

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

SEMICONDUCTOR DEVICE PACKAGE ASSEMBLY METHODS AND APPARATUSES

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 63/513,273, entitled “SEMICONDUCTOR DEVICE PACKAGE ASSEMBLY METHODS AND APPARATUSES,” filed on July 12, 2023, the disclosure of which is hereby incorporated by reference in its entirety and for all purposes.

BACKGROUND

Technical Field

[0002] This disclosure relates to semiconductor device packages. In particular, some embodiments relate to methods and apparatuses for assembling semiconductor device packages utilizing a multi-height assembly fixture.

Description of Related Technology

[0003] Semiconductor devices are used in a wide variety of applications. In some applications, semiconductor devices can experience high electrical loads that can result in significant heating of the semiconductor device. There may be technical problems associated with high electrical loads, such as detrimental heating of the semiconductor device from the high load. The mass of the semiconductor device can be increased to effectively dissipate such significant heating. For example, a thick die paddle can be used. There are technical challenges associated with manufacturing semiconductor device with a thick die paddle.

SUMMARY

[0004] The innovations described in the claims each have several aspects, no single one of which is solely responsible for its desirable attributes. Without limiting the scope of the claims, some prominent features of this disclosure will now be briefly described.

[0005] One aspect of the present disclosure is a method of assembling a packaged integrated circuit device. The method includes setting support posts of an assembly apparatus to a height for applying a die paddle and, while the support posts are at the height for applying

the die paddle, applying solder over a semiconductor die positioned over a stage of the assembly apparatus and positioning the die paddle over the solder and the semiconductor die.

[0006] In one embodiment, the method can further include performing a reflow process with the support posts at the height for applying the die paddle. The support posts can support the die paddle during the reflow process. In addition, a fixture cover can be positioned over the die paddle, and force can be applied to the die paddle during the reflow process.

[0007] In one embodiment, the die paddle can have a thickness of at least 1.9 millimeters.

[0008] In one embodiment, the die paddle can have a thickness in a range from 2.5 millimeters to 5 millimeters.

[0009] In one embodiment, the method can further include setting the support posts to a first height for applying solder on a lead frame prior to positioning the semiconductor die over the lead frame. In addition, the method can also include setting the support posts to a second height to place the semiconductor die over the lead frame.

[0010] In one embodiment, the method can further include placing a fixture cover over the die paddle with the support posts at the height for applying the die paddle.

[0011] In one embodiment, the method can further include applying force to the stage of the assembly apparatus with a post stage of the assembly apparatus.

[0012] In one embodiment, the method can further include dissipating heat generated during the method using channels of the assembly apparatus.

[0013] In one embodiment, applying the solder can be performed by using a solder stencil supported by the support posts.

[0014] In one embodiment, a controller can be configured to cause the support posts to raise to the height for applying the die paddle.

[0015] Another aspect of the present disclosure is an assembly system for assembling a packaged integrated circuit device. The assembly system includes an assembly apparatus comprising a stage and support posts and a controller that includes a processor and a memory that can store instructions. The processor is configured to execute instructions to cause the assembly system to perform operations that include setting the support posts to a first height while a lead frame is positioned over the stage and raising the support posts to a height

for applying a die paddle after a semiconductor die is positioned over the lead frame. The semiconductor die is positioned over the lead frame between the setting and the raising.

[0016] In one embodiment, the operations can further include setting the support posts to a second height. The second height can be positioned between the first height and the height for applying the die paddle.

[0017] In one embodiment, the assembly apparatus can further include a post stage positioned on a side opposite the stage. The post stage can be configured to apply force to the support posts.

[0018] In one embodiment, the assembly apparatus can further include a fixture cover. In addition, the assembly apparatus can include alignment posts configured to receive legs of the fixture cover.

[0019] In one embodiment, the assembly apparatus can include channels for heat dissipation.

[0020] In one embodiment, the assembly system can be configured to concurrently assemble a plurality of packaged integrated circuit devices.

[0021] Another aspect of the present disclosure is an assembly apparatus for assembling a packaged integrated circuit device. The assembly apparatus includes a stage dimensioned to accommodate the packaged integrated circuit device, support posts configured to extend above the stage, a post stage positioned on a side opposite the stage, a fixture cover comprising legs, and cover alignment posts positioned around the stage. The support posts are configurable to adjust height. The post stage is configured to apply force to the support posts. The cover alignment posts are configured to receive the legs of the fixture cover.

[0022] In one embodiment, the assembly apparatus can also include channels that can be configured to dissipate heat associated with assembling the packaged integrated circuit device.

[0023] For purposes of summarizing the disclosure, certain aspects, advantages, and novel features of the innovations have been described herein. It is to be understood that not necessarily all such advantages may be achieved in accordance with any particular embodiment. Thus, the innovations may be embodied or carried out in a manner that achieves or optimizes one advantage or group of advantages as taught herein without necessarily achieving other advantages as may be taught or suggested herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] These and other features, aspects, and advantages of the disclosure are described with reference to the drawings of certain embodiments, which are intended to illustrate, but not to limit, the present disclosure. It is to be understood that the accompanying drawings, which are incorporated in and constitute a part of this specification, are for the purpose of illustrating concepts disclosed herein and may not be to scale.

[0025] FIG. 1A illustrates an exploded view of a packaged integrated circuit (IC) device according to some embodiments.

[0026] FIG. 1B illustrates an exploded view of another embodiment of a packaged IC device according to some embodiments.

[0027] FIG. 2A illustrates a schematic isometric view of an example of an assembly apparatus that can be used for assembling a packaged IC device according to some embodiments.

[0028] FIG. 2B illustrates a schematic side and cross-sectional view of the assembly apparatus of FIG. 2A that also shows a fixture cover and a spring.

[0029] FIG. 2C is a schematic block diagram of an example of a controller that can control the assembly apparatus of FIG. 2A and/or FIG. 2B according to some embodiments.

[0030] FIG. 3 is a flowchart of an example process for assembling a packaged IC device according to some embodiments.

[0031] FIGS. 4A and 4B are schematic isometric views that illustrate a step in an assembly process according to some embodiments.

[0032] FIGS. 5A and 5B are schematic isometric views that illustrate a next step in an assembly process according to some embodiments.

[0033] FIG. 6A is a schematic isometric view that illustrates the assembly positioned on an assembly apparatus and ready for clip placement.

[0034] FIG. 6B is a schematic isometric view that illustrates the assembly after a die paddle has been placed.

[0035] FIGS. 7A and 7B are schematic isometric views that illustrate a next step in an assembly process according to some embodiments.

[0036] FIG. 8 is a schematic diagram of an array of interconnected lead frames according to some embodiments.

[0037] FIG. 9 illustrates an exploded view of components of an assembly apparatus according to some embodiments.

[0038] FIG. 10 illustrates a cross-sectional view of an assembly apparatus according to some embodiments.

DETAILED DESCRIPTION OF CERTAIN EMBODIMENTS

[0039] The following detailed description of certain embodiments presents various descriptions of specific embodiments. However, the innovations described herein can be embodied in a multitude of different ways, for example, as defined and covered by the claims. In this description, reference is made to the drawings where like reference numerals and/or terms can indicate identical or functionally similar elements. It will be understood that elements illustrated in the figures are not necessarily drawn to scale. Moreover, it will be understood that certain embodiments can include more elements than illustrated in a drawing and/or a subset of the elements illustrated in a drawing. Further, some embodiments can incorporate any suitable combination of features from two or more drawings. The headings provided herein are for convenience only and do not necessarily affect the scope or meaning of the claims.

Introduction

[0040] Electronic components containing one or more integrated circuit (IC) dies can be deployed in a wide variety of applications. For example, such components can form part of a power electronics system. In some cases, such power electronics systems can be used for providing power for a heating, ventilation, and air conditioning (HVAC) system, an electric vehicle, and so forth. For example, in an electric vehicle, such systems can be used to convert alternating current to direct current for charging, from direct current to alternating current, or direct current at a certain voltage to direct current at another voltage to provide power output. Power electronics systems can also be used as part of a stationary energy storage system, such as a system for storing solar energy, or for other applications where there is a need for power delivery. A power electronics system can be used, for example, to convert direct current from

a solar panel or battery to alternating current. In some cases, such power electronics systems can be used in utility applications, such as a grid-tie inverter that converts direct current to alternating current for insertion into an electrical power grid. These are merely examples, and there are many other applications for such systems. In some cases, components of such systems can comprise diode switches, field effect transistors (FETs) such as metal-oxide-semiconductor field effect transistors (MOSFETs) (e.g., GaN MOSFETs), insulated-gate bipolar transistors (IGBTs), other bipolar transistors, the like, or any suitable combination thereof. In certain applications, such switches can be included in an inverter that may unidirectionally or bidirectionally convert a direct current (DC) voltage to an alternating current (AC) voltage. These components can have significant heat output when operational.

[0041] Power electronics systems can produce significant amounts of heat both under steady state load conditions and under surge conditions. Such heat can present significant problems. For example, excess heat can lead to one or more of component damage, reduced lifetime, lower reliability, decreased performance, or the like. For example, excessive thermal stresses can weaken solder joints and/or damage semiconductor components. In some applications, surge loads can result in rapid temperature rises. High surge loads can be encountered in various applications, for example when starting portable compressors, HVAC systems, refrigeration systems, electric motors, or the like.

[0042] Packaged IC devices may utilize wire bonding approaches for assembling electrical connections from the packaged IC device to one more other components. However, the use of individual wires and wire-bonding can have several technical challenges. For example, a relatively large number of wires can be involved to limit electric resistance. Rather than using wire-bonding, in some cases, clips, die paddles, and so forth can be used to make the electrical connections. The use of a clip and/or die paddle can provide several benefits. For example, resistive losses in a packaged IC device can be reduced significantly when using a clip and/or die paddle (which can comprise, for example, copper, aluminum, and/or other conductors) instead of wires and/or wire-bonding. The clip and/or die paddle can also help with thermal management by providing a relatively large thermally conductive mass that can dissipate heat generated from the electrical components of the packaged IC device. In some cases, a heat spreader can be utilized to dissipate the heat by placing the heat spreader in thermal contact with a die paddle. In some embodiments, a heat spreader and a die paddle can

be integrated as a single component. For example, a die paddle can be relatively thick so that it provides electrical contact as well as thermal management. In some cases, a die paddle can have a substantial thickness. For example, in some cases, a die paddle can extend to a top surface of a packaged IC device. The die paddle can be referred to as a die clip in certain applications. The die paddle can have significant mass. The die paddle can be referred to as a heavy clip in certain applications.

Packaged IC Device Assembly with Assembly Apparatus

[0043] Assembling a packaged IC device with a thick die paddle can present several technical challenges. In some examples, the thickness of the die paddle may be sufficiently thick to effectively dissipate heat generated from the die of the packaged IC device under a power surge condition. A thick die paddle can have a high thermal dissipation performance and also have a substantial weight due to the thickness of the die paddle. Such a substantial weight of the die paddle can cause technical challenges in the assembly of a packaged IC device. For example, during a reflow process, the die paddle can sink (e.g., due to the substantial weight of the thick die paddle) towards an integrated circuit die (also generally referred to as a semiconductor die). Such sinking during the assembly process can affect electrical connections, the overall height of the packaged IC device, and so forth. For example, due to the sinking, one or more electrical connections to the semiconductor die can be shorted. Accordingly, there is a need for apparatuses and methods for assembling packaged IC devices that include relatively heavy components such as a thick die paddle. The thick die paddle can also be referred to as a heavy clip.

[0044] FIG. 1A illustrates an exploded view of a packaged IC device 100A according to some embodiments. When assembled, the components shown in FIG. 1A can be encapsulated in a housing comprising, for example, a mold resin (not shown). As shown in FIG. 1A, the packaged IC device 100A can include a packaged semiconductor component 150A mounted on a lead frame 102. In some embodiments, the lead frame 102 can provide electrical contacts for electrical connections with terminals of a semiconductor die 106, such as drain, source, gate, and/or Kelvin source terminals.

[0045] As shown in FIG. 1A, the packaged semiconductor component 150A can include a die paddle 116, spacer solder 110, a conductive spacer 108, the semiconductor die

106, and solder 104. As illustrated, the die paddle 116 is relatively thick and heavy relative to other components of the packaged semiconductor component 150A. In some examples, the lead frame 102 can be extended (e.g., upward) relative to what is shown in FIG. 1A and the conductive spacer 108 can be omitted. A thickness of the die paddle 116 can be at least 1.9 millimeters (mm). In some instances, the die paddle 116 can be at least 2.5 mm thick. The thickness of the die paddle 116 can be in a range from 1.9 mm to 5 mm, for example. In certain instances, the thickness of the die paddle 116 can be in a range from 1.9 mm to 3 mm. In some instances, the thickness of the die paddle 116 can be in a range from 2.5 mm to 5 mm, for example. In some instances, the thickness of the die paddle 116 can be in a range from 2.5 mm to 3 mm. In some examples, the thickness of the die paddle 116 is at least 2.5 times of a thickness of the lead frame 102. For example, the die paddle 116 can have a thickness in a range from 2.5 times to 10 times a thickness of the lead frame 102. As another example, the die paddle 116 can have a thickness in a range from 4 times to 10 times a thickness of the lead frame 102. In another example, the die paddle 116 can have a thickness up to about 12 times a thickness of the lead frame 102. For example, the die paddle 116 can have a thickness in a range from about 2 times a thickness of the lead frame 102 to about 12 times the thickness of the lead frame 102. As another example, the die paddle 116 can have a thickness in a range from about 3 times a thickness of the lead frame 102 to about 12 times the thickness of the lead frame 102. A relatively thick die paddle 116 can present technical challenges during assembly that are addressed by embodiments of this disclosure.

