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**Roberts et al.**

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(54) **HIGH POWER RADIATION EMITTER  
DEVICE AND HEAT DISSIPATING PACKAGE  
FOR ELECTRONIC COMPONENTS**

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cation No. PCT/US02/03161 on Jan. 31, 2002, now  
Pat. No. 7,075,112, which is a continuation-in-part of  
application No. 09/835,238, filed on Apr. 13, 2001,  
now Pat. No. 6,639,360.

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(51) **Int. Cl.**  
**H01L 23/22** (2006.01)

(52) **U.S. Cl.** ..... **257/687; 257/99; 257/E51.032**

(58) **Field of Classification Search** ..... 257/13,  
257/21, 79–82, 98–100, 687, E51.032  
See application file for complete search history.

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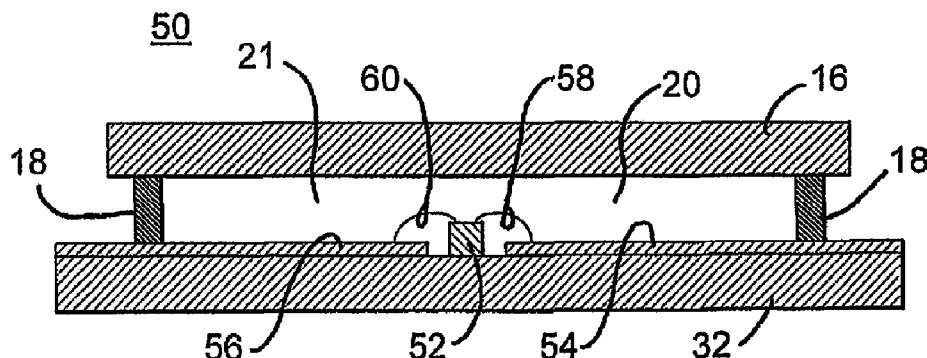
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(57) **ABSTRACT**

The electronic component package of the present invention includes a sealed chamber; a liquid or gel contained in the sealed chamber; at least one electronic component disposed in the sealed chamber in physical and thermal contact with the liquid or gel; and at least one electrical conductor electrically coupled to the electronic component and extending out of the sealed chamber. The electronic component(s) may include any one or combination of a radiation emitter, a thermal or optical sensor, a resistor, and a microprocessor or other semiconductor component.

**26 Claims, 13 Drawing Sheets**



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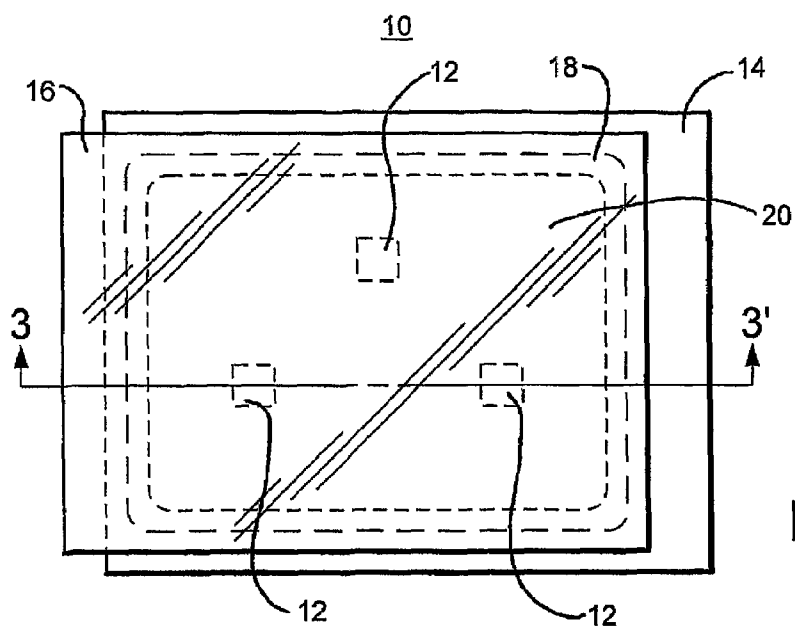


FIG. 1

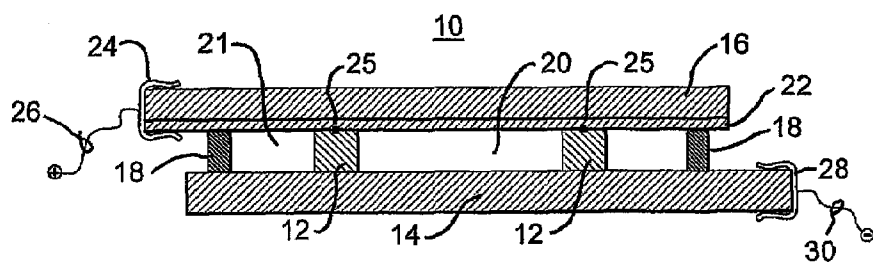


FIG. 3A

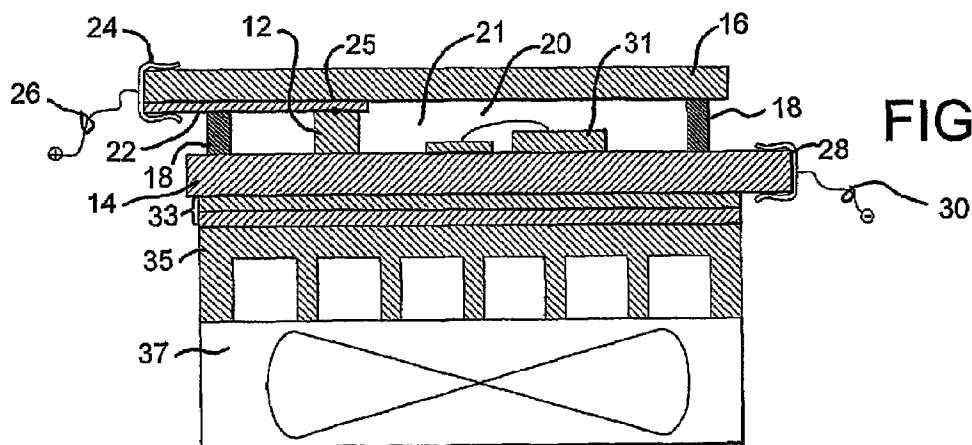


FIG. 3B

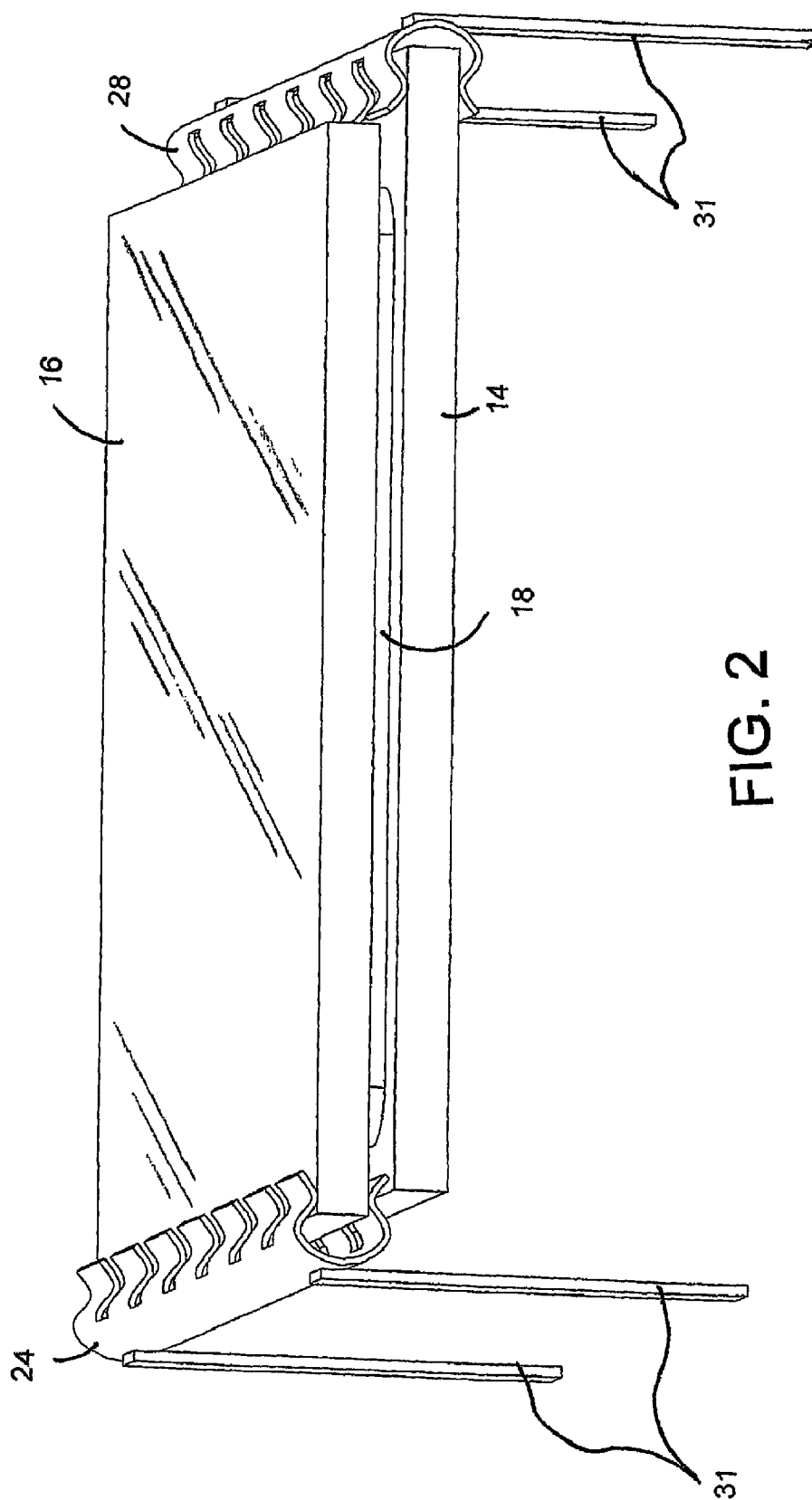


FIG. 3C

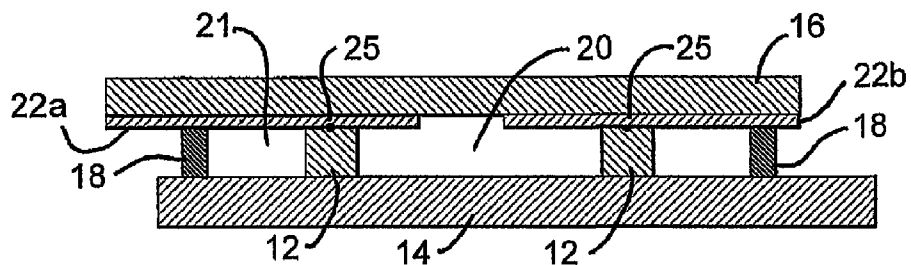


FIG. 4

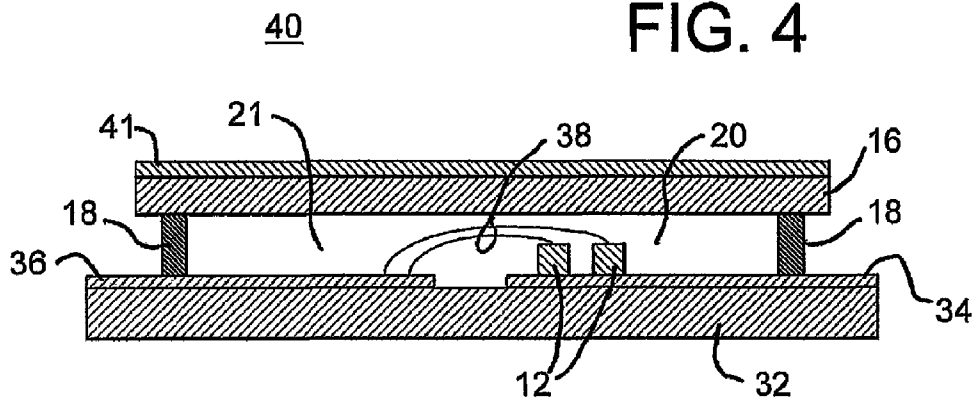
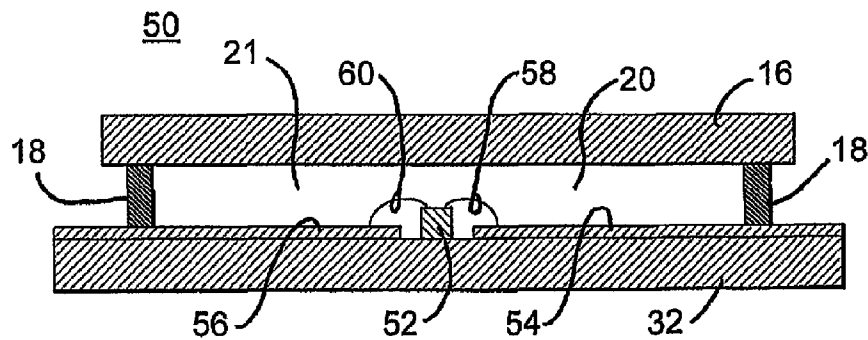


