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(54) **LID WITH SELF SEALING PLUG ALLOWING FOR A THERMAL INTERFACE MATERIAL WITH FLUIDITY IN A LIDDED FLIP CHIP PACKAGE**

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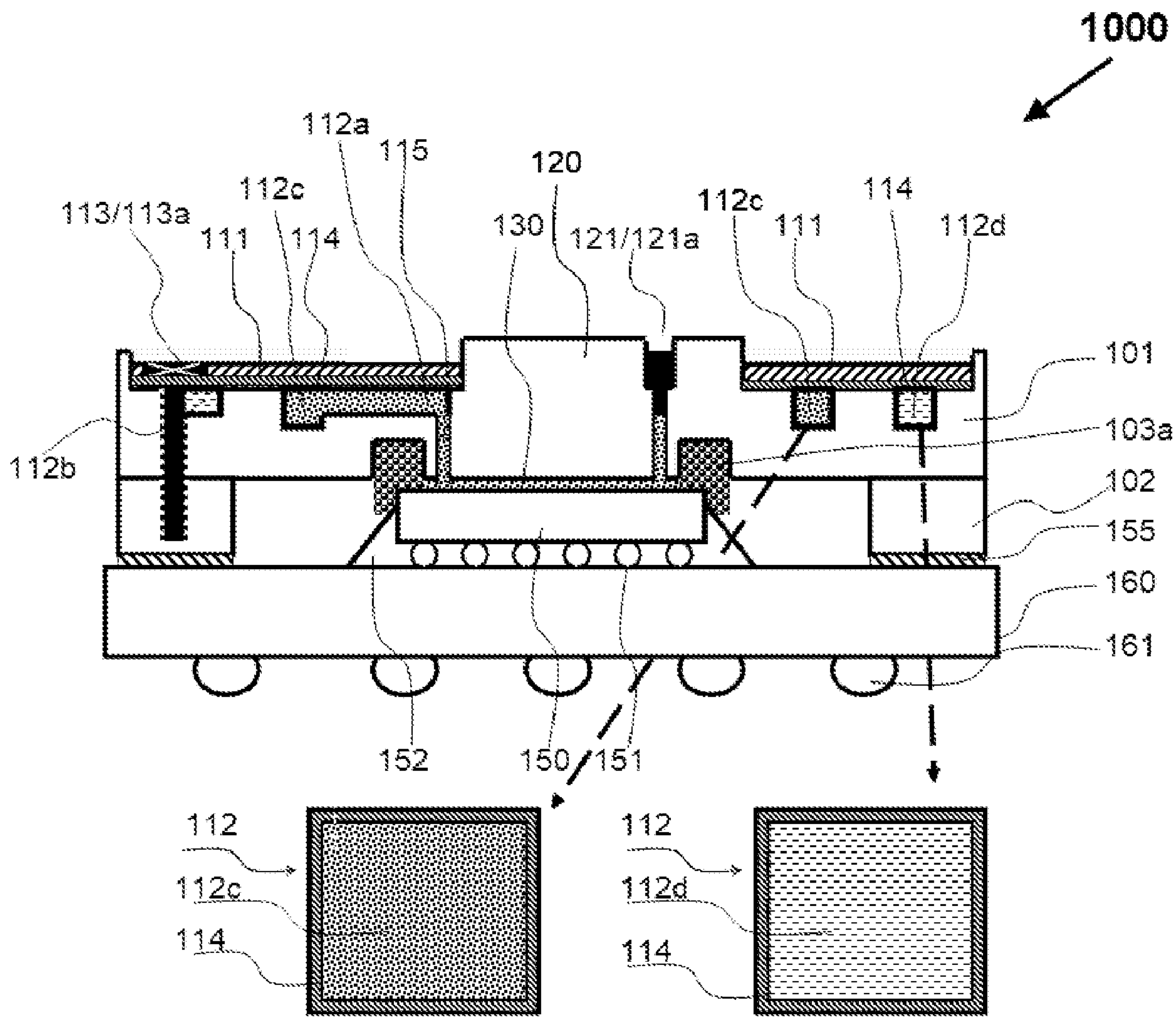
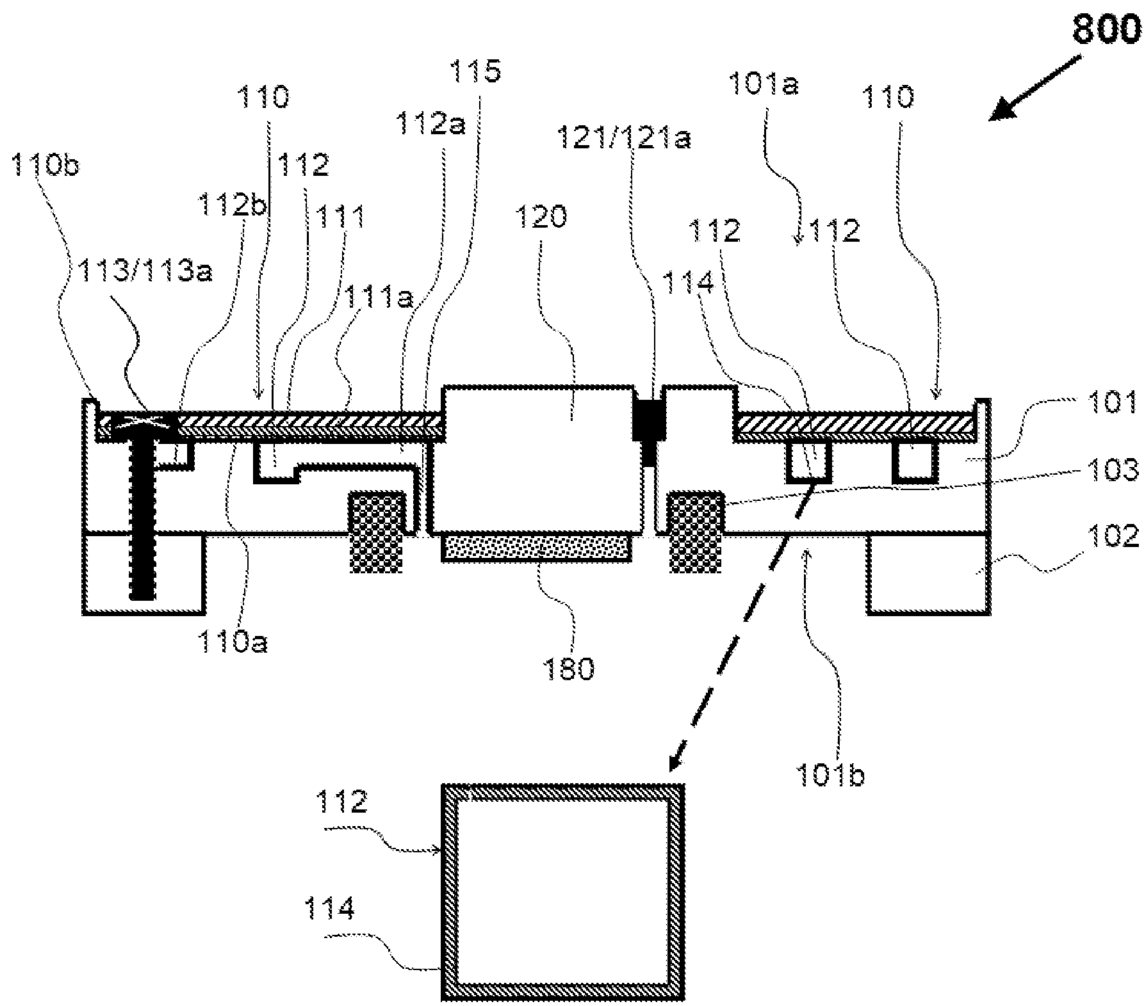
H01L 23/42 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 23/42*** (2013.01); *H01L 24/16* (2013.01)

(57) **ABSTRACT**

The disclosure describes a lidded flip chip package allowing for a thermal interface material (TIM) with fluidity, like a liquid metal, including: a lid, a sealing ring for forming a sealed gap between a flip chip and the lid, a storage tunnel as a reservoir for accepting or releasing a liquid metal from or to the sealed gap, and an injection tunnel for filling a liquid metal into the sealed gap, wherein a self-sealing plug structure is integrated with the storage tunnel and the injection tunnel, the sealed gap is completely filled with a liquid metal, and a portion of the storage tunnel is filled with the same liquid metal and its remaining portion is filled with a gas. The disclosure also describes a method for filling a liquid metal into the lidded flip chip package based on the self-sealing plug structure.

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110a
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101b
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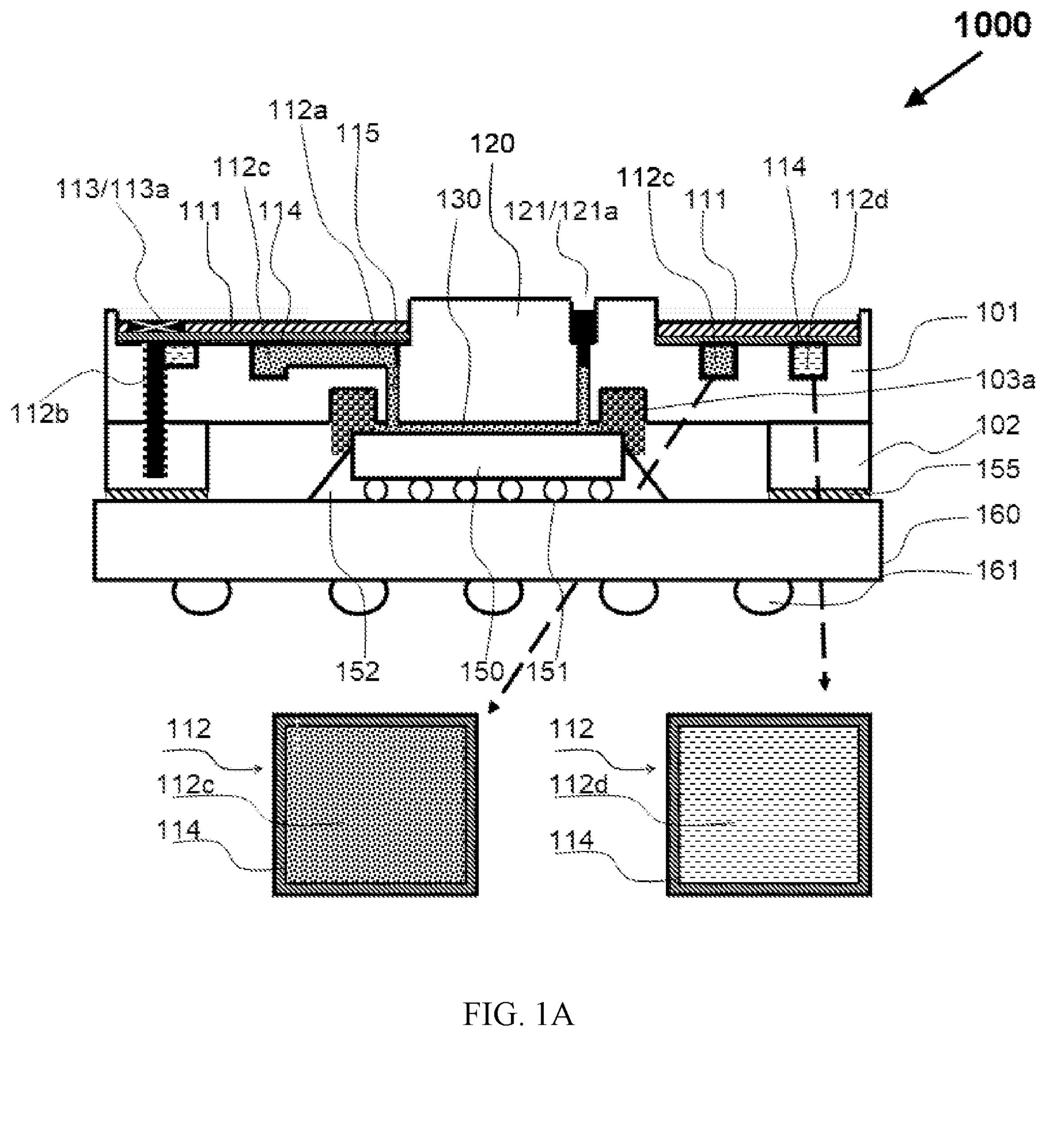
114

FIG. 1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161
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112c
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112d
114

FIG. 1A

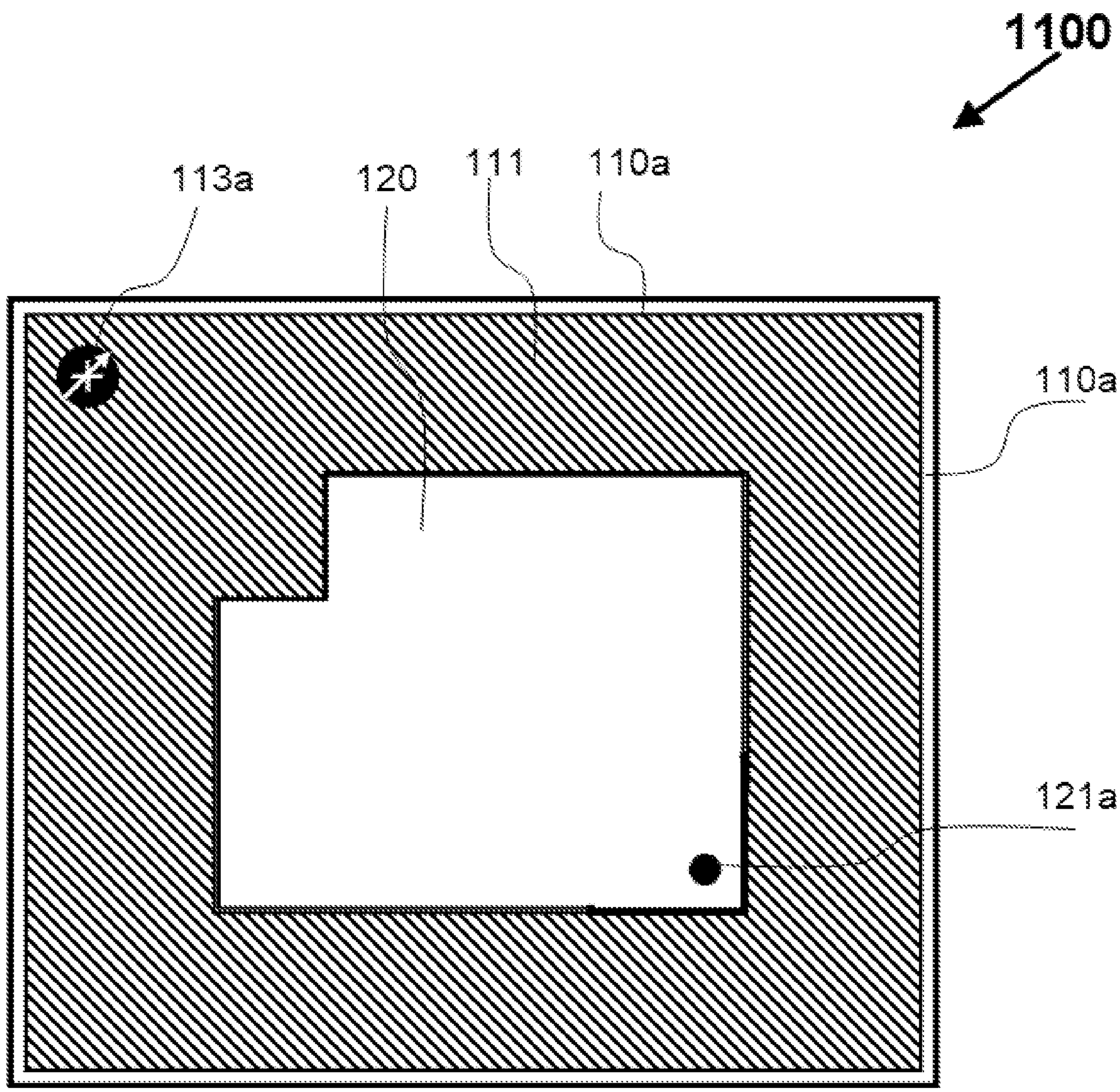
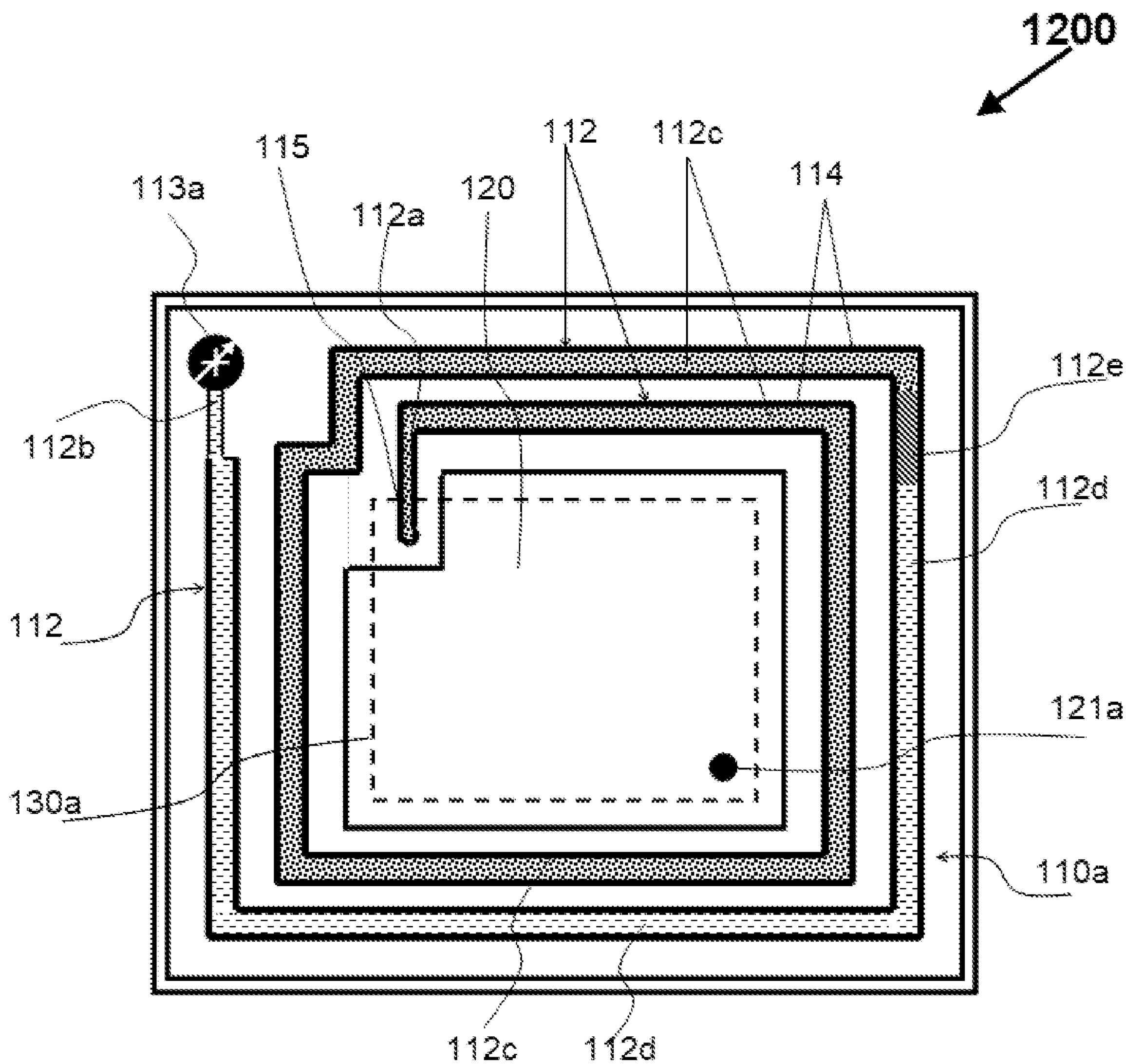


FIG. 2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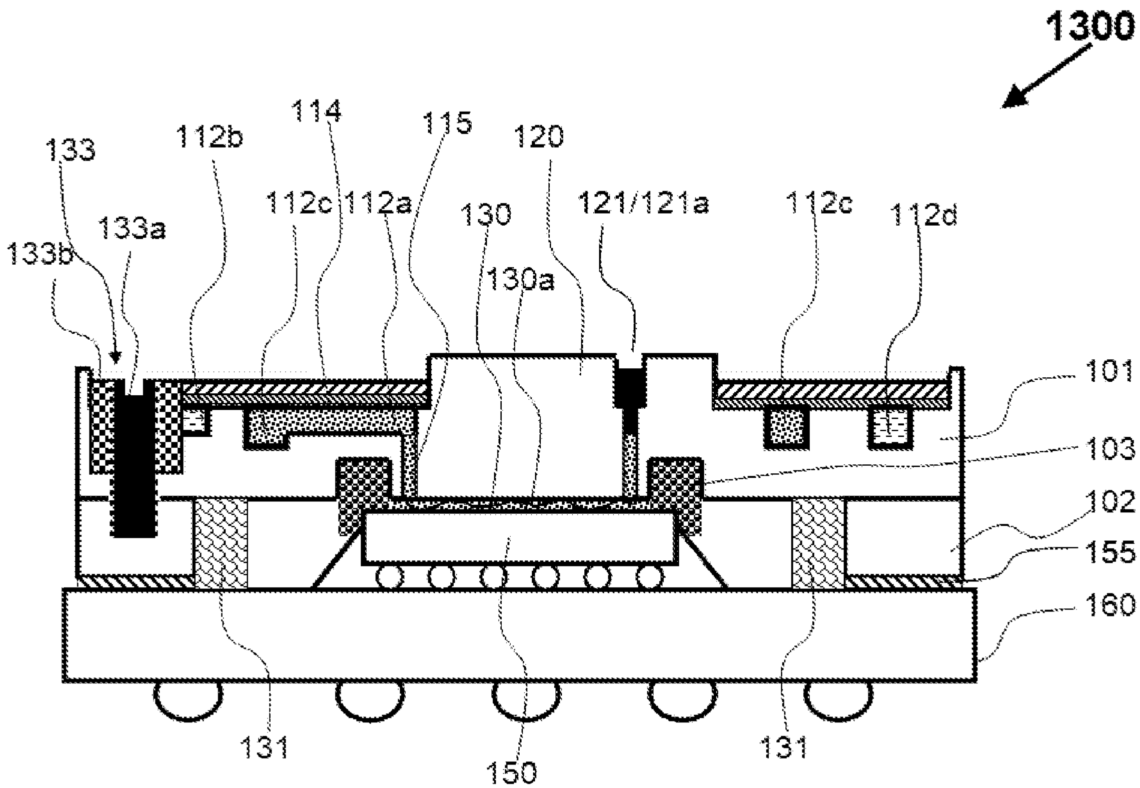
112d

FIG. 3



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133
133b
133a
112b
114
112c
112a
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130a
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121/121a
112c
112d
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160
131
150
131

