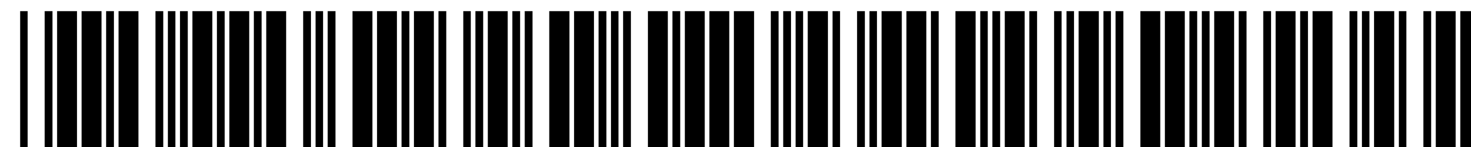
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Spory

(10) **Patent No.: US 10,431,510 B2**
(45) **Date of Patent: Oct. 1, 2019**

(54) **HERMETIC LID SEAL PRINTING METHOD**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/954,256**

(22) Filed: **Apr. 16, 2018**

(65) **Prior Publication Data**

US 2018/0240722 A1 Aug. 23, 2018

Related U.S. Application Data

(60) Provisional application No. 62/632,249, filed on Feb. 19, 2018, provisional application No. 62/569,717, filed on Oct. 9, 2017.

(51) **Int. Cl.**
H01L 23/10 (2006.01)
H01L 21/48 (2006.01)
H01L 21/50 (2006.01)

(52) **U.S. Cl.**
CPC ***H01L 23/10*** (2013.01); ***H01L 21/4803*** (2013.01); ***H01L 21/50*** (2013.01)

(58) **Field of Classification Search**
CPC H01L 23/10; H01L 21/50; H01L 21/4803
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,315,486 A * 5/1994 Fillion H01L 23/057 361/795
5,372,296 A 12/1994 Konecke et al.
5,771,562 A * 6/1998 Harvey, III H01L 51/5243 29/592.1
6,037,193 A 3/2000 Interrante et al.
6,216,939 B1 4/2001 Thackara
6,222,737 B1 4/2001 Ross
6,360,433 B1 3/2002 Ross
8,129,032 B2 3/2012 Dabadie et al.
9,165,961 B2 10/2015 Iwama et al.
9,196,555 B1 * 11/2015 Lower H01L 23/24
2003/0183920 A1 10/2003 Goodrich et al.
2006/0067641 A1 * 3/2006 Palmateer B81C 1/00285 385/147
2008/0217752 A1 * 9/2008 Hata B81C 1/00269 257/686
2009/0309459 A1 * 12/2009 Ogashiwa B22F 1/0074 310/348
2014/0252584 A1 * 9/2014 Spory H01L 24/83 257/690

* cited by examiner

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(57) **ABSTRACT**

A method is provided. The method includes one or more of securing a die into a cavity of a hermetic package base, providing one or more bond connections to the die, placing a hermetic package lid on the package base, and 3D printing, by a 3D printer, hermetic lid seal material to a joint between the hermetic package base and the hermetic package lid, at a temperature at or below 100 degrees Celsius.

