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(54) **LED BULB WITH CHASSIS FOR PASSIVE CONVECTIVE LIQUID COOLING**

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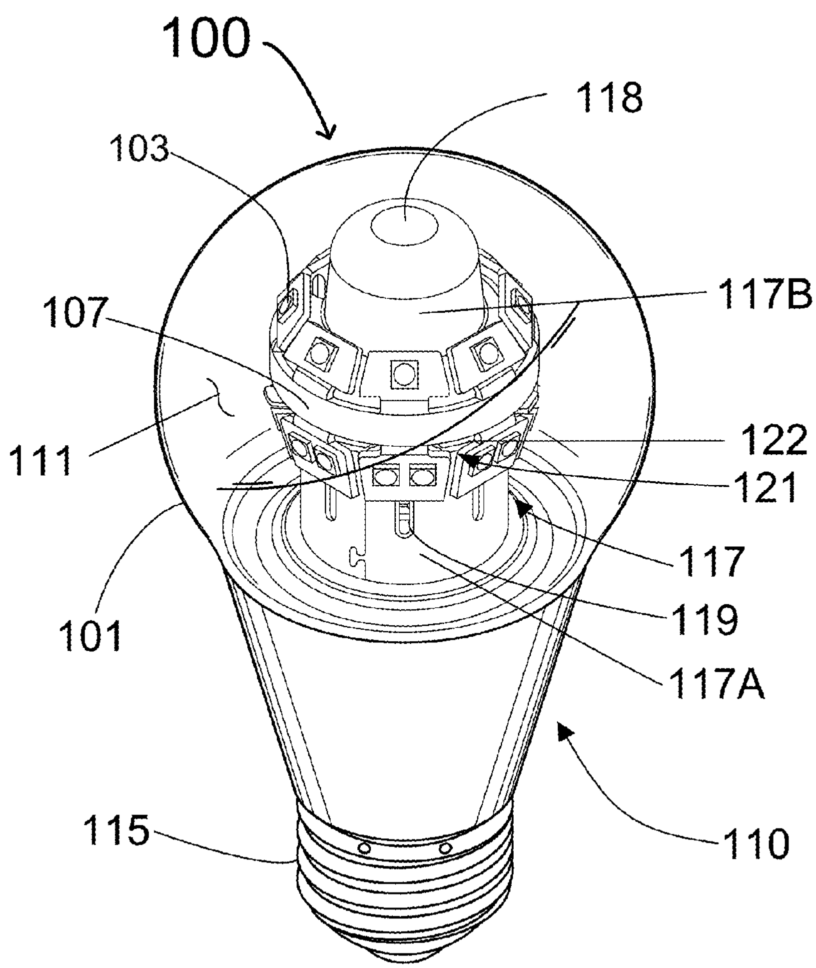
(57) **ABSTRACT**

A light emitting diode (LED) bulb includes a base, a shell connected to the base forming an enclosed volume, a chassis disposed within the shell, and a plurality of LEDs disposed with the shell. The LED bulb also includes a thermally conductive liquid disposed within the enclosed volume. The LEDs and the chassis are immersed in the thermally conductive liquid. The chassis has a first opening and a second opening. The second opening is spaced from the first opening to facilitate a passive convective flow of the thermally conductive liquid to exchange a first volume of the thermally conductive liquid interior the chassis with a second volume of the thermally conductive liquid exterior the chassis.



