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(54) X-RAY GENERATOR

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(57) **ABSTRACT**

An X-ray generator includes: an X-ray tube configured to cause an X-ray beam to be generated; a source configured to generate a voltage to be applied to the X-ray tube; a container storing at least part of the X-ray tube; a first insulator that is liquid, the first insulator being sealed in the container, the first insulator covering the at least part of the X-ray tube; and a gas sensor including a detector disposed in the container to detect gas generated in the first insulator.

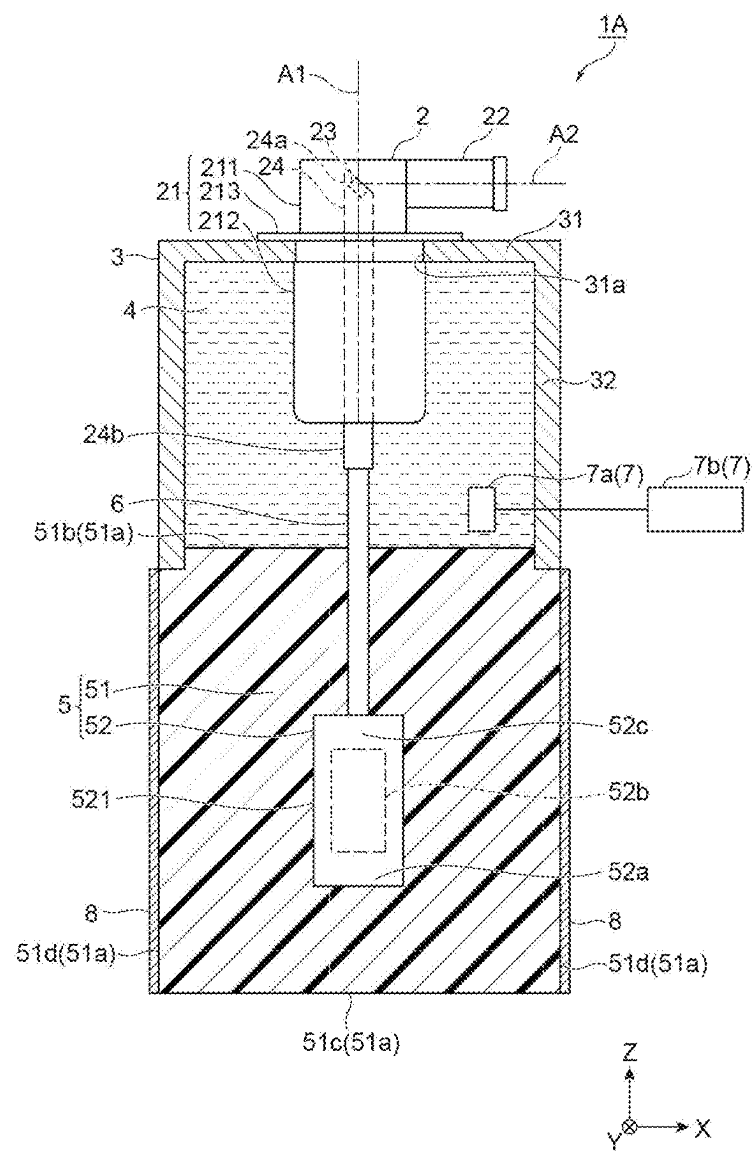
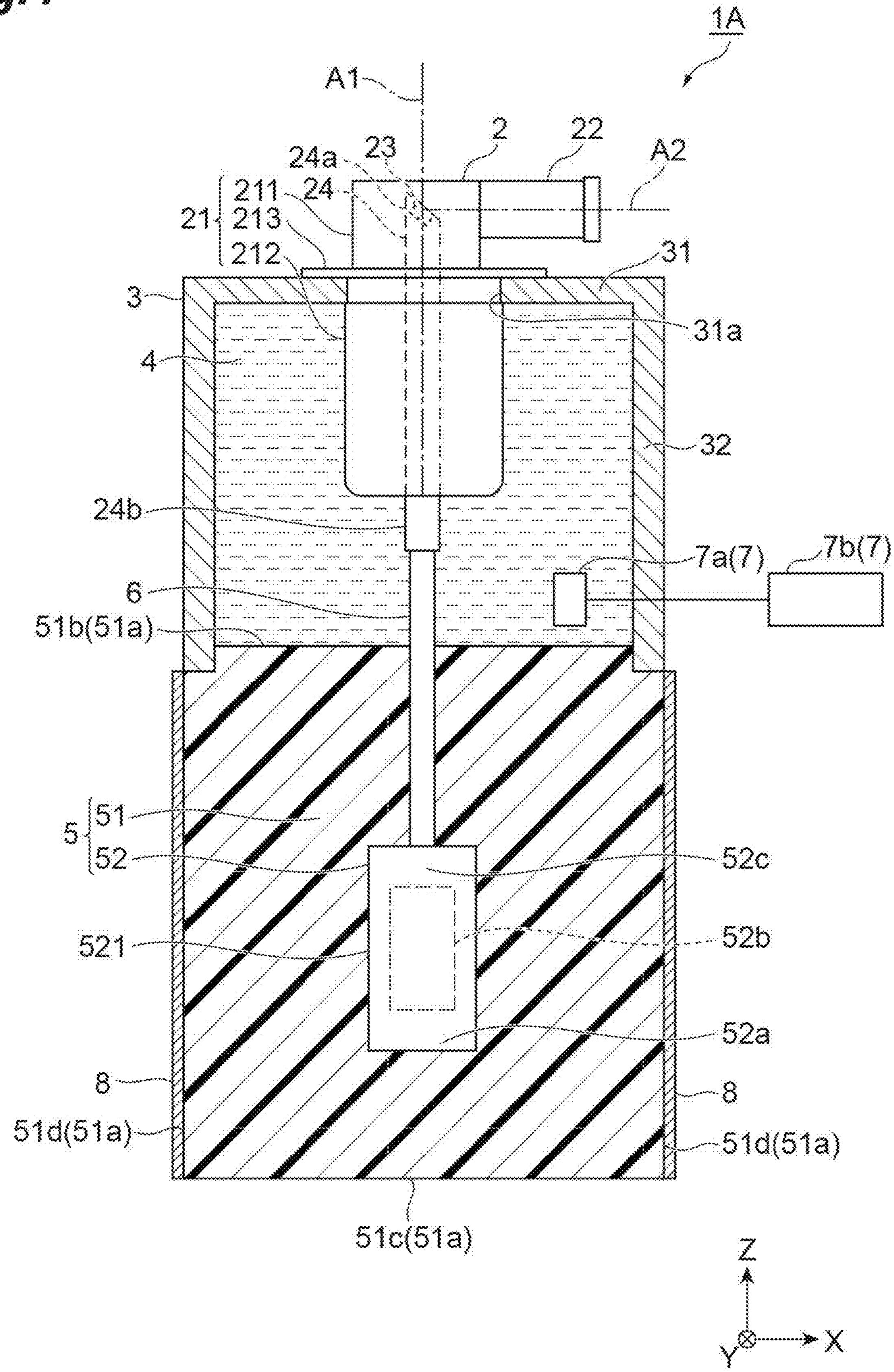


