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(54) **SUBSTRATE-FREE LIGHT EMITTING DIODE CHIP**


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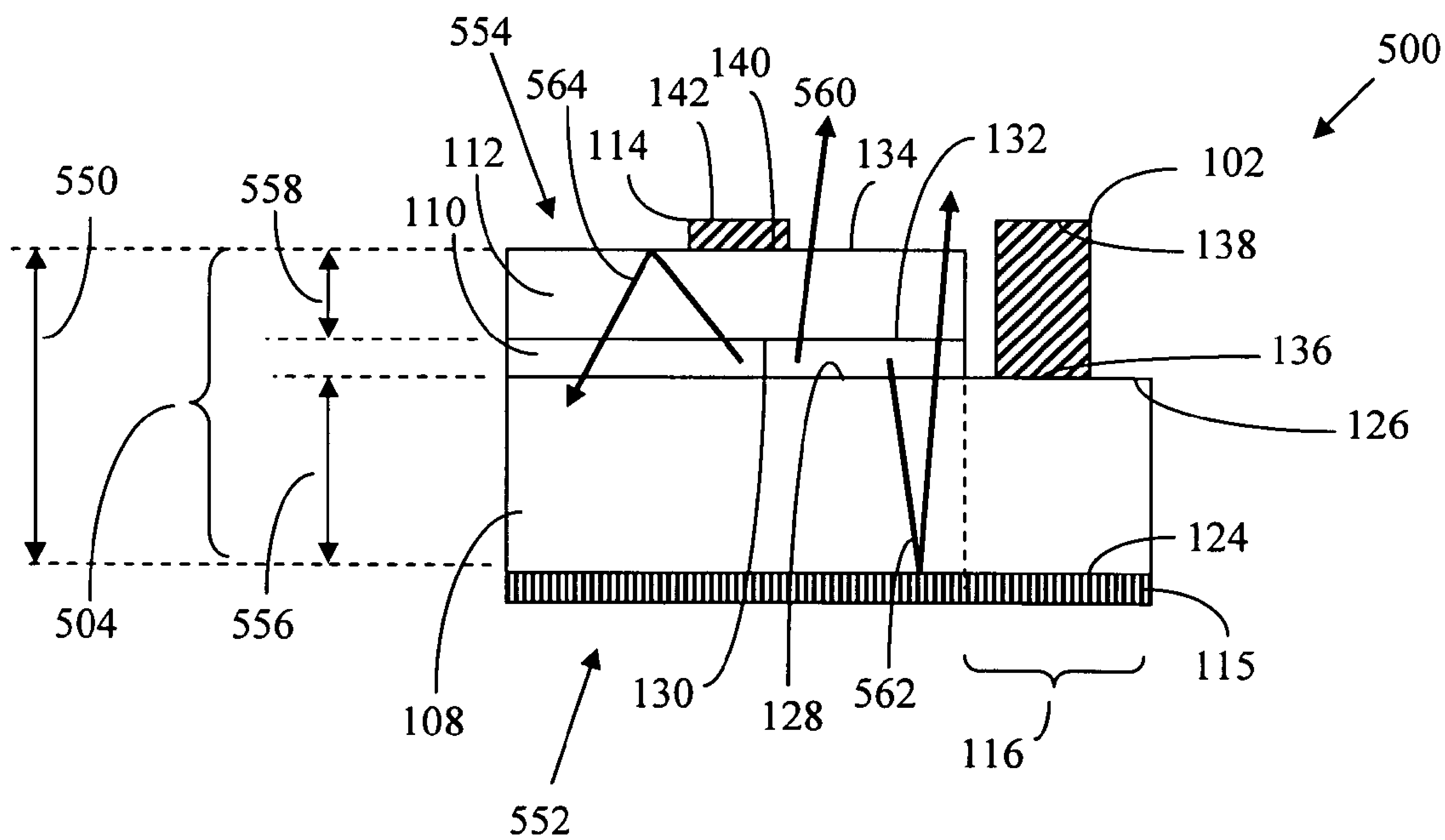
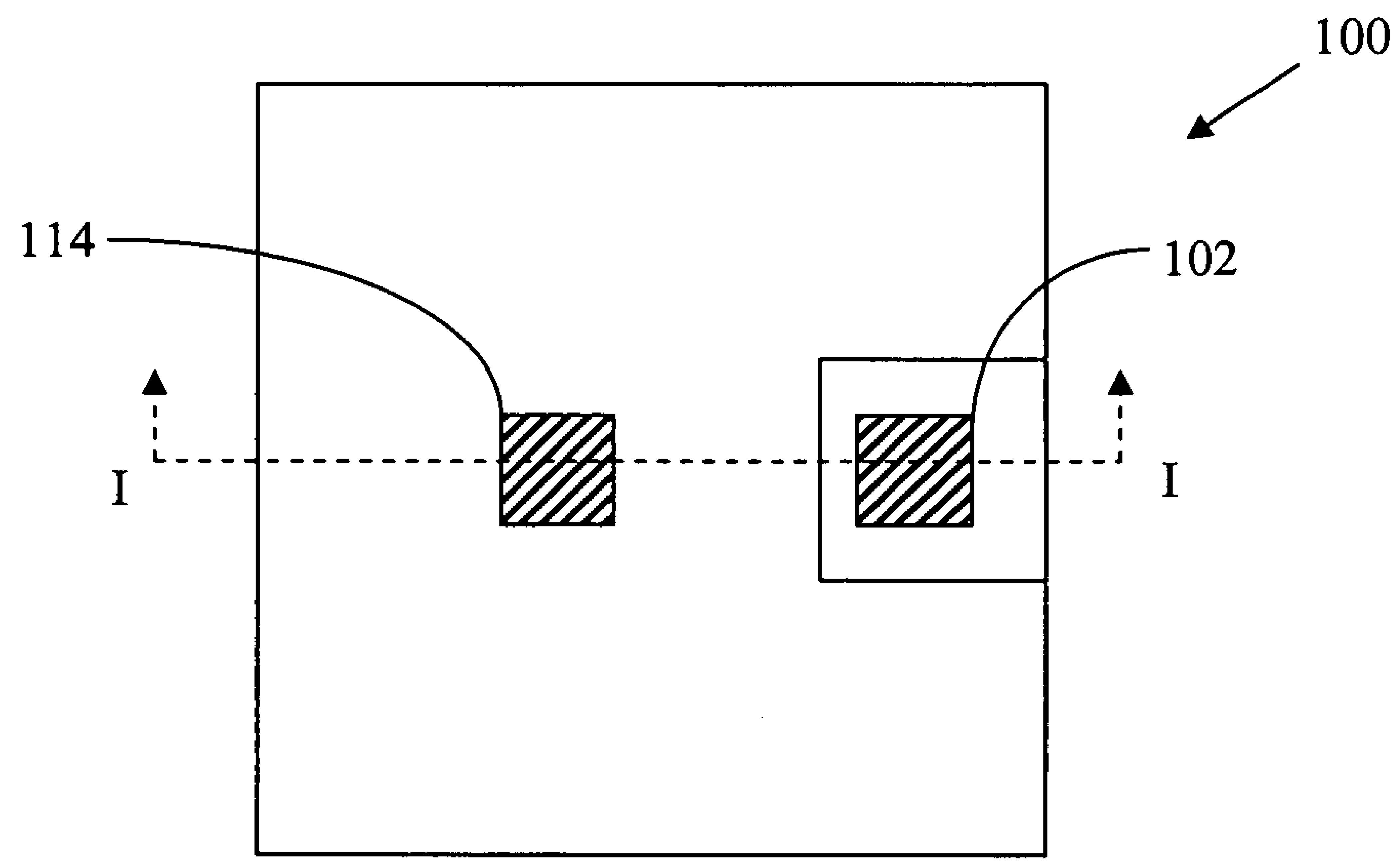
*H01L 33/00* (2006.01)

(52) **U.S. Cl.** .................................. **257/98**; 257/E33.023

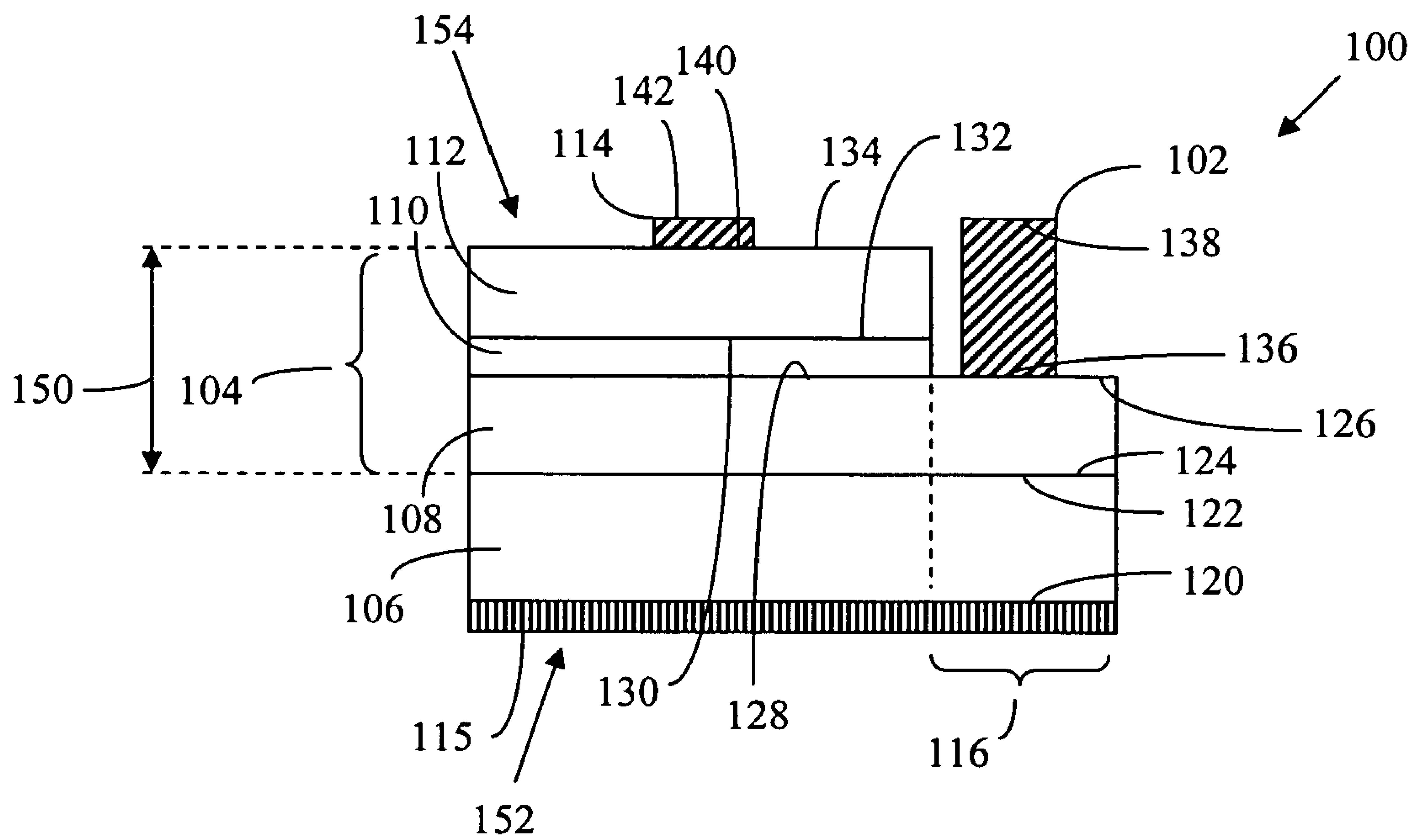

(57) **ABSTRACT**


A light emitting diode (LED) chip has a multilayer semiconductor structure that is at least 10 microns thick and does not require an attached growth substrate or transfer substrate for structural rigidity or support. The multilayer semiconductor structure includes a first doped layer, a second doped layer and an active region interposed between the first doped layer and the second doped layer. Optionally, the multilayer semiconductor structure includes an undoped layer. At least one of the layers of the multilayer semiconductor structure is at least 5 microns thick and is preferably deposited by hydride vapor phase epitaxy.