FIG. 5



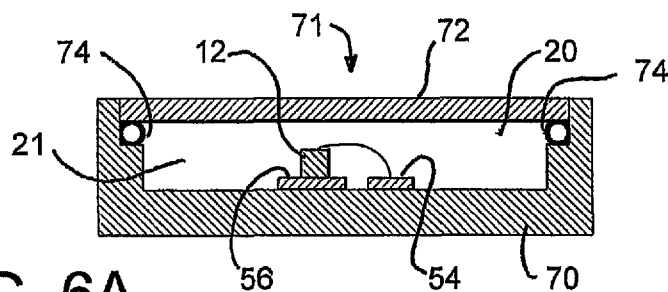


FIG. 6A

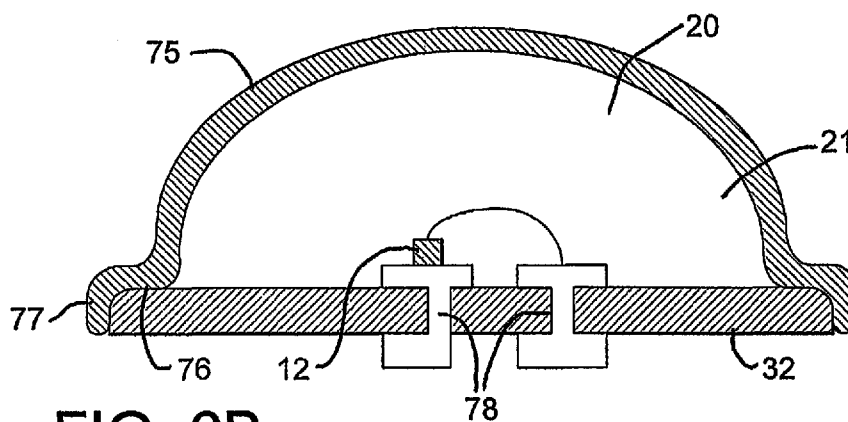


FIG. 6B

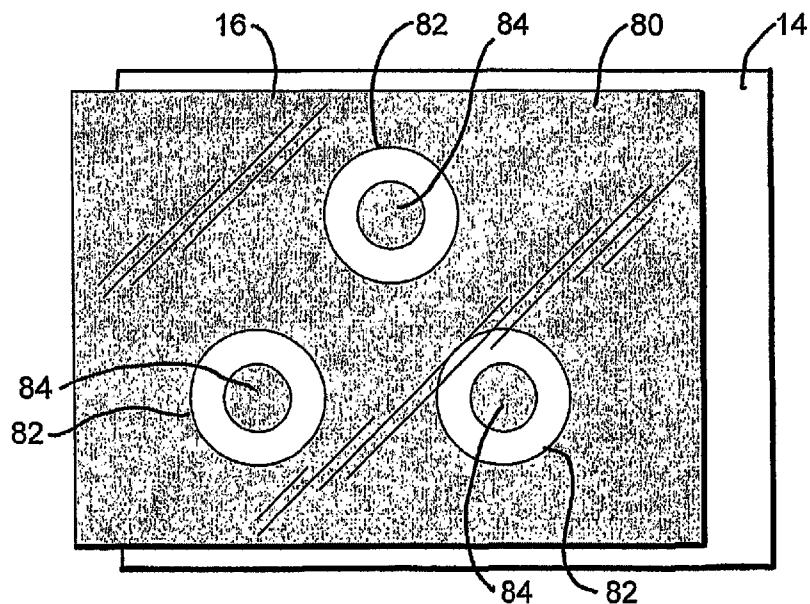


FIG. 7

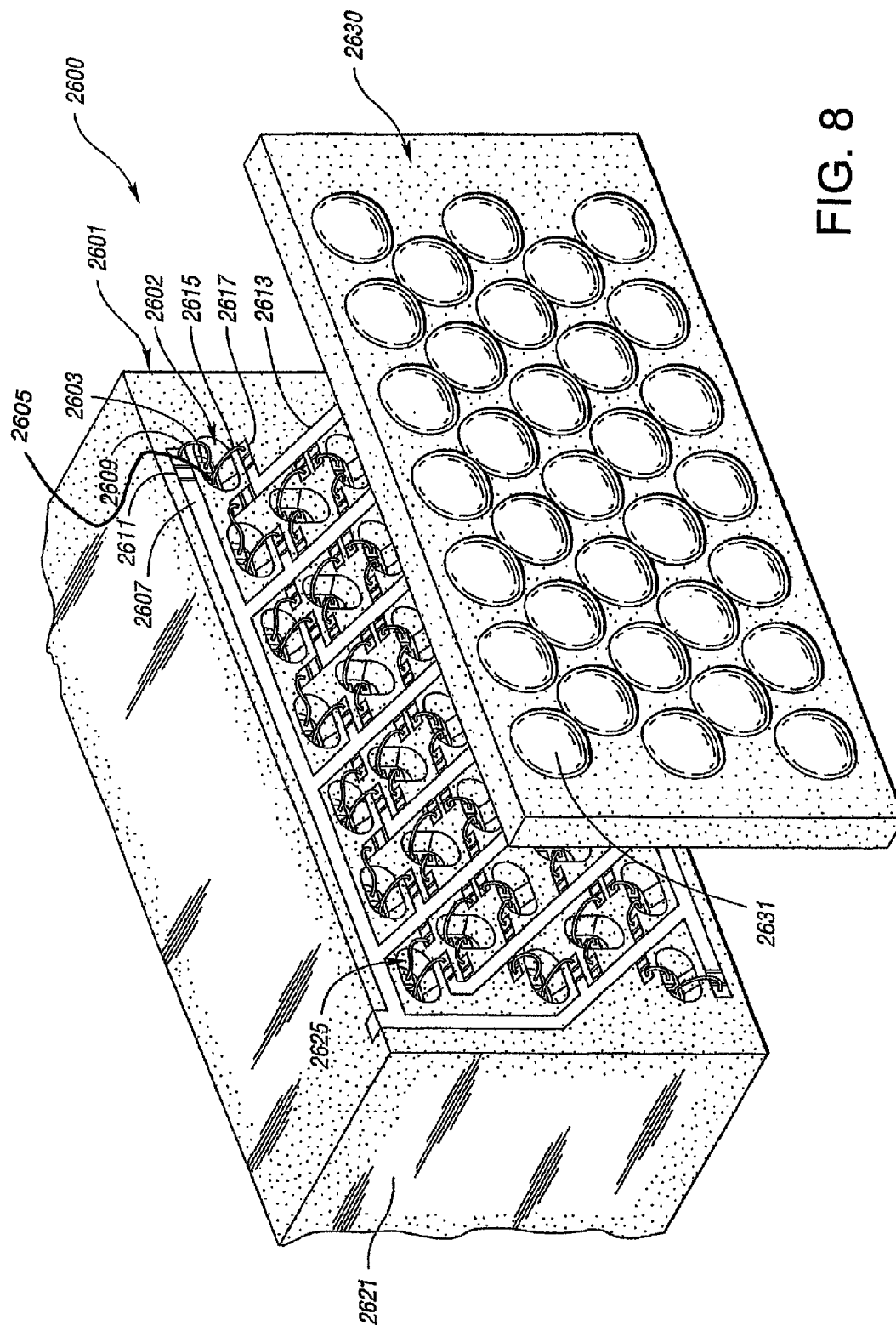


FIG. 8

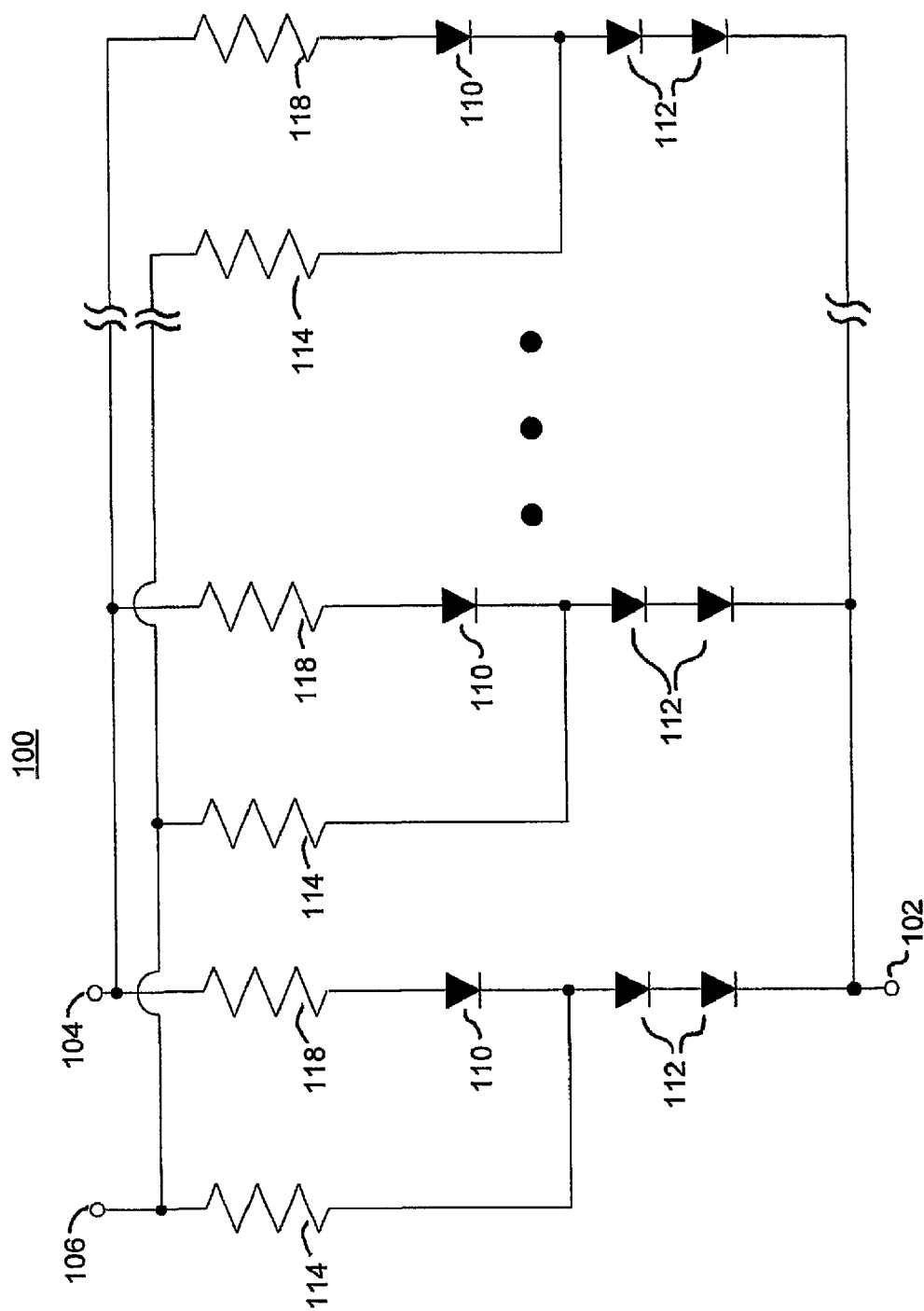


FIG. 9

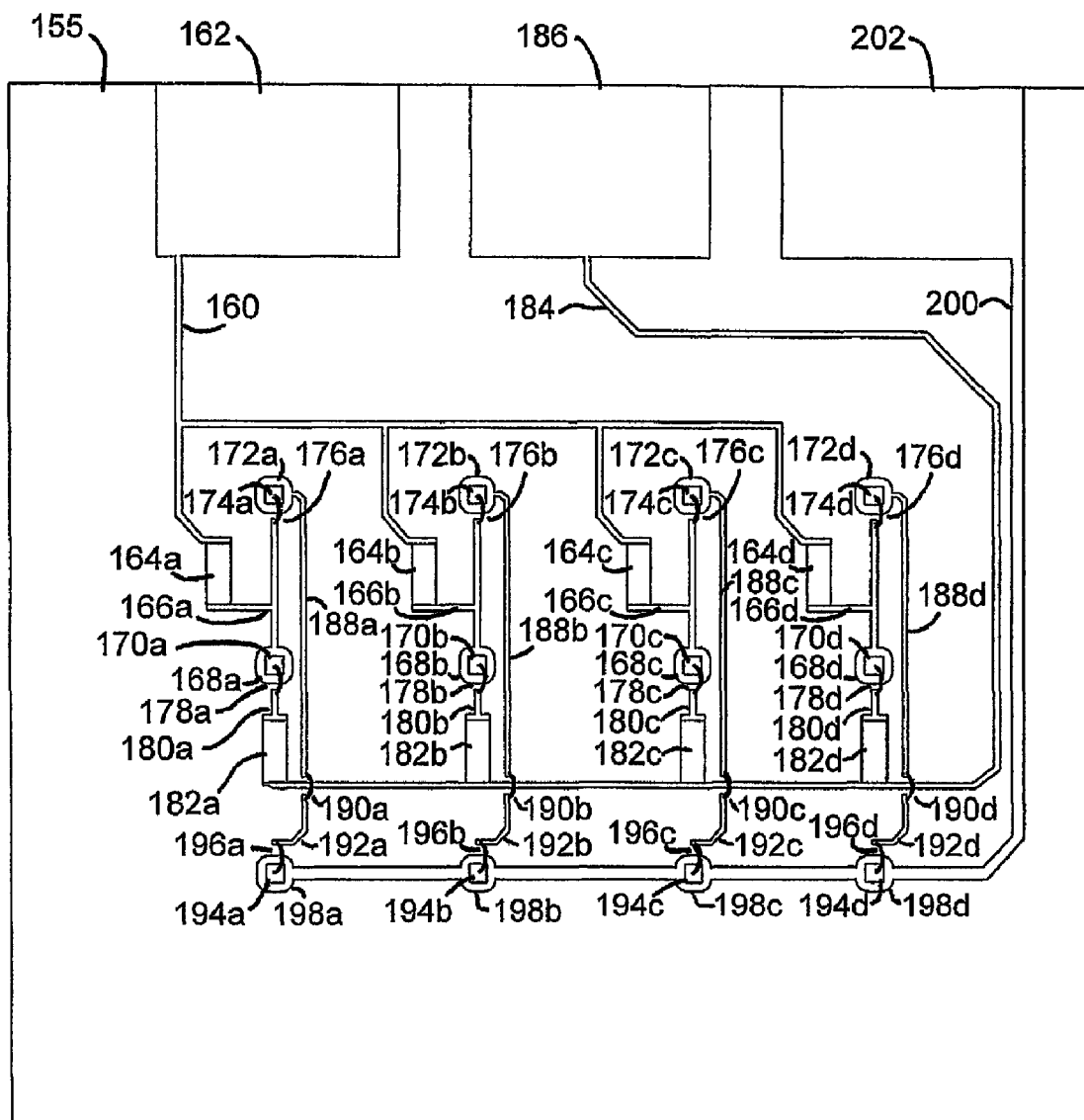