20 Claims, 11 Drawing Sheets

Applying Hermetic Overspray with 3D Printer

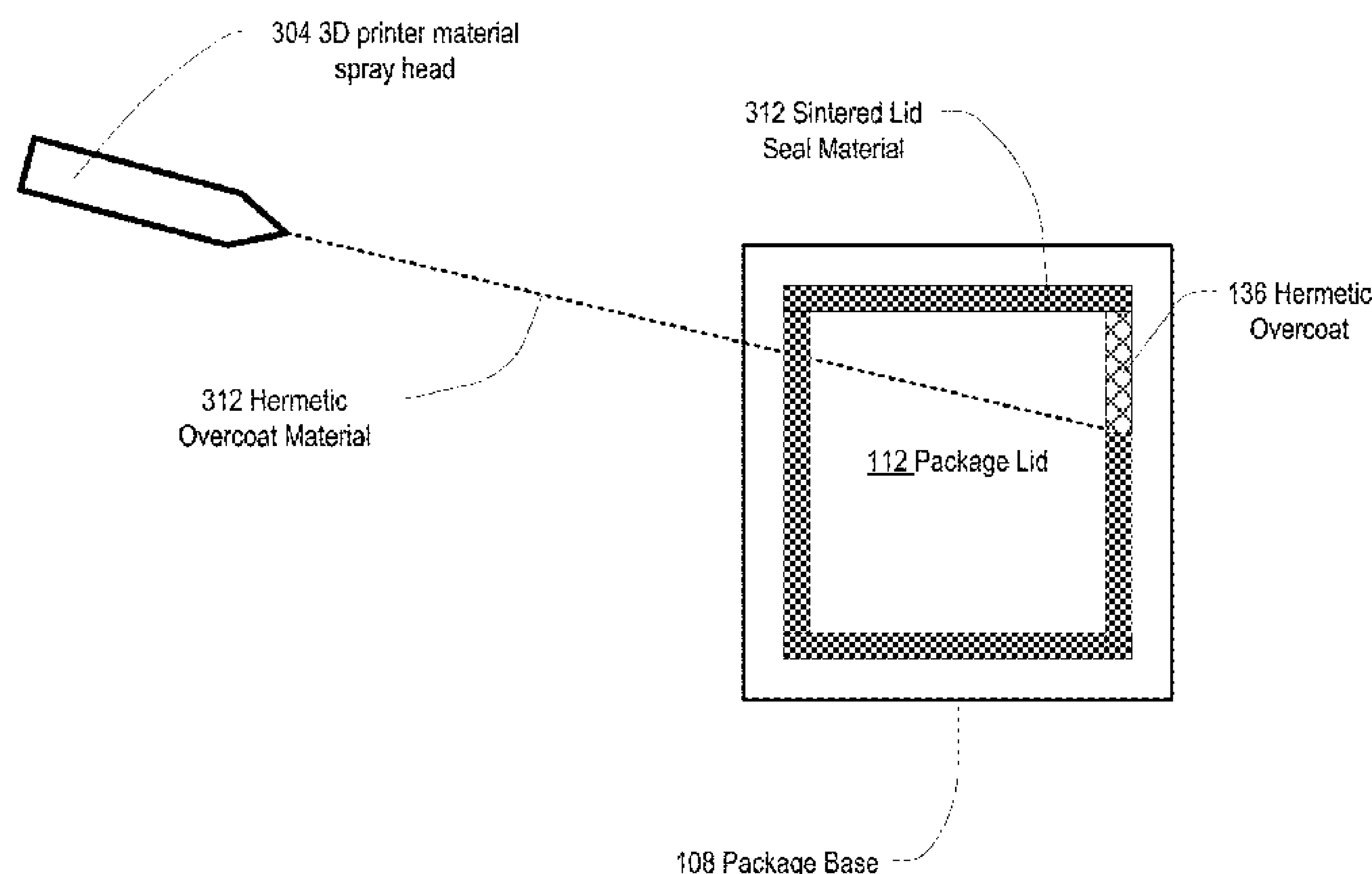


Fig. 1A Hermetic Seal Configuration

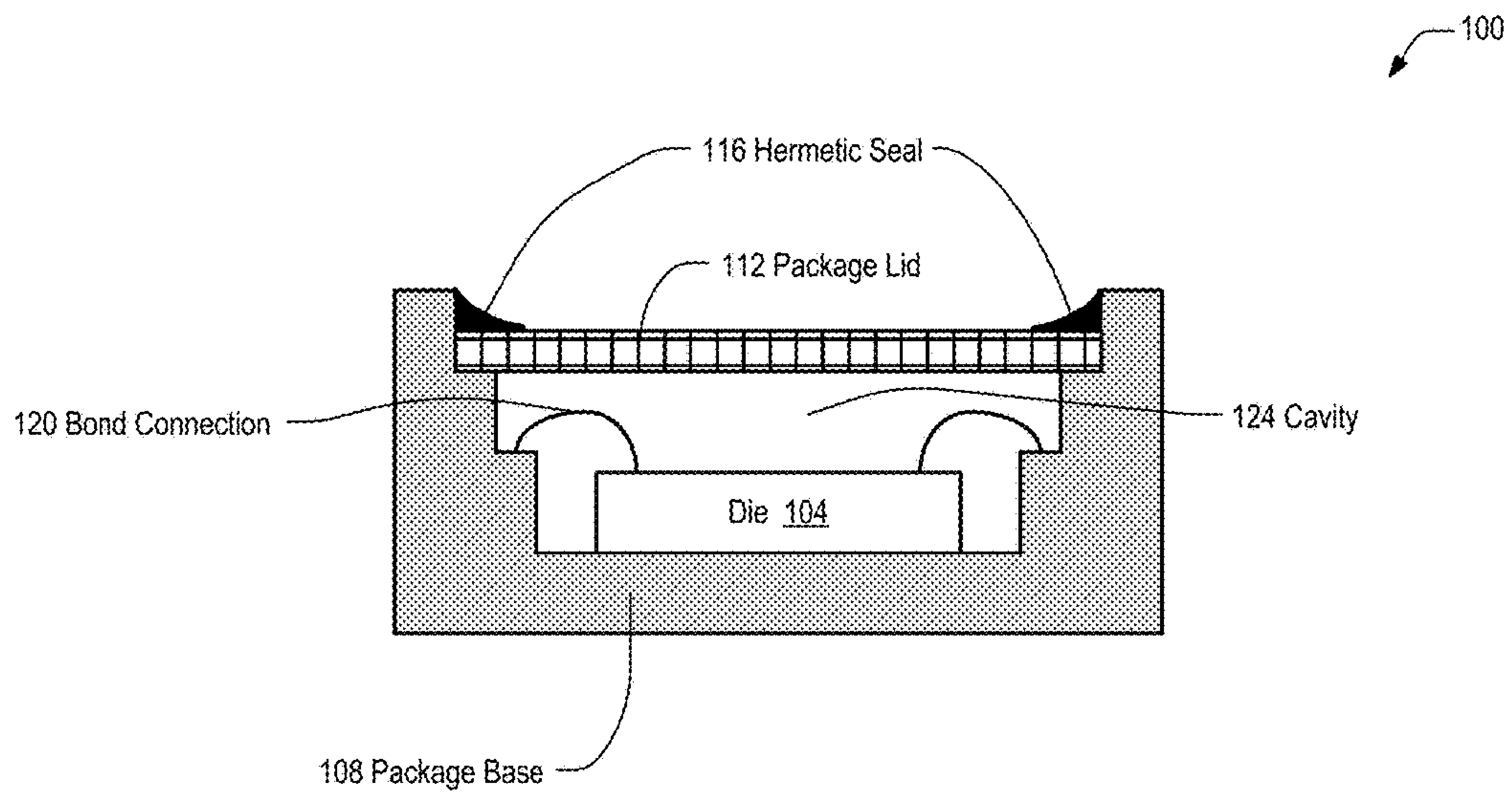


Fig. 1B Hermetic Seal Configuration

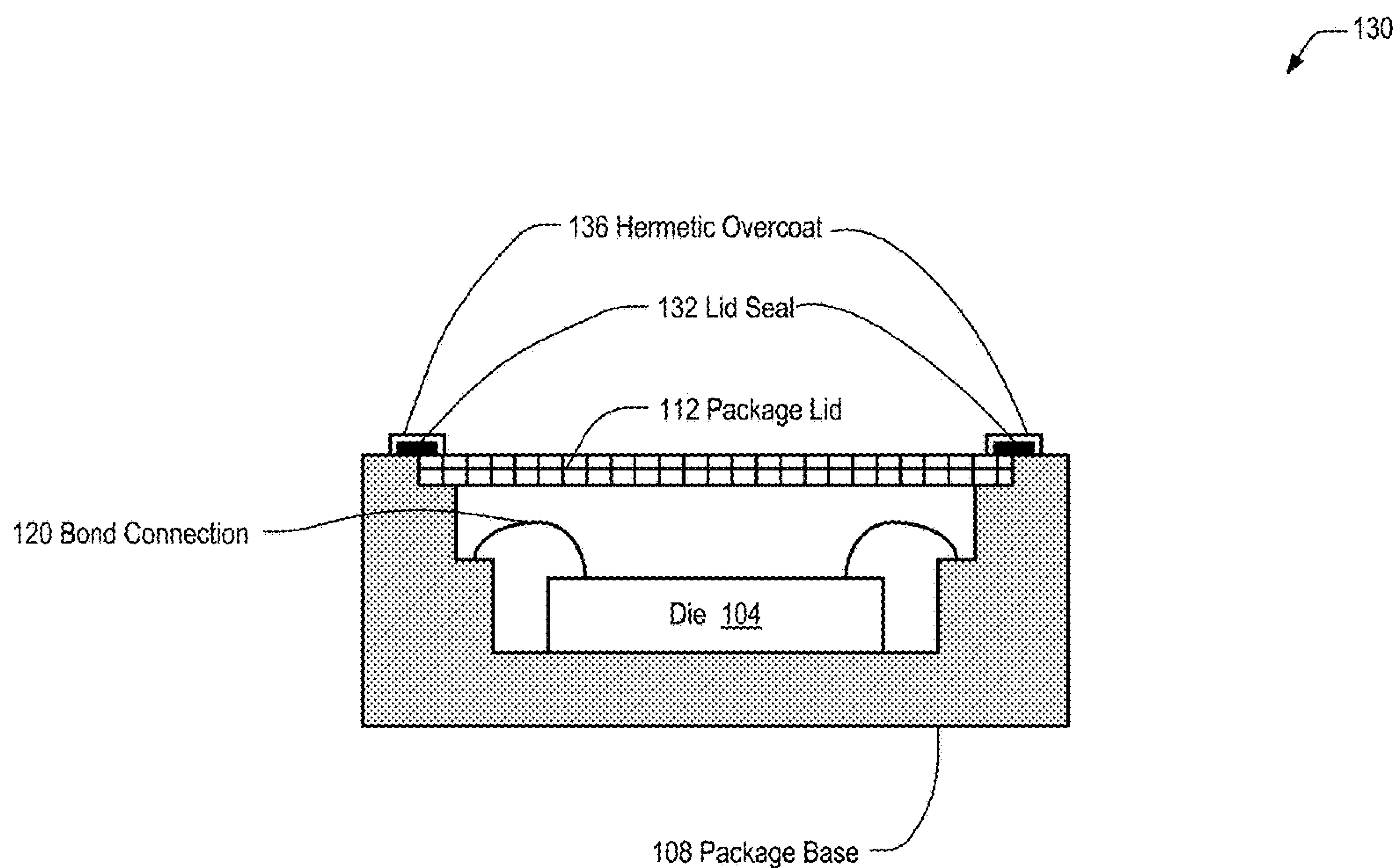


Fig. 1C Hermetic Seal Configuration

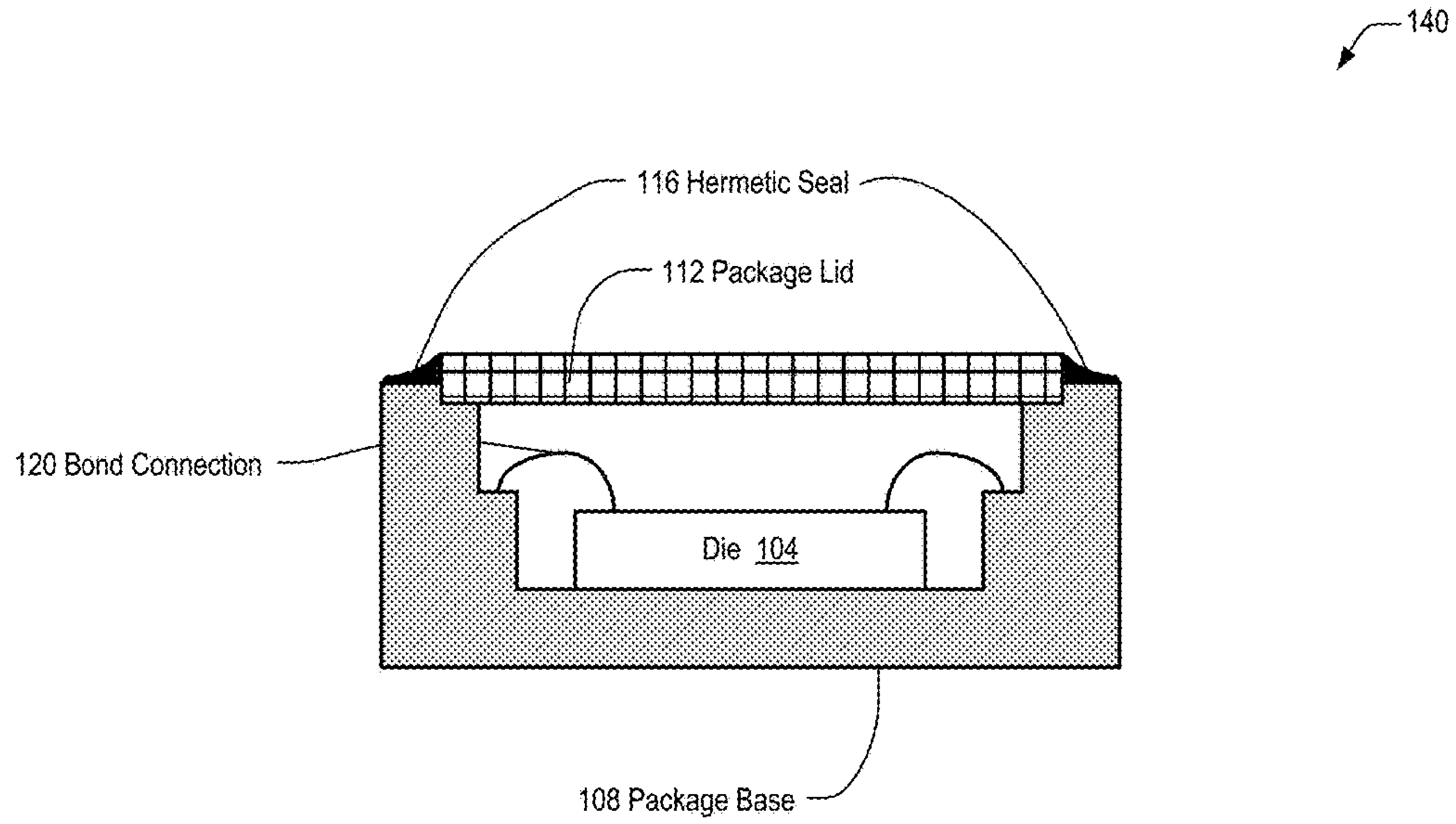


Fig. 1D Hermetic Seal Configuration

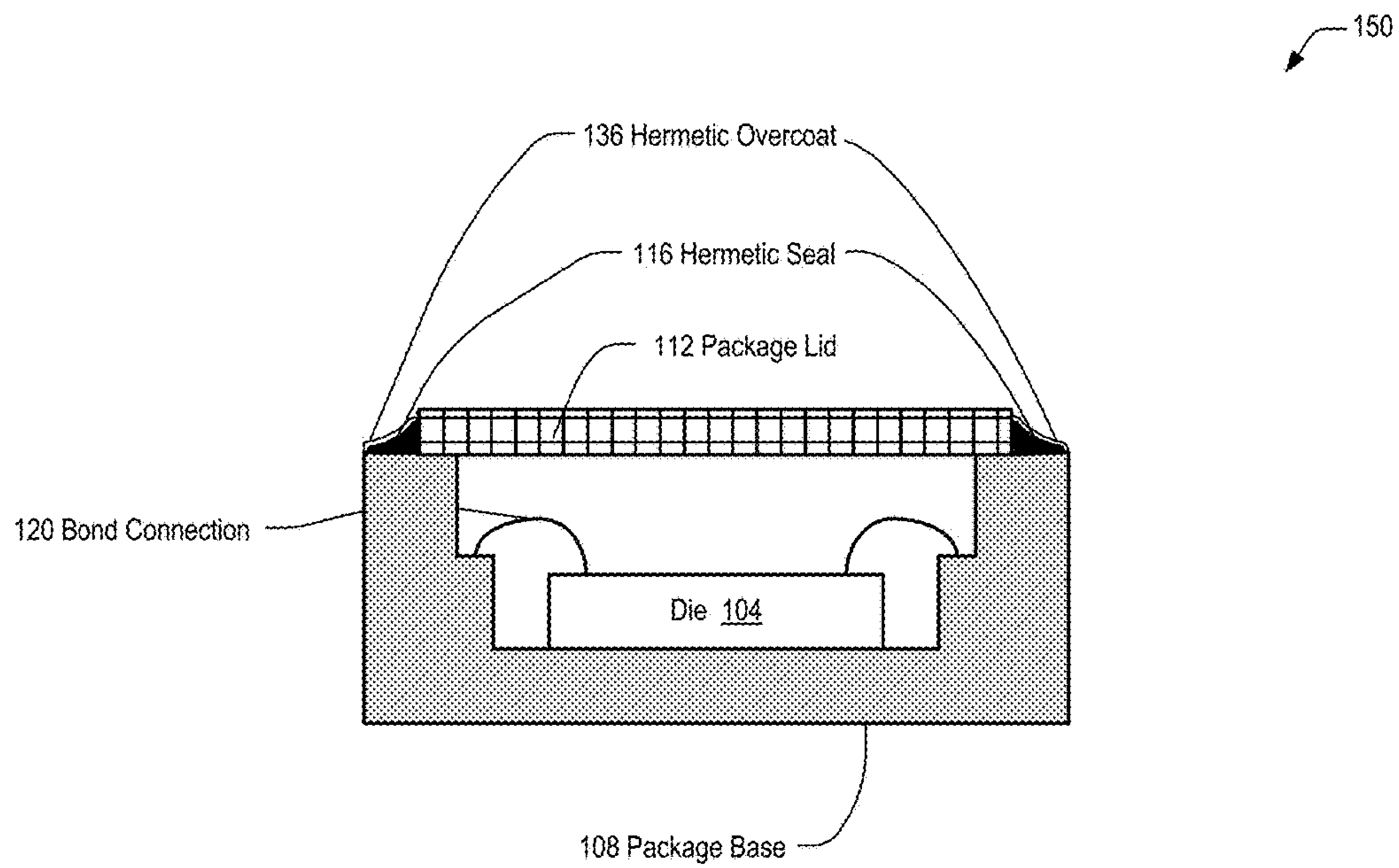


Fig. 2A Applying Hermetic Lid Seal Material with 3D Printer

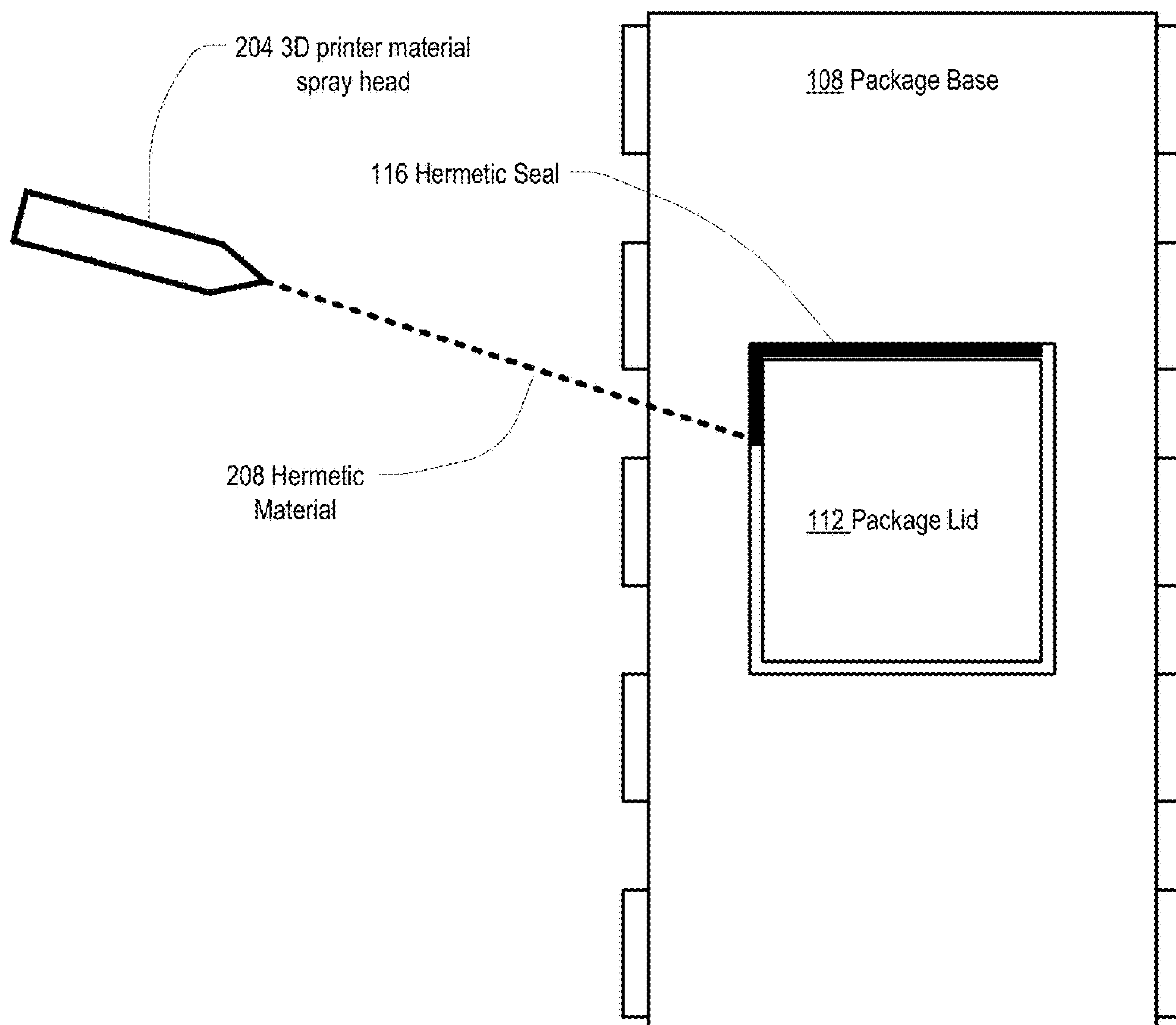


Fig. 2B Laser Sintering Hermetic Lid Seal Material

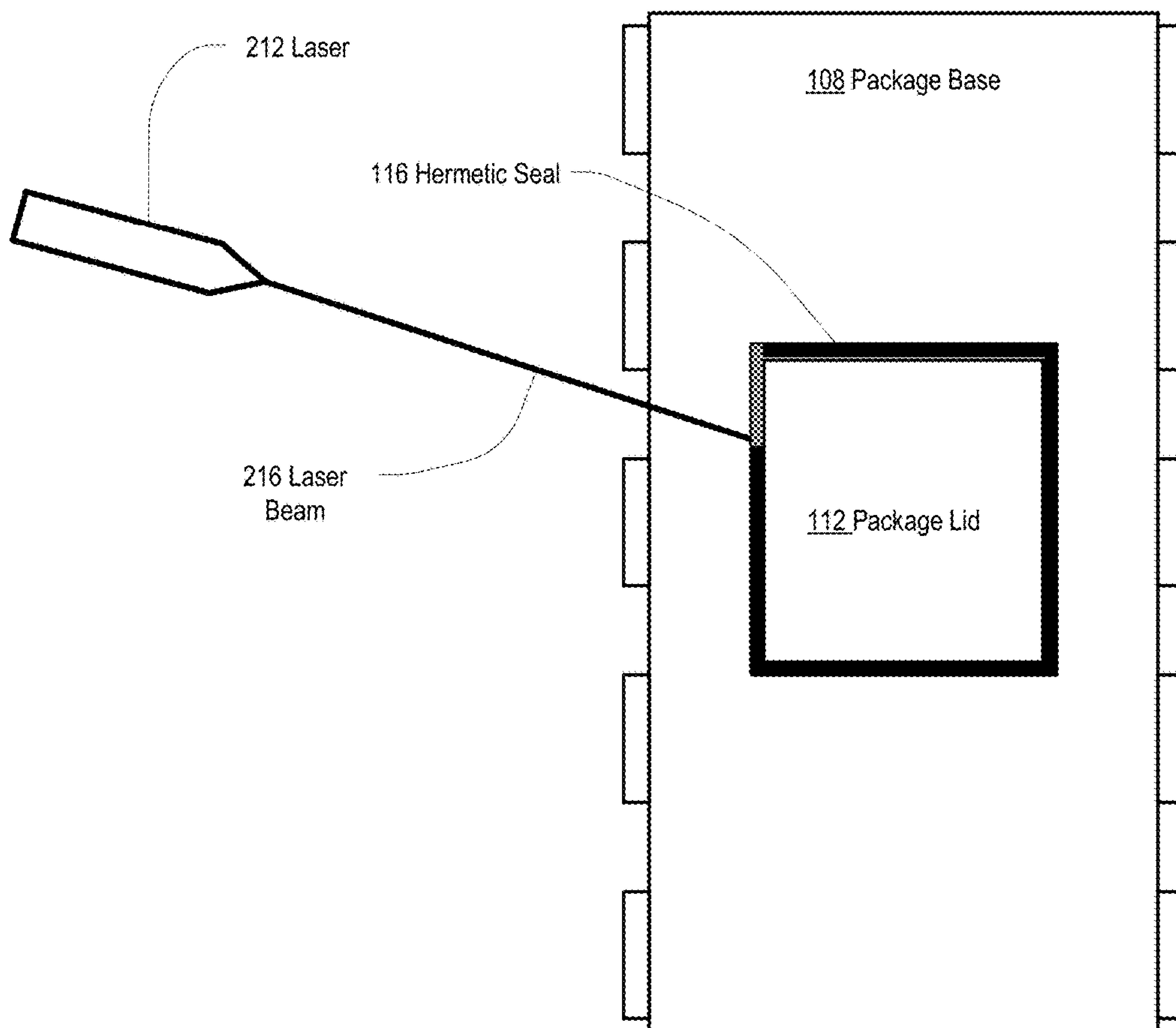