FIG. 4

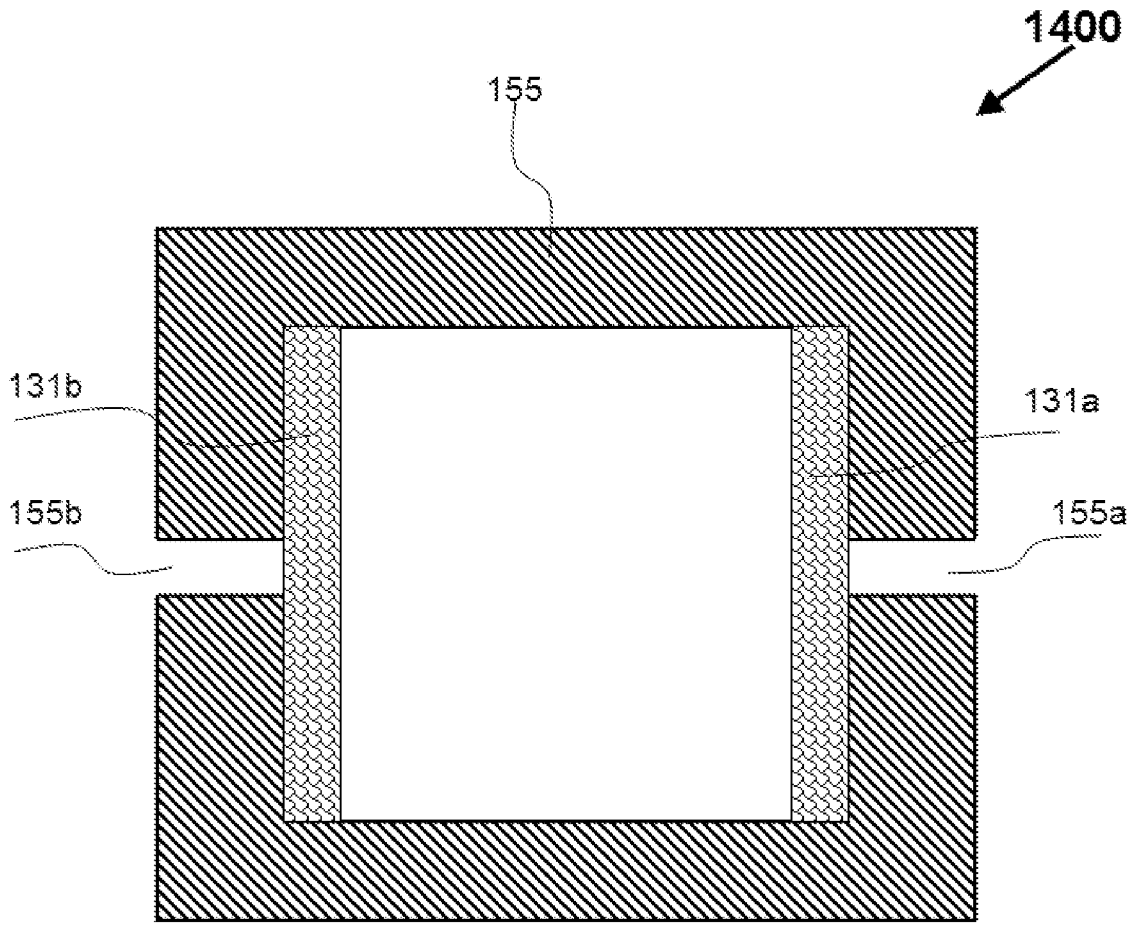

FIG. 4A

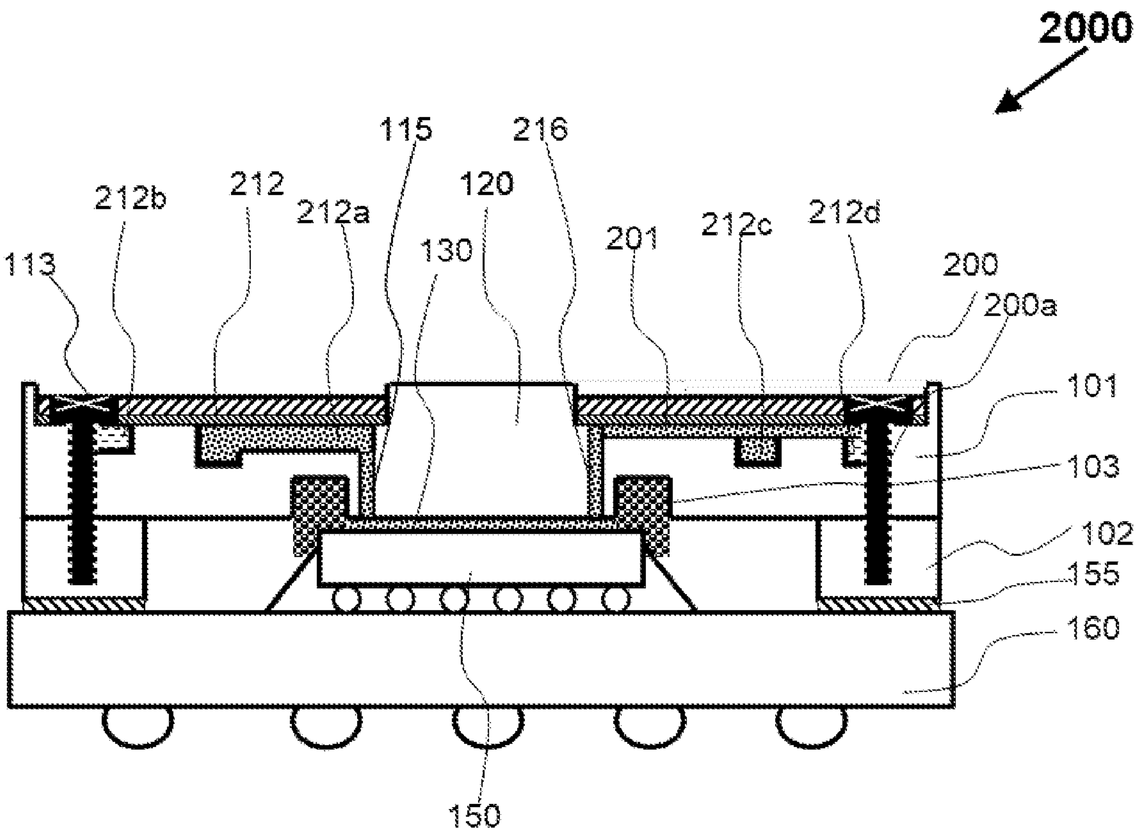
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FIG. 5

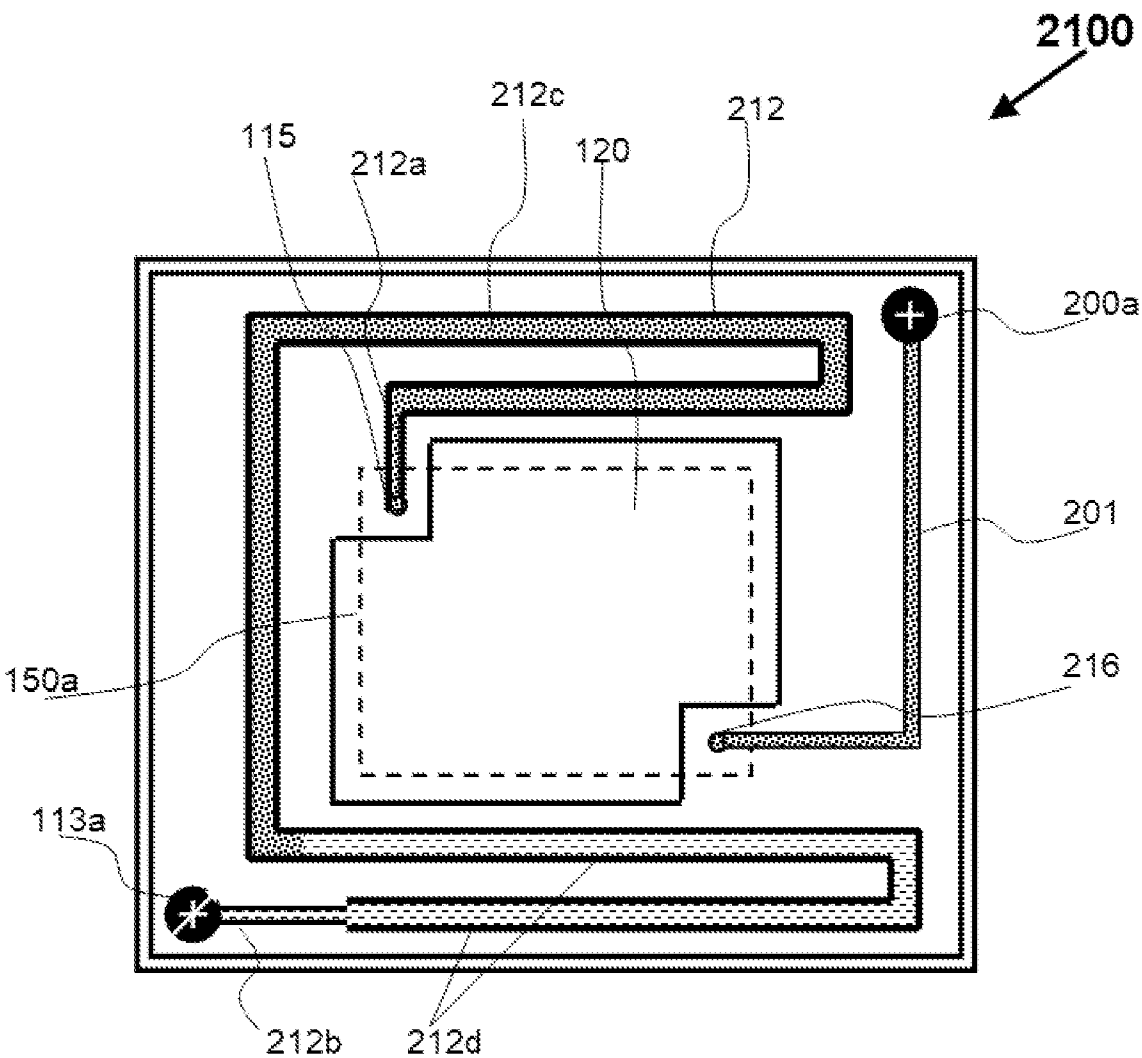

FIG. 5A

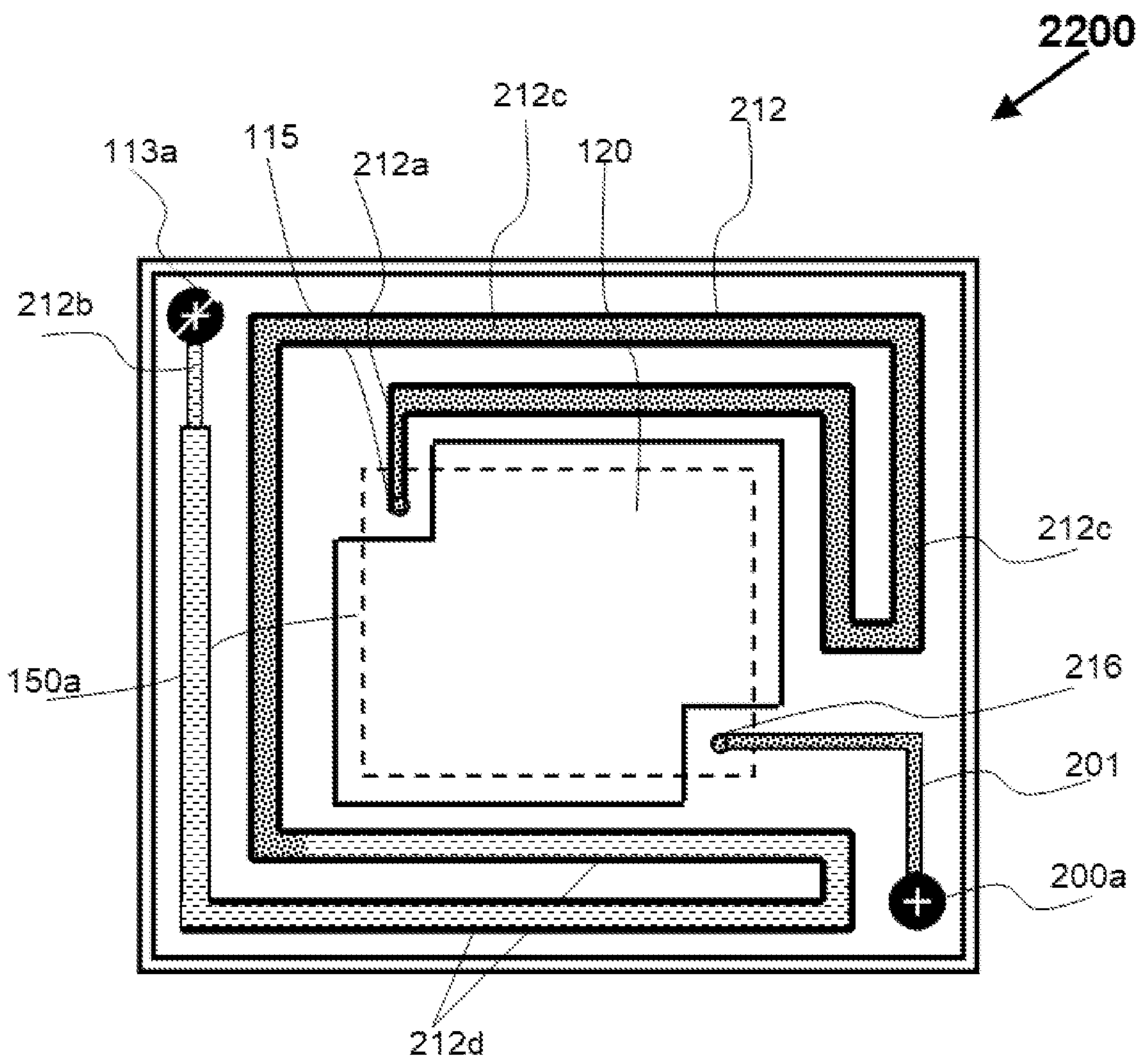
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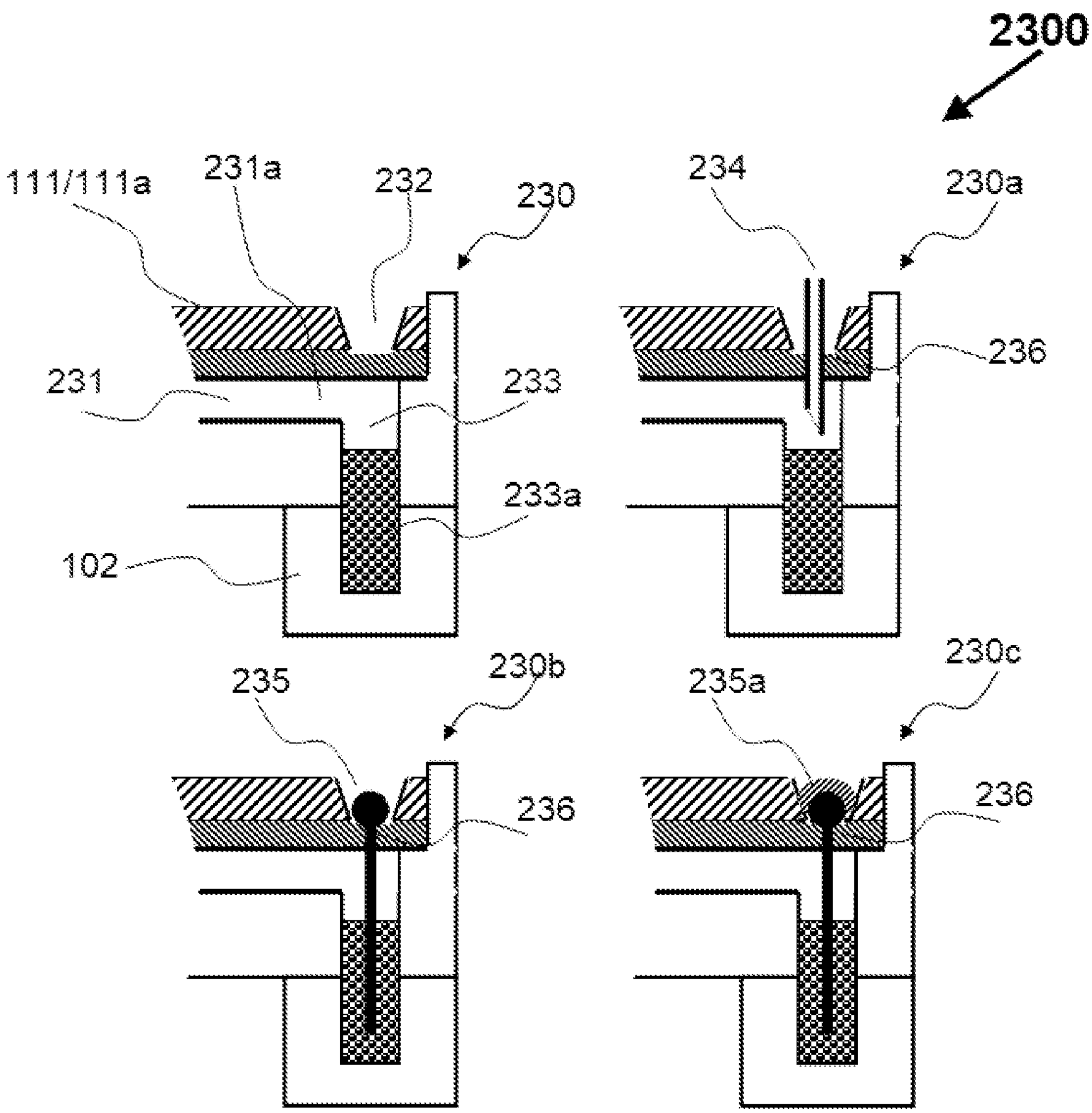
FIG. 5B


2300
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231
233
233a
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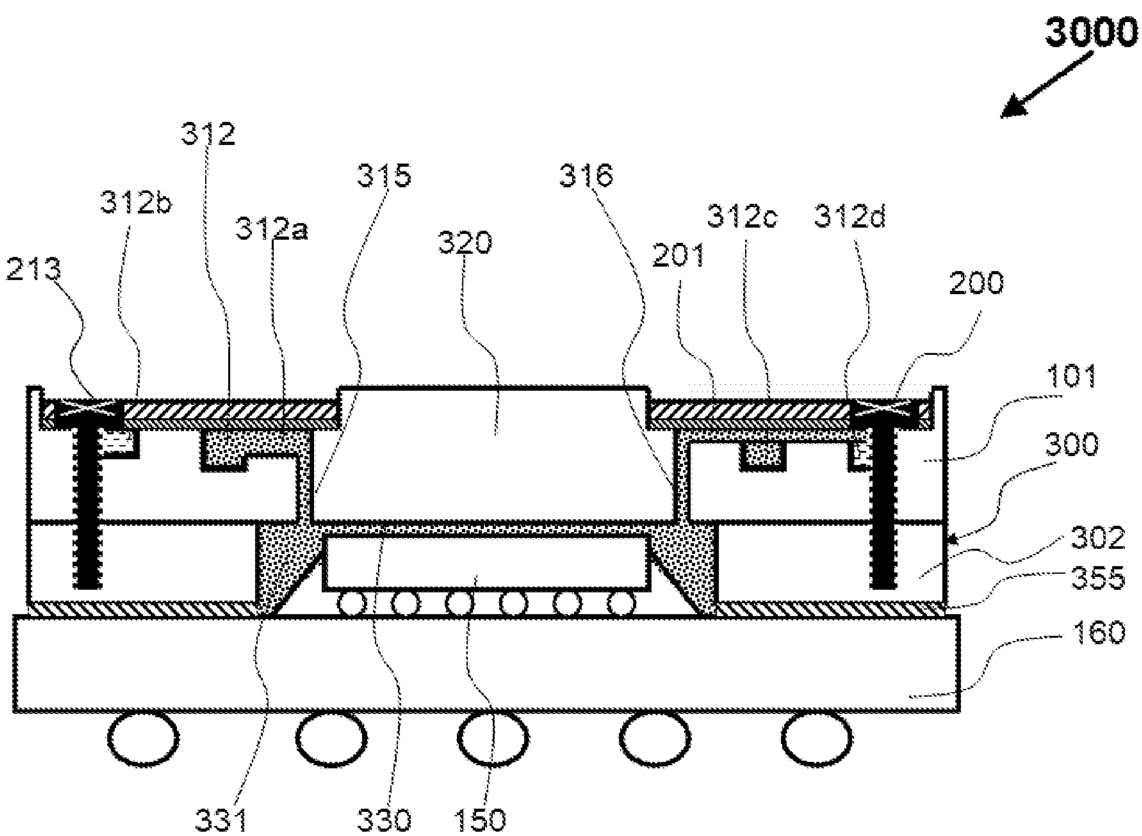
230a
236
235
230b
236
235a
230c
236

FIG. 6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330
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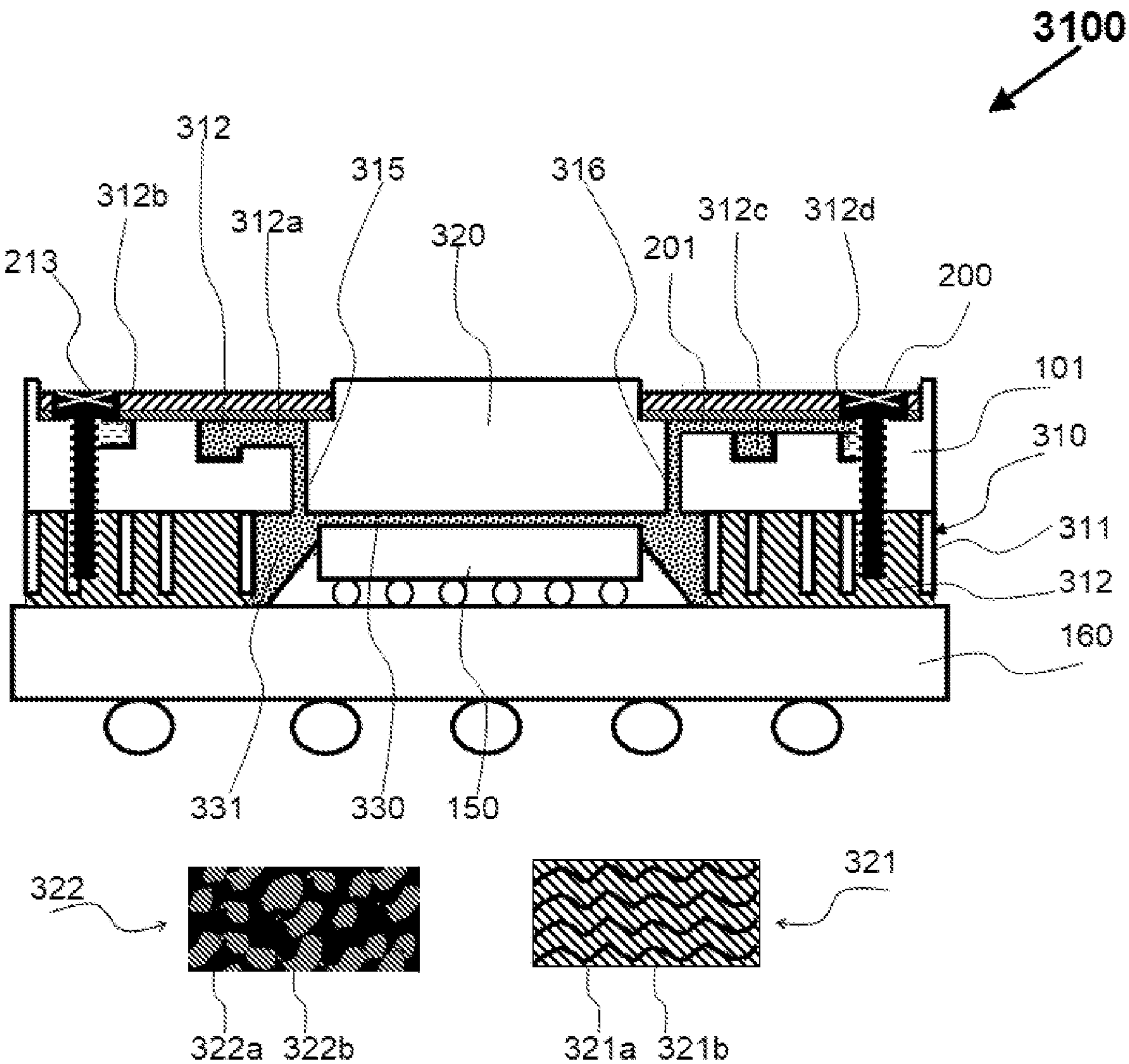
FIG. 7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321a
321b