Fig.1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A1
2
22
A2
24a
23
211
24
21
213
212
31
3
31a
4
32
24b
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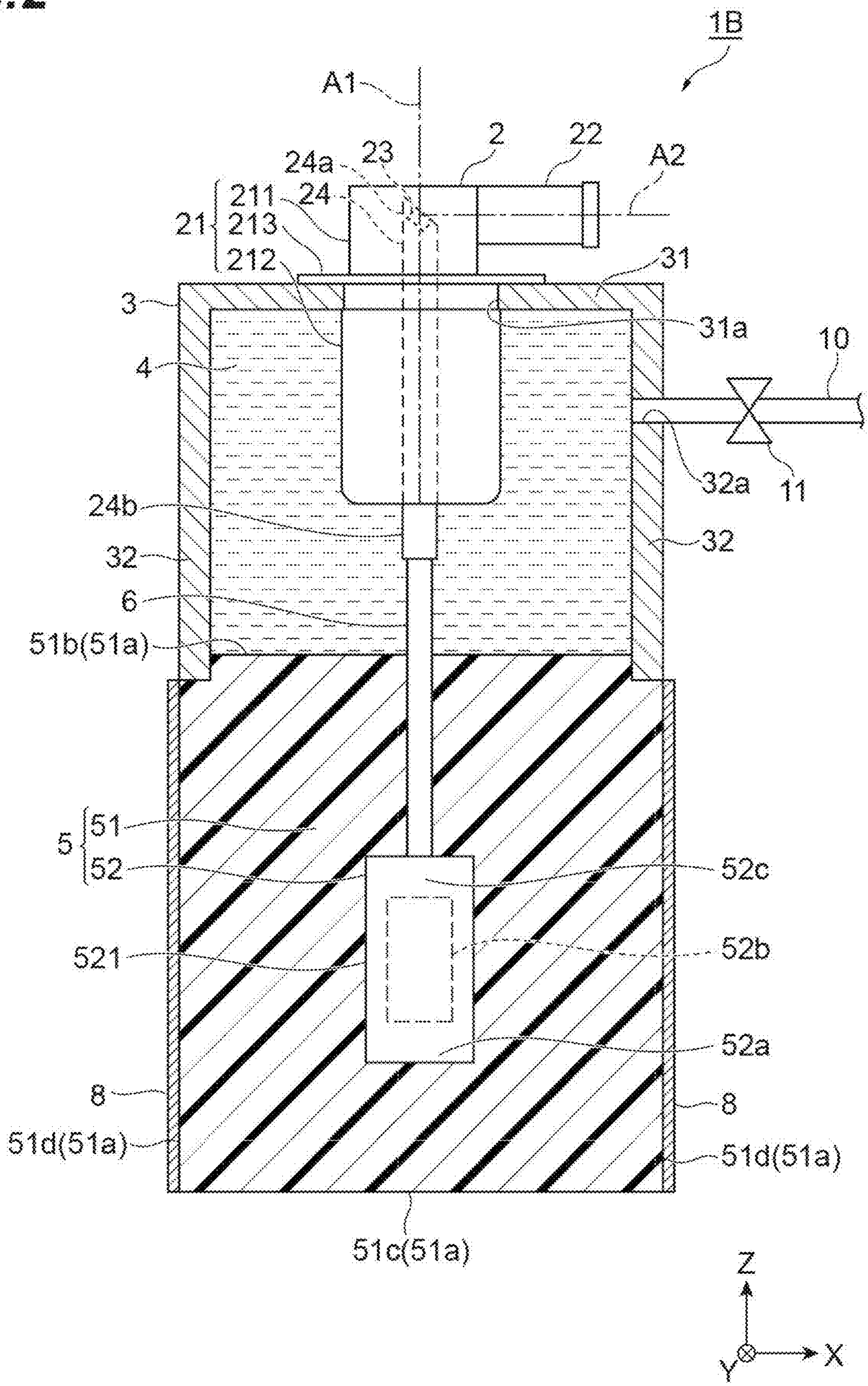
7b(7)
6
51b(51a)
5
51
52
52c
521
52b
52a
8
8
51d(51a)
51d(51a)
51c(51a)
Z
Y
X

Fig.2



1B
A1
2
22
24a
23
A2
211
24
21
213
212
31
3
31a
10
4
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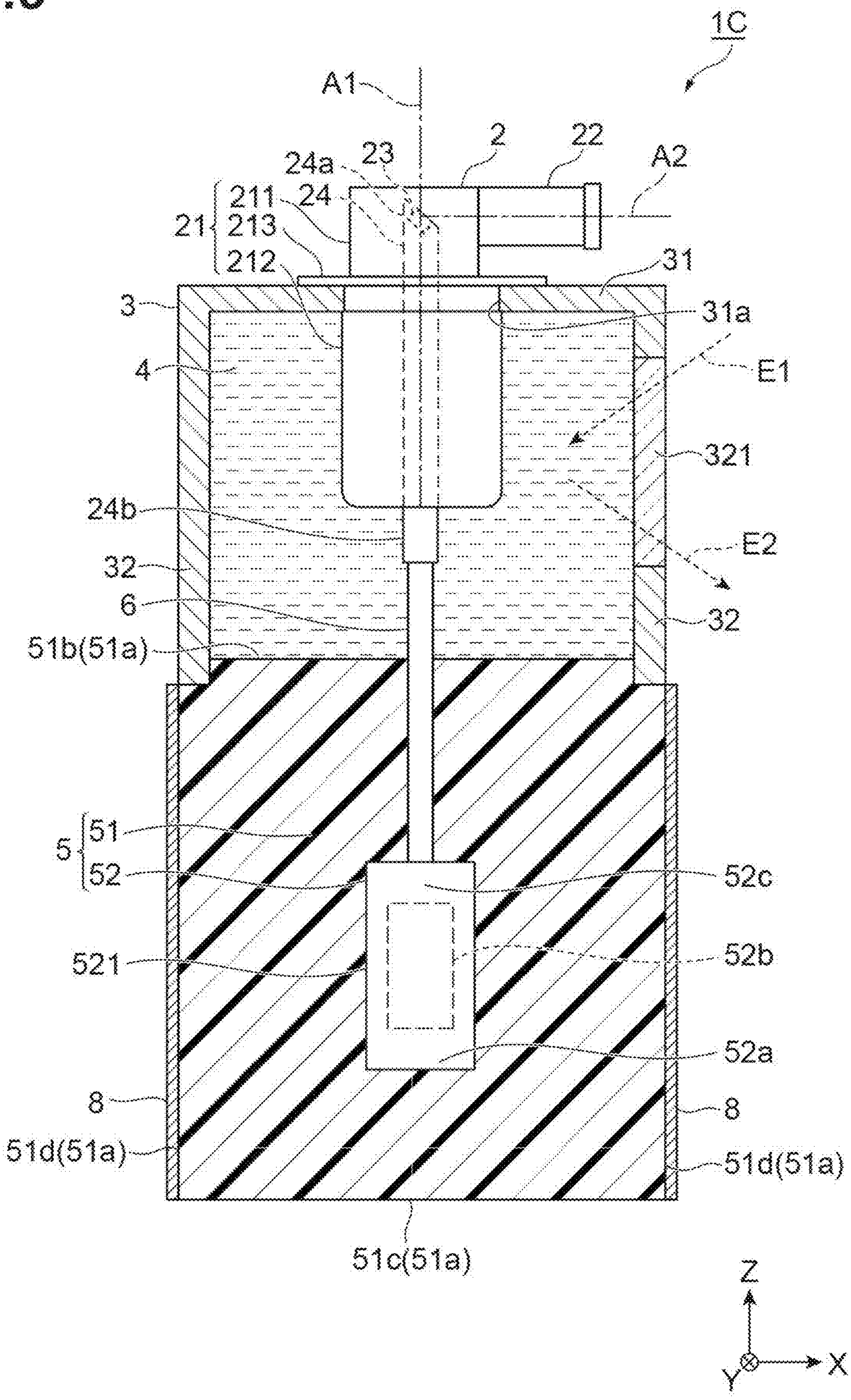
11
24b
32
32
6
51b(51a)
5
51
52
52c
521
52b
52a
8
8
51d(51a)
51d(51a)
51c(51a)
Z
Y
X

