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(54) **HIGH POWER LIGHT EMITTING DIODE DEVICE**

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(76) Inventors: **Kee Yean Ng**, Prai (MY); **Cheng Why Tan**, Bukit Mertajam (MY); **Ji Kin Tham**, Gelugor (MY)

(57) **ABSTRACT**

Correspondence Address:
AGILENT TECHNOLOGIES, INC.
Intellectual Property Administration
Legal Department, DL429
P.O. Box 7599
Loveland, CO 80537-0599 (US)

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A circuit element having a heat-conducting body having top and bottom surfaces, and a die having an electronic circuit thereon is disclosed. The die includes first and second contact points for powering the electronic circuit. The die is in thermal contact with the heat-conducting body, the die having a bottom surface that is smaller than the top surface of the heat-conducting body. The first contact point on the die is connected to a first trace bonded to the top surface of the heat-conducting body. An encapsulating cap covers the die. The first trace has a first portion that extends outside of the encapsulating cap and a second portion that is covered by the encapsulating cap. The heat-conducting body is preferably constructed from copper or aluminum and includes a cavity having an opening on the first surface in which the die is mounted. The die preferably includes a light-emitting device.

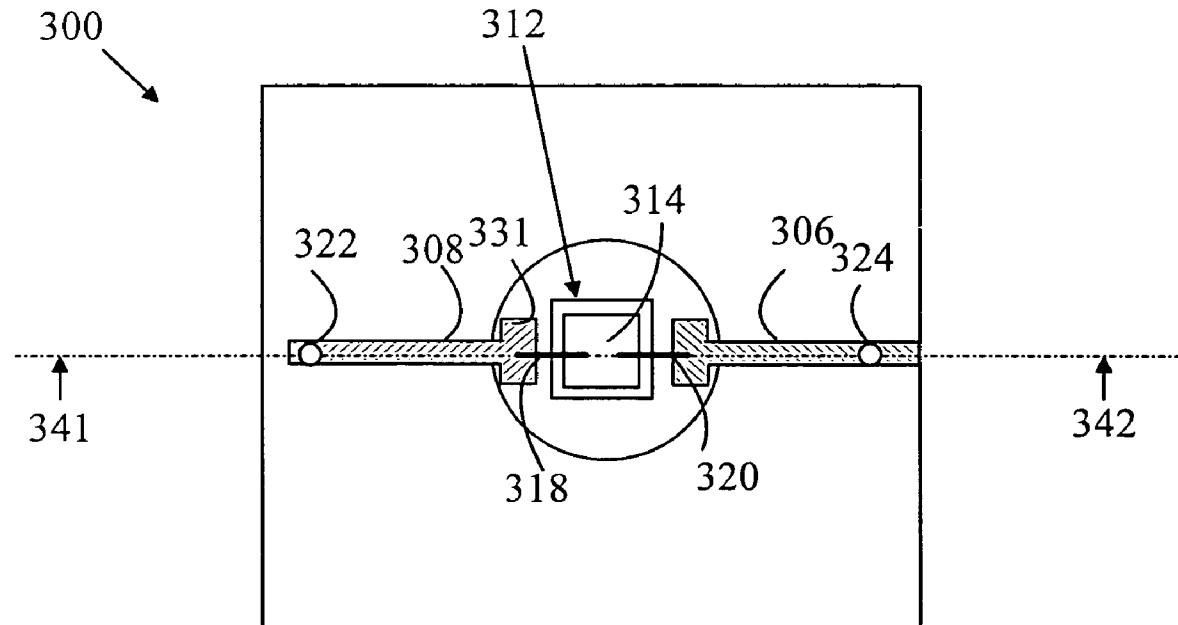


FIGURE 1
(PRIOR ART)

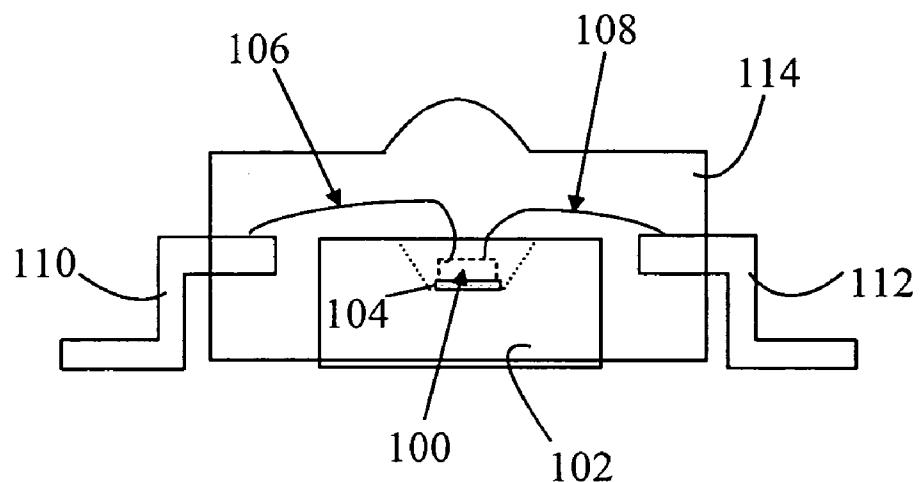


FIGURE 2
(PRIOR ART)