Fig. 2C Packaged Integrated Circuit with Hermetic Lid Seal

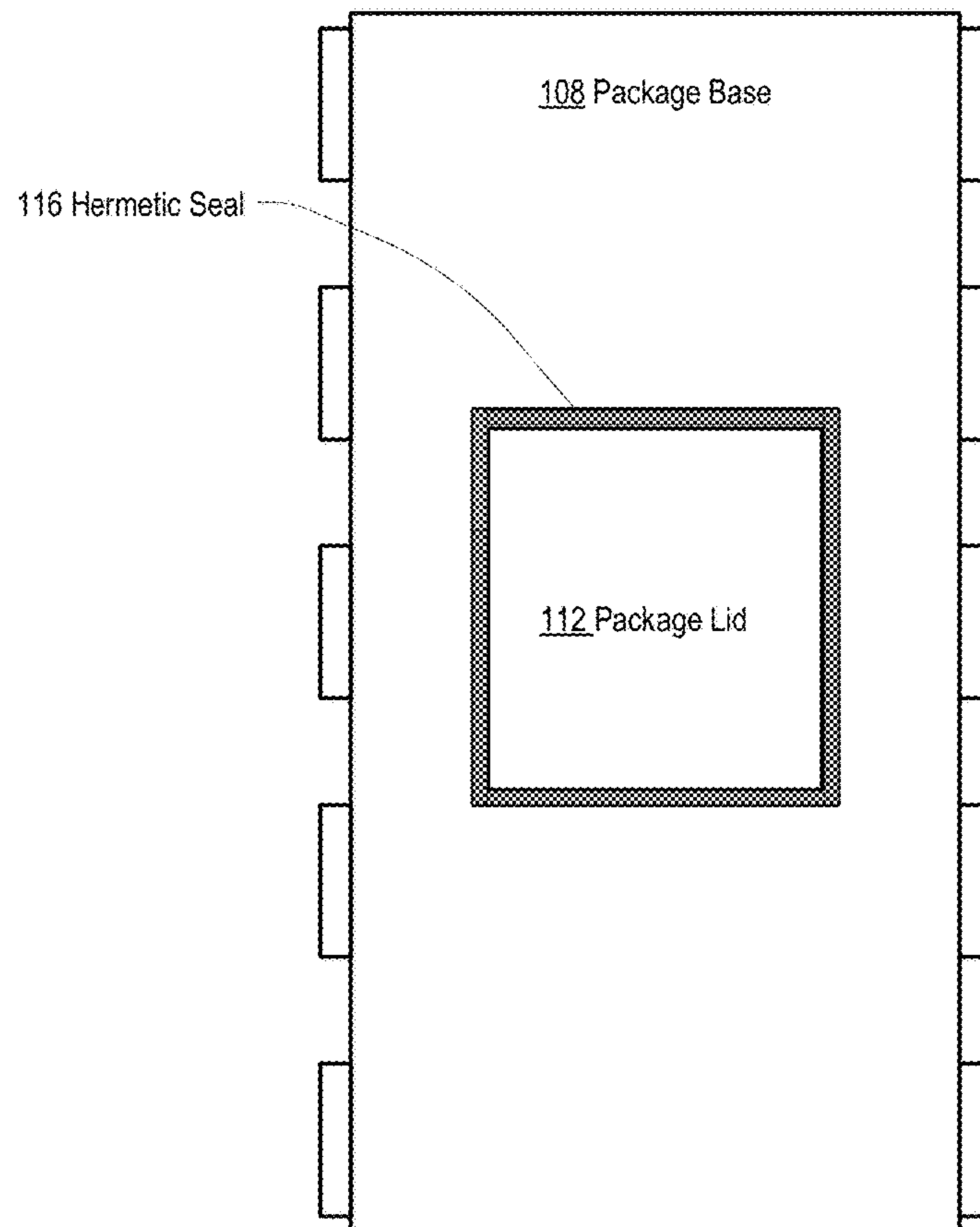


Fig. 3A Applying Lid Seal Material with 3D Printer

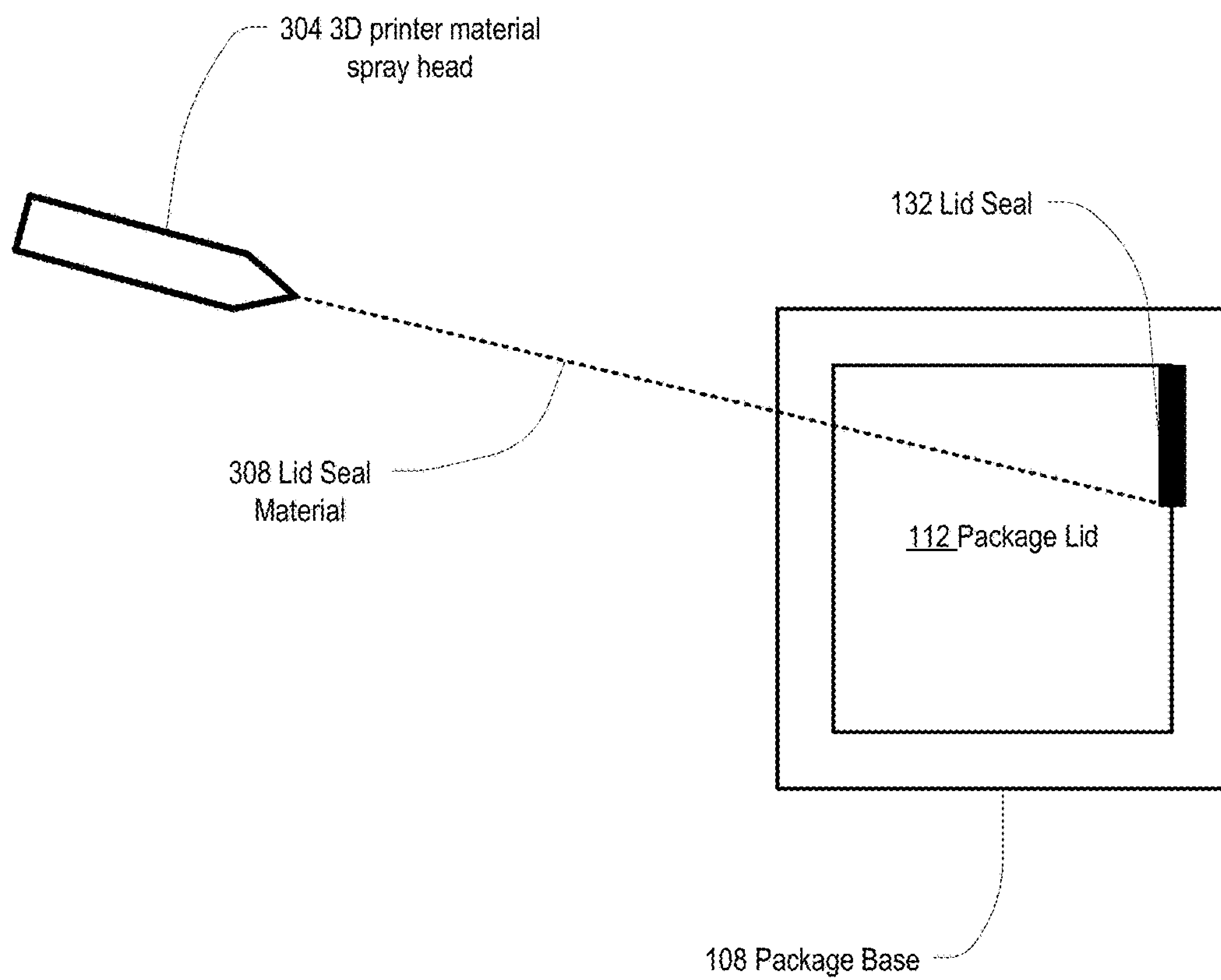


Fig. 3B Laser Sintering Lid Seal Material

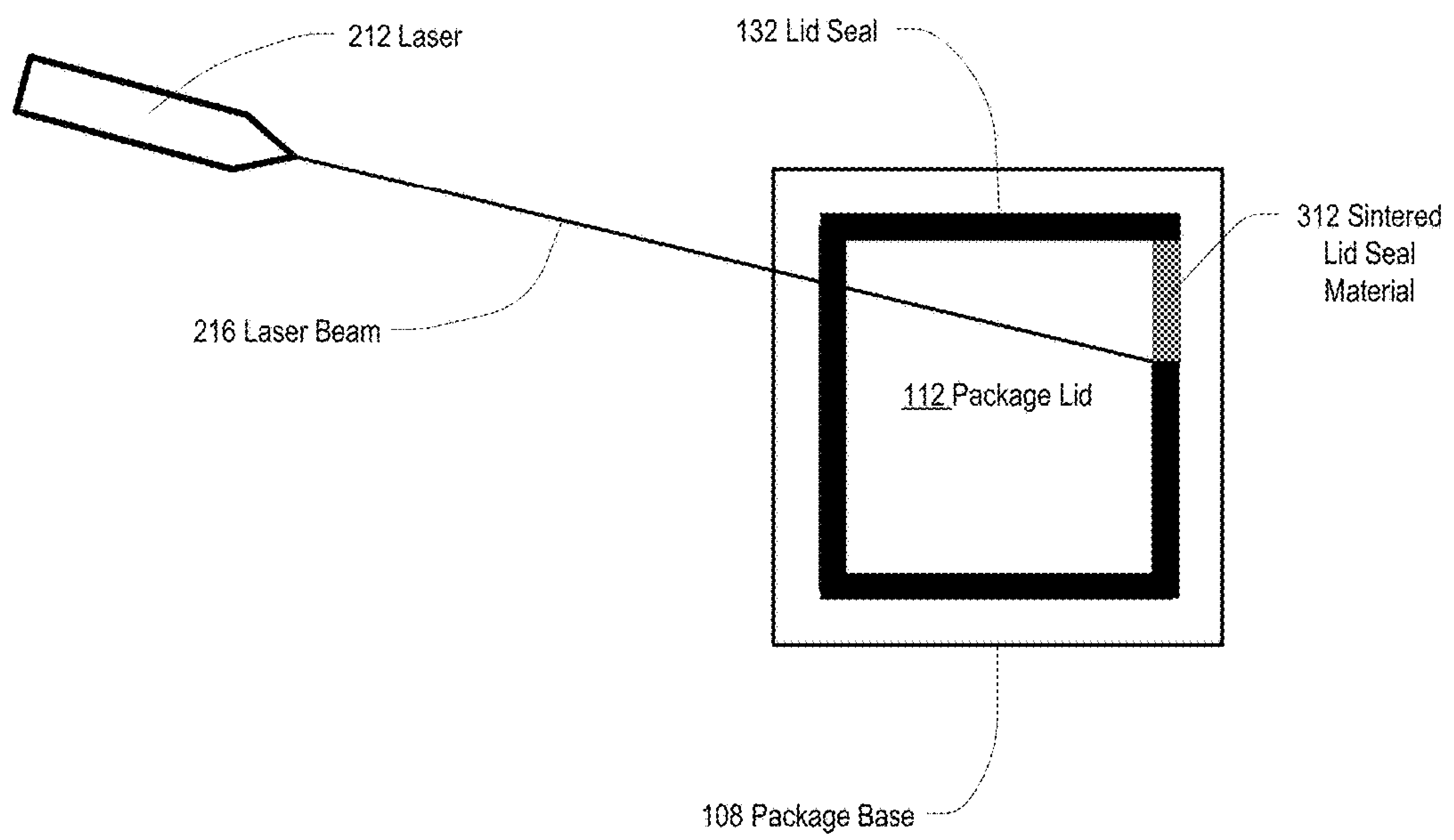


Fig. 3C Applying Hermetic Overspray with 3D Printer

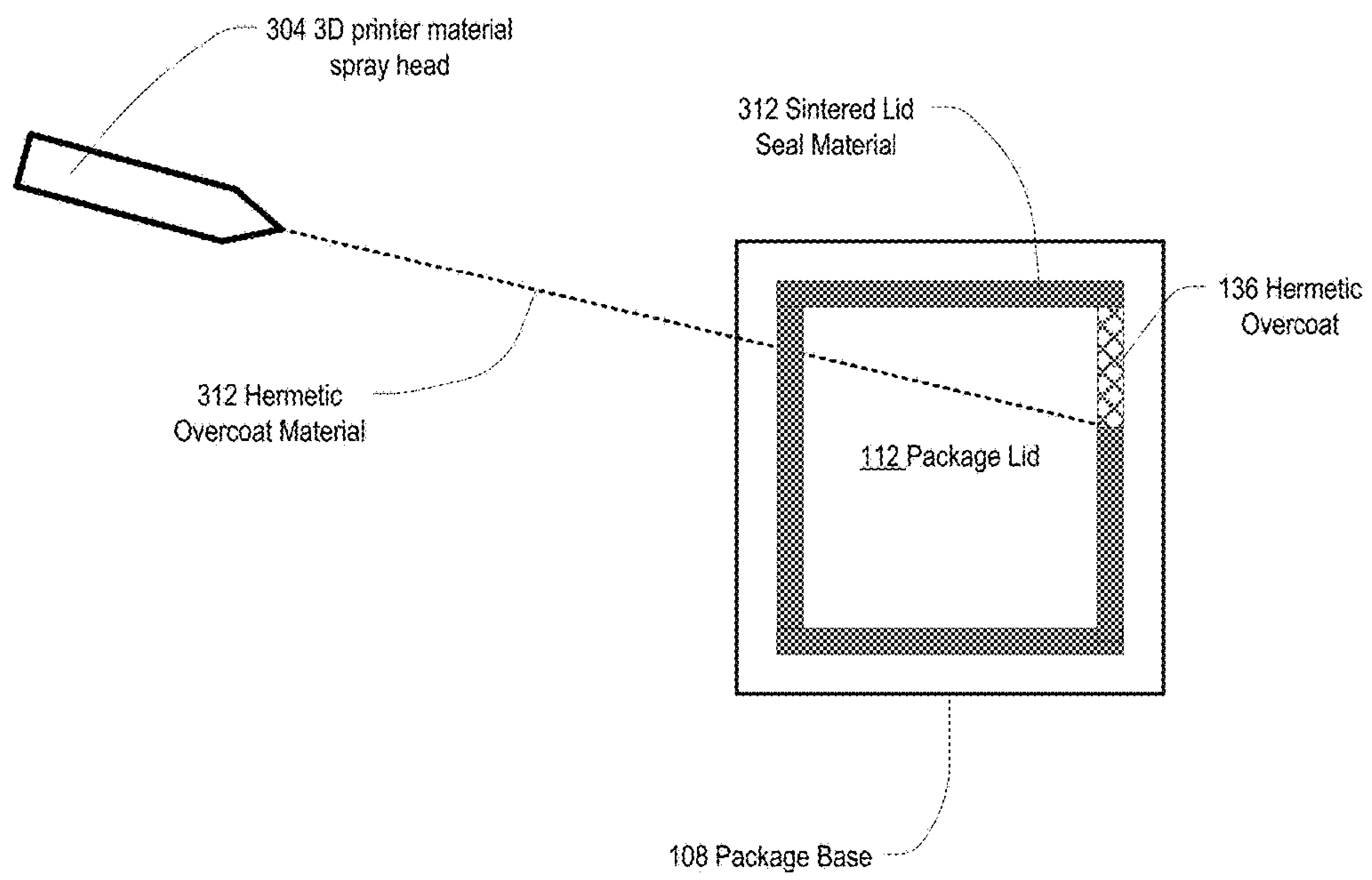


Fig. 3D Packaged Integrated Circuit with Lid Seal and Hermetic Overcoat

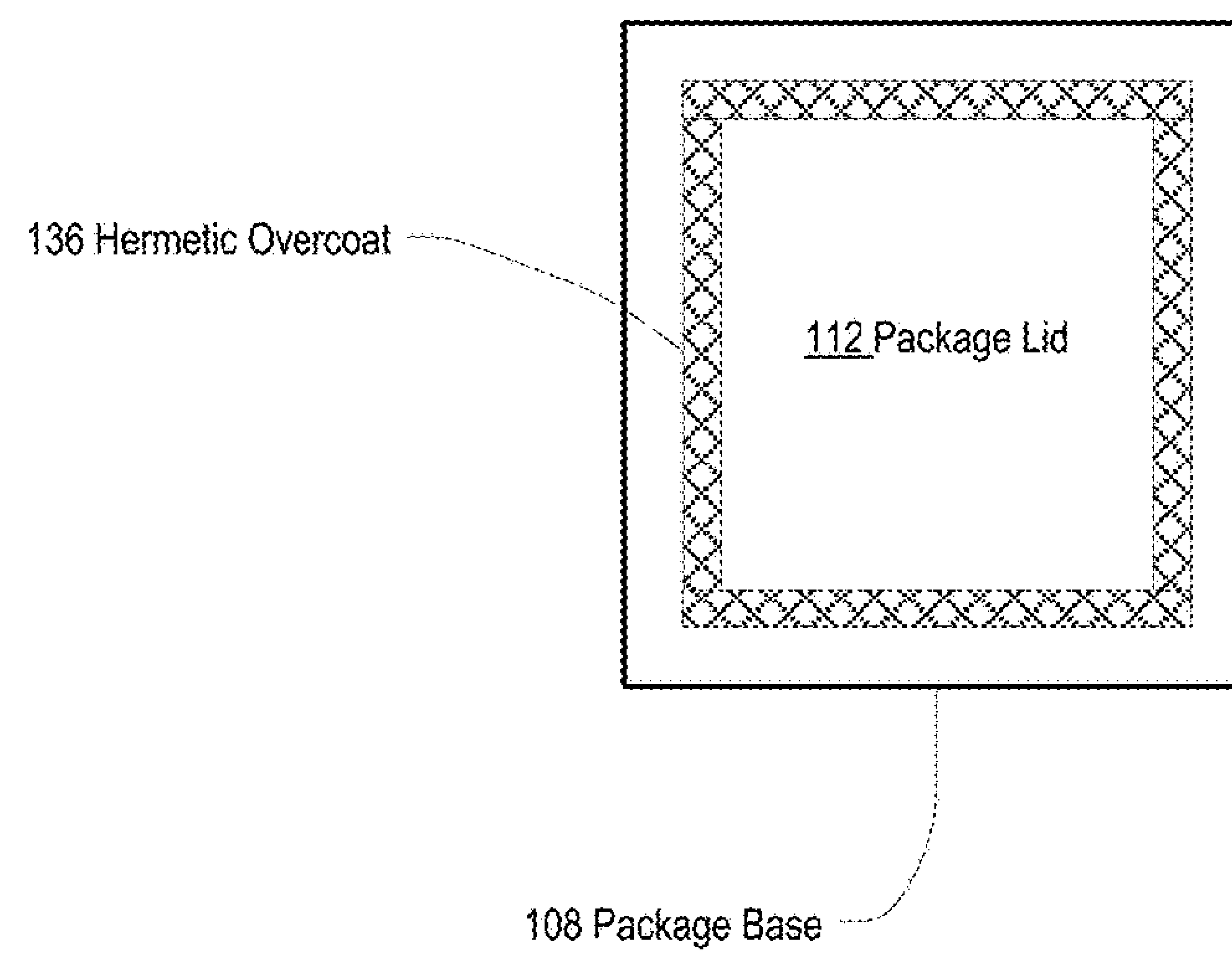


Fig. 4 Assembly Method for Hermetic Integrated Circuit

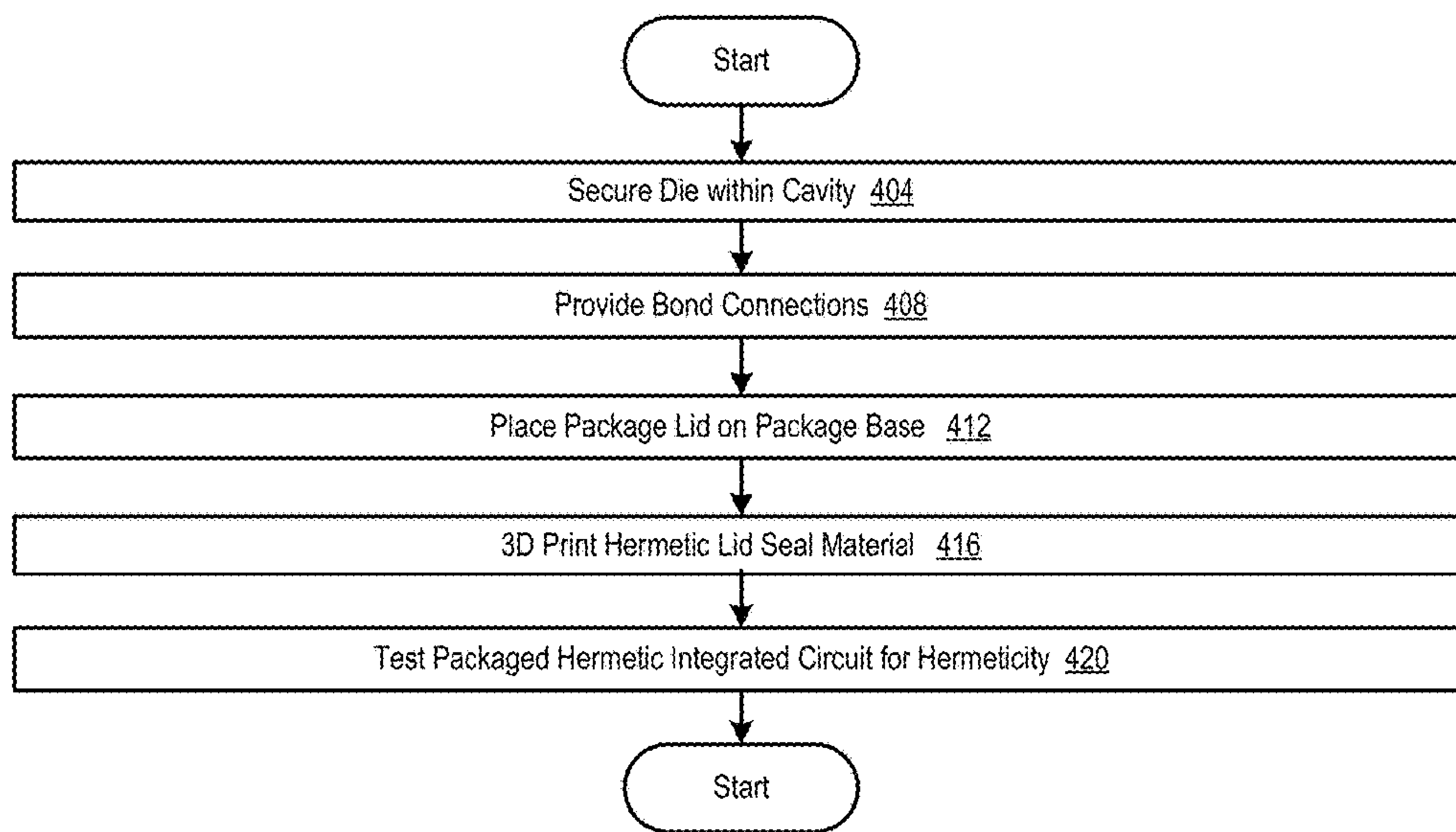
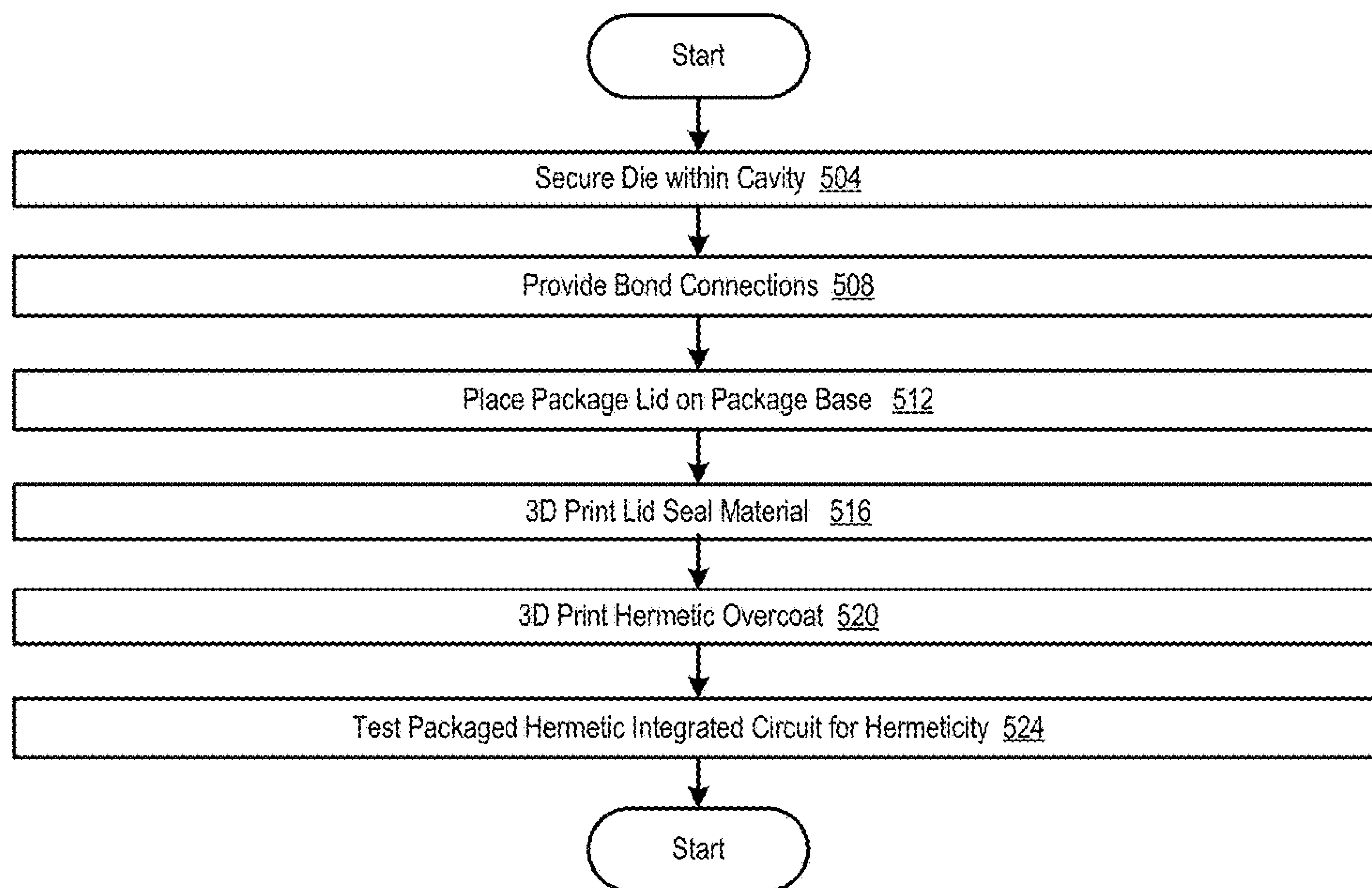


Fig. 5 Assembly Method for Hermetic Integrated Circuit



HERMETIC LID SEAL PRINTING METHOD

CROSS REFERENCE TO RELATED APPLICATION(S)

This application claims priority to earlier filed provisional application no. 62/569,717 filed Oct. 9, 2017 and entitled "HERMETIC LID SEAL METHOD AND APPARATUS", the entire contents of which are hereby incorporated by reference. This application also claims priority to earlier filed provisional application no. 62/632,249 filed Feb. 19, 2018 and entitled "HERMETIC LID SEAL METHOD AND APPARATUS", the entire contents of which are hereby incorporated by reference.

FIELD

The present invention is directed to integrated circuit packaging. In particular, the present invention is directed to methods and apparatuses for providing printed bond connections in integrated circuits.

BACKGROUND

The term "hermetic" means a seal that is gas tight or impervious to gas flow. In the context of microelectronics it implies an airtight seal that will keep moisture and other harmful gases from penetrating the sealed package. Metals, ceramics and glasses are the materials used to form hermetic packages and prevent water vapor from contaminating components inside the package. A properly made hermetic seal with a sufficiently low leak rate can keep a package dry and moisture free for many years.