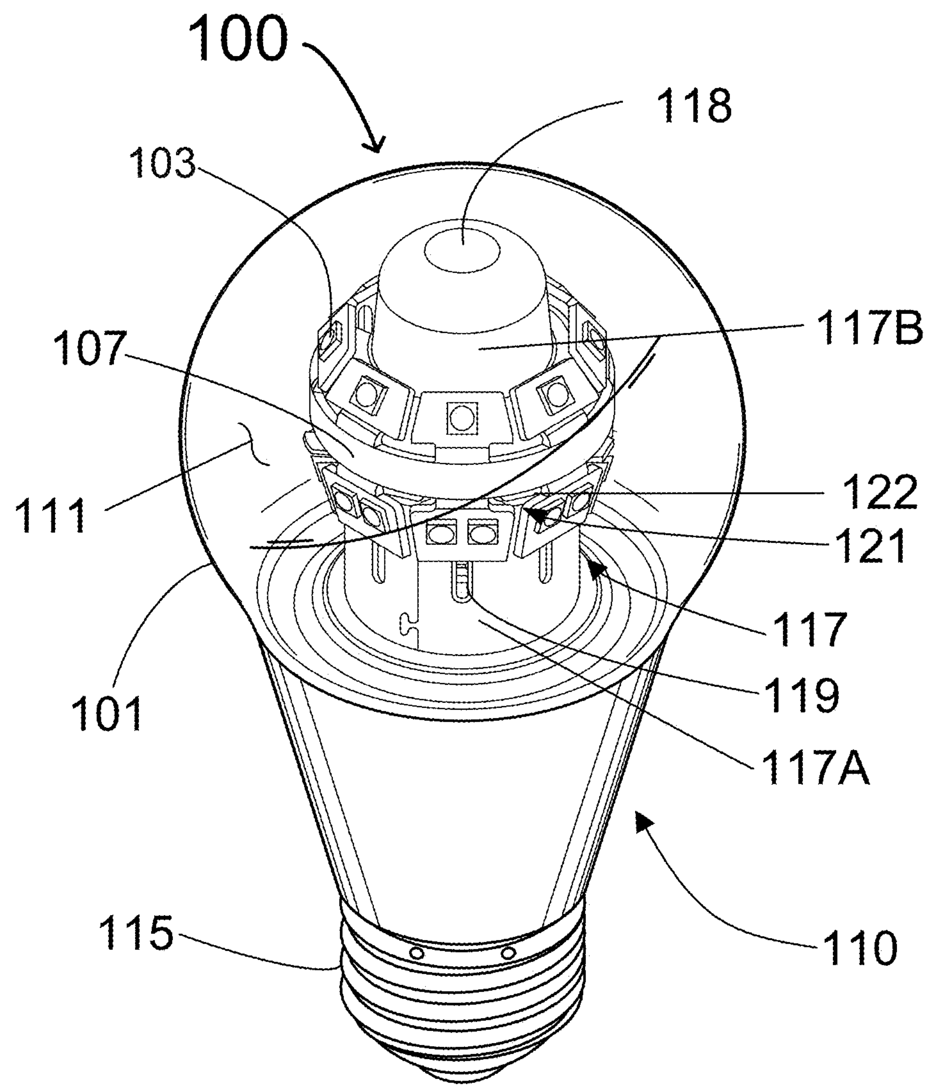


FIG. 1A

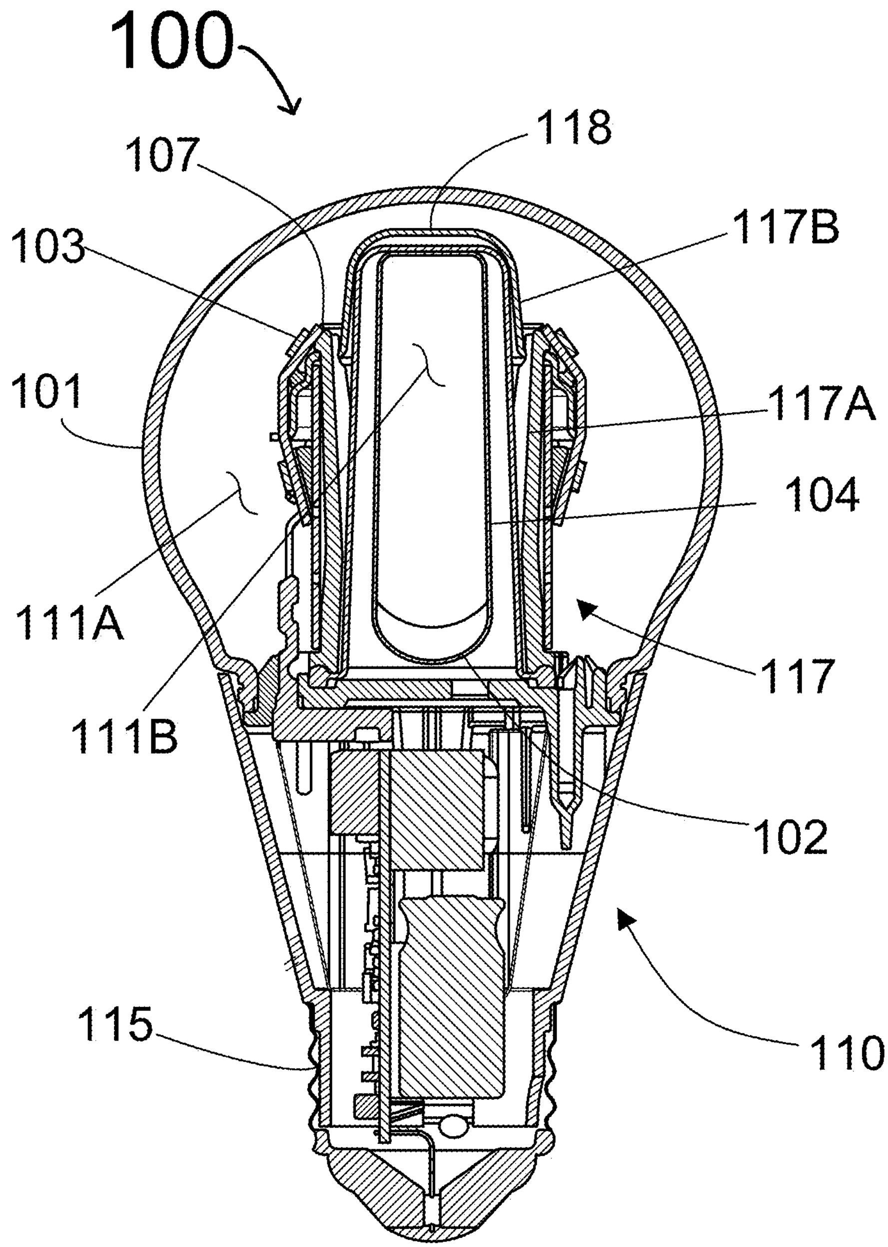


FIG. 1B

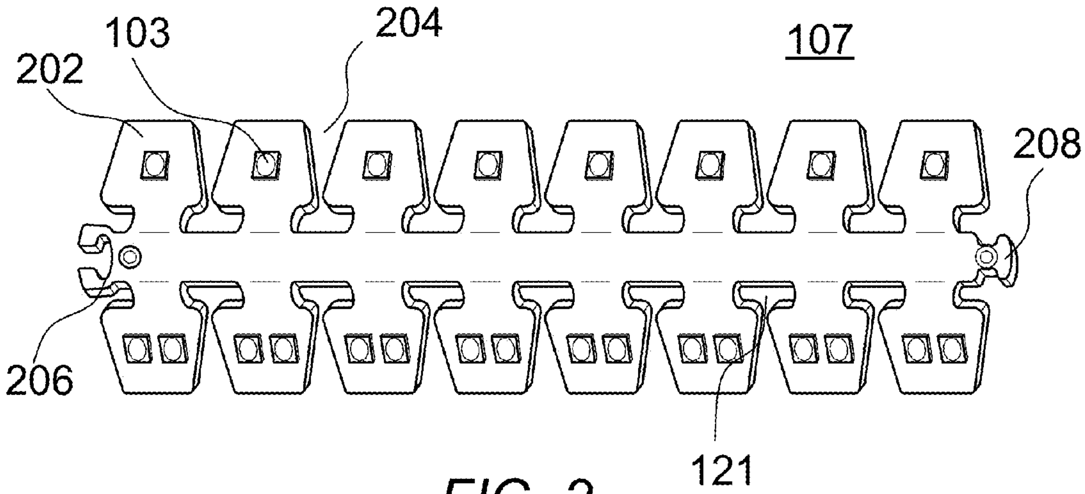

103
204
107
202
208
206
121

FIG. 2

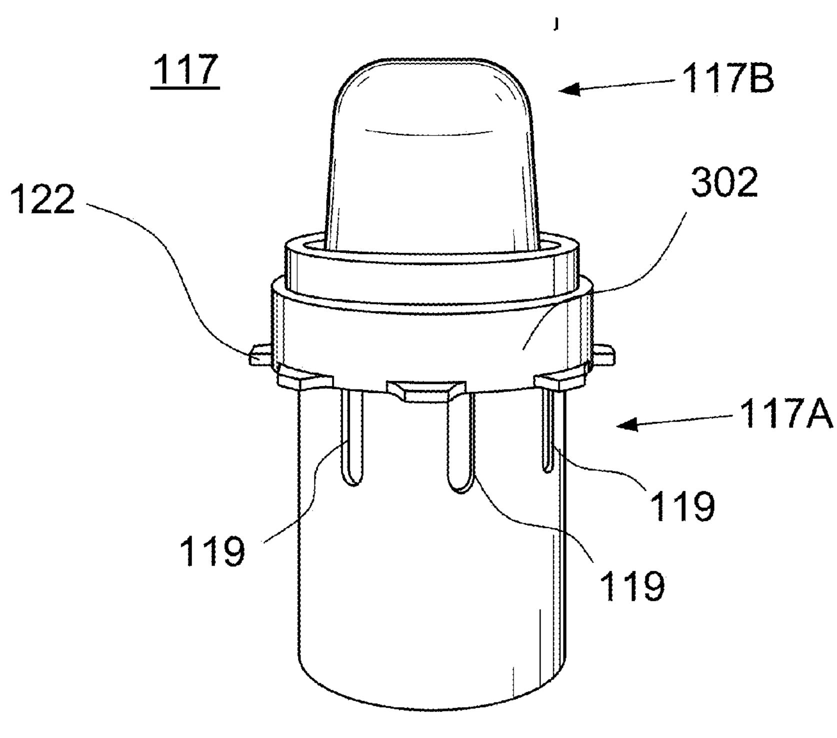

117
117B
302
122
117A
119
119
119
119

FIG. 3

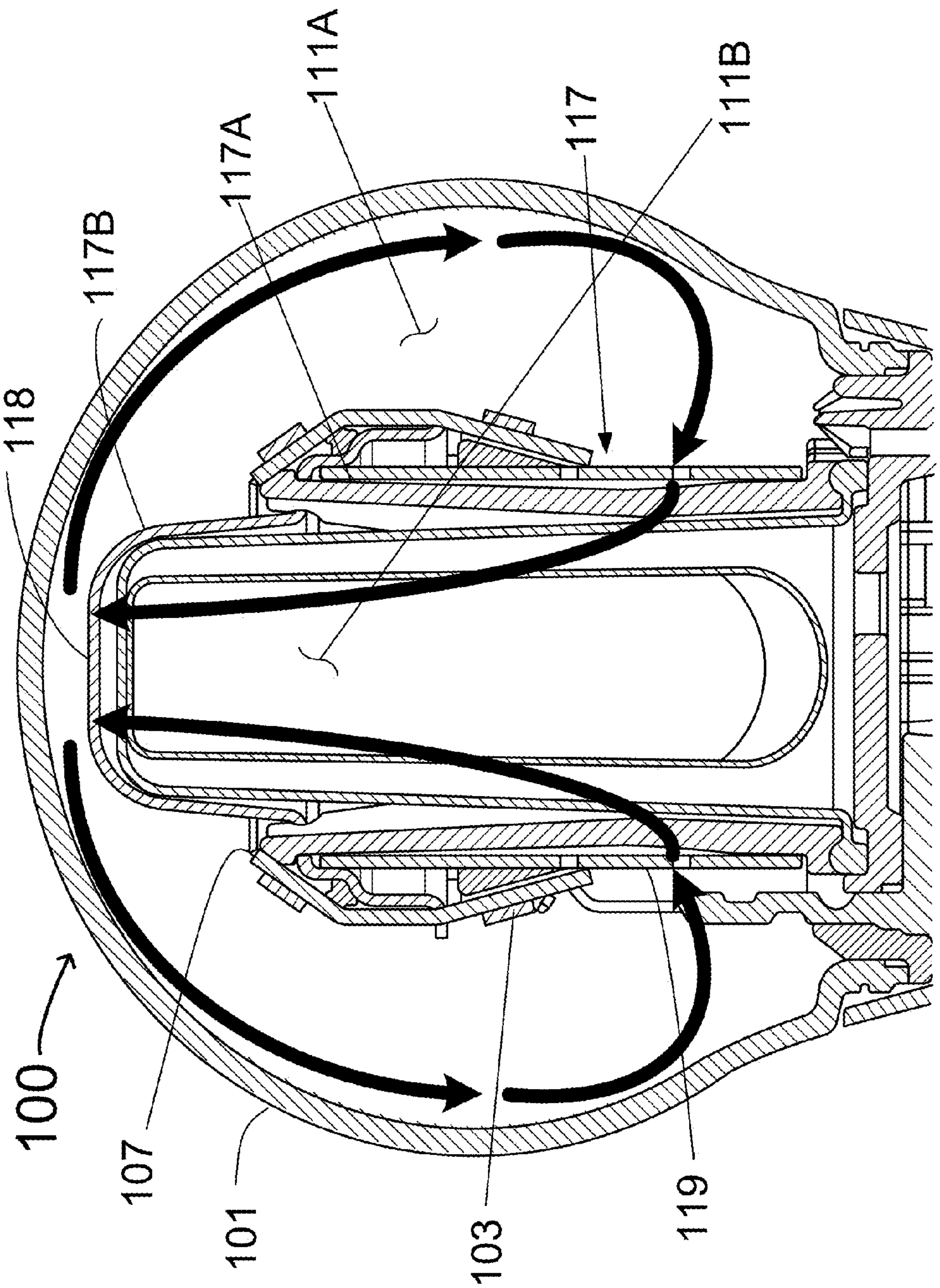


FIG. 4A

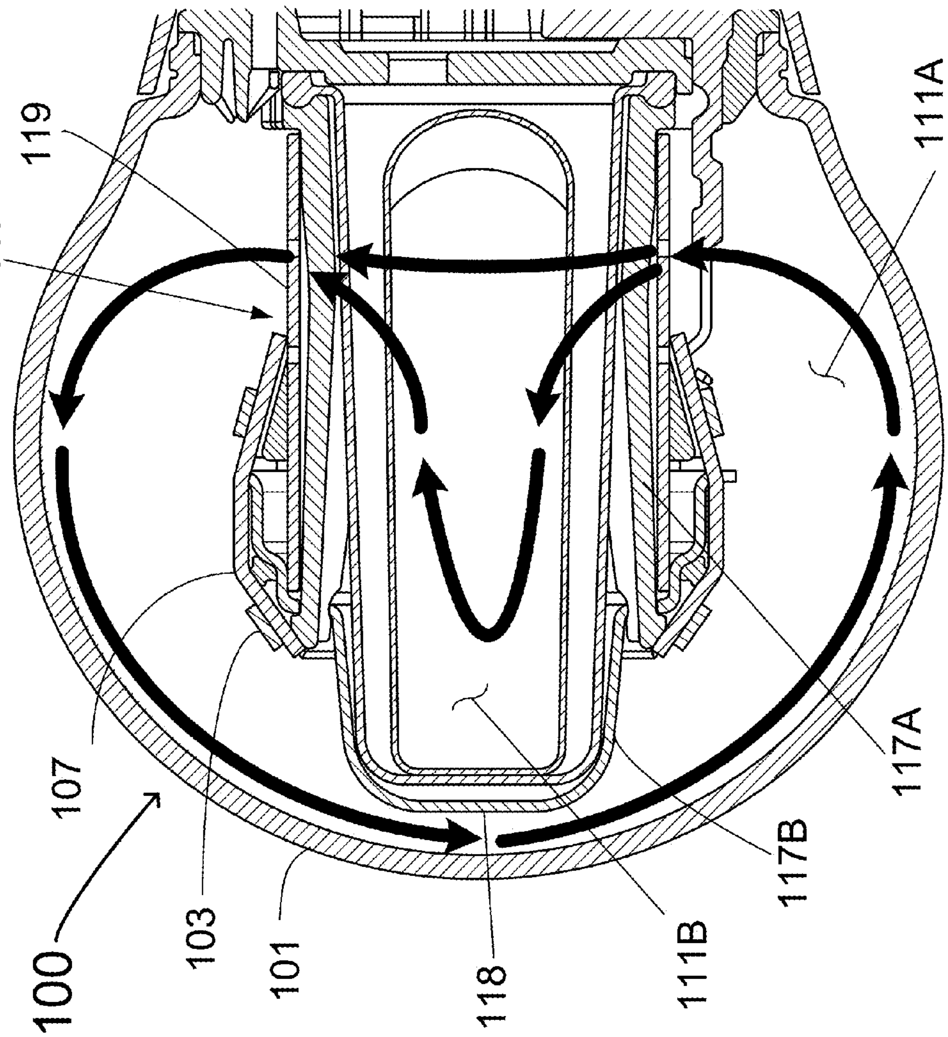


FIG. 4B

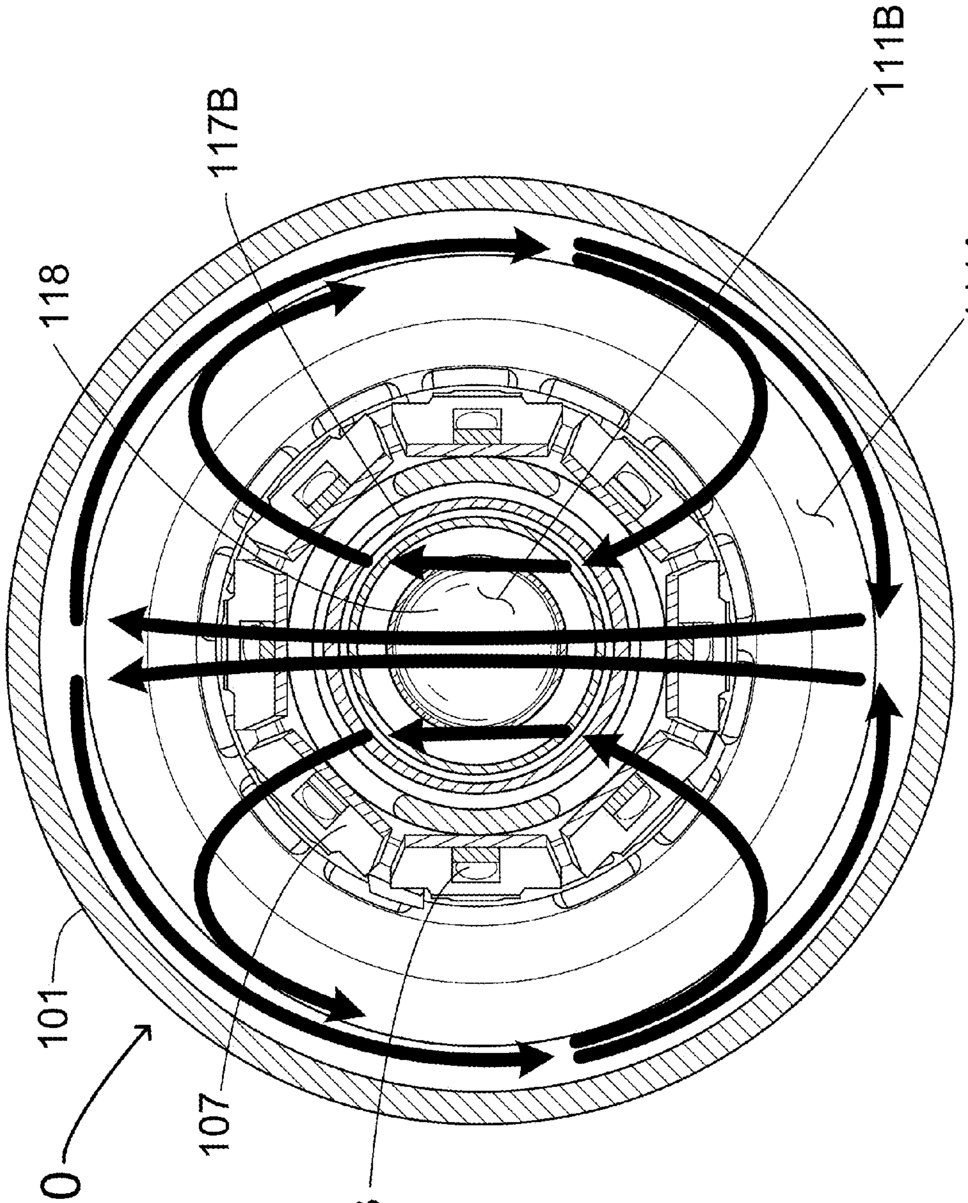


FIG. 4B Cont'd

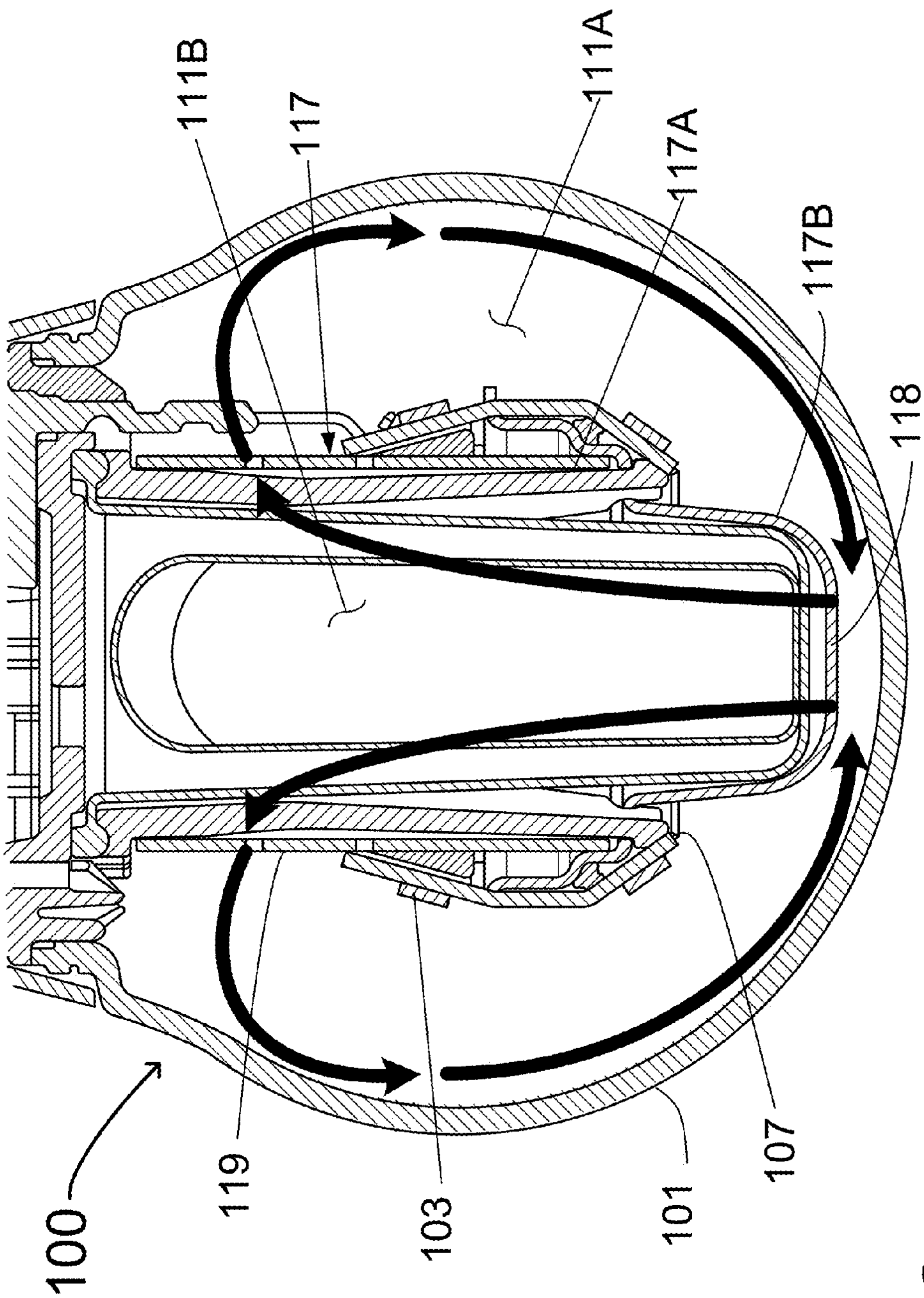


FIG. 4C

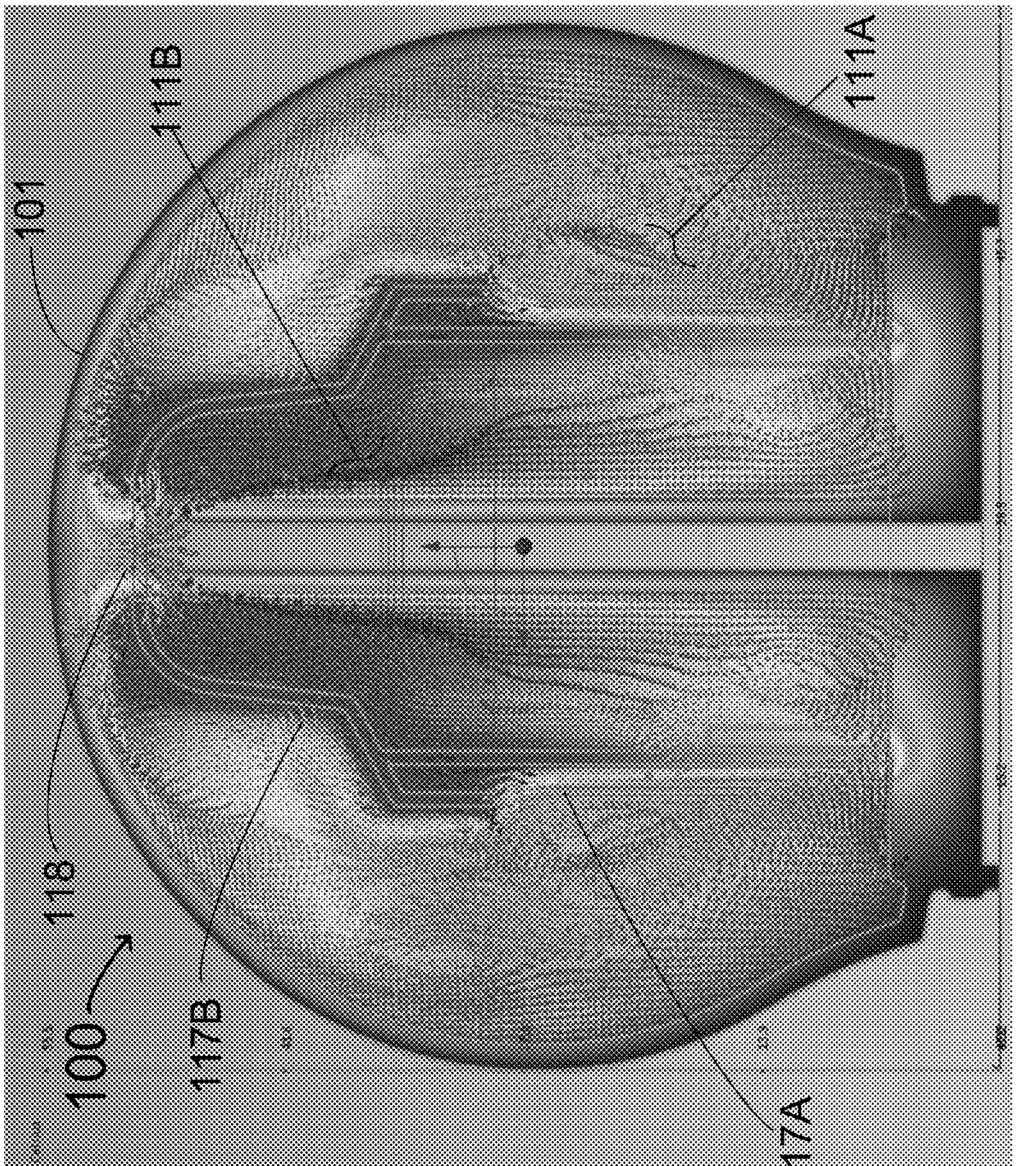


FIG. 5A

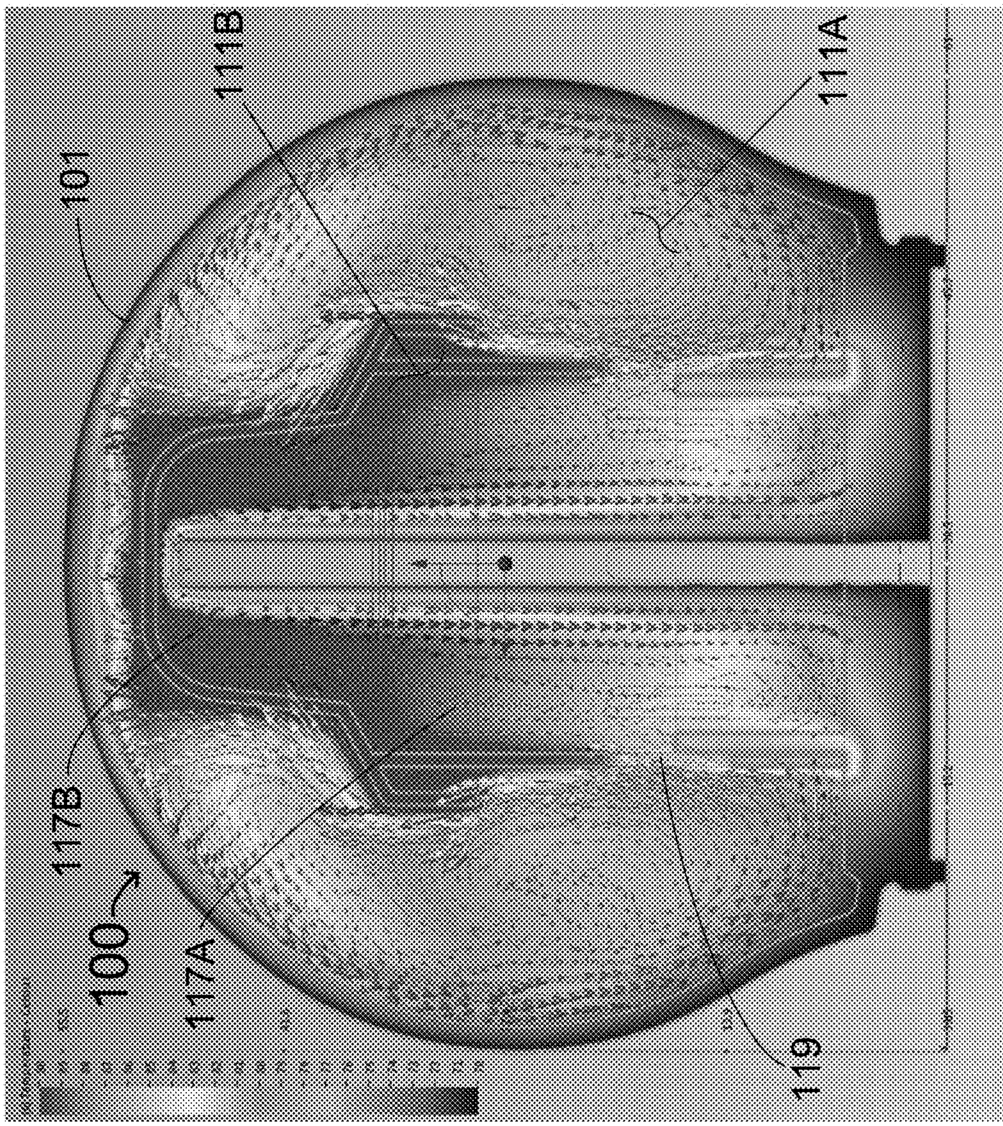


FIG. 5B

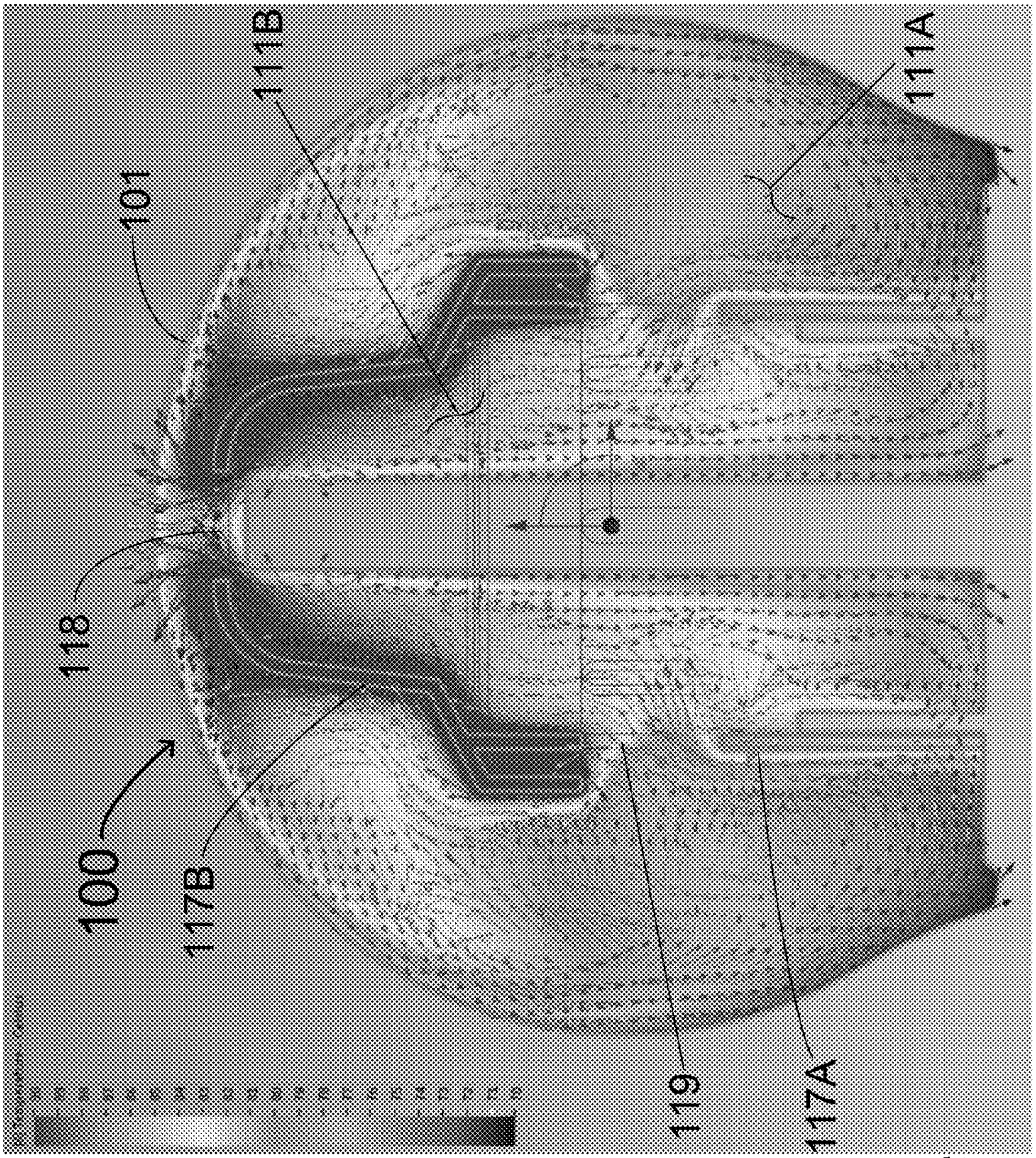


FIG. 5C

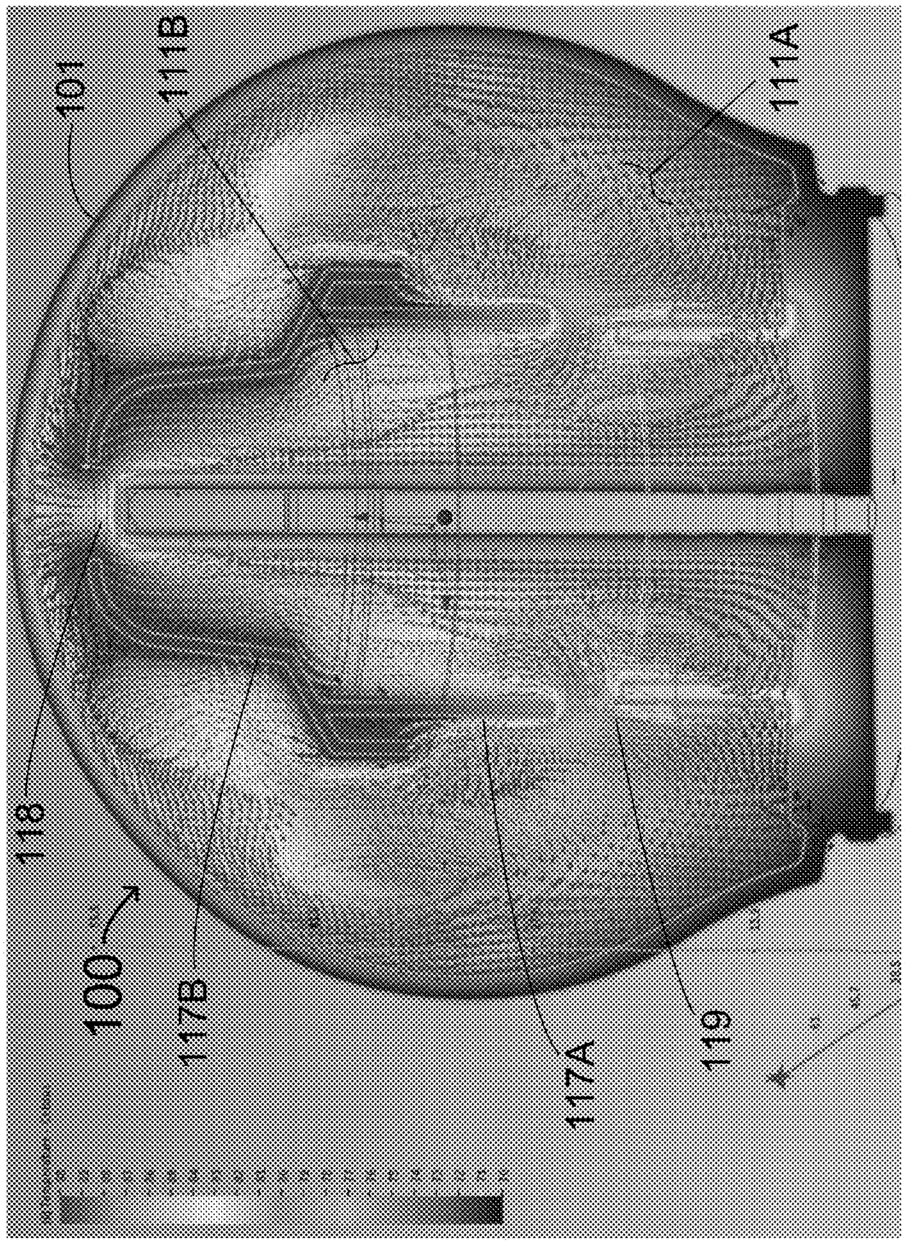


FIG. 5D

LED BULB WITH CHASSIS FOR PASSIVE CONVECTIVE LIQUID COOLING

BACKGROUND

[0001] 1. Field

[0002] The present disclosure relates generally to liquid-filled light emitting diode (LED) bulbs, and more specifically to an LED bulb with a chassis configured to provide passive convective liquid cooling of LEDs.

[0003] 2. Description of Related Art

[0004] Traditionally, lighting has been generated using fluorescent and incandescent light bulbs. While both types of light bulbs have been reliably used, each suffers from certain drawbacks. For instance, incandescent bulbs tend to be inefficient, using only 2-3% of their power to produce light, while the remaining 97-98% of their power is lost as heat. Fluorescent bulbs, while more efficient than incandescent bulbs, do not produce the same warm light as that generated by incandescent bulbs. Additionally, there are health and environmental concerns regarding the mercury contained in fluorescent bulbs.

[0005] Thus, an alternative light source is desired. One such alternative is a bulb utilizing an LED. An LED comprises a semiconductor junction that emits light due to an electrical current flowing through the junction. Compared to a traditional incandescent bulb, an LED bulb is capable of producing more light using the same amount of power. Additionally, the operational life of an LED bulb is orders of magnitude longer than that of an incandescent bulb, for example, 10,000-100,000 hours as opposed to 1,000-2,000 hours.