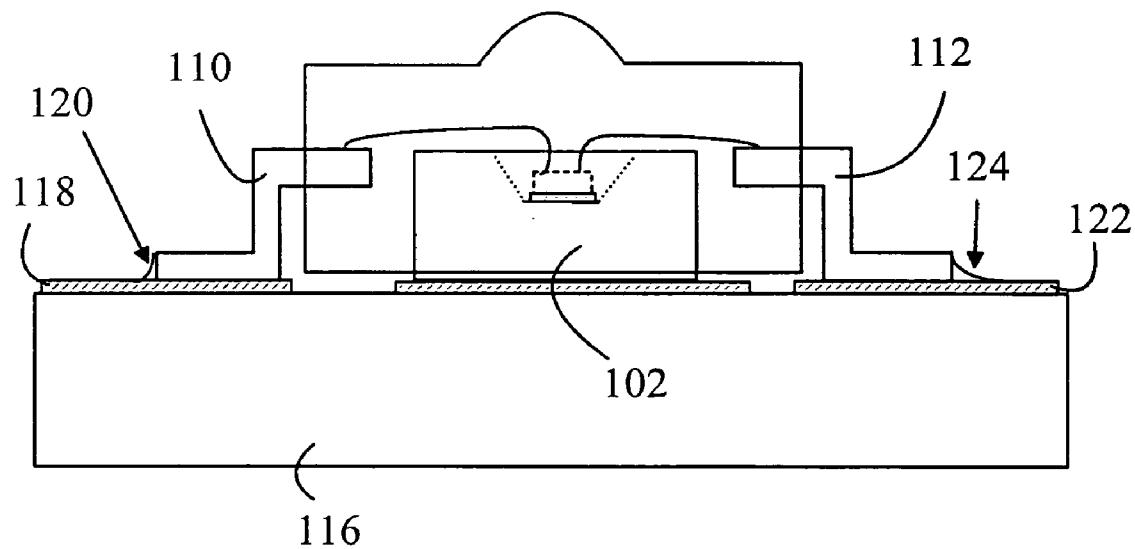


FIGURE 3B

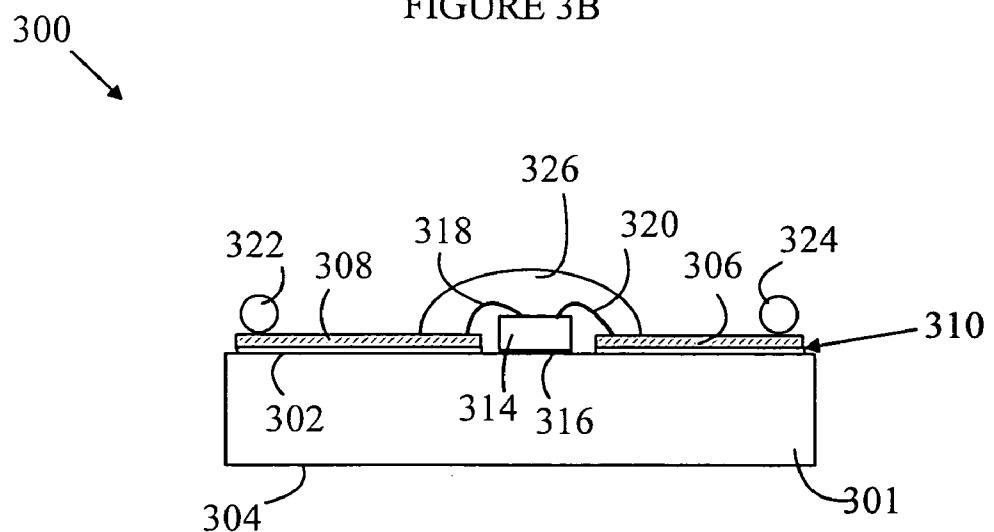


FIGURE 3A