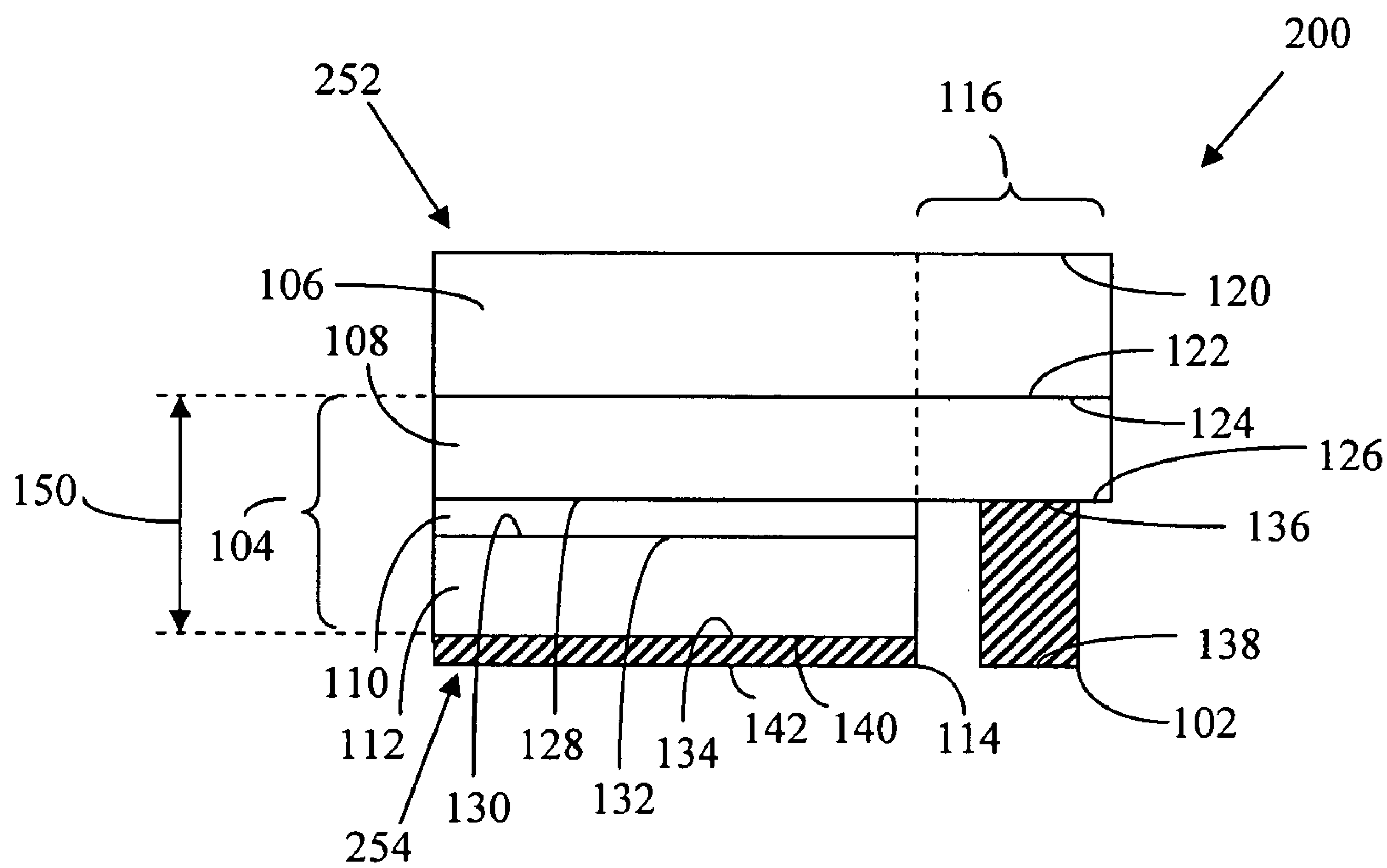





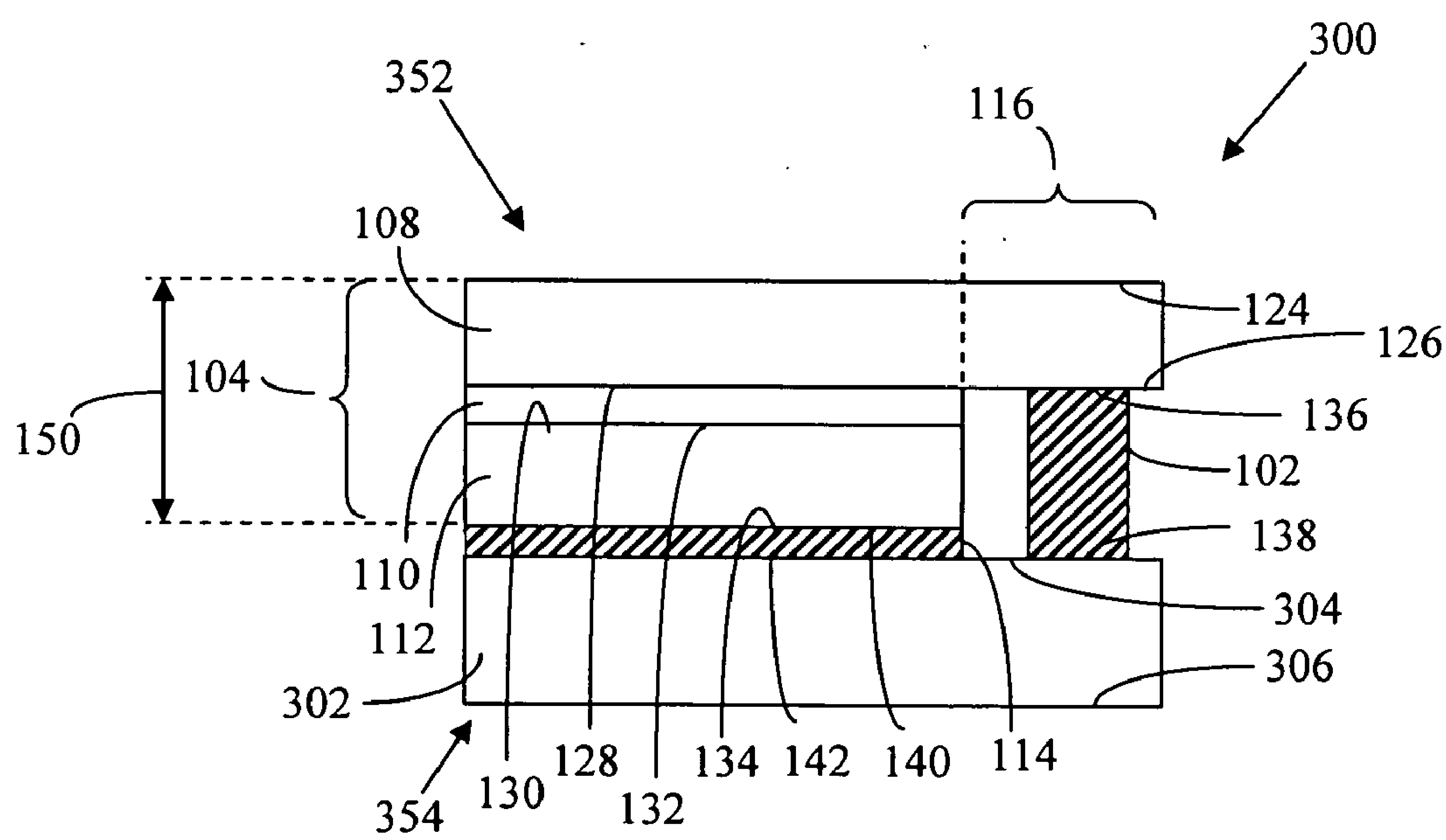

PRIOR ART
FIG. 1A



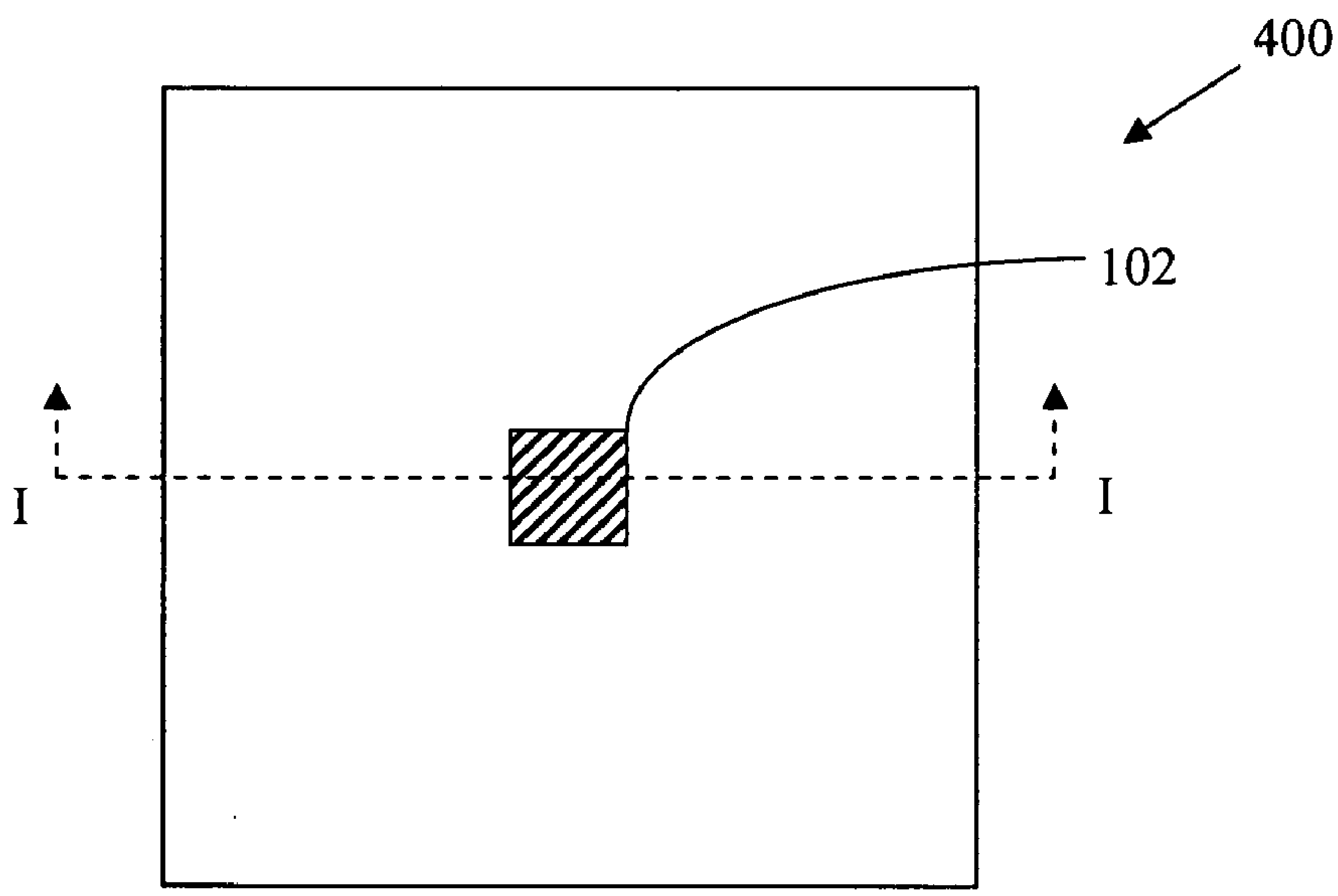

PRIOR ART
FIG. 1B



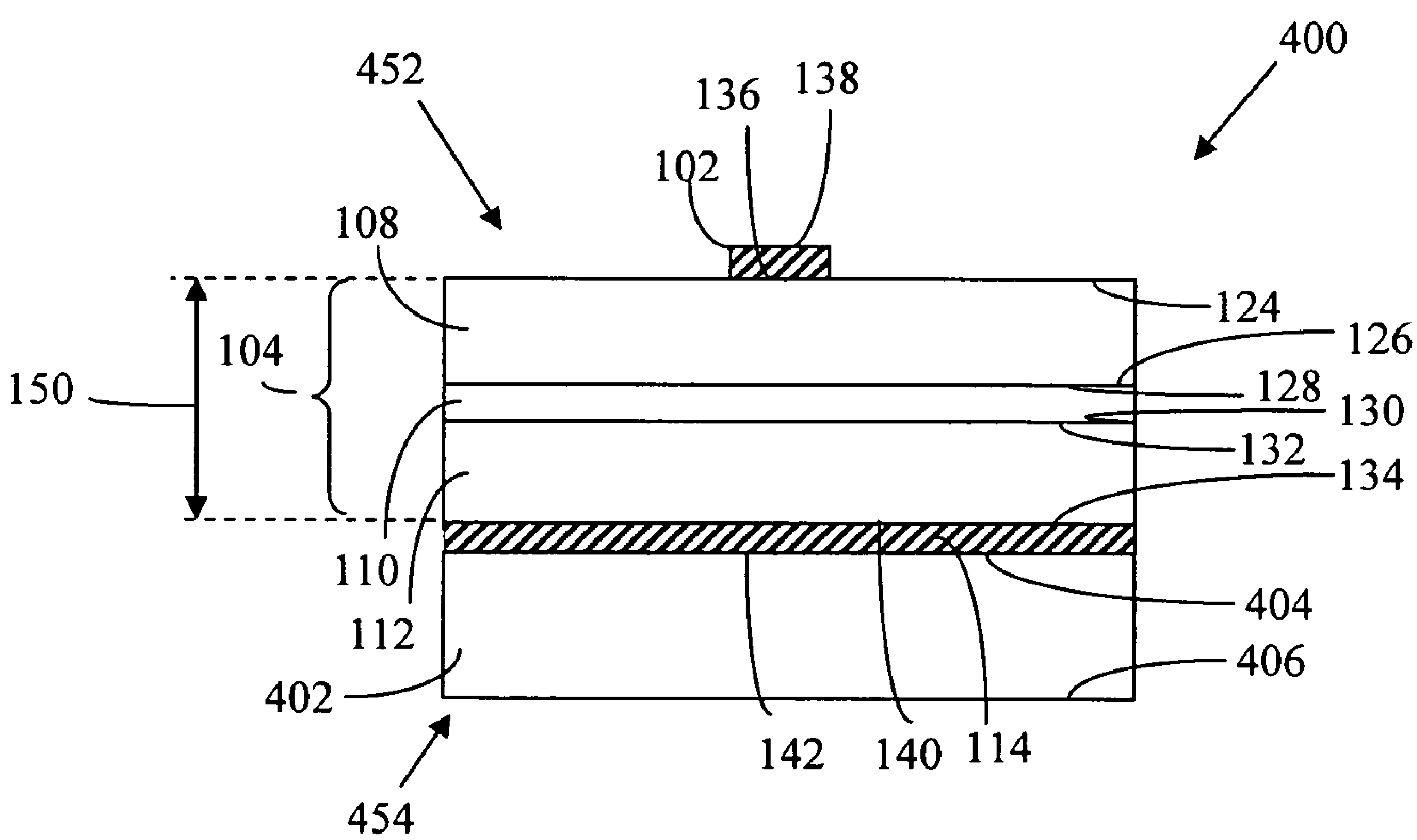

PRIOR ART
FIG. 2



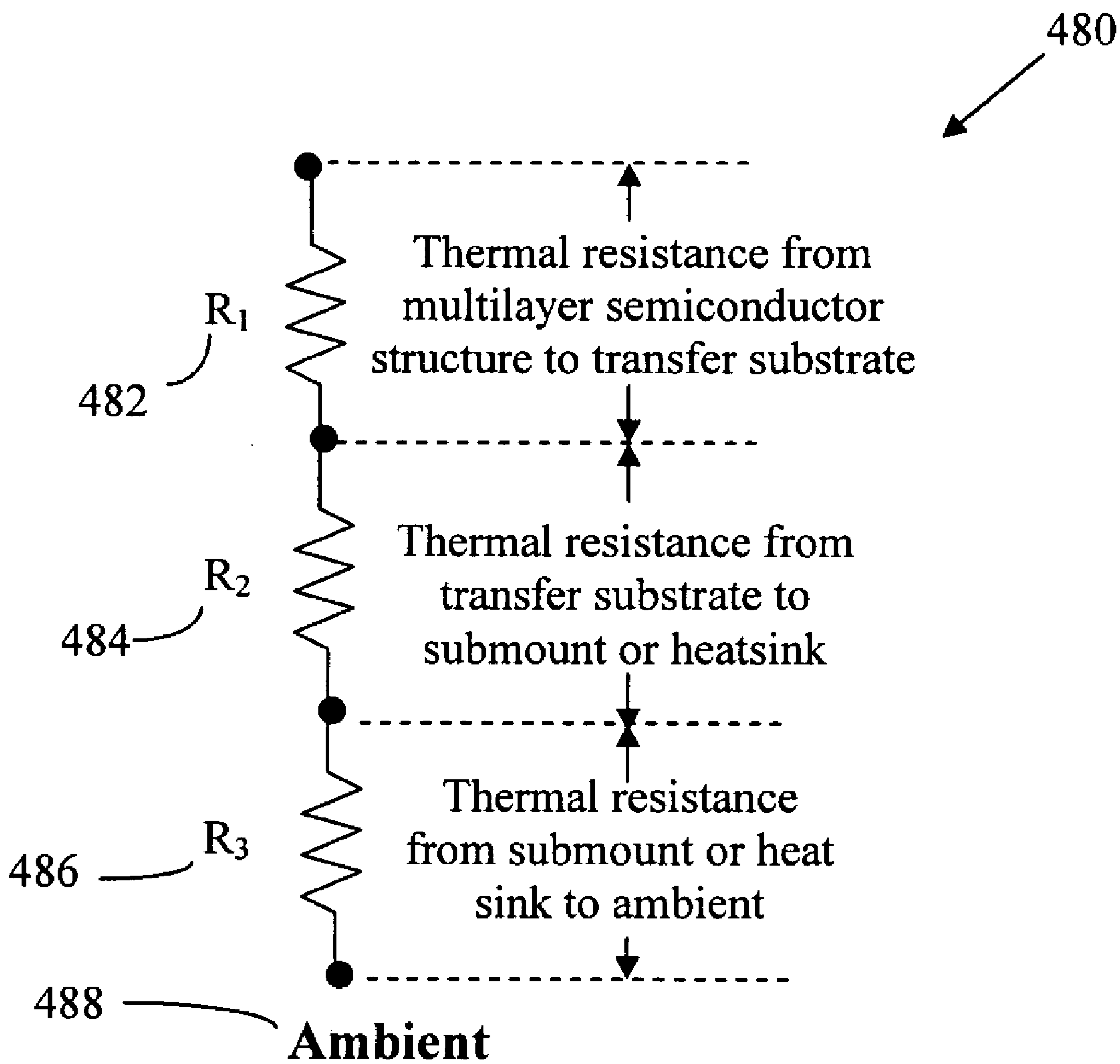

PRIOR ART
FIG. 3




**PRIOR ART**
**FIG. 4A**




**PRIOR ART**
**FIG. 4B**




PRIOR ART
FIG. 4C

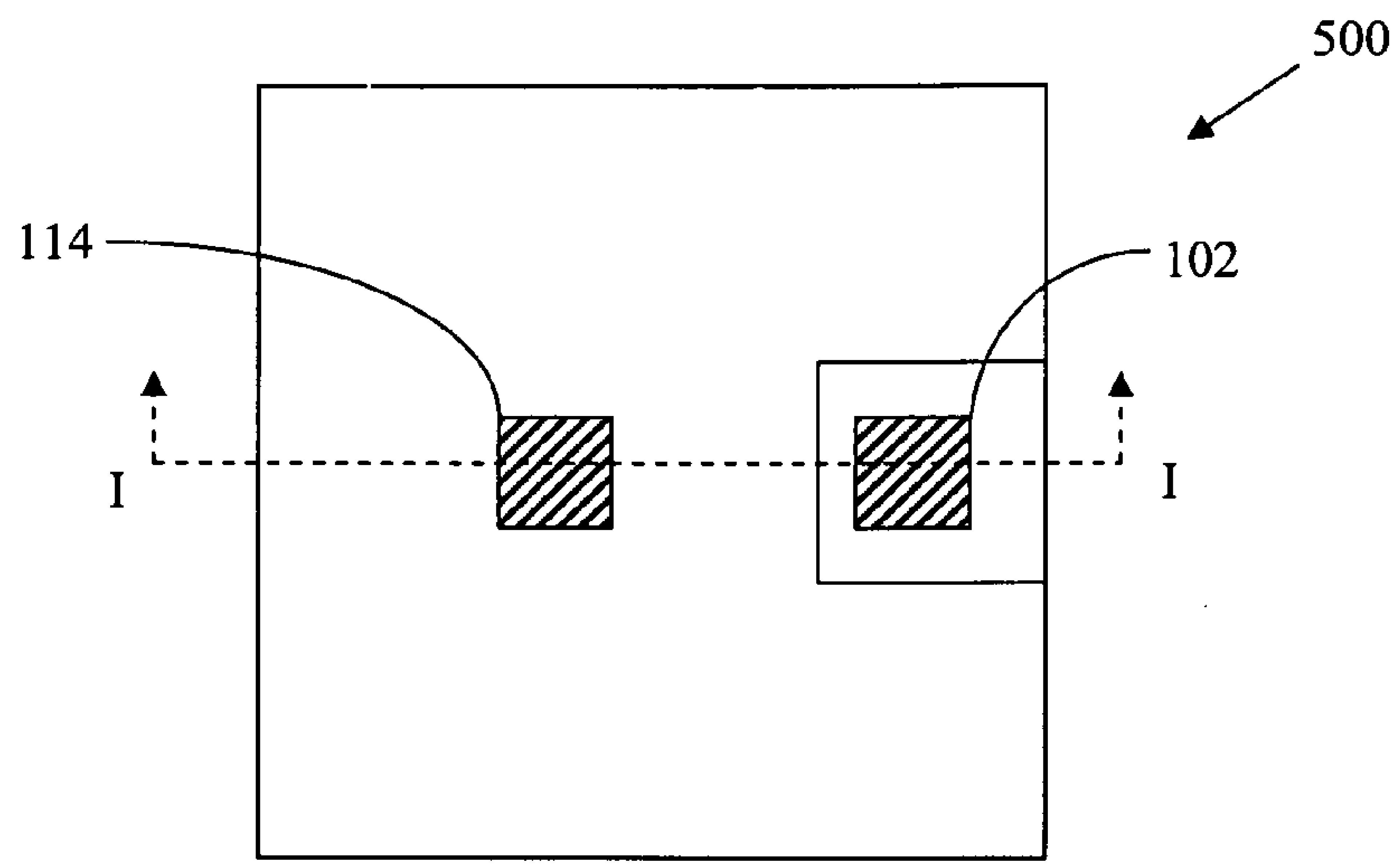

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FIG. 5A

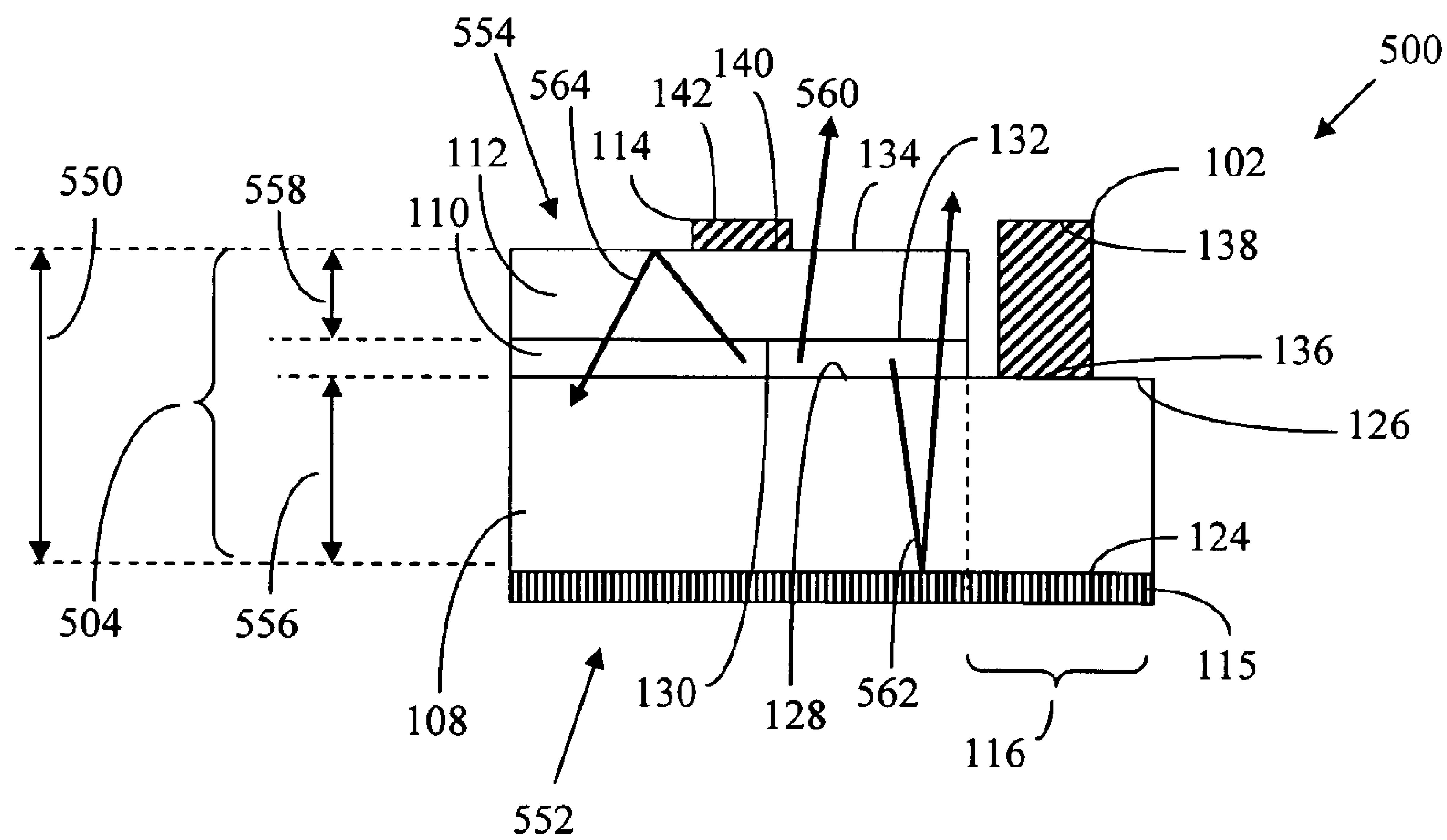
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FIG. 5B