Fig.3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A2
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24a
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211
213
212
21
31
3
31a
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E1
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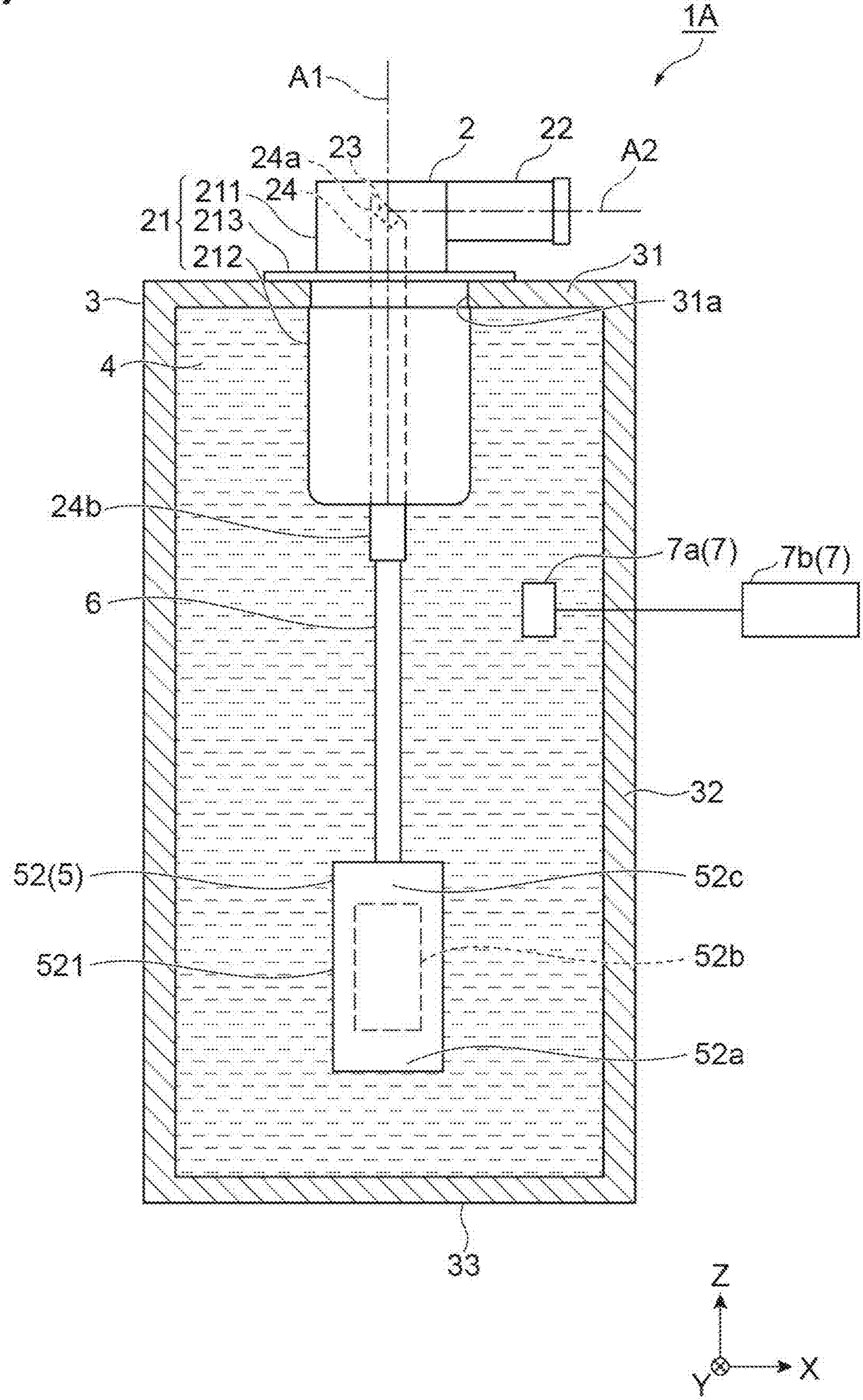
24b
E2
32
6
32
51b(51a)
5
51
52
52c
521
52b
52a
8
8
51d(51a)
51d(51a)
51c(51a)
Z
Y
X

Fig.4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A1
2
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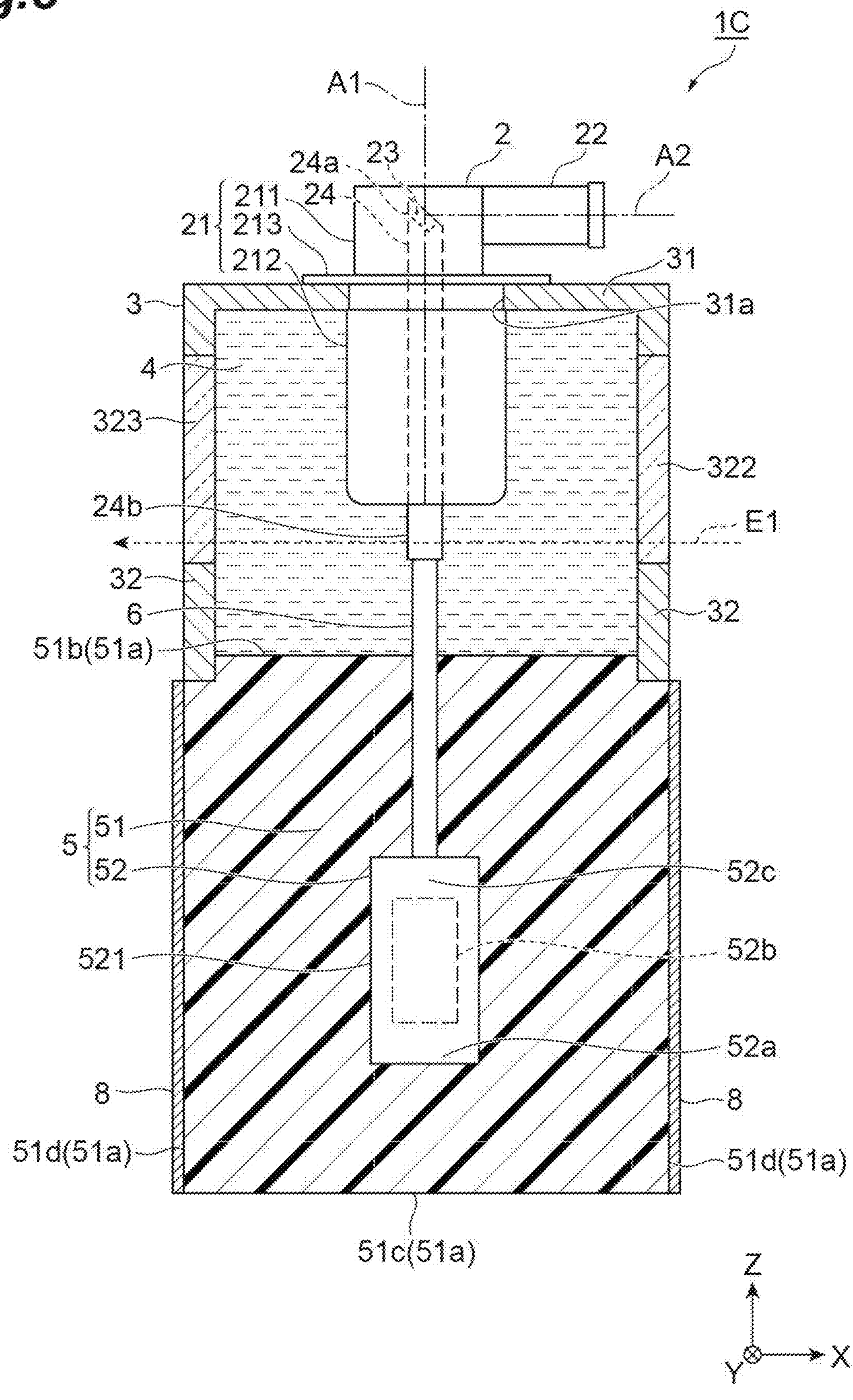
A2
24a
23
24
21
211
213
212
31
3
31a
4
24b
7a(7)
7b(7)
6
32
52(5)
52c
521
52b
52a
33
Z
Y
X

Fig.5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A2
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23
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213
212
31
31a
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323
322
24b
E1
32
32
6
51b(51a)
5
51
52
52c
521
52b
52a
8
8
51d(51a)
51d(51a)
51c(51a)
Z
Y
X

X-RAY GENERATOR

TECHNICAL FIELD

[0001] The present disclosure relates to an X-ray generator.