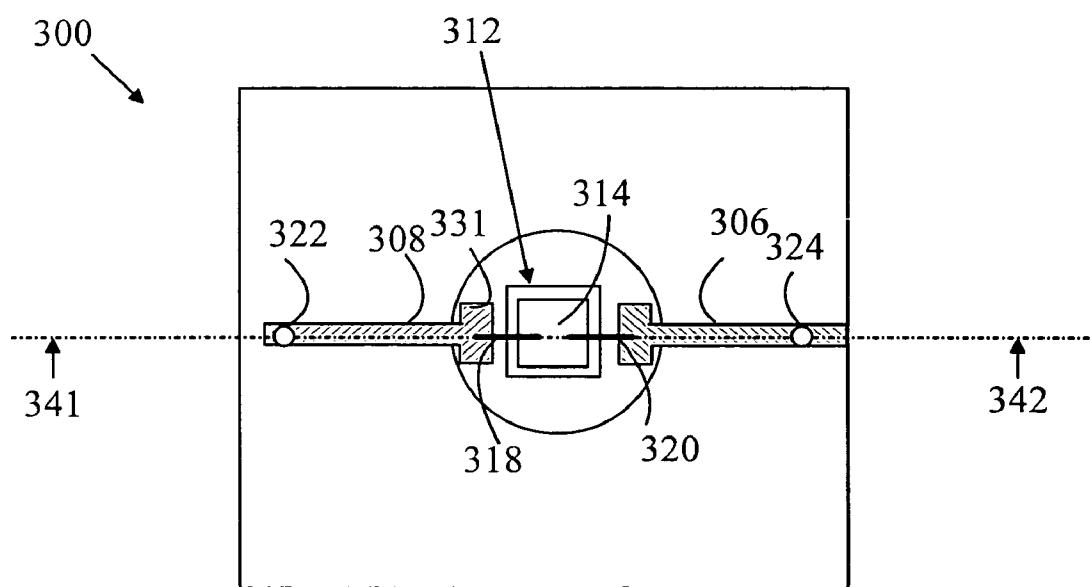


FIGURE 3D

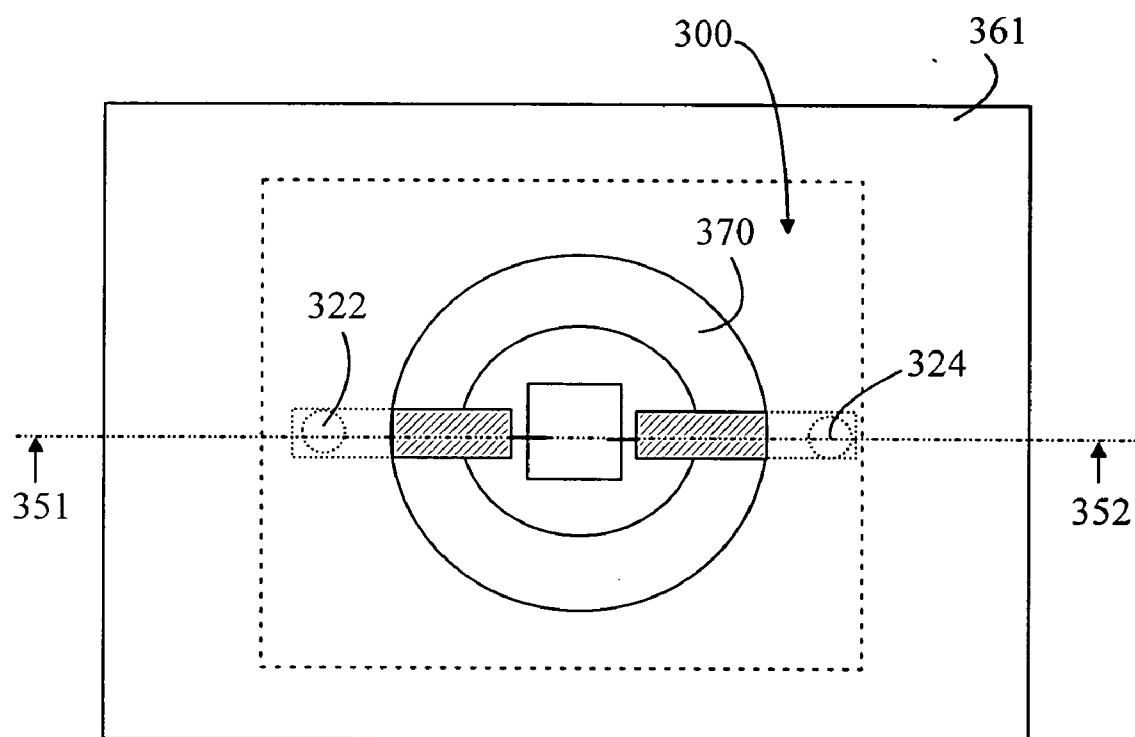
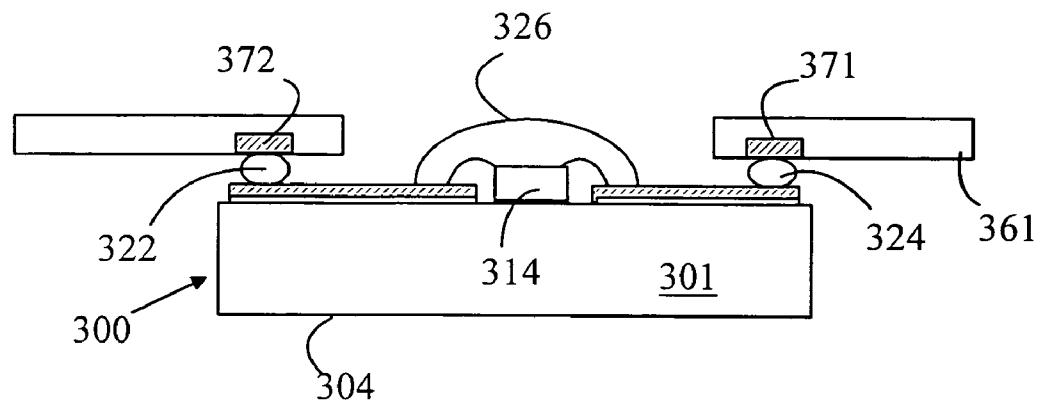