[0006] While there are many advantages to using an LED bulb rather than an incandescent or fluorescent bulb, LEDs have a number of drawbacks that have prevented them from being as widely adopted as incandescent and fluorescent replacements. One drawback is that an LED, being a semiconductor, generally cannot be allowed to get hotter than approximately 120° C. As an example, A-type LED bulbs have been limited to very low power (i.e., less than approximately 8 W), producing insufficient illumination for incandescent or fluorescent replacements.

[0007] One potential solution to this problem is to use a large metallic heat sink attached to the LEDs and extending away from the bulb. However, this solution is undesirable because of the common perception that customers will not use a bulb that is shaped radically different from the traditionally shaped A-type form factor bulb. Additionally, the heat sink may make it difficult for the LED bulb to fit into preexisting fixtures.

BRIEF SUMMARY

[0008] In one exemplary embodiment, a light emitting diode (LED) bulb includes a base, a shell connected to the base forming an enclosed volume, a chassis disposed within the shell, and a plurality of LEDs disposed with the shell. The LED bulb also includes a thermally conductive liquid disposed within the enclosed volume. The LEDs and the chassis are immersed in the thermally conductive liquid. The chassis has a first opening and a second opening. The second opening is spaced from the first opening to facilitate a passive convective flow of the thermally conductive liquid to exchange a first volume of the thermally conductive liquid interior the chassis with a second volume of the thermally conductive liquid exterior the chassis.

DESCRIPTION OF THE FIGURES

[0009] The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

[0010] FIG. **1**A depicts an exemplary LED bulb.

[0011] FIG. **1**B depicts a cross-sectional view of the exemplary LED bulb.