[0046] In some examples, the spacer solder 110 and the solder 104 can be formed based on a pattern that can include multiple areas to provide electrical connections with corresponding die connection terminals (e.g., contact terminals), such as source, Kelvin source, drain, and gate terminals of the semiconductor die 106. In some examples, the spacer solder 110 and the solder 104 can be formed of a conductive material, such as, without limitation, solder, conductive epoxy, or the like. In some embodiments, the semiconductor component 150A can also include additional die, such as a thermistor die 112. In some examples, the thermistor die 112 can be implemented to the packaged IC device to sense temperature. For example, a lead 102A can be connected to the thermistor die 112 via a wire bond 114 and be configured to provide an indication of temperature from a terminal of the thermistor die 112. It will be appreciated that not all components may be present in all packaged IC devices. For

example, some packaged IC devices may not include a separate thermistor or thermistor wire bond. Moreover, some packaged IC devices can include one or more additional components as suitable.

[0047] FIG. 1B illustrates an exploded view of parts of an example of a packaged IC device 100B according to some embodiments. As shown in FIG. 1B, the packaged IC device 100B can include a packaged semiconductor component 150B mounted on a lead frame 102. In some embodiments, the lead frame 102 can provide electrical contacts for electrical connections with terminals of the semiconductor die 106, such as drain, source, gate, and/or Kelvin source terminals. Furthermore, in some embodiments, the lead frame 102 can provide an electrical contact for an electrical connection with the thermistor die 112.

[0048] As further shown in FIG. 1B, the packaged semiconductor component 150B can include a die paddle 116, spacer solders 110 (e.g., a die back and spacer solder), a conductive spacer 108, the semiconductor die 106, solder 104 (e.g., a die back and spacer solder). In some examples, the spacer solders 110 can include powders or particles acting as spacers to stay solid during a reflow process (e.g., at the reflow temperature). In some other examples, the spacer solders 110 can completely liquify during reflow. In some examples, the solders 104 and 110 can be formed based on a pattern that can include multiple areas to provide electrical connections with corresponding die connection terminals (e.g., contact terminals), such as source (including Kelvin source), drain, and gate terminals of the semiconductor die 106. In some examples, the solders 104 and 110 can be formed by a conductive material, such as, without limitation, solder, conductive epoxy, or the like. In some embodiments, the packaged semiconductor component 150B can also include a thermistor die 112 and a thermistor die clip 118. In some embodiments, the die paddle 116 can be referred to as a heat spreader clip, heavy clip, a heat slug, a cooling solution, or the like. In some cases, the solders 104 and 110 can be referred to as bonding layers.

[0049] Referring to FIGS. 1A and 1B, in some examples, field effect transistors (FETs) such as metal-oxide-semiconductor field effect transistors (MOSFETs) (e.g., GaN MOSFETs) can be implemented on the semiconductor die 106. Thus, the semiconductor die 106 can include terminals, such as the drain, source, Kelvin source, and gate. In some cases, the solder 110 can be assembled (e.g., bonded) on the top (e.g., a first side) of the semiconductor die 106. The solder 104 can be configured to bond the semiconductor die 106

with the lead frame 102 on the bottom side (e.g., a second side, opposite side of the first side) of the semiconductor die 106. The solders 110, 104 can be formed with a same type of material (e.g., conductive material) in certain applications.

[0050] In some embodiments, the lead frame 102, for example as shown in FIGS. 1A and 1B, can have flat leads, such as the flat leads 170 and 180 shown in FIG. 1B. For example, a first side of the lead frame 102 can have the flat leads 170, and a second side (e.g., opposite the first side) of the lead frame 102 can have the flat leads 180. As illustrated, the flat leads 170 can include leads 102A-102F, and the flat leads 180 can include leads 102G-102H. In some embodiments, source leads 102A and 102B are connected to one or more source terminals of the semiconductor die 106, a gate lead 102C is connected to a gate terminal of the semiconductor die 106, and a Kelvin source lead 102D is connected to a Kelvin source terminal of the semiconductor die 106. In some embodiments, the leads 170 can also include an additional lead 102E. The additional lead 102E can be connected to an additional circuitry or die configured to measure voltage or current of the lead frame 102. Additionally, the leads 170 can include a sense lead 102F connected to a terminal of the thermistor die 112, for example, via the thermistor die clip 118 in the semiconductor device 110B or a wire bond 114 in the semiconductor device 110A. In some embodiments, the leads 180 can include drain leads 102G and 102H connected to one or more drain terminals of the semiconductor die 106. In some embodiments, the drain leads 102G and 102H are electrically coupled with the die paddle 116 via the conductive spacer 108. For example, a drain terminal of the semiconductor die 106 can be electrically coupled with the die paddle 116, and the drain leads 102G and 102H can be electrically coupled with the die paddle 116. In some examples, one or more passive electrical components, such as one or more capacitors and/or one or more inductors, can be connected between the drain leads 102G and 102H and the die paddle 116.

[0051] In some embodiments, the leads 170 and 180 can be flat leads that extend outside area of the die paddle 116. For example, when the packaged semiconductor component 150B is assembled on top of the lead frame 102, the flat leads 170 and 180 extend outside of the packaged semiconductor component 150B.

[0052] In some embodiments, the leads 170 and 180 of the lead frame 102 being flat leads can enable a thinner profile (e.g., low profile) for the packaged IC device 100A and 100B. In some examples, the leads 170 and 180 can serve as electrical contact points (e.g.,

terminals) for the packaged IC device 100A or 100B, where each lead can be a flat lead having an appropriate thickness to facilitate the transfer of the generated signal or electrical power. For instance, the thickness of a flat portion of leads 170 and 180 can be a minimum of 5 mil or 0.127 mm. In some examples, the flat leads can include a wettable flank.

[0053] The lead frame 102 of FIGS. 1A and 1B can include various electrical contacts. The lead frame 102 can be implemented with a pattern that can provide electrical contact with terminals of the semiconductor die 106, such as drain, source, and gate and/or one or more terminals of the thermistor die 112.

[0054] FIG. 2A illustrates an example of an assembly apparatus 200 that can be used for assembling a packaged IC device (e.g., the packaged IC device 100A of FIG. 1A and/or the packaged IC device of FIG. 1B) according to some embodiments. The assembly apparatus 200 can include a fixture base 202. The fixture base 202 can include a stage 204 on a top surface of the fixture base 202. In some embodiments, the stage 204 is dimensioned to accommodate the packaged IC device. The fixture base 202 can include two hollow portions 250A, 250B, where the stage 204 is located between these two hollow portions 250A, 250B. In some examples, each of the two hollow portions 250A, 250B has cylindrical shape. In some embodiments, the assembly apparatus 200 can include channels 209 in the fixture base 202 for hot air circulation for melting solder and/or light access to initiate curing. In some embodiments, cover alignment posts 206A, 206B can be inserted each corresponding hollow portion. For example, a cover alignment post 206A can be inserted into the hollow portion 250A, and another cover alignment post 206B can be inserted into the hollow portion 250B. In some embodiments, the cover alignment posts 206A, 206B are used to align the fixture base 202 and the fixture cover 216 (illustrated in FIG. 2B). In FIG. 2A, two cover alignment posts 206A and 206B (and also the two hollow portions 250A, 250B) are illustrated, but there can be any suitable number of alignment posts, for example one alignment post (with one hollow portion), two alignment posts (with two hollow portions), three alignment posts (with three hollow portion), four alignment posts (with four hollow portions), five alignment posts (with five hollow portions), or more if desired. In some embodiments, cover alignment posts 206A, 206B may not be used and other features such as ledges, bumps, walls, steps, and so forth can be used instead. In some embodiments, cover alignment posts 206A, 206B and one or more other features can be included in an assembly apparatus. In some embodiments where friction

between the fixture base 202 and the cover 216 (illustrated in FIG. 2B) is sufficient to restrict relative movement, no posts may be utilized.

[0055] In some embodiments, the stage 204 can include a plurality of hollow portions. For example, the stage 204 can include cylindrical hollow portions (e.g., hollow portions 205A, and 20B shown in FIG. 2A). In some embodiments, assembly support posts 208 can pass through the fixture base 202 and emerge through the stage 204. For example, each of the assembly support posts 208 can emerge through the stage 204 via a corresponding hollow portion (e.g., hollow portions 205A, 205B). In some embodiments, the fixture base 202 can include a center groove portion 207 on a side opposite the stage 204. In some embodiments, a post stage 210 can be positioned inside the groove portion 207.

[0056] FIG. 2B illustrates a cross-sectional view of the assembly apparatus 200 of FIG. 2A that shows additional elements as compared to FIG. 2A. FIG. 2B illustrates a fixture cover 216, a spring 214, and a spring plate 212 of the assembly apparatus 200 that are not shown in FIG. 2A. In some embodiments, the fixture cover 216 can have two legs 216A and 216B. Each leg 216A and 216B can be assembled on top of the hollow portions 250A and 250B, respectively. The assembly support posts 208 (only two assembly support posts are shown in FIG. 2B) can be adjustable so the height 260 of the assembly support posts 208 above the fixture base 202 can be altered as desired. For example, as components are added (during the assembly), the assembly support posts 208 can be raised to a desired height at each assembly step. In some embodiments, the post stage 210 is connected with the assembly support posts 208 (e.g., the bottom of each assembly support post 208 can be connected to a top portion of the post stage 210). The post stage 210 can cause the assembly support posts 208 to raise by a desired amount using any suitable mechanism. In some examples, the fixture base 202 can be positioned over a spring plate 212 and a spring 214. The spring plate 212 can press against the post stage 210 to push the post stage 210 upward. The assembly support posts 208 can be affixed to a post stage 210. In some embodiments, the assembly apparatus 200 can include one or more channels 209 in the fixture base 202 for hot air circulation for melting solder and/or light access to initiate curing. FIG. 2B illustrates one channel 209 (e.g., two channels 209 are shown in FIG. 2A), however, multiple channels can be included in the fixture base 202 in various applications. In some embodiments, an aperture may be provided for

positional inspection. For example, channels can be provided in the fixture cover 216, fixture base 202, and/or cover alignment posts 206A, 206B (shown in FIG. 2A).

[0057] FIG. 2C illustrates an example of controller 270 that controls the operation of the assembly apparatus 200 of FIGS. 2A and 2B. In some embodiments, the assembly operations of the assembly apparatus can be controlled by the controller 270 without user involvement. For example, the height 260 of the assembly support posts 208 illustrated in FIG. 2B can be adjusted by the controller 270 at one or more assembly stages. In some examples, the controller 270 can cause the post stage 210 to move so that the assembly support posts 208 are at a desired height for an assembly step. For example, a motor can be connected to the post stage 210, the controller 270, and a mechanical movement of the motor can cause the post stage 210 to move upward and/or downward based on an output signal from the controller 270. The controller 270 can cause the assembly apparatus 200 to perform any suitable operations disclosed herein. The height and thicknesses of plates and stacked features may also be set specifically to allow sequential stacking of plates atop one another to achieve step-wise height changes desired during assembly to support, lift, and/or press parts into or towards apparatus surfaces for height or planarity control.

[0058] FIG. 2C depicts one embodiment of an example hardware architecture of a controller 270. In some embodiments, the general architecture of the controller 270 depicted in FIG. 2C includes an arrangement of computer hardware and memory storing instructions that may be used to implement aspects of the present disclosure. As illustrated, in some embodiments, the controller 270 includes a processor 272, an interface 274, and a memory 280, all of which may communicate with one another by way of a communication bus. The components of the controller 270 may be physical hardware components. The processor 272 can include any suitable processor. In some embodiments, the interface 274 may provide connectivity to the assembly apparatus 200. For example, the assembly apparatus 200 may receive various controlling instructions from the controller 270 via the interface 274. In some cases, the interface 274 can be any suitable combination of a wired interface and/or a wireless interface.

[0059] In some embodiments, the memory 280 may include computer program instructions that the processor 272 executes in order to implement one or more embodiments. In some embodiments, the memory 280 generally includes random access memory (RAM),

read only memory (ROM), or other persistent and/or non-transitory memory. In some embodiments, the memory 280 may store computer program instructions for implementing aspects of the present disclosure. For example, in one embodiment, the memory 280 stores controller instructions 282 to control the operation of the assembly apparatus 200 in accordance with various embodiments disclosed herein.

[0060] FIG. 3 is a flowchart that illustrates an example process for assembling a packaged IC device according to some embodiments. The process depicted in FIG. 3 can be carried out using the assembly apparatus 200 of FIGS. 2A and 2B, for example. References will be made to the apparatus of FIGS. 2A and 2B for illustrative purposes. The controller 270 can cause the assembly apparatus 200 to perform one or more operations of the process of FIG. 3, such as adjusting assembly post heights.

[0061] At block 302, a lead frame 102 can be placed in the assembly apparatus 200. This can involve positioning the lead frame 102 on the stage 204. In some embodiments, the assembly support posts 208 can provide alignment reference points for placing the lead frame 102 on the stage 204. At block 304, pins, such as the assembly support posts 208, can be set to a first height. The first height can be a predetermined height for applying solder. For example, setting the support posts 208 to the first height for applying solder on a lead frame 102 prior to positioning the semiconductor die 106 over the lead frame 102. With the assembly support posts 208 at the first height, solder (e.g., solder 104 of FIGS. 1A and 1B) can be placed in desired locations of the lead frame 102. In some examples, the height of each post of the assembly support posts 208 is same after being set to the first height. At block 306, solder can be placed in desired locations. This can involve placing a solder stencil and then printing solder.

