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(52) U.S. Cl. 257/239

(57) **ABSTRACT**

A light emitting diode (LED) package for high temperature operation which includes a printed wire board and a heat sink. The LED package may include a formed heat sink layer, which may be thermally coupled to an external heat sink. The printed wire board may include apertures that correspond to the heat sink such that the heat sink is integrated with the printed wire board layer. The LED package may include castellations for mounting the package on a secondary component such as a printed wire board. The LED package may further comprise an isolator disposed between a base metal layer and one or more LED die. Optionally, the LED die may be mounted directly on a base metal layer. The LED package may include a PWB assembly having a stepped cavity, in which one or more LED die are disposed. The LED package is advantageously laminated together using a pre-punched pre-preg material or a pressure sensitive adhesive.

(22) Filed: **Jun. 27, 2006**

(60) Provisional application No. 60/694,788, filed on Jun. 27, 2005. Provisional application No. 60/738,478, filed on Nov. 21, 2005. Provisional application No. 60/763,828, filed on Jan. 31, 2006.

(51) **Int. Cl.**
H01L 29/768 (2006.01)

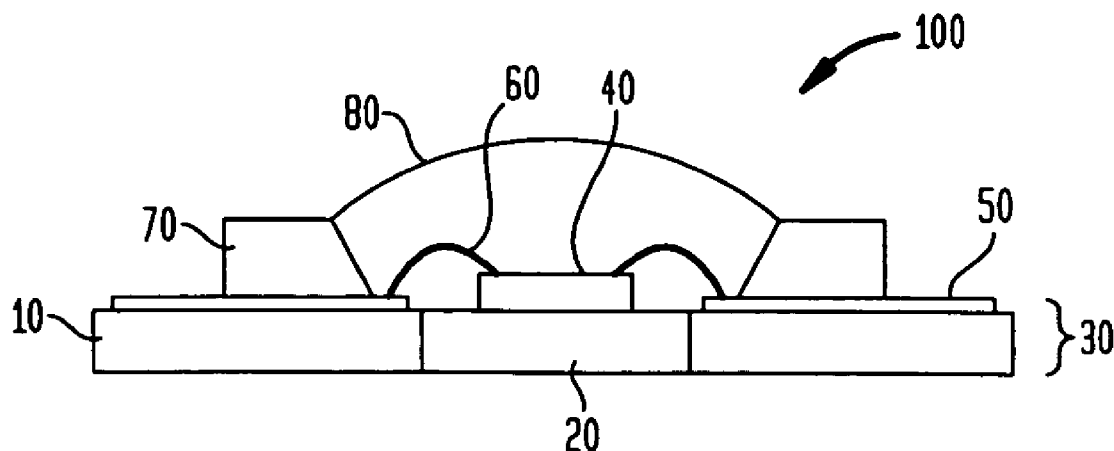


FIG. 1

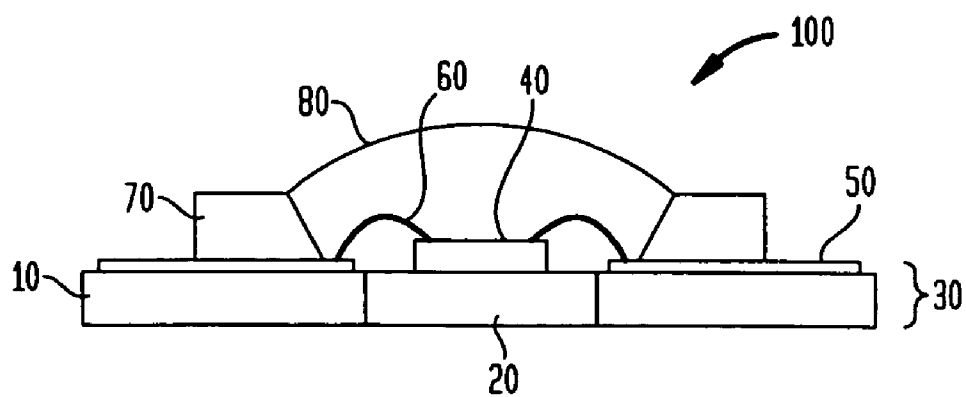


FIG. 2

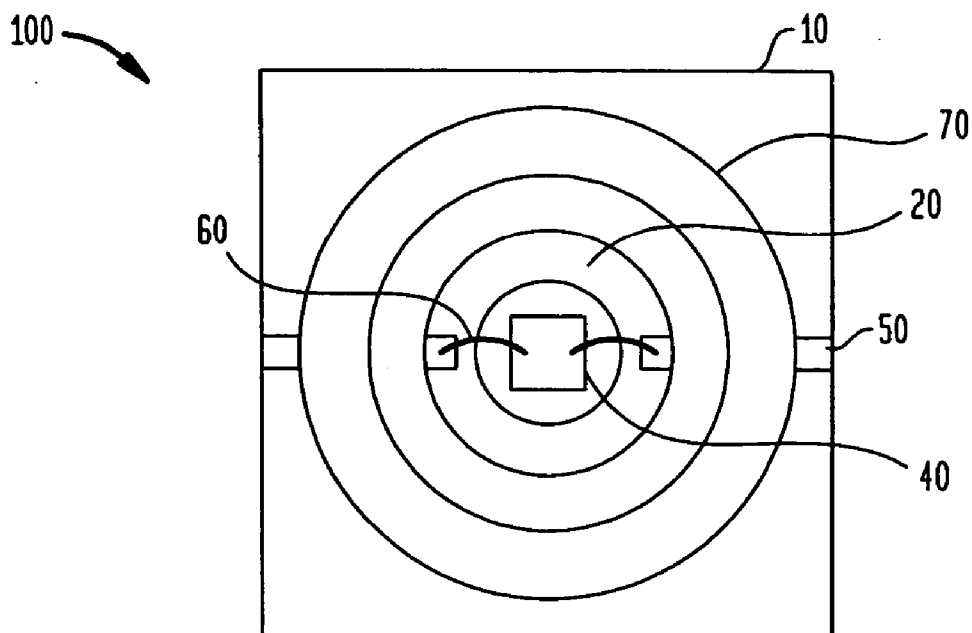


FIG. 3

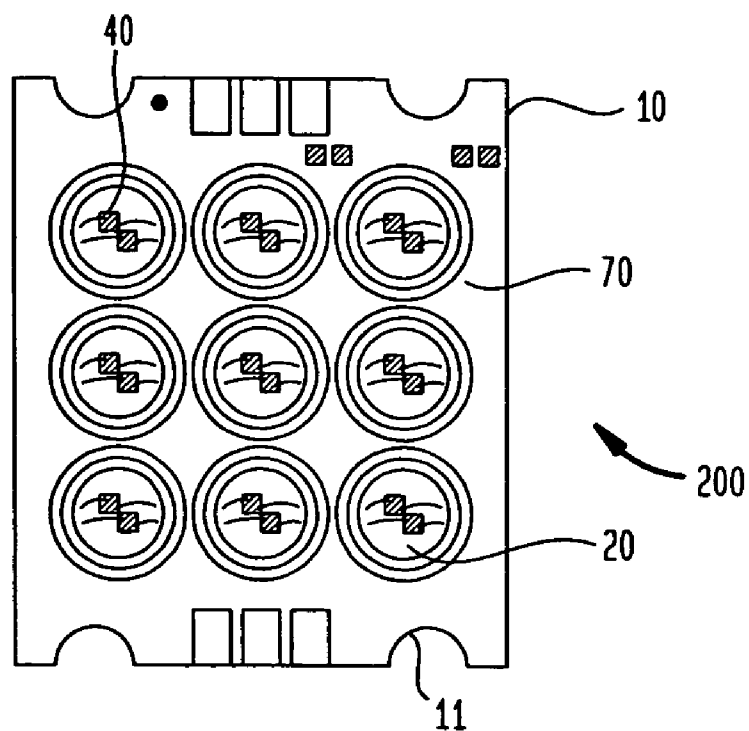


FIG. 4

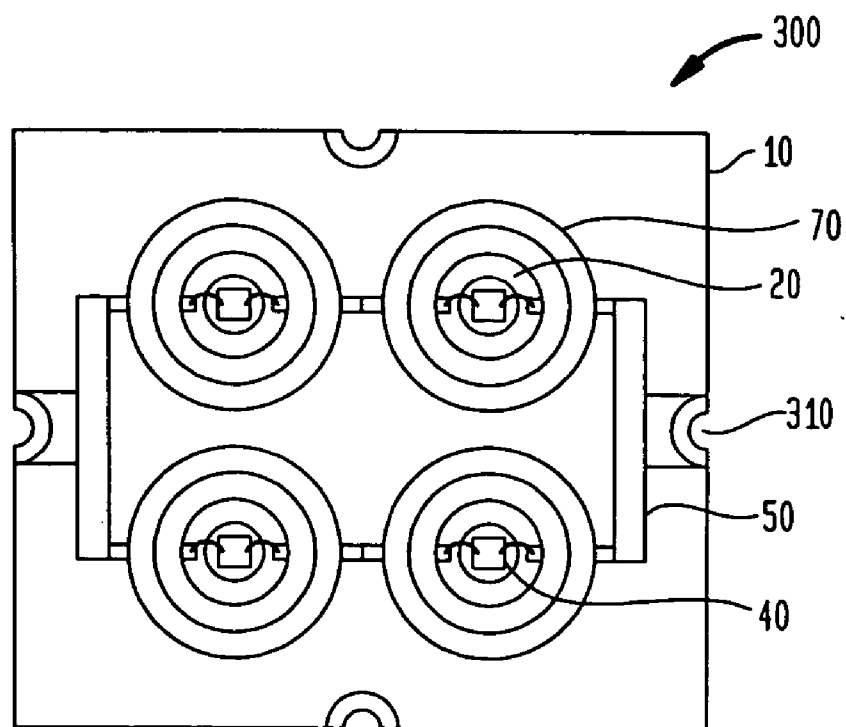


FIG. 5

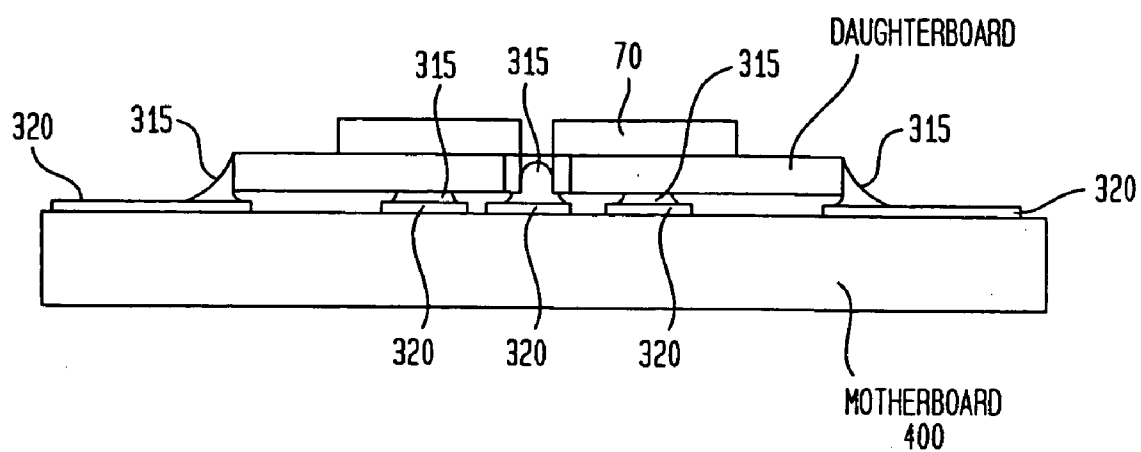


FIG. 6

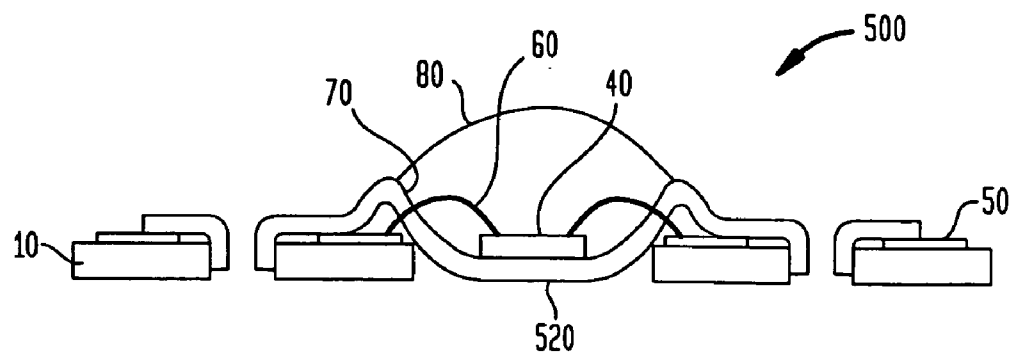


FIG. 7

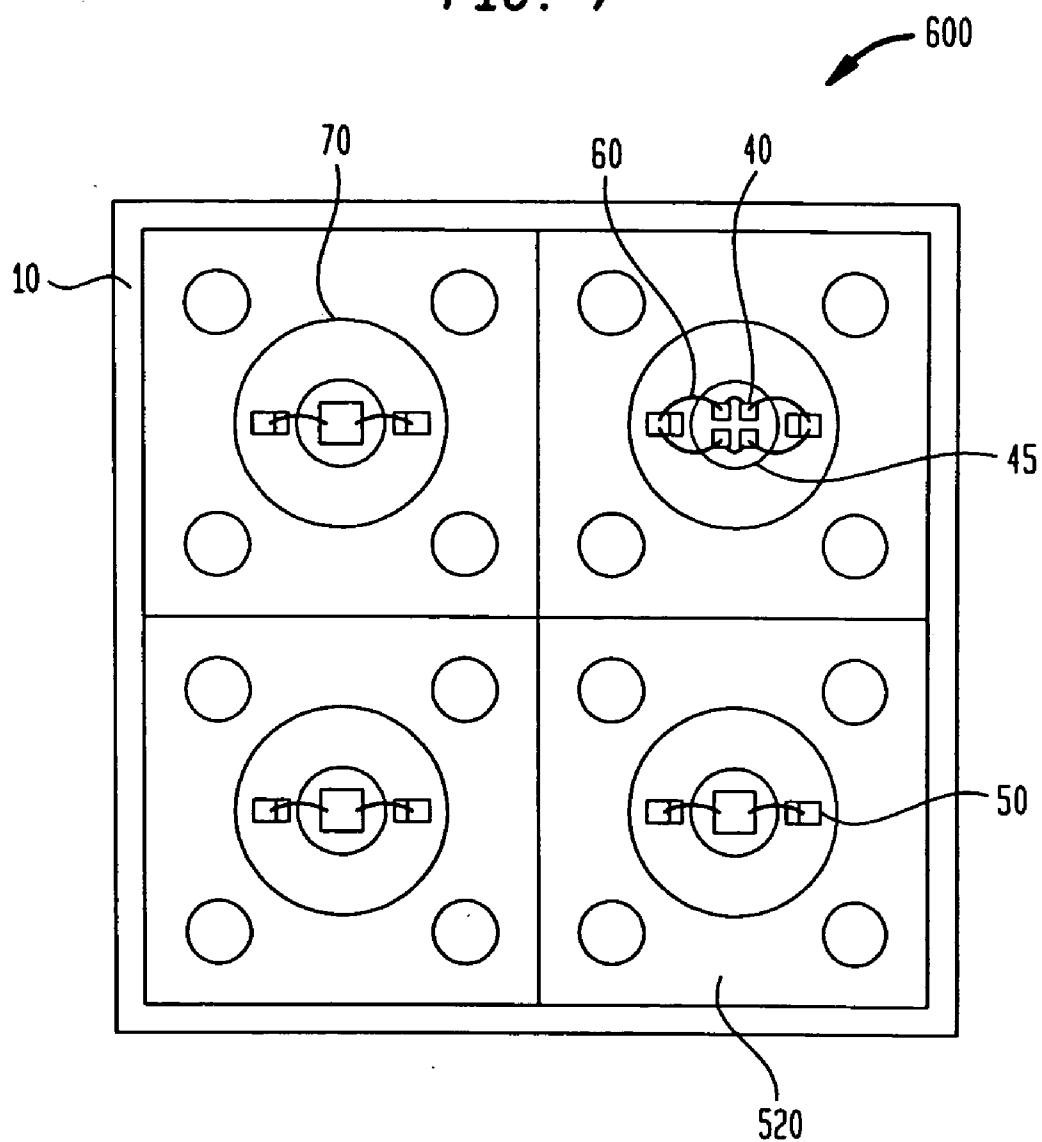


FIG. 8

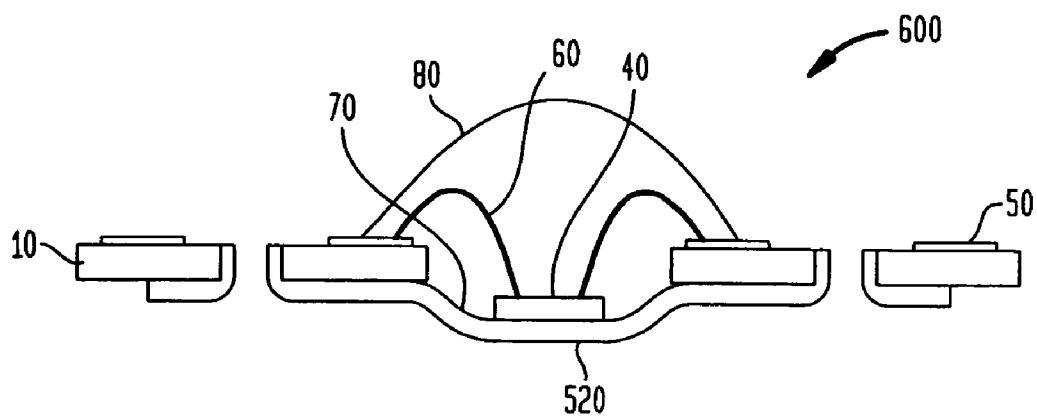


FIG. 9

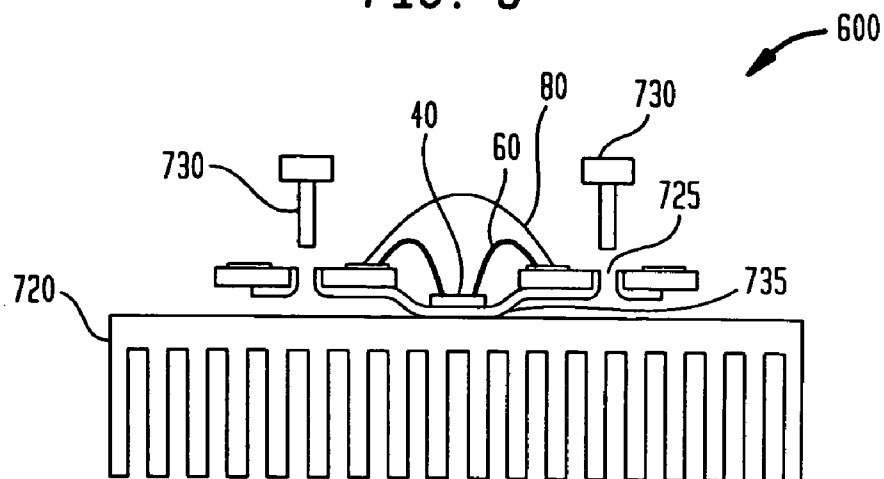


FIG. 10

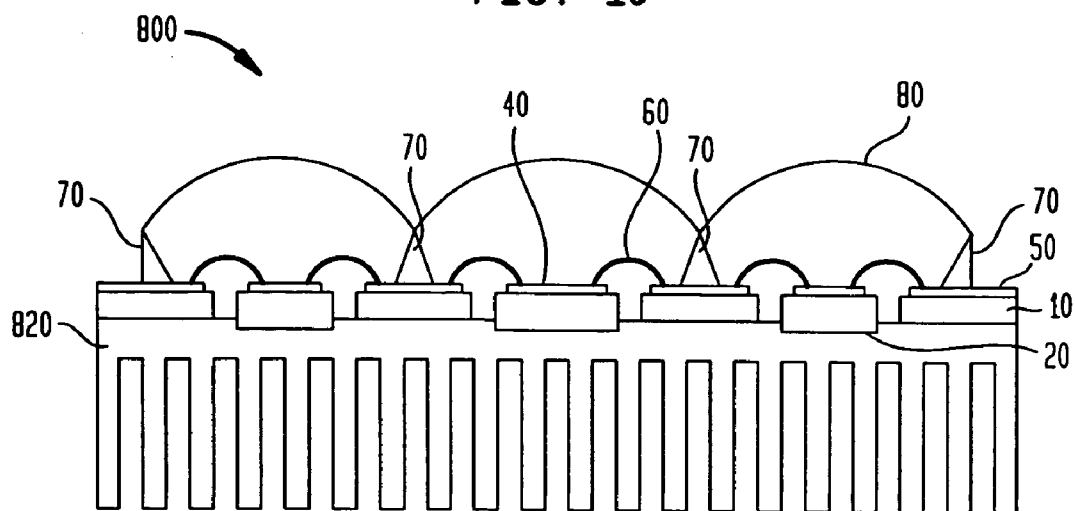


FIG. 11