FIG. 10

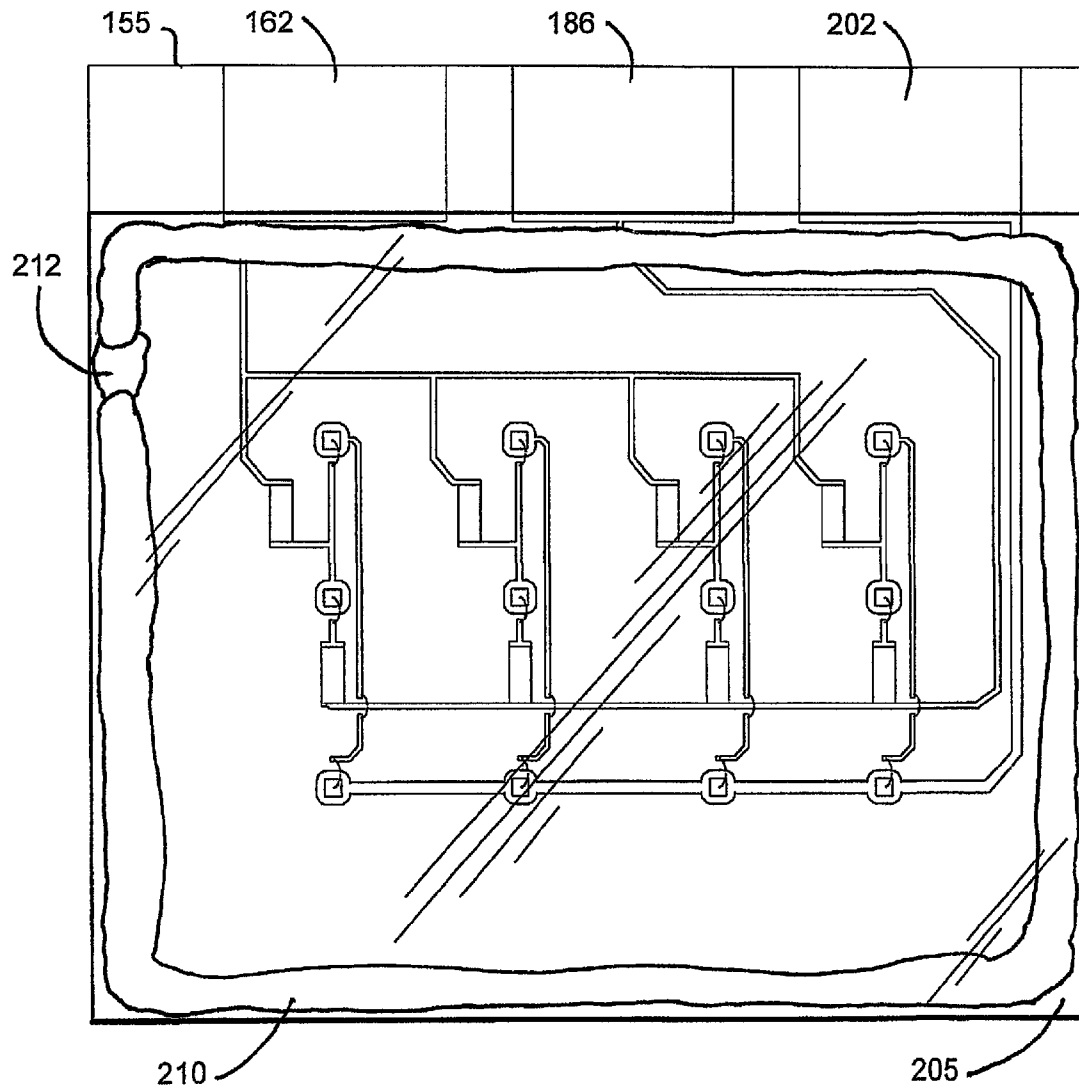


FIG. 11

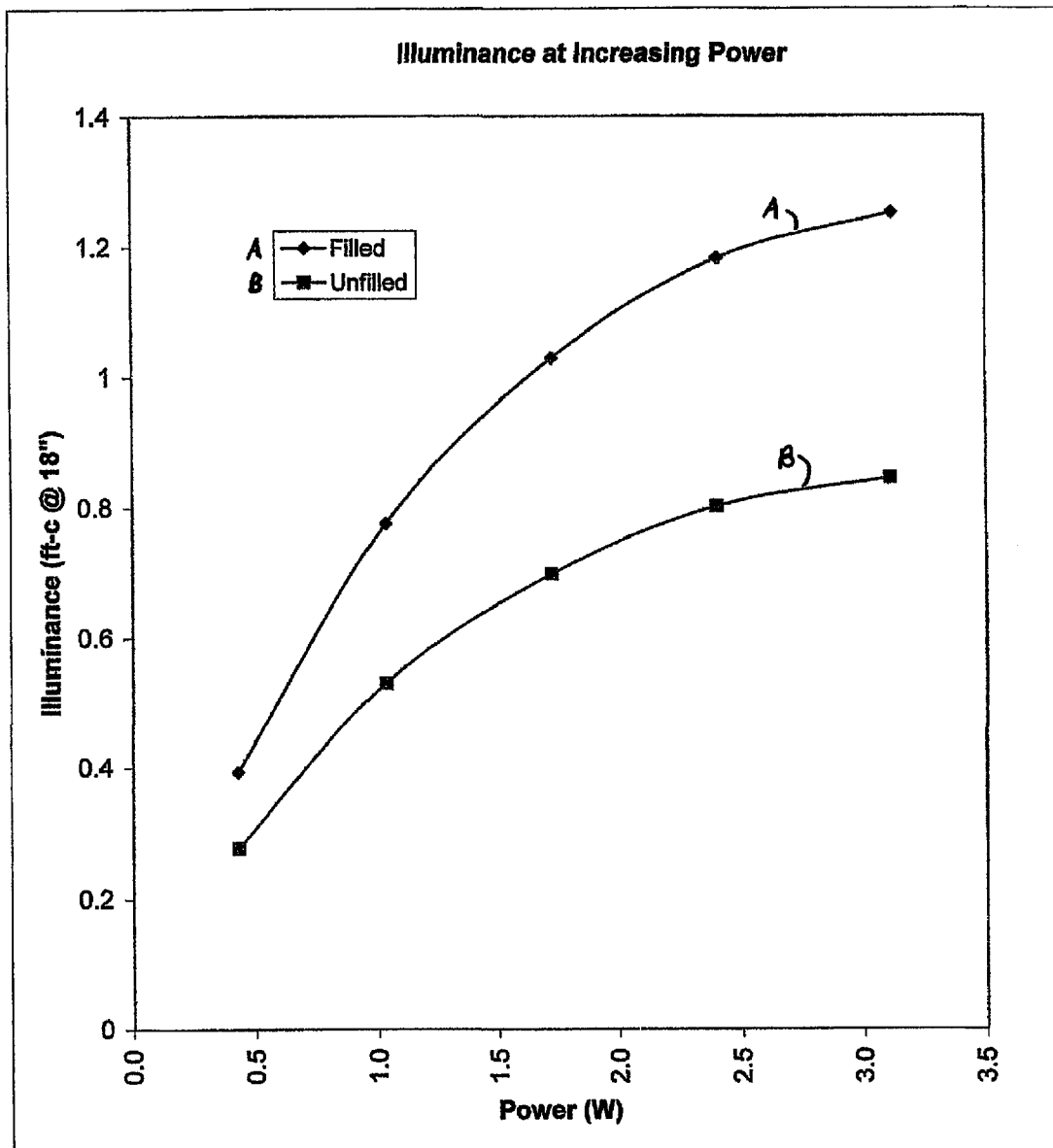


FIG. 12

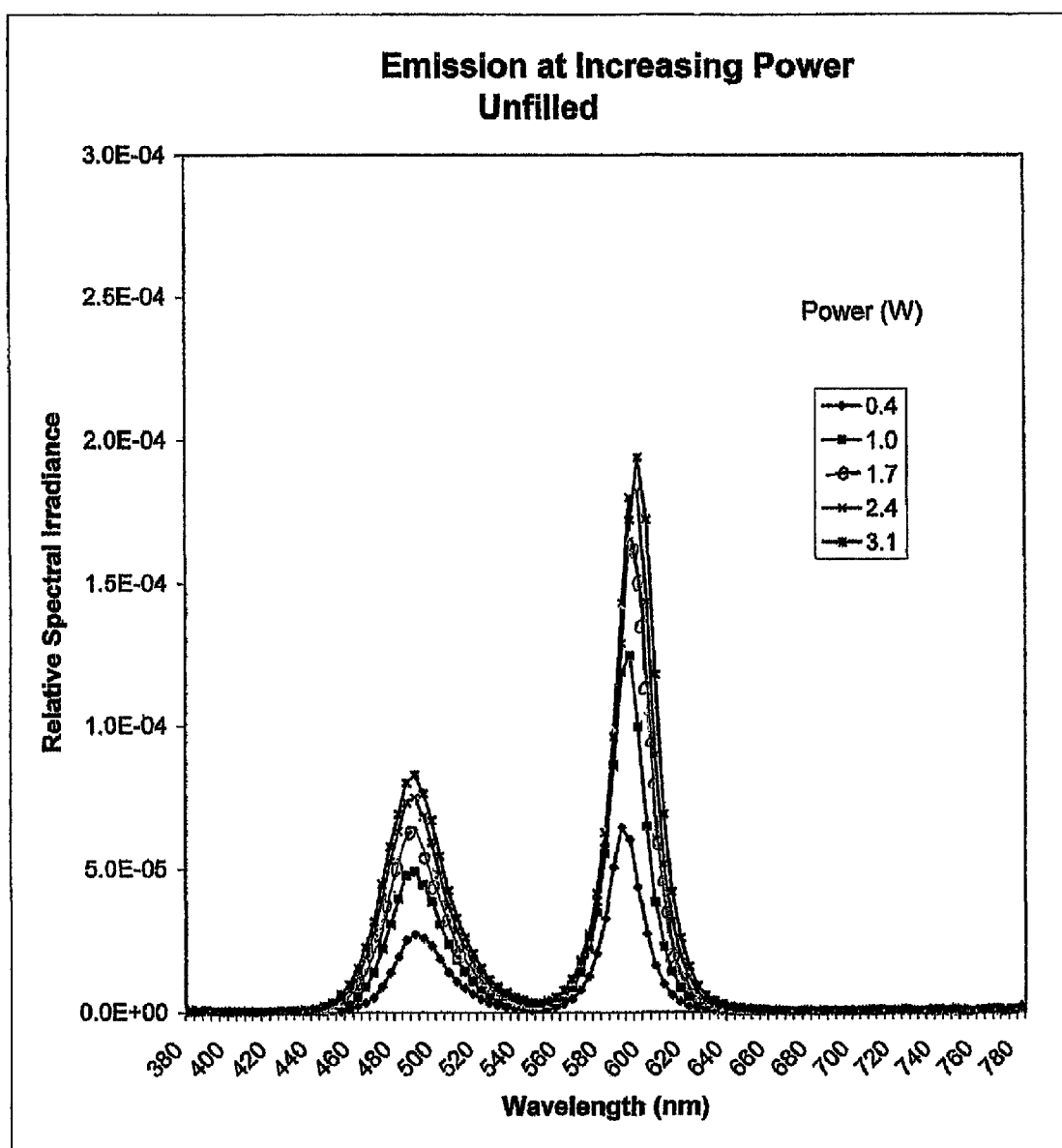


FIG. 13

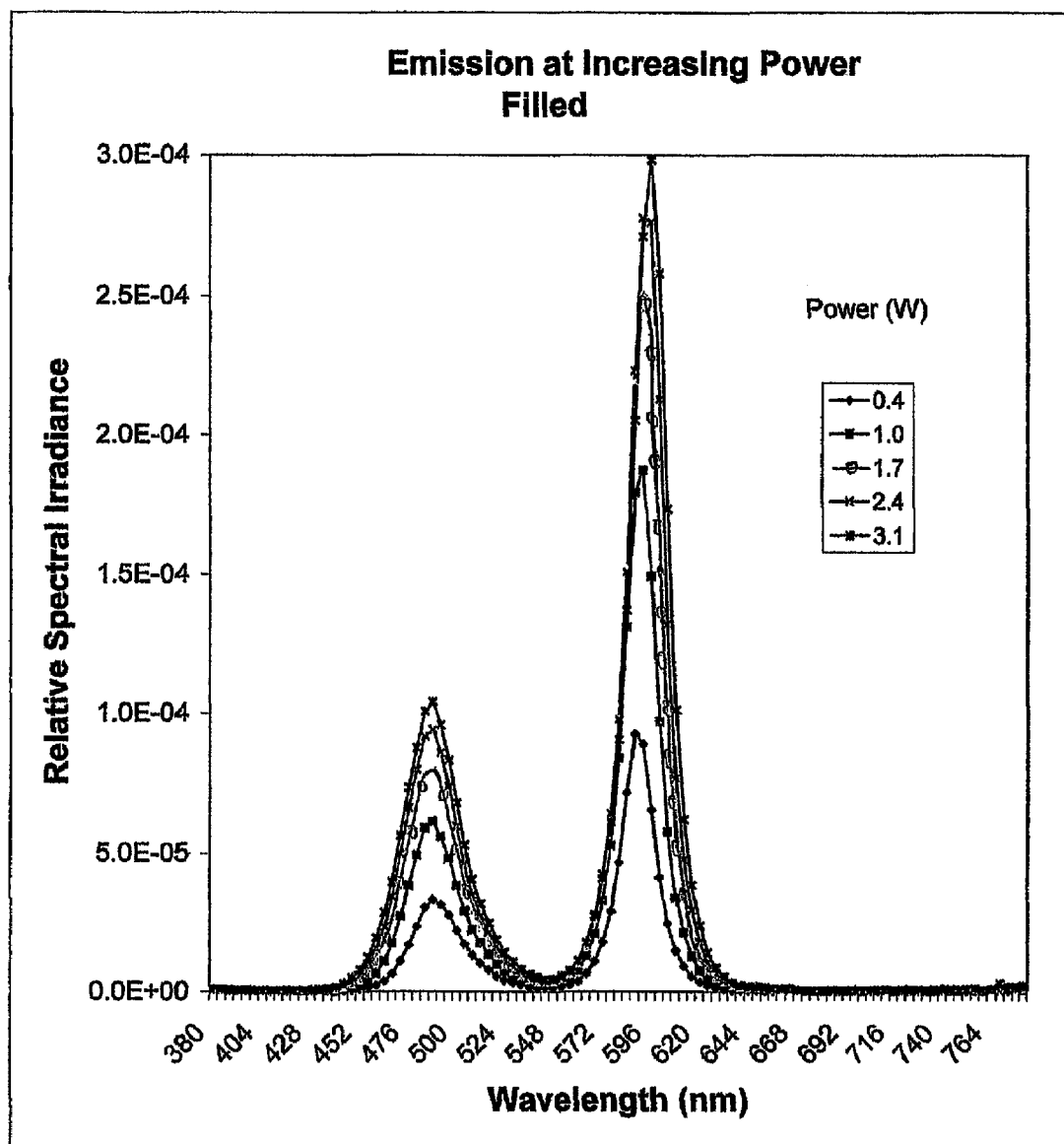


FIG. 14

FIG. 15

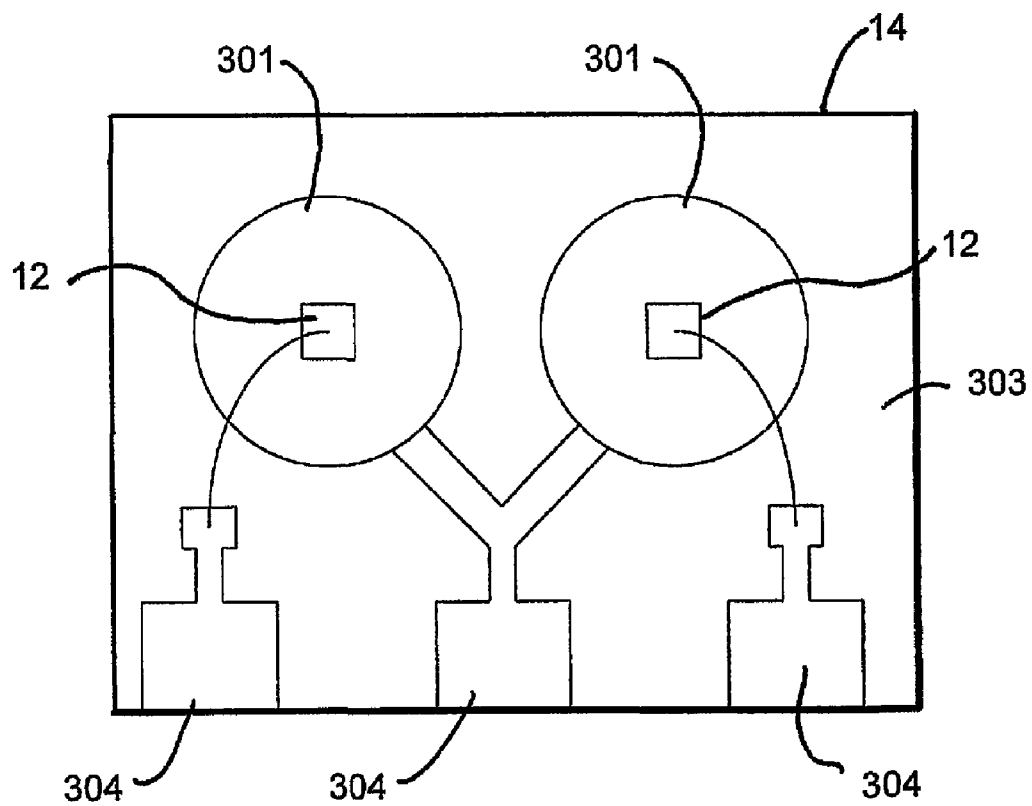
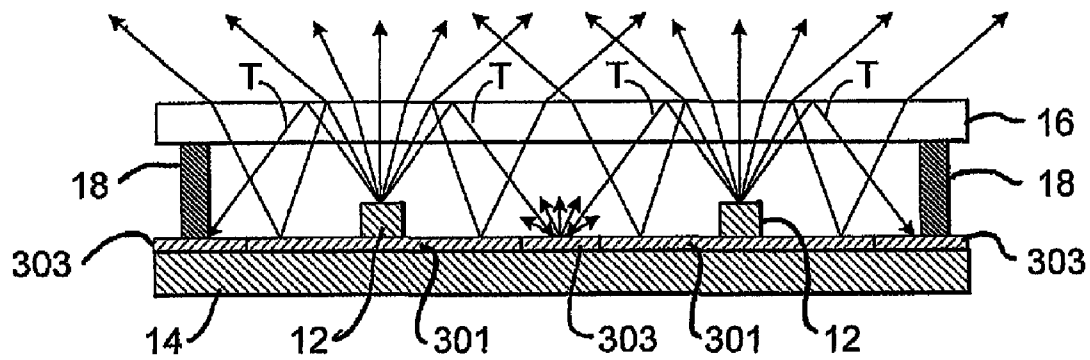