[0012] FIG. **2** depicts an exemplary support structure of the exemplary LED bulb.

[0013] FIG. **3** depicts an exemplary chassis of the exemplary LED bulb.

[0014] FIGS. **4**A-**4**C depict passive convective flow of thermally conductive liquid overlaid on a cross-sectional view of the exemplary LED bulb.

[0015] FIGS. **5**A-**5**D depict cross-sectional views of thermal models of the heat distribution for various configurations of the exemplary LED bulb.

DETAILED DESCRIPTION

[0016] The following description is presented to enable a person of ordinary skill in the art to make and use the various embodiments. Descriptions of specific devices, techniques, and applications are provided only as examples. Various modifications to the examples described herein will be readily apparent to those of ordinary skill in the art, and the general principles defined herein may be applied to other examples and applications without departing from the spirit and scope of the various embodiments. Thus, the various embodiments are not intended to be limited to the examples described herein and shown, but are to be accorded the scope consistent with the claims.

[0017] Various embodiments are described below, relating to LED bulbs. As used herein, an "LED bulb" refers to any light-generating device (e.g., a lamp) in which at least one LED is used to generate the light. Thus, as used herein, an "LED bulb" does not include a light-generating device in which a filament is used to generate the light, such as a conventional incandescent light bulb.

[0018] As used herein, the term "liquid" refers to a substance capable of flowing. Also, the substance used as the thermally conductive liquid is a liquid or at the liquid state within, at least, the operating ambient temperature range of the bulb. An exemplary temperature range includes temperatures between −40° C. to +40° C. Also, as used herein, "passive convective flow" refers to the circulation of a liquid without the aid of a fan or other mechanical devices driving the flow of the thermally conductive liquid.