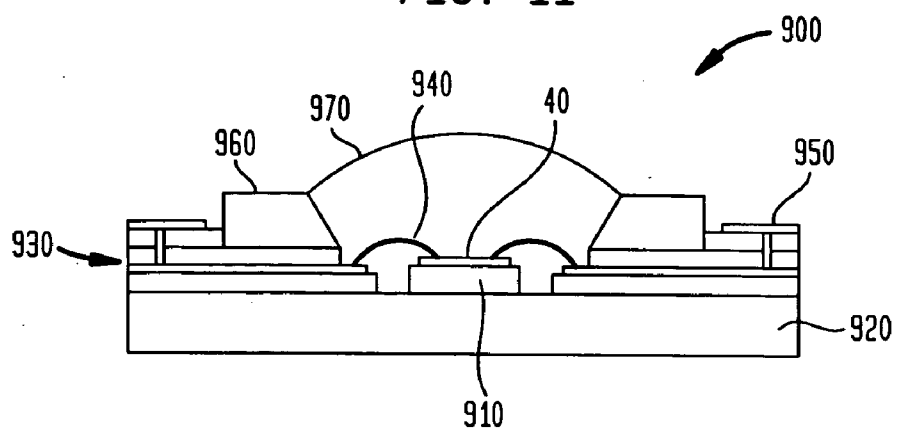


FIG. 12

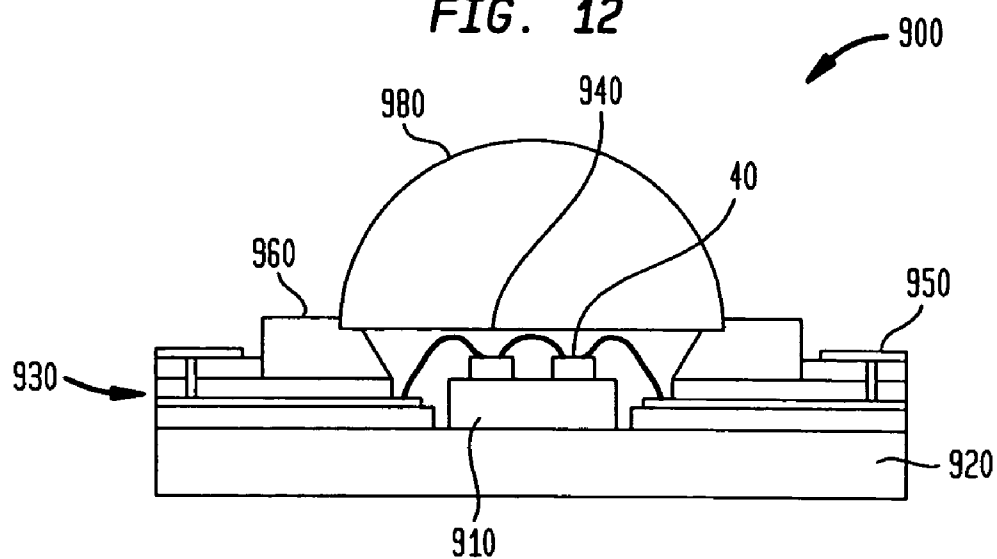


FIG. 13

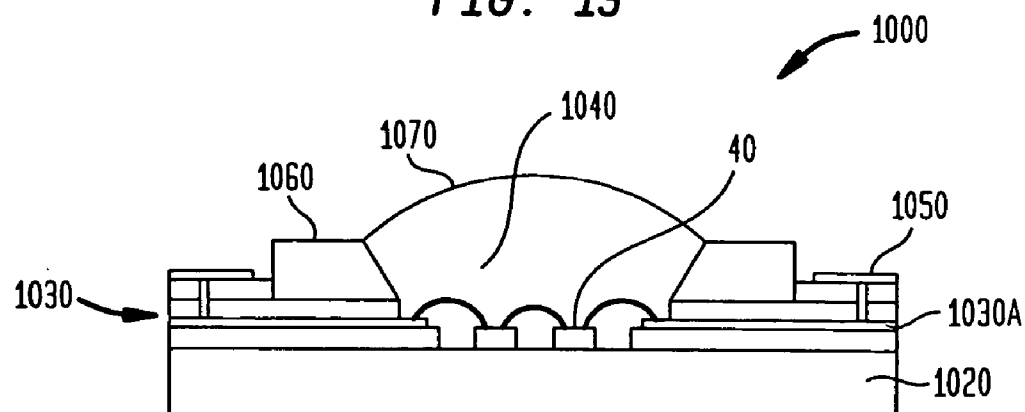


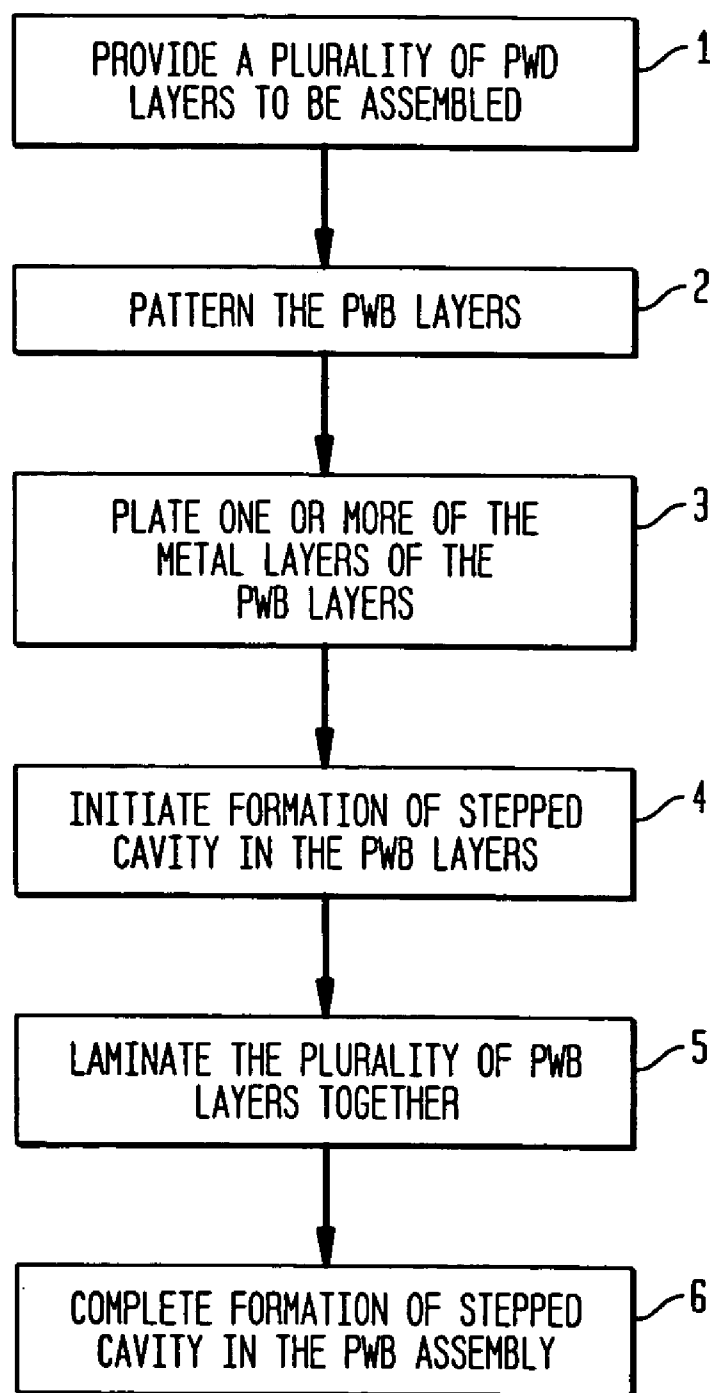
FIG. 14

FIG. 15A

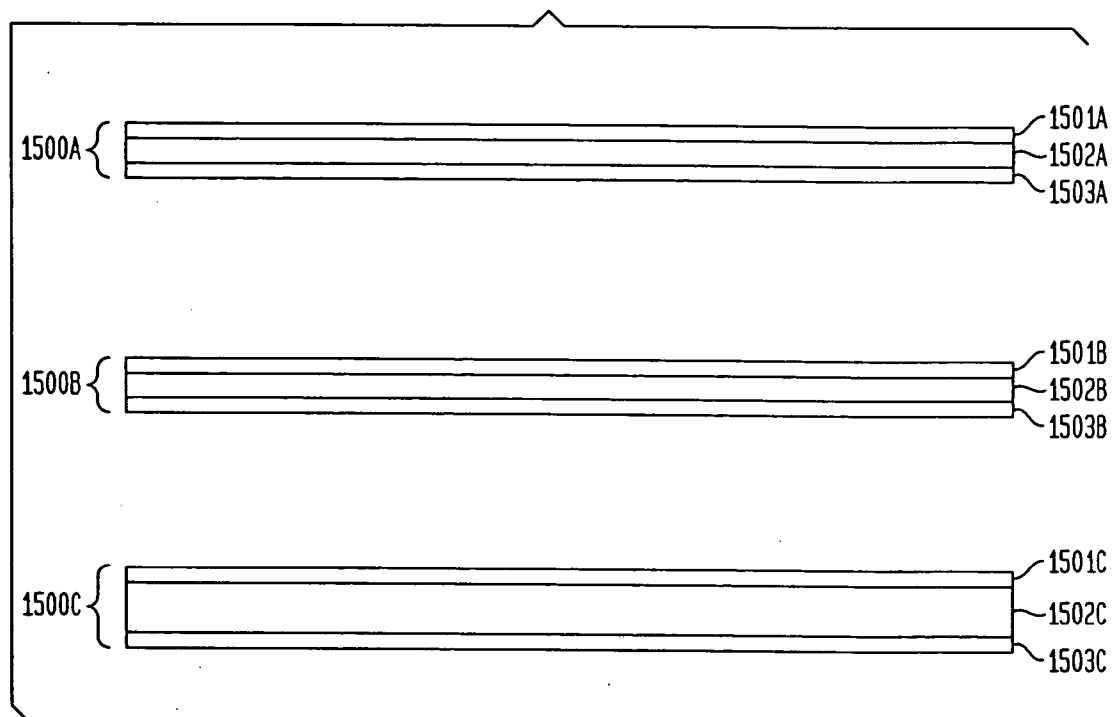


FIG. 15B

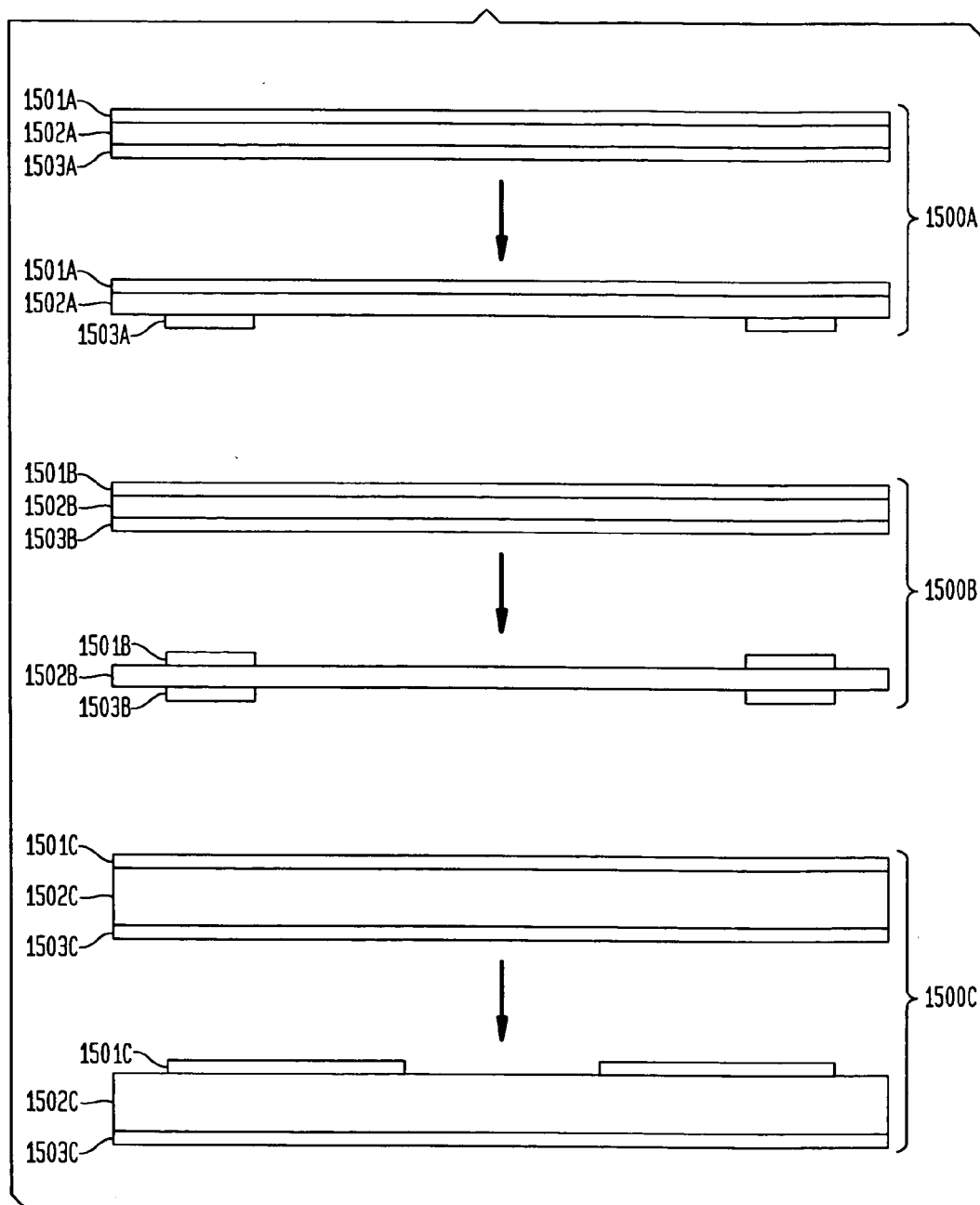


FIG. 15C

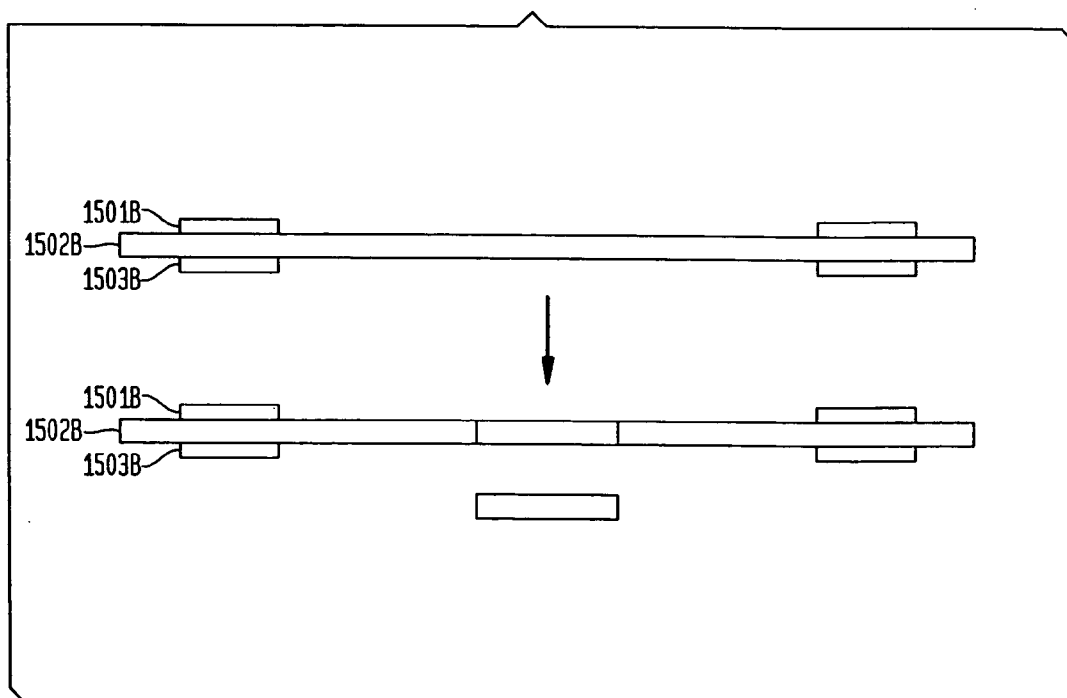


FIG. 150

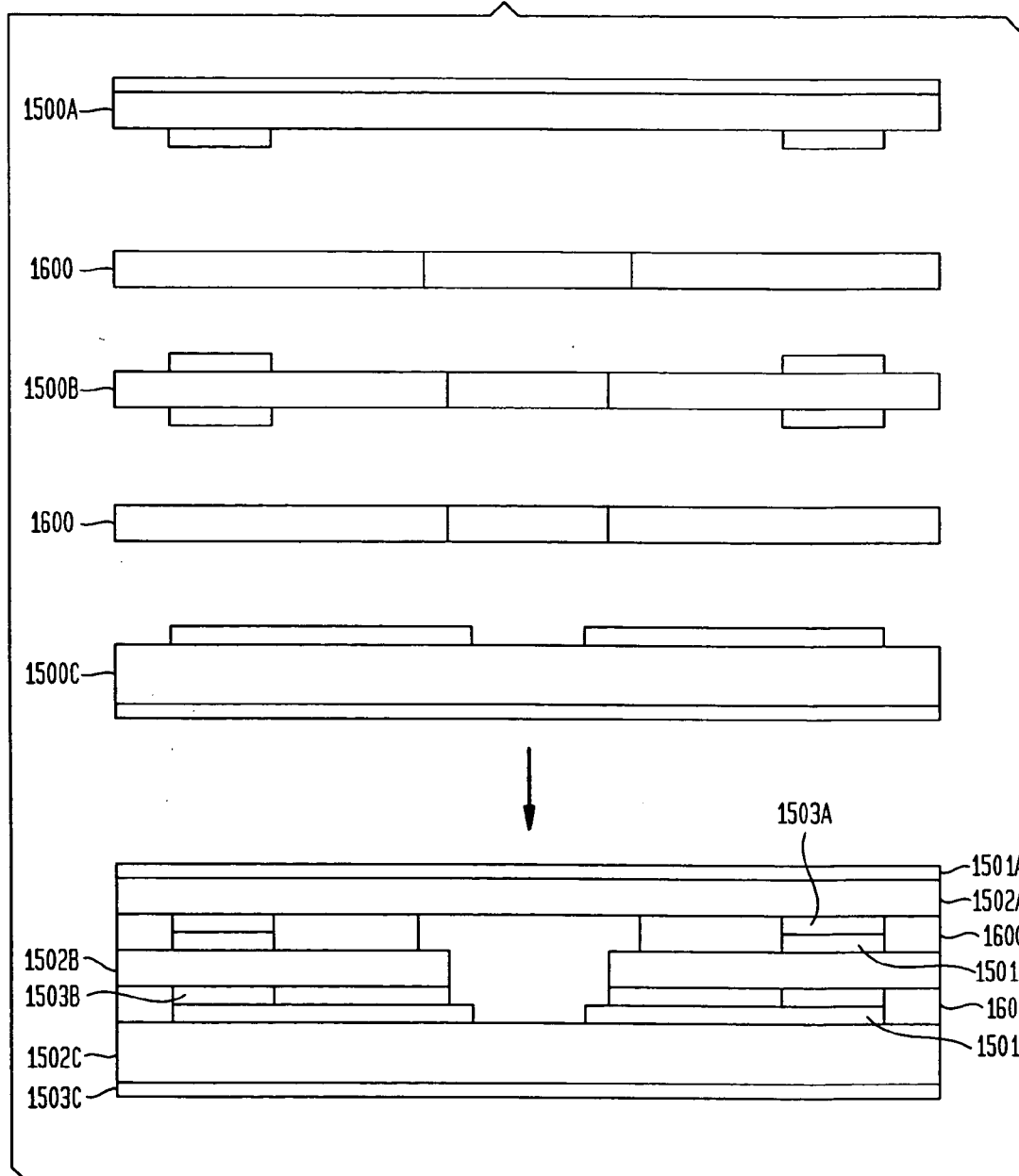


FIG. 15E

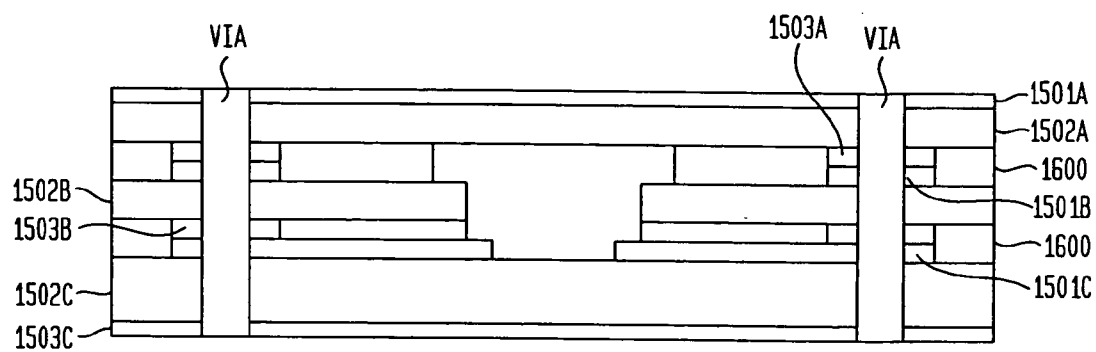


FIG. 15F

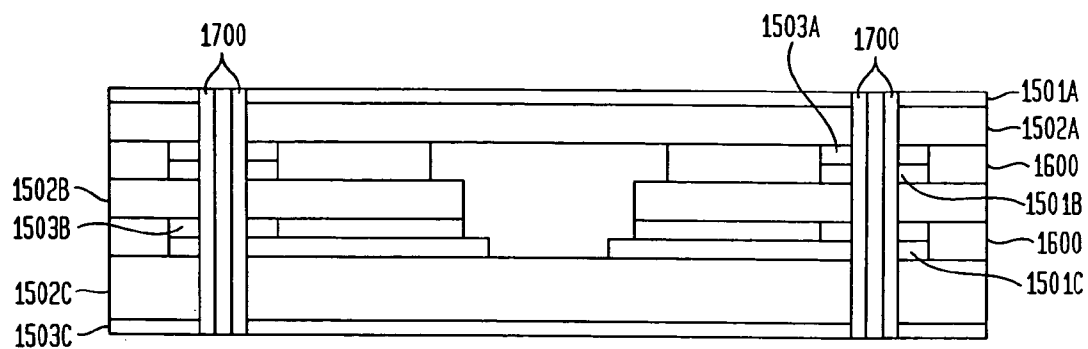


FIG. 15G

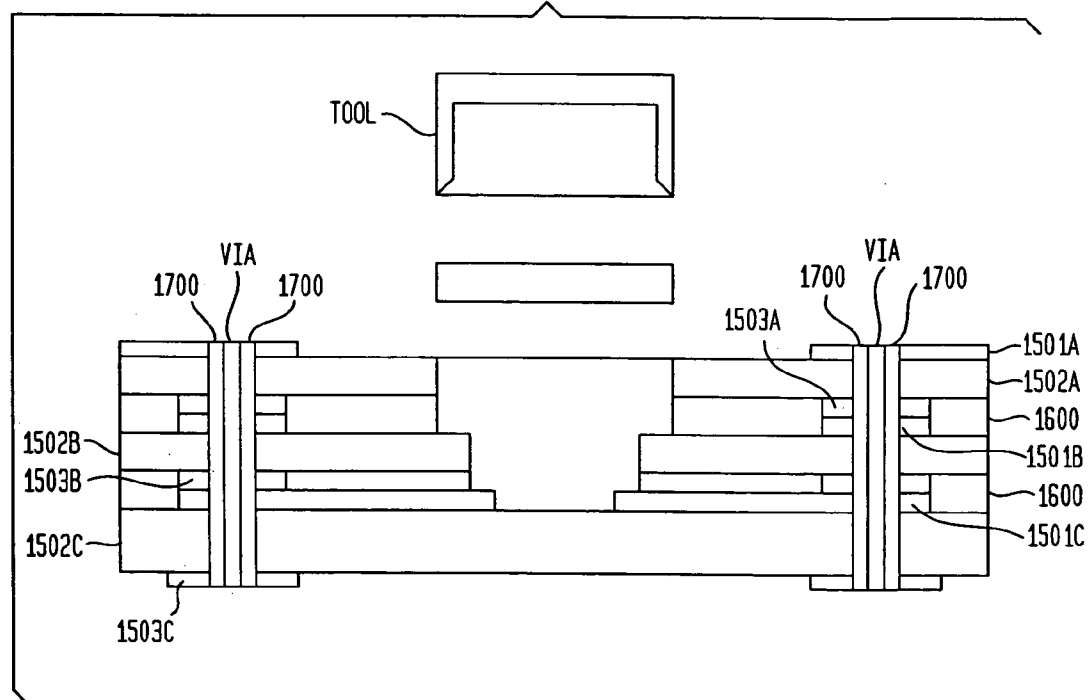


FIG. 15H

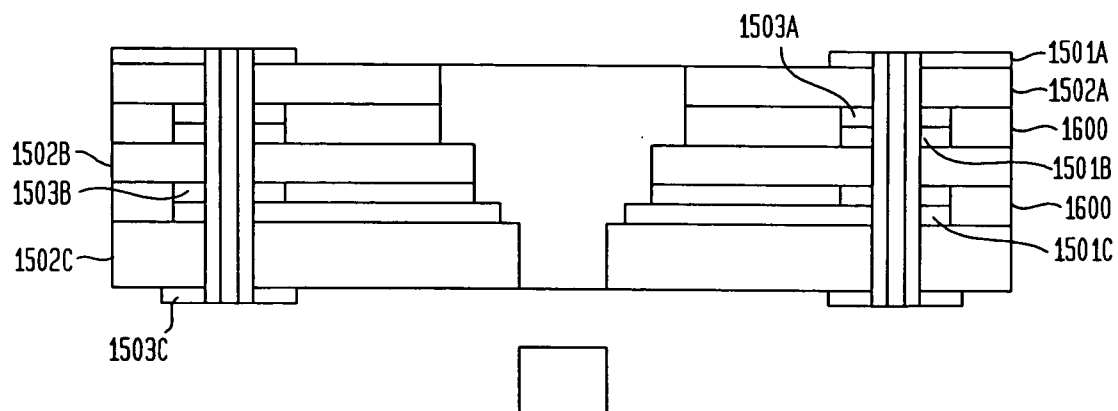


FIG. 15I

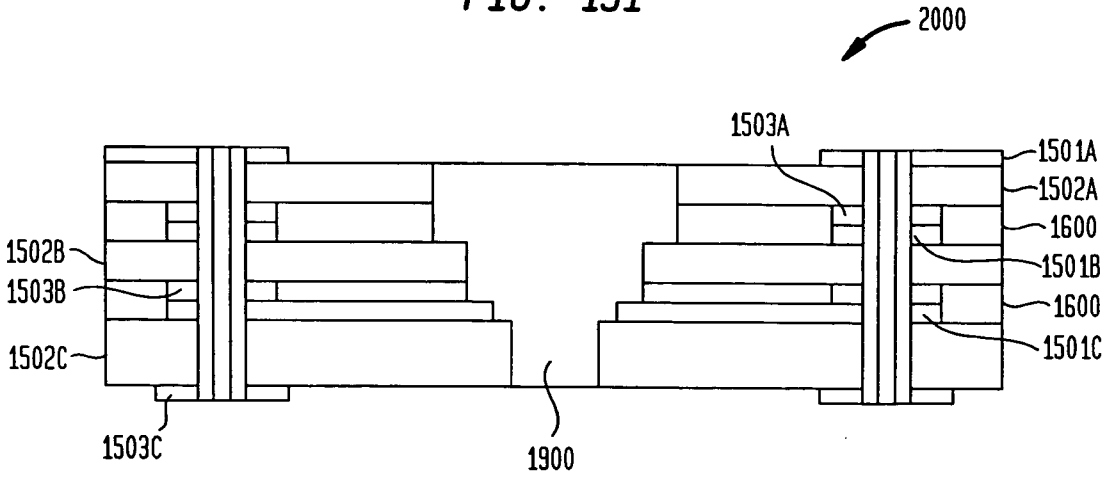


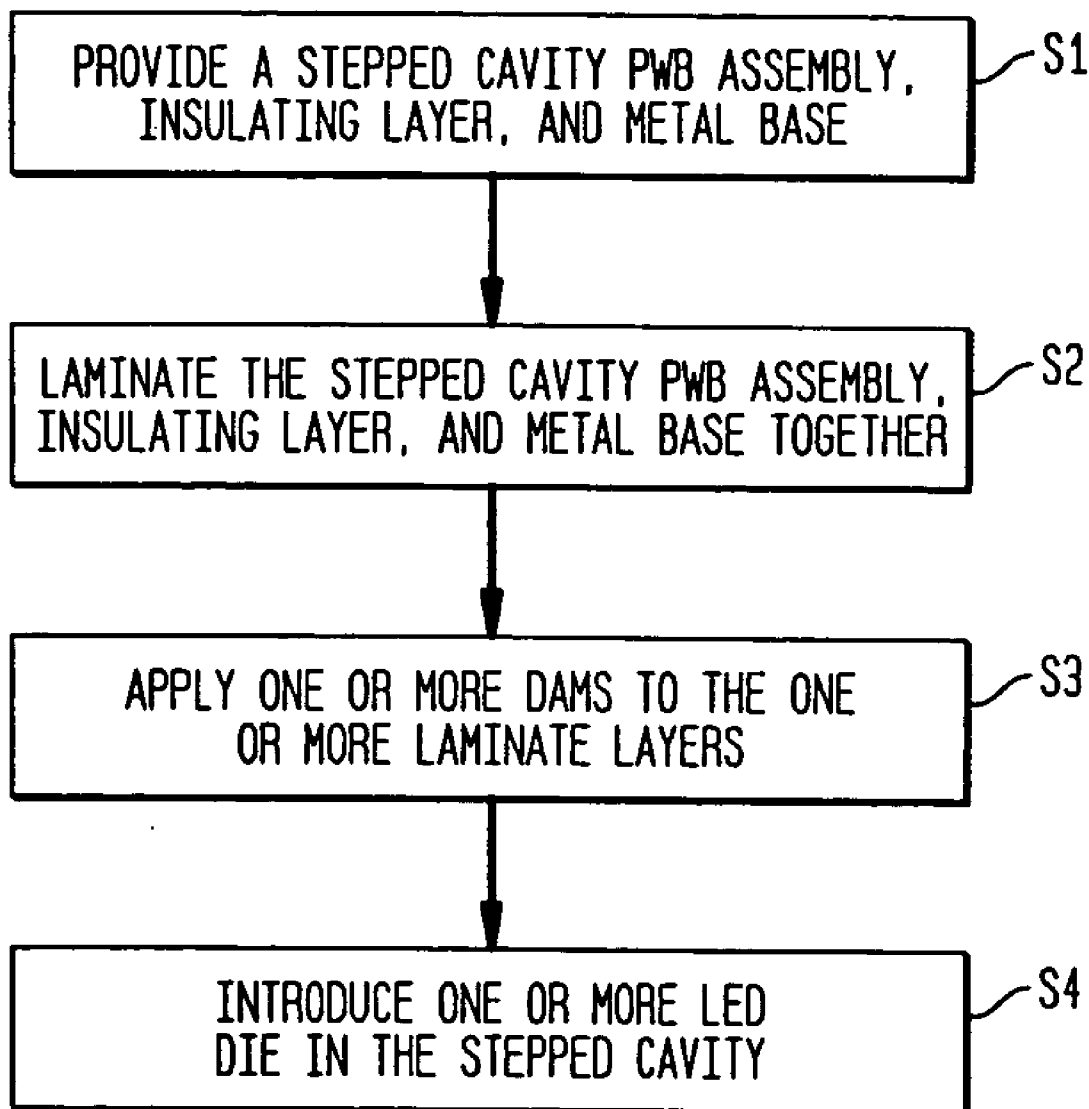
FIG. 16

FIG. 17A

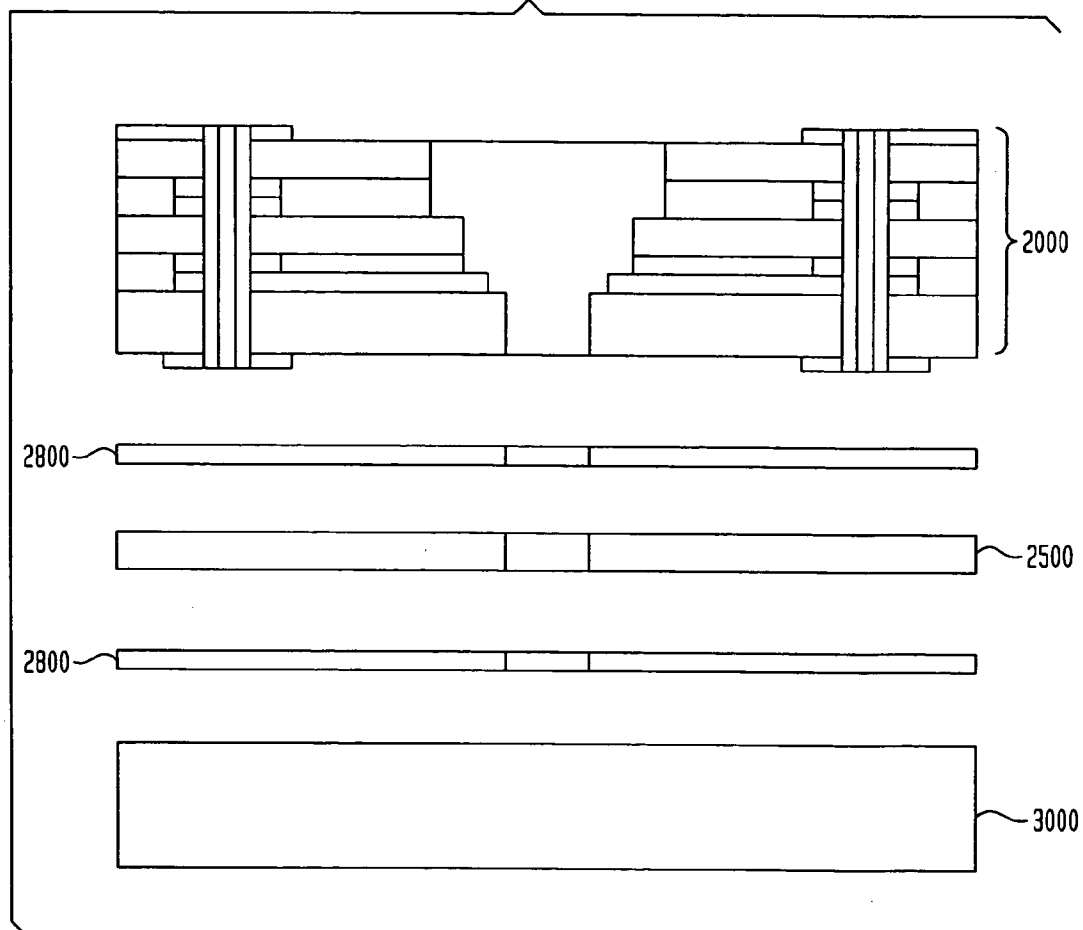


FIG. 17B

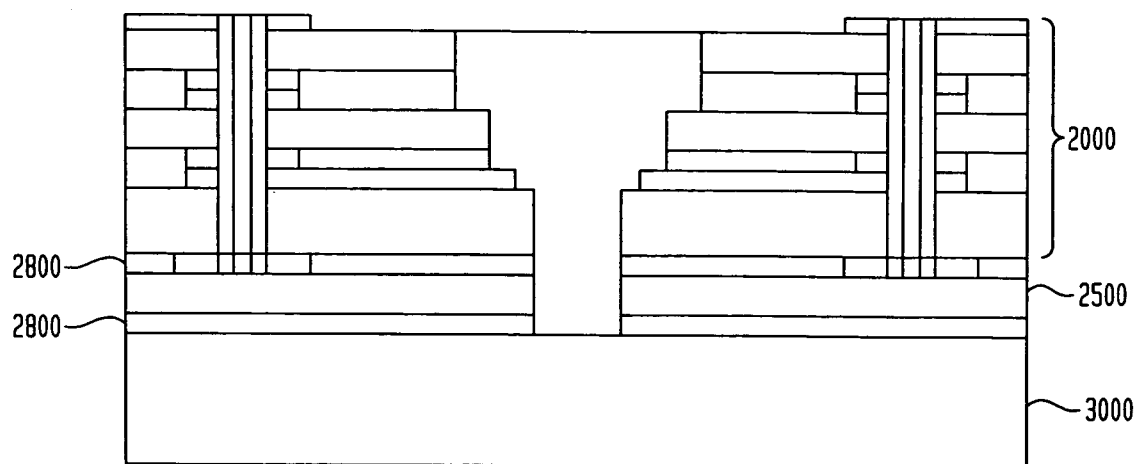


FIG. 17C

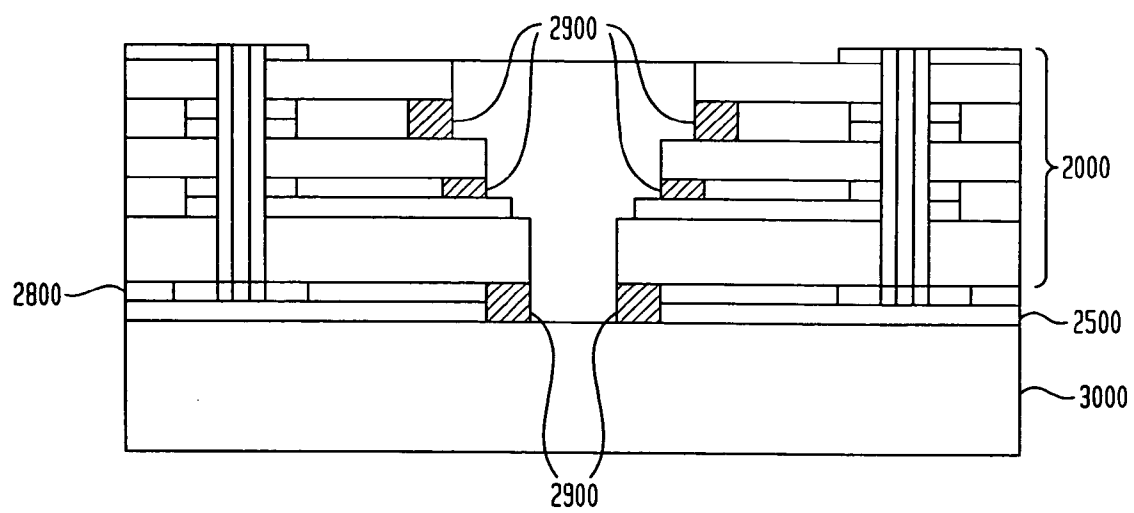
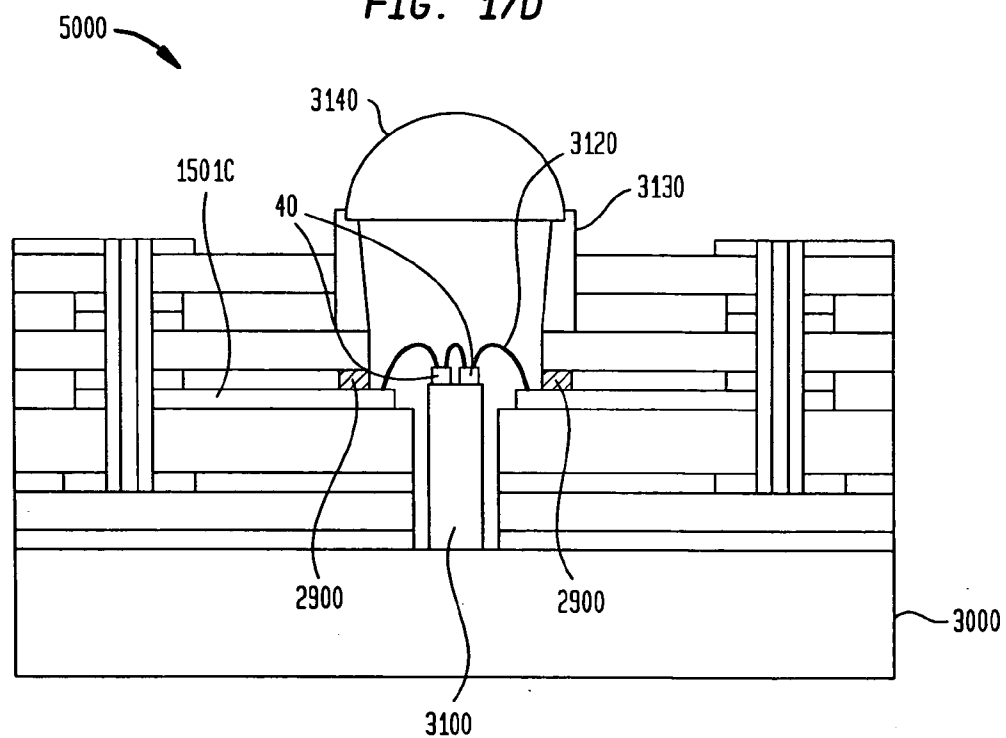


FIG. 17D



LIGHT EMITTING DIODE PACKAGE AND METHOD FOR MAKING SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/694,788 filed on Jun. 27, 2005, U.S. Provisional Application No. 60/738,478 filed Nov. 21, 2005, and U.S. Provisional Application No. 60/763,828 filed Jan. 31, 2006. U.S. Provisional Application Nos. 60/694,788, 60/738,478, and 60/763,828 are hereby incorporated by reference herein.

FIELD OF THE INVENTION

[0002] The present invention relates generally to a light emitting diode (LED) package and method for making same, and, in particular to a LED package adapted for high temperature operation.

BACKGROUND OF THE INVENTION

[0003] Conventional light emitting diode (LED) packages include a specialized, moldable plastic housing having a separate transparent cover exhibiting specific optical properties. Generally, these LED packages are designed exclusively for direct surface mount technology (SMT) connection