FIGURE 3C

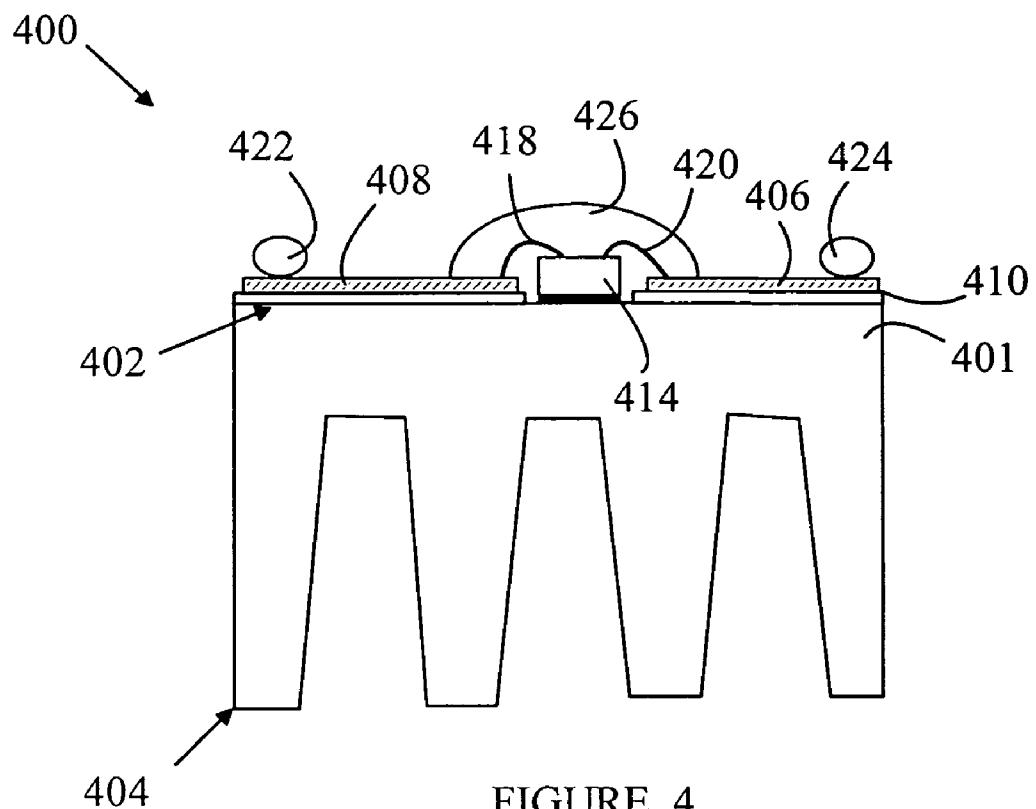


FIGURE 4

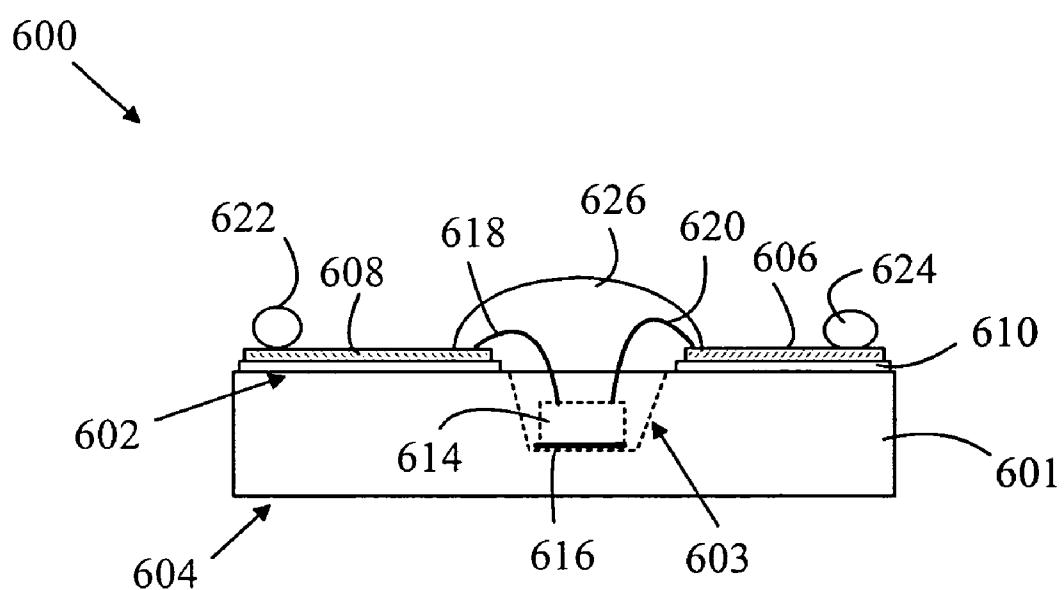


FIGURE 5

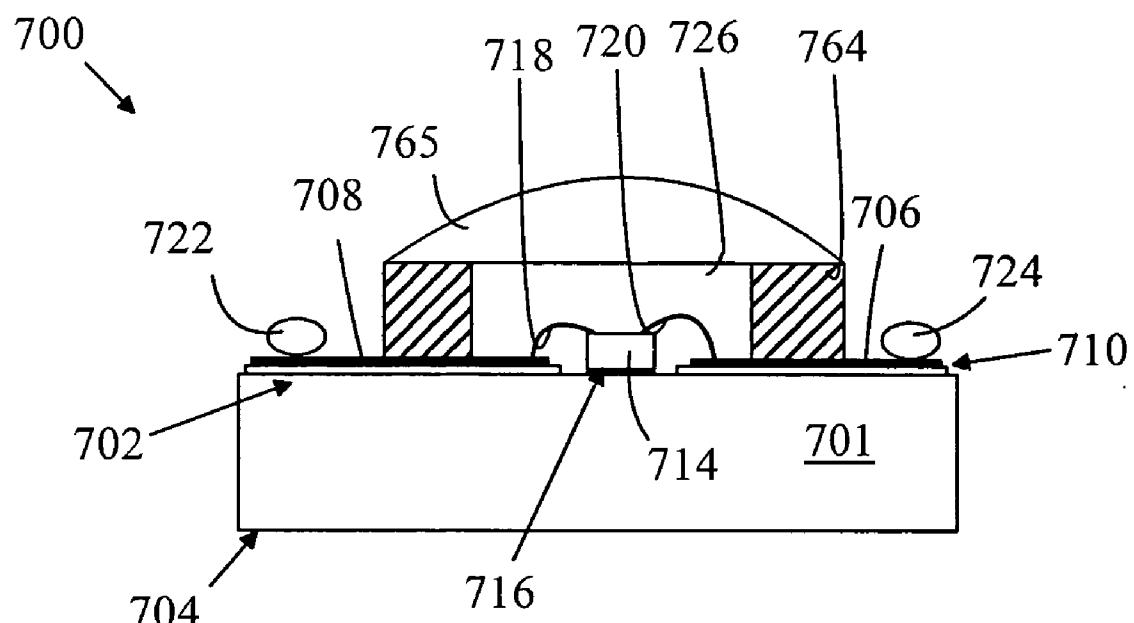


FIGURE 6B

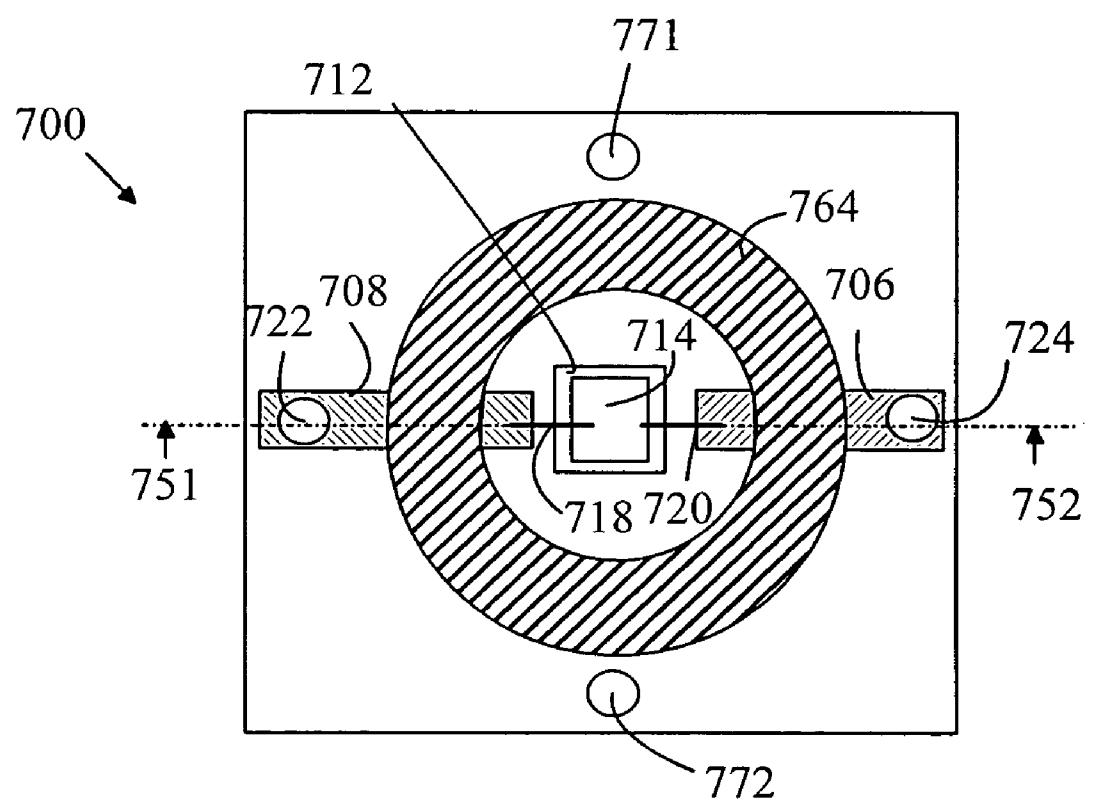


FIGURE 6A

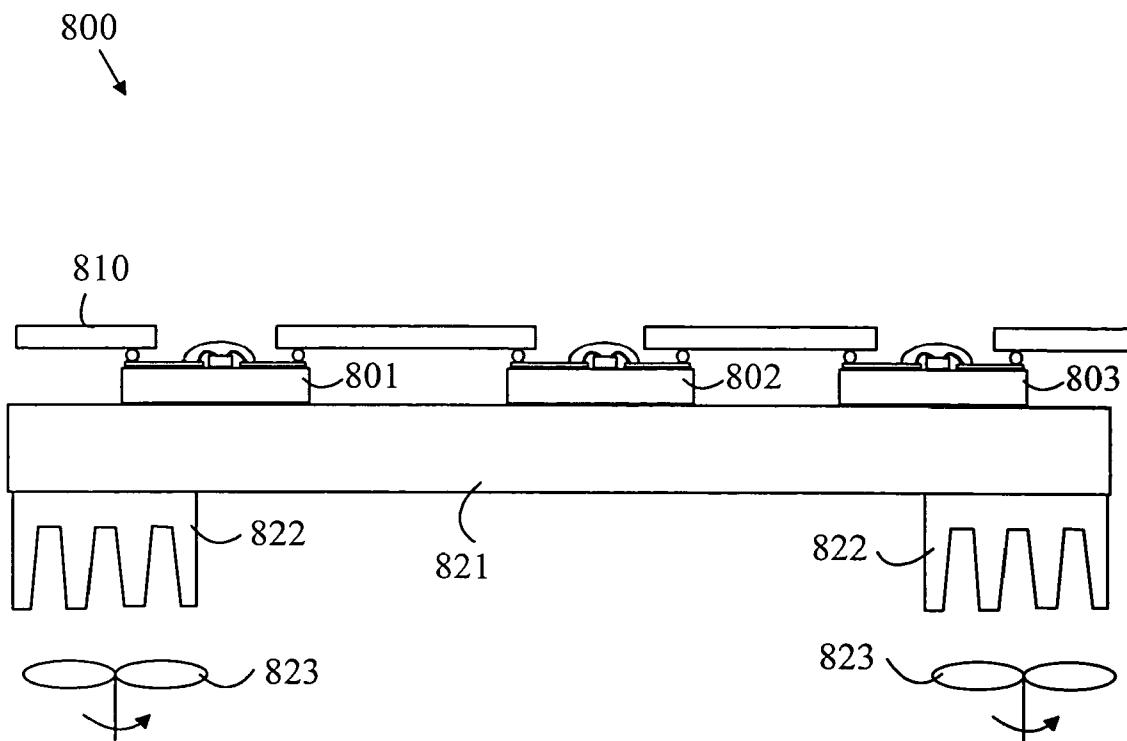


FIGURE 7

HIGH POWER LIGHT EMITTING DIODE DEVICE

FIELD OF THE INVENTION

[0001] The present invention relates to packaged integrated circuits, and more particularly, to high-power LEDs.

BACKGROUND OF THE INVENTION

[0002] Light emitting diodes (LEDs) are fabricated from compound semiconductor materials, which have the characteristic of emitting light when biased with a forward current. LEDs are widely used as indicators or displays in various types of appliances. Historically, LEDs emitted a relatively low level of light compared to other light sources and were suitable for indoor applications only.

[0003] Recent advances in compound semiconductor materials research have yielded new LEDs, which emit very high levels of light. Examples of these new LED materials are Aluminum Indium Gallium Phosphide (AlInGaP) and Indium Gallium Nitride (InGaN). These high brightness LEDs have given rise to new LED devices suitable for applications in areas such as outdoor video displays, automotive signals, traffic signals and illumination.

[0004] The high output achieved with these devices is the result of efficient semiconductor materials and of driving the LEDs at very high forward currents. Drive currents in the hundreds or thousands of milliamperes (mA) are often utilized. Unfortunately, such high drive currents produce excessive heat. Since the efficiency of an LED decreases at these high temperatures, light output starts to drop. In addition, the packaging of the devices starts to break down due to prolonged exposure to the elevated temperatures. Such packaging failures limit useful life of the device. A number of device packages have been proposed; however, none of these provide sufficient heat dissipation for the current generation of high-power LEDs.

SUMMARY OF THE INVENTION

[0005] The present invention includes a circuit element having a heat-conducting body having top and bottom surfaces, and a die having an electronic circuit thereon. The die includes first and second contact points for powering the electronic circuit. The die is in thermal contact with the heat-conducting body, the die having a bottom surface that is smaller than the top surface of the heat-conducting body. A first trace constructed from an electrically conducting material bonded to the top surface of the heat-conducting body and electrically insulated therefrom is connected to the first contact point by an electrically conducting path that is preferably a wire bond. An encapsulating cap covers the die and the first electrically conducting path. The first trace has a first portion that extends outside of the encapsulating cap and a second portion that is covered by the encapsulating cap. The heat-conducting body is preferably constructed from copper or aluminum and includes a cavity having an opening on the first surface in which the die is mounted. The die preferably includes a light-emitting device that emits light in a direction pointing away from the top surface, the encapsulating cap being optically transparent to the emitted light. The encapsulating cap can include a dam surrounding the die, the dam is filled with a clear encapsulating material.