1. Exemplary LED Bulb

[0019] FIGS. **1**A and **1**B illustrate a perspective view and a cross-sectional view, respectively, of exemplary LED bulb **100**. LED bulb **100** includes a shell **101** and a base **110** forming an enclosed volume. For convenience, all examples provided in the present disclosure describe and show LED bulb **100** being a standard A-type form factor bulb. It should be appreciated, however, that the present disclosure may be applied to LED bulbs having any shape, such as a tubular bulb, globe-shaped bulb, or the like.

[0020] Shell **101** may be made from any transparent or translucent material such as plastic, glass, polycarbonate, or the like. Shell **101** may include dispersion material spread throughout the shell to disperse light. The dispersion material prevents LED bulb **100** from appearing to have one or more point sources of light.

[0021] Base **110** of LED bulb **100** includes a connector base **115** for connecting the bulb to a lighting fixture. In the present embodiment, connector base **115** has threads for insertion into a conventional light socket in the U.S. It should be appreciated, however, that connector base **115** may be any type of connector, such as a screw-in base, a dual-prong connector, a standard two- or three-prong wall outlet plug, bayonet base, Edison Screw base, single pin base, multiple pin base, recessed base, flanged base, grooved base, side base, or the like.

[0022] A thermally conductive liquid **111** is disposed within the enclosed volume formed by shell **101** and base **110**. Thermally conductive liquid **111** may be any thermally conductive liquid, mineral oil, silicone oil, glycols (PAGs), fluorocarbons, or other material capable of flowing. It may be desirable to have the liquid chosen be a non-corrosive dielectric. Selecting such a liquid can reduce the likelihood that the liquid will cause electrical shorts and reduce damage done to the components of LED bulb **100**.