to a printed wire board (PWB). However, because conventional packages require a special, molded plastic housing (i.e., liquid crystal polymer) and optical element, the packages are not well suited for multi-die arrays that may be easily, quickly, and inexpensively modified to suit a particular lighting application.

[0004] Another fabrication and design challenge faced by high-temperature operation LED packages is the need to effectively manage the heat generated by the array of LEDs. Traditionally, to deal with heat management issues, conventional LED packages include a large, homogeneous metal carrier or heat sink, which spans the entire bottom of the LED package. The metal carrier is generally composed of a relatively expensive material (e.g., molybdenum copper), adding significant cost to the fabrication of the LED package. Accordingly, there is a need in the art for an improved light emitting package adapted for high temperature operation in a variety of lighting applications.

SUMMARY OF THE INVENTION

[0005] The present invention relates to a LED package assembly including a PWB having one or more through-holes or apertures. Inserted into each of the apertures is a heat sink stud to form an integrated/monolithic assembly. According to an embodiment of the present invention, one or more light sources (i.e., LED die) may be placed (directly) on the heat sink stud, which carries away the heat generated by the LED die. In application, the assembly may be mounted on an external component, such as an external heat sink. Advantageously, the use of discretely-sized heat sink studs, integrated into the PWB allows for a compact, versatile and cost-efficient construction.

[0006] According to an embodiment of the present invention, the LED package assembly utilizes PWB techniques, SMT assembly techniques, and/or chip-on-board (COB) semiconductor die attachment techniques. Advantageously, the LED package assembly of the present invention reduces