FIG. 16

FIG. 17A

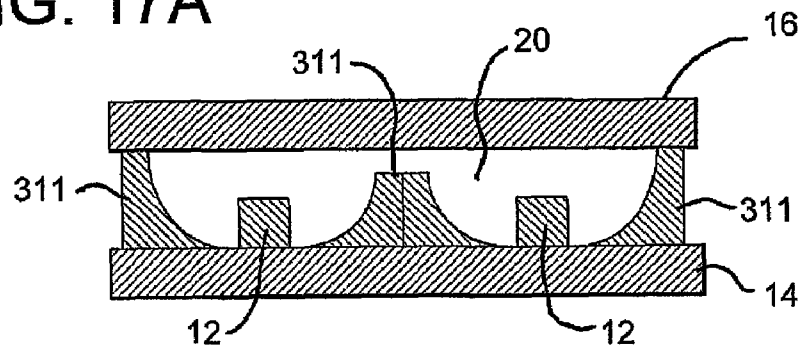


FIG. 17B

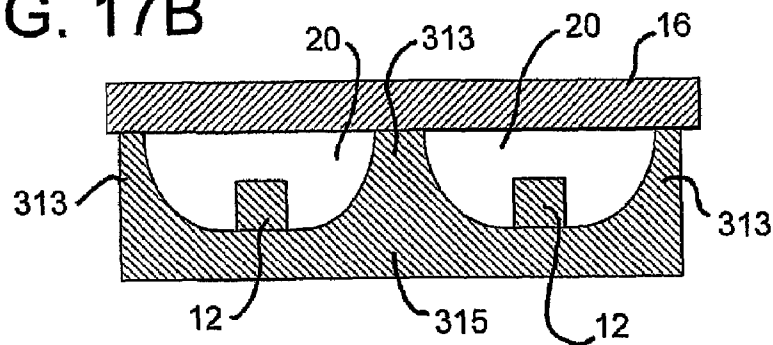
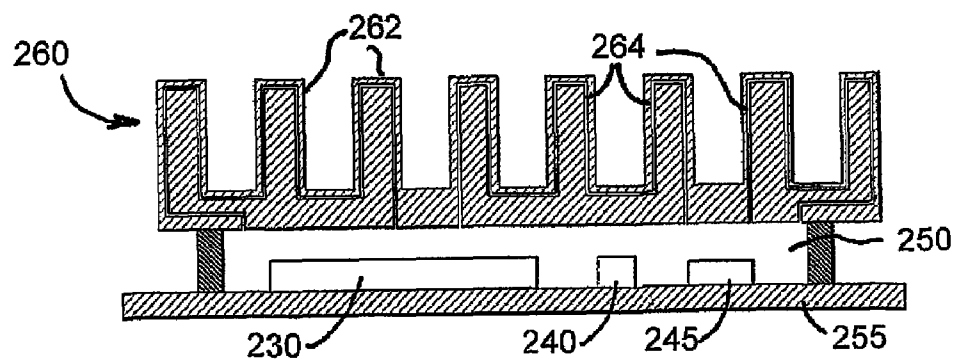


FIG. 18



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# HIGH POWER RADIATION EMITTER DEVICE AND HEAT DISSIPATING PACKAGE FOR ELECTRONIC COMPONENTS

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a division of U.S. patent application Ser. No. 10/470,879, filed on Jan. 29, 2004, now U.S. Pat. No. 7,075,112, which is the national stage application of International Application No. PCT/US02/03161, filed on Jan. 31, 2002, which claims priority to U.S. patent application Ser. No. 09/835,238 filed on Apr. 13, 2001, now U.S. Pat. No. 6,639,360, which claims priority under 35 U.S.C. §119(e) on U.S. Provisional Patent Application No. 60/265,487, filed on Jan. 31, 2001, the entire disclosures of which are incorporated herein by reference.

## BACKGROUND OF THE INVENTION

The present invention generally relates to radiation emitter assemblies such as, for example, light emitting diode (LED) packages and to heat dissipating packages for electronic components.

Radiation emitters, particularly optical radiation emitters, are used in a wide variety of commercial and industrial products and systems, and accordingly come in many forms and packages. As used herein, the term "optical radiation emitter" includes all emitter devices that emit visible light, near infrared (IR) radiation, and ultraviolet (UV) radiation. Such optical radiation emitters may be photoluminescent, electroluminescent, or other solid state emitter. Photoluminescent sources include phosphorescent and fluorescent dyes. Fluorescent sources include phosphors and fluorescent dyes, pigments, crystals, substrates, coatings, and other materials.

Electroluminescent sources include semiconductor optical radiation emitters and other devices that emit optical radiation in response to electrical excitation. Semiconductor optical radiation emitters include light emitting diode (LED) chips, light emitting polymers (LEPs), organic light emitting devices (OLEDs), polymer light emitting devices (PLEDs), etc.

Semiconductor optical emitter components, particularly LED devices, have become commonplace in a wide variety of consumer and industrial opto-electronic applications. Other types of semiconductor optical emitter components, including OLEDs, LEPs, and the like, may also be packaged in discrete components suitable as substitutes for conventional inorganic LEDs in many of these applications.

Visible LED components of all colors are used alone or in small clusters as status indicators on such products as computer monitors, coffee makers, stereo receivers, CD players, VCRs, and the like. Such indicators are also found in a diversity of systems such as instrument panels in aircraft, trains, ships, cars, trucks, minivans and sport utility vehicles, etc. Addressable arrays containing hundreds or thousands of visible LED components are found in moving-message displays such as those found in many airports and stock market trading centers and also as high brightness large-area outdoor television screens found in many sports complexes and on some urban billboards.

Amber, red, and red-orange emitting visible LEDs are used in arrays of up to 100 components in visual signaling systems such as vehicle center high-mounted stop lamps (CHMSLs), brake lamps, exterior turn signals and hazard flashers, exterior signaling mirrors, and for roadway construction hazard markers. Amber, red, and blue-green emitting visible LEDs

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are increasingly being used in much larger arrays of up to 300 components as stop/slow/go lights at intersections in urban and suburban intersections.

Multi-color combinations of pluralities of visible colored LEDs are being used as the source of projected white light for illumination in binary-complementary and ternary RGB illuminators. Such illuminators are useful as vehicle or aircraft maplights, for example, or as vehicle or aircraft reading or courtesy lights, cargo lights, license plate illuminators, backup lights, and exterior mirror puddle lights. Other pertinent uses include portable flashlights and other illuminator applications where rugged, compact, lightweight, high efficiency, long-life, low voltage sources of white illumination are needed. Phosphor-enhanced "white" LEDs may also be used in some of these instances as illuminators.

IR emitting LEDs are being used for remote control and communication in such devices as VCR, TV, CD, and other audio-visual remote control units. Similarly, high intensity IR-emitting LEDs are being used for communication between IRDA devices such as desktop, laptop and palmtop computers; PDAs (personal digital assistants); and computer peripherals such as printers, network adapters, pointing devices ("mice," trackballs, etc.), keyboards, and other computers. IR LED emitters and IR receivers also serve as sensors for proximity or presence in industrial control systems, for location or orientation within such opto-electronic devices such as pointing devices and optical encoders, and as read heads in such systems as barcode scanners. IR LED emitters may also be used in a night vision system for automobiles.

Blue, violet, and UV emitting LEDs and LED lasers are being used extensively for data storage and retrieval applications such as reading and writing to high-density optical storage disks.

Performance and reliability of LED components, chips, and systems are heavily influenced by the thermal performance of those components, chips, and systems, and by ambient temperature. Elevated operating temperatures simultaneously reduce the emission efficiency of LEDs and increase the probability of failure in most conditions. This elevated temperature may be the result of high system thermal resistance acting in concert with internal LED power dissipation and may also be the result of high ambient operating temperature or other influence. Regardless of the cause, LED efficiency and reliability are normal adversely affected by increases in temperature. Thus, it is advantageous to minimize temperature rise of LED components, chips, and systems attributable to internal power dissipation during operation. This can be accomplished by reducing the conductive, convective, and radiative thermal resistance between the LED chip and ambient environment, such as by optimizing the materials and construction of the packaged device containing the LED chip. These methods, as applicable to mass-solderable, auto-insertable, and other discrete LED components, are disclosed in commonly assigned U.S. Pat. No. 6,335,548, entitled "SEMICONDUCTOR RADIATION EMITTER PACKAGE," filed on Oct. 22, 1999, by John K. Roberts et al., and published PCT International Publication No. WO 00/55914.

For high power LED systems and high power density LED systems, system thermal performance is especially critical. LED illuminators and high power signal lights generating more than ten lumens (or more than one watt of power dissipation) are examples of systems which can benefit from improved thermal performance, especially if package area/volume must be minimized (increasing power density).

To limit the operational temperature of the LED, the power that is allowed to be dissipated through the LED is typically

limited. To limit the dissipated power, however, the current that may be passed through the LED must be limited, which in turn limits the emitted flux of the LED since the emitted flux is typically proportional to the electrical current passed through the LED.

Other fundamental properties of LEDs place further restrictions on the useful operational temperature change  $\Delta T$ . Semiconductor LEDs, including IR, visible, and UV emitters, emit light via the physical mechanism of electro-luminescence. Their emission is characteristic of the band gap of the materials from which they are composed and their quantum efficiency varies inversely with their internal temperature. An increase in LED chip temperature results in a corresponding decrease in their emission efficiency. This effect is quite significant for all common types of LEDs for visible, UV, and IR emission. Commonly, a 1° C. increase ( $\Delta T$ ) in chip temperature typically results in up to a 1 percent reduction in useful radiation and up to a 0.1 nm shift in the peak wavelength of the emission, assuming operation at a constant power. Thus, a  $\Delta T$  of 40° C. can result in up to a 40 percent reduction in emitted flux and a 4 nm shift in peak wavelength.

From the preceding discussion, it can be seen that to avoid thermal damage and achieve optimal LED emission performance, it is very important to minimize the  $\Delta T$  experienced by the LED device chip and package during operation. This may be achieved by limiting power or reducing thermal resistance.

Limiting LED power, of course, is antithetical to the purpose of high power LEDs, i.e., to produce more useful radiation. Generating higher flux with an LED generally requires higher current (and therefore higher power). Most prior art devices, however, exhibit relatively high thermal resistance from their semiconductor radiation emitter to ambient and are compelled to limit power dissipation in order to avoid internal damage. Thus, the best 5 mm T-1 $\frac{3}{4}$  THD packages are limited to about 110 mW continuous power dissipation at 25° C. ambient temperature.

An additional problem faced by designers of conventional LED devices is that the wire bond used to join one of the LED leads to the LED chip can break or lose contact with the lead or the chip. Such failure can occur, for example, due to shear forces that are transferred to the wire bond through the encapsulant or thermal expansion/contraction of the encapsulant around the wire bond.

The other forms of radiation emitters mentioned above also experience performance degradation, damage, increased failure probability or accelerated decay if exposed to excessive operating temperatures.

Consequently, it is desirable to provide a radiation emitter device that has a higher emission output than conventional LED devices while being less susceptible to failure due to a break in the wire bond contact or other defect that may be caused by excessive operating temperatures.

Similar heat dissipation problems exist with respect to other electronic components. For example, large heat sinks are often attached to microprocessors of the type used in personal computers. Accordingly, an improved heat dissipation package for such electronic components is desirable.

### SUMMARY OF THE INVENTION

It is an aspect of the present invention to provide a relatively high power and high power density radiation emitter device capable of high radiant flux and/or luminous flux emission. It is a further aspect of the present invention to provide a radiation emitter device exhibiting relatively low temperature rise due to internal power dissipation and

increased reliability by virtue of relatively low thermal resistance. To achieve these and other aspects and advantages in accordance with one embodiment of the present invention, the radiation emitting device of the present invention comprises a sealed chamber; one or more liquids or gels contained in the sealed chamber; an electroluminescent emitter that emits optical radiation in response to an electrical signal, the electroluminescent emitter is disposed in the sealed chamber in physical and thermal contact with one of the liquids or gels; and first and second electrical conductors electrically coupled to the electroluminescent emitter for energizing the electroluminescent emitter. A portion of the structure defining the sealed chamber may be partially transparent to allow the radiation to enter or exit.

It is another aspect of the present invention to provide a package for electronic components having improved heat dissipation characteristics. To achieve these and other aspects and advantages, the electronic component package comprises first and second substrates sealed together and spaced apart to define a sealed chamber, one or more liquids or gels contained in the sealed chamber, and at least one electronic component disposed in the sealed chamber and thermal contact with one of the liquids or gels. According to one embodiment, the at least one electronic component includes a semiconductor electronic component. According to another embodiment of the invention, the first substrate is a printed circuit board.

According to another embodiment, an optical radiation emitting device comprises: a sealed chamber; a fluid intermediary material contained in the sealed chamber and having a refractive index greater than 1.0; an electroluminescent emitter that emits optical radiation in response to an electrical signal, the electroluminescent emitter disposed in the sealed chamber in physical and thermal contact with the fluid intermediary material; and first and second electrical conductors electrically coupled to the electroluminescent emitter for energizing the electroluminescent emitter.