[0006] The first trace preferably includes a solder ball on the first portion thereof. The circuit element may include a

second trace for making the connection to the second contact point on the die. Alternatively, the second connection can be made through the heat-conducting die itself. A second solder ball is preferably placed on the second trace or the heat-conducting body to provide an electrical connection to the second contact point of the die. A third solder ball is preferably provided on the top surface of the heat conducting body at a location that is non-collinear with the first and second solder balls. The solder balls provide a mechanism for coupling the circuit element to a printed circuit board as well as providing power to the die. To further facilitate heat transfer from the heat-conducting body, the bottom surface of the heat conducting body may include fins or other features for increasing the surface area of the bottom surface relative to the top surface of the heat conducting body.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a cross-sectional view of a packaged LED according to one prior art design.

[0008] FIG. 2 is a cross-sectional view of the packed LED shown in FIG. 1 attached to a typical printed circuit board (PCB).

[0009] FIG. 3A is a top view of LED device.

[0010] FIG. 3B is a cross-sectional view through line 341-342 of LED device shown in FIG. 3A.

[0011] FIG. 3C is a top view of substrate 361 that illustrates the manner in which an LED device is mounted on a substrate such as a PCB.

[0012] FIG. 3D is a cross-sectional view through line 351-352 of the LED device shown in FIG. 3C.

[0013] FIG. 4 is a cross-sectional view of an LED device with a greater surface area according to another embodiment of the present invention.

[0014] FIG. 5 is a cross-sectional view of an LED device that provides a reflector according to another embodiment of the present invention.

[0015] FIG. 6A is a top view of an LED device.

[0016] FIG. 6B is a cross-sectional view of the LED device shown in FIG. 6A through line 751-752.

[0017] FIG. 7 is a cross-sectional view of an array of LED devices that share a single heat sink according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

[0018] The manner in which the present invention provides its advantages can be more easily understood with reference to FIGS. 1 and 2, which illustrate the manner in which one class of prior art LED provides heat dissipation. Refer now to FIG. 1, which is cross-sectional view of a packaged LED according to one prior art design. An LED 100 is mounted in a cavity of a substrate 102 using a conductive medium 104. A first bond wire 106 electrically connects one terminal of the LED 100 to one electrical contact 110 while a second bond wire 108 electrically connects a second terminal of LED 100 to another electrical contact 112. An encapsulating body 114 substantially

encases the LED, the bond wires, the substrate and the contacts to provide protection for the LED.

[0019] Refer now to **FIG. 2**, which is a cross-sectional view of the packed LED shown in **FIG. 1** attached to a typical printed circuit board (PCB) **116**. The base of substrate **102** is mounted on a PCB **116** so that it is in direct contact with PCB **116**. One electrical contact **110** is electrically connected to the trace **118** of the PCB via an electrically conductive medium **120** while the other electrical contact **112** is electrically connected to trace **122** of the PCB via an electrically conductive medium **124**. Typically, solder is used for these connections. The heat generated in LED **100** is conducted to the PCB through substrate **102**.

[0020] The LED device in **FIG. 1** has many disadvantages. For instance, the ability of substrate **102** to act as a heat sink and heat transfer conduit depends on the size of the substrate. Since the electrical contacts at the sides of the substrate increase the footprint of the device without providing additional surface area for heat conduction, these devices cannot incorporate heat sinks as large as the footprint of the device. That is, the lateral size of the heat sink will always be smaller than the overall footprint of the device. Furthermore, there is a limit to how tall or thick the substrate can be without having to increase device design complexity. Hence, the ability of the substrate to act as a heat sink for temporarily absorbing heat from the LED is limited.

[0021] Prior art devices attempt to overcome the limitations of the substrate size by relying on a secondary heat sink in the form of the PCB **116** to help conduct the heat away from the LED, and hence, limit the temperature rise to which the LED is subjected. This solution moves the heat dissipation problem to the PCB. To provide adequate heat conduction and sinking, a metal core PCB with some provision for transferring the heat to the surrounding air is often needed. Since the cost of such metal core PCBs is significantly greater than the cost of the more common glass epoxy PCBs, this solution significantly increases the cost of the final circuit utilizing the LED. In addition, this solution increases the design complexity of the final PCB since the PCB must be arranged to dissipate the heat without subjecting other components on the PCB to excessive temperatures.

[0022] In addition, these prior art solutions require a good contact between the PCB and substrate **102**. The coplanarity among the leads **110 & 112** and the substrate **102** can make achieving adequate thermal contact difficult. Even if a layer of thermal glue is used to ensure good contact, air gaps or voids may still exist in between the device and the mounting PCB. Furthermore, such thermal glue layers can also restrict the flow of heat. Finally, the thermal glue further increases the cost and complexity of the assembly of the final PCB.

[0023] The present invention provides a high power LED device, which has sufficient heat sinking capability to absorb fluctuations in the heat output of the LED. In addition, the present invention dissipates heat without relying on secondary heat sinks. Refer now to FIGS. 3A-D, which illustrate an LED device **300** according to one embodiment of the present invention. **FIG. 3A** is a top view of LED device **300**, and **FIG. 3B** is a cross-sectional view through line **341-342** shown in **FIG. 3A**. LED device **300** has a body **301** with a first surface **302** and a second surface **304** on the opposite side. A circuit trace having electrical contacts **306** and **308** on a thin film layer **310** is attached to surface **302**. The

circuit layer has an opening **312** in the center that provides access to surface **302**. An LED **314** is attached to surface **302** using an adhesive **316**. Electrical connections by way of bond wires **318** and **320** connect the LED to the electrical contacts **306** and **308**. Solder bumps **322** and **324** are then deposited on one portion of the electrical contacts **306** and **308**. The LED and bond wires and a portion of the electrical contacts are encapsulated in an optically clear material **326**.

[0024] To facilitate the wire bonding operation, traces **306** and **308** preferably include a T-shaped region as shown at **331** in **FIG. 3A**. This enlarged area reduces the precision required in the wire bonding process.