the cost and design cycle time for light emitting components, and is suitable for use in a variety of lighting applications including but not limited to general illumination, accent lighting, electronic display illumination, machine vision, etc. Advantageously, an array of LED die may be arranged in a single, low-cost, versatile package which is operable in high temperature environments.

[0007] According to an embodiment of the present invention, a LED package may be fabricated by thermally coupling one or more heat sink studs to an external heat sink, placing a printed wire board (substrate) over the external heat sink, wherein the printed wire board (substrate) includes one or more openings/apertures in registration with the one or more heat sink studs, and mounting one or more LED die to each of the one or more heat sink studs, wherein the heat sink studs are embedded at least partially in the external heat sink.

[0008] The one or more LED die are electrically connected to the printed wire board, preferably to one or more conductors attached to the PWB, preferably by a wire bond. Optionally, one or more reflectors may be arranged on the printed wire board, such that the one or more reflectors form a cavity at least partially surrounding the one or more LED die. An encapsulant material may be introduced into the cavity in order to cover or encapsulate the LED die.

[0009] According to an embodiment of the present invention, the one or more heat sink studs may be thermally coupled to the external heat sink using a thermal grease. In addition, the PWB may include one or more castellations, adapted to allow the LED package to be assembled onto a secondary component, such as a mother PWB.