Mil-STD-883 Test Method 1014 is the universally accepted test designed to determine the effectiveness or hermeticity of the seal. There are several techniques for testing hermeticity, but the most common method is to measure the rate at which helium escapes from a package that has been pressurized or backfilled with helium (the tracer gas). This measured helium leak rate is then correlated with an "air" leak rate. The hermeticity specification is based on a maximum "air" leak rate for a given package volume. The exact definition of hermeticity is defined in Test Method 1014 paragraph 3.1.1.2.1, which lists the failure criteria for a given package volume in terms of an air equivalent leak rate. When a cavity-sealed microelectronic package passes both gross and fine leak test per Test Method 1014 the part is deemed "hermetic".

Polymeric materials such as silicones and epoxies do not provide a hermetic seal and cannot be used to improve or fix a hermetic seal. Cavity packages made from polymers (e.g. LCP) or molded/potted microelectronics are known in the industry as "near-hermetic" or "non- hermetic". A "near" or "non" hermetic configuration provide enhanced resistance to moisture entry into a package, but they are not hermetic as defined by the military standards. If liquid droplets form on the surface of an IC or other active devices sensitive to moisture, then corrosion or other electrochemical reactions may occur and degrade the performance of the device and ultimately lead to failure. Moisture droplets can form as the package is cooled below the dew point. This surface water (H_2O) combines with any available surface ionic contamination, particularly sodium (Na) or chlorine (Cl), and along with a bias will chemically attack and corrode exposed aluminum metal at wirebond pads. The conductor metallization beneath defects, such as, cracks or pinholes in device passivation, or thin film resistor networks are also susceptible to this type of failure mechanism. Three monolayers of moisture on the surface is all that is needed to sustain surface conduction and facilitate electrochemical reactions.

Other problems caused by moisture inside a package include: electrical leakage across pins, damage to the doped layers on a silicon chip if there are pinholes in the surface passivation, arcing in a high voltage device, fogging of optical components, and "stiction" of moving parts in microelectromechanical (MEMS) components. Moisture related problems over the years have been well chronicled in technical journals and discussed at length at conferences.

SUMMARY

The present invention is directed to solving disadvantages of the prior art. In accordance with embodiments of the present invention, a method is provided. The method includes one or more of securing a die into a cavity of a hermetic package base, providing one or more bond connections to the die, placing a hermetic package lid on the package base, and 3D printing, by a 3D printer, hermetic lid seal material to a joint between the hermetic package base and the hermetic package lid, at a temperature at or below 100° C.

In accordance with another embodiment of the present invention, a method is provided. The method includes securing a die into a cavity of a hermetic package base, providing one or more bond connections to the die, placing a hermetic package lid on the hermetic package base, 3D printing, by a 3D printer, lid seal material to a joint between the hermetic package base and the hermetic package lid, at a temperature at or below 100° C., and 3D printing a hermetic overcoat over the lid seal material, the hermetic overcoat completely covering the lid seal material.

An advantage of the present invention is that it provides methods for creating a hermetic packaged integrated circuit without risking thermal degradation or destruction to a semiconductor die. Conventional lid seal processes require furnaces and other heating apparatuses that require either ambient temperatures or package heating temperatures at hundreds of degrees Celsius. This may damage thermally sensitive electro-optical, MEMS, or other devices. By utilizing 3D printing technologies for hermetic lid seal processes, the die itself is not exposed to temperatures over 100° C.

Yet another advantage of the present invention is does not require expensive furnaces or other heating apparatuses for lid seal operations. This increases production throughput for integrated circuits and saves power by not requiring high temperature heating devices.

Additional features and advantages of embodiments of the present invention will become more readily apparent from the following description, particularly when taken together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a diagram illustrating a packaged integrated circuit hermetic seal configuration in accordance with a first embodiment of the present invention.

FIG. **1**B is a diagram illustrating a packaged integrated circuit hermetic seal configuration in accordance with a second embodiment of the present invention.

FIG. **1**C is a diagram illustrating a packaged integrated circuit hermetic seal configuration in accordance with a third embodiment of the present invention.

FIG. 1D is a diagram illustrating a packaged integrated circuit hermetic seal configuration in accordance with a fourth embodiment of the present invention.

FIG. 2A is an illustration depicting applying hermetic lid seal material with a 3D printer, in accordance with embodiments of the present invention.

FIG. 2B is an illustration depicting laser sintering hermetic lid seal material in accordance with embodiments of the present invention.

FIG. 2C is an illustration depicting a packed integrated circuit with a hermetic lid seal, in accordance with embodiments of the present invention.

FIG. 3A is an illustration depicting applying lid seal material with a 3D printer, in accordance with embodiments of the present invention.

FIG. 3B is an illustration depicting laser sintering hermetic lid seal material, in accordance with embodiments of the present invention.

FIG. 3C is an illustration depicting applying hermetic overcoat material with a 3D printer, in accordance with embodiments of the present invention.

FIG. 3D is an illustration depicting a packed integrated circuit with lid seal and hermetic overcoat, in accordance with embodiments of the present invention.

FIG. 4 is a flowchart illustrating an assembly method for a hermetic integrated circuit in accordance with a first embodiment of the present invention.

FIG. 5 is a flowchart illustrating an assembly method for a hermetic integrated circuit in accordance with a second embodiment of the present invention.

DETAILED DESCRIPTION

Some integrated circuits are required to be hermetically packaged in order to prevent external contamination, including moisture, from coming in contact with a semiconductor die. Often, optoelectronic, piezoelectronic, and MEMS devices have this type of requirement. However, sometimes these semiconductor devices are thermally sensitive and can potentially be degraded or destroyed by high temperatures encountered during packaging operations. Most frequently, high temperatures have been conventionally encountered during hermetic lid seal operations, where temperatures of well over 200° C. (300-350° Celsius or even higher is common), may be encountered. Sometimes, these are ambient temperatures within a furnace apparatus and sometimes the hermetic package itself (which thermally conducts to a die or semiconductor device within) is heated to high and potentially destructive temperatures. The present application discloses inventive processes to keep the majority of a hermetic package below 100° C. during the lid seal deposition process. In some embodiments, the majority of a hermetic package may achieve no more than 85° C. The methods of the present application disclose lid seal processes able to be conducted at room temperature.

Currently, processes such as seam seal and room temperature epoxies are used to meet packaging requirements. Seam seal may be ideal for low volume assembly, but requires package designs that add additional costs, weight, and dimensional footprint to the final product. Package designs that use epoxy seals may be useful for low cost applications. Although various epoxy materials have been proven to provide hermetic seals, they have also been tested to consistently outgas moisture into the cavity during cure. Typical epoxy sealed cavities have water vapor levels of 10,000 to 100,000 ppm (parts per million) levels, where typical MIL-STD-883 limits are a maximum of 5,000 ppm.

3D printing technologies have rapidly evolved in recent years. At first, only simple-to-work-with plastics were able to be 3D printed using additive manufacturing techniques. Most commonly, they were able to fabricate ornamental and decorative items for consumer goods. However, as material research has progressed, other more useful industrial materials have been able to be 3D printed: https://all3dp.com/l/3d-metal-3d-printer-metal-3d-printing/. Perhaps more importantly, liquid as well as solid materials may be deposited: https://www.youtube.com/watch?v=ql3pXn8-sHA and http://www.buffalo.edu/news/releases/2017/01/020.html .

Referring now to FIG. 1A, a diagram illustrating a packaged integrated circuit hermetic seal configuration **100** in accordance with a first embodiment of the present invention is shown. Die **104** is an individual semiconductor die or substrate, and is usually fabricated in suitable technologies including Silicon (Si) and Gallium Arsenide (GaAs). Die **104** may have a single die or multiple interconnected dice.

The die **104** is connected to the hermetic package base **108**, package leads or downbonds (not shown), other substrates or interposers, or other circuitry within a cavity **124** of the packaged hermetic integrated circuit **100** with one or more bond connections **120**. Although conventional bond wires are shown providing bond connections **120**, it should be understood that any type of bond connections **120**, including 3D printed bond connections, may be used in conduction with any of the disclosed lid seal processes herein.

FIG. 1A illustrates a packaged hermetic integrated circuit **100** where a hermetic package lid **112** is oriented within a recess of the hermetic package base **108**, and a top surface of the hermetic package base **108** is above a top surface of the hermetic package lid **112**. A hermetic lid seal **116** is applied around the periphery of the hermetic package lid **112** by a 3D printer using an additive process to completely cover the joint between the hermetic package base **108** and the hermetic package lid **112**. The hermetic lid seal material **116**, **208** may be any 3D-printable solid or liquid hermetic material, and includes ceramics, metals, and glasses. In one embodiment, the hermetic lid seal material **116**, **208** includes zinc oxide ink or zinc oxide nanoparticle ink. In another embodiment, the hermetic lid seal material **116**, **208** is 3D-printable metals in solid or liquid form including nickel, cobalt, aluminum, and steel alloys.

In the embodiment illustrated, a hermetic overcoat **136** is not required since the lid seal material **116**, **208** is hermetic material. However, in other embodiments, a hermetic overcoat **136** may be required if the lid seal material **116**, **208** is not hermetic material. The hermetic overcoat **136** material may the same or different than the lid seal material **116**, **208**. For additional protection, both the lid seal material **132** and hermetic overspray material **136** may both be hermetic materials.

Referring now to FIG. 1B, a diagram illustrating a packaged integrated circuit hermetic seal configuration **130** in accordance with a second embodiment of the present invention is shown. Die **104** is an individual semiconductor die or substrate, and is usually fabricated in suitable technologies including Silicon (Si) and Gallium Arsenide (GaAs). Die **104** may have a single die or multiple interconnected dice.

The die **104** is connected to the hermetic package base **108**, package leads or downbonds (not shown), other substrates or interposers, or other circuitry within a cavity **124** of the packaged hermetic integrated circuit **100** with one or more bond connections **120**, as previously described.

FIG. 1B illustrates a packaged hermetic integrated circuit **130** where a hermetic package lid **112** is oriented flush with

a recess of the hermetic package base **108**, and a top surface of the hermetic package base **108** is flush with a top surface of the hermetic package lid **112**. A non-hermetic lid seal **132** may be applied around the periphery of the hermetic package lid **112** by a 3D printer to completely cover the joint between the hermetic package base **108** and the hermetic package lid **112**. In the embodiment illustrated, a hermetic overcoat **136** is required since the lid seal **132** material is non-hermetic material. However, in other embodiments, a hermetic overcoat **136** may not be required if the lid seal **132** material is hermetic material. For additional protection, both the lid seal material **132** and hermetic overspray material **136** may both be hermetic materials.

Referring now to FIG. **1**C, a diagram illustrating a packaged integrated circuit hermetic seal configuration **140** in accordance with a third embodiment of the present invention is shown. Die **104** is an individual semiconductor die or substrate, and is usually fabricated in suitable technologies including Silicon (Si) and Gallium Arsenide (GaAs). Die **104** may have a single die or multiple interconnected dice.

The die **104** is connected to the hermetic package base **108**, package leads or downbonds (not shown), other substrates or interposers, or other circuitry within a cavity **124** of the packaged hermetic integrated circuit **100** with one or more bond connections **120**, as previously described.

FIG. **1**C illustrates a packaged hermetic integrated circuit **140** where a hermetic package lid **112** is oriented partially above a recess of the hermetic package base **108**, and a top surface of the hermetic package base **108** is below a top surface of the hermetic package lid **112**. A hermetic lid seal **116** is applied around the periphery of the hermetic package lid **112** by a 3D printer to completely cover the joint between the hermetic package base **108** and the hermetic package lid **112**. In the embodiment illustrated, a hermetic overcoat **136** may not required since the lid seal **116** material is hermetic material. However, in other embodiments, a hermetic overcoat **136** may be required if the lid seal **116** material is not hermetic material **132**. For additional protection, both the lid seal material **132** and hermetic overspray material **136** may both be hermetic materials.