FIG. 8

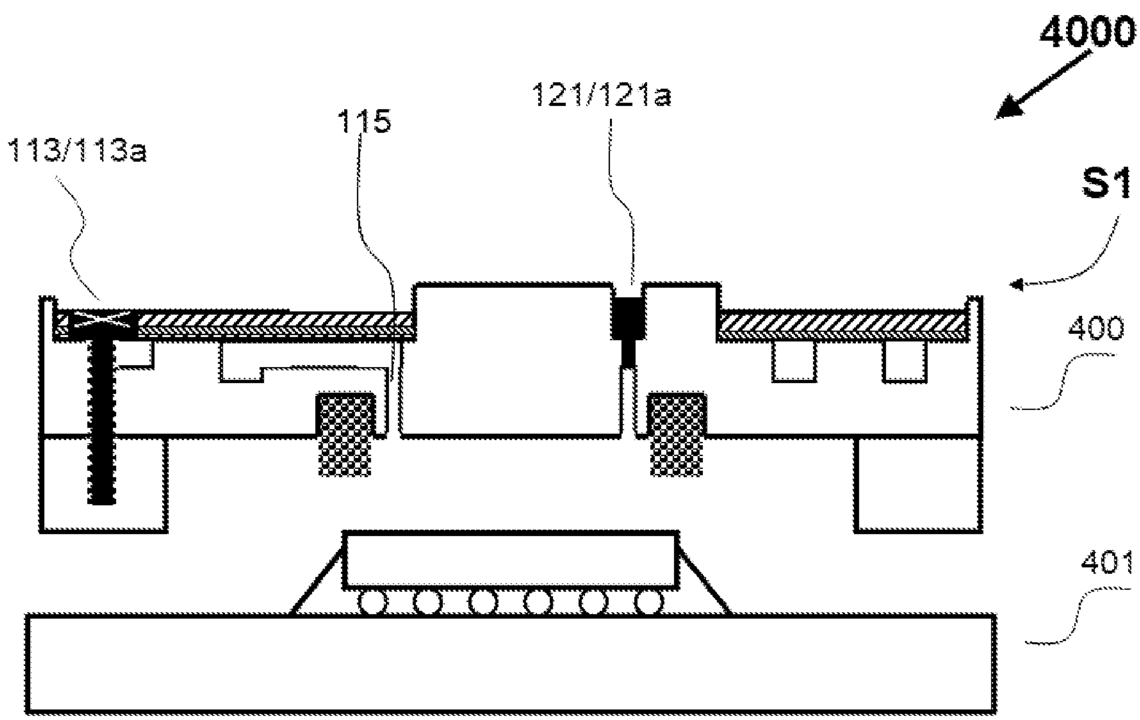
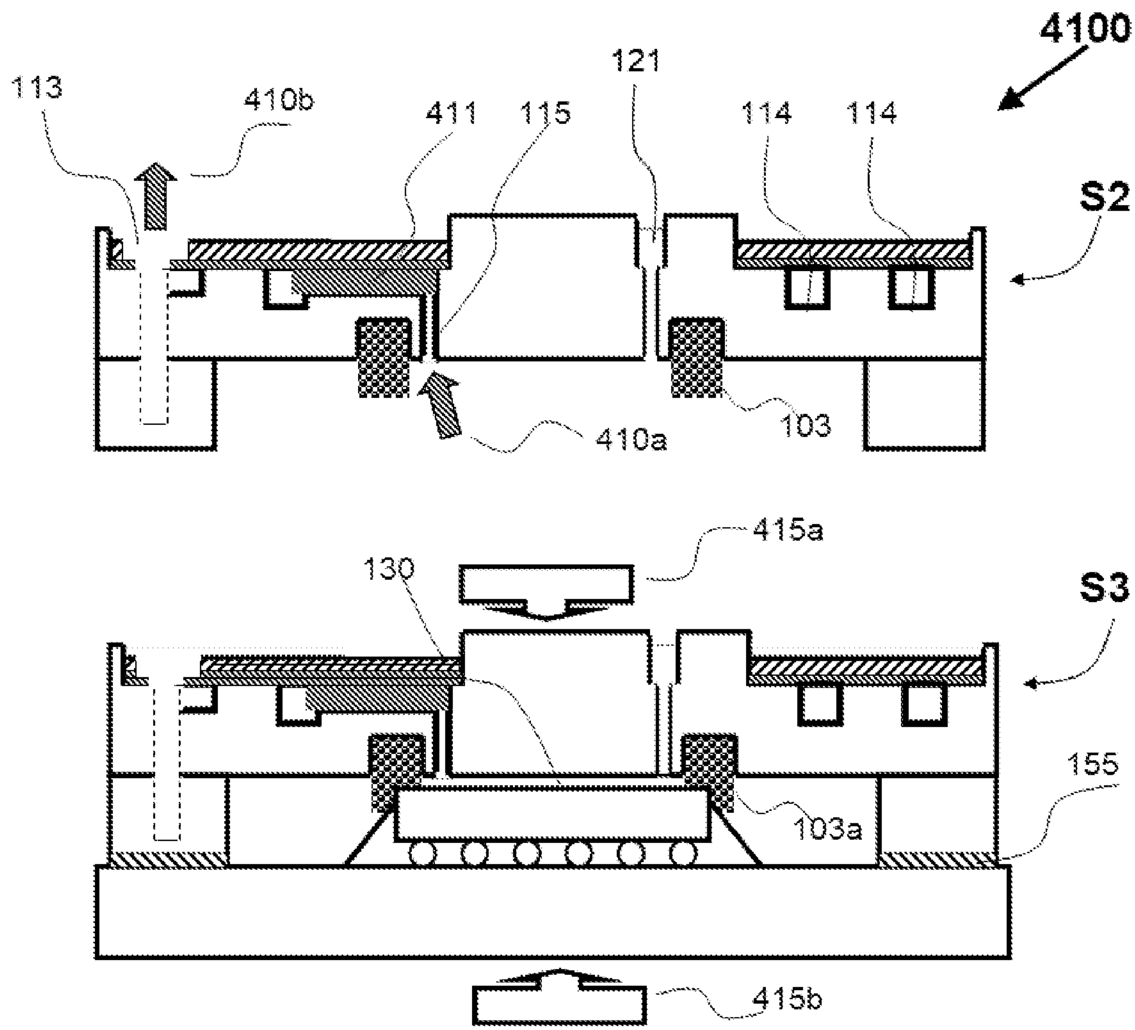


FIG. 9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S3
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415b

FIG. 10

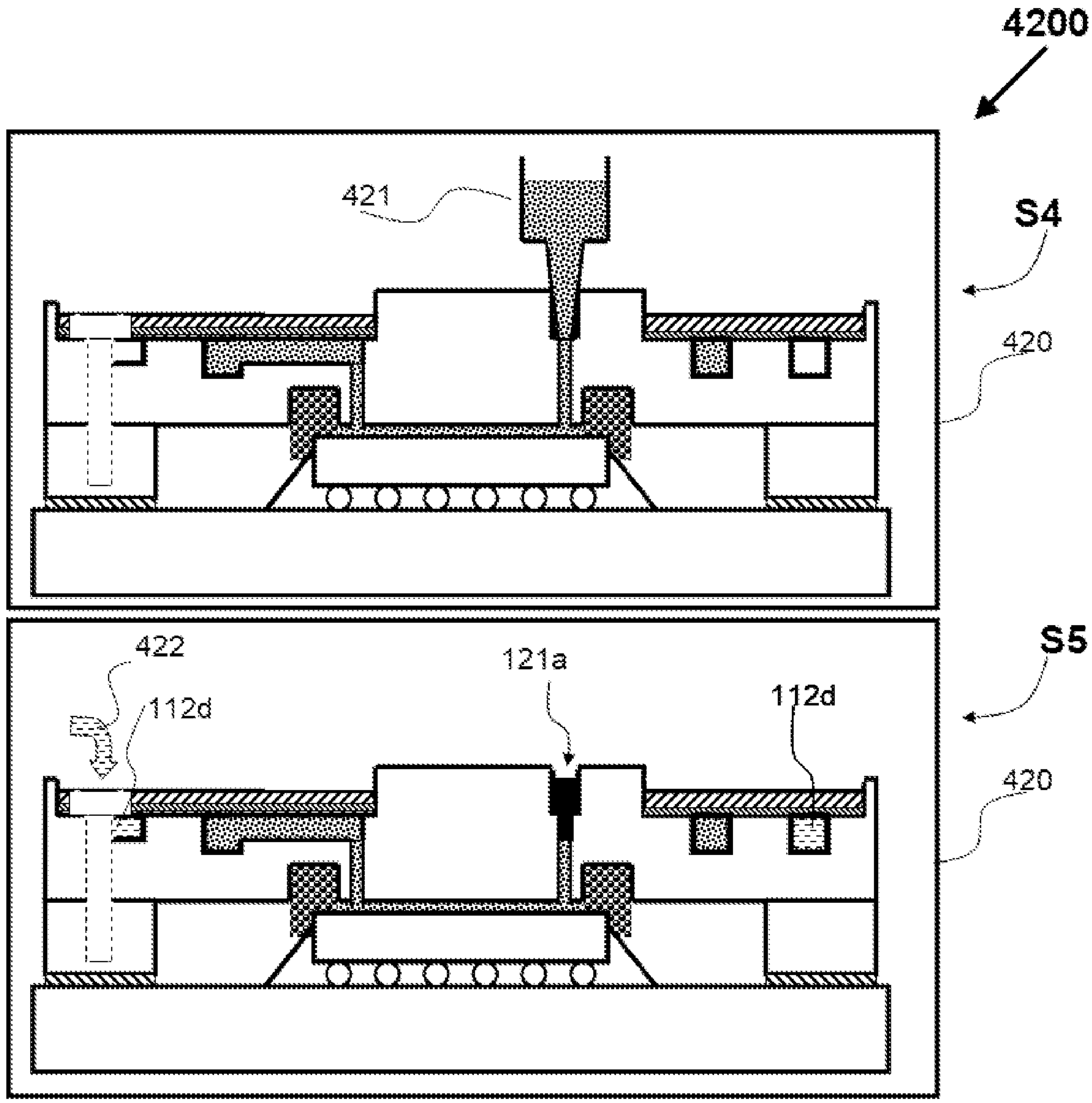


FIG. 11

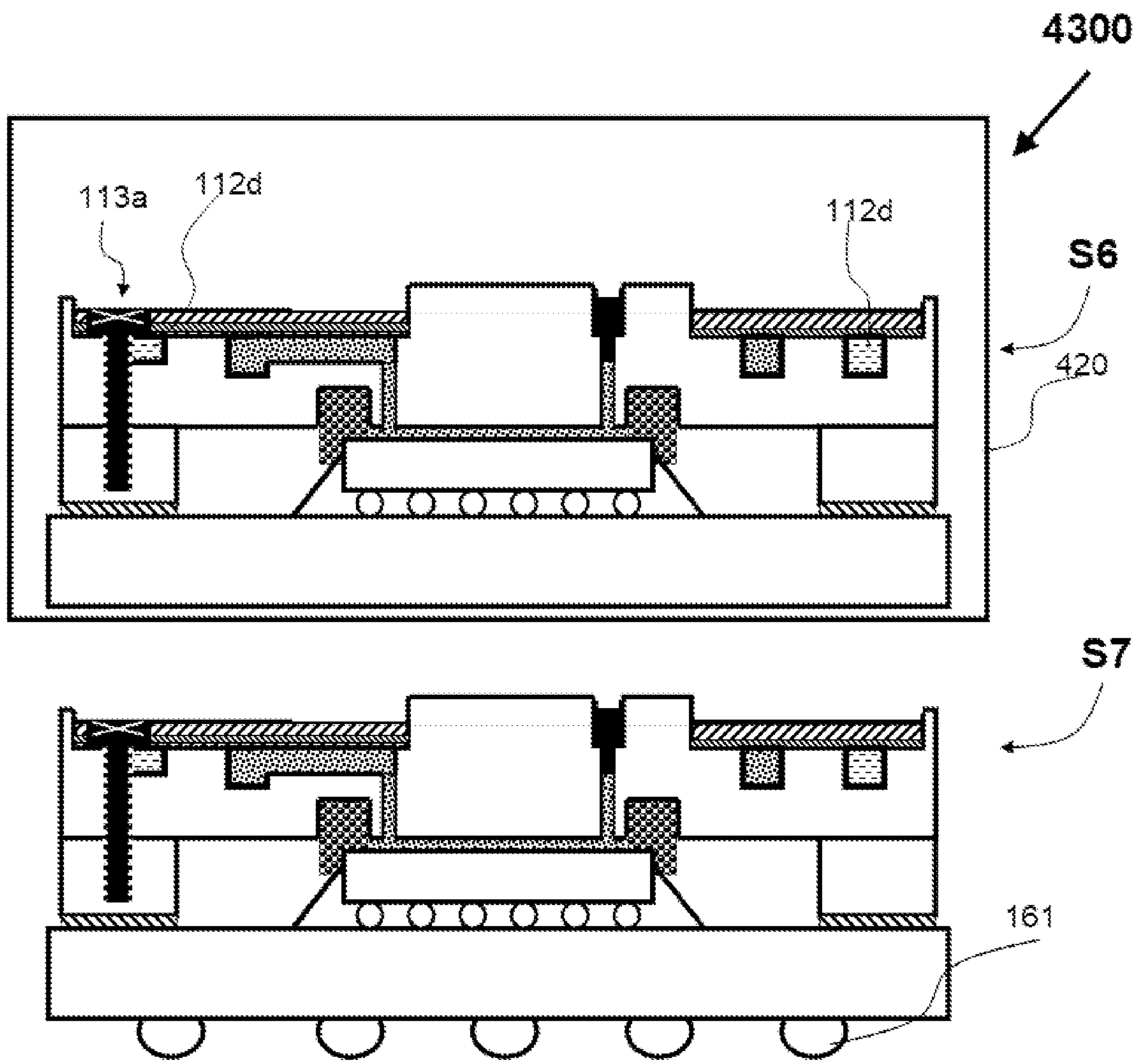


FIG. 12

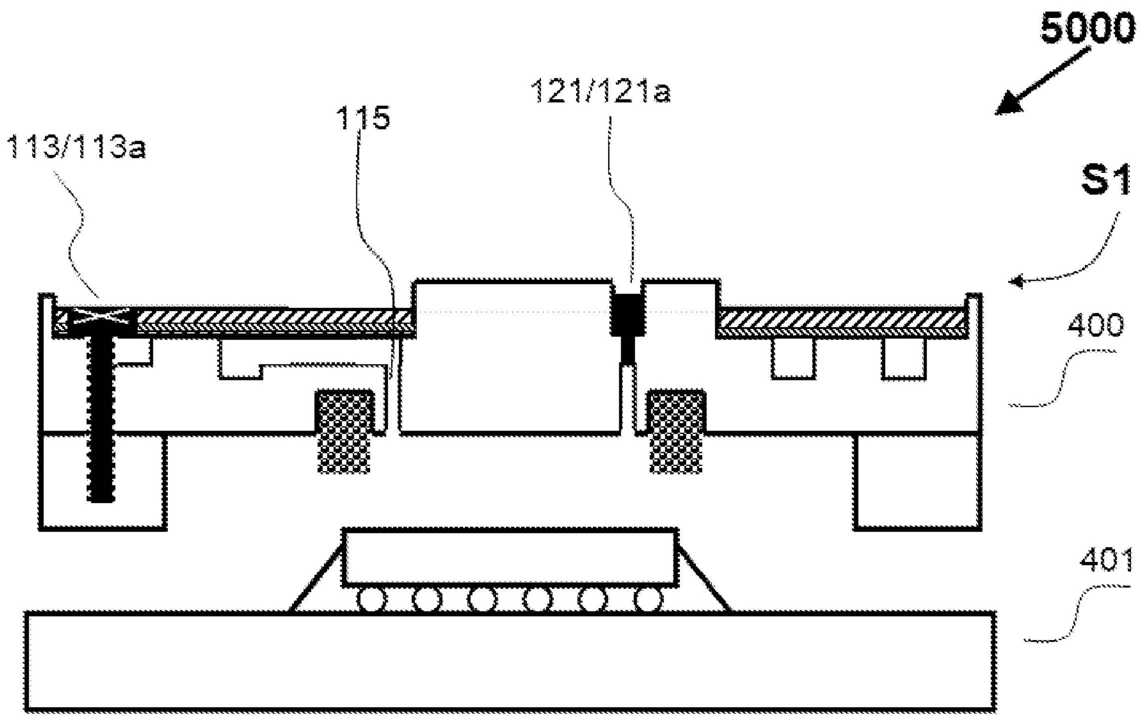


FIG. 13

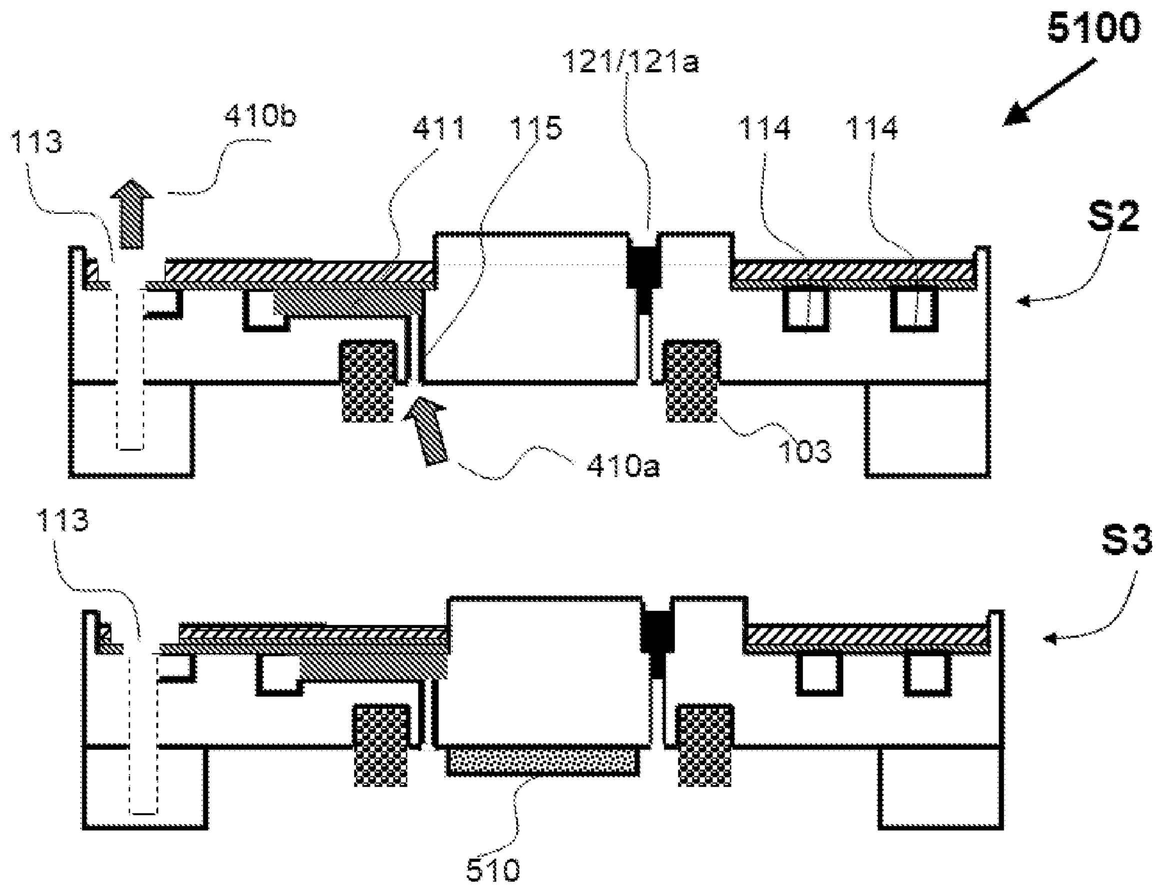
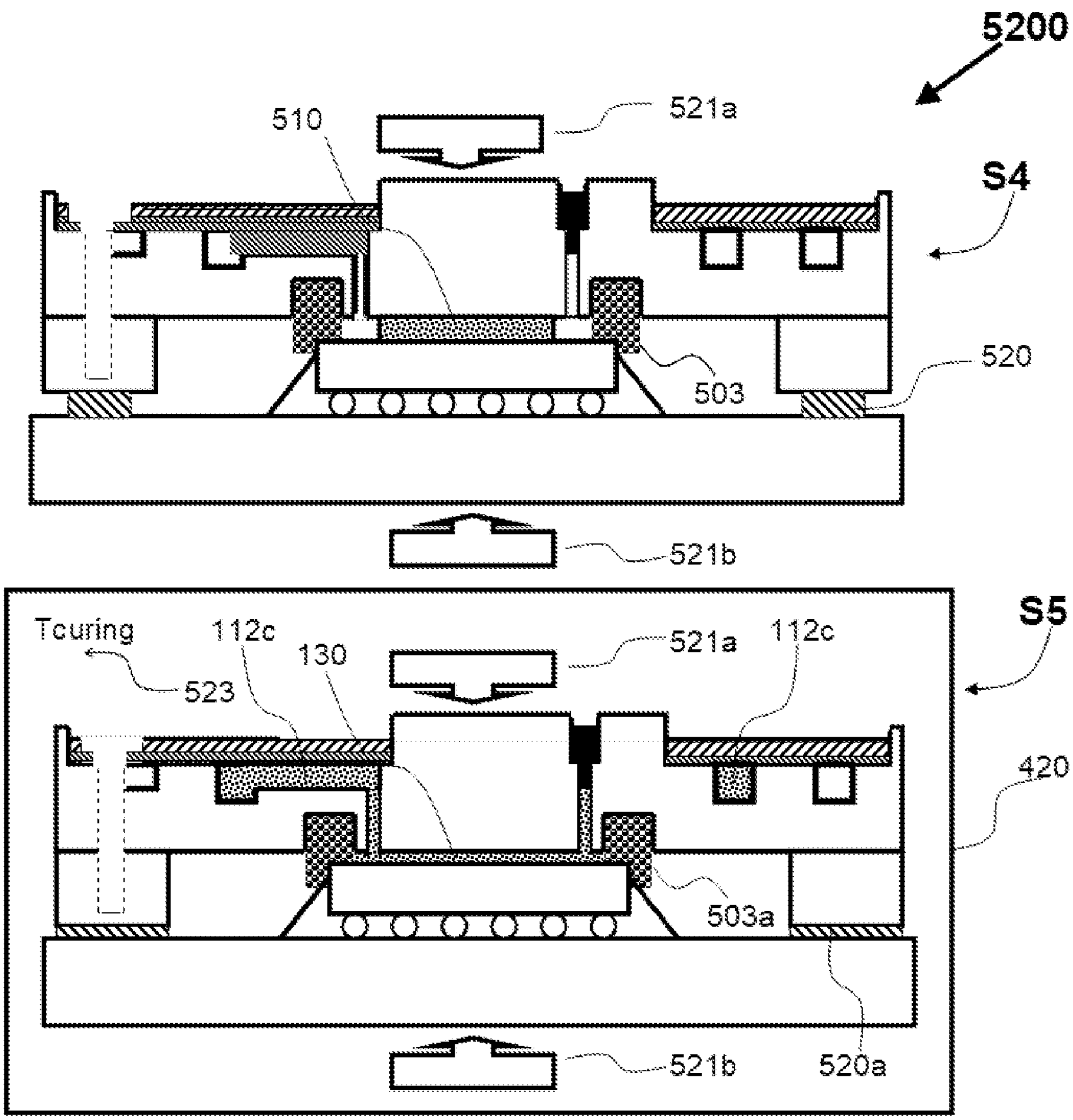


FIG. 14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112c
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521b
520a