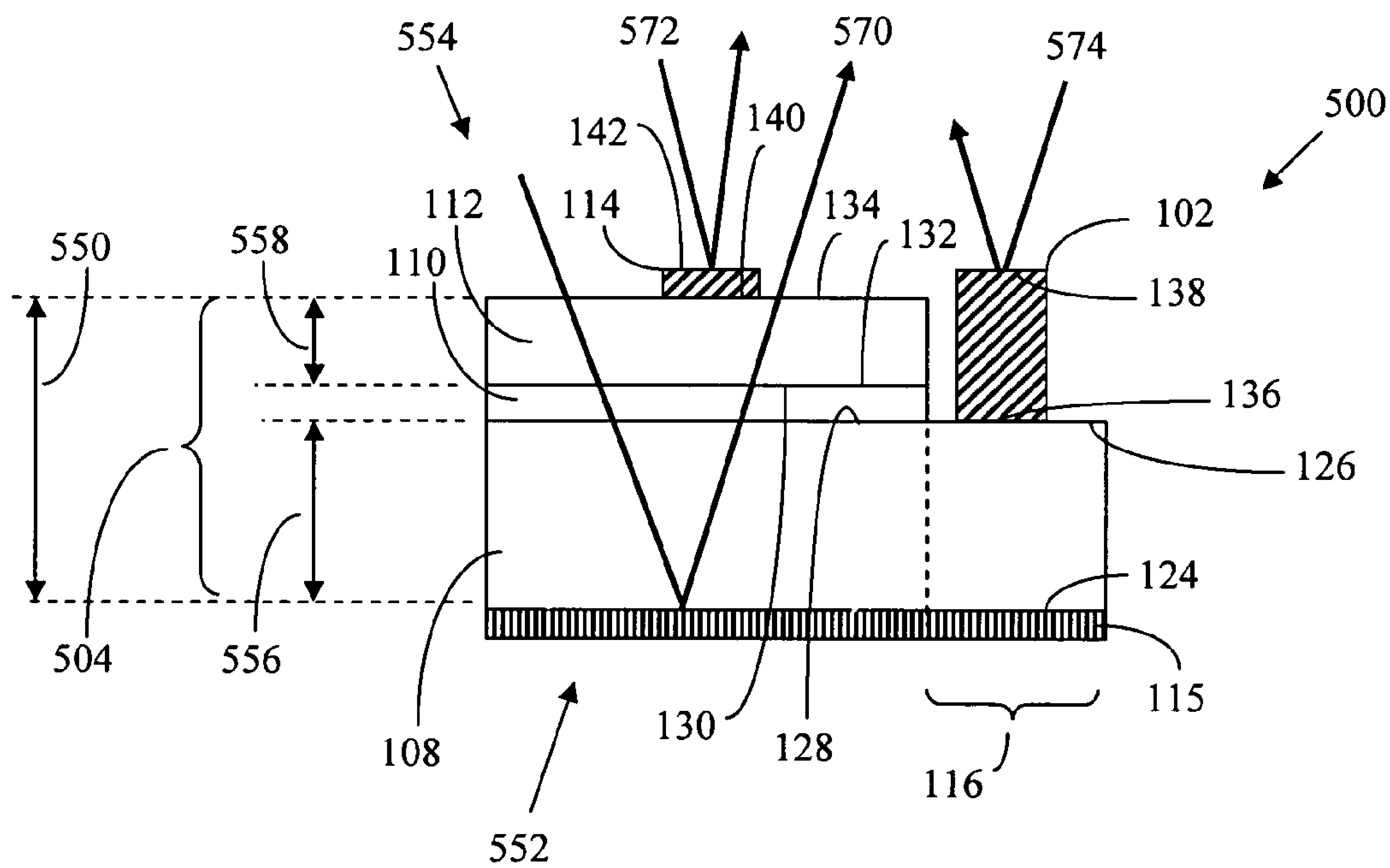
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FIG. 5C

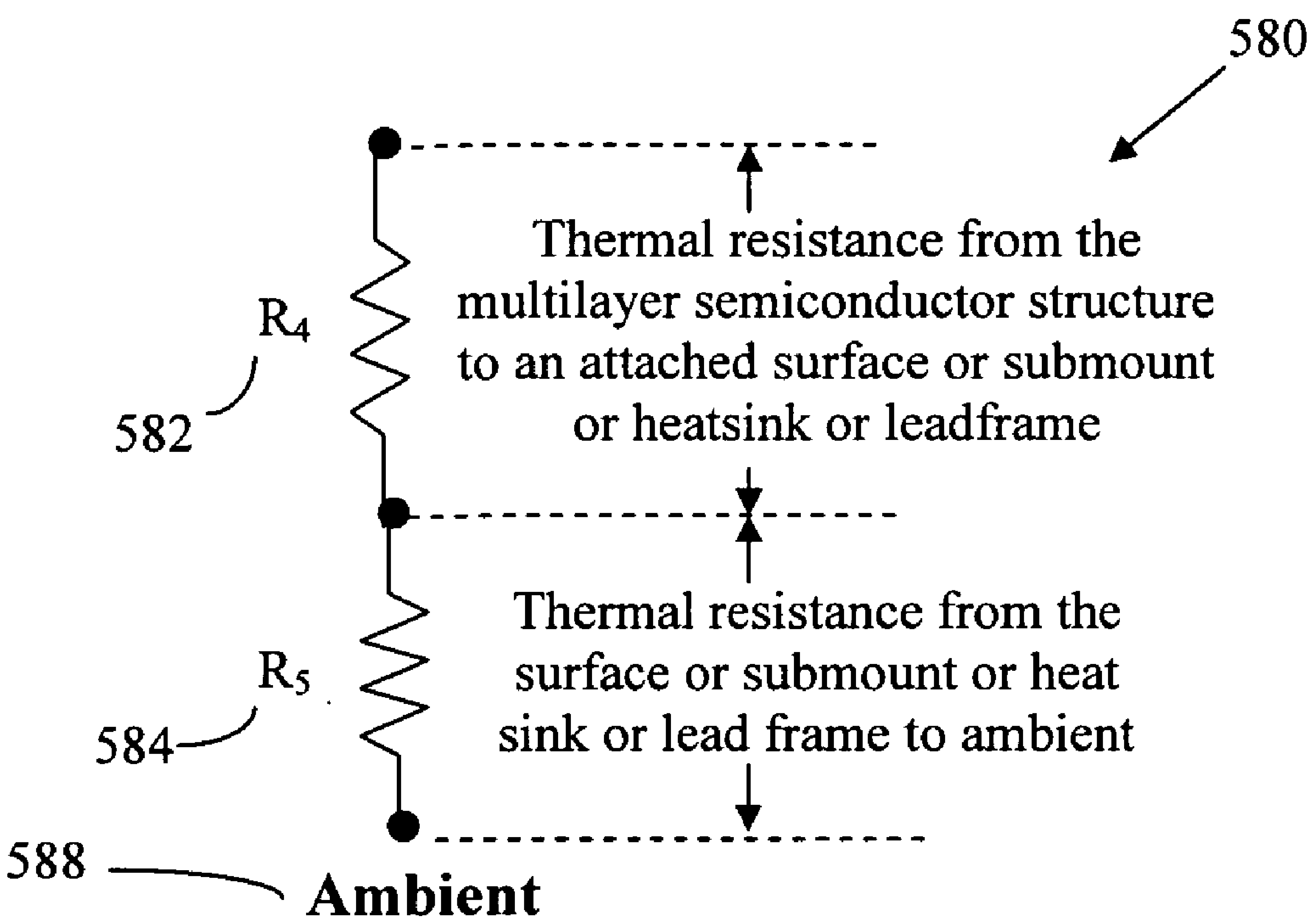
580
Thermal resistance from the multilayer semiconductor structure to an attached surface or submount or heatsink or leadframe
R4
582
Thermal resistance from the surface or submount or heat sink or lead frame to ambient
R5
584
588
Ambient

FIG. 5D

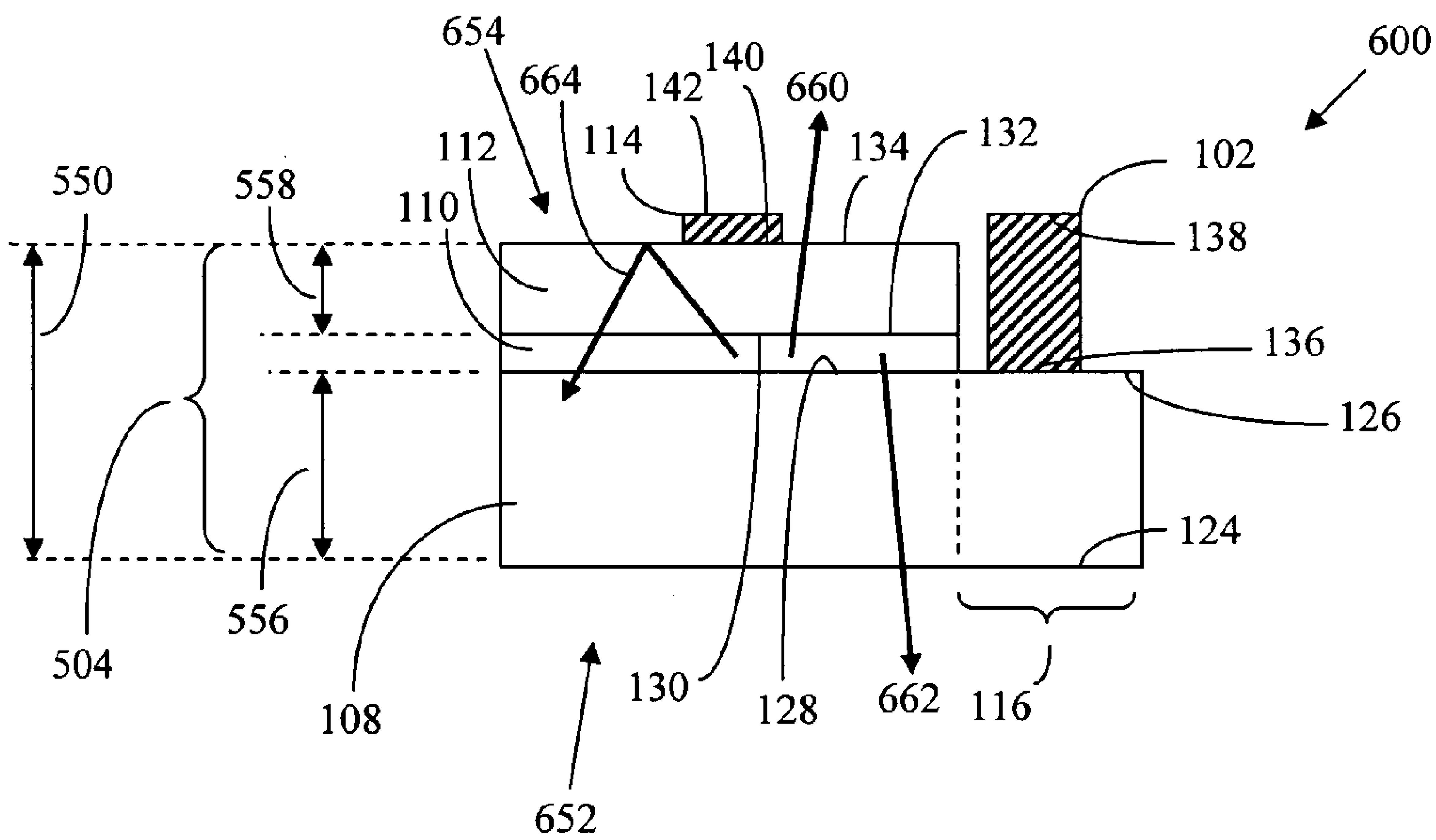
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**FIG. 6A**

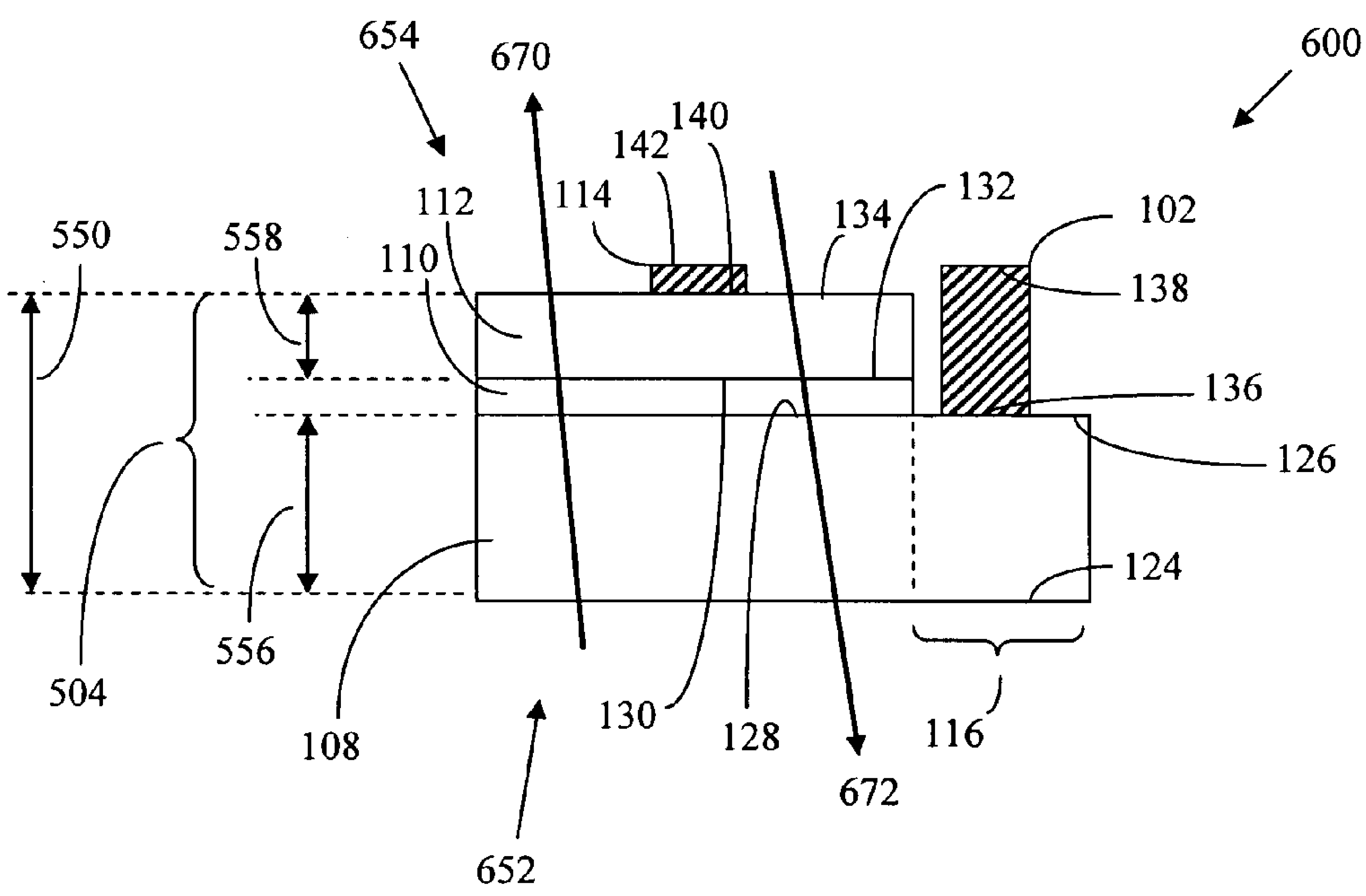
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**FIG. 6B**

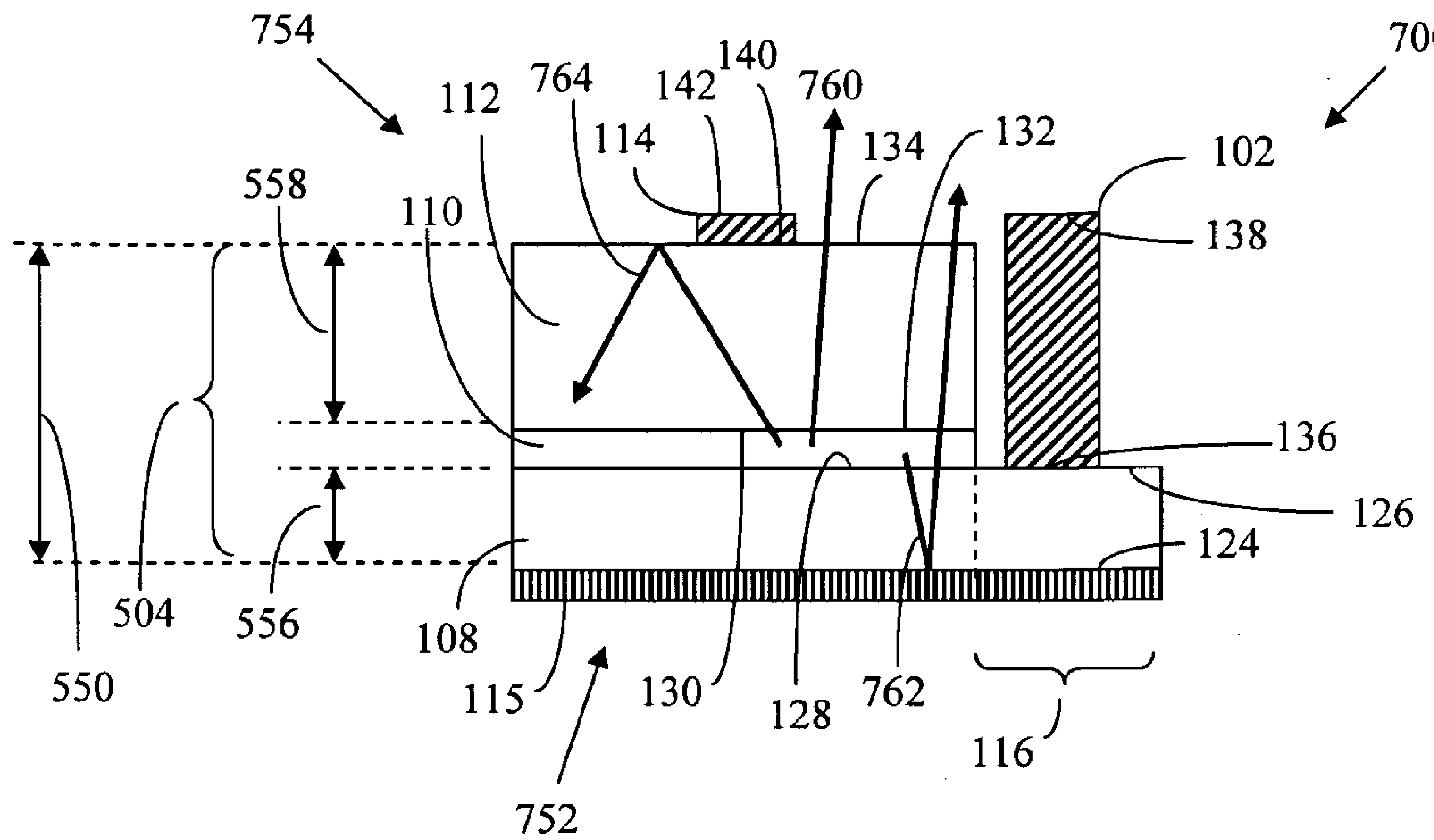
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FIG. 7