Referring now to FIG. **1**D, a diagram illustrating a packaged integrated circuit hermetic seal configuration **150** in accordance with a fourth embodiment of the present invention is shown. Die **104** is an individual semiconductor die or substrate, and is usually fabricated in suitable technologies including Silicon (Si) and Gallium Arsenide (GaAs). Die **104** may have a single die or multiple interconnected dice.

The die **104** is connected to the hermetic package base **108**, package leads or downbonds (not shown), other substrates or interposers, or other circuitry within a cavity **124** of the packaged hermetic integrated circuit **100** with one or more bond connections **120**, as previously described.

FIG. **1**D illustrates a packaged hermetic integrated circuit **150** where a hermetic package lid **112** is oriented completely above the hermetic package base **108**, and a top surface of the hermetic package base **108** is flush with a bottom surface of the hermetic package lid **112**. A hermetic lid seal **116** is applied around the periphery of the hermetic package lid **112** by a 3D printer to completely cover the joint between the hermetic package base **108** and the hermetic package lid **112**. In the embodiment illustrated, a hermetic overcoat **136** is applied over the hermetic lid seal **116** to provide a second layer of hermetic protection to the joint between the hermetic package base **108** and hermetic package lid **112**. However, in other embodiments, a hermetic overcoat **136** may not be required if the lid seal material **132** is not hermetic material.

Referring now to FIG. **2**A, an illustration depicting applying hermetic material **208** with a 3D printer, in accordance with embodiments of the present invention is shown. 3D printers are able to precisely deposit hermetic **116** or non-hermetic lid seal **132** or hermetic overcoat **136** materials on complex shapes, and are able to build up or layer the lid seal **116**, **132** or overcoat **136** material to a precise thickness. FIG. **2**A illustrates a lid seal configuration similar to that shown in FIG. **1**D, where a hermetic package lid **112** is placed upon a top surface of a hermetic package base **108**. In some embodiments, surfaces of the hermetic package lid **112** and/or hermetic package base **108** are cleaned or otherwise prepared prior to application of 3D printing processes for the low-temperature lid seal **116**, **132** and/or the hermetic overcoat **136**.

The 3D printer includes one or more 3D printer material spray heads **204**, which apply lid seal material **116**, **132** or hermetic overcoat material **136** to selected areas of the hermetic package base **108** and hermetic package lid **112**. 3D printers typically deposit material in layers, and build up a desired thickness of material by depositing multiple layers. 3D printers are computer controlled equipment, and spray material according to a file or files prepared beforehand designating specific locations that material will be applied to.

In one embodiment, the 3D printer uses an extrusion process to apply either the lid seal material **116**, **132** or the hermetic overcoat material **136**, or both. The extrusion process, sometimes referred to as Fused Deposition Modeling (FDM) uses a heated nozzle to extrude molten material.

In another embodiment, the 3D printer uses a Colorjet Printing (CJP) process to apply either the lid seal material **116**, **132** or the hermetic overcoat material **136**, or both. The CJP process utilizes an inkjet-based technology to spread fine layers of a dry substrate material. The dry substrate is most often in a powder form. The inkjet applies a binder to the substrate after applying the dry substrate material in order to solidify and cure the dry substrate.

In a preferred embodiment, the 3D printer uses a selective laser sintering process. Either lid seal material **116**, **132** or the hermetic overcoat material **136**, or both is applied in powder form to the joint between hermetic package base **108** and the hermetic package lid **112**.

In another embodiment, the 3D printer uses drop-on-demand inkjet printing and deposits liquid metal materials based on the principles of magnetohydrodynamics, i.e. the manipulation of conductive fluids using a magnetic field. In one embodiment, an electrically-pulsed magnetic field permeates liquid metal in an ejection chamber and creates circulating electrical currents that interact with the magnetic field to produce a pressure that squeezes droplets out of an ejector nozzle. A strand of aluminum is fed into a heat element that melts it at 750° C. (1,382° F.). The liquefied metal is then passed to a ceramic tube that forms an ejection chamber and has a submillimeter orifice. A magnetic coil surrounds the tube and receives a short-lived electrical pulse to create a pressure within the tube that ejects droplets of liquid metal through the orifice. The ejected drops are projected downward onto a maneuvering platform orients itself to deposit the lid seal **116**, **132** or hermetic overcoat **136** materials based on layer-by-layer deposition and the coalescence of the droplets.

Any material having suitable coating and hermeticity properties, able to adhere to potentially dissimilar ceramic, glass or metal materials of the hermetic package base **108** and hermetic package lid **112**, and able to be applied with a

3D printer material spray head **204** may be suitable as lid seal **116**, **132** or hermetic overcoat **136**.

Referring now to FIG. **2**B, an illustration depicting laser sintering hermetic lid seal material in accordance with embodiments of the present invention is shown. In a laser sintering process, a laser **212** melts and cures using a laser beam **216** material applied in powder form by a 3D printer. FIG. **2**A illustrates the hermetic material **208** being applied. The laser beam **216** contacts the hermetic material **208** and melts the hermetic material to form a hermetic seal **116**.

Referring now to FIG. **2**C, an illustration depicting a packed integrated circuit with a hermetic lid seal, in accordance with embodiments of the present invention is shown. Once the laser **212** has completely sintered the hermetic material **208** around the periphery of the hermetic lid **112**, the packaged integrated circuit has a hermetic lid seal **116**. In the illustrated embodiment, the lid seal material is hermetic **116**, and a hermetic overcoat **136** is not required.

Referring now to FIG. **3**A, an illustration depicting applying lid seal material with a 3D printer, in accordance with embodiments of the present invention is shown. 3D printers are able to precisely deposit hermetic **116** or non-hermetic **132** lid seal or overcoat **136** materials on complex shapes, and are able to build up or layer the lid seal **116**, **132** or overcoat **136** material to a precise thickness. FIG. **3**A illustrates a lid seal configuration similar to that shown in FIG. **1**B, where a top surface of a hermetic package lid **112** is flush with a top surface of a hermetic package base **108**. The applied lid seal material **308** overlaps top surfaces of both the hermetic package lid **112** and the hermetic package base **108**.

The 3D printer includes one or more 3D printer material spray heads **304**, which apply lid seal material **116**, **132** or hermetic overcoat material **136** to selected areas of the hermetic package base **108** and hermetic package lid **112**. 3D printers typically deposit material in layers, and build up a desired thickness of material by depositing multiple layers. 3D printers are computer controlled equipment, and spray material according to a file or files prepared beforehand designating specific locations that material will be applied to.

In one embodiment, the 3D printer uses an extrusion process to apply either the lid seal material **116**, **132** or the hermetic overcoat material **136**, or both. The extrusion process, sometimes referred to as Fused Deposition Modeling (FDM) uses a heated nozzle to extrude molten material.

In another embodiment, the 3D printer uses a Colorjet Printing (CJP) process to apply either the lid seal material **116**, **132** or the hermetic overcoat material **136**, or both. The CJP process utilizes an inkjet-based technology to spread fine layers of a dry substrate material. The dry substrate is most often in a powder form. The inkjet applies a binder to the substrate after applying the dry substrate material in order to solidify and cure the dry substrate.

In a preferred embodiment, the 3D printer uses a selective laser sintering process. Either lid seal material **116**, **132** or the hermetic overcoat material **136**, or both, are applied in powder form to the hermetic package base **108**.

In another embodiment, the 3D printer uses drop-on-demand inkjet printing and deposits liquid metal materials based on the principles of magnetohydrodynamics, i.e. the manipulation of conductive fluids using a magnetic field. In one embodiment, an electrically-pulsed magnetic field permeates liquid metal in an ejection chamber and creates circulating electrical currents that interact with the magnetic field to produce a pressure that squeezes droplets out of an ejector nozzle. A strand of aluminum is fed into a heat element that melts it at 750° C. (1,382° F.). The liquefied metal is then passed to a ceramic tube that forms an ejection chamber and has a submillimeter orifice. A magnetic coil surrounds the tube and receives a short-lived electrical pulse to create a pressure within the tube that ejects droplets of liquid metal through the orifice. The ejected drops are projected downward onto a maneuvering platform orients itself to deposit the lid seal **116**, **132** or hermetic overcoat **136** materials based on layer-by-layer deposition and the coalescence of the droplets.

Referring now to FIG. **3**B, an illustration depicting laser sintering lid seal material in accordance with embodiments of the present invention is shown. In a laser sintering process, a laser **212** melts and cures using a laser beam **216** material applied in powder form by a 3D printer. FIG. **3**A illustrates the lid seal material **308**, which may be either hermetic or non-hermetic material, being applied. The laser beam **216** contacts the lid seal material **308** and melts the lid seal material **308** to produce sintered lid seal material **312**.

Referring now to FIG. **3**C, an illustration depicting applying hermetic overcoat material **312** with a 3D printer, in accordance with embodiments of the present invention is shown. In order to create a hermetic packaged integrated circuit, a hermetic overcoat **312** is required if the lid seal material **308** previously applied is non-hermetic. However, a hermetic overcoat **136** may also be desired if the lid seal is a hermetic lid seal **116** in order to provide additional protection. In either case, the hermetic overcoat material **312** should be applied by the 3D printer material spray head **304** in order to completely cover the sintered lid seal material **312**.

Referring now to FIG. 3D, an illustration depicting a packed integrated circuit with a lid seal and hermetic overcoat, in accordance with embodiments of the present invention is shown. Once the 3D printer material spray head **304** has completely applied the hermetic overcoat **136** (and sintered the applied hermetic material **136**, if necessary) around the periphery of the hermetic lid **112**, the packaged integrated circuit has a hermetic lid seal. In the illustrated embodiment, the lid seal material may or may not be hermetic **116**, and a hermetic overcoat **136** is required.

Any material having suitable coating and hermeticity properties, able to adhere to potentially dissimilar ceramic, glass or metal materials of the hermetic package base **108** and hermetic package lid **112**, and able to be applied with a 3D printer material spray head **304** may be suitable as lid seal **116**, **132** or hermetic overcoat **136**.

Referring now to FIG. **4**, a flowchart illustrating an assembly method for a hermetic integrated circuit **100**, **130**, **140**, **150** in accordance with a first embodiment of the present invention is shown. Flow begins at block **404**.

At block **404**, a die **104** is secured within a cavity **124** of a hermetic package base **108**. The hermetic package base **108** may be constructed from any of ceramic, glass, or metal hermetic materials. The die **104** may be any type of semiconductor die, including optical devices, MEMS devices, a die bonded to an interposer or substrate, or any sort of semiconductor device requiring hermetic packaging that is also sensitive to high temperatures. In some embodiments, the die **104** is secured to the hermetic package base **108** with a suitable die attach adhesive, including low-halide die attach adhesives. Flow proceeds to block **408**.

At block **408**, one or more bond connections **120** are provided between the die **104** and package leads or other conductive surfaces within the hermetic package base **108**. The one or more bond connections **120** may include any type

of bond wire or other form of electrical connections, including 3D printed bond connections. Flow proceeds to block **412**.

At block **412**, a hermetic package lid **112** is placed on the hermetic package base **108**. The hermetic package lid **112** may be constructed from any of ceramic, glass, or metal hermetic materials. In some embodiments, the hermetic package lid **112** and hermetic package base **108** are constructed from the same material. In other embodiments, the hermetic package lid **112** and hermetic package base **108** are constructed from different materials. The hermetic package lid **112** is placed over the cavity **124** such that the hermetic package lid **112** evenly overlaps areas of the hermetic package base or substrate **108**. In some embodiments (where the microelectronic component **104** is an optoelectronic component), an optically-transparent window may be present in the hermetic package lid **112**. The window allows predetermined wavelengths of light to pass through the hermetic package lid **112** to the microelectronic component **104**.