According to another embodiment, an optical radiation emitting device comprises: a semiconductor radiation emitter that emits optical radiation in response to an electrical signal; a protective barrier for protecting the semiconductor radiation emitter, the protective barrier comprises a material that substantially maintains its in-band optical properties over time; and first and second electrical conductors electrically coupled to the semiconductor radiation emitter for energizing the semiconductor radiation emitter.

These and other features, advantages, and objects of the present invention will be further understood and appreciated by those skilled in the art by reference to the following specification, claims, and appended drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a top elevational view of a radiation emitting device constructed in accordance with a first embodiment of the present invention;

FIG. 2 is a perspective view of the radiation emitting device of the first embodiment of the present invention;

FIG. 3A is a cross-sectional view taken along line 3-3' of the radiation emitting device shown in FIG. 1;

FIG. 3B is a cross-sectional view of an alternative embodiment of the device shown in FIG. 1;

FIG. 3C is a cross-sectional view of an alternative embodiment of the device shown in FIG. 1;

FIG. 4 is a cross-sectional view of a radiation emitter device constructed in accordance with a second embodiment of the present invention;

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FIG. 5 is a cross-sectional view of a radiation emitter device constructed in accordance with a third embodiment of the present invention;

FIG. 6A is a cross-sectional view of a radiation emitter device constructed in accordance with a first variation of a fourth embodiment of the present invention;

FIG. 6B is a cross-sectional view of a radiation emitter device constructed in accordance with a second variation of a fourth embodiment of the present invention;

FIG. 7 is a top view of a radiation emitter device constructed in accordance with a fifth embodiment of the present invention;

FIG. 8 is a perspective view of a vehicle headlamp assembly constructed in accordance with the present invention;

FIG. 9 is a schematic diagram of an electrical circuit that may be provided in one or more of the above embodiments;

FIG. 10 is a top view of an initial package subassembly in accordance with a sixth embodiment of the present invention;

FIG. 11 is a top view of a finished package assembly constructed in accordance with the sixth embodiment of the present invention;

FIG. 12 is a graph illustrating the illuminance as a function of power for the package assembly shown in FIG. 11 with the chamber filled with liquid and with the sealed chamber not filled with any liquid;

FIG. 13 is a graph of the relative spectral irradiance as a function of wavelength obtained for the package assembly shown in FIG. 11 with the chamber not filled with any liquid for various power levels;

FIG. 14 is a graph of the relative spectral irradiance as a function of wavelength obtained for the package assembly shown in FIG. 11 with the chamber filled with liquid for various power levels;

FIG. 15 is a cross-sectional view of an alternative embodiment of the device shown in FIG. 1;

FIG. 16 is a plan view of a subassembly of the device shown in FIG. 15;

FIG. 17A is a cross-sectional view of an alternative embodiment of the device shown in FIG. 1;

FIG. 17B is a cross-sectional view of an alternative embodiment of the device shown in FIG. 1; and

FIG. 18 is a cross-sectional view of an electronic component package assembly constructed in accordance with an alternate embodiment of the present invention.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the present preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numerals will be used throughout the drawings to refer to the same or like parts.

For purposes of description herein, the terms "upper," "lower," "right," "left," "rear," "front," "vertical," "horizontal," "top," "bottom," and derivatives thereof shall relate to the invention as viewed by a person looking directly at the radiation emitting source along the principal optical axis of the source. However, it is to be understood that the invention may assume various alternative orientations, except where expressly specified to the contrary. It is also to be understood that the specific device illustrated in the attached drawings and described in the following specification is simply an exemplary embodiment of the inventive concepts defined in the appended claims. Hence, specific dimensions, proportions, and other physical characteristics relating to the

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embodiment disclosed herein are not to be considered as limiting, unless the claims expressly state otherwise.

Several embodiments of the present invention generally relate to an improved optical radiation-emitting device useful in both high and low power applications. Such embodiments of the present invention are particularly well suited for use in limited power applications such as vehicles, portable lamps, and specialty lighting. By vehicles, we mean over-land vehicles, watercraft, aircraft and manned spacecraft, including but not limited to automobiles, trucks, vans, buses, recreational vehicles (RVs), bicycles, motorcycles and mopeds, motorized carts, electric cars, electric carts, electric bicycles, ships, boats, hovercraft, submarines, airplanes, helicopters, space stations, shuttlecraft and the like. By portable lamps, we mean camping lanterns, head or helmet-mounted lamps such as for mining, mountaineering, and spelunking, hand-held flashlights and the like. By specialty lighting we mean emergency lighting activated during power failures, fires or smoke accumulations in buildings, microscope stage illuminators, billboard front-lighting, backlighting for signs, etc. The light emitting assembly of the present invention may be used as either an illuminator or an indicator. Examples of some of the applications in which the present invention may be utilized are disclosed in commonly assigned PCT International Publication No. WO 00/55685 entitled "INDICATORS AND ILLUMINATORS USING A SEMICONDUCTOR RADIATION EMITTER PACKAGE," by John K. Roberts et al.

Some of the embodiments of the present invention provide a highly reliable, low-voltage, long-lived, light source for vehicles, portable lighting, and specialty lighting capable of producing white light with sufficient luminous intensity to illuminate subjects of interest well enough to be seen and to have sufficient apparent color and contrast so as to be readily identifiable. Several of the radiation emitter devices of the present invention may be well suited for use with AC or DC power sources, pulse-width modulated DC power sources, and electronic control systems. The radiation emitting devices of the present invention may further be used to emit light of various colors and/or to emit non-visible radiation such as IR and UV radiation.

As used herein, the terms "radiation emitter" and "radiation emitting device" shall include any structure that generates and emits optical or non-optical radiation, while the term "optical radiation emitter" or "optical radiation emitting device" includes those radiation emitters that emit optical radiation, which includes visible light, near infrared (IR) radiation, and/or ultraviolet (UV) radiation. As noted above, optical radiation emitters may include electroluminescent sources or other solid-state sources and/or photoluminescent or other sources. One form of electroluminescent source includes semiconductor optical radiation emitters. For purposes of the present invention, "semiconductor optical radiation emitters" comprise any semiconductor component or material that emits electromagnetic radiation having a wavelength between 100 nm and 2000 nm by the physical mechanism of electroluminescence, upon passage of electrical current through the component or material. The principal function of a semiconductor optical radiation emitter within the present invention is the conversion of conducted electrical power to radiated optical power. A semiconductor optical radiation emitter may include a typical IR, visible or UV LED chip or die well known in the art and used in a wide variety of prior art devices, or it may include any alternate form of semiconductor optical radiation emitter as described below.

Alternate forms of semiconductor optical radiation emitters which may be used in the present invention are light

emitting polymers (LEPs), polymer light emitting diodes (PLEDs), organic light emitting diodes (OLEDs) and the like. Such materials and optoelectronic structures made from them are electrically similar to traditional inorganic LEDs, but rely on organic compositions such as derivatives of the conductive polymer polyaniline for electroluminescence. Such semiconductor optical radiation emitters are relatively new, but may be obtained from sources such as Cambridge Display Technology, Ltd. of Cambridge, Mass., and from Uniax of Santa Barbara, Calif.

For brevity, the term "semiconductor optical radiation emitter" may be substituted with the term "LED" or the alternate forms of emitters described above or known in the art. Examples of emitters suitable for the present invention include varieties of LED chips with associated conductive pads for electrical attachment and that are emissive principally at P-N or N-P junctions within doped inorganic compounds of AlGaAs, AlInGaP, GaAs, GaP, InGaN, AlInGaN, GaN, SiC, ZnSe and the like.

LEDs are a preferred electroluminescent light source for use in the radiation emitting devices of the present invention because LEDs do not suffer appreciable reliability or field-service life degradation when mechanically or electronically switched on and off for millions of cycles. The luminous intensity and illuminance from LEDs closely approximates a linear response function with respect to applied electrical current over a broad range of conditions, making control of their intensity a relatively simple matter. Finally, recent generations of AlInGaP, AlGaAs, InGaN, AlInGaN, and GaN LEDs draw less electrical power per lumen or candela of visible light produced than incandescent lamps, resulting in more cost-effective, compact, and lightweight illuminator wiring harnesses, fuses, connectors, batteries, generators, alternators, switches, electronic controls, and optics. Many examples have previously been mentioned and are incorporated within the scope of the present invention, although it should be recognized that the present invention has other obvious applications beyond the specific ones mentioned which do not deviate appreciably from the teachings herein and therefore are included in the scope of this invention.

Another preferred radiation source that may be used in the inventive light emitting assembly is a photoluminescent source. Photoluminescent sources produce visible light by partially absorbing visible or invisible radiation and re-emitting visible radiation. Photoluminescent sources typically include phosphorescent and/or fluorescent materials, which include fluorescent dyes, pigments, crystals, substrates, coatings, as well as phosphors. Such a fluorescent or phosphorescent material may be excited by an LED or other radiation emitter and may be disposed within or on the LED, or within or on a separate optical element, such as a lens or diffuser that is not integral with an LED. Exemplary structures using a fluorescent or phosphorescent source are described further below.

As explained in more detail below, the present invention exhibits a significantly lower thermal resistance than conventional LED structures by extracting heat from the LED chip(s) via all of the surfaces of the LED chip(s) simultaneously instead of from primarily only one surface as in typical prior art LED devices. More specifically, the radiation emitter package of the present invention provides a sealed chamber or cavity containing a liquid or gel surrounding the LED chips, the liquid or gel having a moderate to high thermal conductivity, a moderate to high convectivity, or both. A material that is "moderate to highly convective" is a material that is more effectively convective than either air or a conventional clear solid polymer such as epoxy or silicone. "Effectively convective"

means transporting substantial proportions of heat dissipated from a source by natural convection. The LED chips may be mounted to a moderate to high thermal conductivity plate to which a transparent plate is sealed in spaced-apart relation to define the sealed chamber or cavity. This combination is uniquely effective because heat is removed from large surfaces of the chip by conduction and by convective transport due to the natural convection of the liquid in the sealed chamber or cavity. Embodiments of the present invention are discussed below in connection with FIGS. 1-18. It will be appreciated that these embodiments are provided for purposes of illustration only and are not limiting to the present invention.

FIGS. 1-3 show a radiation emitter device **10** constructed in accordance with a first embodiment of the present invention. Device **10** includes one or more radiation emitting sources **12**, which are shown in FIG. 1 mounted to a first substrate **14**. Although radiation emitters **12** are preferably LED chips or dies, other forms of radiation emitters may be used. The LED chips may be any conventional LED chip including those with vertical and lateral structure, transparent or absorbing substrate, electrically conductive or insulating substrate, tapered sides, Truncated Inverted Pyramid (TIP) construction, partial TIP construction, or flip chip, or other chip geometry, including LED chips utilizing AlGaAs, AlInGaP, GaAs, GaP, InGaN, AlInGaN, GaN, SiC, ZnSe and other inorganic compound semiconductor materials. The anode can be on the topmost surface of the chip, normally used for wirebond, and the cathode may be on the bottom of the chip, normally connected with die attach adhesive, solder or eutectic bonding. As with some InGaN/SiC LED chips, this polarity may be reversed such that the cathode is at the top side, normally used for wirebond and the anode is at the bottom, normally connected with die attach adhesive, solder or eutectic bonding. Alternately, both anode and cathode may be top side of the chip as in a lateral-type InGaN/sapphire LED chip structure, normally connected by wirebonding. Both contacts may also be at the bottom side of the chip in flip-chip configuration, and normally attached with solder or die attach adhesive. LED chips suitable for use in the present invention included are available from sources such as Cree, AXTI, UOE, LumiLEDs and UEC and others. For purposes of this first embodiment, first substrate **14** may be made of any electrically conductive material, and preferably a material that has relatively high thermal conductivity. Preferably, first substrate **14** has a thickness of 0.5 to 6.1 mm and is made of copper or aluminum. As described below with respect to other embodiments, the first substrate may alternately be made of electrically nonconductive material (such as a ceramic, PC board, passivated metal clad board, etc.). The first substrate may also comprise all or a portion of or surface of an external cooling structure such as a heat sink or thermoelectric cooler. An optional submount made of silicon, silicon carbide, metal or other like materials may be mounted between emitters **12** and first substrate **14** to facilitate distribution of electrical power or to moderate the physical properties of the emitters and the first substrate.

Radiation emitter assembly **10** further includes a second substrate **16** serving as a protective barrier that is spaced apart from first substrate **14**. At least a portion of second substrate **16** through which radiation is emitted from radiation emitters **12** is substantially transparent to some or all of the wavelengths of radiation emitted from emitters **12**. Alternatively, all of second substrate **16** may be transparent to the radiation emitted from radiation emitters **12** or alternatively transparent to all visible, IR, and/or UV radiation. For example, second substrate **16** may be made of a 0.5 to 6.1 mm glass cover plate.

For some embodiments, this glass may be conventional soda-lime float glass, and in others it may be fused silica glass, borosilicate float glass or other glass composition. Second substrate **16** may also be made of tempered glass, an epoxy sheet, or transparent plastics that are aliphatic or olefinic in nature (e.g., polypropylene, polyethylene, dicyclopentadienes and polymethylpentenes). Such transparent aliphatic or olefinic plastics do not degrade when exposed to aprotic solvents such as propylene carbonate, which is one possible liquid that may be used in the present invention. These transparent plastics also function well in solid-state systems that include pure solution-phase and partial solution-phase electrolytes. These transparent plastics include: cyclic olefin copolymers such as TOPAS® available from Ticona, LLC of Summit, N.J.; polymethylpentenes such as TPX™ manufactured by Mitsui; hydrogenated cyclo-olefin polymers such as ZEONEX® (based on dicyclopentadiene) manufactured by Nippon Zeon Company; and amorphous cyclo-olefin copolymers such as APEL™ manufactured by Mitsui. Another suitable polymer for the second substrate is polysulfone. Second substrate **16** should maintain its “in-band” optical properties over an extended period of time. The term “in-band” optical properties shall mean those optical properties that affect or substantially influence radiation at wavelengths emitted by the radiation emitters within the assembly. Specifically, it should maintain an absence of optical absorption (particularly, at the wavelength emitted by radiation sources within the assembly), be resistant to hazing and scattering, and be resistant to reactions that cause it to turn yellow or other color over time in such a manner as to unintentionally absorb significant portions of radiation emitted by light sources within the assembly. In many embodiments, second substrate **16** should be resistant to degradation upon prolonged, repeated or intense exposure to short-wavelength radiation such as blue, violet or UV light or upon exposure to ambient heat, heat from processing the assembly or from internal heat generated by operating the assembly. For embodiments of the present invention containing emitters of blue-green, blue, violet or UV light, it may be especially important for the second substrate **16** to start and remain substantially transparent in the short wavelength bands emitted, avoiding the yellowing phenomena typical of some transparent polymer materials, and thus avoiding excessive tendencies toward increased absorption of radiation produced by those emitters. Second substrate **16** may also be treated with a coating (not shown), such as an anti-reflection coating, a barrier coating or other thin-film coating, on one or more of its surfaces. Such a coating may be employed, for example, to enhance extraction efficiency for optical radiation emitted by sources within the chamber **21** and exiting through surfaces of second substrate **16**. Another coating may be used to prevent permeation of oxygen, water vapor or other agents through second substrate **16** into the chamber **21**, to prevent impurities from leaching out of second substrate **16** into liquid **20**, or to prevent portions of liquid **20** from permeating into or reacting with second substrate **16**.