BACKGROUND

[0002] As an X-ray generator, known is an X-ray generator including an X-ray tube that causes an X-ray beam to be generated, a source that generates a voltage to be applied to the X-ray tube, a container that stores at least part of the X-ray tube, and a liquid insulator that is sealed in the container and covers the at least the part of the X-ray tube (see, for example, Japanese Patent No. 6190563).

SUMMARY

[0003] In such an X-ray generator as described above, due to occurrence of discharging in the insulator, thermal decomposition of the insulator may occur. In this case, because the insulating performance of the insulator is decreased, the operational stability of the X-ray generator may be decreased. In order to maintain the operational stability of the X-ray generator, the gas derived, in the insulator, from the thermal decomposition of the insulator is detected, so that the insulating performance of the insulator is checked for the level of decrease.

[0004] An object of the present disclosure is to provide an X-ray generator that can easily detect gas generated in an insulator.

Solution to Problem

[0005] An X-ray generator according to one aspect of the present disclosure includes: an X-ray tube configured to cause an X-ray beam to be generated; a source configured to generate a voltage to be applied to the X-ray tube; a container storing at least part of the X-ray tube; a first insulator that is liquid, the first insulator being sealed in the container, the first insulator covering the at least part of the X-ray tube; and a gas sensor including a detector disposed in the container to detect gas generated in the first insulator.

[0006] An X-ray generator according to one aspect of the present disclosure includes: an X-ray tube configured to cause an X-ray beam to be generated; a source configured to generate a voltage to be applied to the X-ray tube; a container storing at least part of the X-ray tube; and a first insulator that is liquid, the first insulator being sealed in the container, the first insulator covering the at least part of the X-ray tube, in which the container is provided with a discharge port through which an inside of the container and an outside of the container are in communication with each other.

[0007] An X-ray generator according to one aspect of the present disclosure includes: an X-ray tube configured to cause an X-ray beam to be generated; a source configured to generate a voltage to be applied to the X-ray tube; a container storing at least part of the X-ray tube; and a first insulator that is liquid, the first insulator being sealed in the container, the first insulator covering the at least part of the X-ray tube, in which at least part of the container is made of a material that allows light having a predetermined wavelength to travel through the material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. **1** is a sectional view of an X-ray generator according to a first embodiment;

[0009] FIG. **2** is a sectional view of an X-ray generator according to a second embodiment;

[0010] FIG. **3** is a sectional view of an X-ray generator according to a third embodiment;

[0011] FIG. **4** is a sectional view of an X-ray generator according to a modification; and

[0012] FIG. **5** is a sectional view of an X-ray generator according to another modification.

DETAILED DESCRIPTION

[0013] Hereinafter, embodiments of the present disclosure will be described in detail with reference to the accompanying drawings. In the drawings, the same or corresponding parts are denoted by the same reference signs, and redundant description will be not be given.

X-ray Generator of First Embodiment

[0014] As illustrated in FIG. **1**, an X-ray generator **1**A of a first embodiment includes an X-ray tube **2**, a container **3**, a first insulator **4**, a source **5**, a conductive member **6**, a gas sensor **7**, and a conductive paint **8**. The X-ray generator **1**A is, for example, a microfocus X-ray source to be used for X-ray non-destructive inspection.

[0015] The X-ray tube **2** is a vacuum tube for generating an X-ray beam. The X-ray tube **2** includes a housing **21**, an electron gun **22**, a target **23**, and an anode **24**. The housing **21** houses the electron gun **22**, the target **23**, and the anode **24**. The space in the housing **21** is a space to be evacuated. The housing **21** includes a head **211**, a valve **212**, and a flange **213**. The head **211** made of a metal material such as stainless steel has a bottomed cylindrical shape. The valve **212** made of an insulating material such as glass has a bottomed cylindrical shape. The head **211** is airtightly joined to the valve **212** such that the inside of the head **211** is in communication with the inside of the valve **212**. The flange **213** made of a metal material such as stainless steel has an annular shape along the outer edge of the head **211**. Here, a direction along the central axis (pipe axis) A**1** of the valve **212** is referred to as a Z-axis direction, a direction perpendicular to the Z-axis direction is referred to as an X-axis direction, and a direction perpendicular to both the Z-axis direction and the X-axis direction is referred to as a Y-axis direction.

[0016] The electron gun **22** emits an electron beam to the target **23** in the housing **21**. The electron gun **22** includes a hot cathode that emits thermoelectrons, an anode that accelerates electrons, and an electron lens that adjusts convergence of an electron beam (all not illustrated), for example. The electron gun **22** is fixed to the head **211** such that the central axis A**2** of the electron gun **22** is orthogonal to the central axis A**1** of the valve **212**. The central axis A**2** of the electron gun **22** is along the X-axis direction.

[0017] The target **23** generates an X-ray beam in the housing **21**, in response to incidence of the electron beam emitted from the electron gun **22** on the target **23**. The target **23** made of a high melting point metal material such as tungsten has a plate shape. The target **23** is supported by the anode **24** in the housing **21** so as to face the electron gun **22** in the X-axis direction.

[0018] The anode **24** applies a voltage generated by the source **5** to the target **23**. Therefore, the anode **24** is in conduction with the target **23**. The anode **24** made of a metal material such as copper has a rod shape extending along the Z-axis direction. The anode **24** extends from the outside of the housing **21** to the inside of the housing **21** such that the central axis of the anode **24** coincides with the central axis A**1** of the valve **212**. The anode **24** is fixed to the bottom of the valve **212**. The anode **24** has a leading end face in the housing **21**, and the leading end face is an inclined face inclined to both the central axis A**1** and the central axis A**2**. The anode **24** has a leading end portion **24***a*, and the target **23** is embedded in the leading end portion **24***a* such that the target **23** is flush with the leading end face of the anode **24**.

[0019] The container **3** houses part of the X-ray tube **2**. In the X-ray generator **1**A of the first embodiment, the container **3** houses the valve **212**. The container **3** made of a metal material such as aluminum has a bottomed cylindrical shape. The container **3** has an upper portion **31** and a side portion **32**. The side portion **32** has a tubular shape with the Z-axis direction as a height direction. The side portion **32** has one end portion (an upper end portion in the present embodiment) in the Z-axis direction, and the upper portion **31** occludes the one end portion. The upper portion **31** is provided with an opening **31***a*. The X-ray tube **2** is located inside the opening **31***a*. The flange **213** is fixed to the upper portion **31** with the valve **212** located inside the container **3**. The side portion **32** has the other end portion (a lower end portion in the present embodiment) in the Z-axis direction is fixed to the upper end of the source **5** (an upper face **51***b* that a second insulator **51** has). The first insulator **4** is sealed in the container **3**.

[0020] The first insulator **4** electrically insulates the X-ray tube **2** from other members. The first insulator **4** is a liquid insulator. The first insulator **4** is, for example, an insulating oil containing mineral oil or ester oil as a main component. The first insulator **4** covers, in the container **3**, the valve **212**, part of the anode **24** exposed outward from the housing **21**, and part of the conductive member **6** exposed outward from the second insulator **51**. In the X-ray generator **1**A of the first embodiment, the inside of the container **3** is filled with the first insulator **4**.