FIG. 15

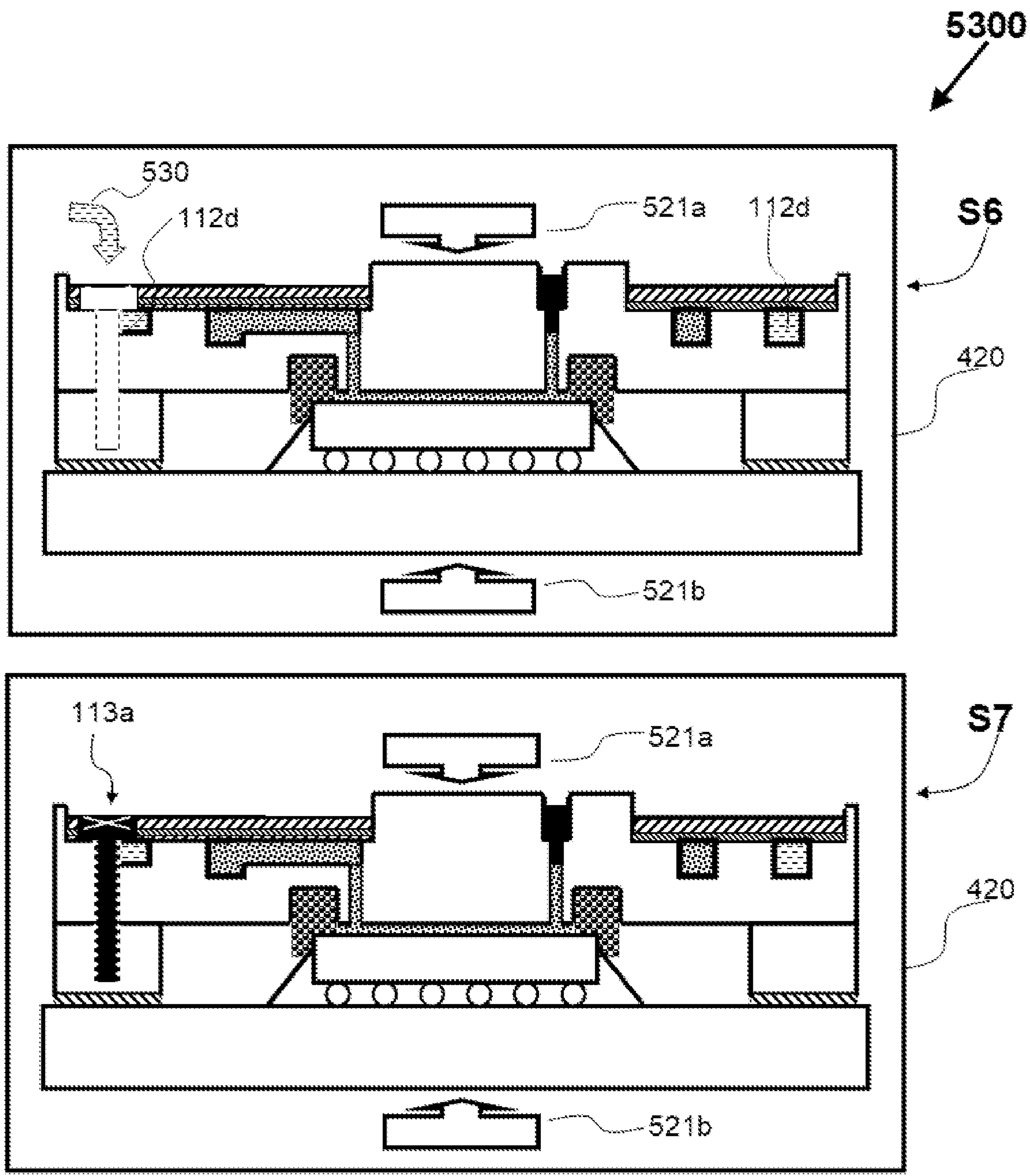


FIG. 16

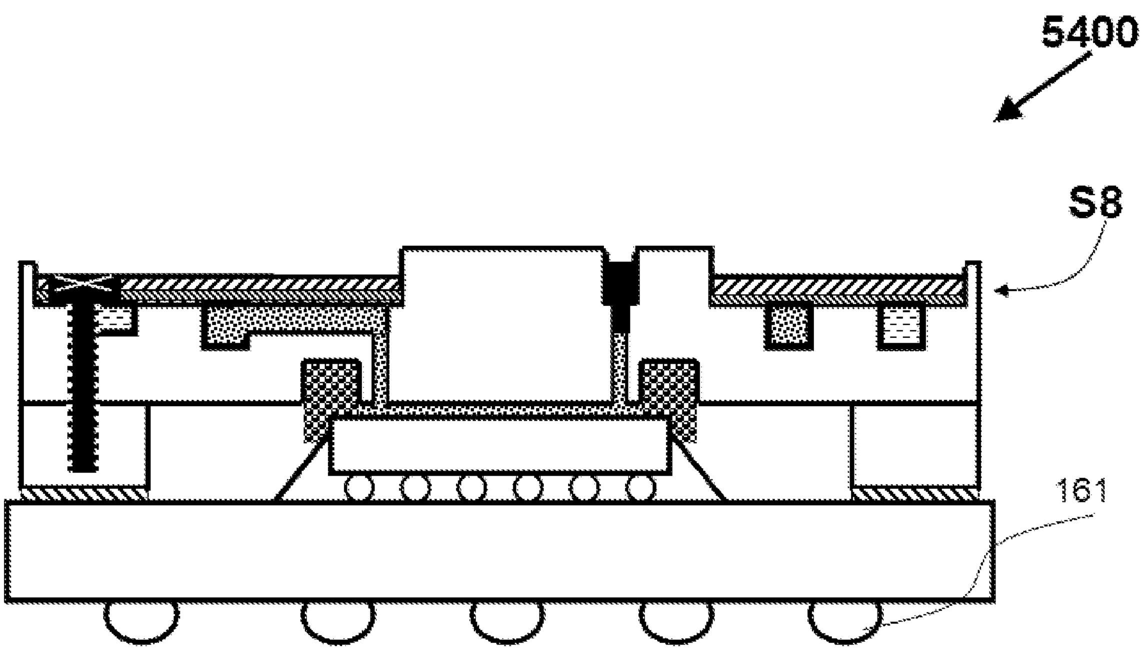
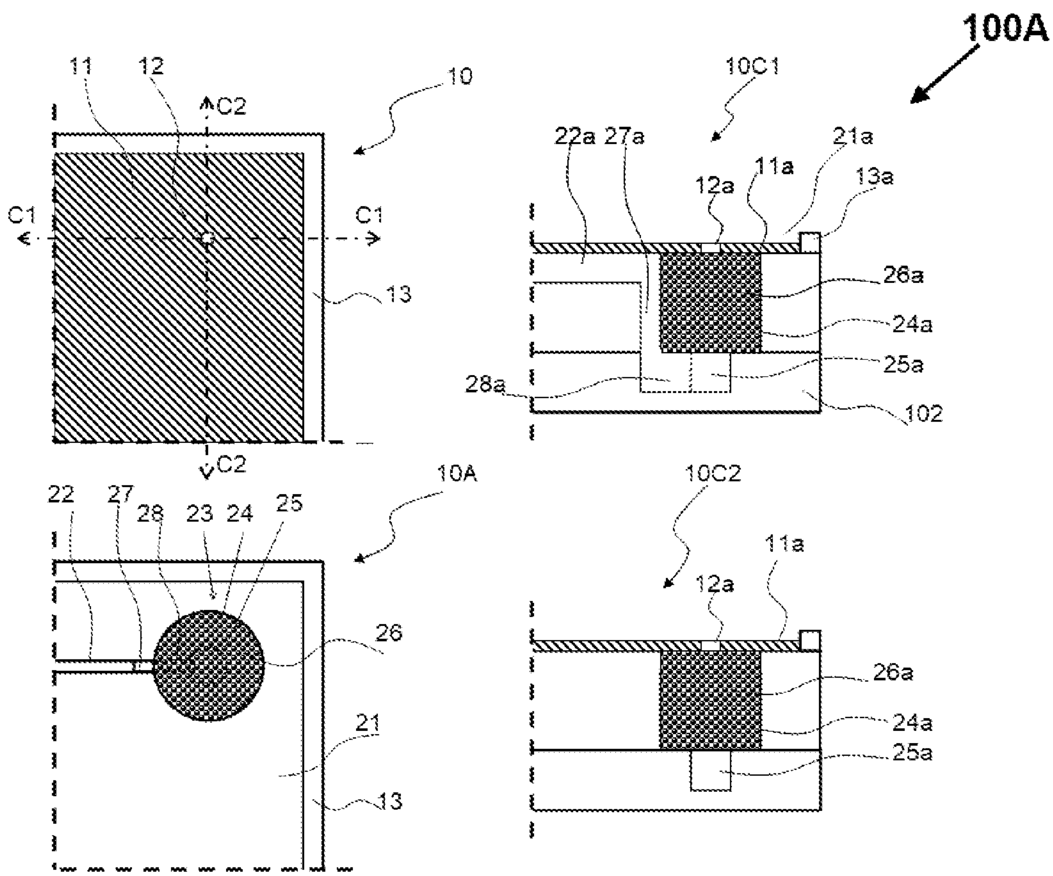


FIG. 17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C1
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27a
21a
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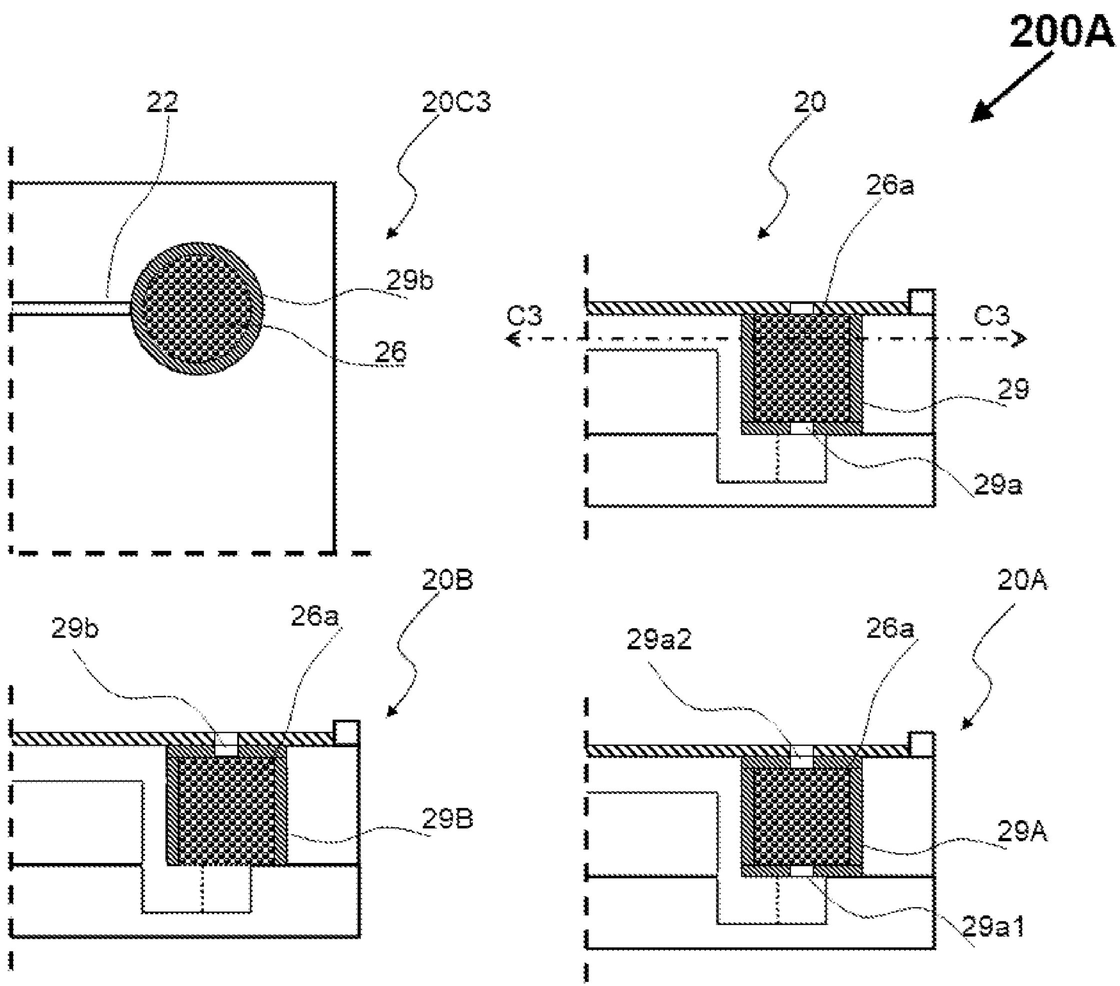
11a
12a
26a
24a
25a