[0010] According to an embodiment of the present invention, an outer edge of the heat sink studs may be knurled to allow the heat sink studs to be fitted within the corresponding opening of the printed wire board. Optionally, the openings of the PWB may plated with a solderable material, such that the solderable material may be flowed to join the PWB and the heat sink stud.

[0011] According to an embodiment of the present invention, a LED package may comprise an external heat sink, one or more heat sink studs in thermal contact with the external heat sink, a printed wire board overlying the external heat sink, wherein the printed wire board includes one or more openings aligned with the one or more heat sink studs, and one or more LED die mounted on each of the one or more heat sink studs. The one or more heat sink studs may be embedded in the external heat sink. In addition, one or more reflectors may be attached to the printed wire board, wherein each of the one or more reflectors forms a cavity around the one or more LED die. Preferably, the printed wire board may comprise a standard fiberglass reinforced epoxy laminate material (FR4) or a high temperature fiberglass reinforced epoxy laminate material (FR4-5) and the LED die is composed of a material having a thermal coefficient of expansion (TCE) that is closely matched to that of the heat sink stud material. Preferably, the one or more sink studs comprise a high thermal conductivity material, such as copper molybdenum copper. Optionally, the LED package may comprise multi-color LEDs.

[0012] An exemplary LED package according to an embodiment of the present invention may comprise an

external heat sink, a formed heat sink thermally connected to the external heat sink, a PWB mounted above the formed heat sink, and one or more LED die mounted on the formed heat sink.