[0062] At block 308, pins, such as the assembly support posts 208, can be set to a second height greater than the first height. With the assembly support posts 208 at the second height, operations at blocks 310 and 312 can be performed. For example, setting the support posts 208 to the second height is to place the semiconductor die 106 over the lead frame 102. At block 310, a semiconductor die (e.g., the semiconductor die 106 of FIGS. 1A and 1B) and a conductive spacer (e.g., the spacer 108 of FIGS. 1A and 1B) can be placed (e.g., placed on top of at least a portion of the solder 104). At block 312, solder (e.g., solder 110 of FIGS. 1A and 1B) can be placed selectively (e.g., on top of the die and/or on top of the conductive

spacer). The solder can be placed selectively by placing a solder stencil and printing solder on top of the stack.

[0063] At block 314, pins, such as the assembly support posts 208, can be set to a third height. In some other applications, the pins can be set to the third height at a different point in the manufacturing process, such as after the fixture cover is placed or during a reflow process. For example, the reflow process can be performed with the support posts 208 at the height (e.g., the third height) for applying the heat spreader clip (e.g., the die paddle 116 of FIGS. 1A and 1B). The pins at the third height can support the relatively heavy heat spreader clip (e.g., the die paddle 116 of FIGS. 1A and 1B). This can maintain the height of the heat spreader clip during solder liquification. Accordingly, the assembly apparatus 200 can provide support for a relatively heavy heat spreader clip during assembly so that the heat spreader clip is maintained at a precise position for soldering. The posts of the can push and hold the heat spreader clip up against a top-limiting structure, such one that fixes the upper outer surface into a relatively well-controlled height and parallelism that will match the mold cavity and thus reduce overmolding flash. With the pins at the third height, solder can be applied. This can involve applying the die backside and spacer solder 110 of FIGS. 1A and 1B.

[0064] At block 316, a die paddle can be placed on top of the solder. At block 318, a fixture cover 216 can be placed on top of the fixture base 202 and the components of the packaged IC device. The fixture cover 216 can be positioned over the die paddle and applies force to the die paddle during the reflow process. For example, the fixture cover 216 can be placed over the heat spreader clip (e.g., the die paddle 116 of FIGS. 1A and 1B) with the support posts 208 at the height for applying the heat spreader clip (e.g., the die paddle 116 of FIGS. 1A and 1B). At block 320, a reflow process can be carried out, for example by heating the components of the packaged IC device.

[0065] In some embodiments, the controller 270 illustrated in FIG. 2C can control assembly operations of the assembly apparatus. For example, the controller 270 can provide various instructions to the assembly apparatus, such as setting pins to first, second, and third heights at blocks 304, 308, and 314. In some embodiments, operations of the one or more other blocks can be performed in response to an instruction from the controller 270. For example, reflow at block 320 can be initiated in response to receiving an instruction from the controller 270. As another example, the fixture cover 216 can be positioned over the

components of the packaged IC device at block 3218 in response to an instruction from the controller 270.

[0066] In some embodiments, additional steps may be performed. For example, before placing the clip, a thermistor and thermistor wire bond can be placed. In some embodiments, one or more steps can be omitted. For example, in some embodiments, the assembly support posts 208 may start at an initial position and may not be raised until it is time to place the die paddle. In some embodiments, the assembly support posts 208 can be at a fixed height (e.g., at a desired height of the die paddle).

[0067] **FIGS. 4A and 4B** illustrate steps in an assembly process according to some embodiments. As shown in FIG. 4A, a lead frame 102 can be placed on the fixture base 202 (e.g., on the stage 204 of the fixture base 202). The assembly support posts 208 can be set to an initial height so that the top surfaces of the assembly support posts 208 are coplanar with areas where solder 104 is to be placed. The surfaces 402 (including areas where solder 104 is placed and top surfaces of assembly posts 208 shown in FIG. 4B) can be coplanar to support a solder stencil and solder paste blade downforce during solder printing operation. Solder 104 can be placed in desired locations, for example, as shown in FIG. 4B. The solder 104 can be printed using a solder stencil in certain applications. The assembly support posts 208 can provide support for a solder paste stencil. This can contribute to even and accurate solder printing in the desired locations and reduce stencil distortion from stencil blade pressure. The assembly support posts 208 can cause the solder to be positioned at a desired height in the packaged IC device and/or to have a desired thickness. The solder 104 can also be a solid preform that is placed and tacked with another low-residue substance to hold position in some applications.

[0068] **FIGS. 5A and 5B** illustrate next steps in an assembly process according to some embodiments. These steps are performed after the steps corresponding to FIGS. 4A and 4B. A semiconductor die 106 and a conductive spacer 108 can be placed (e.g., placed on top of the solder 104). The semiconductor die 106 can be flipped prior to placement such that the backside of the semiconductor die 106 is facing upward. The assembly support posts 208 can be raised to a second height that is higher than the first height to be coplanar with areas where solder is to be deposited. In the example of FIG. 5A, the surfaces 502 can be coplanar. The solder 110 can be printed with a solder stencil or otherwise dispensed in desired locations in

certain applications. Solder 110 can be a solder preform if desired. The assembly support posts 208 can provide support for the solder stencil. This can offer several benefits, such as contributing to the even and accurate solder paste printing in desired locations, achieving a desired solder thickness, and so forth. The solder 110 can be performed and tacked in some applications. FIG. 5B shows the result of applying die backside and spacer solder 110.

[0069] **FIGS. 6A and 6B** illustrate next steps in an assembly process according to some embodiments. These steps are performed after the steps corresponding to FIGS. 5A and 5B. After dispensing the die backside and spacer solder 110, the assembly support posts 208 can be raised to a third height that is greater than the second height. The third height can be set for a desired position of the clip. For example, the third height can be positioned to achieve a desired overall height of the packaged IC device. The clip can be a heavy clip, such as the die paddle 116. FIG. 6A illustrates the assembly ready for clip placement. The surfaces 602 can be coplanar. Having the surfaces 602 be coplanar can help ensure that the die paddle 116 will be positioned and aligned at a desired height. The die paddle 116 can be placed on top of the die backside and spacer solder 110 and assembly support posts 208 and can be supported by the assembly support posts 208, which can alleviate pressure of the die paddle 116 on the semiconductor die 106 and other elements of the component stack. FIG. 6B illustrates the assembly after the die paddle 116 has been placed. A thermistor die and thermistor clip can be bonded in FIG. 6B. Mass of the die paddle 116 can be supported by the assembly support posts 208. The assembly support posts 208 can impede the die paddle 116 from sinking during a reflow process. Accordingly, with the assembly support posts 208, the die paddle 116 can stay in place with tilting effectively limited during the reflow process. In some embodiments, the die paddle 116 can include alignment features, such as recesses, which can align with the assembly support posts 208. The alignment features can impede lateral movement of the die paddle 116 during a reflow process.

[0070] **FIGS. 7A and 7B** illustrate next steps in an assembly process according to some embodiments. These steps are performed after the steps corresponding to FIGS. 6A and 6B. After placing the die paddle 116, a fixture cover 216 can be placed on top of the fixture base 202. The fixture cover 216 can be aligned with the fixture base 202 via the cover alignment posts 206. The fixture cover 216 can be fastened or clamped in place. The fixture cover 216 can apply pressure on the die paddle 116 to apply force on the stacked components.

After the fixture cover 216 is placed, a reflow process can be carried out, for example by heating in a controlled atmosphere reflow oven, vacuum reflow, or formic acid reflow oven. In some embodiments, the fixture base 202 can be placed on a plate 212 that includes a spring 214, which can push against the post stage 210 to provide an upward force, pressing the die paddle 116 against the fixture cover 216. In some embodiments, the spring 214 may be replaced with a rigid structure of desired height to provide upward force. For example, force can be applied to the stage 204 of the assembly apparatus with a post stage 210 of the assembly apparatus.

[0071] The discussion above focuses on the assembly of a single device. However, it can be desirable to form arrays of devices in a same process. The apparatuses and methods described herein can be configured and/or adapted for the assembly of arrays of stacked components. As an example, the controller 270 can control a plurality of assembly apparatus 200 to adjust heights of respective assembly support post 208.

[0072] Handling of an assembly of stacked components and an assembly apparatus, such as during conveyance, stepwise transfer between heating zones, and/or indexed moving that can occur during loading into or unloading from ovens such as linear or rotary ovens can present opportunities for stacked components to be jostled and lose alignment. In the case of multiple stacked assemblies that may be widely distributed in an array, the heating of an interconnected array of lead frames (e.g., copper lead frames) can cause unequal lateral expansion relative to the reflow fixture. For example, the reflow fixture may be made of a different material such as graphite that has a different coefficient of thermal expansion (CTE) than the interconnected array of lead frames. For example, a graphite reflow fixture may have a relatively high degree of dimensional stability over a relatively wide temperature range (e.g., a CTE of about 4 to about 8 micrometers/°C), while other materials may have significantly greater dimensional variations, such as copper which may have a CTE of about 16 to about 16.7 micrometers/°C or 304 stainless steel, which may have a CTE of about 17.3 micrometers/°C.

[0073] Components that are desired to stay laterally fixed to features on a lead frame that is thermally expanding and/or contracting may translate accordingly in order to stay aligned. For example, when heating from 25°C to 325°C, a 100 millimeter (mm) x 300 mm copper lead frame array may expand by about 850 micrometers more than a graphite fixture.

For some semiconductor assemblies, this mismatch in thermal expansion may be unacceptable. For example, in some semiconductor assemblies, alignment should be maintained within a relatively narrow window, for example within about ± 25 micrometers. In some embodiments, support structures can be provided. In some embodiments, the support structures can have the same or similar thermal behavior (e.g., the same or similar CTEs). Accordingly, the support structures can be used to hold an array comprising many individual stacks without significant lateral shifting during heating and/or cooling. In some embodiments, matching the expansion of the lead frame array can maintain the stacked components in vertical alignment during heating and/or cooling.

[0074] FIG. 8 illustrates an example of an array of interconnected lead frames according to some embodiments. In some embodiments, each packaged semiconductor component 150A (illustrated in FIG. 1A) and/or 150B (illustrated in FIG. 1B) can be attached to a support frame 806. The support frame 806 can be used during manufacturing to facilitate transport, positioning, alignment, etc., of a plurality of packaged semiconductor components.

[0075] FIG. 9 illustrates an exploded view of components of an assembly apparatus 900 according to some embodiments. As shown in FIG. 9, the assembly apparatus 900 can include a cover 902, cover liner 904, lead main carrier 906, spring frame 908, spring plate 910, and spacer plate 912. The spring frame 908 can move in a Z direction in certain applications. In some embodiments, the spring frame 908 can be used for more rigid, lateral movement matching, which can provide lateral CTE expansion matching. In such embodiments, the spring frame may have little or no spring movement in the Z direction. A lead frame array 914 can be disposed between the cover liner 904 and the main carrier 906. The assembly apparatus 900 can be used in manufacturing an array of packaged IC devices. The assembly apparatus 900 can apply features of the assembly apparatus 200 of FIGS. 2A and 2B to an array context.

[0076] In some embodiments, the cover liner 904 and the spring frame 908 can have coefficients of thermal expansion that are similar to or the same as the coefficient of thermal expansion of the lead frame array 914. The lead frame array 914 can comprise, for example, copper or another metal. By matching the CTEs of the cover liner 904, spring frame 908, and lead frame array 914, components of a stacked assembly can be maintained in alignment during heating and/or cooling.

[0077] The components of the assembly apparatus 900 may include a centered round hole 916 for receiving a pin and slotted edge holes 918 for receiving other pins, which can help to maintain alignment of the assembly apparatus 900.

[0078] FIG. 10 shows a side view of the assembly apparatus 900 according to some embodiments. A lead frame array 914 is disposed within the assembly apparatus 900. An array of packaged IC devices 920 is disposed within the assembly apparatus 900. Accordingly, the assembly apparatus 900 can be used to manufacture a plurality of packaged IC devices 920. The assembly apparatus 900 can apply any suitable principles and advantages discussed with reference to FIGS. 2A to 7B to assembling the plurality of packaged IC devices 920 concurrently.

Additional Embodiments

[0079] In the foregoing specification, the disclosure has been described with reference to specific embodiments. It will, however, be evident that various modifications and changes may be made thereto without departing from the broader spirit and scope of the disclosure. The specification and drawings are, accordingly, to be regarded in an illustrative rather than restrictive sense.

[0080] Indeed, although this disclosure is in the context of certain embodiments and examples, it will be understood by those skilled in the art that the inventions extend beyond the specifically disclosed embodiments to other alternative embodiments and/or uses of the inventions and equivalents thereof. In addition, while several variations of the embodiments have been shown and described in detail, other modifications, which are within the scope of this disclosure, will be readily apparent to those of skill in the art based upon this disclosure. It is also contemplated that various combinations or sub-combinations of the specific features and aspects of the embodiments may be made and still fall within the scope of the disclosure. It should be understood that various features and aspects of the disclosed embodiments can be combined with, or substituted for, one another in order to form varying modes of the embodiments disclosed herein. Any methods disclosed herein need not be performed in the order recited. Thus, it is intended that the scope of the disclosure should not be limited by the particular embodiments described above.