[0025] Refer now to **FIGS. 3C and 3D**, which illustrate the manner in which LED device **300** is mounted on a substrate **361** such as a PCB. **FIG. 3C** is a top view of substrate **361**, and **FIG. 3D** is a cross-sectional view through line **351-352**. Substrate **361** includes an opening **370** through which LED **314** is viewed. Substrate **361** also includes two traces shown at **371** and **372**, which are positioned to connect to solder bumps **322** and **324**.

[0026] LED device **300** is connected to substrate **361** via traces **371** and **372** by any of a number of methods. For example, heat can be applied to substrate **361** sufficient to cause the solder to reflow and make the connections between LED device **300** and substrate **361**. In another example, the solder can be deposited on the PCB before the placement of device **300**, and the assembly subsequently reflowed. Additionally, an electrically conductive adhesive such as epoxy, silicone or suitable plastic can be used to make the attachment. Such adhesive can be either cured by heat or other means, such as exposure to ultraviolet (UV) light.

[0027] Body **301** provides two functions. First, body **301** acts as a heat sink that buffers thermal fluctuations. Surface **304** dissipates heat to the surrounding air. Body **301** is preferably made of a metal such as copper or aluminum to provide a high thermal conductivity. Since surface **304** is as large as the footprint of the device, this embodiment of the present invention provides substantially more heat transfer area than the prior art devices discussed above.

[0028] It should be noted that the heat transfer capability of the present invention can be enhanced by including a surface having a greater surface area in place of surface **304**. Such an embodiment is shown in **FIG. 4**, which is a cross-sectional view of an LED device **400** according to another embodiment of the present invention. In construction, LED device **400** is similar to LED device **300** discussed above except for the second surface of the device body. LED device **400** has a body **401** with a first surface **402** and a second surface **404** on the opposite side. A circuit trace consisting of electrical contacts **406** and **408** on a thin film layer **410** is attached to the said first surface of the body. The circuit layer has an opening in the center to provide access to surface **402**. An LED **414** is attached to surface **402** using an adhesive layer. Electrical connections by way of bond wires **418** and **420** connect the LED to the electrical contacts **406** and **408**. Solder bumps **422** and **424** are then deposited on one portion of the electrical contacts **406** and **408**. The LED and bond wires and a portion of the electrical contacts are encapsulated with an optically clear material **426**. Instead of a planar profile, the surface **404** has a fin-like, rib-like or stub-like shape to enhance heat dissipation. In effect, body **401** is a heat sink. The fin can be advantageously

designed into any shape such as taper, rectangular, stubs etc. The fins can be molded as part of a single body as shown in the drawing or attached to surface **404** discussed above by any mechanism that provides good heat conduction.

[0029] The above-described embodiments utilize a body having a flat surface such as surface **302** on which the LED is mounted. However, the present invention can be implemented by using a body that includes a cavity having reflective sides that improve light extraction from the LED by reflecting light leaving the sides of the LED such that the reflected light becomes part of the output light from the device. Refer now to **FIG. 5**, which is a cross-sectional view of an LED device **600** that provides such a reflector. In construction, LED device **600** is similar to LED device **300** discussed above except that a recess cavity is provided in the first surface **602**. LED device **600** includes a body **601** having a first surface **602** and a second surface **604** on the opposite side. A circuit trace consisting of electrical contacts **606** and **608** on a thin film layer **610** is attached to surface **602**. The circuit layer has an opening in the center to provide access to surface **602**. An LED **614** is attached to the first surface **602** inside a cavity **603** using an adhesive **616**. Electrical connections by way of bond wires **618** and **620** connect the LED to the electrical contacts **606** and **608**. Solder bumps **622** and **624** are then deposited on one portion of the electrical contacts **606** and **608**. The LED and bond wires and a portion of the electrical contacts are encapsulated in an optically clear material **626**.

[0030] The above-described embodiments of the present invention utilize an encapsulating layer to protect the LED and bond wires. Embodiments that utilize a mold ring to aid in this encapsulating process can also be incorporated. Refer now to **FIGS. 6A and 6B**, which illustrate an LED device **700** according to another embodiment of the present invention. **FIG. 6A** is a top view of LED device **700**, and **FIG. 6B** is a cross-sectional view of LED device **700** through line **751-752**. In construction, LED device **700** is similar to LED device **300** discussed above except that an annular ring **764** is provided on the first surface **702**. LED device **700** has a body **701** having a first surface **702** and a second surface **704** on the opposite side. An annular shaped ring **764** is attached on the first surface **702** by any known method such as using a thermally conductive adhesive, solder or just mechanically attached with fasteners. A circuit trace consisting of electrical contacts **706** and **708** on a thin film layer **710** is attached to surface **702**. The circuit layer has an opening **712** in the center thereof to provide access to surface **702**. An LED **714** is attached to surface **702** using an adhesive **716**. Electrical connections by way of bond wires **718** and **720** connect the LED to the electrical contacts **706** and **708**. Solder bumps **722** and **724** are then deposited on one portion of the electrical contacts **706** and **708**. The LED and bond wires, and a portion of the electrical contacts, are encapsulated with optically clear material **726** by filling the cavity created by annular ring **764**.

[0031] The annular-shaped ring **764** can be of any shape such as circular or polygonal. It acts as a reservoir to contain the optically clear encapsulant **726**. Additionally, an optically clear lens **765** made of plastic, polymer or glass can be incorporated on top of the annular-shaped body so as to direct the light in a desired direction. The lens can be glued to the surface of the encapsulant or formed in the encapsulant by a molding operation.

[0032] It should be noted that surface **702** may include additional solder bumps to provide additional adhesion points for connecting the LED device to a PCB or the like. Such solder bumps are shown at **771** and **772** in **FIG. 6A**. These solder bumps may be formed on a conducting trace that is attached to surface **702** by an appropriate adhesive or directly on surface **702** if the metal chosen for body **701** is wet by solder. In this regard, copper is the preferred material for body **701**.