[0013] An exemplary LED package according to an embodiment of the present invention may comprise a metal layer, a PWB having one or more layers and a cavity, wherein the printed wire board is mounted on the metal layer, one or more isolators or interposers disposed in the cavity of the PWB and mounted on the metal layer, and one or more LED die mounted on the isolator wherein the isolator comprises a material having a TCE that matches that of the one or more LED die mounted thereon. Preferably, the metal layer may comprise copper. Optionally, an encapsulant may be disposed over the one or more LED die. According to another option, the LED assembly may further comprise a reflector attached to the PWB.

[0014] According to an embodiment of the present invention, a method is provided for fabricating an LED assembly including a stepped cavity formed or buried in a multi-layer PWB structure. The multi-layer PWB structure includes a plurality of layers of PWB secured together using one or more adhesive layers. According to an embodiment of the present invention, the adhesive is a pressure sensitive adhesive (PSA). According to another embodiment of the present invention the adhesive layers are comprised of pre-impregnated composite fiber, herein referred to as "pre-preg" material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The features and advantages of the present invention will be apparent from the description of the preferred embodiment(s) presented below considered in conjunction with the attached figures, of which:

[0016] FIG. 1 shows a side cross-section view of a LED package, according to an embodiment of the present invention;

[0017] FIG. 2 shows a top view of a LED package, according to an embodiment of the present invention;

[0018] FIG. 3 illustrates a top view of a LED package including an array of LED assemblies, according to an embodiment of the present invention;

[0019] FIG. 4 shows a top view of a LED package including an array of LED assemblies, wherein the package includes castellations for SMT-type mounting, according to an embodiment of the present invention;

[0020] FIG. 5 illustrates a side view of a LED package including castellations mounted upon a secondary PWB using a SMT technique, according to an embodiment of the present invention;

[0021] FIG. 6 shows a side cross section view of a LED package including a formed heat sink providing a reflective cavity, according to an embodiment of the present invention;

[0022] FIG. 7 depicts a top view of a LED array package including a formed heat sink, according to an embodiment of the present invention;

[0023] FIG. 8 shows a side cross section view of a LED package including a PWB arranged above a formed heat sink, according to an embodiment of the present invention;

[0024] FIG. 9 shows a side cross section view of a LED array package including a PWB arranged above a formed heat sink thermally coupled to an external heat sink, according to an embodiment of the present invention;

[0025] FIG. 10 shows a side cross section view of a LED array package including a direct external heat sink connection, according to an embodiment of the present invention;

[0026] FIG. 11 shows a side cross section view of a LED package including an isolator, according to an embodiment of the present invention;

[0027] FIG. 12 shows a side cross section view of a LED package including an isolator and an optical element, according to an embodiment of the present invention;

[0028] FIG. 13 shows a side cross section view of a LED package including one or more LED die disposed directly on a metal layer composed of a TCE matching material;

[0029] FIG. 14 illustrates the steps of an exemplary process for fabricating a PWB assembly having a stepped cavity, according to an embodiment of the present invention;

[0030] FIG. 15A-15I illustrate a cross section of an exemplary PWB assembly with stepped cavity at different stages of a fabrication process, according to an embodiment of the present invention;

[0031] FIG. 16 illustrates the steps of an exemplary process for fabricating a LED package including a PWB having a stepped cavity; and

[0032] FIGS. 17A-17D illustrate a cross section of an exemplary multi-layer LED package at different stages of a fabrication process, according to an embodiment of the present invention.

[0033] It is to be understood that these figures are representative in nature for purposes of illustrating the concepts of the invention and may not be to scale, and are not intended to be exacting in all details.

DETAILED DESCRIPTION OF THE INVENTION

[0034] The present invention relates to light emitting packages, and methods for making same, wherein the light emitting package comprising at least one light emitting assembly including a printed wired board having one or more heat sink studs integrated therein to form a monolithic integrated base for mounting one or more light sources thereon. As used herein, the term "package" or "LED package" is intended to include, but is not limited to, an LED assembly comprising one LED or an array of LEDs, according to the present invention. As used herein, the term "array" is intended to refer to a plurality of elements, and is not intended to be limited to elements arranged in regular columns and/or rows. According to an embodiment of the present invention, the LED package may include an array of LED assemblies, with each LED assembly including an array of LED die.

[0035] According to an embodiment of the present invention, the one or more light sources comprise light emitting diode (LED) die. According to this embodiment of the present invention, each of the one or more LED die are mounted directly on a heat sink stud. The heat sink stud may be pressed or otherwise attached to the external heat sink.

The external heat sink may be composed of aluminum, copper, or other suitable material having high thermal conductivity. The heat sink studs may be composed of copper, aluminum, or other suitable material with high thermal conductivity. A high thermal conductivity material, such as tungsten copper, with a TCE that is close to that of the LED die may be used to reduce thermal mismatch stresses. Preferably, a thermal material, such as for example thermal grease or conductive epoxy, may be disposed between the assembly and the external heat sink to strengthen the mechanical and thermal connection therebetween.

[0036] The present invention relates to a LED package fabricated using widely-available PWB material as a basis for the LED package. FIG. 1 illustrates an exemplary LED package 100, shown here with a single LED die 40, including a PWB 10 having one or more pre-formed through-holes or apertures. A heat sink stud or slug 20 is inserted into each of the apertures to form a base assembly 30 for packaging one or more light sources (e.g., LED die 40). One having ordinary skill in the art will appreciate that the aperture may be formed in the PWB 10 by drilling, stamping, punching, or other suitable technique. According to an embodiment of the present invention, the PWB 10 may include any number of parts disposed on a large panel.

[0037] The PWB 10 may be constructed using any of a variety of commonly used PWB materials including, but not limited to, a standard fiberglass reinforced epoxy laminate material such as Flame Retardant 4 (FR4), woven PTFE, polyamide, etc. Optionally, multi-layer PWB structures may be used to minimize total board size, among other design reasons appreciated by one having ordinary skill in the art.

[0038] In a preferred embodiment, the PWB 10 has a working temperature of approximately 150 C. An exemplary PWB 10 suitable for use in the present invention is the commercially available high temperature fiberglass reinforced epoxy laminate such as Flame Retardant 4-5 (FR4-5). One having ordinary skill in the art will appreciate that other suitable printed wire boards may be used in the present invention, selected in accordance with the desired operating specifications of the assembly.

[0039] A heat sink stud 20 is inserted into each of the apertures of the PWB 10 to form an integral, monolithic base assembly 30. One having ordinary skill in the art will appreciate that the heat sink stud 20 may be fixed within the aperture of the PWB 10 using an adhesive or by soldering. Alternatively, the heat sink stud 20 may be secured in the PWB 10 using a suitable mechanical means to hold the heat sink in place over a variety of environmental conditions, such as temperature changes and mechanical stresses (PWB flexure).

[0040] According to an embodiment of the present invention, the outer edge of the heat sink stud 20 may be knurled for fitting the heat sink stud 20 into the aperture of the PWB 10. The knurls may be arranged such that they dig into the PWB 10 to form a fitted connection between the two components.

[0041] According to an embodiment of the present invention, the heat sink stud 20 and the aperture of the PWB 10 are shaped and dimensioned such that the heat sink stud 20 may be pressed into the PWB 10 to form a tight friction fit.

[0042] According to another embodiment, the perimeter edges of the PWB aperture may be plated or lined with a

solderable material. To form the base assembly 30, the heat sink stud 20 may be pressed into the aperture and heated (to approximately 250° C.) causing the solder to flow and bond the heat sink stud 20 to the PWB 10.

[0043] According to yet another embodiment, the heat sink stud 20 may be peened. The peened heat sink stud 20 is fitted within the PWB aperture. Next, a peening tool may be used to mechanically stretch the perimeter of the heat sink stud 20 such that the heat sink stud 20 is forced into the sides of the aperture and locked in place. Optionally, the heat sink stud 20 may be pressed into the PWB 10 in panel form.

[0044] One having ordinary skill in the art will appreciate that the heat sink stud 20 may be inserted and fixed within the PWB 10 using any combination of techniques described above or otherwise known in the art.

[0045] According to an embodiment of the present invention, the heat sink stud 20 may be made of copper, aluminum, molybdenum copper, or other suitable high-thermal conductivity material. Optionally, the heat sink stud 20 may be fabricated using an electrically conductive material or an insulating material, such as, for example, aluminum nitride.

[0046] Referring to FIG. 1, the assembly 30 may be used as a substrate or base for a light source (or LED) package 100. According to an embodiment of the present invention, a light source, such as a LED die 40, may be placed directly on the heat sink stud 20 of the assembly 30. According to this arrangement, the heat generated by the LED die 40 is dissipated by the heat sink stud 20, thus allowing for high temperature operation of the LED package 100. Advantageously, in order to improve LED die performance reliability, a heat sink stud 20 material may be selected which has a thermal coefficient of expansion (TCE) that is closely matched to that of the LED die 40. For example, the heat sink stud 20 may comprise tungsten copper, copper molybdenum copper, aluminum nitride, copper, or boron nitride.

[0047] According to an embodiment of the present invention, one or more conductors 50 may be provided on the PWB 10 for external electrical connections and for making electrical connections to the LED die 40, using, for example, wire-bonds 60.

[0048] The LED package 100 may include a reflector 70 for providing improved light extraction or for beam forming. Arrangement of the reflector 70 may, also provide a cavity surrounding the LED die 40, as shown in FIG. 1, that protects the LED die 40 and provides a retention area for encapsulation of the LED die 40 with, for example, an epoxy resin or silicone. The reflector 70 may be composed of any suitable material, such as a high-temperature plastic (e.g., a liquid crystal polymer, or other suitable plastic), ceramic, aluminum, or other optically reflective and electrically insulating material. Optionally, the reflector material may also compose electrically conductive materials, such as, for example, aluminum or nickel, provided an electrically insulating layer is disposed between the reflector 70 and each of the one or more PWB conductors 50. Optionally, the reflector 70 may be attached to the PWB 10 using any suitable adhesive.

[0049] According to an embodiment of the present invention, the LED die 40 may be attached to the heat sink stud 20 using any common chip-and-wire materials, such as an epoxy or solder. Encapsulation of the LED die 40 may be

carried out by dispensing an encapsulant **80** into the reflector **70**. Optionally, the optical element may be a transparent dome, disposed on and attached to the LED package **100** as a secondary component. The transparent dome may be attached in the LED package **100** using the encapsulant **80** as an adhesive, using a secondary adhesive, or by any suitable mechanical retention means. Although FIG. **1** shows an LED package **100** including a single LED die **40**, one having ordinary skill in the art will appreciate that the package may include any number of LED die **40**.

[0050] FIG. **2** shows a top view of an exemplary LED package **100**, according to an embodiment of the present invention. As shown, external electrical connections may be made to the LED die **40** by attaching it to the one or more PWB conductors **50**.

[0051] FIG. **3** shows an exemplary LED package including an array of LED assemblies, according to an embodiment of the present invention. As shown in FIG. **3**, pairs of LED die **40** are connected to separate heat sink studs **20** to form LED assemblies. The array of LED assemblies are packaged together into a single LED array package **200**. Spreading the heat sink studs **20** out over the PWB **10** reduces any stress that may result from a TCE mismatch between the materials of the PWB **10** and one or more of the heat sink studs **20**. Mounting holes **11** are provided for part-mounting to ensure a mechanical connection and to minimize the resistance of the thermal connection both initially, and over time.

[0052] FIG. **4** depicts an exemplary LED array package **300** wherein the PWB **10** of the LED array package **300** includes terminals (e.g., metallized inset terminations), known as castellations **310**, adapted for making one or more external connections (e.g., physical and/or electrical connections). The castellations **310** are useful for assembling the LED array package **300** onto a secondary component, such as a larger PWB (not shown in FIG. **4**), using, for example, Surface Mount Technology (SMT) techniques. Optionally, the castellations **310** may be soldered or plated, to facilitate the mounting of the entire LED package **310** to another PWB or other secondary component.

[0053] FIG. **5** shows a side view of the LED package **300** depicted in FIG. **4** ("daughter board") mounted and/or soldered onto a larger PWB **400** ("mother board") using common SMT techniques. The thermal connections to the heat sink studs may be made using any suitable material having a low thermal resistance, such as, for example, conductive epoxy, thermal grease, or solder. According to an embodiment of the present invention, solder or epoxy fillets **315** may be used to connect the daughter board **300**, at the sites of the one or more castellations, to a conductive region **320** of the mother board **400**.

[0054] FIG. **6** shows yet another embodiment of the present invention wherein the LED package **500** includes a sheet-like heat sink which is formed with concavities which align or register with one or more apertures of the PWB **10**, herein referred to as a formed heat sink **520**. According to this embodiment of the present invention, at least a portion of the formed heat sink **520** (i.e., a concavity) is pressed into or otherwise inserted into the apertures of the PWB **10**. The end portions of the formed heat sink **520** may extend out of the aperture and are attached to the surface of the PWB **10**. One having ordinary skill in the art will appreciate that the

ends of the formed heat sink **520** may be attached directly to the surface of the PWB **10**, or attached to a PWB conductor **50** (as shown in FIG. **10**). As shown, the formed heat sink **520** may be arranged such that it forms a pocket or cavity for disposal therein of one or more LED die **40**. The formed heat sink **520** may be attached to the PWB **10** using any suitable adhesive or mechanical attachment technique.

[0055] Optionally, the cavity portion of the formed heat sink **520** may be composed of, or coated with, a reflective material, such as for example aluminum or nickel, to provide a reflective cavity **70** around the one or more LED die **40**. The formed heat sink cavity may be filled with an encapsulant **80** to protect and manage the light extraction from the LED die **40**. According to this embodiment of the present invention, the formed heat sink **520** may be composed of any suitable thermally conductive material, such as, for example, aluminum or copper. Optionally, the sheet-type heat sink layer **520** may also be composed of a material that is both thermally conductive and has a TCE that is closely matched to the LED die **40**, such as tungsten copper or copper-molybdenum-copper.