[0023] In the present exemplary embodiment, LED bulb **100** includes a liquid-volume compensator mechanism to facilitate thermal expansion of thermally conductive liquid **111** contained in the LED bulb **100**. In the exemplary embodiment depicted in FIG. **1**B, the liquid-volume compensation mechanism is a compressible bladder **104**, which contains a compressible medium (e.g., a gas, foam, compressible gel, or the like). The volume compensation mechanism, however, can be a diaphragm, such as a flexible membrane made of an elastomer or synthetic rubber, such as Viton, silicone, fluorosilicone, fluorocarbon, Nitrile rubber, or the like. The liquid-volume compensator mechanism can also be formed from a disk, piston, vane, plunger, slide, closed cell foam, bellow, or the like.

[0024] LED bulb **100** includes LEDs **103** disposed within shell **101** and immersed in thermally conductive liquid **111**. LED bulb **100** also includes a chassis **117**, which is also disposed within shell **101** and immersed in thermally conductive liquid **111**. Chassis **117** may be formed from a thermally conductive material, such as aluminum, copper, brass, magnesium, zinc, or the like. As will be described in more detail below, chassis **117** has a first opening **118** and a second opening **119**, which is spaced from first opening **118**, to facilitate a passive convective flow of thermally conductive liquid **111** to transfer heat generated by LEDs **103** to shell **101**.

[0025] With reference to FIG. **2**, in the present embodiment, LEDs **103** are mounted to support structure **107**. In particular, LEDs **103** are mechanically, electrically, and thermally coupled to mounts **202** of support structure **107**. In the present embodiment, mounts **202** are fingerlike projections with a channel **204** formed between pairs of mounts **202**. Mounts **202** and channels **204** are configured to facilitate a passive convective flow of thermally conductive liquid through channels **204**, when LED bulb **100** (FIG. **1**A) is oriented in at least three different orientations. With reference to FIG. **1**A, in a first orientation, shell **101** is disposed vertically above base **110**. In a second orientation, shell **101** is disposed on the same horizontal plane as base **110**. In a third orientation, shell **101** is disposed vertically below base **110**. It should be recognized that mounts **202** can also be described as being posts, tabs, and the like.

[0026] Support structure **107** is preferably formed from a composite laminate material. Support structure **107** may comprise a thermally conductive material (e.g., aluminum, copper, brass, magnesium, zinc, or the like) to act as a heat sink and conduct heat energy away from LEDs **103**. In the present embodiment, each LED **103** mounted on support structure **107** may be angled such that the plurality of LEDs **103** emits light that projects radially outward from the center of shell **101** to emulate the isotropic emission of point light source. It should be recognized, however, that LEDs **103** need not be angled. Also, LEDs **103** can be mounted directly to chassis **117** rather than to support structure **107**.

[0027] As depicted in FIG. **1**A, in the present embodiment, support structure **107** is formed in a toroidal configuration around chassis **117**. Support structure **107** is secured around chassis **117** by engaging corresponding interlocking members disposed on opposite ends of support structure **107**. As shown in FIG. **2**, in the present embodiment, male interlocking member **208** and female interlocking member **206** are disposed on opposite ends of support structure **107**. Male interlocking member **208** may be frictionally fitted into female interlocking member **206** to secure support structure **107** around chassis **117** in a toroidal configuration. It should be recognized that interlocking members **206** and **208** shown in FIG. **2** are exemplary and that other configurations may be used to engage together the opposite ends of support structure **107**.

[0028] With reference to FIG. **1**A, in the present embodiment, support structure **107** has openings **121** that engage with corresponding tabs **122** of chassis **117** to secure support structure **107** around chassis **117**. Openings **121** of support structure **107** engage tabs **122** of chassis **117** to resist support structure **107** from slipping down or rotating with respect to chassis **117**. One advantage of such a configuration is greater ease of assembly and lower production costs where, in the present embodiment, support structure **107** may be secured around chassis **117** without the use of fasteners or adhesives. It should be recognized, however, that instead of support structure **107** having openings that engage with corresponding tabs of chassis **117**, support structure **107** may alternatively have tabs that engage with corresponding openings on chassis **117**. Additionally, LED bulb **100** may include more than one support structure **107** and the support structures **107** may be attached in various configurations around chassis **117**.

[0029] With reference to FIG. **3**, in the present embodiment, chassis **117** comprises a body portion **117**A and a cap portion **117**B. In particular, body portion **117**A interlocks with cap portion **117**B. In the present embodiment, body portion **117**A is tubular shaped, and cap portion **117**B is dome shaped. Chassis **117** includes a center ridge portion **302**. Center ridge portion **302** extends out from the outer surface of chassis **117**. Tabs **122** are disposed on center ridge portion **302**. As described above, referring back to FIG. **1**A, support structure **107** is attached to chassis **117** at center ridge portion **302** (FIG. **3**). It should be recognized, however, that chassis **117** may have various shapes.

[0030] As mentioned above and depicted in FIG. **1**A, chassis **117** has first opening **118** and second opening **119**, which is spaced from first opening **118**, to facilitate a passive convective flow of thermally conductive liquid **111** to transfer heat generated by LEDs **103** to shell **101**. In the present embodiment, first opening **118** is formed in cap portion **117**B opposite base **110**. First opening **118** is proximate a first end (depicted in FIG. **1**A as being the top end) of the enclosed volume formed by shell **101** and base **110**. Second opening **119** is proximate a second end (depicted in FIG. **1**A as being the bottom end) of the enclosed volume formed by shell **101** and base **110**. As depicted in FIG. **3**, second opening **119** is formed as a set of slots spaced around the circumference of body portion **117**A.

[0031] FIG. **1**B depicts the interior of chassis **117** that encloses a volume of thermally conductive liquid. Heat generated by LEDs **103** is directed preferentially through chassis **117**. As a result, the volume of thermally conductive liquid within the chassis **117** (volume **111**B) near cap portion **117**B heats up faster than the volume of thermally conductive liquid exterior chassis **117** (volume **111**A). As will be described in greater detail below with respect to FIGS. **4**A-**4**C, the thermal gradient between the inside and outside of chassis **117**, combined with openings **118** and **119**, facilitate the passive convective flow of liquid, which exchanges the cooler volume thermally conductive liquid exterior chassis **117** (volume **111**A) with warmer volume of thermally conductive liquid within the chassis **117** (volume **111**B).

[0032] FIGS. **4**A-**4**C illustrate the passive convective flow of thermally conductive liquid overlaid on a cross-sectional view of LED bulb **100**. In particular, FIG. **4**A illustrates a cross-sectional view of the top portion of LED bulb **100** positioned in an upright vertical orientation in which shell **101** is disposed vertically above base **110** (FIG. **1**A). The arrows indicate the direction of liquid flow during operation of LED bulb **100**. The volume of thermally conductive liquid within the chassis **117** (volume **111**B) at the center of LED bulb **100** is shown rising towards the top of shell **101**. This is due to the heat generated by LEDs **103** and conductively transferred to the thermally conductive liquid via LEDs **103** to chassis **117**. As the thermally conductive liquid is heated, its density decreases relative to the surrounding liquid, thereby causing the heated liquid to rise to the top of shell **101**.

[0033] Chassis **117** separates the warmer volume of thermally conductive liquid within chassis **117** (volume **111**B) from the cooler volume of thermally conductive liquid exterior the chassis **117** (volume **111**A). This separation causes a thermal gradient that, when combined with openings **118** and **119**, facilities the liquid to flow and intermix the cooler to the warmer regions of LED bulb **100**. For example, since the volume of thermally conductive liquid within chassis **117** (volume **111**B) heats faster than the surrounding liquid, an upward flow of thermally conductive liquid is generated within chassis **117**. The warmer liquid rises through opening **118** passing from the interior to the exterior of chassis **117**.

[0034] Once heated, the thermally conductive liquid reaches the top portion of shell **101**. Heat is conductively transferred to shell **101**, causing the volume of thermally conductive liquid exterior the chassis **117** (volume **111**A) to cool. As the liquid cools, its density increases, thereby causing the liquid to fall. In one example, as illustrated by FIG. **4**A, the volume of thermally conductive liquid within the chassis **117** (volume **111**B) rises through opening **118** and forces a cooler volume of thermally conductive liquid exterior the chassis **117** (volume **111**A) to flow down in close proximity to shell **101**. By doing so, the liquid remains in contact with shell **101** for a greater period of time, allowing more heat to be conductively transferred to shell **101**. In addition, since the downward flow of the liquid is concentrated along the surface of shell **101**, the shear force between the upward flowing liquid at the center of LED bulb **100** and the downward flowing liquid along the surface of shell **101** is reduced, thereby increasing the convective flow of thermally conductive liquid within LED bulb **100**.

[0035] Once reaching the bottom of shell **101**, the volume of thermally conductive liquid exterior the chassis **117** (volume **111**A) flows inwards through opening **119** and rises within chassis **117** as heat generated by LEDs **103** warms the liquid. The heated volume of thermally conductive liquid within chassis **117** (volume **111**B) is again guided within the chassis **117** as described above. The described convective cycle continuously repeats during operation of LED bulb **100** to cool LEDs **103**. It should be appreciated that the convective flow described above represents the general flow of liquid within shell **101**. One of ordinary skill in the art will recognize that some of the thermally conductive liquid may not reach the top and bottom of shell **101** before being cooled or heated sufficiently to cause the liquid to fall or rise. It should also be recognized that the convective flow created by chassis **117** can supplement the convective flow created by mounts **202** and channels **204** (FIG. **2**).