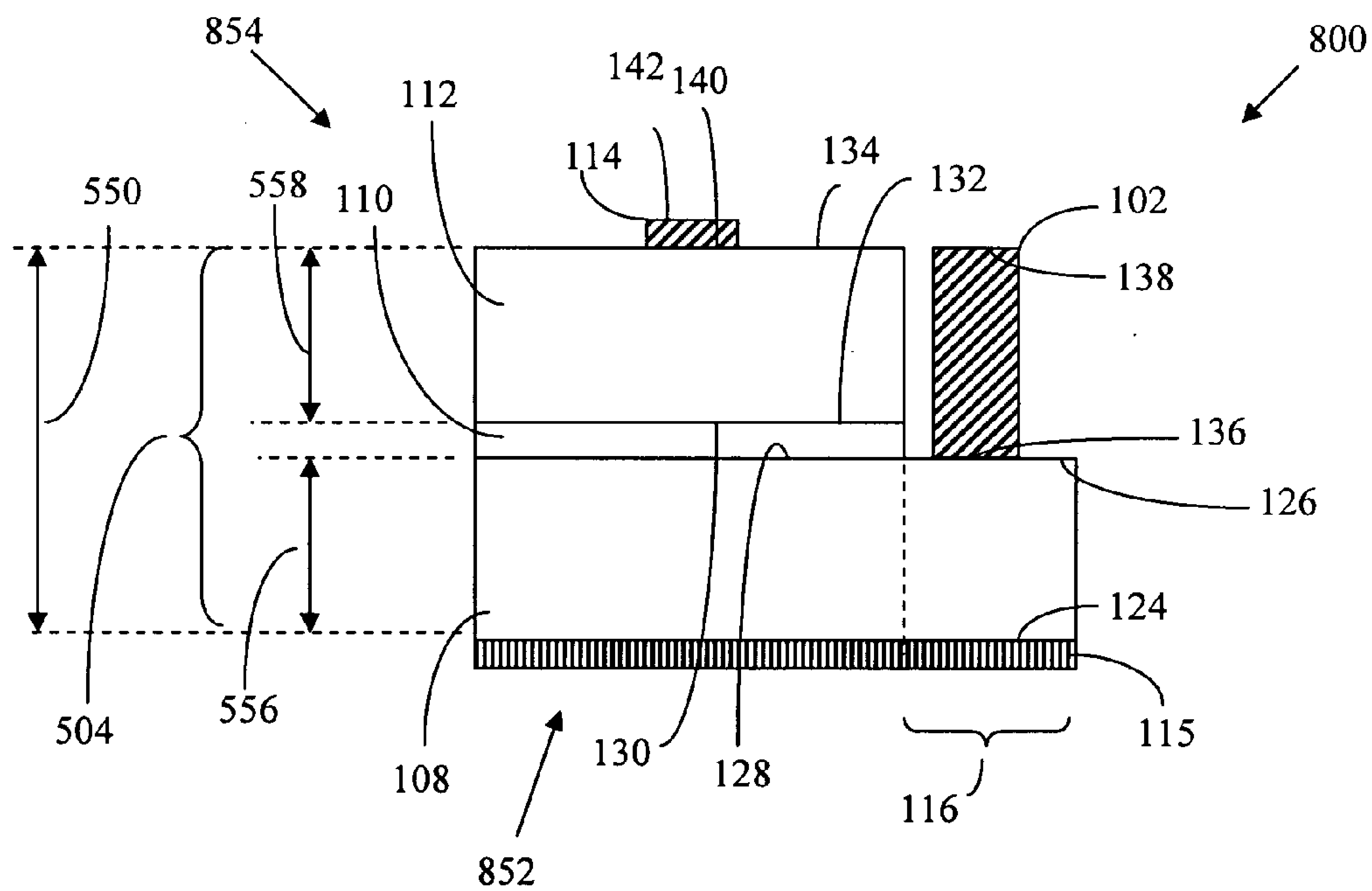
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FIG. 8

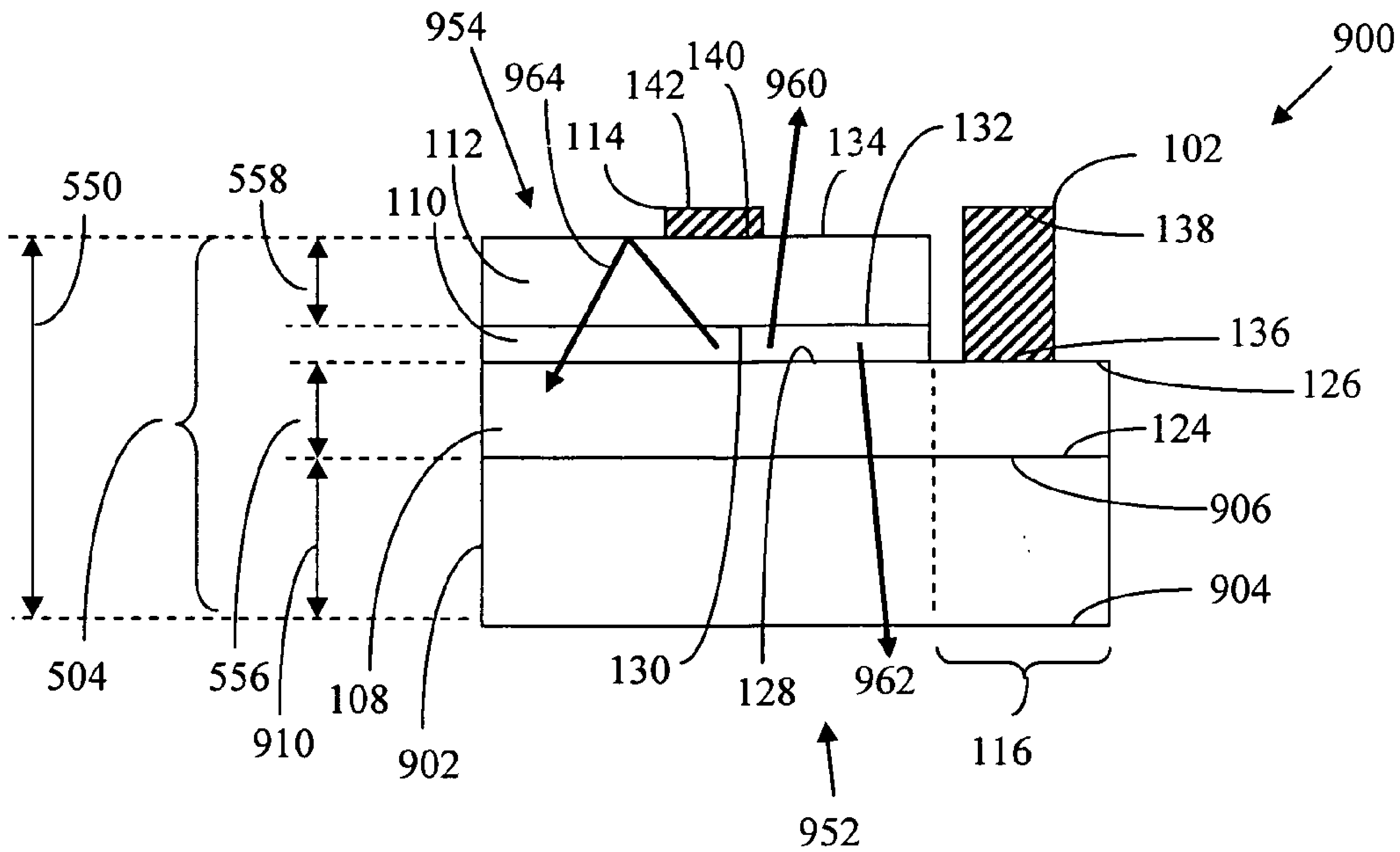
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**FIG. 9**

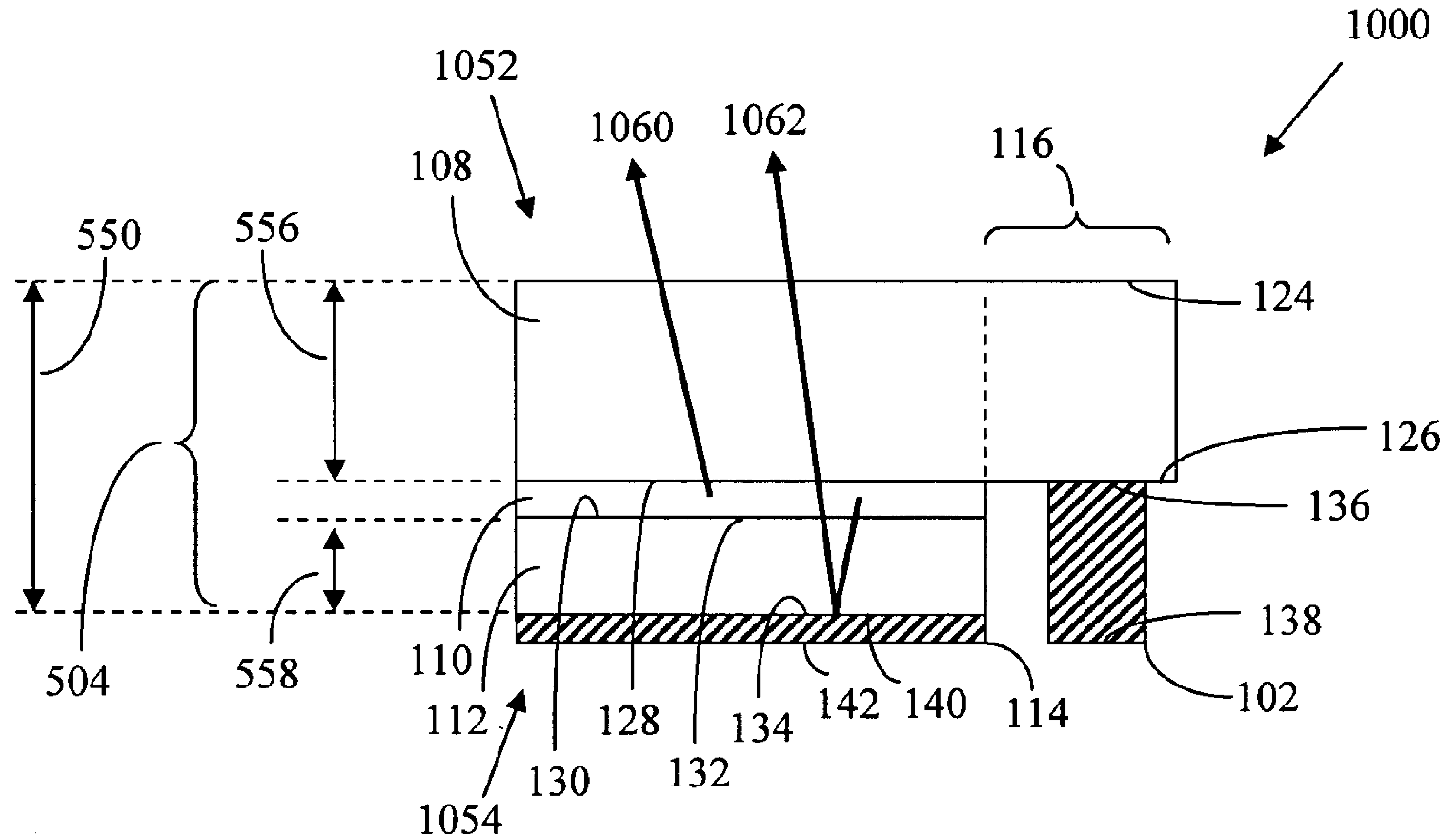
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FIG. 10

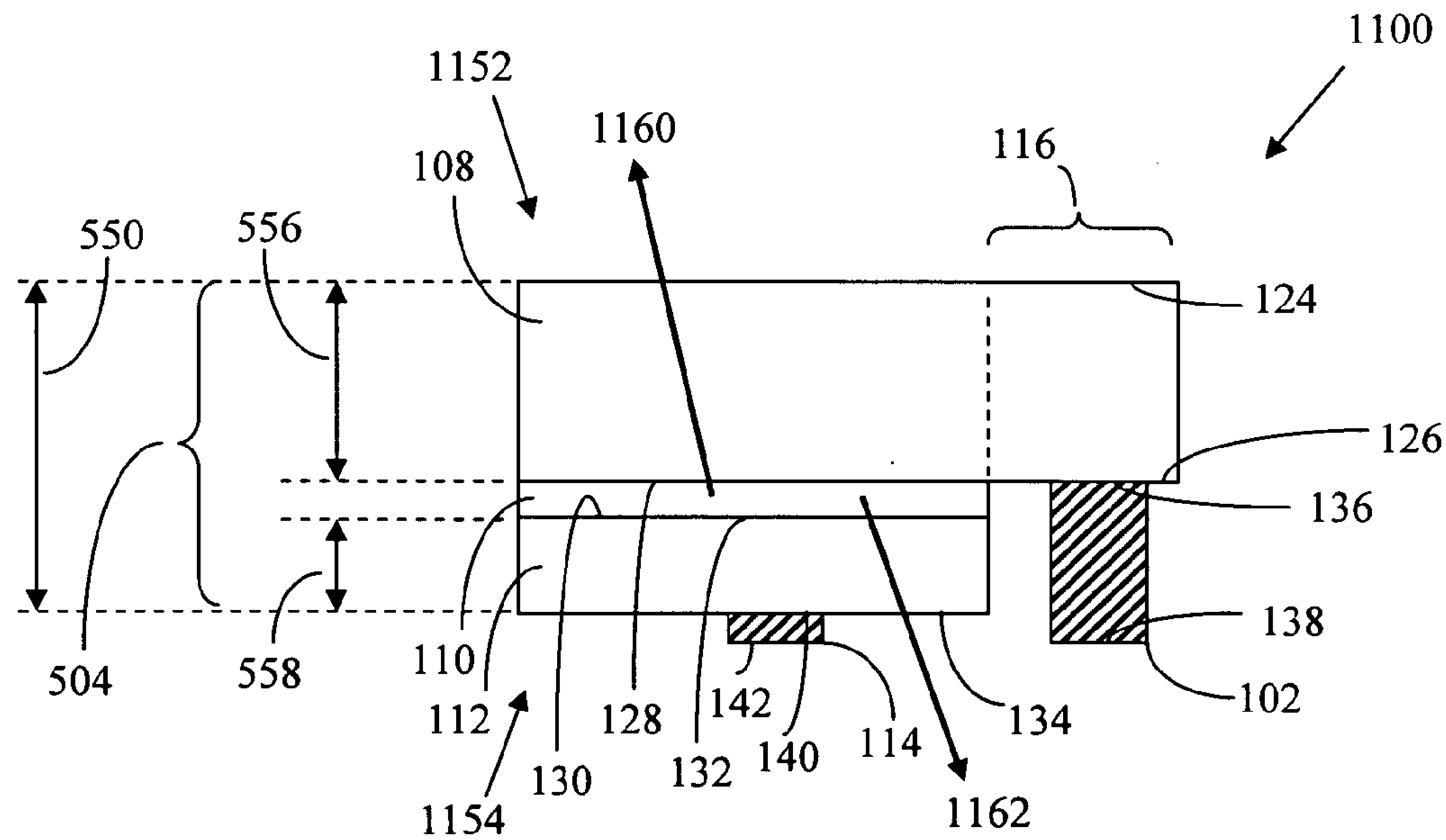
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FIG. 11