[0056] FIG. **7** shows a top view of a LED array package **600** including a formed heat sink **520**, as described in connection with FIG. **6** above. One having ordinary skill in the art will appreciate that, according to this embodiment of the present invention, the formed heat sink **520** may be isolated (i.e., one heat sink per LED die **40** or LED cluster **45**). Alternatively, according to an embodiment of the present invention, there may be one solid, formed heat sink **520** upon which all LED die **40** and LED clusters **45** are arranged. As shown in FIG. **7**, the formed heat sink **520** may include one or more openings for allowing the connection of the one or more wire bonds **60** to the PWB conductors **50**. Optionally, a solder mask, or other electrically insulating layer, may be provided between the formed heat sink **520** and the PWB conductors **50** to prevent making an electrical connection between the electrical conductor and the formed heat sink **520**.

[0057] FIG. **8** depicts a LED package **600** wherein the PWB **10** is mounted above the formed heat sink **520**, which is formed with concavities in registration with the apertures of the PWB **10**. As described above, the formed heat sink **520** may be shaped such that it forms a cavity **70** in which the one or more LED die **40** may be disposed. By disposing the formed heat sink **520** below the PWB **10**, an improved thermal connection may be made to an external heat sink. One having ordinary skill in the art will appreciate that the formed heat sink **520** may be attached to the PWB **10** using any suitable means, including an adhesive or a mechanical means.

[0058] FIG. **9** shows an LED package **600** according to an embodiment of the present invention in a typical connection arrangement with an external heat sink **720**. Materials and construction for the embodiment depicted in FIGS. **8** and **9** are similar to the those depicted in FIG. **6** and described in detail above. Optionally, as shown in FIG. **9**, one or more holes, or eyelets **725**, may be punched or otherwise formed in the formed heat sink **520**. The eyelets are adapted to accept a securing mechanism, such as a screw or rivet, for connecting the formed heat sink **520**. For example, one or more clamping screws **730** may be used to secure together the formed heat sink **520**, the PWB **10**, and the external heat

sink 720. Optionally, the LED package 600 and the external heat sink 720 may be joined using a suitable adhesive, such as, for example, thermal grease 735.

[0059] FIG. 10 illustrates an embodiment of the present invention wherein one or more grooves, notches, or holes are formed in the surface of an external heat sink 820. One or more heat sink studs 20 are pressed into the grooves of the external heat sink 820. Once the heat sink studs 20 are pressed or attached in place, a PWB 10, having openings or apertures aligning with the heat sink studs 20 is laid over the protruding heat sink studs 20 and attached to the external heat sink 820. The LED dice 40 are then mounted on the heat sink studs 20. Optionally, reflectors 70 are arranged around each of the LED dice 40, using, for example, an adhesive. Further, the LED dice 40 may be electrically connected to the PWB conductor 50 using one or more wire bonds 60, and may be encapsulated by encapsulant 80.

[0060] Optionally, the LED package 800 may be attached to the external heat sink 820 by a low thermal resistance connection where the heat sink stud 20 is pressed into the external heat sink 820, and between the external heat sink stud 820 and the PWB 10. The low thermal resistance attachment may be made using, for example, a thermally-conductive epoxy, thermal grease, solder, or other suitable material. Heat produced by each of the one or more LED die 40 during operation is carried away from the LED die 40 through the heat sink stud 20, and into the external heat sink 820. Advantageously, removing the heat generated by the LED die 40 increases both the LED die life and the light output. Another advantage of this arrangement is that it eliminates the additional expenses associated with adding the thermal resistance of a secondary assembly. Although FIG. 10 depicts the LED package 800 attached to the external heat sink 820, one having ordinary skill in the art will appreciate that the LED package 800 may be attached to or mounted on any suitable component.

[0061] FIG. 11 illustrates a LED package 900 according to an embodiment of the present invention, wherein a metal layer 920 is disposed underlying a PWB 930. The metal layer 920 may be attached or laminated to the PWB 930 using any suitable PWB laminate (e.g., pressure sensitive adhesive or pre-punched pre-preg material) according to any suitable lamination process. The metal layer 920 may be composed of any suitable material having a high thermal conductivity (TC) and a low TCE, such as, for example, copper.

[0062] The LED package 900 further includes one or more LED die 40 arranged on an isolator 910. The isolator 910 and LED die 40 assembly are disposed in an aperture or cavity formed in a PWB 930, as shown in FIG. 11. The one or more LED die 40 may be attached to the isolator 910 using any suitable attachment means including, but not limited to, a conductive epoxy, a solder, etc.

[0063] As shown in FIG. 11, the isolator 910 may be attached directly to the metal layer 920, according to any suitable attachment means or material, such as conductive epoxy, solder, brazing, mechanical means, etc. One having ordinary skill in the art will appreciate that in fabrication, the isolator 910 and LED die 40 assembly may be disposed on the metal layer 920, followed by the disposition of the PWB 930 onto the metal layer 910 such that the aperture or cavity of the PWB 930 aligns with or corresponds to the isolator

910 and LED die 40 assembly. Alternatively, one having ordinary skill in the art will appreciate that the PWB 930 may be disposed on the metal layer 920, followed by the disposition of the isolator 910 and LED die 40 assembly in the aperture or cavity of the PWB 930.

[0064] The PWB 930 may comprise one or more layers, and may include one or more PWB conductor layers 930A. The LED die 40 may be electrically connected to the PWB conductor layer(s) 930A using any suitable connection means, such as a wire bond 940, as shown in FIG. 11. In addition, a solder pad 950 may be disposed on the PWB 930.

[0065] According to an embodiment of the present invention, the isolator 910 is composed of a material adapted to tolerate expansion excursions caused by the heat produced by the attached LED die 40. Preferably, the isolator 910 is composed of a material that has a TCE that approximately matches the TCE of the LED die 40. Suitable TCE-matching materials that may be used in accordance with the present invention include, but are not limited to, copper-molybdenum-copper (CuMoCu), tungsten-copper (WCu), aluminum-silicon-carbide (AlSiC), aluminum nitride (AlN), silicon (Si), beryllium oxide (BeO), diamond, or other material that has a TCE that is matched to that of the LED.

[0066] According to an embodiment of the present invention, the LED package 900 may include a reflector 960 disposed on a layer of the PWB 930 to provide improved light extraction and/or for efficient beam forming. As described above, the reflector 960 may be composed of any suitable high temperature plastic (e.g., liquid crystal polymer), a ceramic material, or other optically reflective and electrically insulating material. The reflector 960 may be attached to the PWB 930 using any suitable adhesive.

[0067] According to an embodiment of the present invention, an encapsulant 970 may be disposed in the cavity of the PWB 930 such that the encapsulant 970 covers all or a portion of the LED die 40. The encapsulant material may be composed of any suitable transparent optical material. Optionally, as shown in FIG. 12 and as described above in conjunction with FIG. 1, a secondary optical element 980, such as a transparent dome, may be disposed over the LED die 40. According to an embodiment of the present invention, the optical element may be attached in the LED package 900 using an encapsulant 970 or other adhesive. Furthermore, as shown in FIG. 12, a plurality of LED dice 40 may be mounted on the isolator 910, to form an LED assembly including an array of LED dice 40, included within a single LED package 900.

[0068] FIG. 13 illustrates an exemplary LED package 1000, according to an embodiment of the present invention, which is similar to LED package 900 described above in conjunction with FIG. 12. In this embodiment, however, the one or more LED die 40 are attached directly to a metal layer 1020 composed of a material having a TCE that matches that of the LED die 40. The metal layer 1020 is preferably a low TCE material, such as, for example, copper-molybdenum-copper (CuMoCu), tungsten-copper (WCu), aluminum-silicon-carbide (AlSiC), aluminum nitride (AlN), silicon (Si), beryllium oxide (BeO), diamond, or other material that has a TCE that is matched to that of the LED die 40. The LED die 40 may be attached or adhered to the TCE-matching metal layer 1020 using a conductive epoxy, solder, or other suitable attachment means or material.

[0069] Advantageously, the heat generated by the LED die **40** and the stresses associated with the thermal expansion of the LED die **40** and the metal layer **1020** are efficiently managed by using the TCE-matching metal layer **1020**.

[0070] The one or more LED die **40** are disposed within a cavity of a PWB **1030**. The PWB **1030** may be comprised of one or more layers, and include a conductive layer **1030A** that is electrically connected to the LED die **40** using any suitable connection means, such as, for example, a wire bond **1040**.

[0071] According to an embodiment of the present invention, the LED package **1000** may include a reflector **1060** attached to the PWB **1030** and at least partially surrounding the LED die **40**. Optionally, the LED package **1000** may comprise an encapsulant **1070** dispensed in the cavity of the PWB **1030** and/or the reflector **1060**, such that it at least partially covers the LED die **40**.

[0072] According to yet another embodiment of the present invention, a method is provided for fabricating a multi-layer PWB assembly having a stepped cavity formed therein, particularly suited for housing light emitting devices, such as, for example, one or more LED die **40**. According to an embodiment of the present invention, the stepped cavity is buried in the PWB assembly. The present invention further relates to a PWB assembly including a stepped cavity made according to the fabrication method. In addition, the present application describes a method for fabricating a LED package comprising a PWB assembly having a stepped cavity

[0073] FIG. **14** illustrates an exemplary process for fabricating a PWB assembly having a stepped cavity, according to an embodiment of the present invention. FIGS. **15A-15I** depict an exemplary PWB assembly at different stages of the fabrication process illustrated in FIG. **14** and described in detail below. FIG. **15I** depicts an exemplary PWB assembly **2000** including a stepped cavity **1900**, fabricated according to an embodiment of the present invention.

[0074] In step **1**, a number of PWB layers **1500** to be assembled are provided. Although the exemplary embodiment described herein and illustrated in FIGS. **14** and **15A-15I** includes three PWB layers **1500A**, **1500B**, **1500C**, one having ordinary skill in the art will appreciate that the PWB assembly **2000** may include any suitable number of PWB layers **1500**. One having ordinary skill in the art will appreciate that each of the PWB layers **1500A**, **1500B**, **1500C** may comprise any suitable number of layers.

[0075] According to an exemplary embodiment of the present invention, each of the PWB layers **1500A**, **1500B**, **1500C** comprises a double sided FR4 (or FR4-5) board, which includes a dielectric layer (e.g., a layer of FR4 material) **1502** disposed between a top metal layer **1501** and a bottom metal layer **1503**, as shown in FIG. **15A**. The metal layers **1501**, **1503** of the PWB layer **1500** may be composed of any suitable metal, including but not limited to copper.

[0076] The PWB layers **1500A**, **1500B**, **1500C** may be of any suitable thickness (e.g., approximately 0.002 inches thick). According to an embodiment of the present invention, the bottom-most PWB layer (**1500C** in FIG. **15A**) is thicker than the other PWB layers (e.g., approximately 0.004 inches thick).

[0077] In step **2**, one or more of metal layers **1501**, **1503** are patterned with wiring traces appropriately to enable assembly of the PWB layers such that the metal portions of the individual PWB layers are properly aligned for desired interconnection. For example, as shown in FIG. **15B**, the bottom metal layer **1503A** of PWB layer **1500A** is patterned to include features adapted for assembly with adjacent PWB layer **1500B**, and so on, as described in detail below.

[0078] Optionally, in step **3**, one or more of the metal layers **1501**, **1503** may be plated with a suitable metal for electrical connectivity with a light emitting device. Any suitable material may be used for the plating, such as, for example, nickel or gold.

[0079] In step **4**, the process of forming a stepped cavity is initiated. Specifically, an aperture is formed in the dielectric layer **1502** of each of the one or more intermediate PWB layers. In the exemplary embodiment illustrated in FIG. **15C**, the aperture or hole is formed in the dielectric layer **1502B** of PWB layer **1500B**. One having ordinary skill in the art will appreciate that the aperture may be of any suitable size and/or shape, such as a circle, square, etc. In addition, the aperture may be formed according to any suitable method, such as, for example, punching, routing or drilling.

[0080] In step **5**, the plurality of PWB layers **1500A**, **1500B**, **1500C** are laminated together, as shown in FIG. **15D** to form a multi-layer PWB structure. To laminate the PWB layers together, a suitable adhesive layer **1600** is disposed in between each adjacent PWB layer, and the layers are pressed together. The adhesive layer **1600** may be comprised of any suitable adhesive material. According to an embodiment of the present invention, the adhesive layer **1600** is composed of a suitable pressure sensitive adhesive (PSA), such as, for example, 3M™ High Tack Tape PSA 3794. According to another embodiment of the present invention, the adhesive layer **1600** may be composed of a pre-punched pre-preg material, such as, for example, Arlon 49N and Arlon 37N.

[0081] Optionally, via holes may be formed through the PWB layers **1500A**, **1500B**, **1500C** according to any suitable method (e.g., drilling), as shown in FIG. **15E**. In addition, the via holes may be plated with a suitable metallization material **1700** (e.g., copper) for electrical continuity, as shown in FIG. **15F**.

[0082] In step **6**, formation of the stepped cavity in the PWB assembly is finalized, by removing at least a portion of the top and bottom dielectric layers **1502A** and **1502B**. According to an embodiment of the present invention, a portion of the top dielectric layer **1502A** is removed using any suitable technique or tool, such as, for example, a piercing tool, a routing tool or a flat bottom drill, as shown in FIG. **15G**. Furthermore, in step **6**, a portion of the bottom dielectric layer **1502C** is removed, as shown in FIG. **15H**.

[0083] As a result of the process described in detail above with reference to FIG. **14**, the PWB assembly **2000** including a stepped cavity **1900** is formed, as shown in FIG. **15I**.