[0081] It will be appreciated that the systems and methods of the disclosure each have several innovative aspects, no single one of which is solely responsible or required for the desirable attributes disclosed herein. The various features and processes described above may be used independently of one another or may be combined in various ways. All possible combinations and subcombinations are intended to fall within the scope of this disclosure.

[0082] Certain features that are described in this specification in the context of separate embodiments also may be implemented in combination in a single embodiment. Conversely, various features that are described in the context of a single embodiment also may be implemented in multiple embodiments separately or in any suitable subcombination. Moreover, although features may be described above as acting in certain combinations and even initially claimed as such, one or more features from a claimed combination may in some cases be excised from the combination, and the claimed combination may be directed to a subcombination or variation of a subcombination. No single feature or group of features is necessary or indispensable to each and every embodiment.

[0083] It will also be appreciated that conditional language used herein, such as, among others, “can,” “could,” “might,” “may,” “e.g.,” and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements and/or steps. Thus, such conditional language is not generally intended to imply that features, elements and/or steps are in any way required for one or more embodiments or that one or more embodiments necessarily include logic for deciding, with or without author input or prompting, whether these features, elements and/or steps are included or are to be performed in any particular embodiment. The terms “comprising,” “including,” “having,” and the like are synonymous and are used inclusively, in an open-ended fashion, and do not exclude additional elements, features, acts, operations, and so forth. In addition, the term “or” is used in its inclusive sense (and not in its exclusive sense) so that when used, for example, to connect a list of elements, the term “or” means one, some, or all of the elements in the list. In addition, the articles “a,” “an,” and “the” as used in this application and the appended claims are to be construed to mean “one or more” or “at least one” unless specified otherwise. Similarly, while operations may be depicted in the drawings in a particular order, it is to be recognized that such operations need not be performed in the particular order shown or in sequential order, or that

all illustrated operations be performed, to achieve desirable results. Further, the drawings may schematically depict one more example processes in the form of a flowchart. However, other operations that are not depicted may be incorporated in the example methods and processes that are schematically illustrated. For example, one or more additional operations may be performed before, after, simultaneously, or between any of the illustrated operations. Additionally, the operations may be rearranged or reordered in other embodiments. In certain circumstances, multitasking and parallel processing may be advantageous. Moreover, the separation of various system components in the embodiments described above should not be understood as requiring such separation in all embodiments, and it should be understood that the described program components and systems may generally be integrated together in a single software product or packaged into multiple software products. Additionally, other embodiments are within the scope of the following claims. In some cases, the actions recited in the claims may be performed in a different order and still achieve desirable results.

[0084] Further, while the methods and devices described herein may be susceptible to various modifications and alternative forms, specific examples thereof have been shown in the drawings and are herein described in detail. It should be understood, however, that the disclosure is not to be limited to the particular forms or methods disclosed, but, to the contrary, the disclosure is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the various implementations described and the appended claims. Further, the disclosure herein of any particular feature, aspect, method, property, characteristic, quality, attribute, element, or the like in connection with an implementation or embodiment can be used in all other implementations or embodiments set forth herein. Any methods disclosed herein need not be performed in the order recited. The methods disclosed herein may include certain actions taken by a practitioner; however, the methods can also include any third-party instruction of those actions, either expressly or by implication. The ranges disclosed herein also encompass any and all overlap, sub-ranges, and combinations thereof. Language such as “up to,” “at least,” “greater than,” “less than,” “between,” and the like includes the number recited. Numbers preceded by a term such as “about” or “approximately” include the recited numbers and should be interpreted based on the circumstances (e.g., as accurate as reasonably possible under the circumstances, for example $\pm 5\%$, $\pm 10\%$, $\pm 15\%$, etc.). Phrases preceded by a term such as “substantially” include the recited phrase and should be interpreted based on

the circumstances (e.g., as much as reasonably possible under the circumstances). For example, “substantially constant” includes “constant.” Unless stated otherwise, all measurements are at standard conditions including temperature and pressure.

[0085] As used herein, a phrase referring to “at least one of” a list of items refers to any combination of those items, including single members. As an example, “at least one of: A, B, or C” is intended to cover: A, B, C, A and B, A and C, B and C, and A, B, and C. Conjunctive language such as the phrase “at least one of X, Y and Z,” unless specifically stated otherwise, is otherwise understood with the context as used in general to convey that an item, term, etc. may be at least one of X, Y or Z. Thus, such conjunctive language is not generally intended to imply that certain embodiments require at least one of X, at least one of Y, and at least one of Z to each be present. The headings provided herein, if any, are for convenience only and do not necessarily affect the scope or meaning of the devices and methods disclosed herein.

[0086] Accordingly, the claims are not intended to be limited to the embodiments shown herein but are to be accorded the widest scope consistent with this disclosure, the principles and the novel features disclosed herein.

WHAT IS CLAIMED IS:

1. A method of assembling a packaged integrated circuit device, the method comprising:

setting support posts of an assembly apparatus to a height for applying a die paddle; and

while the support posts are at the height for applying the die paddle,

applying solder over a semiconductor die positioned over a stage of the assembly apparatus; and

positioning the die paddle over the solder and the semiconductor die.

2. The method of Claim 1, further comprising performing a reflow process with the support posts at the height for applying the die paddle, the support posts supporting the die paddle during the reflow process.

3. The method of Claim 2, wherein a fixture cover is positioned over the die paddle and applies force to the die paddle during the reflow process.

4. The method of any of Claims 1 to 3, wherein the die paddle has a thickness of at least 1.9 millimeters.

5. The method of any of Claims 1 to 3, wherein the die paddle has a thickness in a range from 2.5 millimeters to 5 millimeters.

6. The method of any of Claims 1 to 5, further comprising setting the support posts to a first height for applying solder on a lead frame prior to positioning the semiconductor die over the lead frame.

7. The method of Claim 6, further comprising setting the support posts to a second height for placing the semiconductor die over the lead frame.

8. The method of any of Claims 1 to 7, further comprising placing a fixture cover over the die paddle with the support posts at the height for applying the die paddle.

9. The method of any of Claims 1 to 8, further comprising applying force to the stage of the assembly apparatus with a post stage of the assembly apparatus.

10. The method of any of Claims 1 to 9, further comprising dissipating heat generated during the method using channels of the assembly apparatus.

11. The method of any of Claims 1 to 10, wherein applying the solder is performed using a solder stencil supported by the support posts.

12. The method of any of Claims 1 to 11, wherein a controller is configured to cause the support posts to raise to the height for applying the die paddle.

13. An assembly system for assembling a packaged integrated circuit device, the assembly system comprising:

an assembly apparatus comprising a stage and support posts; and

a controller comprising a processor and a memory storing instructions, wherein the processor is configured to execute instructions to cause the assembly system to perform operations, the operations comprising:

setting the support posts to a first height while a lead frame is positioned over the stage; and

raising the support posts to a height for applying a die paddle after a semiconductor die is positioned over the lead frame, wherein the semiconductor die is positioned over the lead frame between the setting and the raising.

14. The assembly system of Claim 13, wherein the operations further comprise setting the support posts to a second height, wherein the second height is between the first height and the height for applying the die paddle.

15. The assembly system of Claim 13 or 14, wherein the assembly apparatus further comprises a post stage positioned on a side opposite the stage, wherein the post stage is configured to apply force to the support posts.

16. The assembly system of any of Claims 13 to 15, wherein the assembly apparatus further comprises a fixture cover.

17. The assembly system of Claim 16, wherein the assembly apparatus comprises alignment posts configured to receive legs of the fixture cover.

18. The assembly system of any of Claims 13 to 17, wherein the assembly apparatus comprises channels for heat dissipation.

19. The assembly system of any of Claims 13 to 18, wherein the assembly system is configured to concurrently assemble a plurality of packaged integrated circuit devices.

20. An assembly apparatus for assembling a packaged integrated circuit device, the assembly apparatus comprising:

- a stage dimensioned to accommodate the packaged integrated circuit device;
- support posts configured to extend above the stage, the support posts being configurable to adjust height;
- a post stage positioned on a side opposite the stage, wherein the post stage is configured to apply force to the support posts;
- a fixture cover comprising legs; and
- cover alignment posts positioned around the stage, the cover alignment posts configured to receive the legs of the fixture cover.

21. The assembly apparatus of Claim 20, further comprising channels configured to dissipate heat associated with assembling the packaged integrated circuit device.