Second substrate **16** is generally semi-rigid to rigid; however, it may be advantageous in some embodiments for second substrate **16** to be made substantially flexible. By making second substrate **16** flexible, it may be possible to accommodate bulk thermal expansion of liquid **20** as may occur during prolonged operation of the assembly at high power levels, or during operation in environments having an ambient temperature greater than that prevailing during the manufacture of the assembly. Such flexibility may be accomplished by utilizing thinner sheets of transparent material for construction of second substrate **16** or by choosing more flexible

materials to begin with. Alternately, second substrate **16** may be made flexible by increasing the area of the chamber **21** in such a way that portions of second substrate **16** are disposed at a considerable distance from retaining forces applied by seal **18** (or by other mechanisms in the vicinity of seal **18**).

As shown in FIGS. 1-3, assembly **10** further includes a seal (or gasket) **18** extending between first and second substrates **14** and **16** so as to define a closed region therebetween that is hereinafter referred to as a “sealed chamber.” As used herein, the term “chamber” may include a cavity or similar structure. The seal or gasket **18** is preferably made of epoxy, butyl rubber, a frit of metallic and/or glassy composition, ceramic, metal alloys such as solder, or other relatively inert barrier material. Within the sealed chamber is a liquid, gel, or other material that is either moderate to highly thermally conductive, moderate to highly convective, or both. As used herein, a “gel” is a medium having a solid structure and a liquid permeating the solid structure. Because a gel includes a liquid, the term “liquid” is used hereinafter to refer to liquids contained in gels as well as non-gelled liquids.

The liquid **20** is disposed within the sealed chamber **21** so as to surround each of the LED chips **12** used in the device. Enough liquid **20** may be disposed within the sealed chamber **21** such that the sealed chamber **21** is effectively filled. Alternately, the volume of liquid **20** used may be less than the volume of the sealed chamber **21** such that a portion of the sealed chamber **21** remains occupied by a bubble of air, gas or vacuum (not shown). Such an unfilled portion of the chamber **21** may be useful for accommodating thermal expansion of the liquid **20** or as a visual indication that the remainder of the chamber **21** is filled. More than one type of liquid **20** may also be used within the same sealed chamber **21** such that more than one zone is defined (not shown), and occupied by such liquids if they are not miscible. Such a configuration may be useful if different physical, optical or chemical properties are desired for the liquid **20** present in different portions of the chamber **21**. Liquid **20** is preferably, but not necessarily, electrically nonconductive. The materials utilized for substrates **14** and **16**, seal **18**, and LED chips **12** preferably are selected such that they do not react or otherwise ionize the liquid **20** so as to cause the liquid to become significantly electrically conductive. High electrical conductivity of liquid **20** could create a short circuit across the LED chips **12** depending upon how they are disposed in the sealed chamber **21**. Preferably, liquid **20** has low to moderate thermal expansion, or a thermal expansion that substantially matches that of first substrate **14**, second substrate **16**, or seal **18**, and in some embodiments, a slightly higher thermal expansion may be desired to increase convection while in other embodiments, a low coefficient of thermal expansion may be desired to minimize stress on the optional die attach (not shown), optional solder bumps (**25**) and seal **18**. Liquid **20** is also preferably inert and does not readily decompose or otherwise react with external agents that manage to enter the sealed chamber **21** over time or with impurities contained within the sealed chamber **21** from the time of manufacture. Liquid **20** should also maintain its optical properties over time. Specifically, it should be resistant to reactions that cause the liquid to turn yellow or other color over time in such a manner as to unintentionally absorb significant portions of radiation emitted by light sources within the assembly. For applications where the assembly will be exposed to short wavelength radiation such as UV, violet, blue or blue-green optical radiation from the ambient environment or from emitters within the assembly, liquid **20** should be resistant to degradation upon prolonged, repeated or intense exposure to such radiation. For embodiments of the present invention containing emitters of blue-

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green, blue, violet or UV light, it may be especially important for the liquid 20 to remain substantially colorless, avoiding excessive tendencies toward increased absorption of radiation produced by those emitters. Liquid 20 should also be compatible with the seal material. The liquid should also be substantially transparent to some or all of the wavelengths of radiation emitted from the radiation emitters 12. It will be appreciated, however, that liquids may be selected or dyes may be utilized to selectively filter the radiation emitted from the radiation emitters 12. Liquid 20 also preferably has an index of refraction between that of the radiation emitters 12 and the glass or otherwise has an index that approximately matches one of the emitters or the glass. Another benefit that may result from providing liquid 20 in contact with emitters 12 and any optional wire bond is that the liquid provides viscous damping of any vibration of the wire bond. Additionally, liquid 20 (also referred to herein as an intermediary material that is disposed between the emitter(s) and the second substrate or protective barrier) may provide increased optical extraction efficiency by minimizing internal reflection within the device. In this respect, it should be noted that most LED chip materials possess high refractive indices, such that greater light extraction losses occur by total internal reflection and internal absorption when such chips are surrounded by media with very low refractive indices. Air or other atmospheric gasses typically have a refractive index near 1.0 such that a configuration involving juxtaposition of LED chips directly against air leads to poor optical coupling. For this reason, liquid 20 is selected to have a relatively higher refractive index, consistent with other functional requirements. The refractive index of liquid 20 at the emission wavelength of sources within the assembly is generally higher than about 1.3, but is more preferably higher than 1.4 and in some cases may be higher than 1.5. With the addition of small-particle fillers or other additives, liquid 20 may become a suspension or solution with an effective refractive index as high as 2.5. Such additives may include inorganic fillers or organic materials, including nanoparticles, doped nanocrystals, or conventional phosphors. Certain types of optical fluids, such as oils, may also be available with or without such fillers or additives and having elevated refractive indices greater than 1.4 and as high as 3.0. Liquid 20 may be propylene carbonate or another liquid or gel having one or more of the above-described properties. One commercially available liquid that may be used is Galden® D02TS available from Montedison S.P.A. of Milan, Italy.

The liquid 20 may be dispensed within the sealed chamber 21 by vacuum back-filling or other conventional techniques such as those used to dispense an electrochromic solution between two glass substrates when making an electrochromic mirror or window. One or more fill holes may be provided in either the seal or in one or both of the substrates. After the sealed chamber 21 is filled with liquid 20, the hole(s) may be plugged with a UV-curable or other plug material.

In the embodiment shown in FIGS. 1-3, the substrates are approximately one inch by one and one quarter inch rectangles. The size of the substrates may, however, be much bigger and be as large as an architectural window or the like, or may be smaller depending on the application. Preferably, the volume of liquid in the sealed chamber 21 defined by the seal and the two substrates is more than about 20 times greater than the volume of the radiation emitters to ensure sufficient heat transport. In some embodiments, it may be possible to reduce this volume as low as 2 times the volume of the radiation emitters. Although substrates 14 and 16 are depicted in FIGS. 1 and 2 as being rectangular, it will be appreciated that the substrates may have virtually any shape. Square,

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circular, hexagonal and octagonal shapes may be desirable in specific applications. Seal 18 need not be formed in the same shape as that of the substrates. Seal 18 serves to bond the two substrates together and form sides of the sealed chamber 21 in which liquid 20 is contained. Seal 18 should also serve as an environmental barrier so as to impede diffusion of water, oxygen, and other substances into the sealed chamber 21 while also impeding liquid 20 from exiting the sealed chamber 21. Seal 18 may also function as a spacer for maintaining the separation distance of substrates 14 and 16. Spacers (not shown) in the form of pillars, glass beads, etc. disposed between the substrates may be used as the sole means for maintaining the separation distance of substrates 14 and 16 or as a supplement to the spacing function served by the seal. The radiation emitters or other electrical components in the sealed chamber 21 (described further below) may also provide this spacing function.

To enable electrical current to flow to and through any electroluminescent radiation emitters 12 that may be present in the sealed chamber 21, electrical conductors are provided that are electrically coupled to emitters 12 and extend out from the sealed chamber 21. When an electrically conductive first substrate 14 is utilized, the negative or positive terminal of the emitters 12 may be directly mounted to first substrate 14 while the other of the terminal of emitters 12 may be soldered (note solder bumps 25) or otherwise electrically connected to a conductor 22 provided on the bottom inner surface of second substrate 16. Conductor 22 may be made of metal or made of indium tin oxide (ITO), which is a common transparent conductor. With such a configuration, the spacing between first substrate 14 and second substrate 16 would be approximately equal to the thickness of emitters 12, which is typically on the order of 0.012 inch, but may be as low as 0.001 inch or as high as 0.500 inch. In this embodiment, partial conductivity of liquid 20 may supplement or serve as the replacement for solder bumps 25 at the top of the emitters 12 making electrical connection to conductor(s) 22 on second substrate 16.

As shown in FIG. 2, electrical leads 26 and 30 may be coupled to electrical conductor 22 and first substrate 14 by respective conductive clips 24 and 28. Such clips may have a construction similar to those utilized in electrochromic devices. An example of suitable clips is disclosed in U.S. Pat. No. 6,064,509 entitled "CLIP FOR USE WITH TRANSPARENT CONDUCTIVE ELECTRODES IN ELECTROCHROMIC DEVICES" filed on Aug. 22, 1997, by William L. Tonar et al. Additionally, two pairs of lead posts 31 may extend from opposite ends of clips 24 and 28 so as to function as leads 26 and 30. Such lead posts would allow the package to be mounted to through-holes in a printed circuit board.

While first substrate 14 is shown as a flat plate, it will be appreciated by those skilled in the art that substrate 14 may include recesses, protrusions, fins, etc. to increase the exterior surface area and maximize its effectiveness as a heat sink. For example, a heat sink such as that currently employed on Pentium® or Athlon® CPU chips may be used. Additionally or alternatively, a fan, forced convection system, or Peltier-type cooling system may be used to increase the dissipation of heat from the assembly. For example, a Peltier-type cooling structure may be used optionally comprising a Peltier cooler 33, heat sink 35, and/or fan 37 attached to the backside of first substrate 14, as shown in FIG. 3B, or otherwise made integral with first substrate 14. Other thermoelectric cooling materials, structures or means may also be substituted for the Peltier cooling structure in this configuration. As described further below, at least one electrical component 31 may be provided in the sealed chamber 21 along with emitter(s) 12.

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Furthermore, substrate **14** may include cup-shaped recesses on its upper surface with one such recess for each radiation emitter **12** provided in the device. Provided substrate **14** has a reflective upper surface, such recessed cups would serve to redirect light emitted from the sides of the emitters in a forward direction through second substrate **16**. Alternatively, if substrate **14** is not otherwise reflective, the top surface may be coated with a reflective material, particularly within such recessed cups, or a reflective pad may be located under the emitters. Such a reflective pad may be the electrical conductor, when a nonconductive first substrate is employed.

Similarly, second substrate **16** need not have a flat upper or lower surface. Substrate **16** may include integral microlenses, diffusers, or the like. Additionally, graphic masks, appliques, or color filters may be applied to, or made integral with, one or more of the surfaces of second substrate **16**. For example, an applique may be applied that allows light emitted from the emitters to be transmitted through letters of a sign, such as an exit sign. In this manner a high brightness, back-lit display panel may be provided. The panel may be static (e.g., facia, applique, screen-printed mask, etc.) or dynamic (e.g., a liquid crystal display (LCD) panel). When an LCD panel is used as second substrate **16**, or otherwise attached to or mounted proximate substrate **16**, it is preferred, but not essential, that the radiation emitting device include red, green, and blue (RGB) LEDs or alternatively binary complementary white emission source combination or an InGaN LED/fluorescent white emitting source combination, to enable a dynamic full-color display.

As illustrated in the drawing figures, the radiation emitting assembly may include one or more emitters **12**. Radiation emitters **12** may emit light within the same wavelength bands or may emit light in different wavelength bands. For example, one or more LEDs may emit IR or UV radiation, while the others emit visible radiation. As another example, the radiation emitters may emit light of complementary colors such that the light emitted from radiation emitters **12** overlaps and forms white light or light of a color that is not otherwise emitted from any of the radiation emitters individually. To produce white light or almost any other color of illumination, three radiation emitters may be used with one emitting red light, another emitting blue light, and the third emitting green light. Alternatively, two radiation emitters may be used that emit binary complementary colors to produce effective white light in the manner disclosed in commonly assigned U.S. Pat. No. 5,803,579, entitled "ILLUMINATOR ASSEMBLY INCORPORATING LIGHT EMITTING DIODES," by Robert R. Turnbull et al.

When more than one radiation emitters **12** that are electroluminescent are utilized in the inventive device, separate conductive leads may be provided to each electroluminescent emitter **12** so that the emitters may be independently activated and their intensities independently controlled. For example, rather than utilizing a single transparent conductive layer **22** across the entire surface of second substrate **16** in the embodiment shown in FIGS. 1-3, the transparent conductive layer **22** may be etched or otherwise patterned so as to provide discrete connections to the top, normally positive, terminals of emitters **12**. Such an example is shown in FIG. 3C where the conductive layer is patterned to form two discrete connections **22a** and **22b**. In this case, two separate and smaller clips (not shown) may be used in place of clip **24** (FIG. 2). Conversely, if first substrate **14** is made of an electrically nonconductive material, as in the embodiments described below and shown in FIGS. 4, 5, 6A, 6B, 10, 11, and 18, separate elec-

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trically conductive traces may be formed on the first substrate to provide discrete connections to the positive and/or negative terminals of emitters **12**.

In the event it is desired to have the inventive radiation device emit white light or other colored light with a hue differing from that of light emitted by enclosed electroluminescent emitters **12**, it may be desirable to incorporate a photoluminescent radiation source such as a phosphorescent or fluorescent material into substrate **16** or in a layer on substrate **16**. Alternatively, a photoluminescent source may be applied as one or more blobs over an electroluminescent emitter **12**, or may be dissolved or suspended in liquid **20**. Photoluminescent sources could be used to enable the assembly to emit substantially white light when the photoluminescent source is irradiated by the radiation emitted from electroluminescent emitters **12**. Photoluminescent sources could also be used to generate green, blue-green, amber, orange, or red light when irradiated by UV, violet, or blue emitting electroluminescent emitters **12**. An example of the use of photoluminescent sources in this manner is disclosed in commonly assigned U.S. patent application Ser. No. 09/723,675, entitled "LIGHT EMITTING ASSEMBLY," and filed on Nov. 28, 2000 by John K. Roberts et al., now abandoned.

A photoluminescent source may additionally or alternatively be dispersed, dissolved, or suspended in liquid **20**. The convection of liquid **20** may tend to keep the photoluminescent material in suspension or in solution. Such dispersal of photoluminescent media within the liquid **20** may also help maintain uniformity of color and/or luminance of the device and may help limit degradation of the photoluminescent media with long term use.