[0021] The source **5** generates a voltage to be applied to the target **23** through the conductive member **6** and the anode **24**. The source **5** is disposed on one side of location in the Z-axis direction with respect to the housing **21** (below the housing **21**). The source **5** is aligned with the X-ray tube **2** along the Z-axis direction. The source **5** includes the second insulator **51** and a circuit **52**.

[0022] The second insulator **51** is a solid insulator that electrically insulates the circuit **52** from other members. The second insulator **51** made of a resin material such as epoxy resin has a rectangular parallelepiped shape. The second insulator **51** has a surface **51***a* including the upper face **51***b* as a face on the side of location of the housing **21**, a lower face **51***c* opposed to the upper face **51***b*, and a side face **51***d* connecting the upper face **51***b* and the lower face **51***c* to each other. Part of the upper face **51***b* rises. The part is in contact with the first insulator **4** in the container **3**. The conductive paint **8** is applied to the side face **51***d* of the second insulator **51**, and the potential of the side face **51***d* is set as the ground potential.

[0023] The circuit **52** includes a substrate **521** as a rectangular printed circuit board. The substrate **521** has a front face orthogonal to the Y-axis direction. A first voltage section **52***a*, a booster **52***b*, and a second voltage section **52***c* are mounted on the front face of the substrate **521**. The first voltage section **52***a* is an input terminal that receives a first voltage from the outside, and is electrically connected to the booster **52***b*. The booster **52***b* boosts the first voltage to a second voltage. The booster **52***b* is, for example, a Cockcroft-Walton multiplier. The second voltage section **52***c* is an output terminal that outputs the second voltage to the target **23** through the conductive member **6** and the anode **24**, and is electrically connected to the booster **52***b*.

[0024] The booster **52***b* is located in a central portion of the front face of the substrate **521**. The first voltage section **52***a* is located on one side of location in the Z-axis direction with respect to the booster **52***b* (lower face **51***c* side). The second voltage section **52***c* is located on the other side of location in the Z-axis direction with respect to the booster **52***b* (upper face **51***b* side).

[0025] The circuit **52** is embedded in the second insulator **51** such that the entirety of the circuit **52** is located in the second insulator **51**. The circuit **52** is embedded in the second insulator **51** such that the substrate **521** extends straight along the Z-axis direction.

[0026] The conductive member **6** electrically connects the second voltage section **52***c* and the target **23** through the anode **24**. Therefore, the conductive member **6** is conductive. The conductive member **6** made of a metal material such as aluminum has a rod shape. The conductive member **6** has an end portion electrically connected to the second voltage section **52***c*, and another end portion electrically connected to a base end portion **24***b* that the anode **24** has (a portion of the anode **24** located outside the housing **21**). The conductive member **6** is embedded in the second insulator **51** such that part of the conductive member **6** is located in the second insulator **51**. Part of the conductive member **6** different from the part of the conductive member **6** embedded in the second insulator **51** is exposed outward from the second insulator **51**. The part of the conductive member **6** exposed outward from the second insulator **51** is electrically connected to the base end portion **24***b* of the anode **24** inside the container **3**.

[0027] The gas sensor **7** detects gas generated in the first insulator **4**. The gas sensor **7** has a configuration corresponding to the type of gas to be detected. The gas sensor **7** includes a detector **7***a* and a controller **7***b*. The controller **7***b* functions as, for example, a voltage applier that applies a voltage for driving the detector **7***a* and a signal processor that processes a detection signal from the detector **7***a*. The detector **7***a* is disposed in the container **3**. In the X-ray generator **1**A of the first embodiment, the detector **7***a* is disposed in the first insulator **4**. That is, the detector **7***a* is immersed in the first insulator **4**. The detector **7***a* is electrically connected to the controller **7***b* disposed outside the container **3**. The controller **7***b* may be disposed in the source **5**. For example, the controller **7***b* may be mounted on the substrate **521**. Alternatively, the controller **7***b* may be mounted on a substrate different from the substrate **521**, and the substrate may be embedded in the second insulator **51**.

[0028] The gas sensor **7** is, for example, a non dispersive infrared (NDIR) gas sensor. The NDIR gas sensor detects gas by utilizing a property that gas molecules absorb infrared light having a specific wavelength. The detector **7***a* of the gas sensor **7** as an NDIR gas sensor includes a light emitter and a light receiver. The light emitter is a light emitting element that emits infrared light having a specific wavelength, and is electrically connected to the controller **7***b*. The light receiver is a light receiving element that absorbs infrared light emitted from the light emitter, and is electrically connected to the controller **7***b*. The light receiver outputs a signal corresponding to the amount of absorbed infrared light to the controller **7***b*. In a case where gas (e.g., acetylene gas) is present in the first insulator **4**, the infrared light to the light receiver is reduced in amount because a portion of infrared light emitted from the light emitter is absorbed by the gas. The controller **7***b* calculates the concentration of the gas on the basis of the level of the signal detected through the light receiver. In a case where the gas to be detected is acetylene gas, the light emitter emits infrared light with a wavelength of, for example, 2.9 μm or more and 3.1 μm or less. The infrared light is infrared light that has a molecular structure unique to acetylene and that can be absorbed by acetylene gas.

[0029] The gas sensor **7** may be a gas sensor different from the NDIR gas sensor. For example, the gas sensor **7** may be a semiconductor gas sensor including a detector **7***a* having a substrate layer, a semiconductor layer, a gate electrode, and an ohmic contact. The substrate layer is a substrate made of, for example, sapphire. The semiconductor layer is formed on the substrate layer by epitaxial growth. The gate electrode and the ohmic contact are deposited on the semiconductor layer. The gate electrode is made of a metal material such as platinum. The ohmic contact is, for example, a Ti/Al layer or a Ti/Pt/Au layer formed by electron beam evaporation. A controller **7***b* is electrically connected to each of the gate electrode and the ohmic contact. In case where gas (e.g., hydrogen gas) is generated in the first insulator **4**, the hydrogen gas is adsorbed to the gate electrode, whereby the hydrogen molecules are dissociated into hydrogen atoms. The hydrogen atoms reach the interface between the gate electrode and the semiconductor layer through the gate electrode. As a result, the height of the Schottky barrier at the interface changes, so that the resistance value between the gate electrode and the ohmic contact changes. The controller **7***b* causes a constant voltage to be applied between the gate electrode and the ohmic contact to measure a change in the current flowing between the gate electrode and the ohmic contact. Alternatively, the controller **7***b* may cause a constant current to flow between the gate electrode and the ohmic contact to measure a change in the voltage between the gate electrode and the ohmic contact. The amount of change in the height of the Schottky barrier increases as the concentration of the gas increases. Taking this advantage, the controller **7***b* may calculate the concentration of the gas in the first insulator **4**.

[0030] The detector **7***a* of the gas sensor **7** is disposed in the container **3** so as not to overlap the part of the X-ray tube **2** stored in the container **3** when viewed in any of the Z-axis direction and directions perpendicular to the Z-axis direction. For example, the detector **7***a* does not overlap the valve **212** and the part of the anode **24** exposed outward from the housing **21** when viewed in any of the X-axis direction, the Y-axis direction, and the Z-axis direction. The shortest distance between the detector **7***a* and the X-ray tube **2** is larger than the shortest distance between the detector **7***a* and the side portion **32**. The shortest distance between the detector **7***a* and the X-ray tube **2** is larger than the shortest distance between the detector **7***a* and the second insulator **51**. The shortest distance between the detector **7***a* and the conductive member **6** is larger than the shortest distance between the detector **7***a* and the side portion **32**. The shortest distance between the detector **7***a* and the conductive member **6** is larger than the shortest distance between the detector **7***a* and the second insulator **51**.