1/17

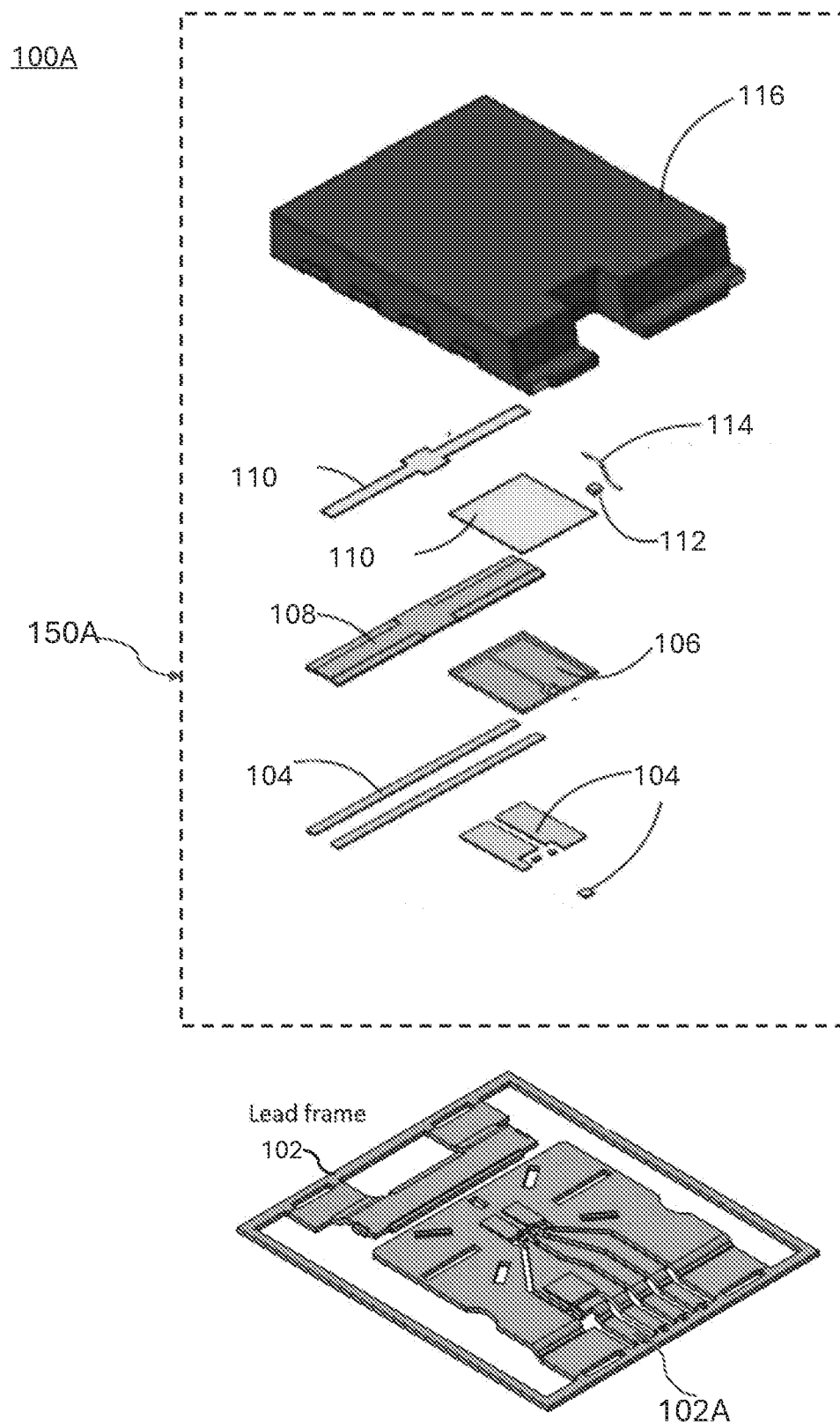


FIG. 1A

1008

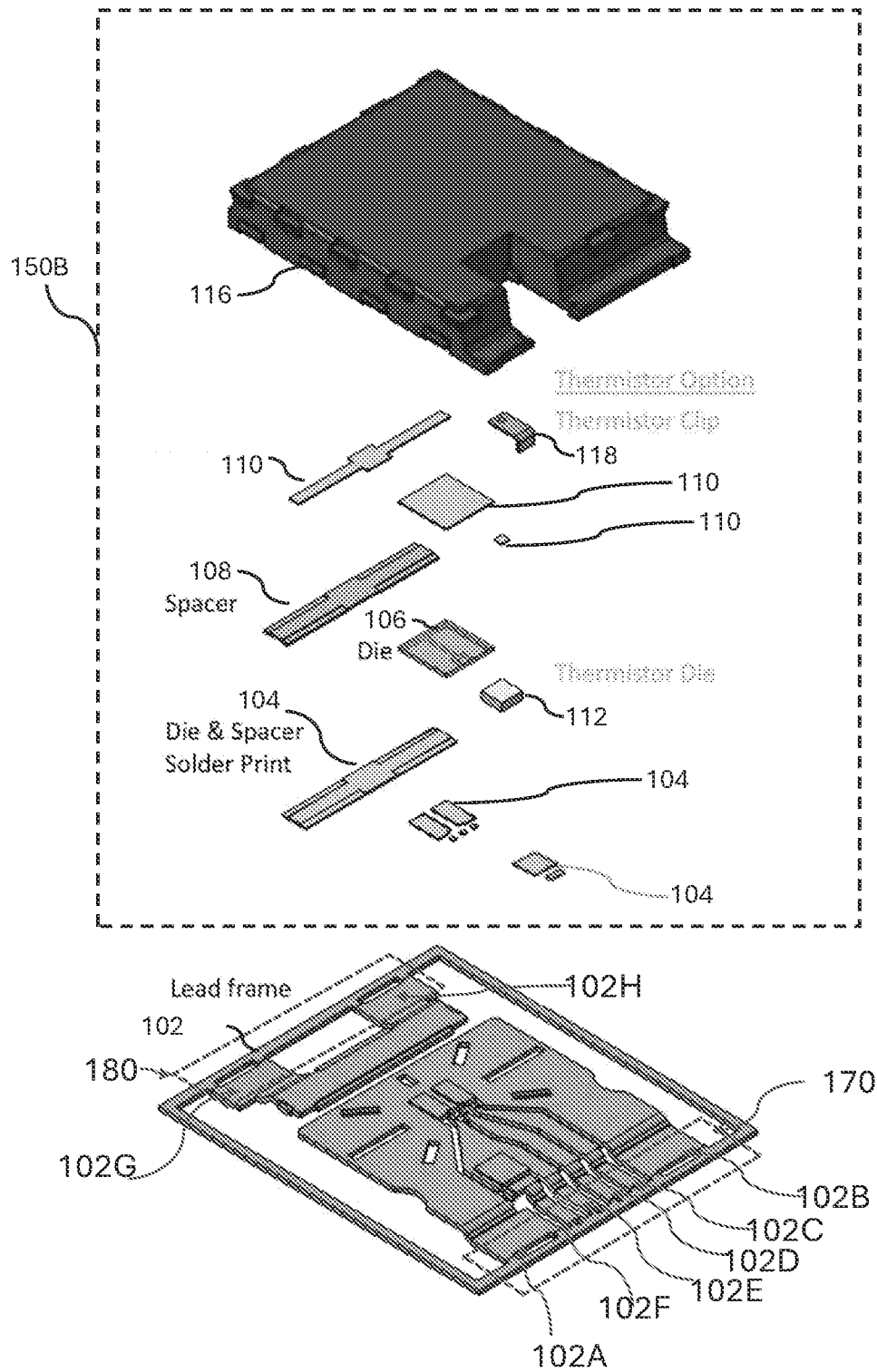
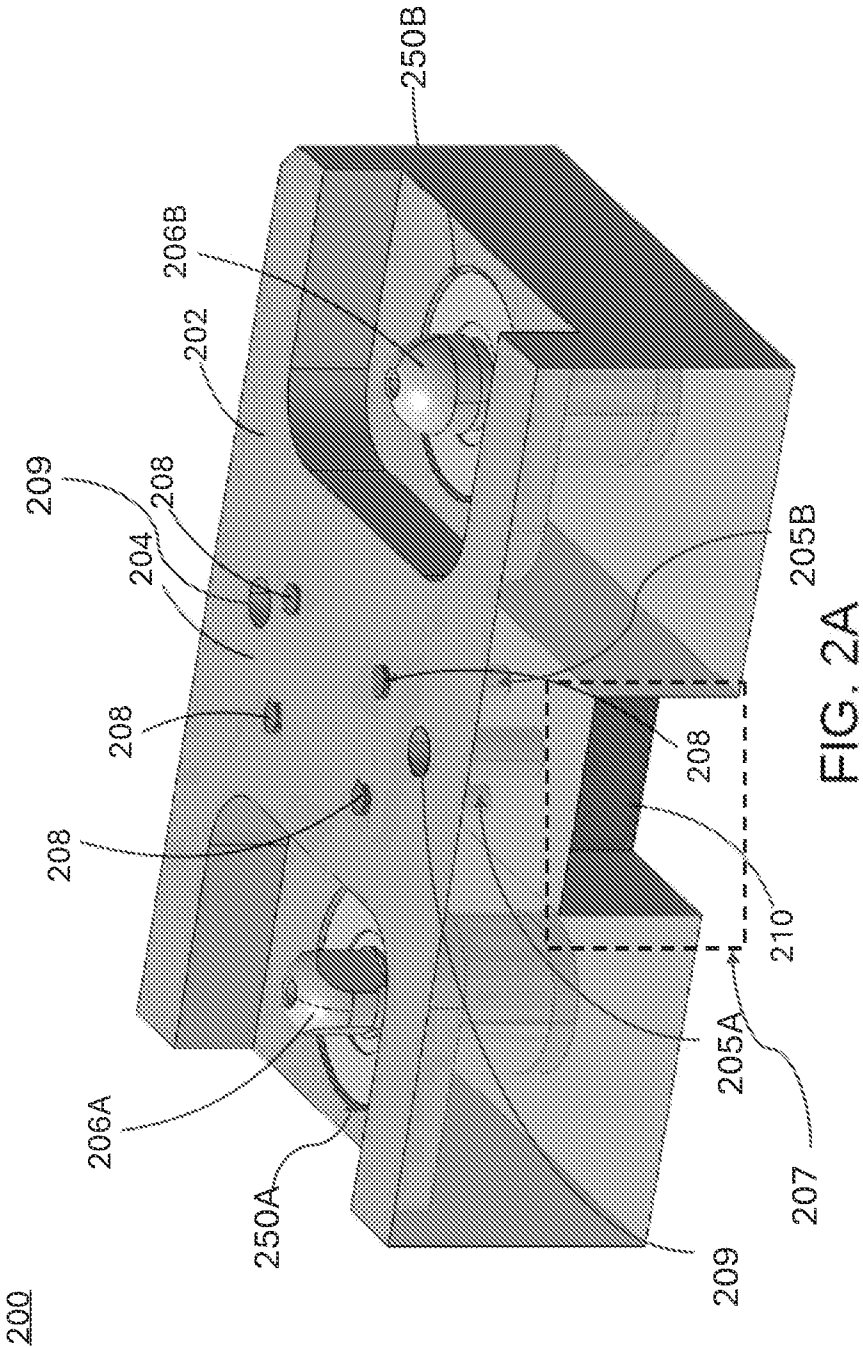