FIG. 18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29A
29a1

FIG. 18A

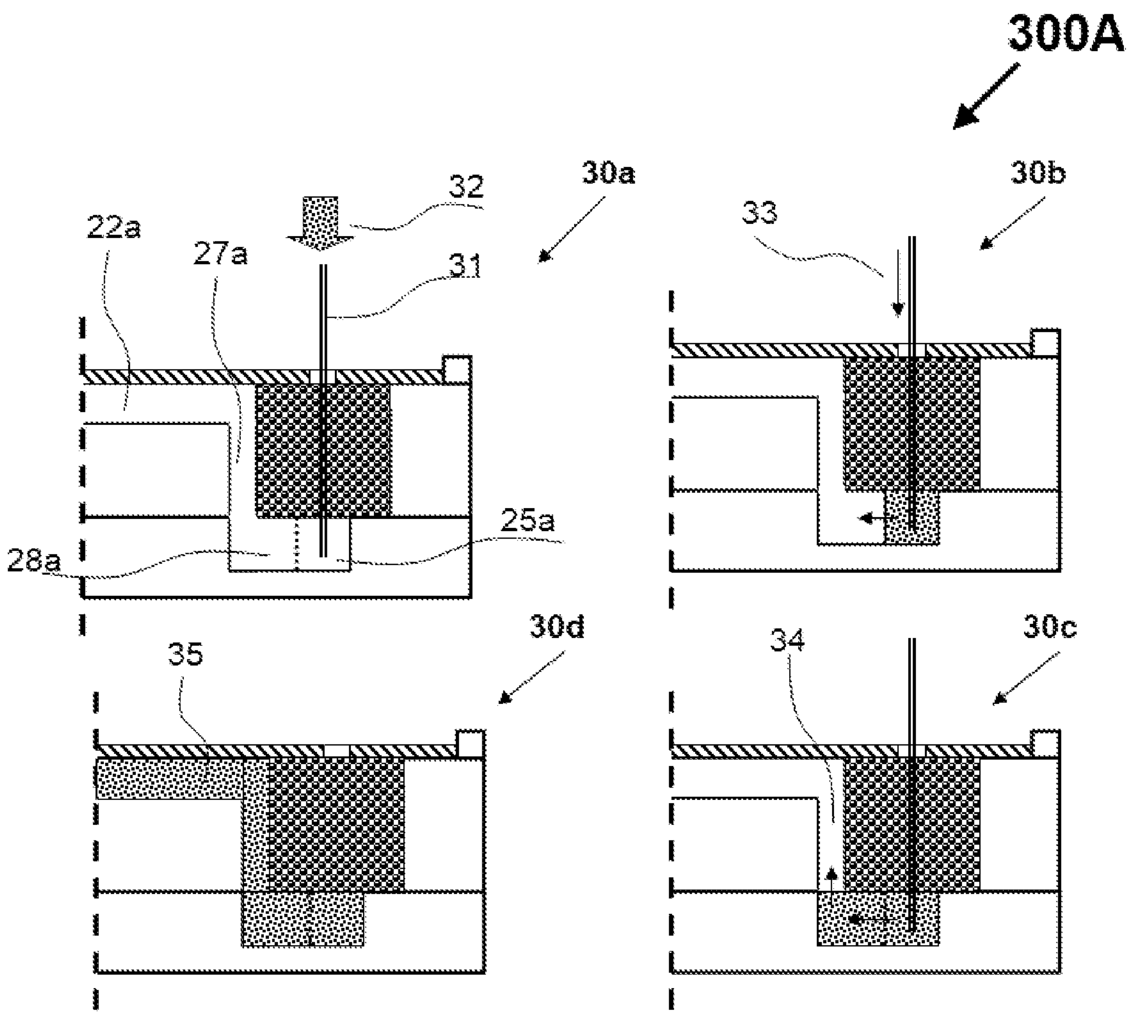

FIG. 19

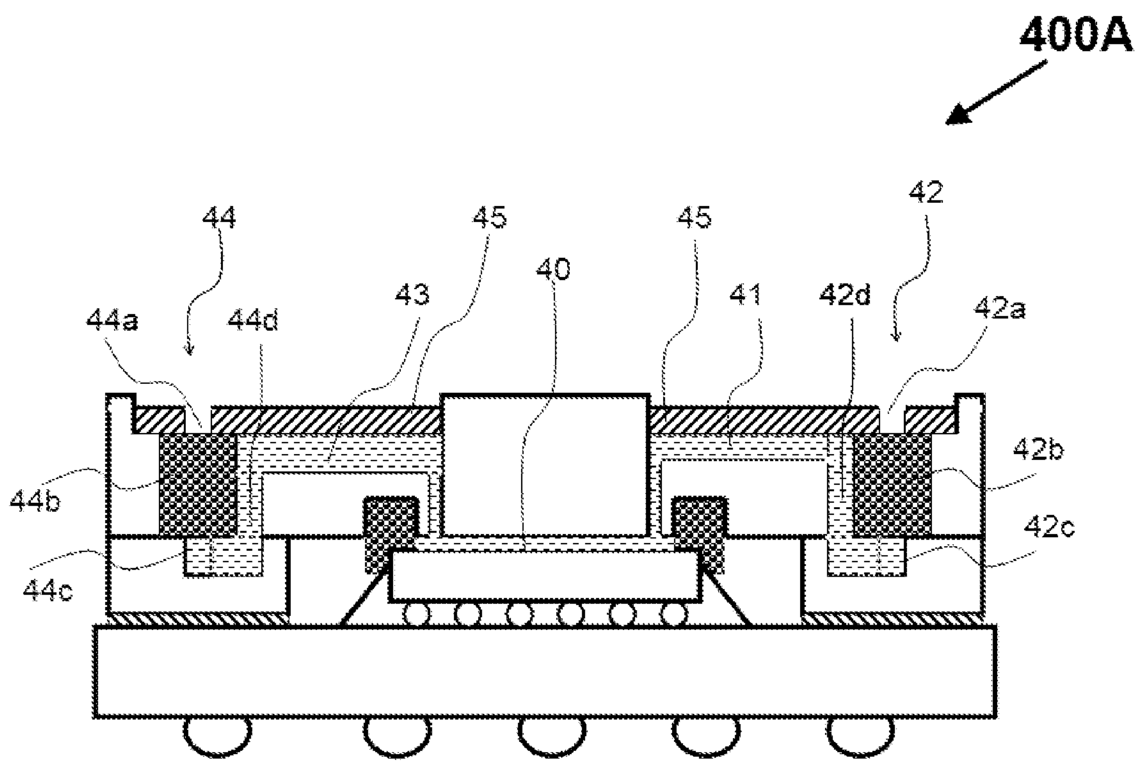

FIG. 20

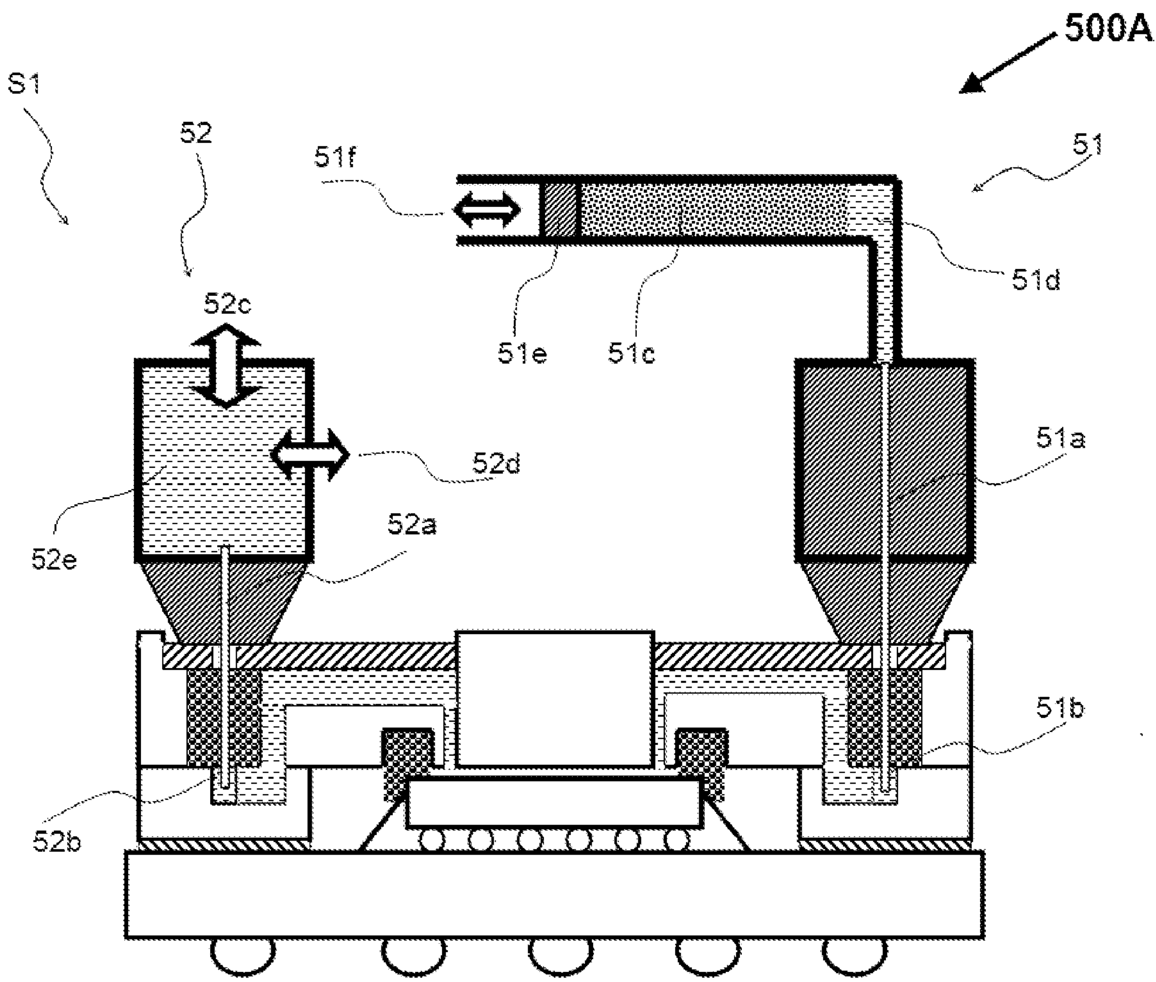

FIG. 21

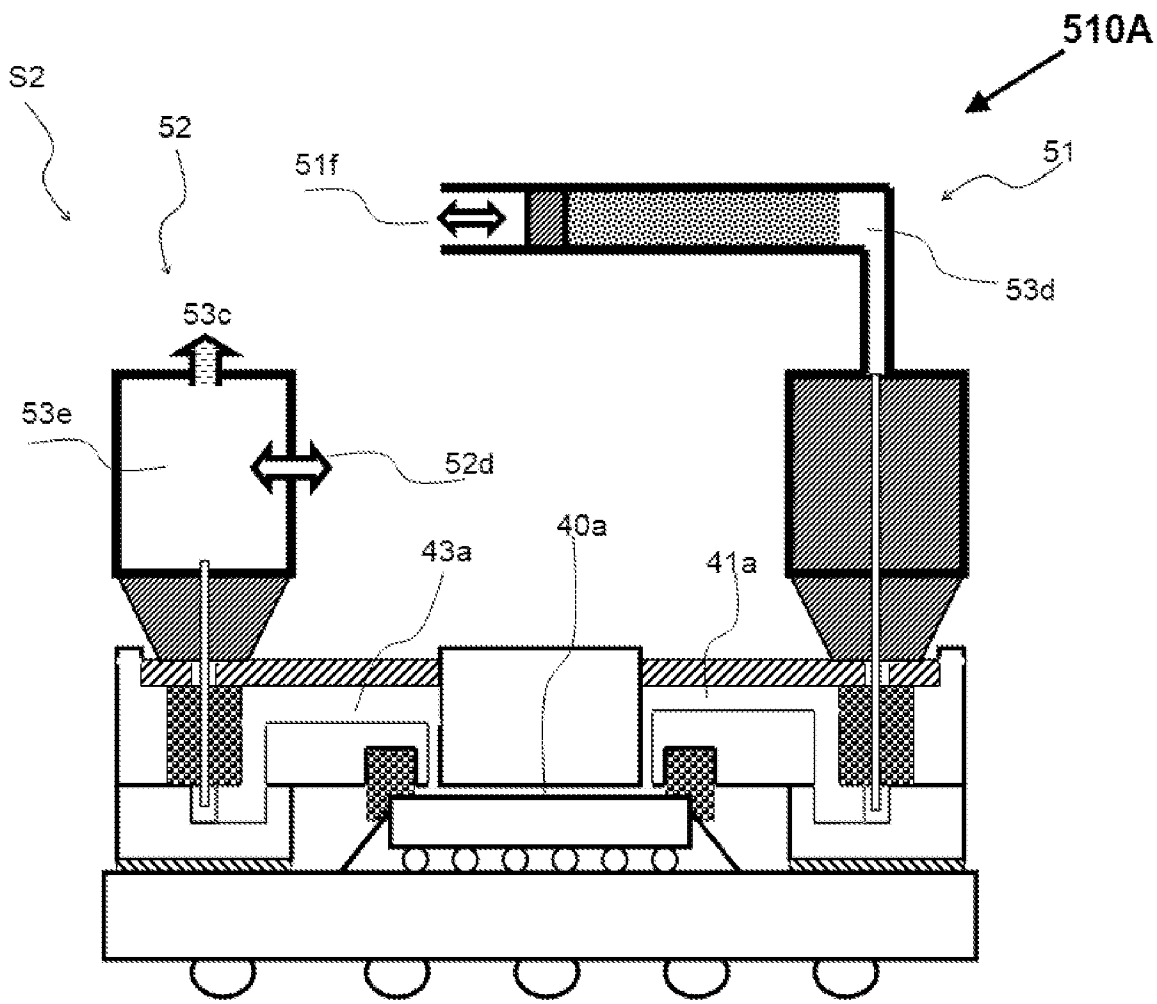

FIG. 22

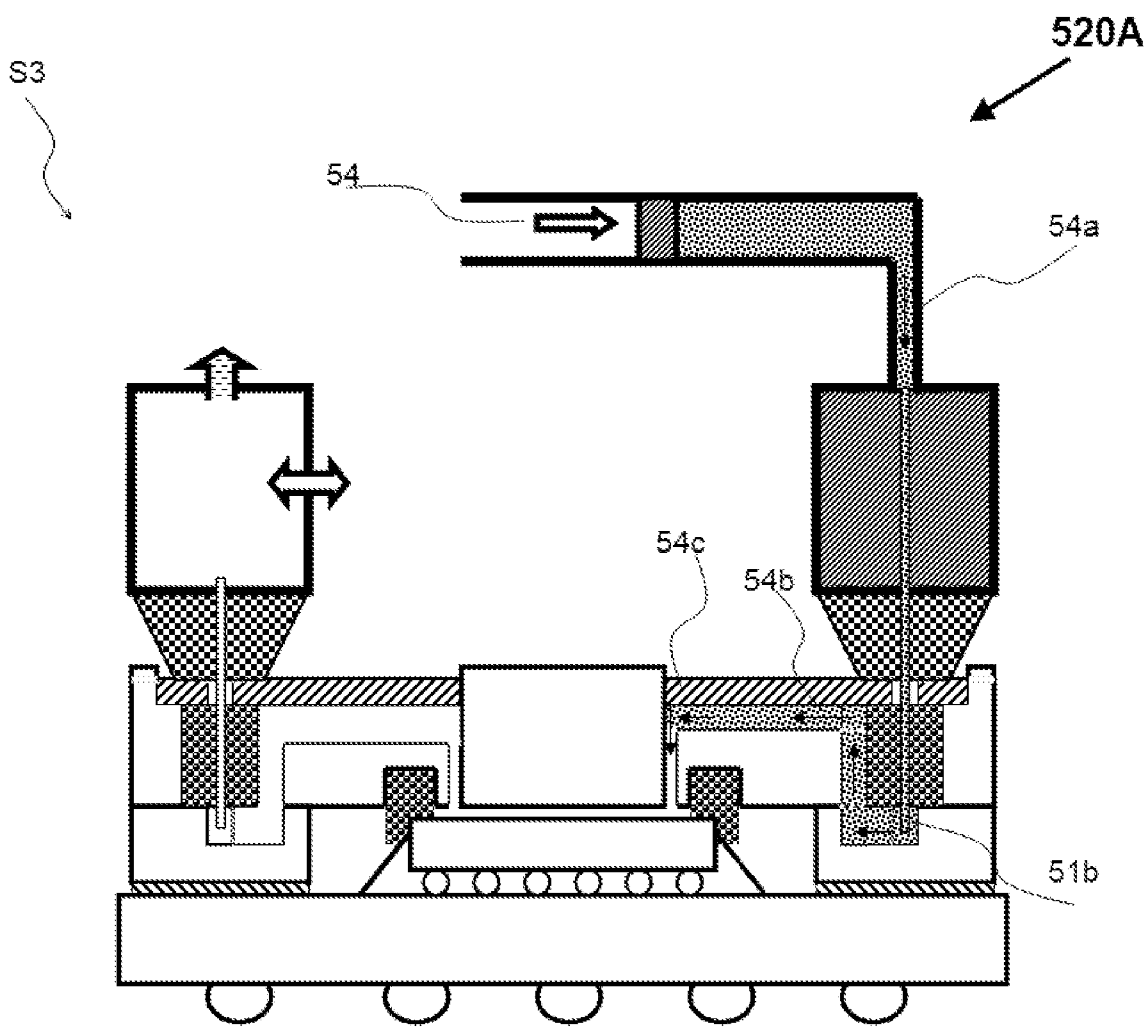

FIG. 23

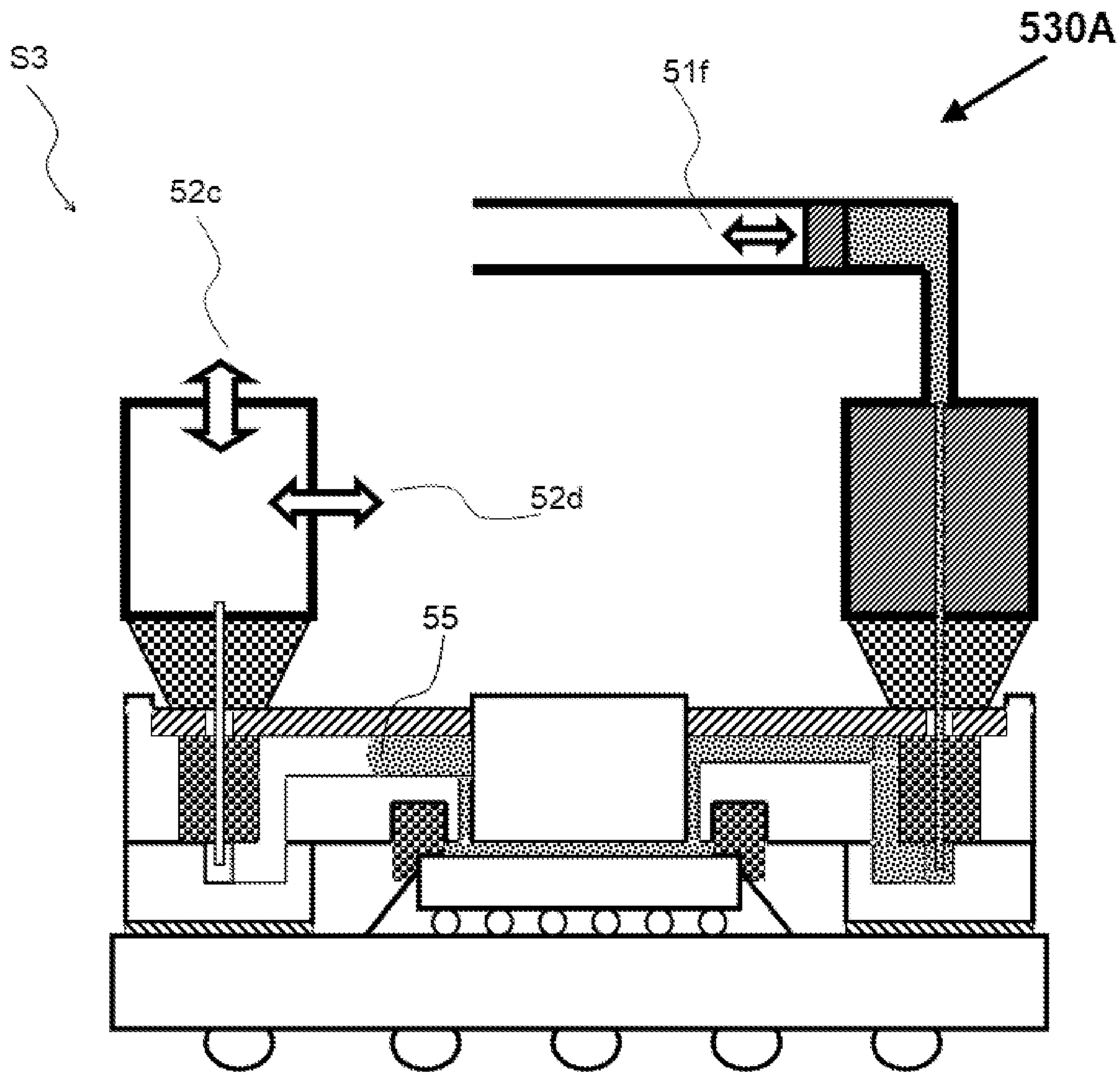

FIG. 24

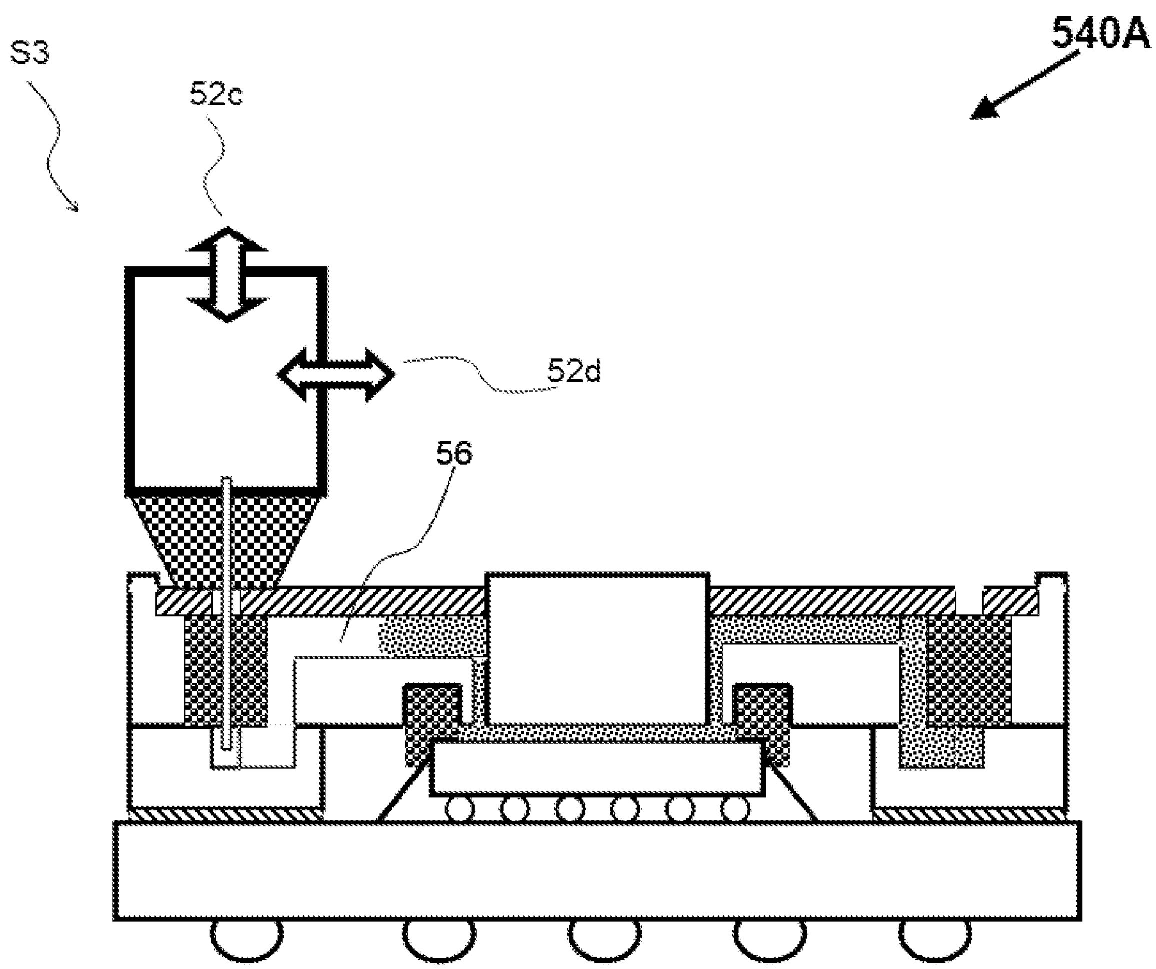

FIG. 25

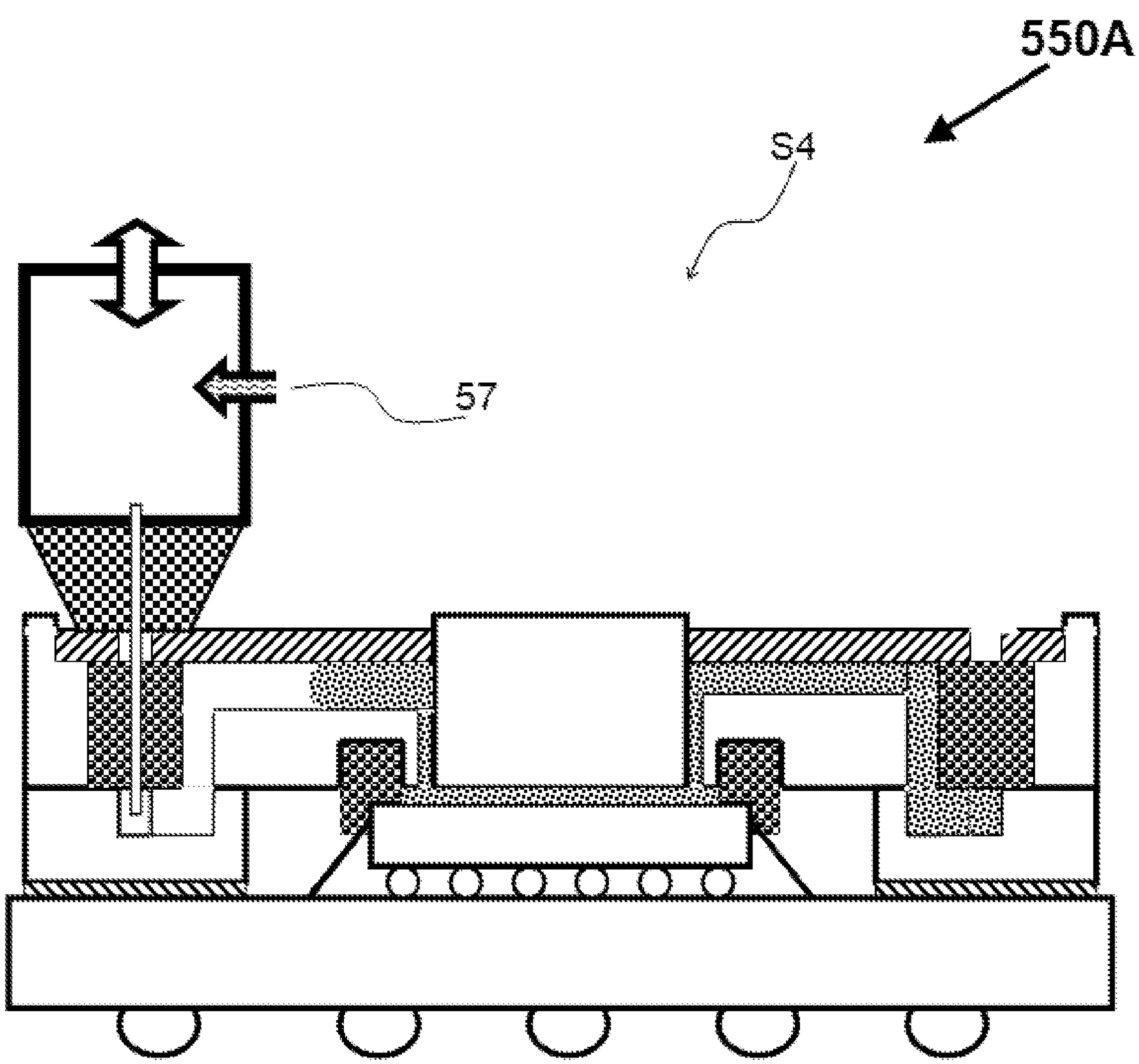

FIG. 26

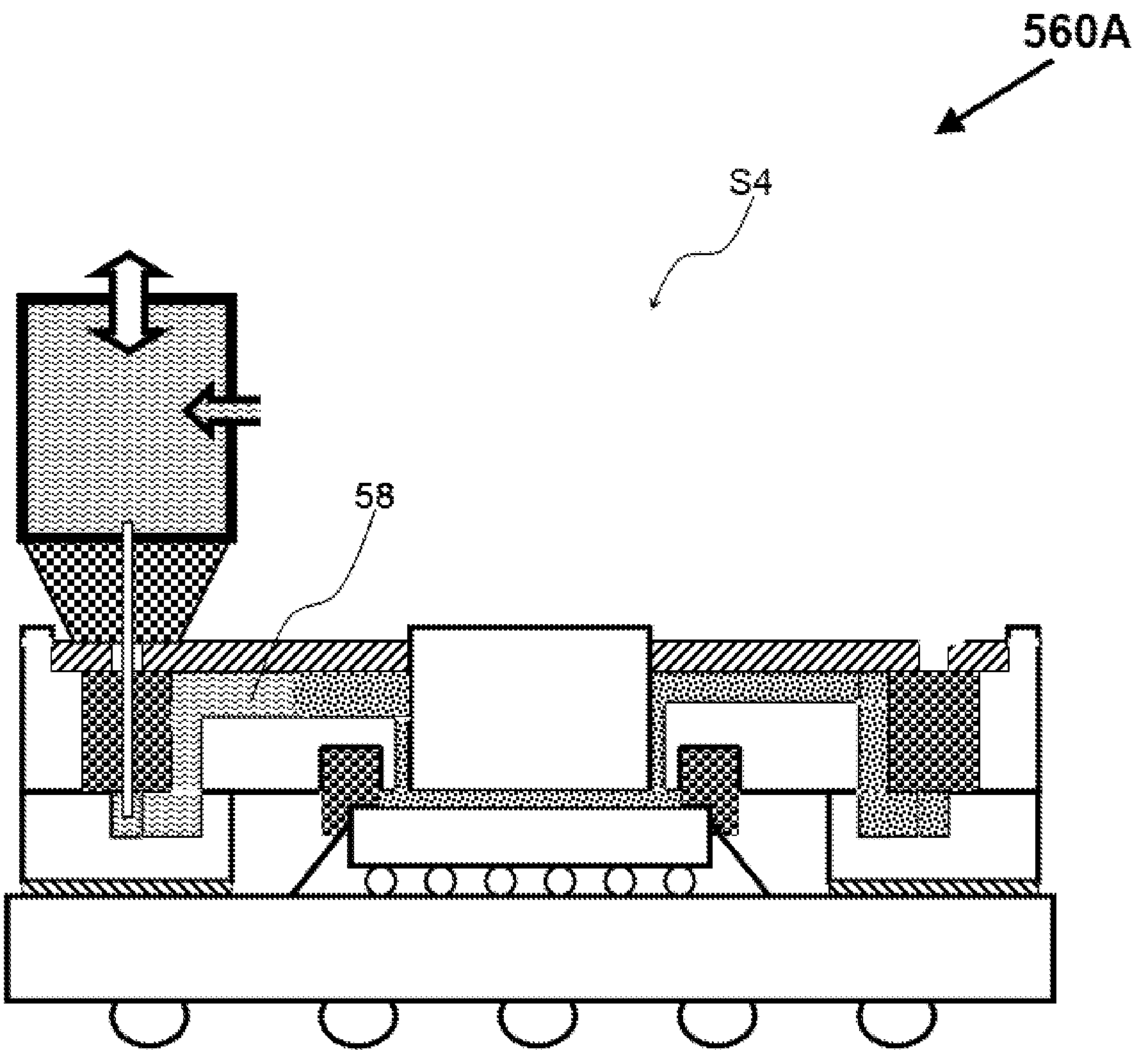

FIG. 27

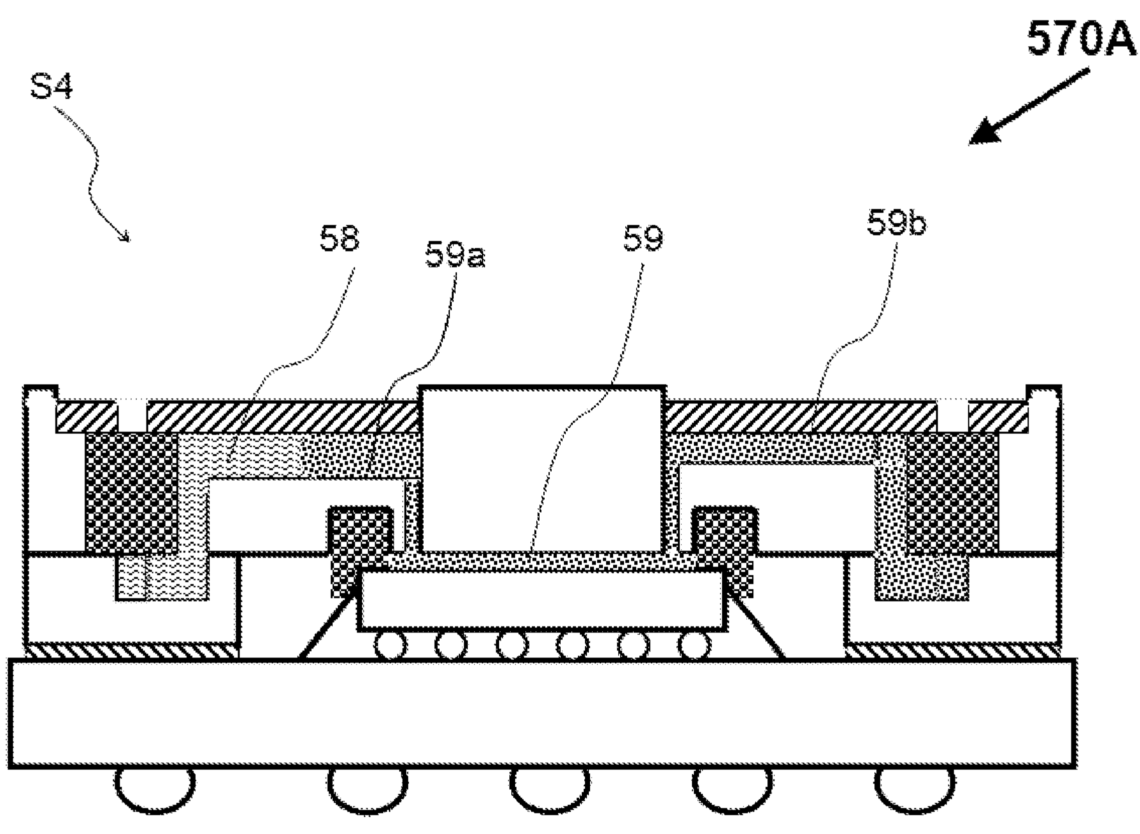

FIG. 28

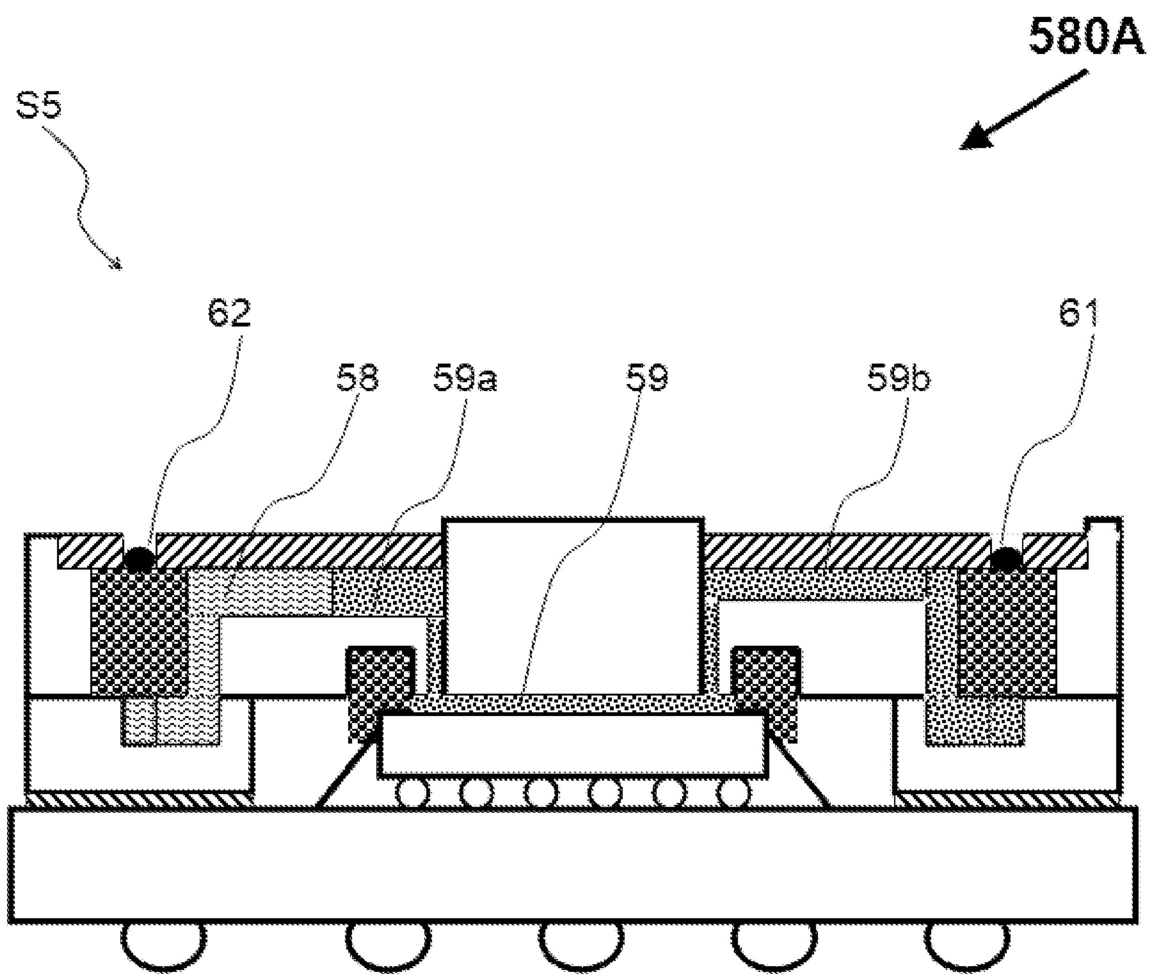

FIG. 29

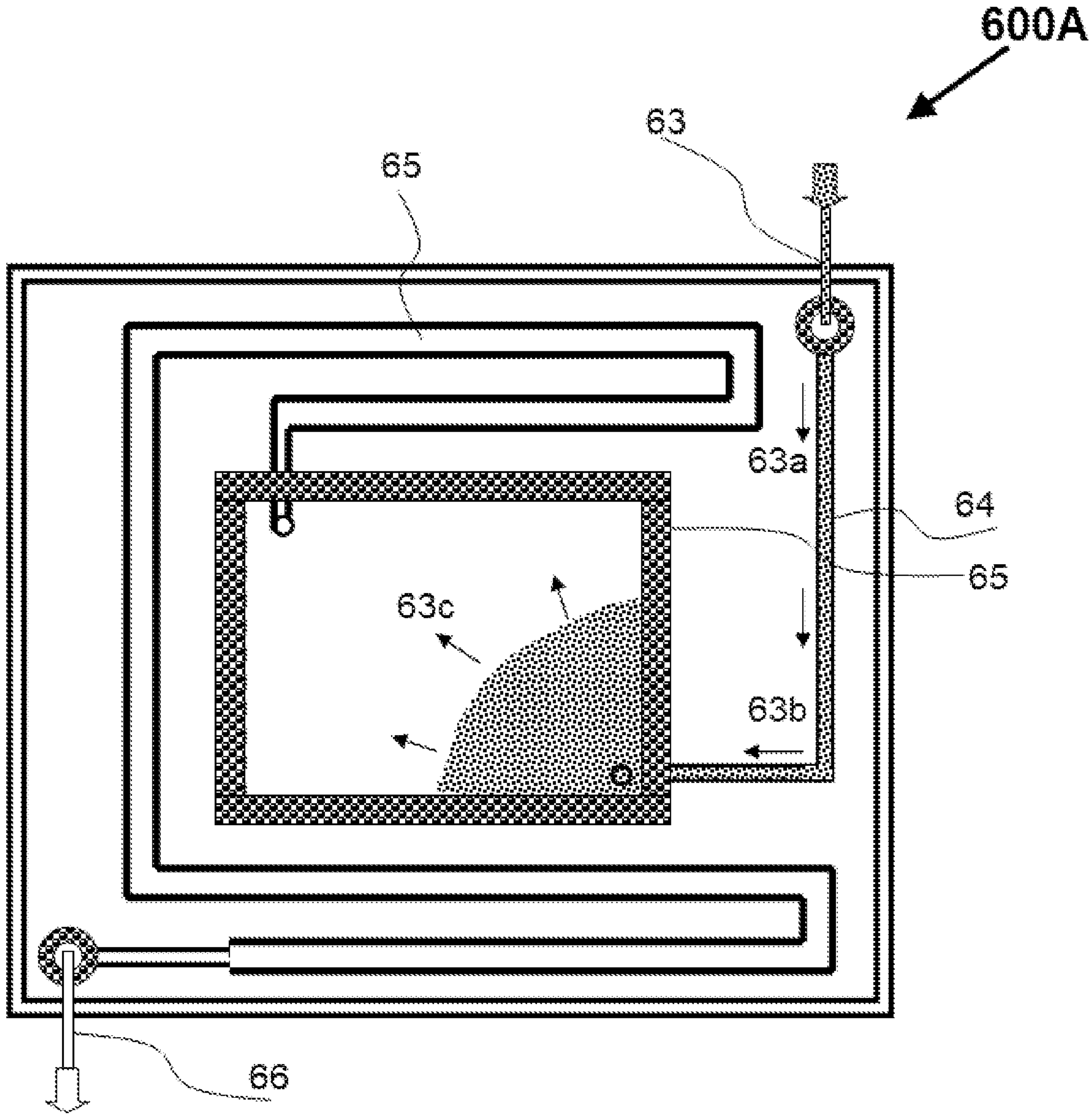

FIG. 30

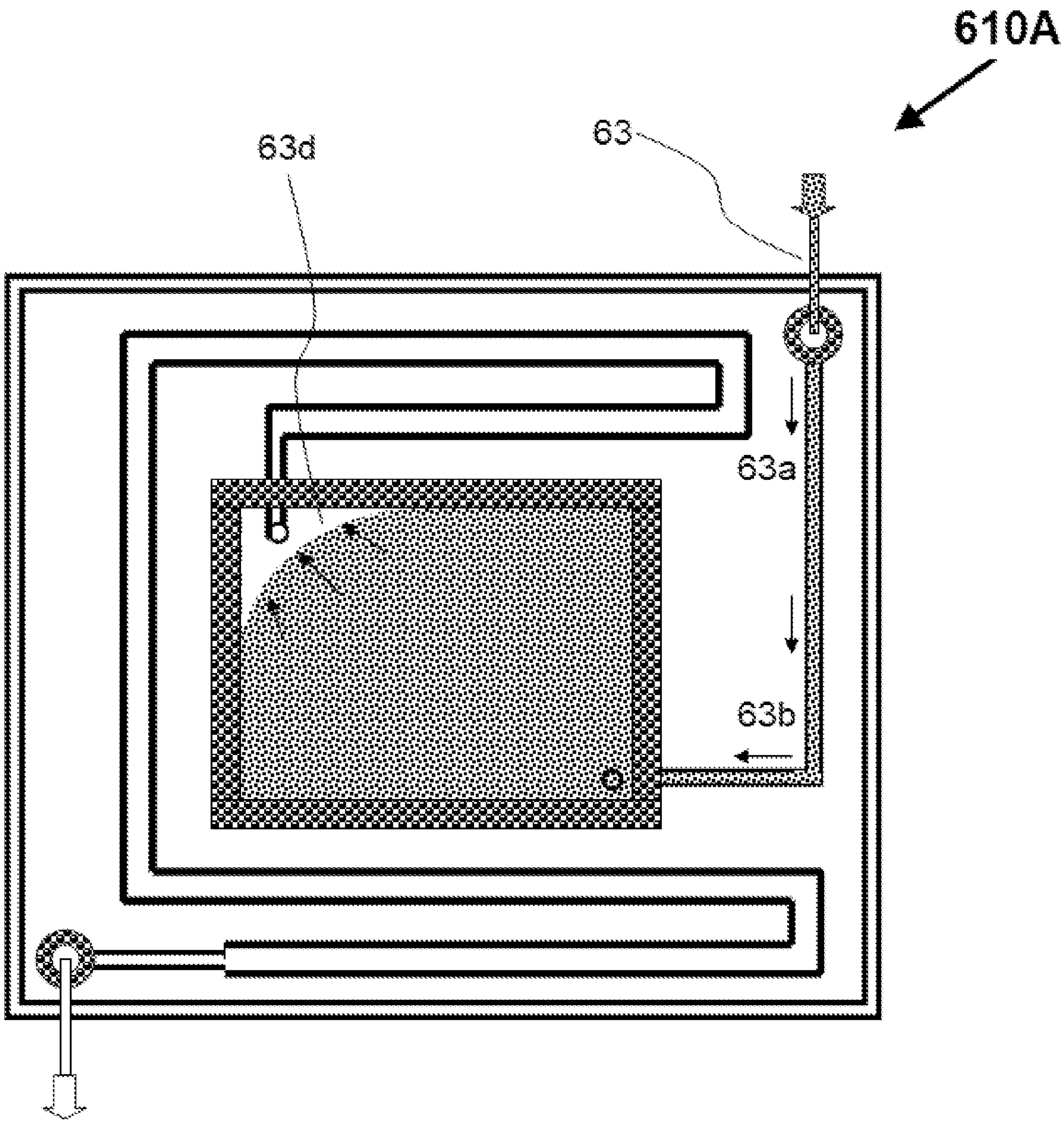

FIG. 31

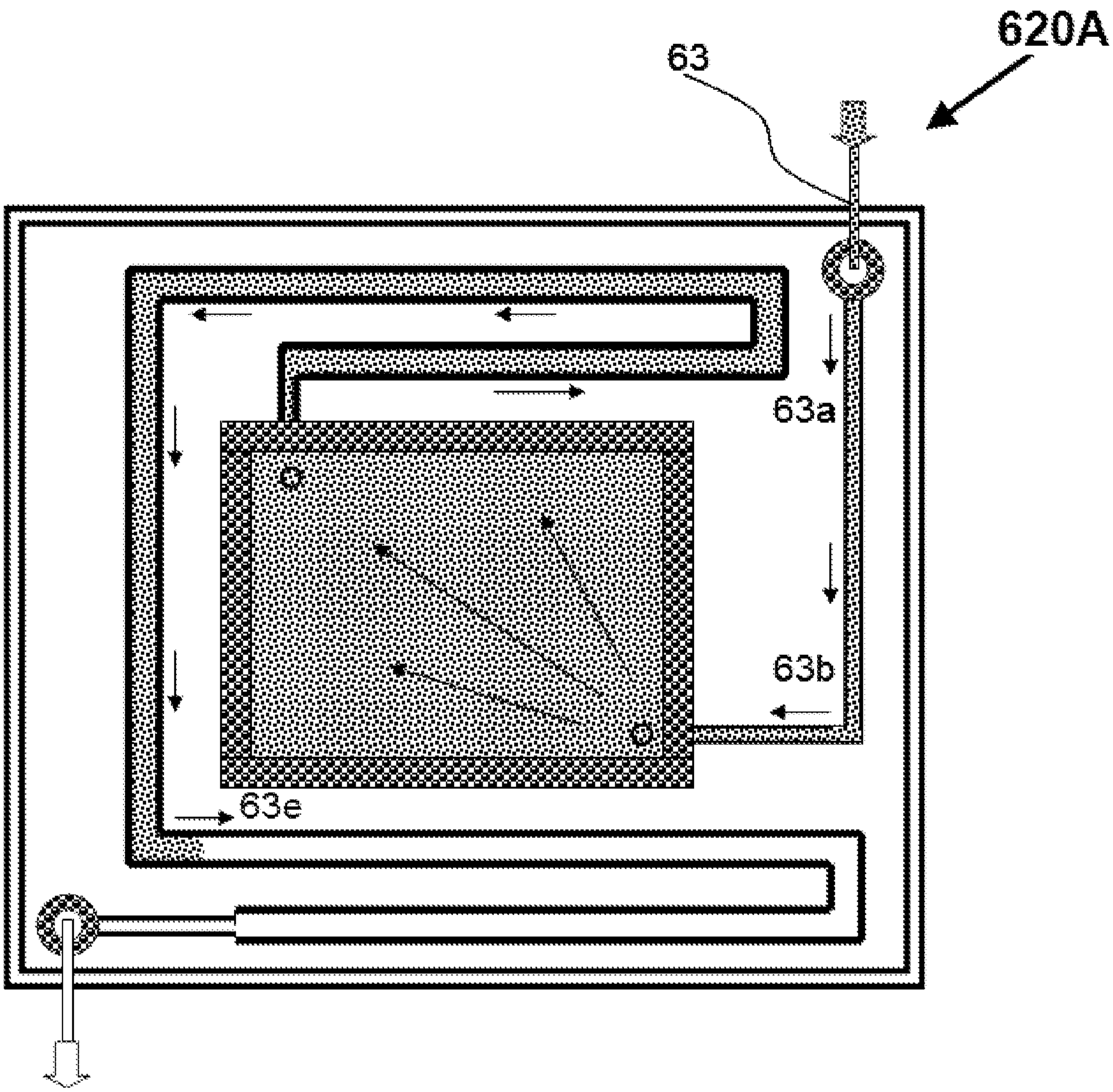

FIG. 32

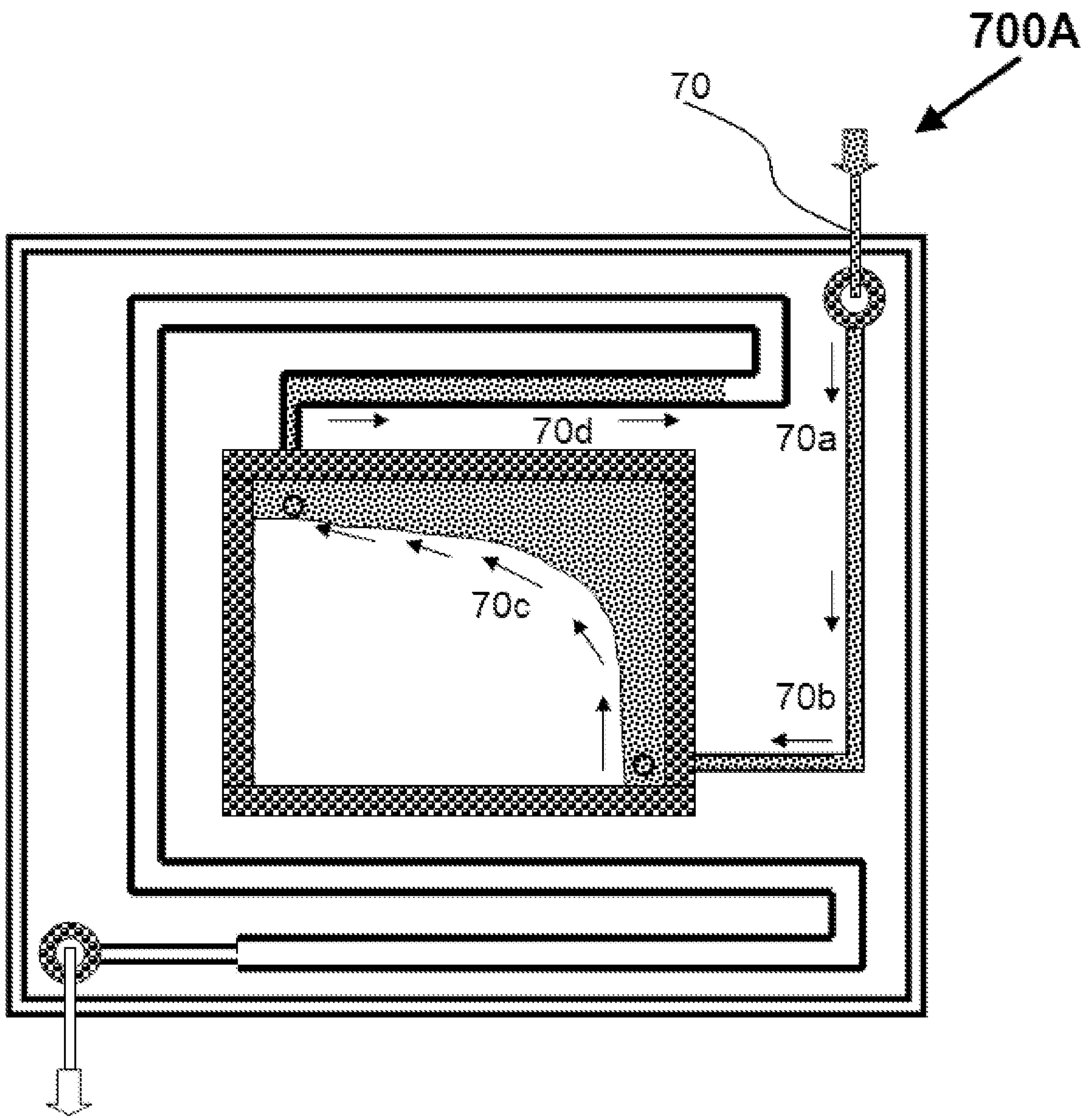

FIG. 33

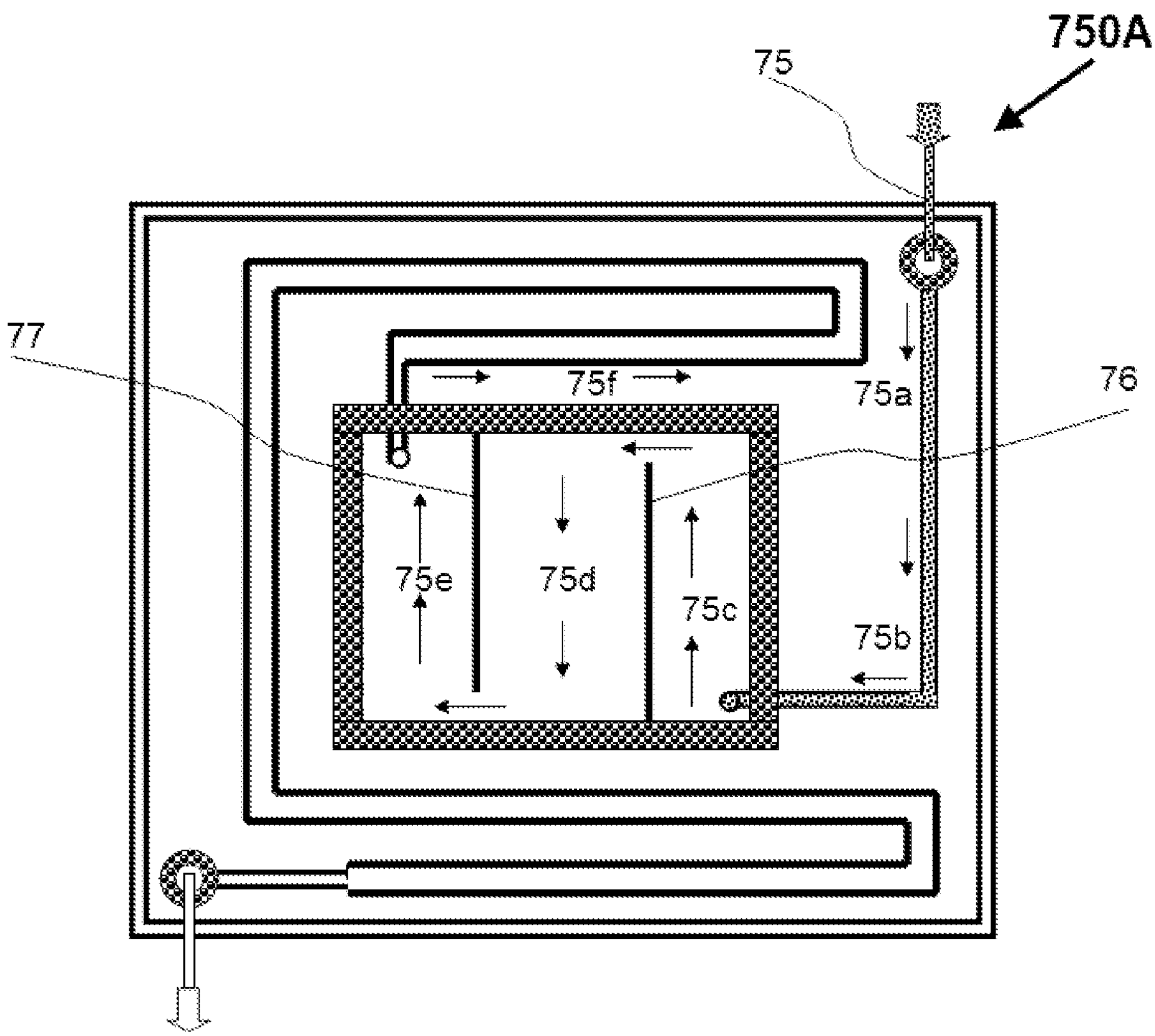

FIG. 34

LID WITH SELF SEALING PLUG ALLOWING FOR A THERMAL INTERFACE MATERIAL WITH FLUIDITY IN A LIDDED FLIP CHIP PACKAGE

[0001] The present application is a continuation-in-part of U.S. patent application Ser. No. 17/695,826 filed on Mar. 15, 2022.

TECHNICAL FIELD OF THE DISCLOSURE

[0002] The disclosure relates generally to a heat-dissipating object for dissipating heat from a heat-generating object in an electronic device, and particularly to a lid for a lidded flip chip package to use a liquid thermal interface material (TIM) or a TIM having fluidity at least during operation temperature of the lidded flip chip package.

BACKGROUND OF THE DISCLOSURE

[0003] In a flip chip package with a semiconductor chip being a heat-generating object, a thermal interface material (TIM) is usually used to fill the gap between the flip chip and a heat-dissipating object, like a lid or a heat sink for transferring the heat from one to the other. The types of the TIM basically include thermal pad, thermal grease, phase change material and liquid metal. A good TIM needs to have 1) a high thermal conductivity, 2) a good surface wetting capability for reducing the thermal contact resistance, 3) a good gap filling capability, and 4) a good thermal reliability in test or application. A liquid metal as TIM usually includes gallium and gallium alloy. The melting point of the gallium is about 29° C., and that of gallium alloy is even lower. The thermal conductivity of the liquid metal is much higher than the extensively used thermal pad or thermal grease. Furthermore, a liquid metal has much better capability for surface wetting and gap filling. So, of all the types of TIM, a liquid metal is an ideal TIM if only looking at the first three items. If a liquid metal can be used in a lidded flip chip package, the temperature of the lidded flip chip package can be reduced significantly as compared to other types of TIM. However, the conventional lidded flip chip packages based on a conventional lid of prior arts are limited to use a liquid metal as its TIM due to the pumping-out issue, that is, when the package is under a thermal cycling test or in its long term of application, the volume of the gap between the flip chip and the lid varies with temperature due to the warpage of the flip chip, causing the liquid metal TIM to be pumped out. The TIM pumping-out issue will cause an incomplete gap filling between the flip chip and the lid, reducing the thermal performance of TIM. More importantly, because liquid metal is electrically conductive, a small amount of TIM pumping-out may damage the whole electronic device. As a result, a liquid metal type of TIM has not been commercially used in a lidded flip chip package. In general, because of similar reasons, a liquid metal type of TIM is rarely interposed between a heat-dissipating object (a heat sink, for example) and a heat-generating object (a semiconductor chip, for example) in an electronic device.

[0004] For overcoming the TIM pumping-out issue for an electronic device such as a lidded flip chip package to use a liquid TIM, a lid coupled with a reservoir structure for a lidded flip chip package to use a liquid thermal interface material has been disclosed in our prior arts, U.S. Ser. No. 10/643,924 B1 and application No. U.S. Ser. No. 17/686,372. However, the lid and the lidded flip chip package of the prior arts still have two disadvantages in its test and application. One is that a preferred liquid metal TIM, including gallium or its alloys, will oxidize when exposed to oxygen in an ambient of the lid and its lidded flip chip package of the prior arts. The liquid metal oxides formed from oxidation may accumulate with time to affect the flow of the liquid metal in the tunnel of the lid. Another disadvantage is that when a tunnel is formed by using an adhesive tape to bond a covering piece over a notch, the flow of the liquid metal in the tunnel is not very good. As a result, the sealed gap between the lid and the flip chip may become incompletely filled with the liquid metal. To eliminate the disadvantages, a lid and its lidded flip chip package are described in the present disclosure.

SUMMARY OF THE DISCLOSURE

[0005] A lid allowing for a thermal interface material with fluidity in a lidded flip chip package, comprising: a top piece with an upper side and a lower side, a foot at the lower side of the top piece, and a reservoir structure including a storage tunnel, an injection hole, and a sealing ring; wherein the sealing ring is mounted at the lower side of the top piece, which seals a peripheral edge region at a top surface of a flip chip and/or seals a peripheral region around a flip chip and at a top surface of a substrate so as to form a sealed gap between the flip chip and the top piece; wherein the lid further includes a ring-form of cavity at the upper side of its top piece, a pattern of notch formed at a bottom of the ring-form of cavity, and a covering piece mounted in the ring-form of cavity so as to cover the pattern of notch and form the storage tunnel; wherein the storage tunnel has two ends, one end of the said two ends connects to the sealed gap through a connecting hole, and a plug structure including a hole and a plug is formed at the other end of the said two ends; wherein the injection hole has two ends, one end of the said two ends connects to the sealed gap directly or through an injection tunnel, and a plug structure including a hole and a plug is formed at the other end of the said two ends; and wherein the sealed gap is completely filled with a thermal interface material having fluidity, a portion of the storage tunnel is filled with the same thermal interface material, and the remaining portion of the storage tunnel is filled with a gas.

