc chamber **107**. For example, in some embodiments, the gas of the other species may be supplied from a gas source configured to supply the gas of the other gas species. The specific configuration of the gas source is not particularly limited as long as the gas source is capable of supplying a gas of the other gas species to the gas piping GP and ultimately to the inlet aperture IA.

[0061] Returning to FIGS. **3**-**5**, an interior of the vaporizer **100** may be in fluid communication with the interior of the plenum chamber **20** through the nozzle **110**. The nozzle **110** of the vaporizer extends through a wall the plenum chamber **20** that is opposite from the plenum plate **40** in the Z-axis direction, and thus a distal portion of the nozzle **110** may extend into the plenum chamber **20**.

[0062] In the ion source **1** illustrated in FIGS. **3**-**5**, an odd number of the plurality of gas feed chambers **30** are included in the ion source **1**. In this case, the vaporizer **100** is offset from the center of the wall of the plenum chamber **20** in the Y-axis direction. The vaporizer **100** may be offset from the center to allow for the gas feed lines **35** to be uniformly spaced along the longitudinal direction (e.g., the Y-axis direction). In other words, the vaporizer **100** may be offset so as not to conflict with one of the gas feed lines **35**.

[0063] In some embodiments, the ion source **1** may include five gas feed chambers **30** and five gas feed lines **35** as illustrated in FIGS. **3-5**. In this case, the vaporizer **100** may be disposed such that two gas feed lines **35** are disposed below the vaporizer **100** and three gas feed lines **35** are disposed above the vaporizer **100** in the Y-axis direction.

[0064] The slit **45** of the plenum plate **40** has a geometry based on the location of the nozzle **110** of the vaporizer **100** in the wall of the plenum chamber **20** in the longitudinal direction (e.g., the Y-axis direction). In an embodiment, the slit **45** may include a top portion **46**, a transition portion **47**, and a bottom portion **48**. The top portion **46** has a width in the X-axis direction that is wider than a width of the bottom portion **48** in the X-axis direction. A width of the transition portion **47** in the X-axis direction gradually narrows from the top portion **46** to the bottom portion **48**. A location of the nozzle **110** of the vaporizer **100** in the wall of the plenum chamber **20** in the longitudinal direction generally coincides with a location of the transition portion **47** in the slit **45** in the longitudinal direction. In an embodiment, a bottom of the nozzle **110** may be located at a position in the wall of the plenum chamber **20** in the longitudinal direction that corresponds to a top of the transition portion in the longitudinal direction (best seen in FIG. **3**). In an embodiment, a distance D1 of the bottom of the nozzle **110** of the vaporizer **100** from a bottom wall of the plenum chamber **20** may correspond to a combined length of the bottom portion **48** and the transition portion **47** of the slit **45** in the Y-axis direction. In an embodiment, a distance D2 of the bottom of the nozzle **110** from a top wall of the plenum chamber **20** may correspond to a distance from the top wall of the plenum chamber **20** to a bottom of the transition portion **47** of the slit **45** in the Y-axis direction. Since the location of the vaporizer **100** is offset from a center of the plenum chamber **20** in the Y-axis direction, the distance D2 from the top wall of the plenum chamber **20** is greater than the distance D1.

[0065] In an embodiment, the length in the longitudinal direction of the portion of the slit **45** that has the narrower width may be shorter than a length in the longitudinal direction of the portion of the slit **45** that has the wider width. Thus, assuming a case in which the vaporizer **100** is disposed so as to be offset in the direction of the top wall of the plenum chamber **20** such that two gas feed lines **35** are disposed on top of the vaporizer **100** and three gas feed lines are disposed on the bottom of the vaporizer **100** (i.e., opposite to the example illustrated in FIGS. **3-5**), the top portion **46** of the slit **45** would have a narrower width that the bottom portion **48** of the slit **45** (again opposite to the example illustrated in FIGS. **3-5**) and the width of the transition portion **47** would gradually decrease from the bottom portion **48** to the top portion **46** (i.e., in the opposite direction to that illustrated in FIGS. **3-5**). This configuration is due to the volume of the plenum chamber **20** being less on the side to which the vaporizer **100** is offset such that the portion of the plenum plate **40** with the narrower slit restricts the flow of vapor into the ionization chamber **50** more than the portion of the plenum plate **40** with the wider slit in order that the vapor flows more uniformly into the ionization chamber **50**. With the flow of a more uniform vapor along the longitudinal (e.g., the Y-axis direction) into the ionization chamber **50**, a more uniform plasma may be generated in the ionization chamber **50** and thus a more uniform ribbon ion beam IB may be extracted from the ionization chamber **50**.