FIG. 1B



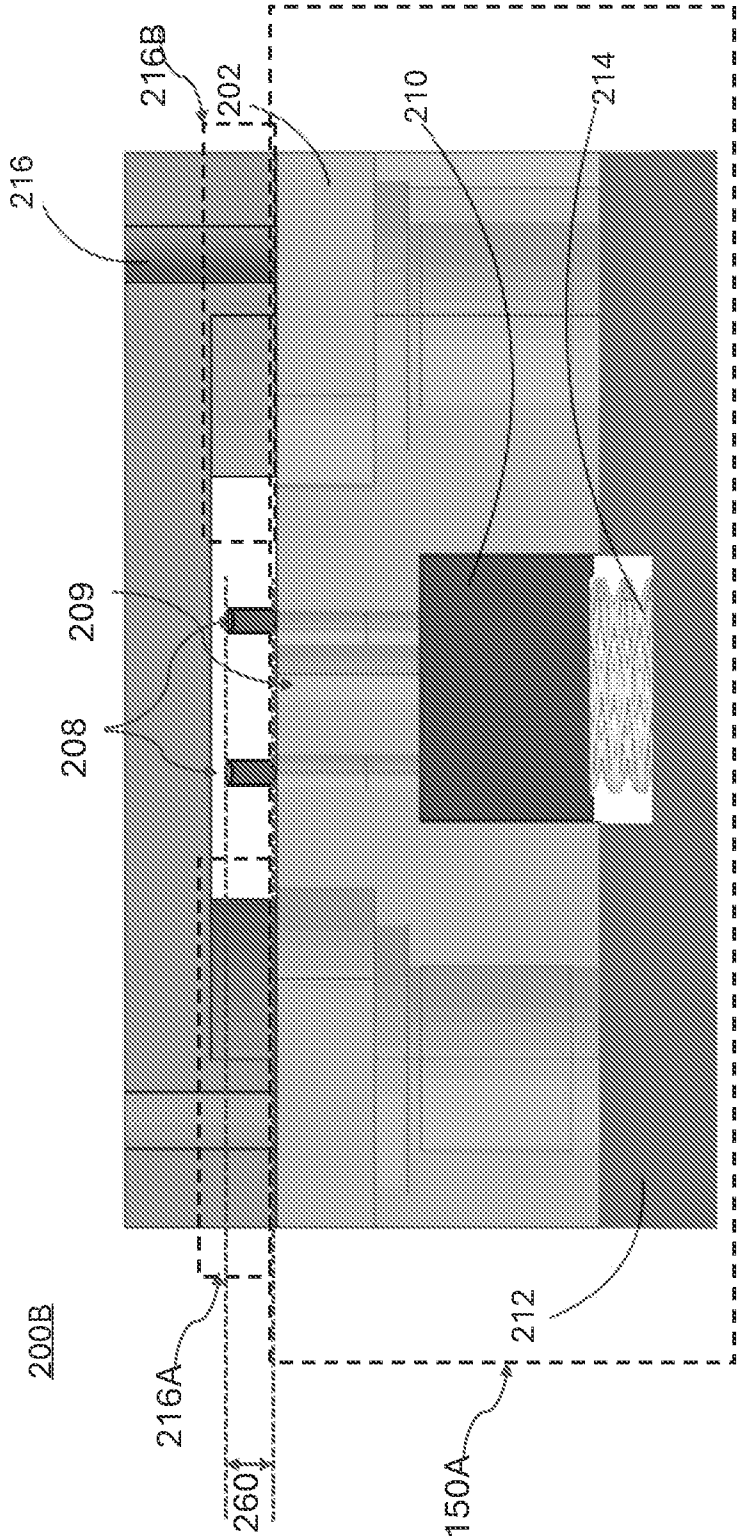


FIG. 2B

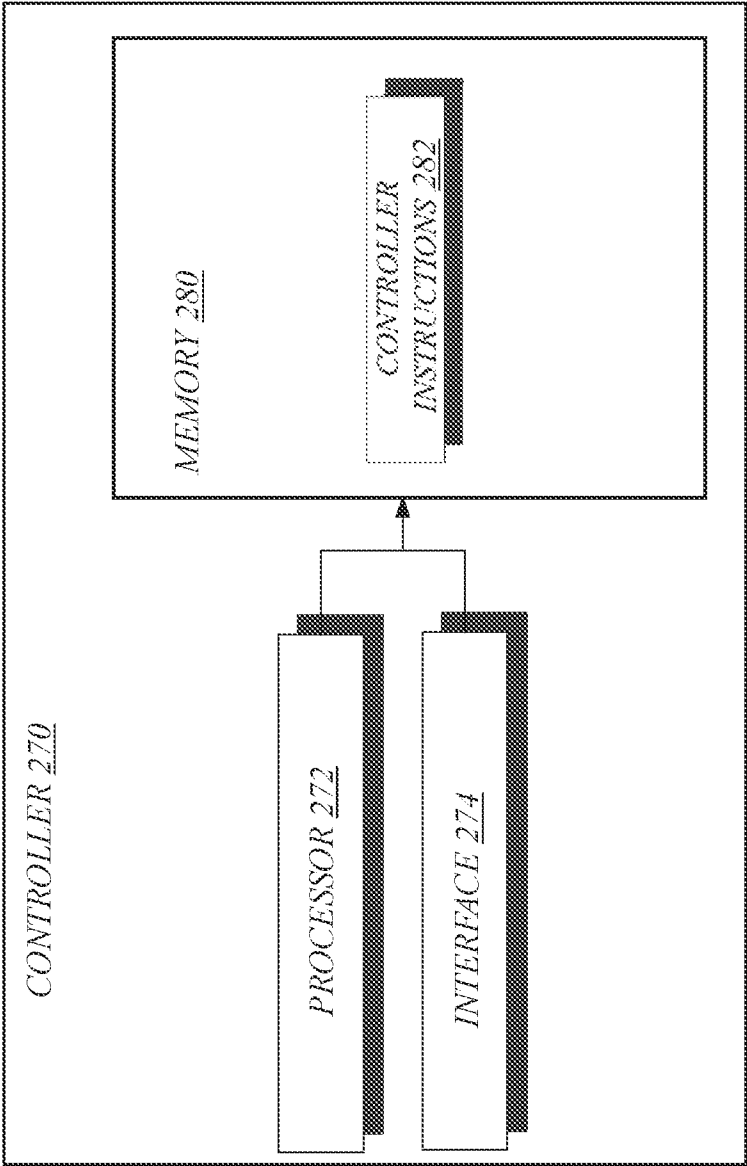


FIG. 2C

6/17

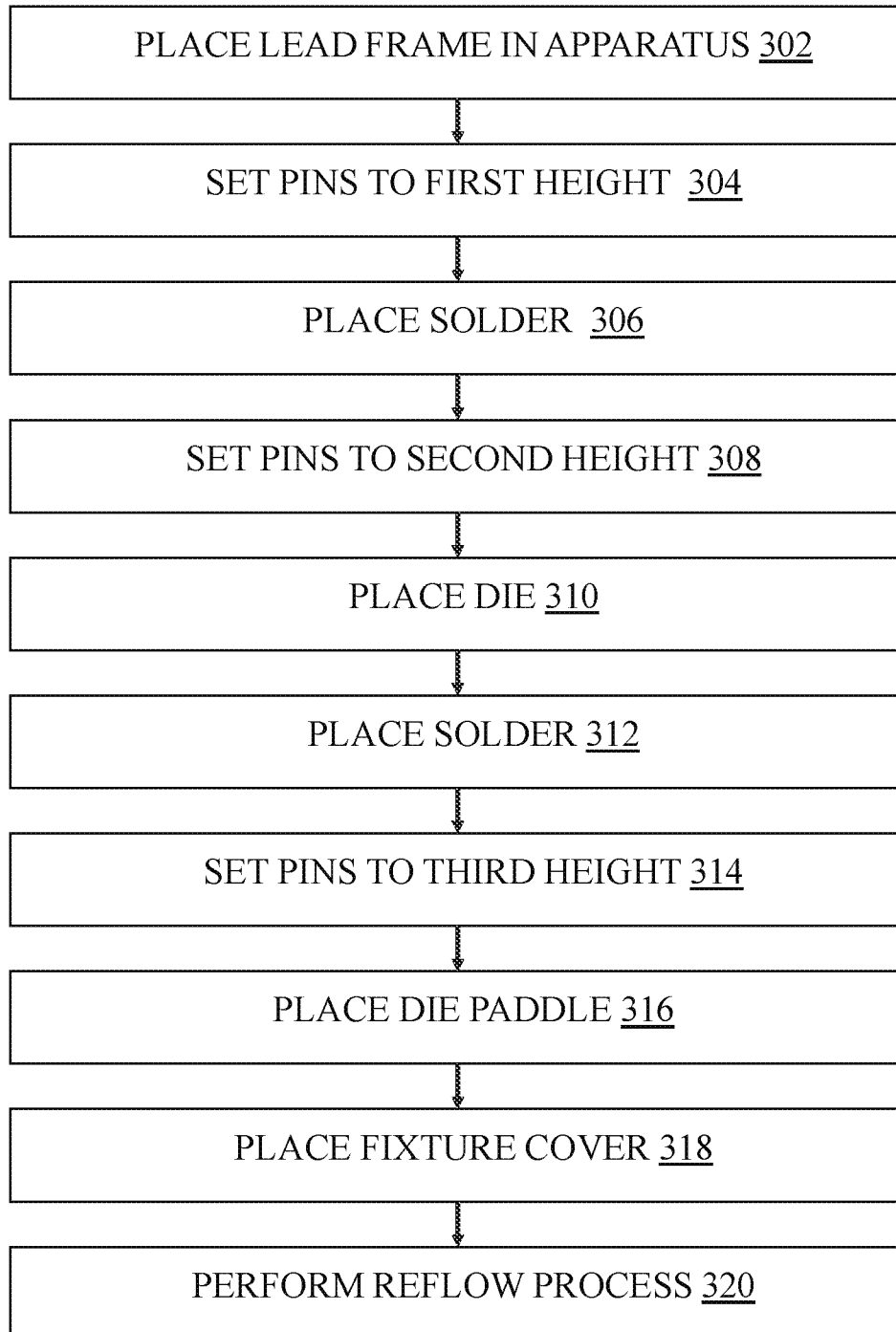


FIG. 3

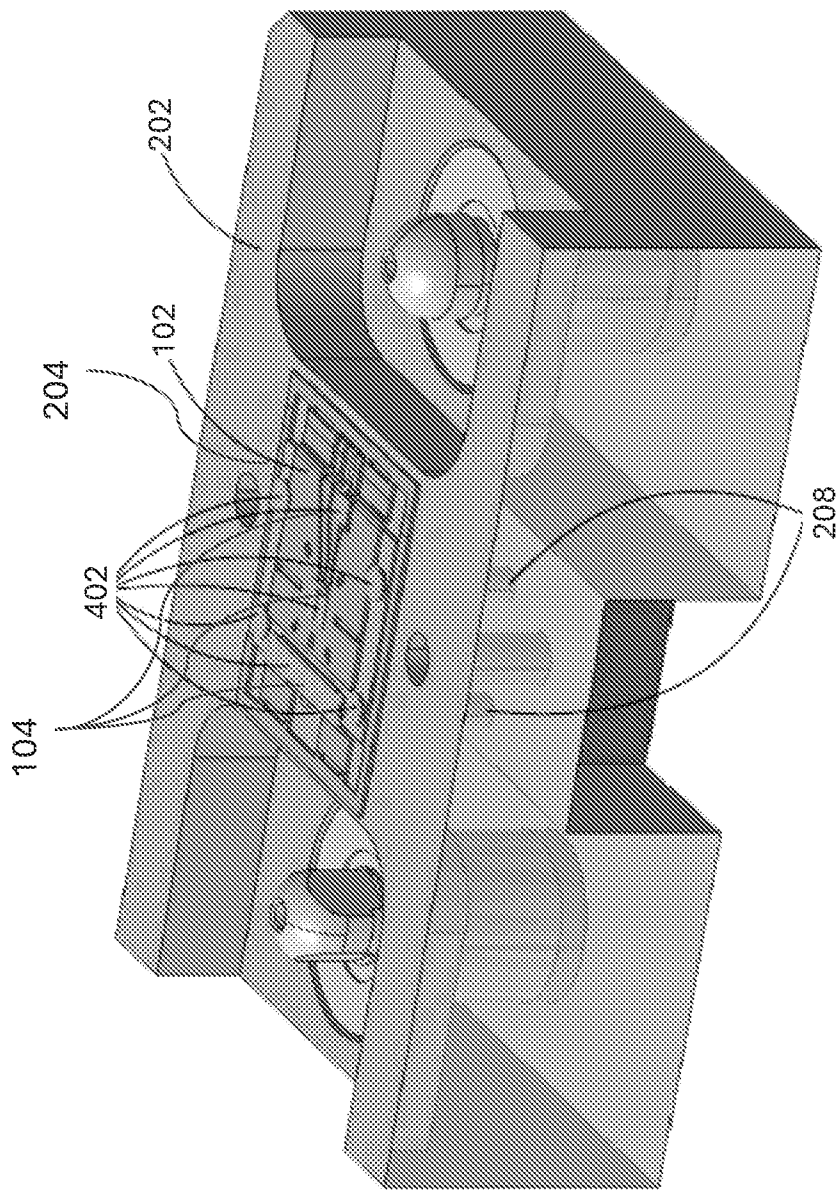


FIG. 4A

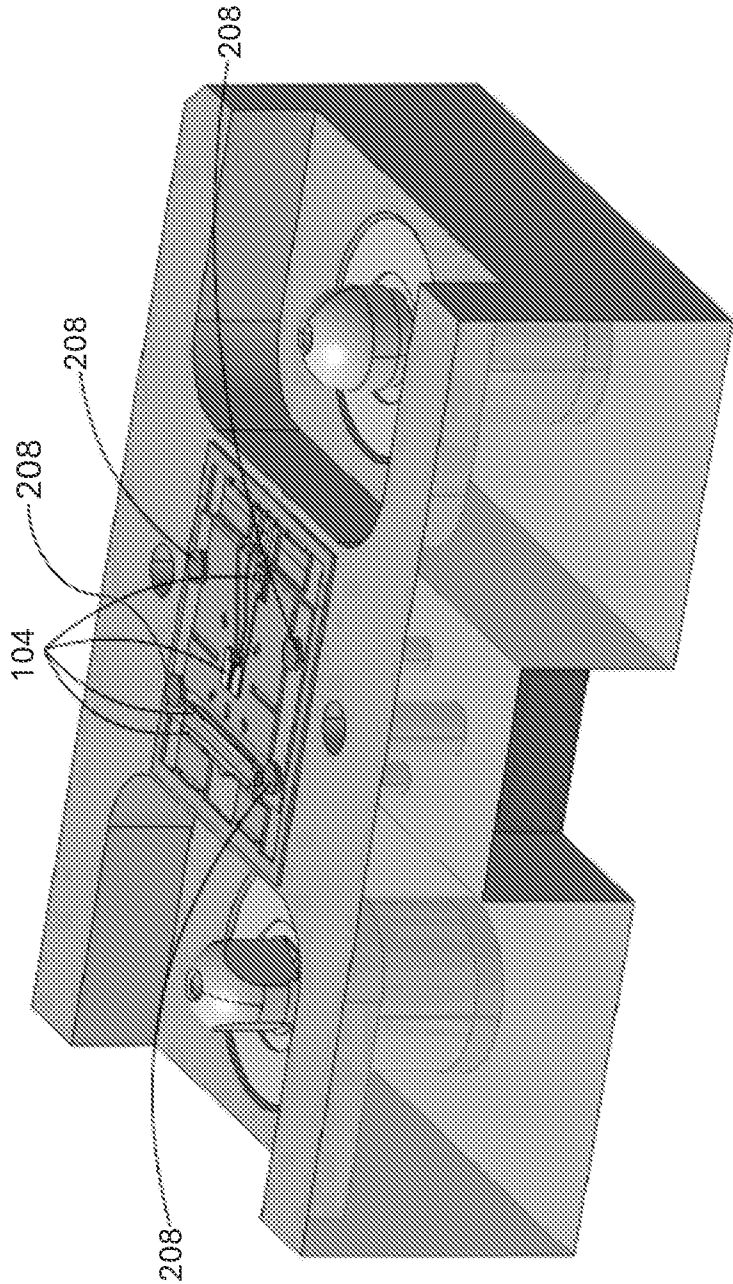


FIG. 4B

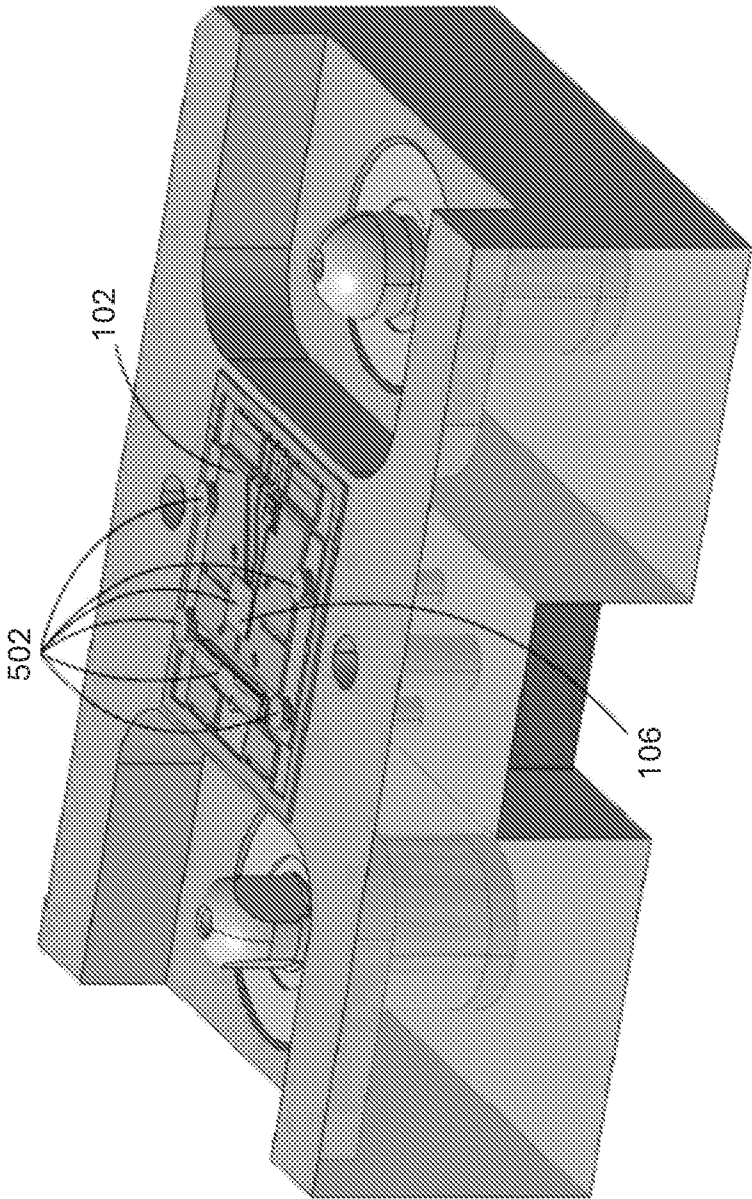


FIG. 5A

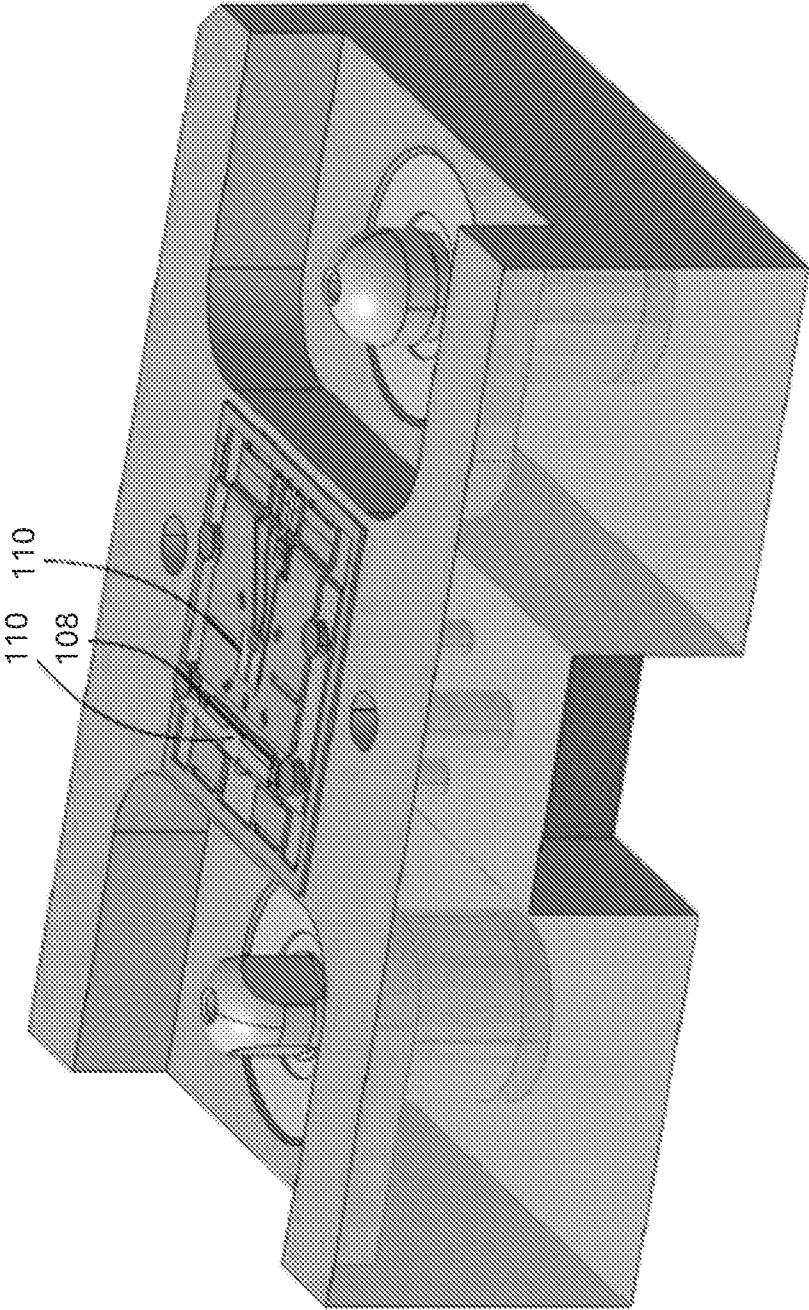


FIG. 5B

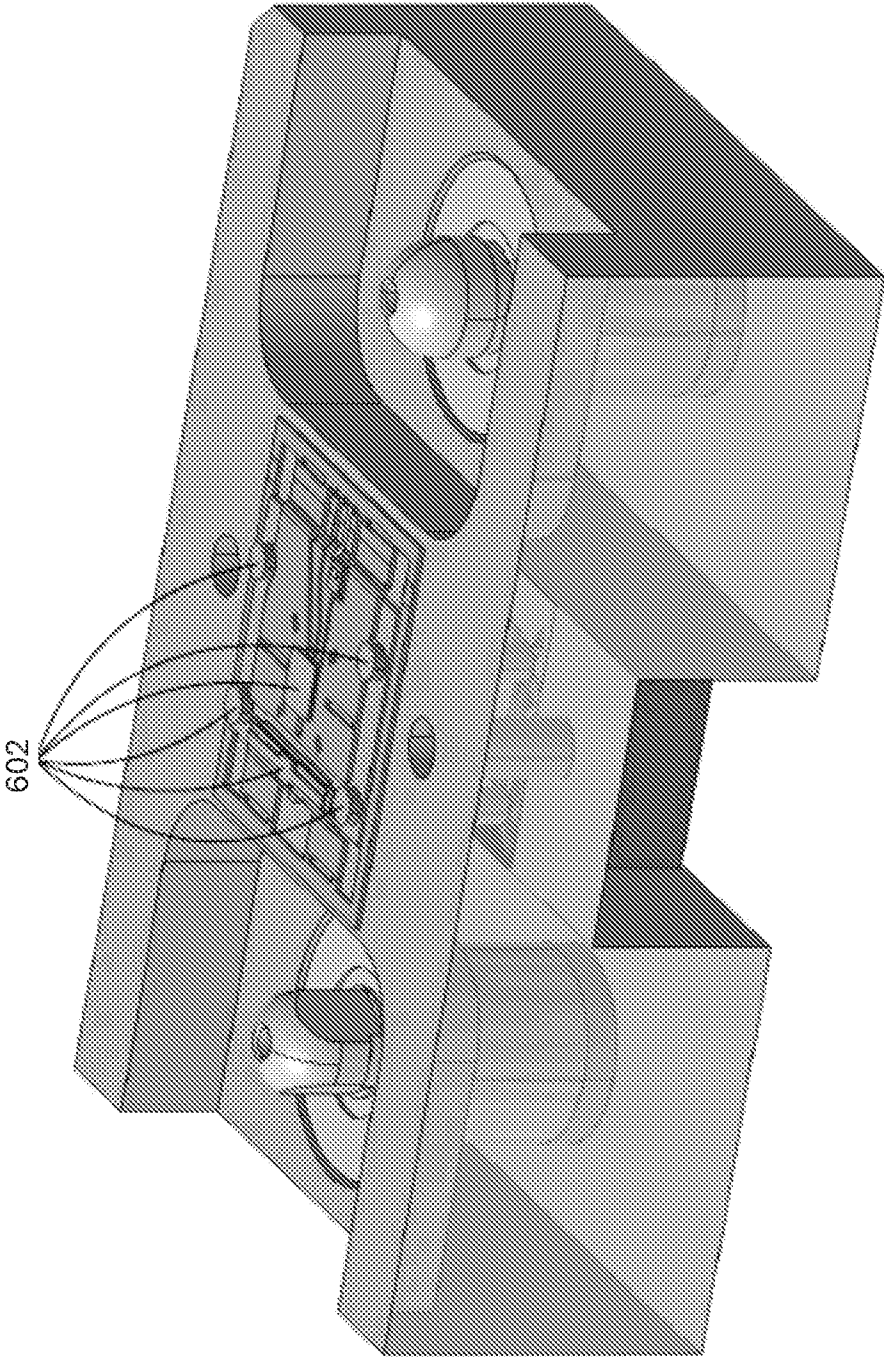


FIG. 6A

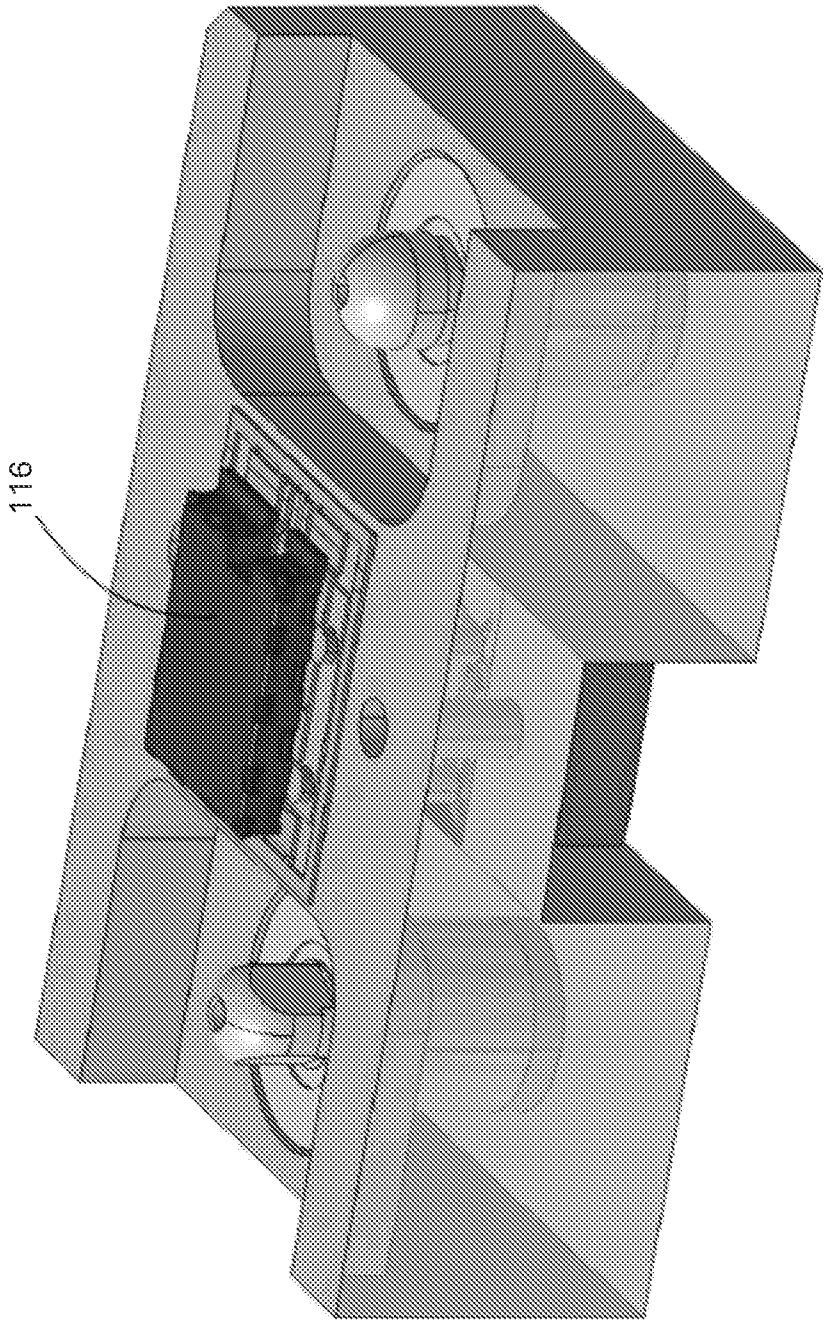


FIG. 6B

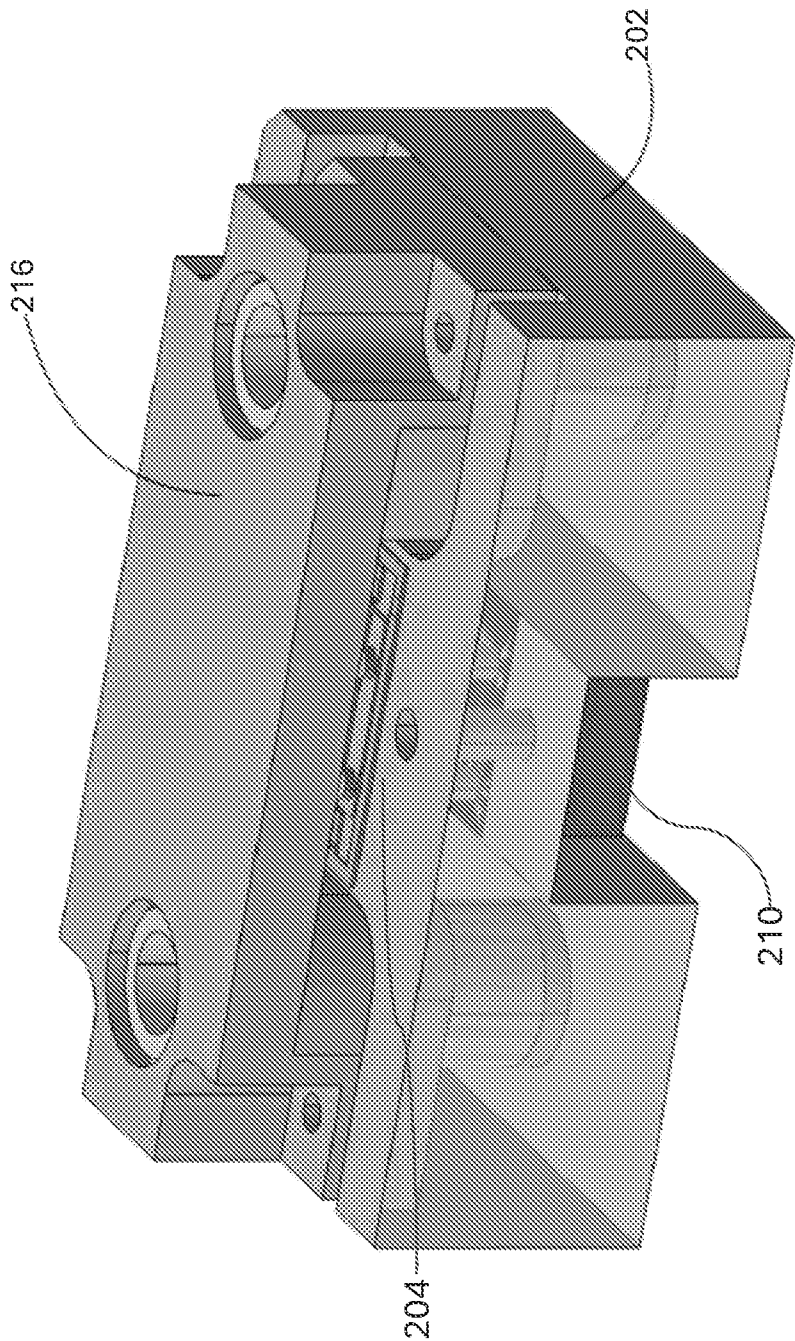


FIG. 7A

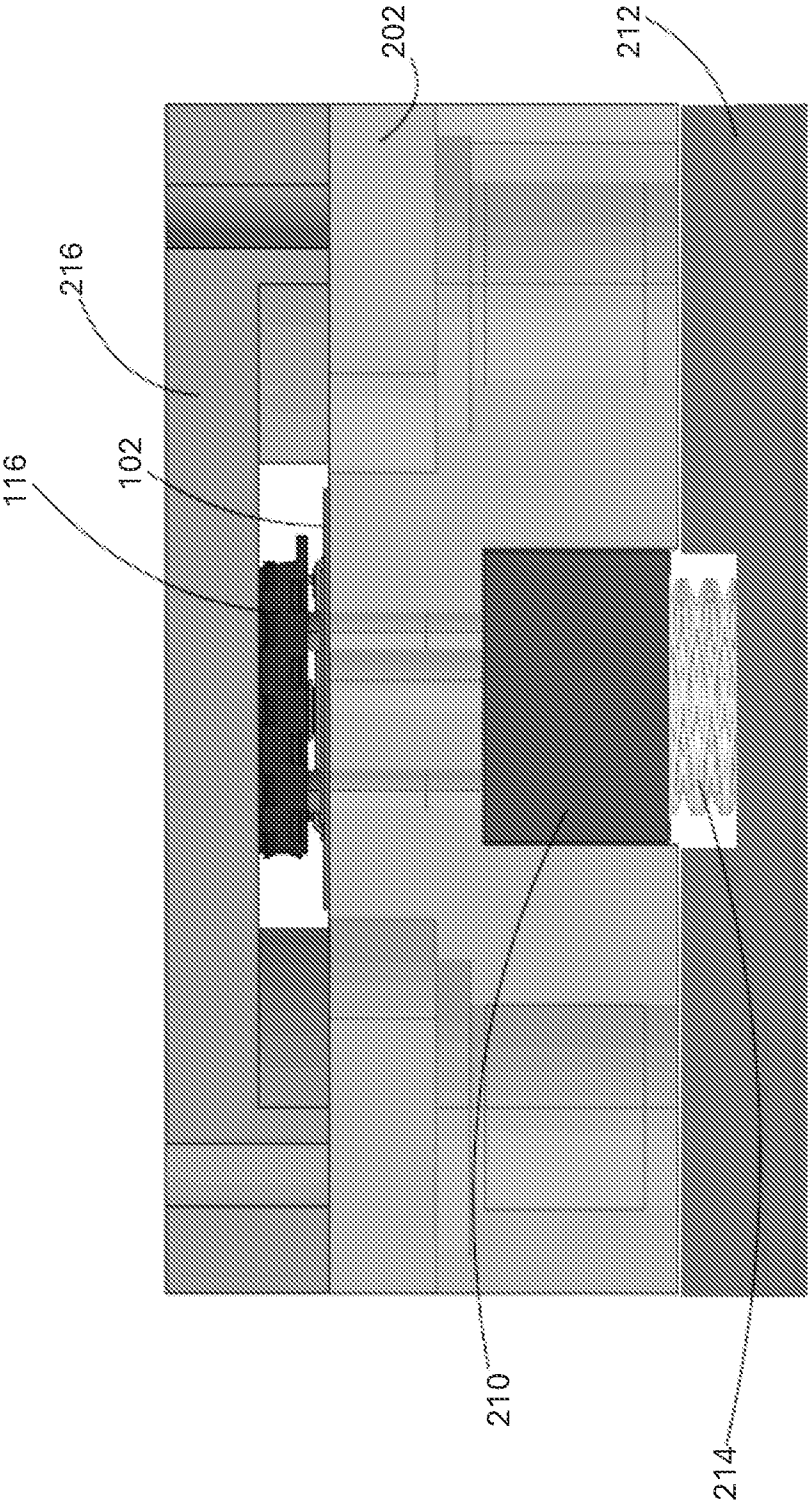


FIG. 7B

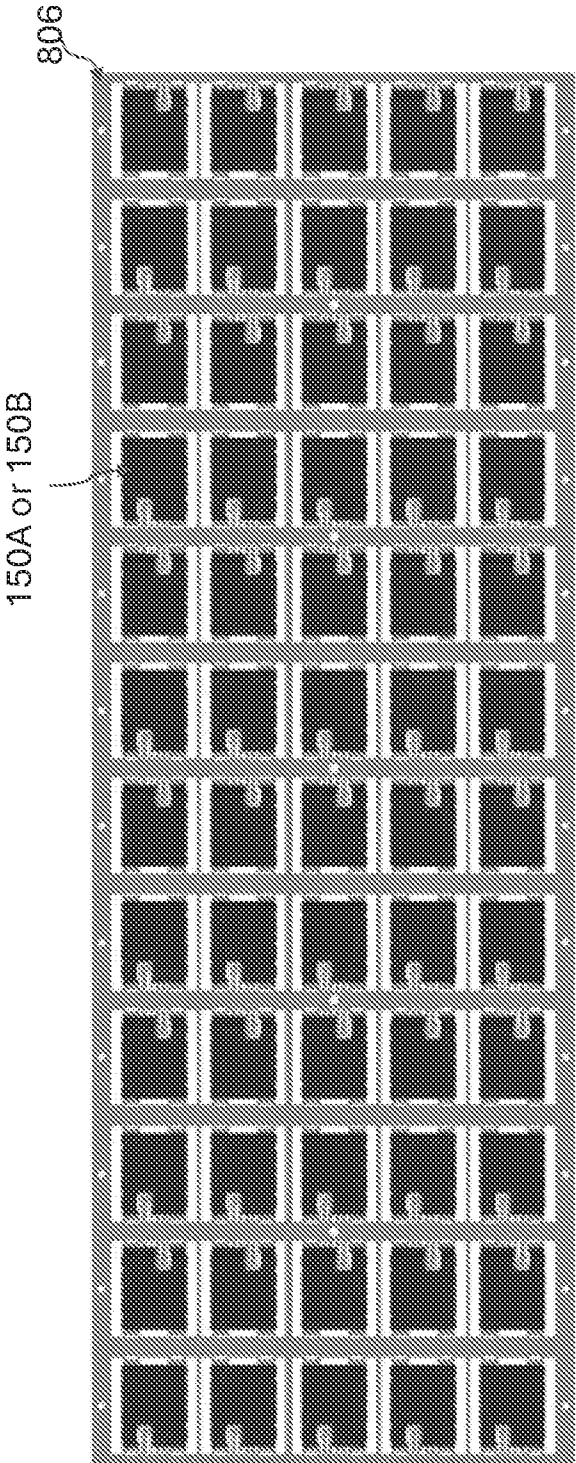