[0006] A method for making a lidded flip chip package based on the lid of present disclosure, comprising the following major steps:

[0007] 1) Prepare a lid according to a flip chip package;

[0008] 2) Form a slippery skin on an inner surface of the storage tunnel;

[0009] 3) Mount the lid on the substrate and over the flip chip, wherein the sealing ring is tightly compressed to seal a peripheral edge region at a top surface of the flip chip and form a sealed gap between the flip chip and the top piece of the lid;

[0010] 4) Put the assembly formed in step 3 into a vacuum oven or container and set it to a vacuum condition to degas the assembly, and then fill a liquid metal through the injection hole into the sealed gap and a portion of the storage tunnel;

[0011] 5) Close the injection hole by putting back its plug at the vacuum condition first, and then put a desired gas with a desired gas pressure into the vacuum oven or container to fill the remaining portion of the storage tunnel with the gas;

[0012] 6) Close the storage tunnel by putting back its plug so that the gas is sealed inside the storage tunnel;

[0013] 7) Mount solder balls at a bottom side of the substrate so that a lidded flip chip package is formed.

[0014] A method for making a lidded flip chip package based on the lid of present disclosure, comprising the following major steps:

[0015] 1) Prepare a lid according to a flip chip package;

[0016] 2) Form a slippery skin on an inner surface of the storage tunnel;

[0017] 3) Attach a piece of pre-formed liquid metal pad or form a liquid metal pad at a bottom surface of the top piece and inside the sealing ring under a low temperature;

[0018] 4) Clamp the lid formed in step 3 onto the flip chip package prepared in step 1 using a clamping force, wherein an adhesive is interposed between the foot of the lid and the substrate, the sealing ring is compressed to seal at a peripheral edge region at a top surface of the flip chip and form a sealed gap between the lid and flip chip, and the liquid metal pad is clamped between the lid and the flip chip and enclosed in the sealed gap;

[0019] 5) Put the assembly formed in step 4 into a vacuum oven or container and set it to a vacuum condition to degas the assembly, and then raise the oven temperature above the melting point of the liquid metal and hold this temperature for a period of time until the liquid metal pad becomes molten, so that the seal ring is further compressed, the thickness of the of the sealed gap becomes thinner, the adhesive is compressed to spread between the foot and the substrate, and the molten liquid metal pad is squeezed to fill the sealed gap and a portion of the storage tunnel; and then raise the oven temperature to a curing temperature of the adhesive and hold it until the adhesive becomes cured;

[0020] 6) Put a desired gas with a desired gas pressure into the vacuum oven or container to fill the remaining portion of the storage tunnel with the gas;

[0021] 7) Close the storage tunnel by putting back its plug so that the gas is sealed inside the storage tunnel;

[0022] 8) Mount solder balls at a bottom side of the substrate so that a lidded flip chip package is formed.

[0023] The features and advantages of the embodiments of the present disclosure will become more apparent from the detailed descriptions in conjunction with the drawings below. The drawings and associated descriptions are to illustrate the embodiments of the present disclosure, not to limit the scope of what is claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] FIG. **1** to FIG. **3** are schematic diagrams for illustrating a lid allowing for a lidded flip chip package to use a thermal interface material with fluidity of one preferred embodiment of the present disclosure.

[0025] FIG. **4** and FIG. **4**A are schematic diagrams for illustrating another plug structure for a storage tunnel, a thermally conductive mesh in the sealed gap as an option, and a foam block as a safety measure adjacent to the adhesive of a lid allowing for a lidded flip chip package to use a thermal interface material with fluidity of one embodiment of the present disclosure.

[0026] FIG. **5** to FIG. **5**B are schematic diagrams for illustrating a preferred design for an injection hole of a lid allowing for a thermal interface material with fluidity in a lidded flip chip package of another preferred embodiment of the present disclosure.

[0027] FIG. **6** is a schematic diagram for illustrating a preferred design for a plug structure for opening or closing a storage tunnel or an injection hole of a lid allowing for a lidded flip chip package to use a thermal interface material with fluidity of one preferred embodiment of the present disclosure.

[0028] FIG. **7** and FIG. **8** are schematic diagrams for illustrating a foot structure being used as a sealing ring of a lid allowing for a lidded flip chip package to use a thermal interface material with fluidity of one preferred embodiment of the present disclosure.

[0029] FIG. **9** to FIG. **12** are schematic diagrams for illustrating a method for making a lidded flip chip package based on a lid of one preferred embodiment of the present disclosure.

[0030] FIG. **13** to FIG. **17** are schematic diagrams for illustrating a method for making a lidded flip chip package based on a lid of another preferred embodiment of the present disclosure.

[0031] FIG. **18**, FIG. **18**A, and FIG. **19** are schematic diagrams for illustrating a self-sealing plug structure integrated with a tunnel for filling and sealing a liquid metal in a lidded flip chip package to form a liquid metal thermal interface material of one preferred embodiment of the present disclosure.