While liquid **20** has been described above as preferably being electrically nonconductive, liquid **20** may nevertheless be conductive provided that the resistance of liquid **20** is greater than that between the negative and positive terminals of the radiation emitters **12** in the chamber **21** and that the resistive path through the liquid between the electrical conductors is much greater than the resistive path through the liquid between each electrical conductor and the negative or positive terminals to which it is respectively coupled. Conceivably, by using a conductive liquid, the need for a wire bond or solder may be eliminated by allowing current to flow to an electroluminescent emitter **12** from first substrate **14** or second substrate **16** via a thin portion of liquid **20**.

Additionally, additives such as anti-oxidants or UV stabilizers may be added to liquid **20** to improve system life. Electrolytes can be carefully added in small quantities to establish any optional electrical conductivity desired.

FIG. 4 shows a radiation emitting device **40** constructed in accordance with a second embodiment of the present invention. As shown, radiation emitting device **40** includes an electrically nonconductive first substrate **32**, a second substrate **16**, and a seal **18** disposed between the two substrates to define a sealed chamber **21** in which a liquid or gel **20** is contained. Device **40** further includes a first electrical trace **34** and a second electrical trace **36** provided on the upper surface of first substrate **32**. As shown in FIG. 4, two radiation emitters **12** are mounted on first electrical trace **34** with their cathodes in electrical contact with trace **34**. Trace **34** extends outward from the sealed chamber **21** so as to enable electrical contact with an external device. Second trace **36** also extends from within the sealed chamber and is electrically coupled to wire bonds **38** that are coupled to the negative or positive terminals of radiation emitters **12**. As suggested above, both radiation emitters **12** may share common electrical traces or may have discrete traces for allowing for independent activation and control.

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First substrate **32** may be made of alumina or other ceramic substrate, such as beryllia ceramic, passivated metals, metal clad or metal core printed circuit board, passivated, anodized, or laminated metal printed circuit board, or may be made of glass, an epoxy sheet, or an aliphatic or olefinic plastic such as those discussed above. If both the first and second substrates are made of plastic, it may be possible to configure and join the two substrates without requiring a seal or other spacers. Commonly assigned U.S. Pat. No. 6,193,379, entitled "ELECTROCHROMIC ASSEMBLY INCLUDING AT LEAST ONE POLYMERIC SUBSTRATE," filed on Jun. 9, 2000, discloses various plastic materials and structures for forming sealed chambers when used for containing an electrochromic medium. Such disclosed structures may be used in the light emitting assembly of the present invention.

Device **40** may further include a micro-groove lens **41**, which may be a Fresnel lens, a diffraction grating, total internal reflection (TIR) lens, catadioptric lens, kinoform lens, a holographic optical element (HOE), or other optical lens. Lens **41** may be integrally formed on either the inside or outside surface of second substrate **16** or may be optically coupled to second substrate **16**. A suitable micro-groove lens is disclosed in commonly assigned U.S. Pat. No. 6,670,207, issued Dec. 30, 2003, entitled "RADIATION EMITTER DEVICE HAVING AN INTEGRAL MICRO-GROOVE LENS."

FIG. **5** shows a radiation emitting device **50** constructed in accordance with a third embodiment of the present invention. Like device **40** of the second embodiment, device **50** utilizes an electrically nonconductive first substrate **32** that is spaced apart from a second substrate **16** by a seal **18** that forms a sealed chamber **21** in which a liquid or gel **20** is contained. Device **50** differs from device **40** in that a lateral-type LED **52** with two top-side electrode contacts is utilized. LED **52** may be directly mounted on substrate **32** within a gap formed between a first electrical trace **54** and a second electrical trace **56** that are provided on the upper surface of substrate **32**. As in the second embodiment, electrical traces **54** and **56** extend from within the sealed chamber **21** to the exterior of the device to allow for an electrical signal to be applied to LED chip **52** from the exterior of device **50**. First trace **54** is provided to be coupled to a first wire bond **58** that is coupled to the anode of LED chip **52**. Second trace **56** is provided for coupling to a second wire bond **60** that is coupled to the cathode of LED chip **52**.

Both the embodiments shown in FIGS. **4** and **5** utilize electrical trace wires that are bonded to one of the contact terminals of the radiation emitters. Preferably, the trace wires are flat ribbon wires having a rectangular cross section and are bonded to the contact terminal of the radiation emitter using a wedge bond. Such a wire and bond reduce the spacing needed to accommodate the radiation emitters between the substrates since they provide a lower profile bond than a conventional wire having a circular cross section that is bonded using a ball-shaped bond. However, in some embodiments, conventional circular bond wire may be used, and in other embodiments, none may be necessary.

FIGS. **6A** and **6B** show two variations of a fourth embodiment of the present invention whereby irregularly shaped substrates are used to form the sealed chamber **21**. Specifically, in FIG. **6A**, a structure is shown in which the back and at least part of the sides of the sealed chamber **21** are defined by an irregularly-shaped substrate **70**, which may be transparent, partially transparent or opaque, and may be made of metal or plastic. Substrate **70** includes an opening **71** that lies above radiation emitter(s) **12**. As illustrated, a window substrate **72** that is substantially transparent to the radiation emit-

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ted from radiation emitters **12** is secured to substrate **70** across opening **71**. A seal or gasket **74** may be disposed between window substrate **72** and irregularly-shaped substrate **70** to seal the chamber **21**.

In FIG. **6B**, a structure is shown in which an irregularly shaped transparent second substrate **75** is provided to define the front and at least a portion of the sides of the sealed chamber **21**. Second substrate **75** may be ultrasonically welded or otherwise bonded to first substrate **32** in order to seal the chamber **21**. As illustrated, second substrate has a dome-like shape and includes a peripheral shoulder **76** and rim **77** for engaging the edges of first substrate **32**. Electrical connections to radiation emitter(s) **12** may extend through vias formed in first substrate **32** that extend from an inner surface to an outer surface thereof. The chamber **21** may be filled with the second substrate inverted and prior to ultrasonic welding. Alternatively, a fill hole may be provided through first substrate so that the chamber may be filled after welding. A UV curable or other plug may then be used to seal the fill hole.

FIG. **7** shows a fifth embodiment of the present invention. In this fifth embodiment, a reflective mask **80** is provided on a surface of second substrate **16**. The reflective mask **80** includes a plurality of non-masked openings **82** above each radiation emitter **12**. Mask **80** may optionally include a small reflective spot **84** directly over each emitter **12** so as to prevent light from directly emitting from an emitter **12** through mask **80**. In this manner, emitters that emit light of different colors may be disposed within the chamber **21**, and the light emitted from the emitters will mix within the chamber **21** prior to being emitted from the assembly. Mask **80** may be a patterned reflective or diffuse coating or a filter and be made integral with patterned conductors if used. Patterns other than those shown may be used to optimize various optical qualities without departing from the scope of the invention.

FIGS. **15** and **16** show yet another embodiment of the present invention. As shown in the cross-sectional view of FIG. **15**, radiation emitted from emitters **12** is either nearly completely transmitted, partially transmitted and partially internally reflected, or nearly completely internally reflected from second substrate **16** depending upon the angle at which the radiation strikes the surfaces of second substrate **16**. Whether radiation (i.e., a light ray) is internally reflected depends upon whether the light ray strikes the surface at an angle that is greater than the critical angle as determined by application of Fresnel's equations and Snell's Laws. If the entire upper surface of first substrate **14** served as a specular reflector, those light rays **T** that are totally internally reflected from a surface of second substrate **16** would continue to be totally internally reflected from the upper surface of first substrate **14** and then again from the surfaces of second substrate **16**. To cause the light rays **T** that would otherwise be totally internally reflected to ultimately exit through the second substrate of the radiation emitting device, upper surface of first substrate **14** may have different reflective zones—namely, a specularly reflective zone **301** and a diffuse reflective zone **303**. As shown in FIGS. **15** and **16**, separate specularly reflective zones **301** are provided for each emitter **12** and are circular in shape with the associated emitter **12** disposed in the center of the circle. The remainder of the upper surface of first substrate **14** (with the exception of that area covered by electrical traces and contact terminals) constitutes the diffuse reflective zone **303**. Specular reflective zones **301** may be provided as a portion of the patterned electrical conductor traces **304**. As will be apparent to those skilled in the art, the diameter of the circular specular reflection zone **301** is selected to be small enough not to reflect light rays that are

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totally internally reflected from a surface of the second substrate **16**, and yet large enough to reflect all other light. The diffuse reflective zone **303** is provided to diffuse those light rays **T** that are totally internally reflected from a surface of the second substrate **16** and thereby reflect the light at angles that are likely to allow the light to exit the second substrate **16**. Diffusely reflective zone **303** may have a coating including a photoluminescent material.

While specular reflection zones **301** are shown as being circular on a planar surface, it will be appreciated that the first substrate **14** may include recessed reflective cups. FIGS. **17A** and **17B** show alternate variations of such a construction. Specifically, FIG. **17A** shows the use of reflective partitions **311** between radiation emitters **12** so as to divert those light rays that would otherwise strike a surface of second substrate **16** at an angle exceeding the critical angle. Reflective partitions may form a parabolic reflective cup or other shaped cup and may be specular or diffuse in surface character. FIG. **17B** shows a variation of the structure shown in FIG. **17A** in which reflective partitions **313** are integrally formed in the upper surface of first substrate **315**. Note that partitions **311** and **313** in the above embodiments may function as a spacer between the first and second substrates.

FIG. **8** shows a vehicle headlamp **2600** constructed in accordance with the present invention. As shown, the headlamp includes a light emitting assembly similar to those shown above, except that it includes an array of radiation emitters **2603** and **2605** within the sealed chamber **21** that is formed between a first substrate **2601**, a second substrate **2630**, and a seal (not shown). Second substrate **2630** preferably includes a plurality of micro-lenses **2631** formed in its outer surface above each one or each group of emitters **2603**, **2605**. First substrate **2601** preferably includes a heat extraction member **2621** and a plurality of reflective cups **2602** in which each one or each group of emitters is mounted. Emitters **2603** are connected to electrical conductor strip **2607** through a wire bond **2609** and a resistor **2611**. Emitters **2605** are connected to electrical conductor strip **2613** through a bonding wire **2615** and a resistor **2617**. A second assembly similar to that shown in FIG. **8** may also be disposed in a common headlamp housing and preferably disposed at an angle relative to the first assembly so as to produce high beams. By utilizing the high power light emitting assembly of the present invention, vehicle headlamps may be constructed that require fewer LEDs or other emitters to produce the requisite illumination levels that are expected for vehicles. Headlamp **2600** may also be a fog lamp or other lamp assembly.

FIG. **9** shows an exemplary circuit **100** that may be used in the above embodiments of the present invention. As shown, three external connections are provided including a ground contact **102**, a first supply voltage contact **104**, and a second supply voltage contact **106**. The second supply voltage contact is provided to enable a bias voltage to be applied between a first LED **110**, and two second LEDs **112** via a resistor **114**, and thereby adjust the relative intensity of the second LEDs relative to the first LED, which is particularly advantageous when the first and second LEDs emit light of different colors. A resistor **118** is coupled between the first LED and first supply voltage contact. Resistor **118**, first LED **110**, and second LEDs **112** are coupled in series between first supply voltage contact **104** and ground contact **102**. As shown in FIG. **9**, a plurality of such series-connected LEDs may be connected in parallel. Portions of circuit **100** may be printed on one or both of substrates **14** and **16**. Portions of circuit **100** may be disposed inside or outside of the sealed chamber **21**, with contacts **102**, **104**, and **106** extending out of the chamber

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for external connection. Resistors **114** and **118** may likewise be provided outside of the chamber to lower the heat generated inside the chamber.

In a preferred embodiment, LEDs **110** emit blue-green light while LEDs **112** emit amber light. With such an arrangement, effective white light may be emitted from the assembly.

FIG. **10** shows an initial subassembly that forms a part of the final assembly shown in FIG. **11** in accordance with a sixth embodiment of the present invention. The package **150** includes a printed circuit board **155**, which in the example provided below, is made of BeO. Various electrically conductive traces are formed on circuit board **155**. In the example shown in FIGS. **10** and **11**, a first trace **160** extends from a first electrical contact **162** to a first terminal of each of four first resistors **164a-164d**. Traces **166a-166b** extend from a second terminal of respective resistors **164a-164d** to a respective anode of a corresponding pad **168a-168d** upon which is mounted a first set of LEDs **170a-170d**. First LEDs **170a-170d** are mounted with their anode in electrical contact with pads **168a-168d**, respectively. Traces **166a-166d** also extend to a position proximate pads **172a-172d** upon which are mounted respective second LEDs **174a-174d**. Second LEDs are mounted with their anodes in electrical contact with pads **172a-172d**. Wire bonds **176a-176d** electrically couple the cathodes of second LEDs **174a-174d** to the end of trace **166**.

The cathodes of first LEDs **170a-170d** are electrically coupled via corresponding wire bonds **178a-178d** to a respective trace **180a-180d**, which in turn are coupled to respective first terminals of second resistors **182a-182d**. Second terminals of resistors **182a-182d**, in turn, are commonly coupled to a trace **184**, which extends and is electrically coupled to a second contact terminal **186**. The resistors **164a-164d** and **182a-182d** are preferably 2Ω, 1 W thick film resistors that are printed on circuit board **155**.

Pads **172a-172d**, to which the anodes of second LEDs **174a-174d** are respectively coupled, are electrically coupled to respective traces **188a-188d**. Each of these traces **188a-188d** is connected by means of a respective wire bond **190a-190d** to another respective trace **192a-192d** on the opposite side of trace **184**. Traces **192a-192d** are respectively coupled to cathodes of respective third LEDs **194a-194d** by a wire bond **196a-196d**. The anodes of third LEDs **194a-194d** are mounted on corresponding pads **198a-198d** which, in turn, are commonly coupled together via a trace **200** that extends and is electrically coupled to a third contact terminal **202**.

With the circuit layout as shown in FIG. **10**, the resulting circuit has a schematic corresponding generally to FIG. **9**, where first LEDs **170a-170d** correspond to LEDs **110**, second and third LEDs **174a-174d** and **194a-194d** correspond to LEDs **112**, first resistors **164a-164d** correspond to resistors **114**, and second resistors **182a-182d** correspond to resistors **118**.

In a preferred embodiment and in the example discussed below, first LEDs **170a-170d** are preferably InGa<sub>N</sub> LED chips that emit blue-green light. Both the second and third LEDs **174a-174d** and **194a-194d** are AlInGaP LED chips that emit amber light. By utilizing these LED chips, effective white light may be emitted from the package in accordance with the teachings of U.S. Pat. No. 5,803,579 entitled "ILLUMINATOR ASSEMBLY INCORPORATING LIGHT EMITTING DIODES" by Robert R. Turnbull et al.

Once the above-described circuit has been constructed, a cover glass **205** is attached to circuit board **155** with an epoxy seal **210**, which encircles the circuit components, with the exception of electrical contacts **162**, **186**, and **202** and with the exception of a small hole through which the resultant sealed chamber **21** may be filled with a liquid or gel. In the

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example discussed below, the seal chamber was filled with Galden® D02TS. Subsequently, the hole provided in the epoxy between cover **205** and circuit board **155** was plugged with a plug **212** made of Dynax UV cure adhesive. The resultant structure is shown in FIG. **11**.