FIG. 8

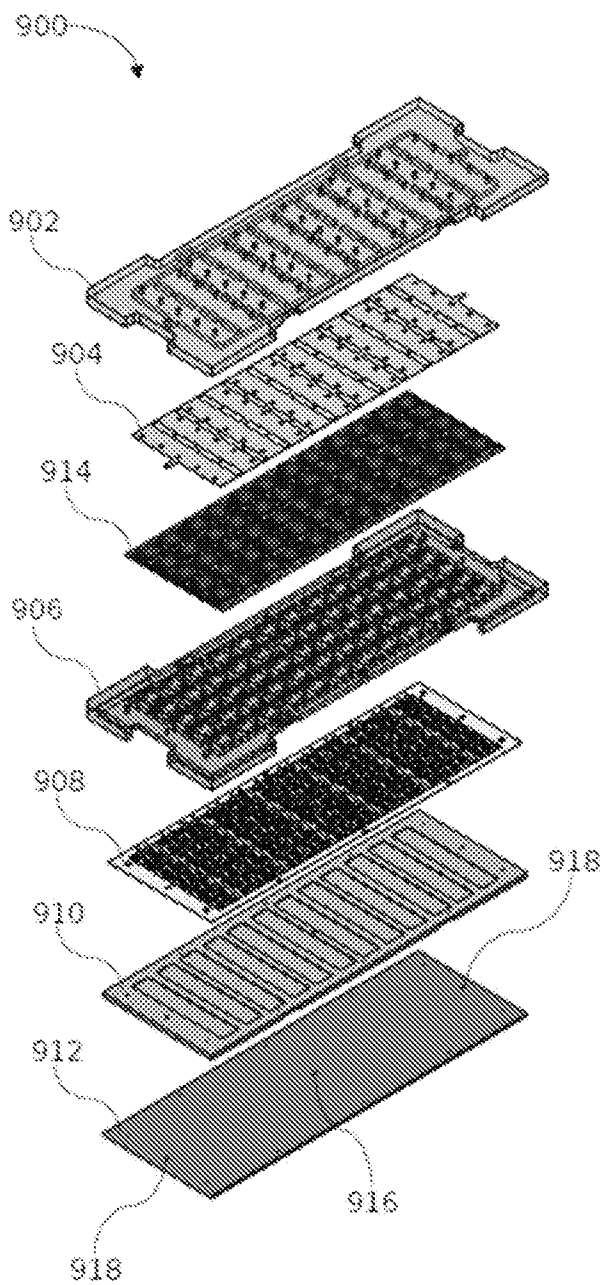


FIG. 9

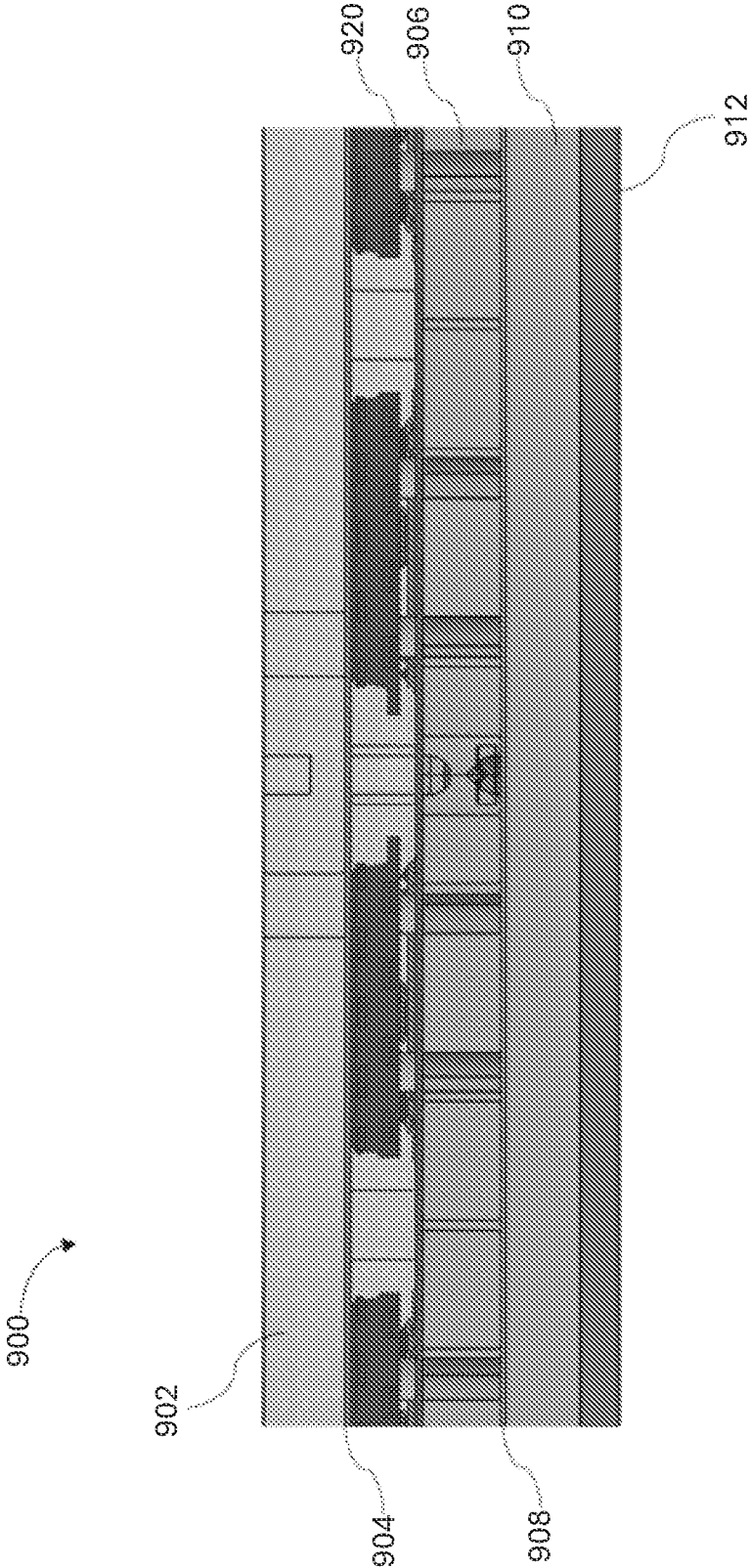


FIG. 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2024/037330

A. CLASSIFICATION OF SUBJECT MATTER INV. H01L21/48 H01L21/603 H01L23/495 H01L23/00 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) H01L Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015/371930 A1 (MERTO RUBY ANN MAYA [PH] ET AL) 24 December 2015 (2015-12-24)	1 - 19
A	paragraphs [0018] - [0023] paragraphs [0031] - [0035] paragraph [0038] figures 4, 8A-8D, 11 -----	20, 21
X	EP 3 016 135 A1 (FURUKAWA ELECTRIC CO LTD [JP]) 4 May 2016 (2016-05-04)	20, 21
A	paragraphs [0001], [0005] - [0007] paragraphs [0056] - [0058] figures 2A-2C -----	1 - 19
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 27 November 2024		Date of mailing of the international search report 02/01/2025
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Keller, Jan

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2024/037330

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015371930 A1	24-12-2015	NONE	
EP 3016135 A1	04-05-2016	EP 3016135 A1	04-05-2016
		JP 6178850 B2	09-08-2017
		JP WO2014208690 A1	23-02-2017
		WO 2014208690 A1	31-12-2014