[0032] FIG. **20** to FIG. **29** are schematic diagrams for illustrating a method for filling a liquid metal into the sealed gap and a portion of the storage tunnel, and for filling a desired gas with a desired gas pressure, like an inert gas with a half of the atmosphere air pressure, into the remaining portion of the storage tunnel to form a lidded flip chip package with a liquid metal TIM based on the present self-sealing plug structure of another preferred embodiment of the present disclosure.

[0033] FIG. **30** to FIG. **34** are schematic diagrams for illustrating a plurality of guiding lines introduced into the sealed gap to better fill a liquid metal into the sealed gap to form a lidded flip chip package with a liquid metal TIM of another preferred embodiment of the present disclosure.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0034] The present disclosure is to eliminate the disadvantages of the prior arts mentioned previously by introducing a plug structure at an end of a storage tunnel and a slippery skin on an inner surface of the storage tunnel of a lid for a lidded flip chip package, which is described in conjunction with the drawings in the following.

[0035] FIG. **1** and FIG. **1**A are schematic diagrams for illustrating a lid allowing for a thermal interface material with fluidity in a lidded flip chip package of one preferred embodiment of the present disclosure. The numerical symbol **800** in FIG. **1** designates a cross-sectional view of a lid, in which the numerical symbol **101** designates a top piece with an upper side **101***a* and a lower side **101***b*, the **102** designates a foot at the lower side **101***b* of the top piece **101**, the **112** designates a storage tunnel as a reservoir for accepting or releasing a liquid, the **121**/**121***a* designates an injection hole **121** with a plug **121***a* as a plug structure, and the **103** designates a sealing ring; wherein the sealing ring **103** is mounted at the lower side **101***b* of the top piece **101**;

wherein the lid **800** further includes a ring-form of cavity **110** at the upper side **101***a* of its top piece **101**, a pattern of notch **112** (which uses the same numerical number **112** as that for the storage tunnel) formed at a bottom **110***a* of the ring-form of cavity **110**, and a covering piece **111** mounted in the ring-form of cavity for covering the pattern of notch **112** so as to form the storage tunnel **112**; wherein the storage tunnel **112** has two ends **112***a* and **112***b*, one end **112***a* connects to a bottom surface of the top piece **101** at its lower side **101***b* and inside the sealing ring **103** through a connecting hole **115**, and a plug structure **113**/**113***a* including a hole **113** and a plug **113***a* is formed at the other end **112***b* of the storage tunnel **112** for opening or closing it to or from an outside of the lid or an ambient, like the atmosphere outside the lid; wherein the lid further includes a slippery skin **114** formed on an inner surface of the storage tunnel **112**, which can be made of either a lubricant oil or some other kind of coating, as showed by the enlarged cross-sectional view of the storage tunnel **112** that the dashed arrow points to; and wherein the injection hole **121** is formed through the top piece **101** and connects to a bottom surface at its lower side **101***b* and inside the sealing ring **103**. The numerical symbol **120** in FIG. **1** designates an island portion of the top piece **101** surrounded by the ring-form cavity **110**, which is directly above a flip chip when the lid is mounted with a flip chip package as illustrated in FIG. **1**A in the following. The **110***b* in FIG. **1** designates a rim of the ring-form cavity **110**. The numerical symbol **180** in FIG. **1** designates a piece of pre-formed liquid metal pad in a solid state mounted on a bottom surface at the lower side of the top piece **101** and inside the sealing ring **103**, which is optionally used to form a liquid metal thermal interface material when the lid is mounted with a flip chip package as illustrated in FIG. **13** to FIG. **17** below for a method for making a lidded flip chip package with a liquid metal thermal interface material of one embodiment of the present disclosure. It is noted that the numerical symbol **111***a* in FIG. **1** designates an adhesive layer as an option for bonding the covering piece **111** to the ring-form cavity in order to cover the pattern of notch **112**. If a metal to metal welding is used to mount a metal covering piece **111** in the ring-form cavity for covering a pattern of notch **112**, the adhesive layer **111***a* can be avoided.

[0036] FIG. **1**A is a schematic diagram for illustrating a lidded flip chip package based on the lid described previously in conjunction with the drawing in FIG. **1** of one preferred embodiment of the present disclosure. It is noted that the same elements in a following drawing will share the same numerical symbols as described in a previous drawing, which may not be repeatedly described in the following drawing for simplicity and clearness, and the descriptions in the previous drawing should be referred to when needed. The numerical symbol **1000** in FIG. **1**A designates a cross-sectional view of a lidded flip chip package based on the lid as described in FIG. **1**, in which the numerical symbol **150** designates a flip chip mounted on a substrate **160** through a plurality of bumps **151** and an underfill material **152**, the numerical symbol **155** designates an adhesive interposed between the foot **102** and the substrate **160** for mounting the lid **800** as described in FIG. **1** on a peripheral region of the substrate **160** and over the flip chip **150**, the numerical symbol **103***a* designates the sealing ring **103** as described in FIG. **1**, which is compressed so as to seal a peripheral edge region at a top surface of the flip chip **150** and form a sealed gap **130** between the flip chip **150** and the top piece **101**, the numerical symbol **115** designates a connecting hole which connects the storage tunnel **112** as described in FIG. **1** with the sealed gap **130**, the numerical symbol **130** also designates a thermal interface material having fluidity, like a liquid metal, completely filled in the sealed gap **130**, the numerical symbols **112***a* and **112***b* designate two ends of the storage tunnel **112** as described in FIG. **1**, and the **112***c* and **112***d* designate two portions of the storage tunnel **112**, a portion **112***c* is filled with the same thermal interface material having fluidity, and the remaining portion **112***d* is filled with a gas, the **112***c* and **112***d* also designate the thermal interface material having fluidity and the gas filled in the two portions, respectively, the **121** designates an injection hole which is closed by a plug **121***a* after the thermal interface material having fluidity is formed in the sealed gap **130** and the portion of the storage tunnel **112***c*, and the **113**/**113***a* designates a plug structure at an outer end **112***b* of the storage tunnel **112**, which is closed as an option in the application of the lidded flip chip package so that a desired gas with a desired pressure can be set in the remaining portion **112***d* of the storage tunnel **112**.

[0037] It is noted that the liquid metal gallium or its alloys are preferred to be a thermal interface material having fluidity of a lidded flip chip package of one preferred embodiment of the present disclosure. However, gallium or its alloys will quickly oxidize when exposed to oxygen or air. Because the liquid metal will move forwards or backwards between the storage tunnel **112** and the sealed gap **130**, a liquid metal oxide formed from continuous oxidation will accumulate with time if the outer end **112***b* of the storage tunnel **112** is not isolated from air in the atmosphere. As a result, it will become difficult for the liquid metal to flow in the storage tunnel **112**. To solve the oxidation issue, a plug structure like the screw hole **113** with the screw **113***a* is formed at the end **112***b* of the storage tunnel **112** so that a desired gas **112***d*, like an inert gas including nitrogen or helium, with a desired gas pressure can be formed in the remaining portion of the storage tunnel **112***d*. The plug structure can be used to open or close the end **112***b* of the storage tunnel **112** when needed, which will be further explained in conjunction with the drawings in FIG. **9** to FIG. **17** below. It is also noted that the gas used in the remaining portion of the storage tunnel **112***d* is not limited to an inert gas. When air is used as the gas in the remaining portion **112***d* of the storage tunnel **112**, there will be some oxidation, but the oxidation will stop when the oxygen inside the storage tube is used up. In addition, to improve the flow of the liquid metal in the storage tube, a slippery skin **114** as an option is formed on an inner surface of the storage tunnel **112**, and a method to form a slippery skin on an inner surface of the storage tunnel **112** and to arrange a desired gas with a desired gas pressure in the remaining portion of the storage tunnel **112***d* will be illustrated in conjunction with drawings in FIG. **9** to FIG. **17** below, where a method for making a lidded flip chip package based on a lid of one preferred embodiment of the present disclosure is described.

[0038] FIG. **2** and FIG. **3** are schematic diagrams for further illustrating the lidded flip chip package **1000** as shown in FIG. **1**A from its top view. It is noted that the same numerical symbol will be used to designate the same element in both cross-sectional view and top view. The numerical symbol **1100** in FIG. **2** designates a top view of the lidded flip chip package as described in FIG. **1**A, in which the numerical symbols **120** and **110***b* designate a top view of the island portion **120** and the rim **110***b* of the top piece **101** as shown in FIG. **1** or FIG. **1**A, the ring-form cavity **110** as shown in FIG. **1** is formed between the island portion **120** and the rim **110***b*, the **111** designates a top view of the covering piece **111** in FIG. **1** or FIG. **1**A, which is mounted in the ring-form cavity **110**, and the numerical symbols **121***a* and **113***a* respectively designate a top view of the plug **121***a* and the plug **113***a* as shown in FIG. **1** or FIG. **1**A. It is noted that the covering piece does not have to be a single layer, and can also be a plurality of layers of foils that are bonded together with adhesive or metal bonded. The numerical symbol **1200** in FIG. **3** designates a top view of the lidded flip chip package as described in FIG. **1**A, where the covering piece **111** as shown in FIG. **2** is removed to better display the structure of the storage tunnel **112**, a thermal interface material with fluidity **112***c*, like a liquid metal, and a gas **112***d* in the storage tunnel **112**. The numerical symbols **112** and **114** in FIG. **3** respectively designate a top view of the storage tunnel **112** (which is a pattern of notch in the ring-form cavity **110** after the covering piece **111** is removed) and the slippery skin **114** on an inner surface of the storage tunnel **112** as shown in FIG. **1** or FIG. **1**A, the **112***a* and the **112***b* in FIG. **3** designate a top view of the two ends of the storage tunnel **112**, the end **112***a*, called an inner end, is connected to the sealed gap **130** through the connecting hole **115**, the end **112***b*, called an outer end, is coupled with the plug structure **113**/**113***a* for opening or closing the storage tunnel **112** to/from an outside environment, like air in outside atmosphere or an inert gas in an oven or container, the **112***c* and the **112***d* in FIG. **3** respectively designate a top view of the thermal interface material having fluidity **112***c*, like a liquid metal in a portion of the storage tunnel **112** and the gas **112***d* in the remaining portion of the storage tunnel **112** as shown in FIG. **1**A. The numerical symbols **121***a* designates a top view of the plug **121***a* in the injection hole **121** as shown in FIG. **1** or FIG. **1**A. The dashed rectangle designated by the numerical symbol **130***a* in FIG. **3** displays the region of the sealed gap **130** as shown in FIG. **1**A from its top view, which can be viewed as a reference to understand the relative locations among the elements in the lidded flip chip package **1000**. The numerical symbol **112***e* designates a small amount of protecting liquid as an option, like a lubricant oil, positioned at an outer end of the liquid metal to avoid it from directly contacting with the gas **112***d* so as to improve the flow of the liquid metal in the storage tunnel from one side and to avoid the oxidation of the liquid metal if air is used as the gas from the other side.

[0039] It is noted that the pattern and dimension of the storage tunnel **112** can be flexibly designed according to a specific application for a specific flip chip package. Some basic considerations to design the storage tunnel **112** include: 1) its volume needs to be big enough to accommodate the volume change of the sealed gap **130**, which can be very big. For example, the maximum volume of the sealed gap may be double that of its minimum volume due to a warpage behavior of the flip chip **150** during a large temperature range, like −40° C. to 245° C.; 2) A division of the storage tunnel **112** as a portion **112***c* for liquid metal and another portion **112***d* for a gas needs to be carefully determined so that the sealed gap can be completely filled with the liquid metal all the time; and 3) a safe and easy plug structure **113**/**113***a* or **121**/**121***a* for the storage tunnel **112** or the injection hole is important, which will be further described below.

[0040] FIG. **4** and FIG. **4**A are schematic diagrams for illustrating some further features including another design for a plug structure and a filter block as a safety measure of a lidded flip chip package of one preferred embodiment of the present disclosure. The numerical symbol **1300** in FIG. **4** designates a cross-sectional view of a lidded flip chip package, in which the numerical symbols **133**, **133***a* and **133***b* designate another design for a plug structure, which includes a step hole **133**, a headless screw **133***a* and a rubber tube **133***b*, wherein the rubber tube **133***b* is pushed out by the headless screw **133** to close the end **112***a* of the storage tunnel **112** when the headless screw **133** is driven into a small central hole of the rubber tube **133***b*. The numerical symbol **131** designates a filter block arranged adjacent to any openings at the adhesive **155** so that if a liquid metal would leak out from the sealed gap **130** into the cavity around the flip chip, the liquid metal would not easily flow out from the openings to the outside of the lid. The numerical symbol **130***a* designates a thermally conductive mesh in the sealed gap as an option. This mesh helps control the thickness of the gap as well as improves the thermal performance of the package. The numerical symbol **1400** in FIG. **4**A designates a top view of the adhesive **155** and the filter block **131** as shown in FIG. **4**, in which the **155***a* and **155***b* designates two example openings at the adhesive **155**, and the **131***a* and **131***b* designates two filter blocks arranged adjacent to the openings. It is known that the adhesive **155** is usually not a closed loop so that the cavity around the flip chip **150** and between the lid and the substrate is not sealed. Otherwise, the air in the cavity may cause reliability issues due to a high pressure at a high temperature. The filter block **131** can also be a ring along the inner side of the adhesive, which can be flexibly designed depending on a specific application. Materials for the filter block **131** can include rubber foam, porous metal, or fiberglass mesh, which allow air in/out but does not allow a liquid metal in/out very easily.

[0041] FIG. **5** to FIG. **5**B are schematic diagrams for illustrating a preferred design for an injection hole of a lid allowing for a thermal interface material with fluidity in a lidded flip chip package of another preferred embodiment of the present disclosure, wherein an injection tunnel is introduced so that a plug structure at an outer end of the injection tunnel is used as an injection hole. It is seen that the injection hole **121** of the embodiments as shown in the previous drawings in FIG. **1** to FIG. **4** needs to be at a region directly above the flip chip and inside the sealing ring **103**. An advantage of using an injection tunnel is that an injection hole can be flexibly designed so that it does not have to be directly above the flip chip and inside the sealing ring **103**, but can be at any location, for example, at a corner location of the top piece and above the foot. The numerical symbol **2000** in FIG. **5** designates a cross-sectional view of a lidded flip chip package, in which the numerical symbols **200** and **200***a* designate a plug structure including a screw **200***a* in a screw hole **200** as an injection hole, which is arranged at a corner region of the lid and above the foot **102** so that the foot **102** can be further used for designing the plug structure, the numerical symbols **201** designates an injection tunnel which is formed in the ring-form cavity **110** as shown in FIG. **1** and is connected to the sealed gap through a connecting hole **216**, the numerical symbol **212** designates a storage tunnel, the numerical symbols **212***a* and **212***b* designate two ends of the storage tunnel **212**, and the **212***c* and **212***d* designate two portions of the storage tunnel **212**, a portion **212***c* is filled with the same thermal interface material having fluidity as that in the sealed gap **130**, and the remaining portion **112***d* is filled with a gas, the **212***c* and **212***d* also designate the thermal interface material having fluidity and the gas filled in the two portions, respectively. It is noted that since the storage tunnel **212** is also formed in the ring-form cavity **110**, it needs to be rearranged to avoid crossing with the injection tunnel **201**. An arrangement for the injection tunnel **201** and the storage tunnel **212** is described in FIG. **5**A, in which the same numerical symbols as those in FIG. **5** designate the top views of the same elements, and are not repeatedly described. It is noted that a storage tunnel and an injection tunnel can be flexibly designed according to the sizes of a flip chip and a substrate of a flip chip package in a specific application, an example has been illustrated in FIG. **5**A, and another example is illustrated in FIG. **5**B, in which the same numerical symbols are used to designate the same elements, and are not repeatedly described. It is noted that the patterns for a storage tunnel and an injection tunnel can be flexibly designed, and a basic rule for designing the two tunnels is that the length of the storage tunnel needs to be designed so that its volume is big enough to accommodate the volume change of the sealed gap, while the injection tunnel is only for flexibly determining a location for the injection hole and its volume is not important. It is also noted that the width and depth of a storage tunnel are not limited to be uniform, but can be flexibly designed. For example, the storage tunnel can be designed thinner near its outer end so that it can be more easily closed by a plug structure.

[0042] It is noted that some designs for a plug structure have been described previously in conjunction with the drawings in FIG. **1** to FIG. **4**. Because a liquid metal and a gas is sealed in the sealed gap and the storage tunnel of a lidded flip chip package in its application as a preferred option, the reliability of a plug structure is also important in addition to its ease of usage. FIG. **6** is a schematic diagram for illustrating a preferred design for a plug structure for opening or closing a storage tunnel or an injection hole of a lid allowing for a lidded flip chip package to use a thermal interface material with fluidity of one preferred embodiment of the present disclosure. The numerical symbol **2300** in FIG. **6** designates a cross-sectional view of a plug structure, comprising: a hole extending down from the outer end of the storage or injection tunnel into the foot, a locking material arranged in a lower portion of the hole, and a pin with a head, wherein the pin goes through the covering piece with its tip portion being inserted into the locking material and its head being kept above the covering piece for sealing a tiny hole which is pre-formed through the covering piece or formed when the pin goes through the covering piece. The numerical symbol **2300** in FIG. **6** designates a cross-sectional view of a plug structure, in which the numerical symbol **230** designates a structure at an outer end **231***a* of a storage or injection tunnel **231**, the **232** designates a point type of notch in a covering piece **111**/**111***a* as an option, the **233** designates a hole extending down from the outer end **231***a* into the foot **102**, and **233***a* designates a locking material, like a rubber, arranged in a lower portion of the hole **233**; the numerical symbol **230***b* illustrates a pin **235** with a head as a plug that goes through the covering piece **111**/**111***a* with its tip portion inserted into the locking material **233***a* and its head kept above the covering piece to seal a tiny hole **236** which is pre-formed in the covering piece **111**/**111***a* or formed when the pin goes through the covering piece **111**/**111***a*; the numerical symbol **230***c* illustrates that the head of the pin **235** also includes an adhesive layer **235***a* to better seal the tiny hole **236**; and the numerical symbol **230***a* illustrates that after the pin **235** is removed to open the outer end **231***a* of the tunnel **231** to an ambient outside the lid, a syringe needle **234** can be inserted into the tiny hole **236** to inject a liquid if the plug structure is for an injection hole. It is noted that after the pin **235** is removed to open the outer end **231***a* of the tunnel **231** as a storage tunnel, a desired gas with a desired gas pressure can be arranged into a storage tunnel by setting an ambient condition, which will be further described below.

[0043] FIG. **7** is a schematic diagram for illustrating another preferred design for a sealing ring of a lidded flip chip package of one preferred embodiment of the present disclosure, wherein the foot is a ring-form of foot along a peripheral region at a lower side of the top piece, an adhesive is completely interposed between the foot and the substrate for bonding the lid on the substrate through the foot, the ring-form of foot with the adhesive also forms a sealing ring around the flip chip so as to form a sealed gap between the lid and the flip chip, and the sealed gap also includes a cavity around the flip chip and between the lid and the substrate. The numerical symbol **3000** in FIG. **7** designates a cross-sectional view of a lidded flip chip package of one preferred embodiment of the present disclosure, in which the numerical symbol **300** designates a sealing ring consisting of a ring-form of foot **302** and an adhesive **355** which is completely interposed between the foot **302** and the substrate **160** for bonding the lid on the substrate, the numerical symbols **330** and **331** designate a sealed gap between the top piece **101** of the lid and the flip chip **150**, which also includes a cavity **331** around the flip chip **150**, the numerical symbol **312** designates a storage tunnel, the numerical symbols **312***a* and **312***b* designate two ends of the storage tunnel **312**, and the **312***c* and **312***d* designate two portions of the storage tunnel **312**, a portion **312***c* is filled with the same thermal interface material having fluidity as that in the sealed gap **330** and **331**, and the remaining portion **312***d* is filled with a gas, the **312***c* and **312***d* also designate the thermal interface material having fluidity and the gas filled in the two portions, the numerical symbols **201** and **200** designates an injection tunnel and a plug structure for an injection hole similar as those described in FIG. **5**, the numerical symbol **315** designates a connecting hole for connecting the storage tunnel **312** with the sealed gap **330** and **331**, and the numerical symbol **316** designates another connecting hole for connecting the injection tunnel **201** with the sealed gap **330** and **331**. It is noted that a benefit to use a sealing ring outside the flip chip **150**, like the foot **302** with the adhesive **355**, is that the connecting holes **315** and **316** can be arranged not to be right above the flip chip **150**, so that the island portion **320** of the top piece can be designed as large as possible and a plug structure **200** for an injection hole can be placed outside the island portion **320** so that it doesn't affect the heat dissipation from the flip chip to ambient.

[0044] FIG. **8** is a schematic diagram for illustrating another preferred design for a foot of a lidded flip chip package of one preferred embodiment of the present disclosure, wherein the foot consists of a plurality of pins filled with an adhesive among them, a piece of porous material impregnated with an adhesive or resin, or a piece of mesh impregnated with an adhesive or resin. The numerical symbol **3100** in FIG. **8** designates a cross-sectional view of a lidded flip chip package of one preferred embodiment of the present disclosure, in which the numerical symbol **310** designates a foot consisting of a plurality of pins **311** filled with an adhesive or resin **312** among them, the adhesive or resin **312** is also used to bond the lid on the substrate, the numerical symbol **322** designates a foot consisting of a piece of porous material **322***a* impregnated with an adhesive or resin **322***b*, and the numerical symbol **321** designates a foot consisting of a piece of mesh **321***a* impregnated with an adhesive or resin **321***b*. It is noted that the various foot structures **310**, **321** or **322** can be also used as a sealing ring as shown in FIG. **8** or only used as a foot to bond the lid on the substrate as shown in the previous drawings in FIG. **1** to FIG. **5**.

[0045] FIG. **9** to FIG. **12** are schematic diagrams for illustrating a method for making a lidded flip chip package as shown in FIG. **1**A or similarly for making a lidded flip chip package as shown in FIG. **5**, FIG. **7** or FIG. **8** of one preferred embodiment of the present disclosure. The method comprises the following major steps 1 to 7 as illustrated by FIG. **9** for Step 1, FIG. **10** for Steps 2 and 3, FIG. **11** for Steps 4 and 5, and FIG. **12** for Steps 6 and 7, which are described in the following:

[0046] The numerical symbols **4000** and S**1** in FIG. **9** are for illustrating Step 1:

[0047] 1) Prepare a lid **400** according to a flip chip package **401**, the lid (referring to FIG. **1** and FIG. **1**A for its description) includes: a top piece with an upper side and a lower side, a foot at the lower side of the top piece, a ring-form of cavity with a bottom at the upper side of the top piece, a covering piece, a storage tunnel as a reservoir, a plug structure **113/113***a* at an outer end of the storage tunnel, another plug structure including an injection hole **121** and a plug **121***a*, and a sealing ring; wherein the sealing ring is mounted at the lower side of the top piece; wherein a pattern of notch is formed at the bottom of the ring-form of cavity, and the covering piece is placed in the ring-form of cavity so as to cover the pattern of notch and form the storage tunnel; wherein a connecting hole has one end at the lower side of the top piece and inside the sealing ring, and has another end connected to one end of the storage tunnel; and wherein another end of the storage tunnel is mounted with the plug structure **113/113***a;*

[0048] The numerical symbols **4100** and S**2** in FIG. **10** are for illustrating Step 2:

[0049] 2) Open the storage tunnel and the injection hole by removing the plug **113***a* and the plug **121***a* respectively, and then fill an amount of lubricant oil **411** into the storage tunnel from the connecting hole **115**, as illustrated by the arrow **410***a*, or use a lubricant oil to wash the storage tunnel from the connecting hole **115** as illustrated by the pair of arrows **410***a* and **410***b* so as to form a slippery skin **114** on an inner surface of the storage tunnel;

[0050] The numerical symbols **4100** and S**3** in FIG. **10** are for illustrating Step 3:

[0051] 3) Mount the lid on the substrate and over the flip chip, wherein an adhesive **155** is interposed between the foot and the substrate and a clamping force as illustrated by the pair of arrows **415***a* to **415***b* is applied so that the adhesive bonds the lid with the substrate at a curing temperature and the sealing ring **103***a* is tightly compressed to seal a peripheral edge region at a top surface of the flip chip and form a sealed gap **130** between the flip chip and the top piece of the lid;

[0052] The numerical symbols **4200** and S**4** in FIG. **11** are for illustrating Step 4:

[0053] 4) Put the assembly formed in Step 3 into a vacuum oven or container **420** and set it to a vacuum condition to degas the assembly, and then fill a liquid metal into the sealed gap and a portion of the storage tunnel from the injection hole, as illustrated by the syringe tip **421**;

[0054] The numerical symbols **4200** and S**5** in FIG. **11** are for illustrating Step 5:

[0055] 5) Close the injection hole by putting back the plug **121***a* during vacuum condition first, and then put a desired gas with a desired gas pressure into the vacuum oven or container **420** to fill the remaining portion of the storage tunnel with the gas **112***d*, as illustrated by the arrow **422**;

[0056] The numerical symbols **4300** and S**6** in FIG. **12** are for illustrating Step 6:

[0057] 6) Close the storage tunnel by putting back the plug **113***a* so that the gas **112***d* is sealed inside the storage tunnel;

[0058] The numerical symbols **4300** and S**7** in FIG. **12** are for illustrating Step 7:

[0059] 7) Mount solder balls **161** at a bottom side of the substrate so that a lidded flip chip package as illustrated in FIG. **1**A is formed.