[0031] In the present embodiment, the target **23** embedded in the leading end portion **24***a* of the anode **24** is located outside the container **3**, whereas the detector **7***a* is disposed in the container **3**. With this arrangement, the X-ray beam generated from the target **23** can be prevented from adversely affecting the detector **7***a*.

[0032] In the X-ray generator **1**A having the configuration as described above, with the side face **51***d* of the second insulator **51** set as the ground potential, for example, several hundreds of voltages (V) as a first voltage are received by the first voltage section **52***a* from an external source device. The booster **52***b* boosts the first voltage to a second voltage of several kilovolts (kV) to several hundreds of kilovolts (kV), for example. Then, the second voltage section **52***c* outputs the second voltage to the target **23** through the conductive member **6** and the anode **24**. In response to incidence of an electron beam on the target **23** from the electron gun **22** with the second voltage applied to the target **23**, an X-ray beam is generated from the target **23**. The X-ray generator **1**A is a so-called sealed reflection type X-ray generator. A negative voltage applied to the electron gun **22** may be performed by a transformer (not illustrated) included in the source **5** or by the circuit **52**.

[0033] As described above, in the X-ray generator **1**A, the second voltage generated by the source **5** is applied to the target **23** (X-ray tube **2**). In response to the application of the second voltage to the X-ray tube **2**, discharging may occur in the first insulator **4**. In a case where the first insulator **4** is an insulating oil containing mineral oil or ester oil as a main component, thermal decomposition of the first insulator **4** occurs due to the discharging. In response to the thermal decomposition due to the discharging, a decomposition product is generated with the generation of acetylene gas or hydrogen gas. As the amount of the decomposition product increases in first insulator **4**, the insulating performance of the first insulator **4** decreases. Both the acetylene gas and the hydrogen gas are gases characteristic of thermal decomposition caused by discharging. According to the X-ray generator **1**A, detection of the acetylene gas or the hydrogen gas by the gas sensor **7** enables indirectly check of the presence or absence of the abnormal phenomenon (discharging) in the first insulator **4** and the level of decrease of the insulating performance.

[0034] As described above, in the X-ray generator **1**A, the detector **7***a* is disposed in the container **3** with the first insulator **4** that is liquid sealed therein. The detector **7***a* included in the gas sensor **7** can detect the gas generated in the first insulator **4**. Therefore, according to the X-ray generator **1**A, the gas generated in the first insulator **4** can be easily detected.

[0035] In the X-ray generator **1**A, the detector **7***a* is disposed in the first insulator **4**. Because the detector **7***a* is disposed in the first insulator **4** that is a gas generation source, the gas generated in the first insulator **4** can be efficiently detected. Thus, the gas generated in the first insulator **4** can be easily and efficiently detected.

[0036] In the X-ray generator **1**A, the detector **7***a* is disposed in the container **3** so as not to overlap the part of the X-ray tube **2** stored in the container **3** when viewed in any of the Z-axis direction and the directions (e.g., the X-axis direction and the Y-axis direction) perpendicular to the Z-axis direction. With this arrangement, discharging between the X-ray tube **2** and the detector **7***a* can be prevented.

[0037] In the X-ray generator **1**A, the source **5** includes the second insulator **51** and the circuit **52** embedded in the second insulator **51**. The circuit **52** includes the first voltage section **52***a* that receives the first voltage from the outside, the booster **52***b* that boosts the first voltage to the second voltage, and the second voltage section **52***c* that outputs the second voltage to the X-ray tube **2**. With this arrangement, the circuit **52** is insulated from other members by the second insulator **51**. Therefore, because occurrence of discharging in the source **5** can be prevented, the operational stability of the X-ray generator **1**A can be improved.

X-ray Generator of Second Embodiment

[0038] As illustrated in FIG. **2**, an X-ray generator **1**B of a second embodiment is mainly different from the X-ray generator **1**A of the first embodiment in that the X-ray generator **1**B includes a pipe **10** and an open and shut part **11**. Hereinafter, the X-ray generator **1**B of the second embodiment will be described focusing on such differences from the X-ray generator **1**A of the first embodiment. The X-ray generator **1**B further includes the pipe **10** and the open and shut part **11**.

[0039] The container **3** has an upper portion **31** and a side portion **32**. The side portion **32** has a tubular shape with the Z-axis direction as a height direction. The side portion **32** has one end portion (an upper end portion in the present embodiment) in the Z-axis direction, and the upper portion **31** occludes the one end portion. The side portion **32** is provided with a discharge port **32***a* through which the inside of the container **3** and the outside of the container **3** are in communication with each other.

[0040] The pipe **10** is a cylindrical member for taking out a first insulator **4** in the container **3** to the outside of the container **3**. The pipe **10** is made of a metal material such as stainless steel. The pipe **10** is connected to the discharge port **32***a* such that the inside of the pipe **10** is in communication with the inside of the container **3**. The pipe **10** is liquid-tightly connected to the discharge port **32***a* such that the first insulator **4** does not leak from between the pipe **10** and the discharge port **32***a*. The first insulator **4** is taken out to the outside of the container **3** through the discharge port **32***a* and the pipe **10**.

[0041] The open and shut part **11** is a member that adjusts the flow of the first insulator **4** in the pipe **10**. The open and shut part **11** is provided to the pipe **10** and brings the inside of the pipe **10** into an open state or a shut state. The open and shut part **11** is a valve such as a manual valve, an electric valve, or a solenoid valve.

[0042] In the X-ray generator **1**B having the configuration as described above, with the open and shut part **11** open, part of the first insulator **4** in the container **3** can be taken out to the outside of the container **3** through the discharge port **32***a* and the pipe **10**. The taken-out part of the first insulator **4** is analyzed with an analyzer such as gas chromatography, so that gas generated in the first insulator **4** can be detected.

[0043] As described above, in the X-ray generator **1**B, the container **3** with the first insulator **4** that is liquid sealed therein is provided with the discharge port **32***a* through which the inside of the container **3** and the outside of the container **3** is in communication with each other. With this arrangement, the first insulator **4** can be easily taken out from the inside of the container **3** through the discharge port **32***a*. Then, the first insulator **4** having been taken out is analyzed, so that the gas generated in the first insulator **4** can be detected. Therefore, according to the X-ray generator **1**B, the gas generated in the first insulator **4** can be easily detected.

[0044] The X-ray generator **1**B includes the pipe **10** connected to the discharge port **32***a*, and the open and shut part **11** that is provided to the pipe **10** and brings the inside of the pipe **10** into the open state or the shut state. With this arrangement, it is easily achievable that leakage of the first insulator **4** from the container **3** is prevented while the first insulator **4** is taken out from the container **3** through the discharge port **32***a*.

X-ray Generator of Third Embodiment

[0045] As illustrated in FIG. **3**, an X-ray generator **1**C of a third embodiment is mainly different from the X-ray generator **1**A of the first embodiment in that at least part of a container **3** is made of a material that allows light having a predetermined wavelength to travel through the material. Hereinafter, the X-ray generator **1**C of the third embodiment will be described focusing on such differences from the X-ray generator **1**A of the first embodiment.

[0046] The container **3** has an upper portion **31** and a side portion **32**. The side portion **32** has a tubular shape with the Z-axis direction as a height direction. The side portion **32** has one end portion (an upper end portion in the present embodiment) in the Z-axis direction, and the upper portion **31** occludes the one end portion.