[0033] The above-described embodiments utilize bond wires to make all of the connections between the LED and the solder bumps that connect to the PCB. However, the body may be used for one of these connections. If the chip is conductive or the bottom of the chip having the LED has a contact thereon, and the chip is mounted to the body by an electrically conducting adhesive, then the body can be used to connect to that contact. In this case, an appropriately placed solder bump is formed directly on surface **702**.

[0034] The above-described embodiments utilize passive convection/conduction to move the heat from the bottom surface of the body, e.g., surface **704** or surface **404**, to the surrounding air. However, embodiments in which a fan is utilized to enhance the airflow can also be constructed. The fan can be attached to the bottom surface of the body or provided in the enclosure in which the LED device is located.

[0035] From the forgoing discussion, it is clear that an LED device according to the present invention has the body, which spans the device footprint. Therefore the LED device has a heat sink that utilizes the full footprint of the device. Additionally, the body is not encased in any kind of thermally insulative encapsulant, and therefore, is able to dissipate heat more efficiently. Further, the problems related to the coplanarity of the leads and the heat sink in prior art devices have been overcome.

[0036] The bottom surface of the body is exposed to the ambient, and hence, efficient heat dissipation can be obtained. Additionally, since the bottom surface does not come in contact with any other surface, the body can be fabricated such that this surface extends as long or deep as possible. Hence, it is now possible to fabricate devices with long or deep heat sinks without having to increase the lateral dimensions of the devices.

[0037] Furthermore, since an LED device according to the present invention does not need to conduct heat to the mounting substrate, the mounting substrate can be constructed from common materials such as those used in inexpensive PCBs. In addition, the end-user does not need to provide an additional heat sink, thus simplifying the design of products that use the LED device.

[0038] The above-described embodiments of the present invention have been described in terms of transferring the heat generated by the LED to the air via contact between the air and the second surface of the body on which the LED is mounted. However, the present invention can be utilized to construct products having a number of LEDs on a single PCB which transfer the heat generated in each of the LEDs to a common heat sink that dissipates the heat. Refer now to **FIG. 7**, which is a cross-sectional view of an array **800** of LED devices that share a single heat sink according to another embodiment of the present invention. Array **800** is

constructed on a PCB **810**. A plurality of LED devices according to the present invention is mounted on PCB **810** in a manner analogous to that described above. Exemplary LED devices are shown at **801-803**. The body of each of the LED devices is in thermal contact with a common heat sink **821**. For example, the individual LED devices can be connected to heat sink **821** by a layer of heat conducting adhesive. Heat sink **821** may also include structures, such as the fins shown at **822** to facilitate the transfer of heat to the surrounding air. Heat sink **821** can also include a fan **823** to further enhance the transfer of heat from heat sink **821** to the surrounding air.

[0039] In the above-described embodiments, the die is mounted on a heat-conducting body that is preferably made from Aluminum or Copper. However, other materials such as ceramics and composites may be utilized for the heat-conducting body.

[0040] Various modifications to the present invention will become apparent to those skilled in the art from the foregoing description and accompanying drawings. Accordingly, the present invention is to be limited solely by the scope of the following claims.

What is claimed is:

1. A circuit element comprising:
 - a heat-conducting body having top and bottom surfaces;
 - a die having an electronic circuit thereon, said die including first and second contact points for powering said electronic circuit, said die being in thermal contact with said heat-conducting body, said die having a bottom surface that is smaller than said top surface of said heat-conducting body;
 - a first trace comprising an electrically conducting material bonded to said top surface of said heat-conducting body and electrically insulated therefrom;
 - a first electrically conducting path from said first contact point to said first trace; and
 - an encapsulating cap covering said die, and said first electrically conducting path, said first trace having a first portion that extends outside of said encapsulating cap and a second portion that is covered by said encapsulating cap.
2. The circuit element of claim 1 wherein said electronic circuit comprises an LED.
3. The circuit element of claim 1 wherein said first trace comprises an electrically conducting material on an insulating substrate, said insulating substrate being bonded to said heat-conducting body.
4. The circuit element of claim 3 wherein said insulating substrate comprises an opening, said die being connected to said heat-conducting body through said opening.
5. The circuit element of claim 1 wherein said heat-conducting body comprises copper.
6. The circuit element of claim 1 wherein said heat-conducting body comprises aluminum.
7. The circuit element of claim 1 wherein said heat-conducting body comprises a cavity having an opening on said first surface and wherein said die is mounted in said cavity.
8. The circuit element of claim 1 wherein said die comprises a light-emitting device that emits light in a direction pointing away from said top surface and wherein said encapsulating cap is optically transparent to said emitted light.
9. The circuit element of claim 1 wherein said first electrically conducting path comprises a wire having a first end bonded to said first contact point and a second end bonded to said first trace.
10. The circuit element of claim 9 wherein said first trace comprises a T-shaped strip of copper.
11. The circuit element of claim 9 further comprising a solder ball on said first portion of said first trace.
12. The circuit element of claim 1 further comprising a second trace comprising an electrically conducting medium bonded to said top surface of said heat-conducting body and insulated therefrom, said second trace being electrically connected to said second contact point by a second electrically conducting path.
13. The circuit element of claim 12 wherein said second trace further comprises a solder ball.
14. The circuit element of claim 12 further comprising a third solder ball positioned on said top surface of said heat-conducting die and positioned non-collinearly with respect to said first and second solder balls.
15. The circuit element of claim 1 wherein said encapsulating cap comprises a dam surrounding said die, said dam being filled with a clear encapsulating material.
16. The circuit element of claim 1 wherein said bottom surface of said heat-conducting body comprises a surface having a greater surface area than said top surface of said heat-conducting body.
17. The circuit element of claim 16 wherein said bottom surface of said heat-conducting body comprises fins for facilitating heat transfer from said bottom surface of said heat conducting body.
18. The circuit element of claim 1 further comprising a circuit board having top and bottom surfaces and a hole therethrough, said first trace being connected to a conductor on said bottom surface of said circuit board such that said die is visible from a location above said top surface of said circuit board.
19. The circuit element of claim 18 wherein said heat conducting body is connected to said circuit board via the second and third locations on said bottom surface of said circuit board.
20. The circuit element of claim 19 wherein said connections between said circuit board, said first trace, and said second and third locations comprise solder joints.

* * * * *