[0066] FIGS. **6-8** illustrate a ion source **1'**, according to some embodiments, in which FIG. **6** illustrates the ion source **1'** when viewed from a Z-axis direction, FIG. **7** illustrates a cross-sectional view of the ion source **1'** taken along A-A' in FIG. **6**, and FIG. **8** illustrates a cross-sectional view of the ion source **1'** taken along B-B' in FIG. **6**. In FIGS. **6-8**, like reference designators represent like components in FIGS. **2-5** that have like structures and functions, and therefore a repeated description thereof is omitted for conciseness.

[0067] FIGS. **6-8** illustrate an example in which the plurality of gas feed chambers **30** and the plurality of gas feed lines **35** are each provided in an even number. In this configuration, the vaporizer **100** may be disposed to feed vapor into the plenum chamber **20** at the center of the wall of the plenum chamber **20**. For example, FIGS. **6-8** illustrate an example of the ion source **1'** in which four gas feed chambers **30** and four gas feed lines **35** are provided and two of the gas feed lines **35** are positioned above the vaporizer **100** and two of the gas feed lines **35** are positioned below the vaporizer **100**. In this case, the nozzle **110** of the vaporizer **100** may be located in the center of the wall of the plenum chamber **20** in the Y-axis direction.

[0068] In an embodiment, similar to the example illustrated in FIGS. **3-5**, a location of the nozzle **110** of the vaporizer **100** in the wall of the plenum chamber **20** in the longitudinal direction may generally coincide with a location of the transition portion **47** in the longitudinal direction of the slit **45**. In an embodiment, a distance D3 of the bottom of the nozzle **110** of the vaporizer **100** from a bottom wall of the plenum chamber **20** may correspond to a combined length of the bottom portion **48** and the transition portion **47** of the slit **45** in the Y-axis direction. In an embodiment, a distance D4 of the bottom of the nozzle **110** from a top wall of the plenum chamber **20** may correspond to a distance from the top wall of the plenum chamber **20** to a bottom of the transition portion **47** of the slit **45** in the Y-axis direction. While, in this example, the location of the vaporizer **100** is at the center of the plenum chamber **20** in the Y-axis direction, the bottom of the nozzle **110** is located below the center and thus the distance D4 from a top wall of the plenum chamber **20** is still greater than the distance D3.

[0069] FIG. **9** illustrates an example of a nozzle of a vaporizer of the ion source **1** or the ion source **1'**, according to some embodiments. The nozzle **110** may include a pipe **112** and a cap **115** on a distal end of the pipe **112**. The pipe **112** may have a plurality of holes **114** formed therein at the distal end of the pipe **112**. In an embodiment, two holes **114** may be provided as illustrated in FIG. **9**. However, this number is only an example and, in some embodiments, more than two holes **114** may be formed.

[0070] In an embodiment, the two holes **114** may be located on opposite sides of the pipe **112**. The holes **114** may be located on lateral sides of the pipe **112** (e.g., in the X-axis direction) as illustrated in FIG. **9**. However, this location is only an example and, in some embodiments, the holes **114** may be formed in the top and bottom of the pipe **112** (e.g., in the Y-axis direction) (see, e.g., FIG. **4**). For example, when the holes **114** are located on the top and bottom of the pipe **112**, the vapor may more easily spread out along a longitudinal direction (e.g., the Y-axis direction) in the plenum chamber **20**. In an embodiment, a diameter of each of the plurality of holes **114** may be the same. The cap **115** may have a hole **116** formed therein (i.e., in the Z-axis direction). In an embodiment, the diameter of the hole **116** may be smaller than a diameter of each of the holes **114**.

[0071] In an embodiment, the pipe **112** may extend through the wall of the plenum chamber **20** as described above. As such, a distal portion of the pipe **112** may extend into the plenum chamber **20**. In use, a vapor generated from a solid raw material in a crucible (not shown) of the vaporizer **100** may travel through the pipe **112** into the plenum chamber **20** and flow out of the holes **114** and the hole **116** into the plenum chamber **20**.