[0047] A part **321** of the side portion **32** is made of a material that allows light having a predetermined wavelength to travel through the material. The part **321** has a circular shape, for example. The material of the part **321** is appropriately selected in accordance with a predetermined wavelength value. The range of predetermined wavelength is, for example, 2.5 μm or more and 25 μm or less in a case where infrared spectroscopy is used. In order to have transparency to light in this wavelength band, the part **321** is made of an infrared light transmitting material such as quartz glass, diamond, sapphire, silicon, or germanium. A part of the side portion **32** different from the part **321** thereof is made of a metal material such as stainless steel or aluminum.

[0048] In the X-ray generator **1**C having the configuration as described above, gas generated in a first insulator **4** is detected as follows. First, incident light E**1** emitted from a light source (not illustrated) travels toward the part **321**. The incident light E**1** has a predetermined wavelength. The incident light E**1** enters the inside of the container **3** from the outside of the container **3** through the part **321**. A portion of the incident light E**1** is reflected as reflected light E**2** containing chemical information regarding the first insulator **4**. The reflected light E**2** is acquired, for example, as follows. That is, the incident angle of the incident light E**1** and the refractive index of a material constituting the first insulator **4** and the material constituting the part **321** are adjusted so as to satisfy the total reflection condition at the interface (contact face) between the first insulator **4** and the part **321**. Then, the incident light E**1** totally reflected at the interface is acquired as the reflected light E**2**. Alternatively, a reflector is disposed so as to reflect the incident light E**1** toward the part **321** inside the first insulator **4**, so that the incident light E**1** reflected by the reflector is acquired as the reflected light E**2**. At least a portion of the reflected light E**2** is emitted to the outside of the container **3** through the part **321**. The absorption (transmission) spectrum obtained from the incident light E**1** and the reflected light E**2** changes proportionally in accordance with the amount of gas generated in the first insulator **4** (the amount of gas present in the first insulator **4**). The reflected light E**2** is detected with a photodetector (not illustrated) to analyze the obtained absorption spectrum. As a result, the type and the abundance of the gas generated in the first insulator **4** can be estimated. Here, in order to measure acetylene gas present in the first insulator **4**, focusing on the peak due to the presence of the acetylene gas observed in the wavelength region of 2.9 μm or more and 3.1 μm or less including the characteristic absorption band of acetylene, the peak intensity and the temporal changes in the peak intensity are examined. As a result, the abundance and the increasing tendency of the acetylene gas generated in the first insulator **4** can be estimated. Therefore, according to the X-ray generator **1**C, the degree of progress in deterioration of the first insulator **4** can be estimated on the basis of the abundance and the increasing tendency of the acetylene gas. Further, in addition to the peak intensity of acetylene, the peak intensity due to the presence of ethane gas observed in the wavelength region of 3.3 μm or more and 3.5 μm or less is obtained by a similar method. As a result, the abundance ratio of acetylene and ethane can be calculated. On the basis of the obtained abundance ratio, it can be presumed that the thermal decomposition due to discharging is dominant when the abundance of acetylene is larger, whereas the thermal decomposition due to overheating is dominant when the abundance of ethane is larger. In such a manner, whether the deterioration of the first insulator **4** is caused by discharging or overheating can be isolated.

[0049] As described above, in the X-ray generator **1**C, the part **321** of the container **3** (side portion **32**) is made of the material that allows the light having the predetermined wavelength to travel through the material. With this arrangement, the light having the predetermined wavelength is allowed to enter the first insulator **4** in the container **3** through the part **321**, so that reflected light from the first insulator **4** can be easily acquired. The absorption spectrum obtained from the reflected light is analyzed, so that the gas generated in the first insulator **4** can be detected. Therefore, according to the X-ray generator **1**C, the gas generated in the first insulator **4** can be easily detected.

Modifications

[0050] The present disclosure is not limited to the above embodiments. In the X-ray generator **1**A of the first embodiment, the container **3** stores the at least part of the X-ray tube **2**, but the aspect of the container **3** is not limited thereto. For example, as illustrated in FIG. **4**, in an X-ray generator **1**A, a container **3** may further store a circuit **52**, and a first insulator **4** may further cover the circuit **52**. The container **3** may further include a lower portion **33** that occludes another end portion (a lower end portion in the present embodiment) of a side portion **32** in the Z-axis direction. In this case, each of an X-ray tube **2** and the circuit **52** can be easily insulated from other members by a single type of the first insulator **4**. Gas can be easily detected also for the first insulator **4** having such a configuration as described above. Also in the X-ray generator **1**B of the second embodiment and the X-ray generator **1**C of the third embodiment, the container **3** may further store the circuit **52**, and the first insulator **4** may further cover the circuit **52**.

[0051] In the X-ray generator **1**C of the third embodiment, the part **321** of the container **3** is made of the material that allows the light having the predetermined wavelength to travel through the material, but the aspect of the container **3** is not limited thereto. For example, as illustrated in FIG. **5**, in an X-ray generator **1**C, a side portion **32** includes a part **322** and a part **323**. The parts **322** and **323** may be each made of a material that allows light having a predetermined wavelength to travel through the corresponding material. The parts **322** and **323** may be located on both side of a first insulator **4** in the X-axis direction (predetermined direction). In this case, the transmitted light traveling along the X-axis direction can be more easily acquired through the parts **322** and **323** located on both sides of the first insulator **4**. Specifically, incident light E**1** traveling along the X-axis direction enters the inside of a container **3** through the part **322**. A portion of the incident light E**1** is absorbed by the first insulator **4**, and other portions of the incident light E**1** are emitted to the outside of the container **3** as transmitted light through the part **323**. The absorption (transmission) spectrum obtained from the transmitted light and the incident light E**1** changes in accordance with the amount (abundance) of gas generated in the first insulator **4**. Therefore, the transmitted light is analyzed, so that the gas generated in the first insulator **4** can be detected and further the type and the abundance of the gas can be estimated. In the X-ray generator IC, the container **3** may include three or more parts each made of a material that allows light having a predetermined wavelength to travel through the corresponding material.

[0052] In the X-ray generator **1**A of the first embodiment, the inside of the container **3** is filled with the first insulator **4**, but part of the inside of the container **3** is not necessarily filled with the first insulator **4**. In this case, the detector **7***a* may be disposed in the container **3** so as not to contact the first insulator **4**.

[0053] In the X-ray generator **1**C of the third embodiment, the part **321** of the container **3** is made of the material that allows the light having the predetermined wavelength to travel through the material, but in the X-ray generator **1**C, the entirety of the container **3** may be made of a material that allows light having a predetermined wavelength to travel through the material.

[0054] The X-ray generator **1**B of the second embodiment includes the pipe **10** and the open and shut part **11**, but the X-ray generator **1**B does not necessarily include the pipe **10** and the open and shut part **11**. In this case, the X-ray generator **1**B may include an open and shut part (e.g., a lid) that brings the discharge port **32***a* into an open state or a shut state.

[0055] In the X-ray generator **1**B of the second embodiment, the open and shut part **11** is a manual valve, a solenoid valve, or an electric valve, but the open and shut part **11** may be, for example, a lid as long as the inside of the pipe **10** is brought into an open state or a shut state.

[0056] In the X-ray generator **1**A of the first embodiment, the X-ray generator **1**B of the second embodiment, and the X-ray generator **1**C of the third embodiment, the container **3** stores the valve **212**, but the container **3** may stores at least part of the X-ray tube **2**.

[0057] The X-ray generator **1**A of the first embodiment, the X-ray generator **1**B of the second embodiment, and the X-ray generator **1**C of the third embodiment are sealed reflection type X-ray generators. However, each of the X-ray generators **1**A, **1**B, and **1**C may be a sealed transmission type X-ray generator.

[0058] An X-ray generator according to one aspect of the present disclosure is [1] "an X-ray generator including: an X-ray tube configured to cause an X-ray beam to be generated; a source configured to generate a voltage to be applied to the X-ray tube; a container storing at least part of the X-ray tube; a first insulator that is liquid, the first insulator being sealed in the container, the first insulator covering the at least part of the X-ray tube; and a gas sensor including a detector disposed in the container to detect gas generated in the first insulator".