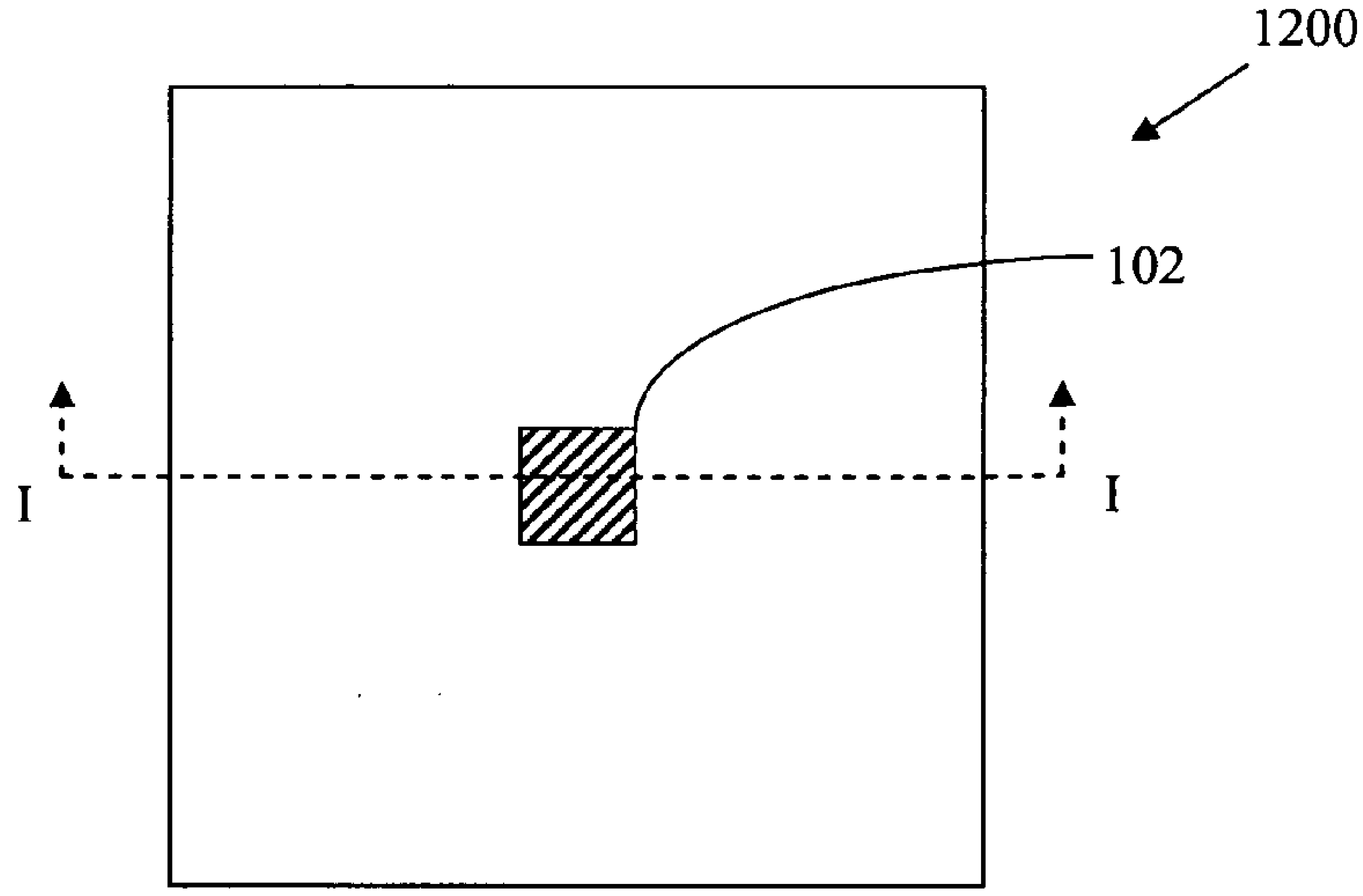


FIG. 12A

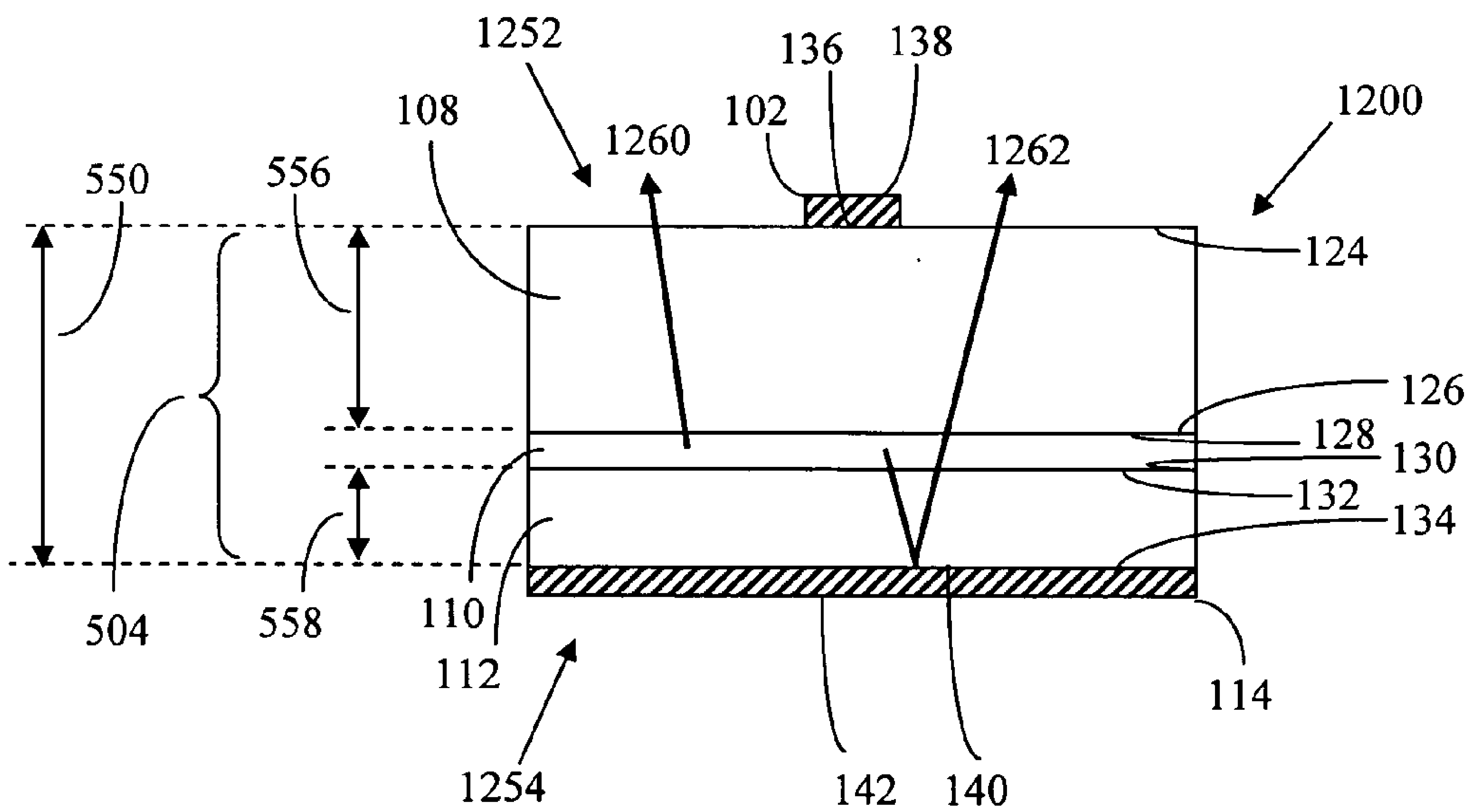


FIG. 12B

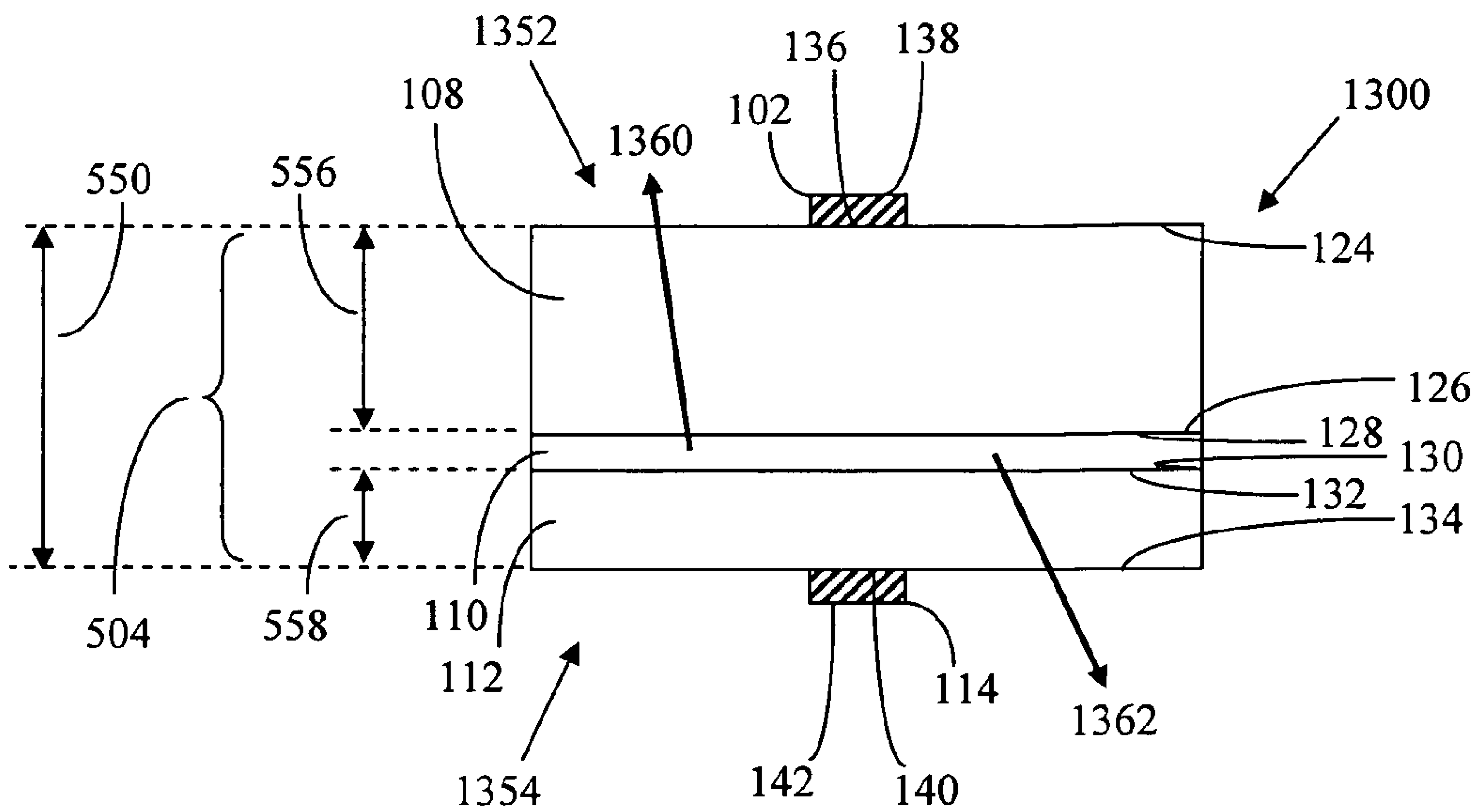
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**FIG. 13**

# SUBSTRATE-FREE LIGHT EMITTING DIODE CHIP

## REFERENCE TO PRIOR APPLICATION

[0001] This application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/005,258, which was filed on Dec. 3, 2007, and which is herein incorporated by reference.

## TECHNICAL FIELD

[0002] The present invention is a thick light emitting diode chip. The chip is substrate-free or free-standing and requires no growth substrate or transfer substrate for structural support.

## BACKGROUND OF THE INVENTION

[0003] Conventional light emitting diodes (LEDs) are fabricated by epitaxially growing multiple layers of semiconductors on a growth substrate. Inorganic light-emitting diodes can be fabricated from GaN-based semiconductor materials containing, for example, gallium nitride (GaN), aluminum nitride (AlN), aluminum gallium nitride (AlGaN), indium nitride (InN), indium gallium nitride (InGaN) and aluminum indium gallium nitride (AlInGaN). Other appropriate materials for LEDs include, for example, aluminum gallium indium phosphide (AlGaInP), gallium arsenide (GaAs), indium gallium arsenide (InGaAs), indium gallium arsenide phosphide (InGaAsP), diamond, boron nitride and zinc oxide (ZnO).

[0004] The total thickness of the semiconductor layers for a conventional GaN-based LED excluding a substrate is less than about 5 microns and usually only about 3 to 4 microns. The layers are fabricated by epitaxially growing a multilayered semiconductor structure on a growth substrate using metal organic chemical vapor deposition (MOCVD), which has a very slow growth rate of approximately 0.1 micron per hour. This results in deposition times of tens of hours and makes the growth of thicker layers prohibitively expensive. The approximately 3 to 4 micron thick multilayer semiconductor structure is very fragile and will break easily if removed from the growth substrate to form a free-standing or substrate-free die. The semiconductor layers must therefore either remain attached to the growth substrate or, alternatively, be attached to a transfer substrate, using wafer bonding techniques before being removed from the growth substrate. The wafer bonding techniques are expensive and can be unreliable. The added steps increase the cost of manufacturing LEDs. Removal of the growth substrate can be done by a laser liftoff process, chemical processing or mechanical polishing.

[0005] The growth substrate for GaN-based LEDs is usually sapphire or silicon carbide and is chosen to closely match the crystallographic structure of the epitaxial layers. A transfer substrate, if utilized, can be a metal, another semiconductor material such as silicon, or a ceramic material such as aluminum nitride. Such growth or transfer substrates may not suitable for the final LED device. For example, sapphire is a poor thermal conductor and is therefore not the most effective thermal conductor to direct heat away from the semiconductor layers. Thermal considerations are very important for LEDs, which generate a significant amount of heat during operation. The heat lowers the light output and operating lifetime of the LED. As LED sizes become larger, such heating effects become more important and can seriously degrade the light-output performance and lifetime of the LEDs.

[0006] Removing the growth substrate and attaching a transfer substrate to the semiconductor layers also adds thermal resistance to the device. The increased thermal resistance can come from the transfer substrate itself and from the bonding layer used to attach the transfer substrate.

[0007] In addition, the growth or transfer substrate may absorb some of the light emitted by the LED, thereby lowering the optical output. The substrate may also trap or reflect some of the light generated by the LED within the LED, resulting in an additional loss in optical output. Light trapping is caused by the high refractive index of the substrate relative to air and results in total internal reflection of emitted light back through the substrate and back through the epitaxial layers.

[0008] It would be desirable to develop thick, substrate-free or free-standing LED chips that do not need the original growth substrate or an attached transfer substrate for structural support. Such thick, substrate-free or free-standing LED chips could be easily manipulated, lifted or handled without breaking and could be subsequently bonded to other surfaces or leadframes in any desired pattern to form light emitting devices. Different growth techniques will be required to make such a structure since MOCVD is too slow to fabricate thick multilayer semiconductor structures.

[0009] In conventional LED designs, the back side of the LED opposite the light emitting side is a reflective surface. It would also be desirable to develop LED chips that do not have a back reflecting surface and that can emit light from all sides. Eliminating the back reflecting surface can reduce the average optical pathlength of the emitted light within the LED structure, thereby reducing optical absorption within the LED, increasing the external quantum efficiency and increasing the light output of the LED.

[0010] Conventional LEDs are cooled by a submount or heat sink in thermal contact with the LED die. The conventional LED die includes either a growth substrate or a transfer substrate. Heat flows from the LED semiconductor layers, through the growth or transfer substrate and through the submount or heat sink to ambient. The heat sink may include fins or other types of structures to transfer heat to an ambient fluid, such as air or water. It would be desirable to develop LED light sources where the LED die does not include a growth substrate or a transfer substrate and where the LED die can be cooled directly without having the added thermal resistance of a growth substrate or a transfer substrate.

[0011] The deficiencies of conventional LEDs described above can be eliminated by the various embodiments of this invention that are described below in the summary, the figures and the detailed descriptions of the preferred embodiments.

## SUMMARY OF THE INVENTION

[0012] A substrate-free or free-standing LED chip of this invention is an LED chip that does not include a growth substrate or transfer substrate as an element of the LED chip. The growth substrate is defined as the substrate onto which the multilayer semiconductor structure is epitaxially grown. For LED chips of this invention, the growth substrate is removed after the multilayer semiconductor structure is fabricated and no transfer substrate is permanently bonded to the multilayer semiconductor structure prior to the removal of the growth substrate. The LED chips of this invention have multilayer semiconductor structures that are at least 10 microns thick and do not require an attached growth substrate or transfer substrate for structural rigidity or support. The LED chips can be handled without damage and without breaking.

**[0013]** After the LED chips of this invention are fabricated, the substrate-free or free-standing LED chips may be packaged into more complex LED light sources. If desired, the LED chips may be attached to a surface, a submount, a heat sink, a leadframe or to any other structure. However, none of these additional surfaces, submounts, heat sinks, leadframes or other structures are elements of the LED chip.

**[0014]** One embodiment of this invention is a thick light emitting diode chip. The LED chip is substrate-free, which means that the chip requires no growth substrate or transfer substrate for structural support. The LED chip includes a multilayer semiconductor structure that has a first side and an opposing second side. The multilayer semiconductor structure includes a first doped layer proximal to the first side, an active region, and a second doped layer proximal to the second side with the active region interposed between the first doped layer and the second doped layer. The first doped layer can be an n-doped layer and the second doped layer can be a p-doped layer or the polarities of the two layers can be reversed. The total thickness of the multilayer semiconductor structure is at least 10 microns, preferably at least 20 microns and more preferably at least 30 microns. The LED chip also includes a first electrode in electrical contact with the first doped layer and a second electrode in electrical contact with the second doped layer. The active region emits internally generated light when a voltage is applied between the first electrode and the second electrode.

**[0015]** An LED chip that has both electrodes on the first side or the second side of the multilayer semiconductor structure may optionally include a substantially undoped layer on the side of the multilayer semiconductor structure opposite the electrodes. The undoped layer can add additional thickness to the multilayer semiconductor structure without affecting the electrical properties of the structure. The additional thickness adds to the structural strength of the multilayer semiconductor structure. In addition, the heat transfer characteristics of an additional undoped layer fabricated from the same semiconductor material (for example, gallium nitride) as the remainder of the multilayer semiconductor structure will be better than the heat transfer characteristics of a growth substrate or transfer substrate of the prior art made from a different material.

**[0016]** The multilayer semiconductor structure of the thick LED chip has at least one thick semiconductor layer to provide structural support to the chip. The thick semiconductor layer can be the first doped layer, the second doped layer, the optional undoped layer or a combination of two or more thick layers. The thick semiconductor layers preferably are fabricated by hydride vapor phase epitaxy (HVPE). Each thick semiconductor layer is at least 5 microns thick, preferably at least 10 microns thick, more preferably at least 15 microns thick and most preferably at least 25 microns thick. When the LED chip includes at least one thick semiconductor layer to provide structural support, the growth or transfer substrate is no longer needed and the LED chip can be handled as a substrate-free or free-standing device without damage.

**[0017]** Another embodiment of this invention is a substrate-free LED chip where at least a portion of the first side of the multilayer semiconductor structure and a portion of the second side of the multilayer semiconductor structure transmit externally incident light. Externally incident light is light that is directed to the LED chip from another light source or light that is emitted by the LED chip and that is recycled back to the chip. Preferably the LED chip transmits at least 60 percent of the externally incident light, more preferably the LED chip transmits at least 70 percent of the externally incident light and most preferably the LED chip transmits at least 80 percent of the externally incident light.

**[0018]** Another embodiment of this invention is a substrate-free LED chip where substantially all of the first side of the multilayer semiconductor structure or substantially all of the second side of the multilayer semiconductor structure reflects light and where, respectively, the second side or the first side is a light emitting side of the LED. Preferably the LED chip reflects at least 60 percent of the externally incident light directed to the light emitting side of the chip, more preferably the LED chip reflects at least 70 percent of the externally incident light and most preferably the LED chip reflects at least 80 percent of the externally incident light.

**[0019]** In order for the substrate-free LED chip to have high external quantum efficiency and to have either high transmission or high reflectivity to externally incident light, the multilayer semiconductor structure should have low optical absorption. The absorption coefficient of the multilayer semiconductor structure should be less than 20 per centimeter, preferably less than 10 per centimeter, more preferably less than 5 per centimeter and most preferably less than 2 per centimeter.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0020]** A more detailed understanding of the present invention, as well as other objects and advantages thereof not enumerated herein, will become apparent upon consideration of the following detailed description and accompanying drawings, wherein:

**[0021]** FIGS. **1**A and **1**B are illustrations of conventional LED chip of the prior art that has two electrodes on the upper side and includes a growth substrate. FIG. **1**A is a top plan view of the LED. FIG. **1**B is a side cross-sectional view along the I-I plane illustrated in FIG. **1**A.

**[0022]** FIG. **2** is a side cross-sectional view of conventional LED chip of the prior art that has two electrodes on the lower side and includes a growth substrate.

**[0023]** FIG. **3** is a side cross-sectional view of conventional LED chip of the prior art that has two electrodes on the lower side and includes a transfer substrate.

**[0024]** FIGS. **4**A and **4**B are illustrations of conventional LED chip of the prior art that has one electrode on the upper side, one electrode on the lower side and includes a transfer substrate. FIG. **4**A is a top plan view of the LED. FIG. **4**B is a side cross-sectional view along the I-I plane illustrated in FIG. **4**A.

**[0025]** FIG. **4**C is a heat flow diagram of the conventional LED chip illustrated in FIGS. **4**A and **4**B.

**[0026]** FIGS. **5**A, **5**B and **5**C illustrate a substrate-free LED chip of the present invention that has two upper electrodes, a thick first doped layer and a lower reflecting layer. FIG. **5**A is a top plan view of the chip. FIGS. **5**B and **5**C are side cross-sectional views along the I-I plane illustrated in FIG. **5**A.

**[0027]** FIG. **5**D is a diagram of the heat flow from a substrate-free LED chip of the present invention to ambient.

**[0028]** FIGS. **6**A and **6**B are side cross-sectional views of substrate-free LED chip of the present invention that has two upper electrodes and no lower reflecting layer.

**[0029]** FIG. **7** is a side cross-sectional view of substrate-free LED chip of the present invention that has two upper electrodes, a thick second doped layer and a lower reflecting layer.

**[0030]** FIG. **8** is a side cross-sectional view of substrate-free LED chip that has two upper electrodes, a thick first doped layer, a thick second doped layer and a lower reflecting layer.

**[0031]** FIG. **9** is a side cross-sectional view of a substrate-free LED chip of the present invention that has two upper electrodes, a thick undoped layer and no lower reflecting layer.

**[0032]** FIG. **10** is a side cross-sectional view of a substrate-free LED chip of the present invention that has two lower electrodes.

**[0033]** FIG. **11** is a side cross-sectional view of another substrate-free LED chip of the present invention that has two lower electrodes.

**[0034]** FIGS. **12**A and **12**B illustrate a substrate-free LED of the present invention that has one upper electrode and one lower electrode. FIG. **12**A is a top plan view. FIG. **12**B is a side cross-sectional view along the I-I plane illustrated in FIG. **12**A.

**[0035]** FIG. **13** is a side cross-sectional view of another substrate-free LED of the present invention that has one upper electrode and one lower electrode.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

**[0036]** The preferred embodiments of the present invention will be better understood by those skilled in the art by reference to the above listed figures. The preferred embodiments of this invention illustrated in the figures are not intended to be exhaustive or to limit the invention to the precise form disclosed. The figures are chosen to describe or to best explain the principles of the invention and its applicable and practical use to thereby enable others skilled in the art to best utilize the invention. For ease of understanding, the thicknesses of the layers in the semiconductor structures in the figures are not drawn to scale.

**[0037]** Light emitting diodes can be fabricated by epitaxially growing multiple layers of semiconductors on a growth substrate. Inorganic light-emitting diodes can be fabricated from gallium nitride (GaN) based semiconductor materials containing, for example, gallium nitride (GaN), aluminum nitride (AlN), aluminum gallium nitride (AlGaN), indium nitride (InN), indium gallium nitride (InGaN) and/or aluminum indium gallium nitride (AlInGaN). Other appropriate materials for LEDs include, for example, aluminum gallium indium phosphide (AlGaInP), gallium arsenide (GaAs), indium gallium arsenide (InGaAs), indium gallium arsenide phosphide (InGaAsP), diamond, boron nitride (BN) and zinc oxide (ZnO).

**[0038]** Especially important LEDs for this invention are GaN-based LEDs that utilize epitaxially-grown layers that can include, for example, GaN, AlN, AlGaN, InN, InGaN or AlInGaN. Depending on the composition of the semiconductor layers, GaN-based LEDs emit light in the ultraviolet, blue, cyan or green regions of the optical spectrum. The growth substrate for GaN-based LEDs is typically sapphire ($Al_2O_3$), silicon carbide (SiC), bulk gallium nitride or bulk aluminum nitride. Although the embodiments of this invention will be described using GaN-based LEDs, other types of LEDs including, but not limited to, AlGaInP and ZnO LEDs may also be utilized in the embodiments.

**[0039]** Typical epitaxial growth methods for thin semiconductor layers of GaN-based materials include chemical vapor deposition (CVD), metal-organic chemical vapor deposition (MOCVD), vapor phase epitaxy (VPE), hydride vapor phase epitaxy (HVPE) and molecular beam epitaxy (MBE). MOCVD is the most common method for conventional GaN-based LEDs where the total thickness of the epitaxial layers is less than about 5 microns. MOCVD is a relatively slow deposition method with growth rates of approximately 0.1 micron per hour. HVPE has much higher growth rates (10 microns per hour is possible). HVPE can be used to fabricate substrate-free LEDs that are described in this invention and where the thickness of one of the layers is at least 5 microns and could be as much as 30 microns or more.