In some embodiments, the hermetic package lid **112** is temporarily clamped to the hermetic package base **108** during lid seal processes. Clamping the lid **112** produces a more secure packaged integrated circuit by making sure the hermetic package lid **112** is in proper and direct contact with the hermetic package base or substrate **108**. The clamping force depends on details of the hermetic package lid **112**, the hermetic package base **108**, and the degree of fit between both. In some embodiments, a 1 lb clip should be sufficient to apply a reasonable amount of pressure. Flow proceeds to block **416**.

Prior to performing lid seal steps of the inventive process, it may be necessary to prepare the package surface(s). In one embodiment, if the hermetic package lid **112** includes a window or other transparent area required for optoelectronic devices, it may be advisable to temporarily place a sticker similar to KAPTON film over the transparent window in order to prevent bonding or sealing materials from contaminating the window and thereby reducing component functionality. In another embodiment, it may be necessary to remove any contaminants from surfaces of the hermetic package lid **112**, base **108**, or substrate that may be in proximity to bonding or sealing areas. Contaminants may be removed by any known material, process, or technique, including wiping the contact areas with Acetone. Removing surface contaminants may include plasma cleaning the surface in a plasma oven or similar apparatus.

At block **416**, a 3D printer prints hermetic lid seal material **116** on the joint between the hermetic package lid **112** and the hermetic package base **108**. In one embodiment, the 3D printer applies the hermetic lid seal material to a width between 0.5-2.0 mm and a thickness of approximately 0.5 mm. The hermetic lid seal material **116** provides a moisture barrier and mechanical reliability, as well as hermetic integrity, between the cavity **124** of the packaged hermetic integrated circuit **100**, **130**, **140**, **150** and the external environment to the packaged hermetic integrated circuit **100**, **130**, **140**, **150**. Following curing of any bonding or sealing materials **208**, **308**, pressure may be removed from the hermetic package lid **112** and the packaged integrated circuit may be removed from any 3D printing or packaging fixture.

The actual bonding or lid seal operation may occur at room temperature and/or atmospheric pressure, eliminating the need for vacuum or vacuum baking apparatuses for manufacture. The bonding and sealing operations may be also be performed at temperatures below 100° C., and above freezing temperatures (0° C.). A typical temperature of 30-40° C. (86-104° F.) may be commonly used for 3D printing operations, although room temperature is also sufficient. In one embodiment, the lid seal steps are performed in either a vacuum or a controlled atmosphere (i.e. in an inert gas environment). In another embodiment, the lid seal steps are performed in a noble gas environment.

In some embodiments, a thinner material layer **208**, **308** is 3D printed at the joint where the hermetic base/substrate **108** and hermetic package lid **112** meet. Thickness of the lid seal layer **116**, **132** is preferably below about 50 microns. The hermetic overcoat layer **136**, when desired is 3D printed over the lid seal layer **116**, **132** in order to completely cover the lid seal layer **116**, **132**. In one embodiment, the lid seal layer **116**, **132** material is the same as the hermetic overcoat layer **136** material. In another embodiment, the lid seal layer **116**, **132** material is different than the hermetic overcoat layer **136** material. This may be helpful for high pressure or temperature (over 100° C.) environments. Also, a cavity pressure of 10^{-9} atmospheres may be helpful when used in high pressure environments. In one embodiment, the lid seal layer **116**, **132** includes a Copper-Nickel alloy. Flow proceeds to block **420**.

At block **420**, the packaged hermetic integrated circuit is tested for hermeticity. In one embodiment, the packaged hermetic integrated circuit **100**, **130**, **140**, **150** is tested for hermeticity per MIL-SPEC-883. Other forms of testing may be performed and include any and all forms of functional testing and electrical testing. Flow ends at block **420**.

Referring now to FIG. **5**, a flowchart illustrating an assembly method for a hermetic integrated circuit **100**, **130**, **140**, **150** in accordance with a second embodiment of the present invention is shown. FIG. **4** provides a separate 3D printing step for providing a hermetic overcoat **136**, but otherwise includes the same considerations and options as previously described in the embodiment of FIG. **4**. Flow begins at block **504**.

At block **504**, a die **104** is secured within a cavity **124** of a hermetic package base **108**. The hermetic package base **108** may be constructed from any of ceramic, glass, or metal hermetic materials. The die **104** may be any type of semiconductor die, including optical devices, MEMS devices, a die bonded to an interposer or substrate, or any sort of semiconductor device requiring hermetic packaging that is also sensitive to high temperatures. In some embodiments, the die **104** is secured to the hermetic package base **108** with a suitable die attach adhesive, including low-halide die attach adhesives. Flow proceeds to block **508**.

At block **508**, one or more bond connections **120** are provided between the die **104** and package leads or other conductive surfaces within the hermetic package base **108**. The one or more bond connections **120** may include any type of bond wire or other form of electrical connections, including 3D printed bond connections. Flow proceeds to block **512**.

At block **512**, a hermetic package lid **112** is placed on the hermetic package base **108**. The hermetic package lid **112** may be constructed from any of ceramic, glass, or metal hermetic materials. In some embodiments, the hermetic package lid **112** and hermetic package base **108** are constructed from the same material. In other embodiments, the hermetic package lid **112** and hermetic package base **108** are constructed from different materials. In some embodiments, the hermetic package lid **112** is temporarily clamped to the hermetic package base **108** during lid seal processes. The clamping force depends on details of the hermetic package lid **112**, the hermetic package base **108**, and the degree of fit between both. Flow proceeds to block **516**.

At block **516**, a 3D printer prints hermetic lid seal material **132** on the joint between the hermetic package lid **112** and the hermetic package base **108**. In one embodiment, the 3D printer applies the lid seal material **208**, **308** to a width between 0.5-2.0 mm and a thickness of approximately 0.5 mm. The lid seal material **132** provides a moisture barrier and mechanical reliability, as well as hermetic integrity (when hermetic lid seal material **208** is used), between the cavity **124** of the packaged hermetic integrated circuit **100**, **130**, **140**, **150** and the external environment to the packaged hermetic integrated circuit **100**, **130**, **140**, **150**. Flow proceeds to block **520**.

At block **520**, a 3D printer 3D prints a hermetic overcoat **136** over the lid seal material **132**. In one embodiment, the hermetic overcoat **136** is non-hermetic material when the lid seal **116** uses hermetic material **208**. In most embodiments, the hermetic overcoat **136** is hermetic material. The hermetic overcoat **136** completely covers the lid seal material **116**, **132** and protects the exposed material. In one embodiment, the thickness of the applied hermetic overcoat **136** is thinner than the thickness of the lid seal material **116**, **132**. In another embodiment, the thickness of the hermetic overcoat **136** material depends on whether the lid seal material is hermetic **116** or non-hermetic **132**. In another embodiment, the thickness of the hermetic overcoat **136** material is thinner whether the lid seal material is hermetic **116** and thicker when the lid seal material is non-hermetic **132**. Flow proceeds to block **524**.

At block **524**, the packaged hermetic integrated circuit is tested for hermeticity. In one embodiment, the packaged hermetic integrated circuit **100**, **130**, **140**, **150** is tested for hermeticity per MIL-SPEC-883. Other forms of testing may be performed and include any and all forms of functional testing and electrical testing. Flow ends at block **524**.

Finally, those skilled in the art should appreciate that they can readily use the disclosed conception and specific embodiments as a basis for designing or modifying other structures for carrying out the same purposes of the present invention without departing from the spirit and scope of the invention as defined by the appended claims.

The invention claimed is:

1. A method, comprising:

securing a die into a cavity of a hermetic package base;

providing one or more bond connections to the die;

placing a hermetic package lid on the package base;

3D printing, by a **3**D printer, hermetic lid seal material to a joint between the hermetic package base and the hermetic package lid, at a temperature at or below **100** degrees Celsius; and

3D printing, by the **3**D printer, a hermetic overcoat over the hermetic lid seal material in order to completely cover the hermetic lid seal material, a thickness of the hermetic overcoat less than a thickness of the hermetic lid seal material.

2. The method as recited in claim **1**, further comprising: clamping the hermetic package lid to the hermetic package base prior to **3**D printing hermetic lid seal material.

3. The method as recited in claim **1**, wherein the die comprises a device that may be damaged at temperatures over **300** degrees Celsius, wherein the hermetic lid seal material is a hermetic compound.

4. The method as recited in claim **3**, wherein the hermetic package base comprises one of ceramic, metal, or glass, wherein the hermetic package lid comprises one of ceramic, metal, or glass.

5. The method as recited in claim **4**, wherein the hermetic package base material is different than the hermetic package lid material.

6. The method as recited in claim **3**, wherein the hermetic lid seal material comprises zinc oxide.

7. The method as recited in claim **3**, wherein the lid seal material is **3**D printed in liquid form.

8. The method as recited in claim **3**, wherein the **3**D printer applies the hermetic lid seal material by a selective laser sintering process, the selective laser sintering process comprising:

3D printing, by a **3**D printer, the lid seal material in powder form to a joint between the hermetic package lid and the hermetic package base; and

melting the lid seal material, by a laser, to form a hermetic bond between the hermetic package lid and the hermetic package base.

9. The method as recited in claim **3**, further comprising: maintaining a die temperature of less than **100** degrees Celsius while **3**D printing one or more of the lid seal material or the hermetic overcoat.

10. The method as recited in claim **3**, further comprising: **3**D printing the lid seal material within an inert gas environment.

11. A method, comprising:

securing a die into a cavity of a hermetic package base;

providing one or more bond connections to the die;

placing a hermetic package lid on the hermetic package base;

3D printing, by a **3**D printer, lid seal material to a joint between the hermetic package base and the hermetic package lid, at a temperature at or below **100** degrees Celsius; and

3D printing a hermetic overcoat over the lid seal material, the hermetic overcoat completely covering the lid seal material, a thickness of the hermetic overcoat depending on whether the lid seal material is hermetic.

12. The method as recited in claim **11**, further comprising: clamping the hermetic package lid to the hermetic package base prior to **3**D printing lid seal material.

13. The method as recited in claim **11**, wherein the die comprises a device that may be damaged at temperatures over **300** degrees Celsius, wherein the hermetic overcoat material is a hermetic compound.

14. The method as recited in claim **13**, wherein the hermetic package base comprises one of ceramic, metal, or glass, wherein the hermetic package lid comprises one of ceramic, metal, or glass.

15. The method as recited in claim **14**, wherein the hermetic package base material is different than the hermetic package lid material.

16. The method as recited in claim **13**, wherein the hermetic lid seal material comprises zinc oxide.

17. The method as recited in claim **13**, wherein at least the lid seal material is **3**D printed in liquid form.

18. The method as recited in claim **13**, wherein the **3**D printer applies one or more of the lid seal material and the hermetic overcoat by a selective laser sintering process, the selective laser sintering process comprising:

3D printing, by a **3**D printer, one or more of the lid seal material and hermetic overcoat material in powder form to a joint between the hermetic package lid and the hermetic package base; and

melting, by a laser, one or more of the lid seal material and hermetic overcoat material to form a hermetic bond between the hermetic package lid and the hermetic package base.

19. The method as recited in claim **13**, further comprising:
maintaining a die temperature of less than **100** degrees Celsius while **3**D printing the lid seal material and the hermetic overcoat.

20. The method as recited in claim **13**, further comprising: 5

3D printing the lid seal material within a noble gas environment; and

3D printing the hermetic overcoat within a noble gas environment, in response to **3**D printing a non-hermetic lid seal material. 10

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