[0084] According to an embodiment of the present invention, the PWB assembly **2000** with stepped cavity **1900** may be used to fabricate a LED package, particularly those suited for high temperature operation.

[0085] FIG. **16** illustrates an exemplary process for the fabrication of a LED package **5000** (shown in FIG. **17D**)

including a stepped-cavity PWB assembly **2000**. One having ordinary skill in the art will appreciate that the steps set forth in the process illustrated in FIG. 16, and described in detail below, do not necessarily need to be performed in the order provided.

[0086] In step S1, as shown in FIG. 17A, a layer is provided which acts to electrically isolate the electrical connections of the PWB assembly **2000** from a metal base **3000**. One having ordinary skill in the art will appreciate that the “insulating layer” **2500** may be composed of any suitable dielectric material. According to an embodiment of the present invention, the insulating layer **2500** may be comprised of a PWB layer. The PWB layer may be composed of any suitable material, such as for example, a fiberglass reinforced material (e.g., FR4 board) or a high temperature fiberglass reinforced material (e.g., FR4-5 board). The insulating layer **2500** includes an aperture or hole **2510** adapted to correspond to the bottommost opening of the stepped cavity of the PWB assembly **2000**, as shown in FIG. 17A. According to another embodiment of the present invention, the insulating layer **2500** may be comprised of one or more pre-preg layers having a desired voltage breakdown. Preferably, a breakdown voltage of greater than or equal to 250 Volts is maintained. The insulating layer **2500** may be of any suitable thickness. Preferably, the insulating layer **2500** is at least approximately 0.002 inches thick.

[0087] The metal base **3000** is provided which serves as a heat sink in the LED package **5000**. According to an embodiment of the present invention, the metal base **3000** may be composed of any suitable metal, such as, for example, copper. In addition, the metal base **3000** may be of any suitable thickness sufficient to manage the heat generated by the one or more LED die of the LED package **5000**. The insulating layer **2500** advantageously isolates the plated vias of the PWB assembly **2000** from the metal base **3000**.

[0088] In step S2, the PWB assembly **2000**, the insulating layer **2500**, and the metal base **3000** are laminated together, as shown in FIG. 17B. According to an embodiment of the present invention, one or more laminate layers **2800** are disposed between the PWB assembly **2000** and the insulating layer **2500**, and the insulating layer **2500** and the metal base **3000**. The laminate layers **2800** include an aperture or opening which corresponds to the bottommost opening of the stepped cavity of the PWB assembly **2000** and the aperture of the insulating layer **2500**, as shown in FIG. 17A. One having ordinary skill in the art will appreciate that the laminate layers **2800** may be composed of any suitable laminate material, including, but not limited to, a pressure sensitive adhesive, a pre-punched pre-preg material, or a combination of both.

[0089] Optionally, the top dielectric layer **1502A** may be left in place until after the PWB assembly **2000** is laminated to the metal base **3000**. By so doing, the PWB assembly **2000** is a more robust and stronger assembly, able to withstand process variations experienced during the lamination process. For example, leaving the top dielectric layer **1502A** intact during integration of the PWB assembly **2000** into the LED package **5000** may result in less pre-punched pre-preg material running out onto the PWB layers and/or the metal base, and less deformation of the stepped cavity **1900** due to the stresses of the lamination process.

[0090] Optionally, according to an embodiment of the present invention, in step S3, in order to block the flow of the

lamine material into the stepped cavity or onto one or more portions of an adjacent PWB layer, one or more dams may be applied to the laminate layers **2800**. The dams **2900**, shown in FIG. 17C, may be fabricated according to any suitable technique, including, but not limited to, a photo-imageable solder mask technique, a screen printed maskant technique, or by pre-scoring the laminate layers **2800** to include the one or more dams. The dams **2900** may be composed of any suitable material, such as, for example, DuPont Vacrel® 8100 Series Photopolymer Dry Film Solder Mask.

[0091] In step S4, one or more LED die **40** are introduced into the stepped cavity of the LED package **5000**. As described in detail above, the one or more LED die **40** may be disposed directly on the metal base **3000**, or, alternatively, the LED die **40** may be disposed on an interposer **3100**, as shown in FIG. 17D. If the interposer **3100** is not included, one having ordinary skill in the art will appreciate that the metal base **3000** may be advantageously composed of CuMoCu, WCu, or other suitable TCE-matching material.

[0092] According to an embodiment of the present invention, the one or more LED die **40** may be electrically connected to a metal layer of the PWB assembly **2000** by any suitable means, including, but not limited to, wire bonds **3120**.

[0093] Optionally, the LED package **5000** may include a reflector **3130** which reflects at least a portion of the light emitted by the one or more LED die **40**. The reflector **3130** may be composed of any suitable reflective material, including, but not limited to, aluminum, polycarbonate, and liquid crystal polymer (LCP).

[0094] Optionally, the LED package **5000** may include an optical element **3140**, such as a lens. The optical element **3140** may be composed of any suitable material, including but not limited to, glass, silicone and polycarbonate.

[0095] According to an embodiment of the present invention, the reflector **3130** and the optical element **3140** may be adapted to produce a desired radiation pattern, such as, for example, a focused, narrow light beam. The pattern forming reflector **3130** may be molded or machined plastic (metalized or un-metalized), molded or machined aluminum, other suitable reflective material, or a stamped metal part with a reflective surface. The reflector **3130** or reflective surface may be roughened to improve color mixing and avoid creating undesirable, non-uniform light output.

[0096] It is to be understood that the exemplary embodiments are merely illustrative of the present invention and that many variations of the above-described embodiments can be devised by one skilled in the art without departing from the scope of the invention. It is therefore intended that all such variations be included within the scope of the invention.

What is claimed is:

1. A light emitting diode (LED) assembly comprising:
 - a printed wire board (PWB) comprising one or more apertures;
 - one or more heat sink studs secured within the one or more apertures; and

one or more LED die mounted on the one or more heat sink studs, wherein the one or more heat sink studs are composed of a material having a thermal coefficient of expansion (TCE) approximately equal to the TCE of the one or more LED die.

2. The LED assembly of claim 1, further comprising one or more reflectors disposed on the PWB, wherein the one or more reflectors form one or more cavities around the one or more LED die.

3. The LED assembly of claim 2, wherein the one or more LED die are at least partially encapsulated within the cavity.

4. The LED assembly of claim 1, further comprising one or more conductors disposed on the PWB, wherein the one or more LED die are electrically connected to the conductors.

5. The LED package of claim 1, wherein the PWB comprises one or more castellations for mounting the LED package to a second PWB.

6. The LED package of claim 1, wherein the one or more heat sink studs are knurled for fitting in the one or more apertures.

7. The LED package of claim 1, wherein the one or more apertures are plated with a solder material which joins the one or more heat sink studs therein.

8. The LED package of claim 1, wherein the one or more heat sink studs are peened for fitting in the one or more apertures.

9. A LED package comprising:

a PWB comprising one or more apertures;

a metal heat sink layer at least partially overlying the PWB, wherein one or more portions of the metal heat sink layer comprise concavities formed in registration with the one or more apertures; and

one or more LED mounted on the one or more concavity portions.

10. The LED package of claim 9, wherein the one or more concavity portions comprise a reflective material.

11. A LED package comprising:

a PWB comprising one or more apertures;

a metal heat sink layer at least partially underlying the PWB, wherein one or more portions of the metal heat sink layer comprise concavities formed in registration with the one or more apertures; and

one or more LED die mounted on the one or more concavity portions.

12. The LED package of claim 11, wherein the concavity portions of the metal heat sink layer are thermally coupled to an external heat sink.

13. A LED package comprising:

a heat sink;

one or more heat sink studs at least partially embedded in the heat sink;

a PWB overlying the heat sink, wherein the PWB comprises one or more apertures in registration with the one or more heat sink studs; and

one or more LED die mounted on the one or more heat sink studs.

14. The LED package of claim 13, further comprising one or more reflectors disposed on the PWB, wherein the one or

more reflectors form one or more cavities at least partially surrounding the one or more LED die.

15. The LED package of claim 14, wherein the one or more LED die are at least partially encapsulated within the one or more cavities.

16. The LED package of claim 13, further comprising one or more conductors disposed on the PWB, wherein the one or more LED die are electrically connected to the conductors.

17. The LED package of claim 13, wherein the PWB comprises a fiberglass reinforced laminate material.

18. The LED package of claim 13, wherein the PWB comprises a high temperature fiberglass reinforced laminate material.

19. The LED package of claim 13, wherein the one or more heat sink studs are composed of a material having a TCE approximately equal to the TCE of the one or more LED die.

20. A LED package comprising:

a metal layer;

a PWB assembly comprising two or more dielectric layers, the assembly comprising one or more stepped apertures, wherein the PWB overlies the metal layer;

one or more isolators disposed in the one or more stepped apertures of the PWB assembly and mounted on the metal layer; and

one or more LED die mounted on the one or more isolators.

21. The LED package of claim 20, wherein the one or more isolators are composed of a material having a TCE approximately equal to the TCE of the one or more LED die.

22. The LED package of claim 20, further comprising an optical element disposed over the one or more LED die.

23. A LED package comprising:

a metal layer;

a PWB assembly comprising two or more dielectric layers, the assembly comprising one or more stepped apertures, wherein the PWB overlies the metal layer; and

one or more LED die mounted on the metal layer, wherein the metal layer is composed of a material having a TCE approximately equal to the TCE of the one or more LED die.

24. A method of fabricating a multi-layer PWB assembly, comprising the steps of:

providing a plurality of PWB layers, wherein each PWB layer includes at least one metal layer and at least one dielectric layer;

patterning the at least one metal layer of the plurality of PWB layer;

forming apertures in each PWB layer, the apertures being aligned and sized to form one or more stepped cavities when the PWB layers are laminated together into a multi-layer assembly; and

laminating the plurality of PWB layers together to form a multi-layer PWB assembly having one or more stepped cavities.

25. The method of claim 24, wherein the laminating step comprises disposing a laminate layer in between the PWB layers.

26. The method of claim 25, wherein the laminate layer comprises a pre-punched pre-preg material.

27. The method of claim 26, further comprising the step of providing one or more plated vias through the multi-layer PWB assembly.

28. The method of claim 25, wherein the laminate layer comprises a pressure sensitive adhesive.

29. The method of claim 24, further comprising the step of providing one or more vias through the multi-layer PWB assembly.

30. The method of claim 29, further comprising the step of plating the one or more vias.

31. A PWB assembly fabricated according to the method of claim 24.

32. A PWB assembly fabricated according to the method of claim 27.

33. A method of fabricating a LED package comprising the steps of:

disposing a multi-layer PWB assembly including a stepped cavity on an insulating layer, the insulating layer having an aperture in registration with the stepped cavity;

laminating the multi-layer PWB assembly, the insulating layer, and a metal base together; and

disposing one or more LED die in the stepped cavity.

34. The method of claim 33, wherein the one or more LED die are disposed on the metal base.

35. The method of claim 33, wherein the one or more LED die are mounted on an isolator disposed on the metal base.

36. The method of claim 35, wherein the isolator is composed of a material having a TCE approximately equal to the TCE of the one or more LED die.

37. The method of claim 33, wherein the insulating layer comprises a dielectric material.

38. The method of claim 33, wherein the insulating layer comprises a high temperature fiberglass reinforced material.

39. The method of claim 33, wherein the insulating layer comprises one or more layers of laminate material.

40. The method of claim 39, wherein the one or more layers of laminate material comprise pre-punched pre-preg material.

41. The method of claim 39, wherein the one or more layers of laminate material comprise pressure sensitive adhesive.

42. The method of claim 33, further comprising the step of disposing an encapsulant over at least a portion of the one or more LED die.

43. The method of claim 33, further comprising the step of attaching a reflector to the multi-layer PWB assembly.

44. The method of claim 33, further comprising the step of disposing one or more dams between the one or more layers of laminate material and the stepped cavity to prevent the laminate material from entering the stepped cavity during the lamination step.

45. A LED package fabricated according to the method of claim 33.

46. The LED package of claim 45, wherein the insulating layer comprises pre-punched pre-preg material.

47. The LED package of claim 45, further comprising one or more dams between the one or more layers of laminate material and the stepped cavity to prevent the laminate material from entering the stepped cavity.

48. A LED package comprising:

a multi-layer PWB assembly including a stepped cavity, an insulating layer, and a metal base laminated together by a laminate material; and

one or more LED die disposed in the stepped cavity.

49. The LED package of claim 48, wherein the PWB assembly comprises one or more vias.

50. The LED package of claim 49, wherein the one or more vias are electrically insulated from the metal base by the insulating layer.

51. The LED package of claim 48, wherein the laminate material comprises a pressure sensitive adhesive.

52. The LED package of claim 48, wherein the laminate material comprises a pre-preg material.

53. The LED package of claim 52, wherein the pre-preg material includes an aperture in registration with the stepped cavity.

54. The LED package of claim 48, wherein the one or more LED die are disposed on the metal base.

55. The LED package of claim 54, wherein the metal base is composed of a material having a TCE approximately equal to the TCE of the one or more LED die.

56. The LED package of claim 48 wherein the one or more LED die are mounted on an isolator disposed on the metal base.

57. The LED package of claim 56, wherein the isolator is composed of a material having a TCE approximately equal to the TCE of the one or more LED die.

58. The LED package of claim 48, wherein the insulating layer comprises a fiberglass reinforced material.

59. The LED package of claim 48, wherein the insulating layer comprises one or more layers of laminate material.

60. The LED package of claim 59, wherein the one or more layers of laminate material comprise pre-punched pre-preg material.

61. The LED package of claim 60, wherein the one or more layers of laminate material comprise pressure sensitive adhesive.

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