**[0040]** Conventional GaN-based LED chips of the prior art are fabricated so that the total thickness of the epitaxial semiconductor layers, which include a first doped layer, an active region, and a second doped layer, with the active region interposed between the first doped layer and the second doped layer, is less than about 5 microns thick. The complete set of epitaxial semiconductor layers is denoted in this application as the multilayer semiconductor structure. The first doped layer and the second doped layers of the multilayer semiconductor structure can be, respectively, an n-doped layer and a p-doped layer or the layers can be reversed so that the first doped layer is a p-doped layer and the second doped layer is an n-doped layer.

**[0041]** When the multilayer semiconductor structure is less that about 5 microns thick, it is too fragile to form a self-supporting device. To provide structural support, a conventional LED chip of the prior art retains the growth substrate upon which the multilayer semiconductor structure is fabricated or includes a transfer substrate that is bonded to the multilayer semiconductor structure opposite the growth substrate during the fabrication process. The transfer substrate, if present, provides structural support to the epitaxial layers once the growth substrate is removed.

**[0042]** A conventional LED chip of the prior art usually emits light predominately from one side of the chip. The opposing side is substantially covered by one or more reflecting layers and emits little, if any, light.

**[0043]** Examples of conventional GaN-based LED chips of the prior art are illustrated in FIGS. **1** to **4**. FIGS. **1**A and **1**B are illustrations of conventional LED chip **100**. FIG. **1**A is a top plan view of the chip. FIG. **1**B is a side cross-sectional view along the I-I plane illustrated in FIG. **1**A. Conventional LED chip **100** in FIG. **1** has both the n-electrode and p-electrode on the "top" surface of the device and the chip includes a growth substrate. Conventional LED chip **100** includes a first electrode **102**, a multilayer semiconductor structure **104**, a second electrode **114**, a growth substrate **106** and a back reflector **115**. The multilayer semiconductor structure **104** includes a first doped layer **108**, an active region **110** and a second doped layer **112**, which is on the opposite side of the active region **110** from the first doped semiconductor layer **108**. Consequently, the active region is interposed between the first doped layer and the second doped layer. The active region is in electrical contact with the first doped layer and the second doped layer and the active region emits light in a first wavelength range when a current is applied through the first and second electrodes.

**[0044]** The first electrode **102** is in electrical contact with the first doped layer **108** and the second electrode **114** is in electrical contact with the second doped layer **112**. The first electrode and the second electrode may be fabricated from reflecting metals.

**[0045]** The multilayer semiconductor structure **104** of the LED chip **100** can be fabricated from GaN-based semiconductor materials containing GaN, AlN, AlGaN, InN, InGaN and/or AlInGaN.

**[0046]** The active region **110** of the multilayer semiconductor structure **104** is a p-n homojunction, a p-n heterojunction, a single quantum well or a multiple quantum well of the appropriate semiconductor material for the LED.

**[0047]** A multilayer semiconductor structure **104** is fabricated on a growth substrate **106** of sapphire. The multilayer semiconductor structure includes a first doped layer **108**, an active region **110** and a second doped layer **112**. The growth substrate **106** has a first surface **120** and a second surface **122** opposite the first surface.

**[0048]** The first doped layer **108** is an n-doped GaN layer, which is epitaxially deposited or otherwise conventionally fabricated on the second surface **122** of the growth substrate. The first doped layer **108** has a first surface **124** and a second surface **126** opposite the first surface. The first surface **124** of the first doped layer is in contact with surface **122** of the growth substrate.

**[0049]** The active region **110** is a GaN-based multiple quantum well structure, which is epitaxially deposited or otherwise conventionally fabricated on the second surface **126** of the first doped layer **108**. The active region **110** has a first surface **128** and a second surface **130** opposite the first surface. The first surface **128** of the active region is in electrical contact with the second surface **126** of the first doped layer.

**[0050]** The second doped layer **112** is a p-doped GaN layer, which is epitaxially deposited or otherwise conventionally fabricated on the second surface **130** of the active region **110**. The second doped layer has a first surface **132** and a second surface **134** opposite the first surface. The first surface **132** of the second doped layer is in electrical contact with the second surface **130** of the active region.

**[0051]** A portion **116** of the second doped layer **112** and the active region **110** is removed to expose a portion **116** of the second surface **126** of the first doped layer. The first electrode **102** and the second electrode **114** are fabricated from aluminum. An aluminum layer is deposited on the second surface **134** of the second doped layer and the exposed portion **116** of the second surface **126** of the first doped layer. The aluminum layer is patterned by standard photolithographic techniques to form the first electrode **102** and the second electrode **114**. First electrode **102** has a first surface **136** and a second surface **138**. The first surface **136** of the first electrode is in electrical contact with the second surface **126** of the first doped layer. Second electrode **114** has a first surface **140** and a second surface **142**. First surface **140** of the second electrode is in electrical contact with the second surface **134** of the second doped layer.

**[0052]** The first electrode **102** only partially covers the exposed portion **116** of the second surface **126** of the first doped layer. The second electrode **114** only partially covers the second surface **134** of the second doped layer. The remaining portion of the exposed portion **116** of the second surface **126** of the first doped layer and the second surface **134** of the second doped layer are an output or exit surface for the light emitted by the LED **100**. To form a back reflector **115**, a layer of silver is deposited on the first surface **120** of the growth substrate.

**[0053]** In summary, LED chip **100** has a first electrode **102**, a multilayer semiconductor structure **104** that includes first-doped, active and second-doped layers, a growth substrate **106** and a second electrode **114**. LED chip **100** has a first side **152** and a second side **154**. The first side **152** is substantially adjacent to the first doped layer **108**. The second side **154** is substantially adjacent to the second doped layer **112**. The active region **110** emits internally generated light in a first wavelength range when a current is applied through the first electrode **102** and the second electrode **114**. The light is emitted from the second side **154** of the LED.

**[0054]** The total thickness **150** of the multilayer semiconductor structure **104** for conventional LED chip **100** of the prior art is less than 5 microns. For example, the thickness of the first doped layer (the n-doped layer) is typically 3 microns, the thickness of the active region (a multi-quantum well structure) is typically 0.5 microns and the thickness of the second doped layer (the p-doped layer) is typically 0.5 microns, resulting in a total thickness of 4 microns. In prior art LEDs, the semiconductor layers are usually grown by MOCVD.

**[0055]** Another conventional LED design of the prior art is illustrated in FIG. **2**. Conventional LED chip **200** in FIG. **2** is similar to LED chip **100** in FIG. **1** except that the LED chip **200** structure is inverted relative to LED chip **100** and has both the first electrode and second electrode on the lower surface of the device. This configuration is sometimes called a flip-chip design. LED **200** also includes a growth substrate.

**[0056]** Except for the back reflecting surfaces, most of the elements of LED chip **200** of the prior art are the same as LED chip **100**. Conventional LED chip **200** includes a first electrode **102**, a multilayer semiconductor structure **104**, a second electrode **114** and a growth substrate **106**. The multilayer semiconductor structure **104** includes a first doped layer **108**, an active region **110** and a second doped layer **112**, which is on the opposite side of the active region **110** from the first doped semiconductor layer **108**.

**[0057]** The first electrode **102** is in electrical contact with the first doped layer **108** and the second electrode **114** is in electrical contact with the second doped layer **112**. For LED chip **200**, the second electrode is a reflecting electrode and covers substantially all of surface **134** of the second doped layer **112**. The first electrode and the second electrode may be fabricated from reflecting metals.

**[0058]** The multilayer semiconductor structure **104** of LED chip **200** can be fabricated from GaN-based semiconductor materials containing GaN, AlN, AlGaN, InN, InGaN and/or AlInGaN. Alternatively, the multilayer semiconductor structure can be fabricated from any appropriate light-emitting semiconductor material.

**[0059]** The active region **110** of the multilayer semiconductor structure **104** is a p-n homojunction, a p-n heterojunction, a single quantum well or a multiple quantum well of the appropriate semiconductor material for the LED chip **200**.

**[0060]** For purposes of illustration, LED chip **200** is assumed to be a GaN-based LED. The important fabrication steps for this GaN-based, illustrative example will be briefly summarized. Many of the fabrication steps are identical to the steps for LED chip **100** and will not be repeated.

**[0061]** First a multilayer semiconductor structure **104** of LED chip **200** is fabricated on a sapphire growth substrate

**106** using the same methods that are described above for LED **100**. The growth substrate **106** has a first surface **120** and a second surface **122** opposite the first surface. The multilayer semiconductor structure includes a first doped layer **108** that is n-doped GaN, an active region **110** that is a GaN-based multiple quantum well structure and a second doped layer **112** that is p-doped GaN.

**[0062]** A portion **116** of the second doped layer **112** and the active region **110** is removed to expose a portion **116** of the second surface **126** of the first doped layer. The first electrode **102** and the second electrode **114** are fabricated from aluminum. An aluminum layer is deposited on the second surface **134** of the second doped layer and the exposed portion **116** of the second surface **126** of the first doped layer. The aluminum layer is patterned by standard photolithographic techniques to form the first electrode **102** and the second electrode **114**. The first surface **136** of the first electrode is in electrical contact with the second surface **126** of the first doped layer. First surface **140** of the second electrode is in electrical contact with the second surface **134** of the second doped layer.

**[0063]** The first electrode **102** partially covers the exposed portion **116** of the second surface **126** of the first doped layer. The second electrode **114** substantially covers the second surface **134** of the second doped layer. Surface **136** of the first electrode and surface **140** of the second electrode form the back reflector for LED chip **200**.

**[0064]** In summary, LED chip **200** has a first electrode **102**, a multilayer semiconductor structure **104** that includes first-doped, active and second-doped layers, a growth substrate **106** and a second electrode **114**. LED chip **200** has a first side **252** and a second side **254**. The first side **252** is substantially adjacent to the first doped layer **108**. The second side **254** is substantially adjacent to the second doped layer **112**. The active region **110** emits internally generated light in a first wavelength range when a current is applied through the first electrode **102** and the second electrode **114**. The light is emitted from the first side **252** of the LED.

**[0065]** The total thickness **150** of the multilayer semiconductor structure **104** for LED chip **200** of the prior art is less than 5 microns. For example, the thickness of the first doped layer (the n-doped layer) is typically 3 microns, the thickness of the active region (a multi-quantum well structure) is typically 0.5 microns and the thickness of the second doped layer (the p-doped layer) is typically 0.5 microns, resulting in a total thickness of 4 microns. The semiconductor layers are usually grown by MOCVD.

**[0066]** When utilized as in a light source, LED chip **200** is normally attached to a submount (not shown). The submount acts as a heat transfer element or heatsink to remove heat generated by the device during operation. The submount also includes electrical interconnections that attach to the first electrode and second electrode.

**[0067]** Another conventional LED design of the prior art is illustrated in FIG. **3**. Conventional LED chip **300** in FIG. **3** is similar to LED chip **100** in FIG. **1** and LED chip **200** in FIG. **2**. The LED chip **300** structure is inverted and has both the n-electrode and p-electrode on the lower side of the device. This configuration is another version of a flip-chip structure. However, for the LED chip **300** design, the LED structure is bonded to a transfer substrate **302** that includes electrical connections (not shown) to the n-electrode and the p-electrode. The original growth substrate has been removed.

**[0068]** Except for the removal of the growth substrate and the addition of a transfer substrate **302**, most of the elements of LED chip **300** are the same as LED chip **200**. Conventional LED chip **300** of the prior art includes a first electrode **102**, a multilayer semiconductor structure **104**, a second electrode **114** and a transfer substrate **302** on the second side **354** of the chip. The multilayer semiconductor structure **104** includes a first doped layer **108** on the first side **352** of the chip, an active region **110** and a second doped layer **112**, which is on the opposite side of the active region **110** from the first doped semiconductor layer **108**.

**[0069]** The first electrode **102** is in electrical contact with the first doped layer **108** and the second electrode **114** is in electrical contact with the second doped layer **112**. For LED **300**, the second electrode is a reflecting electrode and covers substantially all of surface **134** of the second doped layer **112**. The first electrode and the second electrode may be fabricated from reflecting metals.

**[0070]** The active region **110** of the multilayer semiconductor structure **104** can be a p-n homojunction, a p-n heterojunction, a single quantum well or a multiple quantum well of the appropriate semiconductor material for the LED chip **300**.

**[0071]** For purposes of illustration, LED chip **300** is assumed to be a GaN-based LED. The important fabrication steps for this GaN-based, illustrative example will be briefly summarized. Many of the fabrication steps are identical to the steps for LED chip **100** and will not be repeated.

**[0072]** First a multilayer semiconductor structure **104** of LED chip **300** is fabricated on a sapphire growth substrate (not shown) using the same methods that are described above for LED **100**.

**[0073]** A portion **116** of the second doped layer **112** and the active region **110** is removed to expose a portion **116** of the second surface **126** of the first doped layer. To form the electrodes, a metal layer is deposited on the second surface **134** of the second doped layer and the exposed portion **116** of the second surface **126** of the first doped layer. The metal layer is patterned by standard photolithographic techniques to form the first electrode **102** and the second electrode **114**. The first electrode **102** partially covers the exposed portion **116** of the second surface **126** of the first doped layer. The second electrode **114** substantially covers the second surface **134** of the second doped layer. Surface **136** of the first electrode and surface **140** of the second electrode form the back reflector for LED chip **300**.

**[0074]** A transfer substrate **302** is bonded to surface **138** of the first electrode and surface **142** of the second electrode. The transfer substrate includes electrical vias (not shown) in order to make electrical connections to the electrodes. After the transfer substrate is attached, the growth substrate is removed by standard processing steps. For example, the growth substrate can be removed by a laser liftoff process, a chemical process or by mechanical polishing.

**[0075]** The total thickness 150 of the multilayer semiconductor structure **104** for LED chip **300** of the prior art is less than 5 microns. For example, the thickness of the first doped layer (the n-doped layer) is typically 3 microns, the thickness of the active region (a multi-quantum well structure) is typically 0.5 microns and the thickness of the second doped layer (the p-doped layer) is typically 0.5 microns, resulting in a total thickness of 4 microns. The semiconductor layers are usually grown by MOCVD.

**[0076]** When utilized as in a light source, LED chip **300** may also include a submount (not shown), which acts as a heat transfer element or heatsink to remove heat generated by the device during operation.

**[0077]** Another conventional LED of the prior art has one electrode on the upper side of the device and one electrode on the lower side. LED chip **400** illustrated in FIGS. **4**A and **4**B is one example of such a device of the prior art.

**[0078]** FIGS. **4**A and **4**B are illustrations of a conventional LED chip **400** of the prior art that has a upper electrode, a lower electrode and includes a transfer substrate. FIG. **4**A is a top plan view of the chip. FIG. **4**B is a side cross-sectional view along the I-I plane illustrated in FIG. **4**A. The multilayer semiconductor structure of LED chip **400** is inverted relative to the LED chip **100** structure. However, LED chip **400** has one electrode, in this case the n-electrode or first electrode **102**, on the upper side of the device and the other electrode, the p-electrode or the second electrode **114**, on the lower side of the device. In a similar manner as the LED chip **300** design, the LED chip **400** structure is bonded to a transfer substrate. The transfer substrate **402** is either an electrical conductor or includes an electrical connection (not shown) to the second or p-electrode. The original growth substrate has been removed.

**[0079]** Except for the arrangement of the electrodes, most of the elements of LED chip **400** of the prior art are the same as for LED chip **300**. Conventional LED chip **400** includes a first electrode **102** on the first side **452** of the device, a multilayer semiconductor structure **104**, a second electrode **114** proximal to the second side **454** of the device and a transfer substrate **402**. The multilayer semiconductor structure **104** includes a first doped layer **108**, an active region **110** and a second doped layer **112**, which is on the opposite side of the active region **110** from the first doped semiconductor layer **108**.

**[0080]** The first electrode **102** is in electrical contact with the first doped layer **108** and the second electrode **114** is in electrical contact with the second doped layer **112**. For LED chip **400**, the second electrode is a reflecting electrode and covers substantially all of surface **134** of the second doped layer **112**. The first electrode and the second electrode may be fabricated from reflecting metals.

**[0081]** The active region **110** of the multilayer semiconductor structure **104** can be a p-n homojunction, a p-n heterojunction, a single quantum well or a multiple quantum well of the appropriate semiconductor material for the LED chip **400**.

**[0082]** For purposes of illustration, LED chip **400** is assumed to be a GaN-based LED. The important fabrication steps for this GaN-based, illustrative example will be briefly summarized. Many of the fabrication steps, including the fabrication of the multilayer semiconductor structure, are identical to the steps for LED chip **100**, LED chip **200** and LED chip **300** and will not be repeated.

**[0083]** The second electrode **114** is fabricated from a metal. A metal layer is deposited on the second surface **134** of the second doped layer of the multilayer semiconductor structure. The first surface **140** of the second electrode is in electrical contact with the second surface **134** of the second doped layer. Surface **140** of the second electrode also forms the back reflector for LED chip **400**.

**[0084]** A transfer substrate **402**, and in particular surface **404** of the transfer substrate, is bonded to surface **142** of the second electrode. The transfer substrate **402** is either an electrical conductor or includes an electrical interconnect (not shown) to the second electrode.

**[0085]** After the transfer substrate is attached, the growth substrate is removed by standard processing steps, exposing the first surface **124** of the first doped layer. For example, the growth substrate can be removed by a laser liftoff process, a chemical process or by mechanical polishing.

**[0086]** The first electrode **102** is fabricated from a metal. A metal layer is deposited on the first surface **124** of the first doped layer that was exposed by removing the growth substrate. The metal layer is patterned by standard photolithographic techniques to form the first electrode **102**. The first electrode **102** partially covers surface **124** of the first doped layer.

**[0087]** In summary, LED chip **400** has a first electrode **102**, a multilayer semiconductor structure **104** that includes first-doped, active and second-doped layers, a transfer substrate **402** and a second electrode **114**. LED chip **400** has a first side **452** and a second side **454**. The first side **452** is substantially adjacent to the first doped layer **108**. The second side **454** is substantially adjacent to the second doped layer **112**. The active region **110** emits internally generated light in a first wavelength range when a current is applied through the first electrode **102** and the second electrode **114**. The light is emitted from the first side **452** of the LED.

**[0088]** The total thickness 150 of the multilayer semiconductor structure **104** for LED chip **400** is typically less than 5 microns. For example, the thickness of the first doped layer (the n-doped layer) is typically 3 microns, the thickness of the active region (a multi-quantum well structure) is typically 0.5 microns and the thickness of the second doped layer (the p-doped layer) is typically 0.5 microns, resulting in a total thickness of 4 microns. The semiconductor layers are usually grown by MOCVD.

**[0089]** When utilized as in a light source, LED chip **400** may also include a submount or heatsink (neither are shown) that acts as a heat transfer element to remove heat generated by the device during operation.

**[0090]** The heat flow from the multilayer semiconductor structure of LED chip **400** of the prior art is illustrated schematically in FIG. **4**C. Heat flows from the multilayer semiconductor structure to the transfer substrate with thermal resistance **482**, then from the transfer substrate to the submount or heatsink with thermal resistance **484** and finally from the submount or heatsink with thermal resistance **486** to the ambient **488**. The transfer substrate, the bonding material (not shown) used to bond the transfer substrate to the multilayer semiconductor structure and the submount/heatsink increase the thermal resistance of the device.

**[0091]** FIGS. **1** to **4** illustrate conventional LED chips of the prior art that include multilayer semiconductor structures that are less than 5 microns thick and that include either a growth substrate or a transfer substrate.