[0072] FIG. **10** illustrates an example of a heater of the ion source, according to some embodiments. In an embodiment, a heater **200** may be provided on lateral side surfaces of the plenum **10** and the ionization chamber **50**. In an embodiment, the heater **200** may be a block heater as illustrated in FIG. **10**. However, embodiments are not limited thereto and, in some embodiments, the heater **200** may be a coil heater. A heater density of the heater **200** at a top and bottom thereof is different than a heater density of the heater **200** at a middle thereof. In other words, the middle of the heater **200** may generate a higher heating temperature than the top and bottom of the heater **200**. This is because the cathode **52** and the cathode **55** are provided at the top and the bottom of the ionization chamber **50** and the cathode **52** and the cathode **55** each generate heat. Therefore, for uniform heating, it is not needed to heat the top and bottom ends of the plenum **10** and the ionization chamber **50** as much because the cathode **52** and the cathode **55** provide their own heat. In other words, the heater **200** ensures a uniform temperature of the ionization chamber **50**.

[0073] In use, the heater **200** helps mitigate condensation of the vapor supplied by the vaporizer **100**. For example, in an embodiment, the temperature of the ion source **1** or the ion source **1'** may be very low in comparison with a related art ion source that is used for manufacturing semiconductor devices. As an example, the ion source **1** or the ion source **1'** having a height of about 370 mm to 400 mm and a width of about 60 mm may have a temperature during operation of about 100° C. to about 400° C. By contrast, the related art ion source that is used for manufacturing semiconductor device may have a height of about 130 mm to 160 mm and a width of about 60 mm and may have a temperature during operation of about 1000° C. to about 1500° C. The size of the ionization chamber is only one factor that may determine the temperature of the ionization chamber. Other factors may include, for example, an operation method of the ion source, a structure of the cathode in the ionization chamber, etc.

[0074] In some embodiments, the heater **200** may be omitted from the lateral side surfaces of the ionization chamber **50** and the heater **200** may only be provided on the lateral side surfaces of the plenum **10**. For example, when a temperature of the ionization chamber **50** is higher than a condensation temperature of the vapor, the heater **200** may be omitted from the lateral side surfaces of the ionization chamber **50**.

[0075] In some embodiments, the heater **200** may be omitted entirely. For example, when the plenum **10** is heated by heat transfer from the ionization chamber **50** and when the temperature of the plenum **10** is higher than the condensation temperature of the vapor, the heater **200** may be omitted from the ion source **1** or the ion source **1'**.

[0076] FIGS. **11-13** illustrate a liner of the ion source, according to some embodiments, in which FIG. **11** illustrates the liner when viewed from a Z-axis direction in FIG. **2**, FIG. **12** illustrates a cross-sectional view of the liner taken along A-A' in FIG. **11**, and FIG. **13** illustrates a cross-sectional view of the liner taken along B-B' in FIG. **11**.

[0077] As described above, in some embodiments, interior walls of the ionization chamber **50** may be covered by the liner **70**. In some embodiments, the liner **70** may include the top liner **72**, the bottom liner **74**, the two side wall liners **76**, and the rear liner **78**.

[0078] As illustrated in FIG. **11**, the rear liner **78** may be formed with an opening corresponding to the plenum plate **40** and a plurality of openings **79** for the plurality of gas feed chambers **30**. In the example illustrated in FIGS. **11-13**, each gas feed chamber **30** is provided with two openings **79** (best seen in FIG. **13**). However, embodiments are not limited thereto and, in some embodiments, the rear liner **78** may have one opening **79** or more than two openings **79** for each of the gas feed chambers **30**.

[0079] In an embodiment, the top liner **72**, the bottom liner **74**, the two side wall liners **76**, and the rear liner **78** may be formed as one single liner **70**. However, embodiments are not limited thereto and, in some embodiments, separate liners may be provided.

[0080] In an embodiment, the top liner **72**, the bottom liner **74**, the two side wall liners **76**, and the rear liner **78** may each be made of molybdenum. However, this is only an example and, in some embodiments, the top liner **72**, the bottom liner **74**, the two side wall liners **76**, and the rear liner **78** may be made of other materials as long as the material will decrease sputtering onto the walls of the ionization chamber **50**.

[0081] In some embodiments, the liner **70** may be omitted.