[0059] In the X-ray generator described in [1], the detector of the gas sensor is disposed in the container with the first insulator that is liquid sealed therein. The gas sensor can detect the gas generated in the first insulator. Therefore, according to the X-generator described in [1], the gas generated in the first insulator can be easily detected.

[0060] An X-ray generator according to one aspect of the present disclosure may be [2] "the X ray generator according to [1], in which the detector is disposed in the first insulator". According to the X-ray generator described in [2], because the detector of the gas sensor is disposed in the first insulator that is a gas generation source, the gas generated in the first insulator can be efficiently detected. Thus, the gas generated in the first insulator can be easily and efficiently detected.

[0061] An X-ray generator according to one aspect of the present disclosure may be [3] "the X-ray generator according to [1] or [2], in which the detector is disposed in the container such that the detector does not overlap the at least part of the X-ray tube when viewed in any of a predetermined direction in which the at least part of the X-ray tube and the source are aligned and directions perpendicular to the predetermined direction". According to the X-ray generator described in [3], occurrence of discharging between the at least part of the X-ray tube and the detector of the gas sensor can be prevented.

[0062] An X-ray generator according to one aspect of the present disclosure may be [4] "an X-ray generator including: an X-ray tube configured to cause an X-ray beam to be generated; a source configured to generate a voltage to be applied to the X-ray tube; a container storing at least part of the X-ray tube; and a first insulator that is liquid, the first insulator being sealed in the container, the first insulator covering the at least part of the X-ray tube, in which the container is provided with a discharge port through which an inside of the container and an outside of the container are in communication with each other".

[0063] In the X-ray generator according to [4], the container with the first insulator that is liquid sealed therein is provided with the discharge port through which the inside of the container and the outside of the container is in communication with each other. With this arrangement, the first insulator can be taken out from the inside of the container through the discharge port. Then, the first insulator having been taken out is analyzed, so that gas generated in the first insulator can be detected. Therefore, according to the X-generator described in [4], the gas generated in the first insulator can be easily detected.

[0064] An X-ray generator according to one aspect of the present disclosure may be [5] "the X-ray generator according to [4], further including: a pipe connected to the discharge port; and an open and shut part provided to the pipe, the open and shut part being configured to bring an inside of the pipe into an open state or a shut state". According to the X-ray generator described in [5], it is easily achievable that leakage of the first insulator from the container is prevented while the first insulator is taken out from the inside of the container through the discharge port.

[0065] An X-ray generator according to one aspect of the present disclosure is [6] "an X-ray generator including: an X-ray tube configured to cause an X-ray beam to be generated; a source configured to generate a voltage to be applied to the X-ray tube; a container storing at least part of the X-ray tube; and a first insulator that is liquid, the first insulator being sealed in the container, the first insulator covering the at least part of the X-ray tube, in which at least part of the container is made of a material that allows light having a predetermined wavelength to travel through the material".

[0066] In the X-ray generator according to [6], the at least the part of the container is made of the material that allows the light having the predetermined wavelength to travel through the material. With this arrangement, light having a predetermined wavelength is allowed to be incident on the first insulator in the container through the at least part of the container. As a result, for example, transmitted light and reflected light from the first insulator can be easily acquired. These transmitted light and reflected light are analyzed, so that gas generated in the first insulator can be detected. Therefore, according to the X-generator described in [6], the gas generated in the first insulator can be easily detected.

[0067] An X-ray generator according to one aspect of the present disclosure may be [7] "the X-ray generator according to [6], in which the at least part of the container includes a plurality of parts located on both sides of the first insulator in a predetermined direction". According to the X-ray generator described in [7], transmitted light traveling along the predetermined direction can be more easily acquired through the plurality of parts located on both sides of the first insulator.

[0068] An X-ray generator according to one aspect of the present disclosure may be [8] "the X-ray generator according to any one of [1] to [7], in which the source includes: a second insulator; and a circuit embedded in the second insulator, and the circuit includes: a first voltage section configured to receive a first voltage from outside; a booster configured to boost the first voltage to a second voltage as the voltage; and a second voltage section configured to output the second voltage to the X-ray tube". According to the X-ray generator described in [8], the circuit is insulated from other members by the second insulator. With this arrangement, occurrence of discharging in the source can be prevented, so that the operational stability of the X-ray generator can be improved.

[0069] An X-ray generator according to one aspect of the present disclosure may be [9] "the X-ray generator according to any one of [1] to [7], in which the source includes a circuit including: a first voltage section configured to receive a first voltage from outside; a booster configured to boost the first voltage to a second voltage as the voltage; and a second voltage section configured to output the second voltage to the X-ray tube, the container further stores the circuit, and the first insulator further covers the circuit". According to the X-ray generator described in [9], each of the X-ray tube and the circuit can be easily insulated from other members by a single type of the first insulator. Gas can be easily detected also for the first insulator having such a configuration as described above.

[0070] According to the present disclosure, provided can be an X-ray generator that can easily detect gas generated in an insulator.

What is claimed is:

1. An X-ray generator comprising:
- an X-ray tube configured to cause an X-ray beam to be generated;
- a source configured to generate a voltage to be applied to the X-ray tube;
- a container storing at least part of the X-ray tube;
- a first insulator that is liquid, the first insulator being sealed in the container, the first insulator covering the at least part of the X-ray tube; and
- a gas sensor including a detector disposed in the container to detect gas generated in the first insulator.

2. The X-ray generator according to claim **1**, wherein the detector is disposed in the first insulator.

3. The X-ray generator according to claim **1**, wherein the detector is disposed in the container such that the detector does not overlap the at least part of the X-ray tube when viewed in any of a predetermined direction in which the at least part of the X-ray tube and the source are aligned and directions perpendicular to the predetermined direction.

4. An X-ray generator comprising:
- an X-ray tube configured to cause an X-ray beam to be generated;
- a source configured to generate a voltage to be applied to the X-ray tube;
- a container storing at least part of the X-ray tube; and
- a first insulator that is liquid, the first insulator being sealed in the container, the first insulator covering the at least part of the X-ray tube,
- wherein the container is provided with a discharge port through which an inside of the container and an outside of the container are in communication with each other.

5. The X-ray generator according to claim **4**, further comprising:
- a pipe connected to the discharge port; and
- an open and shut part provided to the pipe, the open and shut part being configured to bring an inside of the pipe into an open state or a shut state.

6. An X-ray generator comprising:
- an X-ray tube configured to cause an X-ray beam to be generated;
- a source configured to generate a voltage to be applied to the X-ray tube;
- a container storing at least part of the X-ray tube; and
- a first insulator that is liquid, the first insulator being sealed in the container, the first insulator covering the at least part of the X-ray tube,
- wherein at least part of the container is made of a material that allows light having a predetermined wavelength to travel through the material.

7. The X-ray generator according to claim **6**, wherein the at least part of the container includes a plurality of parts located on both sides of the first insulator in a predetermined direction.

8. The X-ray generator according to claim **1**, wherein
- the source includes: a second insulator; and a circuit embedded in the second insulator, and
- the circuit includes: a first voltage section configured to receive a first voltage from outside; a booster configured to boost the first voltage to a second voltage as the voltage; and a second voltage section configured to output the second voltage to the X-ray tube.

9. The X-ray generator according to claim **1**, wherein
- the source includes a circuit including: a first voltage section configured to receive a first voltage from outside; a booster configured to boost the first voltage to a second voltage as the voltage; and a second voltage section configured to output the second voltage to the X-ray tube,
- the container further stores the circuit, and
- the first insulator further covers the circuit.

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