**[0092]** In contrast to conventional LED chips of the prior are, the LED chips of this present invention are substrate-free. Alternatively, the LED chips of this invention may also be described as free-standing. A substrate-free or free-standing LED chip of this invention is an LED chip that does not include a growth substrate or transfer substrate as an element of the LED chip. The growth substrate is defined as the substrate onto which the multilayer semiconductor structure is epitaxially grown. For LED chips of this present invention, the growth substrate is removed after the multilayer semiconductor structure is fabricated and no transfer substrate is permanently bonded to the multilayer semiconductor structure prior to the removal of the growth substrate. The LED chips of this present invention have multilayer semiconductor structures that are at least 10 microns thick and do not require an attached growth substrate or transfer substrate for structural rigidity or support. The LED chips can be handled without damage and without breaking.

**[0093]** The substrate-free or free-standing LED chips of this present invention may later be packaged into more complex LED light sources. If desired, the LED chips may be attached to a surface, a submount, a heat sink, a leadframe or to any other structure. However, none of these additional surfaces, submounts, heat sinks, leadframes or other structures are elements of the LED chip.

**[0094]** Embodiments of this present invention are substrate-free LED chips that do not include a growth substrate or a transfer substrate. Substrate-free LED chips of this invention have multilayer semiconductor structures that are at least 10 microns thick. It is also within the scope of this invention that the multilayer semiconductor structures can have a thickness of at least 20 microns or at least 30 microns. The multilayer semiconductor structures utilized for the substrate-free LED chips are thick enough so that the LED chips can be handled as free-standing structures without breaking.

**[0095]** For the substrate-free LED chips of this invention, at least one layer of the multilayer semiconductor structure is at least 5 microns thick. The at least one thick layer in the multilayer semiconductor structure can be the first doped layer, the second doped layer or an undoped layer. Preferably the first doped layer, the second doped layer or the updoped layer is at least 10 microns thick. More preferably, the first doped layer, the second doped layer or the undoped layer is at least 15 microns thick. Most preferably, the first doped layer, the second doped layer or the undoped layer is at least 25 microns thick. Alternatively, two or more layers of the multilayer semiconductor structure are each at least 5 microns thick.

**[0096]** The total thickness of the multilayer semiconductor structure for the substrate-free LED chips of this invention is at least 10 microns thick. More preferably the total thickness of the multilayer semiconductor structure is at least 20 microns thick. Most preferably the total thickness of the multilayer semiconductor structure is at least 30 microns thick.

**[0097]** Since thicker semiconductor layers are utilized for the substrate-free LED chip, the optical absorption coefficients for the various layers must be low in order to prevent the absorption of a significant fraction of the internally generated light that is emitted by the active region of the chip and transmitted through the thicker semiconductor layers before exiting the chip. Lower optical absorption within the LED chip will result in higher light extraction from the chip, higher external quantum efficiency and higher light output from the LED.

**[0098]** In some applications, it is also important that the LED chip be highly reflective or highly transmissive to any externally incident light that comes from other light sources or from recycled light that is directed or reflected back toward the chip. The optical absorption coefficients for the various semiconductor layers must also be low in these cases so that any externally incident light that enters the chip will not undergo significant absorption by the semiconductor layers before exiting the chip. Lowering the optical absorption coefficients of the semiconductor layers will increase the reflectivity or transmissivity of the LED chip to externally incident light.

**[0099]** The multilayer semiconductor structure of the LED chip can absorb light and has an absorption coefficient that depends on wavelength. In many cases, the absorption coefficient is not uniform across the different semiconductor layers of the multilayer semiconductor structure. If the different semiconductor layers that make up the multilayer semiconductor structure have different absorption coefficients, the absorption coefficient for the multilayer semiconductor structure is defined in this specification as the thickness-weighted average absorption coefficient. The weighting function is the fractional thickness of each semiconductor layer in the multilayer semiconductor structure. For example, if 100 percent of the thickness of the multilayer semiconductor structure has a uniform absorption coefficient of 40 per centimeter in the emitting wavelength range of the internally generated light, then the thickness-weighted average absorption coefficient is 40 per centimeter. If 50 percent of the thickness of the multilayer semiconductor structure has an absorption coefficient of 30 per centimeter and 50 percent of the thickness of the multilayer semiconductor structure has an absorption coefficient of 50 per centimenter, then the thickness-weighted average absorption coefficient is also 40 per centimeter.

**[0100]** In order to improve the light extraction efficiency and external quantum efficiency of an LED chip and to improve the reflectivity or transmissivity of the LED chip to externally incident light, the absorption coefficient (i.e. the thickness-weighted average absorption coefficient) of the multilayer semiconductor structure in the emitting wavelength range of the internally generated light is less than 20 per centimeter. Preferably the absorption coefficient of the multilayer semiconductor structure in the emitting wavelength range of the internally generated light is less than 10 per centimeter. More preferably, the absorption coefficient of the multilayer semiconductor structure in the emitting wavelength range is less than 5 per centimeter. Most preferably, the absorption coefficient of the multilayer semiconductor structure in the emitting wavelength range is less than 2 per centimeter.

**[0101]** Minimizing the absorption coefficient of the multilayer semiconductor structure in the emitting wavelength range of the internally generated light can be accomplished by improving the deposition processes for the different semiconductor layers in order to reduce impurities or defects and to improve the crystalline structure of the layers.

**[0102]** Thick semiconductor layers can be grown by methods including, but not limited to, CVD, MOCVD, VPE, HVPE and MBE. MOCVD is the most common method for conventional GaN-based LEDs but it has relatively slow deposition rates of approximately 0.1 micron per hour. MOCVD deposited layers also have relatively high optical absorption coefficients due to impurities and defects. HVPE has much faster growth rates and is the preferred method for this invention in order to grow GaN layers that are more than 5 microns thick. HVPE can have growth rates of up to 10 microns per hour or more and can produce GaN-based LED layers that have optical absorption coefficients significantly less than 25 per centimeter.

**[0103]** For example, HVPE can be used to epitaxially grow the first doped layer, the second doped layer, both the first and the second doped layers, any undoped layer or the entire multilayer semiconductor structure of the LED. HVPE does not have the carbon impurities that can be present in the MOCVD processes normally used in GaN LED fabrication. MOCVD may optionally be used to grow active regions that are single- or multiple quantum wells. If the active region of the LED chip is a p-n homojunction or a p-n heterojunction, preferably the entire multilayer semiconductor structure is fabricated by HVPE.

[0104] A substrate-free LED chip may have two electrodes on one side of the chip, either the upper side or the lower side. Alternatively, the substrate-free LED chip may have one electrode on the upper side of the chip and one electrode on the lower side of the chip.

[0105] Both electrodes should be highly reflective to internally generated light to prevent excessive light absorption inside the chip. In addition, making the external surfaces of the electrodes highly reflective will result in an LED chip that has higher reflectivity to externally incident light.

[0106] Gold is a common electrode material. Gold has very good electrical properties, but is a poor optical reflector for visible light in the range of 400 mn to 550 mn. For LEDs that emit light in the 400 to 550 nm range or thereabouts, it is advantageous to replace gold with a more reflective material. Suitable electrode materials include, but are not limited to, aluminum and silver. The electrodes may also be omni-directional reflectors that include a dielectric layer and a metal layer and have electrically conducting pathways through the dielectric layer. Preferably the reflectivity of the electrodes is greater than 90 percent in the emitting wavelength range. More preferably, the reflectivity of the electrodes is greater than 95 percent in the emitting wavelength range. Most preferably, the reflectivity of the electrodes is greater than 98 percent in the emitting wavelength range.

[0107] Examples of substrate-free LED chips for this invention that have at least one thick epitaxial layer and that do not have either a growth substrate or a transfer substrate are illustrated in FIGS. **5** to **13**. In the first set of examples illustrated in FIGS. **5** to **9**, the LED chips each have both electrodes on the upper side of the chip. In the second set of examples illustrated in FIGS. **10** and **11**, the LED chips each have both electrodes on the lower side of the chip. In the third set of examples illustrated in FIGS. **12** and **13**, the LED chips each have one electrode on the upper side of the chip and one electrode on the lower side of the chip.

[0108] FIGS. **5** to **9** illustrate substrate-free LED chips that have both electrodes on the upper side. FIGS. **5** and **6** illustrate LED chips having a thick first doped layer. FIG. **7** illustrates an LED chip with a thick second doped layer. FIG. **8** illustrates an LED chip with both a thick first doped layer and a thick second doped layer. FIG. **9** illustrated an LED chip that has a thick undoped layer.

[0109] FIGS. **10** to **11** illustrate substrate-free LED chips that have both electrodes on the lower side of the chip and that have a thick first doped layer. It is also within the scope of this invention that chips that have both electrodes on the lower side may alternatively have a thick second doped layer or have both a thick first doped layer and a thick second doped layer or have a thick undoped layer. Only examples with a thick first doped layer are illustrated in the figures.

[0110] FIGS. **12** to **13** illustrate substrate-free LED chips that have one electrode on the upper side of the chip, one electrode on the lower side of the chip and have a thick first doped layer. It is also within the scope of this invention that chips that have one electrode on the upper side and one electrode on the lower side may alternatively have a thick second doped layer or have both a thick first doped layer and a thick second doped layer. Only examples with a thick first doped layer are illustrated in the figures.

[0111] First, examples of substrate-free LED chips that have two electrodes on the upper side of the chip are now described. The chips are illustrated in FIGS. **5** to **9**. If the lower electrode or a reflector substantially covers the lower surface of the chip, the substrate-free LED chip will emit light from the upper side and emit little or no light from the lower side. If the lower electrode or reflector covers only a portion of the lower side of the chip, the chip will emit light from both the upper and lower sides, thereby increasing the extraction efficiency, the external quantum efficiency and the light output of the chip.

[0112] Substrate-free LED chip **500** illustrated in FIGS. **5**A, **5**B and **5**C has both the first electrode and the second electrode on the upper surface of the device and has neither a growth substrate nor a transfer substrate. FIG. **5**A is a top plan view of the chip. FIGS. **5**B and **5**C are side cross-sectional views along the I-I plane illustrated in FIG. **5**A.

[0113] Substrate-free LED chip **500** includes a first electrode **102**, a multilayer semiconductor structure **504**, a second electrode **114** and a back reflector **115**. The multilayer semiconductor structure **504** includes a first doped layer **108**, an active region **110** and a second doped layer **112**, which is on the opposite side of the active region **110** from the first doped semiconductor layer **108**. Consequently, the active region is interposed between the first doped layer and the second doped layer. The active region is in electrical contact with the first doped layer and the second doped layer and the active region emits internally generated light when a voltage is applied between the first and second electrodes.

[0114] The first electrode **102** is in electrical contact with the first doped layer **108** and the second electrode **114** is in electrical contact with the second doped layer **112**. The first electrode and the second electrode may be fabricated from reflecting metals. For example, the first electrode and the second electrode may be formed from one or more metals or metal alloys containing, but not limited to, silver, aluminum, nickel, titanium, chromium, platinum, palladium, rhodium, rhenium, ruthenium and tungsten. Preferred metals are aluminum and silver.

[0115] The multilayer semiconductor structure **504** of the LED chip **500** can be fabricated from GaN-based semiconductor materials containing, for example, GaN, AlN, AlGaN, InN, InGaN and/or AlInGaN. Alternatively, the multilayer semiconductor structure can be fabricated from any appropriate light-emitting semiconductor material.

[0116] The active region **110** of the multilayer semiconductor structure **504** is a p-n homojunction, a p-n heterojunction, a single quantum well or a multiple quantum well of the appropriate semiconductor material for the LED.

[0117] For purposes of illustration, LED chip **500** is assumed to be a GaN-based LED chip. The important fabrication steps for a GaN-based, illustrative example will be briefly summarized.

[0118] First a multilayer semiconductor structure **504** is fabricated on a sapphire growth substrate (not shown). The multilayer semiconductor structure illustrated in FIGS. **5**B and **5**C includes a first doped layer **108**, an active region **110** and a second doped layer **112**.

[0119] The first doped layer **108** is an n-doped GaN-based layer, which is epitaxially deposited or otherwise conventionally fabricated on a growth substrate. The first doped layer **108** has a first surface **124** and a second surface **126** opposite the first surface. The first doped layer is at least 5 microns thick. Preferably the first doped layer is at least 10 microns thick. More preferably, the first doped layer is at least 15 microns thick. Most preferably, the first doped layer is at least 25 microns thick. The first doped layer may be deposited by any standard GaN growth technique. Preferably, the first doped layer is deposited by HVPE. In this illustrative example, the first doped layer is 20 microns thick and is deposited by HVPE.

**[0120]** The active region **110** is a GaN-based multiple quantum well structure, which is epitaxially deposited or otherwise conventionally fabricated on the second surface **126** of the first doped layer **108**. The active region **110** has a first surface **128** and a second surface **130** opposite the first surface. The first surface **128** of the active region is in electrical contact with the second surface **126** of the first doped layer. The active region may be deposited by any standard GaN growth technique. Preferably, the multiple quantum well structure is deposited by MOCVD or HVPE. In this illustrative example, the multiple-quantum-well active region is approximately 0.5 micron thick and is deposited by MOCVD.

**[0121]** The second doped layer **112** is a p-doped GaN-based layer, which is epitaxially deposited or otherwise conventionally fabricated on the second surface **130** of the active region **110**. The second doped layer has a first surface **132** and a second surface **134** opposite the first surface. The first surface **132** of the second doped layer is in electrical contact with the second surface **130** of the active region. The second doped layer may be deposited by any GaN growth technique. In this illustrative example, the second doped layer is approximately 0.5 micron thick and is deposited by MOCVD.

**[0122]** A portion **116** of the second doped layer **112** and the active region **110** are removed to expose a portion **116** of the second surface **126** of the first doped layer. The first electrode **102** and the second electrode **114** are fabricated from aluminum. An aluminum layer is deposited on the second surface **134** of the second doped layer and the exposed portion **116** of the second surface **126** of the first doped layer. The aluminum layer is patterned by standard photolithographic techniques to form the first electrode **102** and the second electrode **114**. First electrode **102** has a first surface **136** and a second surface **138**. The first surface **136** of the first electrode is in electrical contact with the second surface **126** of the first doped layer. Second electrode **114** has a first surface **140** and a second surface **142**. First surface **140** of the second electrode is in electrical contact with the second surface **134** of the second doped layer.

**[0123]** The first electrode **102** only partially covers the exposed portion **116** of the second surface **126** of the first doped layer. The second electrode **114** only partially covers the second surface **134** of the second doped layer. The remaining portion of the exposed portion **116** of the second surface **126** of the first doped layer and the second surface **134** of the second doped layer are output or exit surfaces for the light emitted by the LED chip **500**. The first electrode is not in physical or electrical contact with the second doped layer and the active region. The air gap between the first electrode and the second doped layer and the active region may be filled with a non-conducting material or an insulating material (not shown).

**[0124]** The growth substrate (not illustrated) is removed by any conventional process including laser liftoff, chemical processes and mechanical polishing. Removing the growth substrate exposes first surface **124** of the first doped layer. For this illustrative example, the growth substrate is removed using an frequency-quadrupled Nd-YAG laser operating at 266 nanometers.

**[0125]** To form a lower reflector **115**, a layer of silver or other reflective metal is deposited on the exposed first surface **124** of the first doped layer following the removal of the growth substrate. Optionally, the lower reflector may also be an omni-directional reflector that includes a dielectric layer (not shown) and a metal layer such as silver or aluminum.

**[0126]** In summary, substrate-free LED chip **500** illustrated in FIGS. **5**A, **5**B and **5**C has a first electrode **102**, a multilayer semiconductor structure **504** that includes a first doped layer, an active region and a second doped layer and a second electrode **114**. LED chip **500** has neither a growth substrate nor a transfer substrate. LED chip **500** has a first side **552** and a second side **554**. The first side **552** is proximal to the first doped layer **108**. The second side **554** is proximal to the second doped layer **112**. The active region **110** emits internally generated light when a voltage is applied across the first electrode **102** and the second electrode **114**. Second side **554** of LED chip **500** is the light emitting side for internally generated light.

**[0127]** The total thickness **550** of the multilayer semiconductor structure **504** for LED chip **500** is at least 10 microns. In this illustrative example, the thickness **556** of the first doped layer (the n-doped layer) is approximately 20 microns, the thickness of the active region (a multi-quantum well structure) is approximately 0.5 microns and the thickness **558** of the second doped layer (the p-doped layer) is approximately 0.5 microns, resulting in a total thickness of 21 microns. In this example, the first doped layer is grown by HVPE and the remainder of the semiconductor layers are grown by MOCVD.

**[0128]** Example light rays **560**, **562** and **564** in FIG. **5**B illustrate internally generated light that is emitted by the active region **110** of the LED. Internally generated light ray **560** is emitted by active region **110** toward output surface **134** of the LED chip. Internally generated light ray **560** is directed at an angle to surface **134** that is less than the critical angle, which allows light ray **560** to exit the LED chip through surface **134**.

**[0129]** Internally generated light ray **562** is emitted by active region **110** toward the lower reflector **115** of the LED. Internally generated light ray **562** is reflected by reflector **115** and directed to the output surface **134** at an angle less than the critical angle. Internally generated light ray **562** exits the LED chip through surface **134**.

**[0130]** Internally generated light ray **564** is directed to surface **134** at an angle that is greater than the critical angle. Internally generated light ray **564** is reflected by total internal reflection and is redirected toward the rear reflector **115** of the LED chip.

**[0131]** Substantially all of the first side **552** of LED **500** is covered by lower reflector **115**. Due to the reflectivity of reflector **115**, the reflectivity of surface **138** of first electrode **102** and the reflectivity of surface **142** of second electrode **114**, substrate-free LED chip **500** can reflect externally incident light. Externally incident light is light that is directed to the light emitting side of the LED from another light source or light that is emitted by the LED and is reflected back to the light emitting side of the LED as recycled light. For some applications, for example applications utilizing light recycling to increase the effective brightness of the LED, it is important that the LED have high reflectivity to externally incident light. High reflectivity to externally incident light will exist if the reflecting layers of the LED have high reflectivity (e.g. greater than 70%) and if the absorption coefficient of the multilayer semiconductor structure is low (e.g. less than 20 per centimeter). Preferably LED **500** reflects at least 60 percent of externally incident light directed to the light emitting side (second side **554**) of the LED. More preferably, LED **500** reflects at least 70 percent of externally incident light. Most preferably, LED **500** reflects at least 80 of externally incident light.

**[0132]** Example light rays **570**, **572** and **574** in FIG. SC illustrate externally incident light that is incident on the light emitting side or second side **554** of LED chip **500** and is reflected by the chip. Externally incident light ray **570** is incident on surface **134** of the LED chip. Externally incident light ray **570** passes through surface **134**, passes through the multilayer semiconductor structure **504** a first time, is reflected by reflector **115**, passes through the multilayer semiconductor structure **504** a second time and exits LED chip **500** through surface **134**. Externally incident light ray **572** is directed to LED chip **500** and is reflected by surface **142** of the second electrode **114**. Externally incident light **574** is directed to LED chip **500** and is reflected by surface **138** of the first electrode **102**.

**[0133]** In the illustrative example in FIG. **5**, the first doped semiconductor layer **108** is an n-doped layer and the second doped semiconductor layer **112** is a p-doped layer. However, the two layers can in principle be reversed. If the first doped semiconductor layer **108** is a p-doped layer, then the second doped semiconductor layer **112** is an n-doped layer. The two doped semiconductor layers **108** and **112** will have opposite n and p conductivity types.