[0036] FIG. **4**B illustrates two cross-sectional views of the top portion of LED bulb **100** positioned in a horizontal orientation in which shell **101** is disposed on the same plane as base **110**. FIG. **4**B includes both a side view of LED bulb **100** and a front view looking into the top portion of LED bulb **100**. Similar to those in FIG. **4**A, the arrows indicate the direction of liquid flow during operation of LED bulb **100**. In the side view of FIG. **4**B, the volume of thermally conductive liquid within chassis **117** (volume **111**B) heats faster than the surrounding liquid and rises through opening **119** to the top (previously side) of shell **101**. This is due to the heat generated by LEDs **103** and conductively transferred to the thermally conductive liquid via LEDs **103**. As the thermally conductive liquid is heated, its density decreases, thereby causing the heated liquid to rise to the top (previously side) of LED bulb **100**.

[0037] Once the heated, thermally conductive liquid reaches the top (previously side) portion of shell **101**, heat is conductively transferred to shell **101**, causing the volume of thermally conductive liquid exterior the chassis **117** (volume **111**A) to cool. As the volume of thermally conductive liquid exterior the chassis **117** (volume **111**A) cools, its density increases, thereby causing the liquid to fall. In one example, as illustrated by FIG. **4**B, the volume of thermally conductive liquid within chassis **117** (volume **111**B) rises through opening **119**, impinges on shell **101** and cools. The cooler volume of thermally conductive liquid exterior the chassis **117** (volume **111**A) flows down in close proximity to shell **101**. By doing so, liquid remains in contact with shell **101** for a greater period of time, allowing more heat to be conductively transferred to shell **101**.

[0038] As illustrated by the front view of FIG. **4**B, the top-view profile of support structure **107** may be similar to the shape of shell **101**. In the illustrated example, this shape is a circular ring. However, it should be appreciated that shell **101** and support structure **107** may be formed into any other desired shape. As a result of support structure **107** conforming to the shape of shell **101**, the outer side surfaces of support structure **107** may guide the flow of the cooled, thermally conductive liquid down the side surfaces of shell **101**. By doing so, the volume of thermally conductive liquid exterior the chassis **117** (volume **111**A) remains in contact with shell **101** for a greater period of time, allowing more heat to be conductively transferred to shell **101**. Since the downward flow of the liquid is concentrated on the outer surface of shell

101, the shear force between the upward flowing liquid at the center of LED bulb 100 and the downward flowing liquid along the surface of shell 101 is reduced, thereby increasing the convective flow of thermally conductive liquid within LED bulb 100.

[0039] Once reaching the bottom of shell 101, the thermally conductive liquid flows through opening 119, situated towards the bottom, and rises within chassis 117 as heat generated by LEDs 103 warms the liquid. The heated volume of thermally conductive liquid within chassis 117 (volume 111B) is again guided through the chassis as described above. The described convective cycle continuously repeats during operation of LED bulb 100 to cool LEDs 103. It should be appreciated that the convective flow described above represents the general flow of liquid within shell 101. One of ordinary skill in the art will recognize that some of the thermally conductive liquid may not reach the top and bottom of shell 101 before being cooled or heated sufficiently to cause the liquid to fall or rise. It should also be recognized that the convective flow created by chassis 117 can supplement the convective flow created by mounts 202 and channels 204 (FIG. 2).

[0040] FIG. 4C illustrates a cross-sectional view of the top portion of LED bulb 100 positioned in an upside-down vertical orientation in which shell 101 is disposed vertically below base 110. The arrows indicate the direction of liquid flow during operation of LED bulb 100. The volume of thermally conductive liquid within chassis 117 (volume 111B) heats faster than the surrounding liquid and rises through opening 119 to the top (previously bottom) of shell 101. This is due to the heat generated by LEDs 103 conductively transferred to thermally conductive liquid via LEDs 103. As the thermally conductive liquid is heated, its density decreases, thereby causing the heated liquid to rise to the top (previously bottom) of LED bulb 100.

[0041] Once the heated, thermally conductive liquid reaches the top (previously bottom) portion of shell 101, heat is conductively transferred to shell 101, causing a volume of thermally conductive liquid exterior the chassis 117 (volume 111A) to cool. As the thermally conductive liquid cools, its density increases, thereby causing the cooler liquid to fall. Since the heated, thermally conductive liquid is forced up and outwards in an upside-down vertical orientation, the cooled, thermally conductive liquid falls down the sides of shell 101. This allows the volume of thermally conductive liquid exterior the chassis 117 (volume 111A) to remain in contact with shell 101 for a greater period of time, allowing more heat to be conductively transferred to shell 101. In addition, since the downward flow of thermally conductive liquid is concentrated along the surface of shell 101, the shear force between the upward flowing liquid at the center of LED bulb 100 and the downward flowing liquid along the surface of shell 101 is reduced, thereby increasing the convective flow liquid within LED bulb 100.

[0042] Once reaching the bottom (previously top) of shell 101, the volume of thermally conductive liquid exterior the chassis 117 (volume 111A) may move through opening 118 and rise as heat generated by LEDs 103 warms the liquid. The described convective cycle continuously repeats during operation of LED bulb 100 to cool LEDs 103. It should be appreciated that the convective flow described above represents the general flow of liquid within shell 101. One of ordinary skill in the art will recognize that some of thermally conductive liquid may not reach the top and bottom of shell 101 before being cooled or heated sufficiently to cause the liquid to fall or rise. It should also be recognized that the convective flow created by chassis 117 can supplement the convective flow created by mounts 202 and channels 204 (FIG. 2).

2. Thermal Models

[0043] The following examples demonstrate heat distribution within a bulb around a chassis and how the addition of openings 118 and 119 facilitate an effective passive convection flow of the thermal conductive liquid that cools the LEDs. In each of the examples, body portion 117A and cap portion 117B are made of aluminum and form chassis 117. Shell 101 is made from transparent polycarbonate and encloses the silicone oil and the chassis. To account for thermal expansion of the silicone oil, a compressible bladder is added within the shell and chassis that expands and contracts accordingly. For simplicity, the temperature on the outside wall of shell 101 is maintained at 70 degrees Celsius and 6.2 Watts of heat is applied to the side of cap portion 117B.

[0044] The model extrudes in three dimensions using a field solver that discretizes mesh nodal points to resolve solutions for the heat equations for the polycarbonate shell, aluminum chassis, and the diaphragm, as well as the fluid flow heat transfer equations of the silicone oil. Further, each exemplar model orients the top portion of LED bulb 100 positioned upright and vertical in which shell 101 is disposed vertically above base 110.

A. Model with Opening 118

[0045] FIG. 5A illustrates a cross-sectional view of the thermal model of the steady state heat distribution for the bulb with a maximum temperature of 95.1 degrees Celsius. The model includes a 6.5 mm diameter opening 118 formed in the top of cap portion 117B. This configuration impedes the exchange between the cooler volume of silicone oil exterior the chassis 117 (volume 111A) and the warmer volume of silicone oil within the chassis 117 (volume 111B). The exchange is only permitted through opening 118. As such, the passive thermal convective flow of the silicone oil forms two separate cycles: one cycle within the chassis consisting predominately of heated silicon oil and another cycle outside the chassis consisting predominately of cooler silicone oil. For the most part these passive convective flow cycles function separately with limited convective flow exchange.

[0046] The inner chassis passive convective flow cycle has a large volume of heated silicon oil contained within cap portion 117B since the silicone oil is exposed to a large portion of the heated chassis with limited access to cooler silicone oil near the shell surface. As illustrated in FIG. 5A, the cooler silicon oil above opening 118 falls through the center of opening 118 and around the compressible bladder to base 110, while the heated silicone oil rises along chassis 117 and through opening 118 in close proximity to chassis 117. The heated silicone oil exiting chassis 117 rises to shell 101 and cools, where most falls back into chassis 117 and continues the cycle described above.

[0047] The outer chassis passive convective flow cycle has a large volume of colder silicon oil since the silicone oil is exposed to a large portion of the shell surface. Heated silicon oil exterior the chassis 117 (volume 111A) rises along the surface of cap portion 117B to the surface of shell 101 and remains in contact with shell 101 for a greater period of time, allowing more heat to be conductively transferred to shell 101. The silicone oil impinges on the outside surface of chassis **117**, thereby providing significant cooling to the chassis as depicted in FIG. **5**A. The silicone fluid warms, rises, and is directed in close proximity to the chassis toward shell **101** in which the silicone oil continually repeats the cycle described above.

[0048] It should be appreciated that the passive thermal convective flow cycles described above represent the general flow of liquid within shell **101**. One of ordinary skill in the art will recognize that some of the silicone oil may not reach the top and bottom of shell **101** before being cooled or heated sufficiently to cause the silicon to fall or rise.

B. Model with Openings **119**

[0049] FIG. **5**B illustrates a cross-sectional view of the thermal model of the steady state heat distribution for the bulb with a maximum temperature of 94.9 degrees Celsius. The model includes opening **119** configured as a set of slots, each slot 2 mm wide and 6 mm high, spaced around the circumference of body portion **117**A situated toward base **110**.

[0050] This configuration impedes the exchange between the cooler volume of silicone oil exterior the chassis **117** (volume **111**A) and the warmer volume of silicone oil within the chassis **117** (volume **111**B). The exchange is limited to opening **119**. Thus, as depicted in FIG. **5**B, cap portion **117**B encloses the heated silicon oil and maintains a fairly uniform temperature distribution of the heated volume of silicone oil within the chassis **117** (volume **111**B), particularly, within cap portion **117**B. As such, the thermal passive convective flow of the silicone oil forms two separate cycles: one cycle within chassis **117** consisting predominately of heated silicon oil and another cycle outside chassis **117** consisting predominately of cooler silicone oil. For the most part, these passive convective flow cycles function separately with limited exchange.

[0051] The inner chassis passive convective flow cycle is driven by the interaction of the large volume of silicone oil within cap portion **117**B and the coolness of the compressible bladder in the center of chassis **117**, which creates a thermal gradient sufficient to cool some of the heated silicon oil within cap portion **117**B. The cooler compressible bladder diaphragm causes the silicone oil to fall preferentially along the cooler region that is in close proximity to the compressible bladder. The silicone oil then heats and rises along the warmer chassis **117** toward cap portion **117**B. Upon warming, some of the silicone oil may exchange through opening **119** and rise in close proximity to the exterior of the chassis. However, as shown in FIG. **5**B most of the warmed silicone oil is directed to remain on the inside of chassis **117**. Thus, the volume of silicone oil within chassis **117** (volume **111**B), for the most part, cycles only inside chassis **117**.