[0060] FIG. **13** to FIG. **17** are schematic diagrams for illustrating another method for making a lidded flip chip package as shown in FIG. **1**A or similarly for making a lidded flip chip package as shown in FIG. **5**, FIG. **7** or FIG. **8** of one preferred embodiment of the present disclosure. The method comprises the following major steps 1 to 8 as illustrated by FIG. **13** for Step 1, FIG. **14** for Steps 2 and 3, FIG. **15** for Steps 4 and 5, FIG. **16** for Steps 6 and 7, and FIG. **17** for Step 8, which are described in the following:

[0061] The numerical symbols **5000** and S**1** in FIG. **13** are for illustrating Step 1:

[0062] 1) Prepare a lid **400** according to a flip chip package **401**, the lid (referring to FIG. **1** and FIG. **1**A for its description) includes: a top piece with an upper side and a lower side, a foot at the lower side of the top piece, a ring-form of cavity with a bottom at the upper side of the top piece, a covering piece, a storage tunnel as a reservoir, a plug structure **113/113***a* at an outer end of the storage tunnel, another plug structure including an injection hole **121** and a plug **121***a*, and a sealing ring; wherein the sealing ring is mounted at the lower side of the top piece; wherein a pattern of notch is formed at the bottom of the ring-form of cavity, and the covering piece is placed in the ring-form of cavity so as to cover the pattern of notch and form the storage tunnel; wherein a connecting hole has one end at the lower side of the top piece and inside the sealing ring, and has another end connected to one end of the storage tunnel; and wherein another end of the storage tunnel is mounted with the plug structure **113/113***a;*

[0063] The numerical symbols **5100** and S**2** in FIG. **14** are for illustrating Step 2:

[0064] 2) Open the storage tunnel by removing the plug **113***a*, and then fill an amount of lubricant oil **411** into the storage tunnel from the connecting hole **115**, as illustrated by the arrow **410***a*, or use a lubricant oil to wash the storage tunnel from the connecting hole **115** as illustrated by the pair of arrows **410***a* and **410***b* so as to form a slippery skin **114** on an inner surface of the storage tunnel;

[0065] The numerical symbols **5100** and S**3** in FIG. **14** are for illustrating Step 3:

[0066] 3) Attach a piece of preformed liquid metal pad **510** or form a liquid metal pad **510** at a bottom surface of the top piece and inside the sealing ring under a low temperature; wherein the liquid metal pad is in a solid state due to the low temperature;

[0067] The numerical symbols **5200** and S**4** in FIG. **15** are for illustrating Step 4:

[0068] 4) Clamp the lid formed in Step 3 onto the flip chip package prepared in the previous Step 1 using a clamping force as illustrated by the pair of arrows **521***a* and **521***b*, wherein an adhesive **520** is interposed between the foot of the lid and the substrate, the sealing ring **503** is compressed to seal at a peripheral edge region at a top surface of the flip chip and form a sealed gap between the lid and flip chip, and the liquid metal pad **510** is clamped between the lid and the flip chip and enclosed in the sealed gap;

[0069] The numerical symbols **5200** and S**5** in FIG. **15** are for illustrating Step 5:

[0070] 5) Put the assembly formed in Step 4 into a vacuum oven or container and set it at a vacuum condition to degas the assembly, and then raise the oven temperature above the melting point of the liquid metal and hold this temperature for a period of time until the liquid metal becomes molten, so that the seal ring is further compressed, the thickness of the sealed gap becomes thinner, the adhesive is compressed to spread to spread between the foot and the substrate, and the molten liquid metal pad is squeezed to fill the sealed gap and a portion of the storage tunnel; and then raise the oven temperature to a curing temperature of the adhesive and hold it until the adhesive becomes cured;

[0071] The numerical symbols **5300** and S**6** in FIG. **16** are for illustrating Step 6:

[0072] 6) Put a desired gas with a desired gas pressure as illustrated by the arrow **530** into the vacuum oven or container **420** to fill the remaining portion of the storage tunnel **112***d* with the gas;

[0073] The numerical symbols **5300** and S**7** in FIG. **16** are for illustrating Step 7:

[0074] 7) Close the storage tunnel by putting back the plug **113***a* so that the gas **112***d* is sealed inside the storage tunnel;

[0075] The numerical symbols **5400** and S**8** in FIG. **17** are for illustrating Step 8:

[0076] 8) Mount solder balls **161** at a bottom side of the substrate so that a lidded flip chip package as illustrated in FIG. **1**A is formed.

[0077] It is noted that the step 2 for forming a slippery skin on an inner surface of the storage tunnel in the previously described methods for making a lidded flip chip package can be avoided if an inert gas is used in the storage tunnel. It is also noted that a benefit of using a plug structure at an outer end of the storage tunnel is that a desired gas, like an inert gas including nitrogen and helium, can be sealed in the storage tunnel to avoid an oxidation of a liquid metal in the storage tunnel, and the gas pressure can be designed to improve the flow of the liquid metal. Furthermore, even if a natural air is used in the storage tunnel, the oxygen will be quickly exhausted due to oxidation with the liquid metal in the storage tunnel, and the oxidation of the liquid metal will not accumulate to cause a severe issue. Another usage of a pair of plug structures for the injection hole and the storage tunnel is to withdraw out the liquid metal from the sealed gap and the storage tunnel by opening the storage tunnel and the injection hole, which may be needed when using a cross-sectional cut of the lidded flip chip package to perform a failure analysis. However, it is seen from the descriptions for the method illustrated in FIG. **13** to FIG. **17** that when a preformed liquid metal pad is used, the injection hole is not used for making the lidded flip chip package. So, if the liquid metal doesn't need to be withdrawn out from the sealed gap and the storage tunnel, the injection hole can be avoided.

[0078] It is noted that the plug structure for a lidded flip chip package to use a liquid metal thermal interface material described in the U.S. patent application Ser. No. 17/695,826, filed in Mar. 15, 2022 is not very convenient and reliable in its application, wherein the plug needs to be removed to fill a liquid metal into the sealed gap of the lidded flip chip package and then be put back afterwards under vacuum conditions. In the present application as a continuation-in-part of the previous U.S. patent application, a self-sealing plug structure is innovated and integrated with a storage tunnel and an injection tunnel of a lidded flip chip package so that a method to fill a liquid metal into the sealed gap of the lidded flip chip package can be easily performed under ambient conditions.

[0079] FIG. **18** is a schematic diagram for illustrating a self-sealing plug structure formed at an end of a tunnel for filling and sealing a liquid metal in a lidded flip chip package to form a liquid metal thermal interface material of one preferred embodiment of the present disclosure. The numerical symbol **100**A in FIG. **18** designates top views and cross-sectional views of a self-sealing plug structure at a corner portion of a lid, referring to the drawing in FIG. **5** for a detailed description of the lid, which includes a plug structure with a screw, and herein a self-sealing plug structure is innovated to replaced the old plug structure. The numerical symbol **10** designates a top view of the self-sealing plug structure at the corner portion of the lid, in which the **11** designates a covering piece mounted in a ring-form of cavity on the upper side of the lid, the **12** designates a tiny hole through the covering piece for a needle to go through, and the **13** designates a rim of the ring-form of cavity, which can be an option, i.e. the rim can be removed, the arrow lines C**1** and C**2** designates two locations to make cross-sectional views for displaying the self-sealing plug structure further. The numerical symbol **10**A in FIG. **18** designates a top view of the self-sealing plug structure at the corner portion of the lid after the covering piece **11** is removed to display its inner structure, in which the **21** designates a corner portion of the ring-form of cavity on the upper side of a lid, **22** designates an end portion of a tunnel, **23** designates a step-form of hole including an upper portion **24** and a lower portion **25**, **26** designates a self-sealing block mounted in the upper portion **24** and underneath the covering piece **11**, **27** and **28** respectively designate a notch extending down from an end of the tunnel **22** and a notch extending from a bottom of the notch **27** to the lower portion **25** of the step-form of hole **23** so that a connecting hole is formed by the two notches **27** and **28** and the self-sealing block **26**, which connects the tunnel **22** with the lower portion **25** of the step-form of hole **23**. The numerical symbol **10**C**1** in FIG. **18** designates a cross-sectional view along C1 as shown in the top view **10** of the self-sealing plug structure at the corner portion of the lid, in which the **11***a*, **12***a* and **13***a* designate the cross-sectional views of the covering piece **11**, the tiny hole **12**, and the rim **13** in the top view **10**, the **21***a* designates the cross-sectional view of the corner portion of the ring-form of cavity **21** in the top view **10***a*, the **22***a* designates the cross-sectional view of the end portion of a tunnel **22** in the top view **10***a*, the **24***a* and **25***a* designate the cross-sectional view of the upper portion **24** and the lower portion **25**, **26***a* designates the cross-sectional view of the self-sealing block **26** mounted in the upper portion **24***a* and underneath the covering piece **11***a*, the **27***a* and **28***a* designate the notch **27** extending down from an end of the tunnel **22***a* and the notch extending from a bottom of the notch **27***a* to the lower portion **25***a* of the step-form of hole **23** so that the tunnel **22***a* is connected with the lower portion **25***a* of the step-form of hole **23** through the notches **27***a* and **28***a*, and the **102** designate a foot of the lid (referring to FIG. **5**), into which the lower portion **25***a* of the step-form of hole **23** is formed when the top piece of the lid is not thick enough. The numerical symbol **10**C**2** in FIG. **18** designates a cross-sectional view along C2 to C2 as showed in the top view **10** of the self-sealing plug structure at the corner portion of the lid, in which the **11***a* and **12***a* designate the cross-sectional views of the covering piece **11** and the tiny hole **12** in the top view **10**, the **24***a* and **25***a* designate the cross-sectional view of the upper portion **24** and the lower portion **25**, **26***a* designates the cross-sectional view of the self-sealing block **26** mounted in the upper portion **24***a* and underneath the covering piece **11***a*.

[0080] It is noted that a rubber material is preferred to make the self-sealing block **26***a*. To safely seal an end portion of a tunnel, the size of a rubber block is preferred to be bigger than the upper portion **24***a* of the step-form of hole so that it is tightly locked in the upper portion **24***a*. However, one concern is that the rubber material may be squeezed into the small notches **27***a* or **28***a*. To avoid this concern, a rubber block enclosed with a shell is used as a self-sealing block of a self-sealing plug structure of one preferred embodiment of the present disclosure. FIG. **18**A is a schematic diagram for illustrating such a self-sealing plug structure, in which the numerical symbol **200**A designates cross-sectional and top views of a self-sealing plug structure, including a rubber block enclosed with a shell, the **20** designates a cross-sectional view of a self-sealing plug structure with a cup-form of shell **29** for enclosing a rubber block **26**, and the **29***a* designates a tiny hole at the bottom of the cup-form of shell **29** for a needle to go through and reach the lower portion **25***a* of the step-form of hole. The numerical symbol **20**C**3** in FIG. **18**A designates a top view at the cross-section along the arrow line C3 as shown in the cross-sectional view **20** to further describe the cup-form of shell **29**, in which the **29***b* shows a top view of the cup-form of shell **29**, which prevents the rubber block **26** from being squeezed into the tunnel **22**. The numerical symbol **20**A in FIG. **18**A designates a cross-sectional view of a self-sealing plug structure, in which the **29**A designates a shell, which completely encloses the rubble block **26***a* except for two tiny holes **29***a***1** and **29***a***2** respectively at its bottom and top for a needle, which allow a needle to go through and reach the lower portion **25***a* of the step-form of hole. The numerical symbol **20**B in FIG. **18**A designates a cross-sectional view of a self-sealing plug structure, in which the **29**B designates a flipped cup-form of shell, and the **29***b* designates a tiny hole at the bottom of the flipped cup-form of shell **29**B for a needle to go through and reach the lower portion **25***a* of the step-form of hole. It is noted that the rubber plug does not necessarily need to completely fill the shell/cup/upper portion, and is merely illustrated as such as a preferred option.

[0081] FIG. **19** is a schematic diagram for further illustrating the self-sealing plug structure as described in FIG. **18** by displaying a liquid flow when filling a liquid through the plug into the tunnel. The numerical symbol **300**A in FIG. **19** designates a way to fill and seal a liquid in a tunnel of a lid through the self-sealing plug structure, in which the **30***a* illustrates inserting a needle **31** of a liquid dispenser **32** through the self-sealing block **26***a* from the tiny hole **12***a* in the covering piece **11***a* and into the lower portion **25***a* of the step-form of hole first, such that the liquid can be injected; the **30***b* and arrow **33** illustrates that the liquid fills the lower portion **25***a* through the needle **31** first, the **30***c* and arrow **34** illustrate that the liquid further fills the notch **28***a*, and the **30***d* and **35** illustrate that the liquid fills the tunnel **22***a* and the self-sealing block gets closed after the needle **31** is removed.

[0082] It is noted that a rubber material is preferred to make the self-sealing block, which can seal itself after inserting a needle through it and then removing the needle. The self-sealing block based on a rubber material is preferred to be bigger than the upper portion of the step-form of hole so that it is tightly locked in the upper portion of the step-form of hole. Furthermore, a thin layer of glue can be applied on the surface of the self-sealing block first, after which it is mounted in the upper portion of the step-form of hole.

[0083] FIG. **20** to FIG. **29** are schematic diagrams for illustrating a method for filling a liquid metal into the sealed gap and a portion of the storage tunnel, and then filling a desired gas with a desired gas pressure, like an inert gas with a half of the atmosphere air pressure, into the remaining portion of the storage tunnel to form a lidded flip chip package with a liquid metal TIM based on the present self-sealing plug structure of another preferred embodiment of the present disclosure. The numerical symbol **400**A in FIG. **20** designates a lidded flip chip package based on a lid with a self-sealing plug structure, wherein a liquid metal is ready to be filled, in which the numerical symbol **40** designates the sealed gap between the lid and the flip chip, the **41** and **43** designate an injection tunnel and storage tunnel in the lid, the **42** and **44** designate two self-sealing plug structures, one for the injection tunnel **41** and another for the storage tunnel **43**, the **45** designates a ring-form of covering piece for forming the injection tunnel and the storage tunnel, which also locks the self-sealing blocks **42***b* and **44***b* inside the upper portions of the step-form of holes, the **42***c* and **44***c* designate the lower portions of the step-form of holes for the injection tunnel and the storage tunnel, and the **42***d* and **44***d* designate the connecting holes for connecting the injection tunnel and the storage tunnel with the lower portions **42***c* and **44***c* of the step-form of holes, respectively.

[0084] FIG. **21** to FIG. **29** are schematic diagrams for illustrating a method for filling a liquid metal into the lidded flip chip package **400**A, mainly comprising the following steps:

[0085] The numerical symbols **500** and S1 in FIG. **21** are for illustrating Step 1:

[0086] 1) Prepare a liquid metal dispenser **51**, which includes a needle **51***a* with a tip **51***b*, a liquid metal container **51***c* with a piston **51***e*, and a moving controller **51***f* for controlling the movement of the piston **51***e*, and insert the needle tip **51***b* to the lower portion of the step-hole of the self-sealing plug structure for the injection tunnel; and prepare a vacuum pump tool **52**, which includes a needle **52***a* with a tip **52***b*, a vacuum pump **52***c*, a gas filling switch **52***d* and a chamber **52***e*, and insert the needle tip **52***b* to the lower portion of the step-hole of the self-sealing plug structure for the storage tunnel;

[0087] The numerical symbols **510** and S2 in FIG. **22** are for illustrating Step 2:

[0088] 2) Pump out the air in the entire system, including the lidded flip chip package, the liquid metal dispenser **51** and the vacuum pump tool **52** to achieve a vacuum condition, including the sealed gap **40***a*, the injection tunnel **41***a*, the storage tunnel **43***a*, the chamber **53***e* of the vacuum pump tool **52** and the tube **53***d* of the liquid metal dispenser **51**;

[0089] The **520/530/540** and S3 in FIG. **23** to FIG. **25** are for illustrating Step 3:

[0090] 3) Push the piston **51***e* as showed by the arrow **54** in FIG. **23** to fill the liquid metal from the needle tip **51***b* into first the injection tunnel, then the sealed gap, and finally a portion of the storage tunnel, as shown by the arrows **54***a*, **54***b* and **54***c* in FIG. **23** that illustrate the flow of the liquid metal, until a designed amount of liquid metal is filled into the lidded flip chip package, wherein a portion of the storage tunnel is filled with the liquid metal as shown by the numerical number **55** in FIG. **24**; stop pushing the piston **51***e*, as shown by the arrow **51***f*, close the vacuum pump, as shown by the arrow **52***c*, and then remove the needle of the liquid metal dispenser from the self-sealing plug structure for the injection tunnel, as shown in FIG. **25**, in which the numerical symbol **56** designates that the remaining portion of the storage tunnel is at vacuum condition at this point;

[0091] The **550/560/570** and S4 in FIG. **26** to FIG. **28** are for illustrating Step 4:

[0092] 4) Open the gas filling switch of the vacuum pump, as shown by the arrow **57** in FIG. **26**, to fill a desired gas into the remaining portion of the storage tunnel until a desired gap pressure in the remaining portion of the storage tunnel is achieved, as shown by the numerical symbol **58** in FIG. **27**, and then close the gas filling switch and remove the needle of the vacuum pump tool from the self-sealing plug structure for the storage tunnel to get a lidded flip chip package with a liquid metal TIM, as shown by the numerical symbol **570** in FIG. **28**;

[0093] The numerical symbols **580** and S5 in FIG. **29** are for illustrating Step 5:

[0094] 5) Put a drop of adhesive or glue **61** and **62** in each hole of the covering piece associated with the self-sealing plug structures for the injection tunnel and the storage tunnel respectively for achieving a safer sealing.

[0095] It is noted that the self-sealing block is a critical part for the self-sealing plug structure. Its dimensions relative to the step-hole and its material selection need to be optimized. To achieve a safe and secure seal, the self-sealing block can be coupled with a layer of adhesive or glue on its surface so that it can bond with a surface of the step-form of hole or a surface of the covering piece.

[0096] FIG. **30** to FIG. **32** are schematic diagrams for illustrating the flow of a liquid metal from its top view when filling it from the injection tunnel into the sealed gap and then into a portion of the storage tunnel. The numerical symbol **600** in FIG. **30** designates a top view of the flow of a liquid metal from injection tunnel to the sealed gap, in which the **63** designates a needle of a liquid metal dispenser, from which a liquid metal is filled into the injection tunnel, the **63***a*, **63***b* and **63***c* illustrate the flow of the liquid metal into the sealed gap, the **64** designates the injection tunnel, the **65** designates the storage tunnel, and the **66** designates a needle from a vacuum pump; the numerical symbol **610** in FIG. **31** designates a top view of the further flow of the liquid metal in the sealed gap, in which the **63***d* illustrates that the liquid metal flows towards the connecting hole and into the storage tunnel; the numerical symbol **620** in FIG. **32** designates a top view of the further flow of the liquid metal into the storage tunnel, in which the **63***e* illustrates that a portion of the storage tunnel has been filled.

[0097] FIG. **30** to FIG. **32** describes an ideal flow of the liquid metal when filling it from the injection tunnel into the sealed gap and then into a portion of the storage tunnel. However, an abnormal flow of the liquid metal may occasionally happen because the thickness of the sealed gap across the area of the flip chip is not uniform, i.e, the gap along the edge of the sealed gap may be thicker than that at its middle region due to the warpage behavior of the flip chip.

[0098] FIG. **33** is a schematic diagram for illustrating an abnormal flow of the liquid metal, in which the numerical symbols **70**, **70***a*, **70***b*, **70***c* and **70***d* illustrate a flow of the liquid metal when filling it from the injection tunnel into the sealed gap and a portion of the storage tunnel. As a result, the liquid metal may fully fill the storage tunnel and even flow out from another step-form of hole at the outer end of the storage tunnel before completely filling the sealed gap.

[0099] FIG. **34** is a schematic diagram for illustrating a way to avoid this abnormal flow, in which a plurality of guiding lines are introduced in the sealed gap to guide the flow of the liquid metal. The numerical symbols **76** and **77** designate two guiding lines so that the liquid metal is forced to flow according to a desired path as illustrated by the arrows **75***a*, **75***b*, **75***c*, **75***d*, **75***e* and **75***f*. It is noted that the number and shape of the guiding lines can be flexibly designed according to a specific application, and two guiding lines in FIG. **34** are displayed as an example.

[0100] It is noted that even though a self-sealing plug structure is described in FIG. **18**, FIG. **18**A and FIG. **19** and its application is described according to the lidded flip chip package as shown in figures from FIG. **20** to FIG. **34**, it is apparent that it can be combined with one or more features previously described in conjunction with the drawings in figures from FIG. **1** to FIG. **17**.

[0101] Although the present disclosure is described in some details for illustrative purposes with reference to the specific embodiments and drawings, it is apparent that many other modifications and variations may be made without departing from the spirit and scope of the present invention.

What is claimed is:

1. A lid allowing for a thermal interface material with fluidity in a lidded flip chip package, comprising:

a top piece with an upper side and a lower side, a foot at the lower side of the top piece, a storage tunnel as a reservoir, an injection tunnel, a sealing ring, and a self-sealing plug structure;

wherein the sealing ring is mounted at the lower side of the top piece, which seals a peripheral edge region at a top surface of a flip chip and/or seals a peripheral region around a flip chip and at a top surface of a substrate so as to form a sealed gap between the flip chip and the top piece;

wherein the lid further includes a ring-form of cavity at the upper side of its top piece, an island as a portion of the top piece which is surrounded by the ring-form of cavity, a pattern of notches which are formed at a bottom of the ring-form of cavity, and a covering piece mounted in the ring-form of cavity so as to cover the pattern of notches and form the storage tunnel and the injection tunnel;

wherein the storage tunnel has two ends, one end, called inner end herein of the said two ends connects to the sealed gap through a connecting hole, and the other end, called outer end herein of the said two ends includes a step-form of hole, which consists of an upper portion and a lower portion;

wherein the injection tunnel has two ends, one end, called inner end herein of the said two ends connects to the sealed gap through a connecting hole, and the other end, called outer end herein of the said two ends includes a step-form of hole, which consists of an upper portion and a lower portion;

wherein the self-sealing plug structure includes a self-sealing block and a step-form of hole; and

wherein the sealed gap is completely filled with a thermal interface material having fluidity, a portion of the storage tunnel is filled with the same thermal interface material, and the remaining portion of the storage tunnel is filled with a gas.

2. The lid of claim **1**, wherein the self-sealing block is a rubber block.

3. The lid of claim **1**, wherein the self-sealing block is a rubber block with a layer of adhesive or glue.

4. The lid of claim **1**, wherein the self-sealing block consists of a rubber block enclosed with a shell.

5. The lid of claim **1**, wherein the lid further includes a ring-form of notch at the lower side of the top piece, in which the sealing ring is mounted.

6. The lid of claim **1**, wherein the lid further includes a slippery skin formed on an inner surface of the storage tunnel.

7. The lid of claim **1**, wherein one or more filters are arranged adjacent to one or more openings through an adhesive layer.

8. The lid of claim **1**, wherein the covering piece is a metal sheet mounted in the cavity through an adhesive layer.

9. The lid of claim **1**, wherein the covering piece consists of a plurality of layers of metal foils.

10. The lid of claim **1**, wherein the lidded flip chip package further includes a thermal conductive mesh in the sealed gap.

11. The lid of claim **1**, wherein the lidded flip chip package further includes a plurality of guiding lines in the sealed gap.

12. The lid of claim **1**, wherein the thermal interface material with fluidity is a liquid metal, including gallium and its alloys.

13. The lid of claim **1**, wherein the gas in the storage tunnel is an inert gas, including nitrogen and helium.

14. The lid of claim **1**, wherein the slippery skin is a layer of lubricant silicone oil or a layer of coating.

15. The lid of claim **1**, wherein the foot consists of a plurality of pins filled with an adhesive among them, a piece of porous material impregnated with an adhesive or resin, or a piece of mesh impregnated with an adhesive or resin.

16. The lid of claim **1**, wherein the foot is a ring-form of foot, an adhesive is interposed between the foot and the substrate for mounting the lid on the substrate, and the ring-form of foot with the adhesive is also the sealing ring for forming the sealed gap.

17. The lid of claim **16**, wherein the foot consists of a plurality of pins filled with an adhesive among them, or a piece of porous material or mesh impregnated with an adhesive or resin.

18. A method for forming a liquid metal thermal interface material in the lidded flip chip package of claim **1**: mainly comprising the following steps:

1) Prepare a lidded flip chip package, wherein the lid includes a self-sealing plug structure;

2) Insert a needle of a vacuum pump tool into the self-sealing plug structure for the storage tunnel, and insert a needle of a liquid metal dispenser into the self-sealing plug structure for the injection tunnel;

3) Pump out the air in the whole system, including the sealed gap, the storage tunnel and the injection tunnel of the lidded flip chip package;

4) Inject the liquid metal into the sealed gap and a portion of the storage tunnel from the needle of the liquid metal dispenser, and then remove the needle of the liquid metal dispenser;

5) Switch the vacuum pump to its gas filling state and fill a gas into the remaining portion of the storage tunnel, and then remove the needle of the vacuum pump tool.

19. The method of claim **18**, wherein it further comprises the following step:

6) Put an adhesive or glue in one or more holes of the covering piece.

* * * * *