**[0134]** It is well known by those skilled in the art that the multilayer semiconductor structure **504** may include additional layers in order to adjust and improve the operation of the LED chip **500**. For example, a current spreading layer (not shown) may be inserted between surface **136** of the first electrode **102** and surface **126** the first doped layer **108**. Such a current spreading layer will have the same conductivity type as the first doped layer and will improve the uniformity of current injection across the entire active region. In addition, a current spreading layer (not shown) may be inserted between surface **134** of the second doped layer and surface **140** of the second electrode **114**. The latter current spreading layer will have the same conductivity type as the second doped layer. As another example, an electron blocking layer or a hole blocking layer (neither are shown) may be inserted either between surface **126** of the first doped layer **108** and surface **128** of the active region **110** or between surface **130** of the active region **110** and surface **132** of the second doped layer **112**. An electron blocking layer reduces the escape of electrons from the active region into either doped layer. A hole blocking layer reduces the transfer of holes through the doped layer into the active region.

**[0135]** The substrate-free LED chips of this invention, including LED chip **500**, preferably include light extraction elements (not shown) to aid in extracting internally generated light from the chips. The light extraction elements may be fabricated by any means, including chemical means, mechanical means such as grinding, or optical means such as laser ablation.

**[0136]** Substrate-free LED chip **500** does not have a growth substrate or a transfer substrate that can retard heat flow from the chip. If LED chip **500** is bonded to a surface, a submount, a heat sink or a leadframe, the thermal resistance for heat transfer is illustrated in FIG. **5**D. Heat will flow from the LED chip to the surface, submount, heat sink or leadframe with thermal resistance $R_4$ or **582**. Heat will flow from the surface, submount, heat sink or leadframe to ambient with thermal resistance $R_5$ or **584**. The total thermal resistance, $R_4$ plus $R_5$ or, equivalently, the sum of the thermal resistances **582** and **584** of the substrate-free LED chip **500** will be less than for an LED chip such as LED chip **400** that includes a transfer substrate. For LED chip **400**, the total thermal resistance illustrated in FIG. **4**C is $R_1$ plus $R_2$ plus $R_3$ or, equivalently, the sum of the thermal resistances **482**, **484** and **486**.

**[0137]** FIGS. **6** to **9** illustrate substrate-free LED chips that are variations of substrate-free LED chip **500** shown in FIG. **5**.

**[0138]** Substrate-free LED chip **600** in FIGS. **6**A and **6**B is nearly identical to LED chip **500** except that LED chip **600** does not have a reflector on the first side **652**. Internally generated light emitted by the active region **110** can exit from both the upper or second side **654** and the lower or first side **652**. For example, light ray **660** illustrated in FIG. **6**A and emitted by the active region exits LED chip **600** through surface **134** on the second side. Light ray **662** exits LED chip **600** through surface **124** on the first side. Light ray **664** undergoes total internal reflection at surface **134**.

**[0139]** No portion of the first side **652** of LED **600** is covered by a reflecting layer. Only a portion of the second side **654** of LED **600** is covered by the first electrode and the second electrode. Both sides of the multilayer semiconductor structure are light emitting sides and will emit internally generated light. At least a portion of the first side of the multilayer semiconductor structure and at least a portion of the second side of the multilayer semiconductor structure will also transmit externally incident light. Externally incident light is light that is directed to a light emitting side of the LED from another light source or light that is emitted by an LED and is reflected back to the light emitting side of the LED as recycled light. For some applications, where it is desirable for light from a phosphor or light from another LED to pass through the LED, the LED should transmit a large portion of externally incident light. High transmissivity will exist if the absorption coefficient of the multilayer semiconductor structure is low (e.g. less than 20 per centimeter). Preferably LED **600** transmits at least 60 percent of externally incident light directed to a light emitting side (either the first side **652** or the second side **654**) of the LED. More preferably, LED **600** transmits at least 70 percent of externally incident light. Most preferably, LED **600** transmits at least 80 of externally incident light.

**[0140]** FIG. **6**B illustrates externally incident light rays **670** and **672** that are transmitted by LED chip **600**. Externally incident light ray **670** is incident on surface **124** of the first side **652** of LED **600**. Externally incident light ray **670** passes through the multilayer semiconductor structure **504** and exits LED chip **600** through surface **134** on the second side **654**. Externally incident light ray **672** is incident on surface **134** of the second side **654** of LED **600**. Externally incident light ray **672** passes through the multilayer semiconductor structure **504** and exits LED chip **600** through surface **124** on the first side **652**.

**[0141]** In LED chip **600**, the thick epitaxial layer is the first doped layer **108**. Alternatively, the second doped layer **112** may be a thick epitaxial layer as illustrated by LED **700** in FIG. **7**.

[0142] LED chip **700** in FIG. **7** illustrates a substrate-free LED chip that has a thick second doped layer **112**. The thick second doped layer **112** is a p-doped GaN layer, which is epitaxially deposited or otherwise conventionally fabricated on the active region. The thick second doped layer **112** has a first surface **132** and a second surface **134** opposite the first surface. The first surface **132** of the second doped layer is in electrical contact with the second surface **130** of the active region. The thickness **558** of the second doped layer **112** is at least 5 microns. Preferably the second doped layer is at least 10 microns thick. More preferably, the second doped layer is at least 15 microns thick. Most preferably, the second doped layer is at least 25 microns thick. The thick second doped layer may be deposited by any standard GaN growth technique. In this illustrative example, the second doped layer 20 microns thick and is deposited by HVPE. The first doped layer **108** and the active region **110** may be deposited by any standard GaN growth technique. In this illustrative example, the first doped layer and the active region are deposited by MOCVD.

[0143] Example light rays **760**, **762** and **764** illustrate internally generated light that is emitted by the active region **110** of the LED chip **700**. Internally generated light ray **760** is emitted by active region **110** toward output surface **134** of the LED chip. Internally generated light ray **760** is directed at an angle to surface **134** that is less than the critical angle, which allows light ray **760** to exit the LED chip through surface **134**.

[0144] Internally generated light ray **762** is emitted by active region **110** toward the lower reflector **115** of the LED. Internally generated light ray **762** is reflected by reflector **115** and directed to the output surface **134** at an angle less than the critical angle. Internally generated light ray **762** exits the LED chip through surface **134**.

[0145] Internally generated light ray **764** is directed to surface **134** at an angle that is greater than the critical angle. Internally generated light ray **764** is reflected by total internal reflection and is redirected toward the rear reflector **115** of the LED chip.

[0146] FIG. **8** illustrates a side cross-sectional view of a substrate-free LED chip **800** that has both a thick first doped layer and a thick second doped layer. In this illustrative example, the thick first doped layer **108** is an n-doped layer and the thick second doped layer **112** is a p-doped layer. The thickness **556** of the first doped layer and the thickness **558** of the second doped layer are each at least 5 microns. Preferably the first doped layer and the second doped layer are each at least 10 microns thick. More preferably, the first doped layer and the second doped layer are each at least 15 microns thick. Most preferably, the first doped layer and the second doped layer are each at least 25 microns thick. The first doped layer and the second doped layer may have the same thickness or have different thicknesses. In this illustrative example, the first doped layer is 20 microns thick and the second doped layer is 5 microns thick. The first doped layer and the second doped layer may be deposited by any standard GaN growth technique. In this illustrative example, the first doped layer and the second doped layer are deposited by HVPE. For LED chip **800**, the active region **110** may be deposited by any standard GaN growth technique. In this illustrative example, the active region is deposited by MOCVD.

[0147] FIG. **9** illustrates a side cross-sectional view of a substrate-free LED chip **900** that has a thick, substantially-undoped layer **902** adjacent to the first side **952** of the multilayer semiconductor structure. As illustrated in FIG. **9**, an LED chip that has both electrodes on the first side or the second side of the multilayer semiconductor structure may optionally include a substantially undoped layer on the side of the multilayer semiconductor structure opposite the electrodes. The undoped layer adds additional thickness to the multilayer semiconductor structure without affecting the electrical properties of the structure. The additional thickness adds to the structural strength of the multilayer semiconductor structure. In addition, because the thermal resistance to heat transfer tends to be high at interfaces of dissimilar materials, a GaN-based multilayer semiconductor structure that contains a thick, substantially-undoped GaN layer will usually have lower thermal resistance and higher heat transfer than a prior art LED structure that includes a growth substrate or a transfer substrate of a different material. Furthermore, a thick, substantially undoped layer of GaN will have a lower optical absorption coefficient than, for example, a silicon carbide growth substrate of the prior art.

[0148] The thick substantially undoped layer **902** has a first or lower surface **904** and a second or upper surface **906**. The first or lower surface **904** of the undoped layer is also the first or lower surface of the multilayer semiconductor structure. The lower surface **124** of the first doped layer is in contact with the second surface **906** of the undoped layer. In this illustrative GaN-based example, the first doped layer **108** is an n-doped layer with a thickness **556** of approximately 3 microns, the active region is a multiple quantum well approximately 0.5 microns thick and the second doped layer **112** is a p-doped layer with a thickness **558** of approximately 0.5 micron. The first doped layer, the active region and the second doped layer may be deposited by any standard GaN growth technique. In this illustrative example, the three layers are deposited by MOCVD. The thickness **910** of the undoped layer is at least 5 microns. Preferably the undoped layer is at least 10 microns thick. More preferably, the undoped layer is at least 15 microns thick. Most preferably, the undoped layer is at least 25 microns thick. In this illustrative example, the undoped layer is 20 microns thick. The undoped layer may be deposited by any standard GaN growth technique. In this illustrative example, the undoped layer is deposited by HVPE.

[0149] Example light rays **960**, **962** and **964** illustrate internally generated light that is emitted by the active region **110** of the LED chip **900**. Internally generated light ray **960** is emitted by active region **110** toward output surface **134** of the LED chip. Internally generated light ray **960** is directed at an angle to surface **134** that is less than the critical angle, which allows light ray **960** to exit the LED chip through surface **134** on the second side **954**.

[0150] Internally generated light ray **962** is emitted by active region **110** toward the lower surface **904** of the LED at an angle less than the critical angle. Internally generated light ray **962** exits the LED chip through surface **904** on the first side **952**.

[0151] Internally generated light ray **964** is directed to surface **134** at an angle that is greater than the critical angle. Internally generated light ray **964** is reflected by total internal reflection and is redirected toward the lower surface **904** of the LED chip.

[0152] For the remainder of this specification, the substrate-free LED chips will be illustrated as having a thick first doped layer. However, it will be apparent from the above discussion that any of the substrate-free chips illustrated in the following diagrams may instead have a thick second doped layer or may have both a thick first doped layer and a thick second doped layer. In addition, LED chips with both electrodes on the lower side of the chip may also have a thick undoped layer on the upper side of the chip.

**[0153]** FIGS. **10** and **11** illustrate substrate-free LED chips that have both electrodes on the lower side of the chip. LED chip **1000** and LED chip **1100** are flip-chip designs, but neither design includes a growth substrate nor a transfer substrate. The thick layer in FIGS. **10** and **11** is illustrated to be the first doped layer. However, the thick layer could also be the second doped layer or both the first doped layer and the second doped layer or an undoped layer. These latter examples are not illustrated.

**[0154]** LED chip **1000** in FIG. **10** includes a thick first doped layer **108**. In this example design, the first doped layer is on the upper or first side **1052** of the chip. The first doped layer **108** is an n-doped GaN layer, which is epitaxially deposited or otherwise conventionally fabricated on a growth substrate (not shown). The growth substrate is later removed by a standard technique such as laser liftoff, chemical processing or mechanical polishing, thereby exposing the first surface **124** of the first doped layer. It is preferably to utilize a substrate removal process that results in an exposed surface **124** that is rough. A rough surface improves light extraction form LED chip **1000**. The first doped layer **108** has a first surface **124** and a second surface **126** opposite the first surface. The thickness **556** of the first doped layer is at least 5 microns. Preferably the first doped layer is at least 10 microns thick. More preferably, the first doped layer is at least 15 microns thick. Most preferably, the first doped layer is at least 25 microns thick. The first doped layer may be deposited by any standard GaN growth technique. Preferably, the first doped layer is deposited by HVPE.

**[0155]** The first electrode **102** of LED chip **1000** is fabricated on a portion **116** of the second surface **126** of the first doped layer that was previously exposed by an etching process. The second electrode **114** is fabricated on the second surface **134** of the second doped layer. The second electrode substantially covers the second surface **134**. Substantially all of the light emitted by LED chip **1000** is emitted through the upper or first side **1052** of the chip. For example, light ray **1060** is emitted through surface **124**. Light ray **1062** is initially directed to the second side **1054** but is reflected by surface **140** of the second electrode. Light ray **1062** exits LED **1000** through the upper or first side **1052**.

**[0156]** FIG. **11** illustrates example substrate-free LED chip **1100**. LED chip **1100** is nearly identical to LED chip **1000** except that the second electrode **114** of LED chip **1100** covers only a portion of surface **134** of the second doped layer **112**. Second electrode **114** is fabricated by depositing a layer of metal on surface **134** of the second doped layer followed by patterning the metal layer by standard photolithographic techniques. Light can exit LED chip **1100** through both the upper or first side **1152** and the lower or second side **1154** of the chip, thereby increasing the extraction efficiency, the external quantum efficiency and the light emission of the chip. For example, internally generated light ray **1160** exits LED chip **1100** on the upper or first side **1152** of the chip. Light ray **1162** exits LED chip **1100** on the lower or second side **1154**. Preferably, surface **136** of the first electrode **102** and surface **140** of the second electrode **114** are reflective to internally generated light and to light externally incident on the first side **1152** of LED chip **1100**.

**[0157]** FIGS. **12** and **13** illustrate substrate-free LED chips that have one electrode on the upper side of the chip and one electrode on the lower side of the chip. The thick layer in FIGS. **12** and **13** is illustrated to be the first doped layer. However, the thick layer could also be the second doped layer or both the first doped layer and the second doped layer.

**[0158]** LED chip **1200** in FIG. **12** includes a thick first doped layer **108**. In this example design, the first doped layer is on the upper or first side **1252** of the chip. The first doped layer **108** is an n-doped GaN layer, which is epitaxially deposited or otherwise conventionally fabricated on a growth substrate (not shown). The growth substrate is later removed by a standard technique such as laser liftoff, chemical processing or mechanical polishing, thereby exposing the first surface **124** of the first doped layer. The thickness **556** of the first doped layer is at least 5 microns. Preferably the first doped layer is at least 10 microns thick. More preferably, the first doped layer is at least 15 microns thick. Most preferably, the first doped layer is at least 25 microns thick. The first doped layer may be deposited by any standard GaN growth technique. Preferably, the first doped layer is deposited by HVPE.

**[0159]** The first electrode **102** of LED chip **1200** is fabricated on the first surface **124** of the first doped layer. The first surface **124** was previously exposed by removing the growth substrate. The first electrode is fabricated by depositing a metal layer and patterning the layer using standard photolithographic techniques. The second electrode **114** is fabricated on the second surface **134** of the second doped layer. In this example, the second electrode substantially covers the second surface **134**. Substantially all of the light emitted by LED chip **1200** is emitted through the upper or first side **1252** of the chip. For example, light ray **1260** is emitted through surface **124**. Light ray **1262** is initially directed to the second side **1254** but is reflected by surface **140** of the second electrode. Light ray **1262** exits LED **1200** through the upper or first side **1252**.

**[0160]** Substrate-free LED chip **1300** illustrated in FIG. **13** is nearly identical to LED chip **1200** except that the second electrode **114** for LED chip **1300** covers only a portion of the second surface **134** of the second doped layer **112**. Second electrode **114** is fabricated by depositing a layer of metal on surface **134** of the second doped layer followed by patterning the metal layer by standard photolithographic techniques. Light can exit LED chip **1300** through both the upper or first side **1352** and the lower or second side **1354** of the chip, thereby increasing the extraction efficiency, the external quantum efficiency and the light emission of the chip. For example, internally generated light ray **1360** exits LED chip **1300** on the upper or first side **1352** of the chip. Light ray **1362** exits LED chip **1300** on the lower or second side **1354**.

**[0161]** While the invention has been described in conjunction with specific embodiments and examples, it is evident to those skilled in the art that many alternatives, modifications and variations will be apparent in light of the foregoing description. Accordingly, the invention is intended to embrace all such alternatives, modifications and variations as fall within the spirit and scope of the appended claims.

What is claimed is:

**1**. An substrate-free, gallium-nitride-based light emitting diode chip comprising:

a multilayer semiconductor structure that has a first side and an opposing second side and that includes a first doped layer proximal to said first side, an active region, a second doped layer proximal to said second side with said active region interposed between said first doped layer and said second doped layer;

a first electrode in electrical contact with said first doped layer; and

a second electrode in electrical contact with said second doped layer;

wherein said multilayer semiconductor has a total thickness of at least 10 microns and wherein said active region emits internally generated light when an electrical voltage is applied between said first electrode and said second electrode.

**2**. The light emitting diode chip as in claim **1**, wherein said multilayer semiconductor structure is at least 20 microns thick.

**3**. The light emitting diode chip as in claim **2**, wherein said multilayer semiconductor structure is at least 30 microns thick.

**4**. The light emitting diode chip as in claim **1**, wherein at least a portion of said first side of said multilayer semiconductor structure and at least a portion of said second side of said multilayer semiconductor structure transmit externally incident light.

**5**. The light emitting diode chip as in claim **4**, wherein said light emitting diode chip transmits at least 60 percent of said externally incident light that is directed to said first side or said second side of said multiplayer semiconductor structure.

**6**. The light emitting diode chip as in claim **5**, wherein said light emitting diode chip transmits at least 70 percent of said externally incident light.

**7**. The light emitting diode chip as in claim **6**, wherein said light emitting diode chip transmits at least 80 percent of said externally incident light.

**8**. The light emitting diode chip as in claim **1**, further comprising a reflective surface covering substantially all of said first side or substantially all of said second side of said multilayer semiconductor structure, wherein said reflective surface reflects externally incident light.

**9**. The light emitting diode chip of claim **8**, wherein said reflective surface is said first electrode or said second electrode.

**10**. The light emitting diode chip as in claim **8**, wherein said light emitting diode chip reflects at least 60 percent of said externally incident light that is directed to said multiplayer semiconductor structure.

**11**. The light emitting diode chip as in claim **10**, wherein said light emitting diode chip reflects at least 70 percent of said externally incident light.

**12**. The light emitting diode chip as in claim **11**, wherein said light emitting diode chip reflects at least 80 percent of said externally incident light.

**13**. The light emitting diode chip as in claim **1**, wherein said multiplayer semiconductor structure has an absorption coefficient less that 20 per centimeter.

**14**. The light emitting diode chip as in claim **13**, wherein said multiplayer semiconductor structure has an absorption coefficient less that 10 per centimeter.

**15**. The light emitting diode chip as in claim **14**, wherein said multiplayer semiconductor structure has an absorption coefficient less that 5 per centimeter.

**16**. The light emitting diode chip as in claim **15**, wherein said multiplayer semiconductor structure has an absorption coefficient less that 2 per centimeter.

**17**. The light emitting diode chip as in claim **1**, wherein said first doped layer or said second doped layer is at least 5 microns thick and is fabricated by hydride vapor phase epitaxy.

**18**. The light emitting diode chip as in claim **17**, wherein said first doped layer or said second doped layer is at least 10 microns thick.

**19**. The light emitting diode chip as in claim **18**, wherein said first doped layer or said second doped layer is at least 15 microns thick.

**20**. The light emitting diode chip as in claim **19**, wherein said first doped layer or said second doped layer is at least 25 microns thick.

**21**. The light emitting diode chip as in claim **1**, wherein said multiplayer semiconductor structure includes a substantially undoped layer adjacent to said first side or said second side, wherein said undoped layer is at least 5 microns thick and wherein said undoped layer is fabricated by hydride vapor phase epitaxy.

**22**. The light emitting diode chip as in claim **21**, wherein said undoped layer is at least 10 microns thick.

**23**. The light emitting diode chip as in claim **22**, wherein said undoped layer is at least 15 microns thick.

**24**. The light emitting diode chip as in claim **23**, wherein said undoped layer is at least 25 microns thick.

**25**. The light emitting diode chip as in claim **1**, wherein said first doped layer is an n-doped layer and said second doped layer is a p-doped layer.

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