[0052] The volume of silicone oil exterior the chassis **117** (volume **111**A) exhibits a similar heating and cooling cycle where cap portion **117**B heats the silicone oil and rises in close proximity to the surface of cap portion **117**B. The silicone oil is brought into close proximity to the surface of shell **101**, cools, and falls along the surface of shell **101**. The falling silicone oil remains in contact with shell **101** for a large period of time, allowing more heat to be conductively transferred to shell **101**. The colder silicone oil impinges on the outside surface of chassis **117**, drastically cooling the chassis region below opening **119** as depicted in FIG. **5**B. The silicone fluid again warms, rises, and continues the cycle described above.

C. Model with Openings **118** and **119**

[0053] FIG. **5**C illustrates a cross-sectional view of the thermal model of the steady state heat distribution for the bulb with a maximum temperature of 94.0 degrees Celsius. The model includes opening **119** configured as a set of slots, each slot 2 mm wide and 6mm high, spaced around the circumference of body portion **117**A, positioned near cap portion **117**B. The model further has a 6.5 mm diameter opening **118** in the top of cap portion **117**B. This configuration facilitates a passive thermal convective flow cycle that promotes the exchange between the cooler volume of silicone oil exterior the chassis **117** (volume **111**A) and the warmer volume of silicone oil within the chassis **117** (volume **111**B).

[0054] As illustrated in FIG. **5**C, the cap portion **117**B warms the silicone oil within chassis **117**. The heated silicone oil rises though opening **118** and is directed in close proximity to shell **101**. The silicon oil cools and falls along the surface of shell **101** and remains in contact with shell **101** for a large period of time, allowing more heat to be conductively transferred to shell **101**. The colder silicone oil is directed along the surface of shell **101**, and impinges on the outside surface of body portion **117**A, which cools the chassis region below opening **119** as depicted in FIG. **5**C. The silicone fluid again warms, rises, and is preferentially directed up through opening **119** in close proximity of the warm chassis walls towards cap portion **117**B. The described convective cycle continuously repeats. It should be appreciated that the convective flow described above represents the general flow of liquid within shell **101**.

[0055] FIG. **5**C has other minor cycles that mix with the main cycle described above. For example, heated silicone oil on the outside of cap portion **117**B rises toward shell **101**. The silicone oil then cools and falls along the inner surface of shell **101**. The silicone oil may be directed to the region slightly above opening **119**, exterior chassis **117**, where the silicone oil warms and rises, being directed along the surface of the outside of cap portion **117**B where the cycle begins again. It should be recognized that the silicone oil in this cycle intermixes the main cycle described above when the oil is in close proximity to shell **101**, thereby providing greater exchange between the warmer and cooler regions of LED bulb **100**.

[0056] Another minor passive thermal flow cycle example includes volume of silicone oil within the chassis **117** (volume **111**B) that cools in proximity to the compressible bladder in the center of chassis **117**. The cooler silicone oil falls and is directed in proximity to the compressible bladder towards base **110**. The silicone oil then heats and rises along the warmer body portion **117**A toward cap portion **117**B and again cools in proximity to the compressible bladder where the cycle begins again. It should be recognized that the silicone oil in this minor cycle intermixes the main cycle described above when the oil is in close proximity to the chassis interior, thereby providing greater exchange between the cooler volume of silicone oil exterior the chassis **117** (volume **111**A) and the warmer volume of silicone oil within the chassis **117** (volume **111**B).

D. Model with Openings **118** and **119** Near Base

[0057] FIG. **5**D illustrates a cross-sectional view of the thermal model of the steady state heat distribution for LED bulb **100** with a maximum temperature of 93.5 degrees Celsius. The model includes opening **119** configured as a set of slots, each slot 2 mm wide and 6 mm high, spaced around the circumference of body portion **117**A positioned preferentially closer to base **110**. The model further has a 6.5 mm diameter opening **118** in the top of cap portion **117**B.

[0058] This configuration improves the model illustrated in FIG. **5**C by increasing the exchange between the cooler volume of silicone oil exterior the chassis **117** (volume **111**A) and the warmer volume of silicone oil within the chassis **117** (volume **111**B). Specifically, lowering opening **119** provides access to the cooler silicone oil near base **110**. The cooler silicon oil exchange convectively transfers heat from the bottom of chassis **117** as opposed to impinging on the outer surface and conductively transferring the heat. Thus, lowering opening **119** as depicted in FIG. **5**D further optimizes the thermal exchange and decreases the maximum modeled temperature by 0.5 degrees Celsius compared to FIG. **5**C.

[0059] Although the invention has been described in conjunction with particular embodiments, it should be appreciated that various modifications and alterations may be made by those skilled in the art without departing from the spirit and scope of the invention. Embodiments may be combined and aspects described in connection with an embodiment may stand alone.

What is claimed is:

1. A light emitting diode (LED) bulb comprising:

a base;

a shell connected to the base forming an enclosed volume;

a thermally conductive liquid disposed within the enclosed volume;

a plurality of LEDs disposed within the shell and immersed in the thermally conductive liquid; and

a chassis disposed within the shell and immersed in the thermally conductive liquid, wherein the chassis has a first opening and a second opening, wherein the second opening is spaced from the first opening to facilitate a passive convective flow of the thermally conductive liquid to exchange a first volume of the thermally conductive liquid interior the chassis with a second volume of the thermally conductive liquid exterior the chassis.

2. The LED bulb of claim **1**, wherein the chassis comprises:

a body portion; and

a cap portion.

3. The LED bulb of claim **2**, wherein the first opening is formed in the cap portion, and wherein the second opening is formed in the body portion.

4. The LED bulb of claim **3**, wherein the first opening is located proximate a first end of the enclosed volume, wherein the second opening is located proximate a second end of the enclosed volume, and wherein the second end is opposite the first end.

5. The LED bulb of claim **3**, wherein the second opening is configured as a set of slots spaced around the body portion.

6. The LED bulb of claim **2**, wherein the body portion is tubular shaped, and wherein the cap portion is dome shaped.

7. The LED bulb of claim **1**, wherein the chassis is configured to facilitate the passive convective flow when the LED bulb is oriented in at least three different orientations comprising:

a first orientation in which the shell is disposed vertically above the base;

a second in which the shell is disposed on the same horizontal plane as the base; and

a third orientation in which the shell is disposed vertically below the base.

8. The LED bulb of claim **1**, further comprising:

a support structure, wherein the LEDs are mounted to the support structure.

9. The LED bulb of claim **8**, wherein the support structure comprises:

a plurality of tabs, wherein one of the LEDs is mounted to one of the tabs, and wherein a channel is formed between pairs of tabs.

10. The LED bulb of claim **8**, wherein the support structure is secured around the chassis.

11. The LED bulb of claim **10**, wherein the support structure includes openings, wherein the chassis includes tabs, and wherein the openings of the support structure engage with the tabs of the chassis.

12. The LED bulb of claim **1**, further comprising:

a volume compensation mechanism.

13. The LED bulb of claim **12**, wherein the volume compensation mechanism is a compressible bladder or a diaphragm.

14. The LED bulb of claim **1**, wherein the thermally conductive liquid is silicone oil.

15. A light emitting diode (LED) bulb comprising:

a base;

a shell connected to the base forming an enclosed volume;

a thermally conductive liquid disposed within the enclosed volume;

a plurality of LEDs disposed within the shell and immersed in the thermally conductive liquid; and

a chassis disposed within the shell and immersed in the thermally conductive liquid, wherein the chassis has a first opening and a second opening, wherein the first opening is proximate a first end of the enclosed volume and the second opening is proximate a second end of the enclosed volume to facilitate a passive convective flow of the thermally conductive liquid to exchange a first volume of the thermally conductive liquid interior the chassis with a second volume of the thermally conductive liquid exterior the chassis.

16. The LED bulb of claim **15**, wherein the chassis comprises:

a body portion; and

a cap portion.

17. The LED bulb of claim **16**, wherein the first opening is formed in the cap portion, and wherein the second opening is formed in the body portion.

18. The LED bulb of claim **17**, wherein the second opening is configured as a set of slots spaced around the body portion.

19. The LED bulb of claim **16**, wherein the body portion is tubular shaped, and wherein the cap portion is dome shaped.

20. The LED bulb of claim **15**, wherein the chassis is configured to facilitate the passive convective flow when the LED bulb is oriented in at least three different orientations comprising:

a first orientation in which the shell is disposed vertically above the base;

a second in which the shell is disposed on the same horizontal plane as the base; and

a third orientation in which the shell is disposed vertically below the base.

21. The LED bulb of claim **15**, further comprising:

a support structure, wherein the LEDs are mounted to the support structure.

22. The LED bulb of claim **21**, wherein the support structure comprises:

a plurality of tabs, wherein one of the LEDs is mounted to one of the tabs, and wherein a channel is formed between pairs of tabs.

23. The LED bulb of claim **21**, wherein the support structure is secured around the chassis.

24. The LED bulb of claim **23**, wherein the support structure includes openings, wherein the chassis includes tabs, and wherein the openings of the support structure engage with the tabs of the chassis.

25. The LED bulb of claim **15**, further comprising:

a volume compensation mechanism.

26. The LED bulb of claim **25**, wherein the volume compensation mechanism is a compressible bladder or a diaphragm.

27. A method of making a light emitting diode (LED) bulb, comprising:

obtaining a base;

connecting a shell to the base to form an enclosed volume, wherein the enclosed volume is filled with a thermally conductive liquid;

disposing a plurality of LEDs within the shell; and

disposing a chassis within the shell, the chassis having a first opening and a second opening, wherein the second opening is spaced from the first opening to facilitate a passive convective flow of the thermally conductive liquid to exchange a first volume of the thermally conductive liquid interior the chassis with a second volume of the thermally conductive liquid exterior the chassis.

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