As apparent from FIG. **11**, the resultant final package assembly includes three contact pads **162**, **186**, and **202**, which extend outward from the sealed chamber **21** and up to the edge of printed circuit board **155**. In this manner, a conventional low insertion force edge connector may be connected to the contact pads for coupling to the drive circuit. Such an edge connector may be a conventional PCI or ISA slot connector. It should be understood that another number of contact pads may be used, dependent on the electrical configuration used.

The invention will be further clarified by the following example, which is intended to be exemplary of the invention and is not intended in any manner to limit the invention.

#### EXAMPLE

To demonstrate the effectiveness of the present invention, a package assembly was constructed as illustrated in FIGS. **10** and **11** and described above. The structure had a length of approximately 1.5 inches and a width of approximately 1.5 inches, with the external contact pads being approximately 0.25 inch long. To demonstrate the effectiveness of the present invention, the illumination from the device was measured at various power levels prior to filling the sealed chamber **21** with any liquid. Then, the assembly was filled with liquid and plugged and the illuminance was again measured at the same power levels. The results of these measurements are illustrated in FIG. **12**, with the illuminance measured in foot-candles at 18 inches. As apparent from FIG. **12**, the provision of the liquid in physical and thermal contact with the LEDs improved their performance markedly. The improvement increased as the applied power increased. It should be understood that, for this sample, increased illuminance at each indicated power level for the filled radiation emitter relative to the unfilled radiation emitter is an indication of reduced junction operating temperature and reduced assembly thermal resistance.

FIG. **13** is a plot of the relative spectral irradiance as a function of wavelength with the chamber **21** of the device not filled with any liquid. The relative spectral irradiance was measured at five different power levels. Subsequently, after the device was filled with liquid, the same plots were obtained and are illustrated in FIG. **14**.

While the above invention has been described with respect to the provision of optical radiation emitters and other radiation emitting devices within a sealed chamber **21** of the inventive package, the inventive package may similarly be used to improve the heat dissipation from other electronic components. For example, as shown in FIG. **18**, a microprocessor **230**, a sensor **240**, a resistor **245**, and other electronic components, particularly other semiconductor electronic components, may be disposed within sealed chamber **250** that is formed between two members **255** and **260**. Examples of other electronic components that could desirably be placed in the sealed chamber either alone or in combination with radiation emitters, microprocessors, resistors, sensors or other components, including thermistors, diodes, Zener diodes, photodiodes, transistors, voltage regulators, Peltier effect diodes or other thermoelectric cooling chips or materials, phototransistors, etc. Members **255** and **260** may have any of the constructions discussed above. However, if none of the components within the sealed chamber are optical compo-

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nents, both members **255** and **260** may be opaque. Without such a constraint, first member **255** may, for example, be a printed circuit board while second member **260** may be a heat sink, preferably made of a highly thermally conductive material and having a large surface area. Such a large surface area may be provided by including various fins **262** extending outward away from the sealed chamber. As also shown in FIG. **18**, various passageways **264** may be provided through heat sink member **260** through which liquid may flow. These passages may join into sealed chamber **250** to allow the liquid contained therein to flow through the passageways to expedite heat dissipation from the liquid.

The electronic components mounted in the chamber may be surface mount (SMT), through-hole (THD), ball grid array (BGA), chip-on-board, chip-on-glass, or other common semiconductor device form. Electrical connections to/from between these components, and any patterned conductors within the chamber or to contacts exiting the chamber, may be solder, solder bump, solder paste, conductive epoxy, eutectic attach, wire bond, leadframe, or other electrical connection means.

Another alternative embodiment would enable both members **255** and **260** to be printed circuit boards that are sandwiched together by an epoxy seal and filled with a liquid or gel. This may enable heat dissipation in accordance with the present invention from circuit components mounted to either or both of the circuit boards.

It should also be appreciated that the components shown in FIG. **18** may be combined with a radiation emitter as in the other embodiments within a single sealed chamber. It may, for example, be beneficial to include resistors and/or a sensor within the same sealed chamber as the radiation emitters. Such a sensor may be a thermal sensor, such as a thermistor, so as to provide a mechanism for monitoring the temperature of the liquid within the sealed chamber and for enabling the current provided to the LED chips to be controlled as a function of the temperature within the chamber. This would allow the LED chips to be driven at their maximum safe level. It may also be desirable to include a voltage regulator to regulate the electrical drive signal to any electroluminescent radiation sources in the chamber. Additionally, it may be desirable to include any one or combination of transistors, phototransistors, diodes, photodiodes, or Zener diodes in the sealed chamber.

It may further be desirable to dispose an optical sensor within the same sealed chamber as the radiation emitters. Commonly assigned U.S. Pat. No. 6,498,440, issued Dec. 24, 2002, entitled "LAMP ASSEMBLY INCORPORATING OPTICAL FEEDBACK," discloses the advantages of utilizing an optical sensor in combination with a plurality of LED chips. Such sensors may be employed for many purposes such as to provide feedback for the control of electroluminescent emitters **12** in the device. In the event an optical sensor is provided in the sealed chamber, it may be desirable to incorporate light absorbing materials within the sealed chamber so as to effectively filter the light that reaches the sensor.

The radiation emitter device described herein can be used to provide a near IR night vision system for use in automobiles and other applications. A radiation emitter device is constructed as described above using IR LED die emitting radiation at a wavelength longer than the human eye can detect, but still within the sensing capability of an electronic image sensor. Preferably, this wavelength range is between 800 and 880 nm, but may be as low as 700 nm or as high as 1200 nm. Such IR-emitting LED die are available from Tyn-tec Corporation of Hsinchu, Taiwan.

Current vehicular night vision systems have several disadvantages which are overcome by using a near IR night vision system. Current systems sense far IR radiation—essentially heat. Detectors which sense far IR radiation are significantly more expensive than detectors which sense near IR radiation. Additionally, glass is opaque to far IR radiation thus mandating that the sensor be placed outside of the vehicle's cabin thereby subjecting the system to much harsher environmental conditions. Also, glass optics cannot be used, and more expensive optical materials transparent to far IR radiation must be used instead. Finally, objects which are not at a higher temperature than the ambient surroundings are not sensed as well as hot objects. Therefore, it is possible to have an object in the road which is not adequately detected by a far IR system.

The radiation emitter device of the current invention may thus be configured to emit radiation illuminating the scene imaged by the camera. In an automobile, the IR illuminator assemblies may be packaged with or near the vehicle's headlamps. Since IR radiation is not detectable to the human eye, it is possible to substantially illuminate the scene in front of a vehicle without any concern for glare disrupting oncoming or preceding drivers.

The camera is configured to image at least the same spectra of light as the IR LEDs emit. Preferably, the camera's spectral sensitivity is limited by the use of filters to only the wavelength range of light emitted by the IR LEDs. This reduces any washing-out or blooming in the image from other light sources. The camera can be mounted to look through the vehicle's windshield in the region cleaned by the vehicle's wiper and washer system by placing the camera in the mount of a rearview mirror. The camera preferably uses a wide dynamic image sensor to allow for imaging of both bright and faint objects in the forward scene simultaneously. Such an image sensor is described in commonly assigned U.S. Pat. No. 6,008,486 entitled "WIDE DYNAMIC RANGE OPTICAL SENSOR."

If a scene rearward of the vehicle is to be imaged using such a near IR imaging system, the camera may be mounted in the center high-mounted stop lamp (CHMSL) in a tail light, or behind the rear window, while the radiation emitting device of the present invention may be mounted in the same location as the camera or in a different one of the above locations. A similar rear vision system is disclosed in commonly assigned PCT International Publication No. WO 00/15462, entitled "SYSTEMS AND COMPONENTS FOR ENHANCING REAR VISION FROM A VEHICLE," by Frederick T. Bauer et al.

As will be appreciated by those skilled in the art, the radiation emitting device of the present invention allows for more efficient extraction of the heat generated by the radiation emitters. This improved extraction allows for a greater driving current to be delivered to the radiation emitters, which, in turn, generates higher radiation flux levels than previously obtained. The LED construction disclosed in the commonly assigned U.S. Pat. No. 6,335,548 discussed above, achieves power densities of up to about 2 W/in<sup>2</sup> or more while the structure of the present invention may obtain power densities of up to 5 to 10 W/in<sup>2</sup> or more. Certain embodiments of the present invention may be capable of power dissipation in excess of 1 W for miniature lamp applications (i.e., small area embodiments), and up to and exceeding 1000 W for high power lamp applications (i.e., large area embodiments).

Additionally, the likelihood that any wire bonds utilized may fatigue or break is either eliminated (as in the case with the first embodiment where wire bonds are not required), or significantly reduced, since the present invention does not

encapsulate these wire bonds with a solid encapsulant. Because the wire bonds used in the embodiment shown in FIGS. 4 and 5 are surrounded by a liquid or gel, shear forces cannot be transferred to the wire bond as a result of any thermal expansion or contraction as would be the case if they were encapsulated in a conventional encapsulant material.

A manufacturing process for making embodiments of the present invention comprising light engine modules first includes mounting optional surface mount, BGA, chips or other electronic components onto the first substrate. Next, one or more LED chips to the first substrate using eutectic attachment, solder attachment, die-attach adhesive, epoxy or the like. Next, additional optional surface mount, BGA, chips or other electronic components may be mounted onto first substrate. A curing stage or reflow stage is typically performed, as appropriate to form permanent electrical and mechanical bonds between chips and components and the first substrate. Next, wirebonding is performed for embodiments using wirebonds for electrical connection to one or more LED or electronic component chip. Next, a barrier adhesive, seal or gasket material is placed or dispensed onto first or second substrate. The seal material can optionally or additionally be pre-arranged upon or made integral with portions of either first or second substrate. At any point up to this point in the process, optional spacers may be placed within the region subsequently forming the cavity, either by placing or mounting them on the first substrate or the second substrate or by sandwiching them between the two substrates. Next, the first and second substrates are placed in close proximity such that any seal material or structure bridges the narrow gap between them along an appropriate portion of their surfaces. To facilitate large scale manufacturing and production of several modules at one time or modules having several semi-independent chambers, several first substrates may be placed onto one second substrate (and associated seal material) or vice versa. Seal material is next cured, sintered, or melted by thermal treatment or radiation exposure such as baking, IR heating, e-beam or microwave curing, reflow or other similar process. Small openings may be left within first or second substrate or seal material to provide a channel for subsequent filling of the cavity. Fluid may then be introduced into the cavity by vacuum-backfill process, 2-port pressure or gravity filling or other means. After the cavity is filled, openings in the first or second substrate or seal may be plugged with UV curable epoxy or other sealant/barrier material.

The above description is considered that of the preferred embodiments only. Modifications of the invention will occur to those skilled in the art and to those who make or use the invention. Therefore, it is understood that the embodiments shown in the drawings and described above are merely for illustrative purposes and not intended to limit the scope of the invention, which is defined by the following claims as interpreted according to the principles of patent law, including the doctrine of equivalents.

The invention claimed is:

1. A package for at least one electronic semiconductor component, said package comprising:
  - first and second substrates sealed together and spaced apart to define a sealed chamber;
  - a colored liquid or colored gel contained in said sealed chamber for filtering light emitted from the sealed chamber;
  - at least one electronic semiconductor component disposed in said sealed chamber in thermal contact with said colored liquid or colored gel such that heat is conducted by the sides of the sealed chamber; and

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wherein the at least one electronic semiconductor component is positioned within the sealed chamber such that light emitted from the at least one electronic component escapes the sealed chamber after passing through said colored liquid or colored gel.

2. The electronic component package of claim 1, wherein said first and second substrates are printed circuit boards.

3. The electronic component package of claim 1, wherein said second substrate is substantially opaque.

4. The electronic component package of claim 1, wherein said second substrate is substantially transparent.

5. The electronic component package of claim 1, wherein said at least one electronic component includes a radiation emitting device.

6. The electronic component package of claim 1, wherein said at least one electronic component includes an optical sensor.

7. The electronic component package of claim 1, wherein said at least one electronic component includes a microprocessor.

8. The electronic component package of claim 1, wherein said second substrate has a high thermal conductivity.

9. The electronic component package of claim 1, wherein said first substrate is a printed circuit board.

10. The electronic component package of claim 9, wherein a portion of said first circuit board extends outward from said sealed chamber, said portion including at least one electrical contact electrically coupled to at least one of said electronic components disposed in said sealed chamber.

11. The electronic component package of claim 10, wherein said electrical contact is configured to contact a corresponding electrical contact in an edge connector.

12. The electronic component package of claim 1, wherein said second substrate is a heat sink having a large outer surface area.

13. The electronic component package of claim 12, wherein said heat sink has a plurality of fins extending away from said sealed chamber.

14. The electronic component package of claim 12, wherein said heat sink further comprises a plurality of passageways for allowing the flow of a liquid.

15. The electronic component package of claim 14, wherein said passageways open into said sealed chamber for allowing the flow of the liquid through said passageways.

16. A package for at least one electronic component, said package comprising:

a circuit board and a substrate, sealed together and spaced apart to define a sealed chamber;

a colored liquid or colored gel contained in said sealed chamber for filtering light emitted therefrom;

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at least one light emitting diode (LED) mounted on said circuit board and disposed in said sealed chamber in thermal contact with said colored liquid or colored gel; and

wherein the at least one light emitting diode (LED) is positioned within the sealed chamber such that light escapes the sealed chamber after passing through said colored liquid or colored gel.

17. The electronic component package of claim 16, wherein said substrate is substantially opaque.

18. The electronic component package of claim 16, wherein said substrate is substantially transparent.

19. The electronic component package of claim 16, wherein the sealed chamber further comprises an optical sensor.

20. The electronic component package of claim 16, wherein the sealed chamber further includes a microprocessor.

21. The electronic component package of claim 16, wherein the sealed chamber further includes a resistor.

22. The electronic component package of claim 16, wherein said second substrate has a high thermal conductivity.

23. The electronic component package of claim 16, wherein the sealed chamber further includes a semiconductor component.

24. A package for at least one electronic component, said package comprising:

a circuit board and a substrate, sealed together and spaced apart to define a sealed chamber having a substantially clear section for passing light;

a color tinted liquid or color tinted gel contained within the sealed chamber for selectively filtering light emitted therefrom;

an optical sensor mounted on said circuit board and disposed in said sealed chamber;

at least one light emitting diode (LED) mounted on said circuit board and disposed in said sealed chamber in thermal contact with said color tinted liquid or colored tinted gel; and

wherein the at least one LED and optical sensor are positioned within the sealed chamber such that light enters and escapes the sealed chamber after passing through said color tinted liquid or colored tinted gel.

25. A package for at least one electronic component as in claim 24, wherein the index of refraction of the said color tinted liquid or colored tinted gel is substantially equal to that of the LED.

26. A package for at least one electronic component as in claim 24, wherein the index of refraction of the said color tinted liquid or colored tinted gel is substantially equal to that of the substantially clear section.

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