[0082] FIGS. **14-16** illustrate a liner of the ion source, according to some embodiments, in which FIG. **14** illustrates the liner when viewed from a Z-axis direction in FIG. **2**, FIG. **15** illustrates a cross-sectional view of the liner taken along A-A' in FIG. **14**, and FIG. **16** illustrates a cross-sectional view of the liner taken along B-B' in FIG. **14**. FIGS. **14-16** correspond to FIGS. **13-15** and thus repeated description thereof is omitted for conciseness.

[0083] In FIGS. **14-16**, an example of the liner **70** as applied to the ion source **1'** of FIGS. **6-8** is illustrated. As with the example illustrated in FIGS. **11-13**, the rear liner **78** may include a plurality of openings **79** for the plurality of gas feed chambers **30**. In the example illustrated in FIGS. **14-16**, each gas feed chamber **30** is provided with two openings **79** (best seen in FIG. **16**). However, embodiments are not limited thereto and, in some embodiments, the rear liner **78** may have one opening **79** or more than two openings **79** for each of the gas feed chambers **30**.

[0084] It should be understood that embodiments are not limited to the various embodiments described above, but various other changes and modifications may be made therein without departing from the spirit and scope thereof as set forth in appended claims.

What is claimed is:

1. A vaporizer comprising:

a crucible in which an solid material is received, the crucible comprising a reactive gas inlet and a vapor outlet.

2. The vaporizer as recited in claim **1**, further comprising a heater configured to heat the crucible.

3. The vaporizer as recited in claim **1**, wherein the vapor outlet outputs a vapor in a plurality of directions.

4. The vaporizer as recited in claim **1**, wherein an edge of the reactive gas inlet is aligned with a surface of the solid material.

5. An ion source comprising:
the vaporizer according to claim **1**;
an arc chamber configured to generate a plasma therein,
wherein the vapor outlet of the vaporizer is configured to output the vapor into the arc chamber through a wall of the arc chamber.

6. The ion source as recited in claim **5**, wherein the solid material includes at least one of Aluminum, Indium, Titanium, Nickel, Molybdenum, Tungsten, Antinomy, or Sulfur.

7. The ion source as recited in claim **5**, wherein the vapor outlet comprises an end portion that extends through the wall of the arc chamber, the end portion comprising a plurality of holes at a distal end thereof.

8. The ion source as recited in claim **5**, wherein an edge of the reactive gas inlet is aligned with a surface of the solid material.

9. The ion source as recited in claim **5**, wherein the crucible is biased to the arc chamber by an elastic force.

10. The ion source as recited in claim **5**, wherein the arc chamber receives the vapor from the vapor outlet of the crucible and receives a gas that does not contain chemical species constituting the solid material from a flow path that does not pass through the crucible.

11. The ion source as recited in claim **5**, wherein the arc chamber further comprises a gas inlet communicatively connect to a flow path that does not pass through the crucible.

12. The vaporizer as recited in claim **1**, wherein the crucible is cylindrical and extends in a longitudinal direction,
the reactive gas inlet is provided at a first end of the crucible in the longitudinal direction, and
the vapor outlet is provided at a second end of the crucible opposite from the first end in the longitudinal direction.

13. A method for generating a vapor, the method comprising:
preparing a solid material in a crucible; and
introducing a reactive gas into the crucible.

14. A vaporizer comprising:
a first gas source comprising a reactive gas; and
a crucible containing a solid material, the crucible comprising a gas inlet communicatively connected to the first gas source, and a vapor outlet.

15. The vaporizer as recited in claim **14**, further comprising a heater configured to heat the crucible.

16. The vaporizer as recited in claim **14**, wherein the reactive gas includes chlorine.

17. An ion source comprising:
a first gas source comprising a first gas that contains a reactive component;
a vaporizer comprising a crucible containing a solid material, the crucible comprising a gas inlet communicatively connected to the first gas source, and a vapor outlet; and
an arc chamber configured to generate a plasma therein,
wherein the vapor outlet of the vaporizer is configured to output a vapor into the arc chamber through a wall of the arc chamber.

18. The ion source as recited in claim **17**, further comprising:
a second gas source comprising a second gas that does not contain a chemical species constituting the solid material,
wherein the arc chamber comprises a gas inlet communicatively connected to the second gas source, and
wherein a flow path from the second gas source to the gas inlet of the arc chamber does not pass through the crucible.

19. The ion source as recited in claim **17**, wherein the reactive component includes chlorine.

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