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Edwards

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(54) **LIGHT EMITTING DIODE COOLING SYSTEMS AND METHODS**

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(57) **ABSTRACT**

A cooling system for a light emitting diode assembly includes a heat exchanger configured to exchange heat from a fluid to ambient air, an enclosure configured to house the LED assembly, and a pump configured to circulate the fluid through the enclosure, through the LED assembly, or both, and through the heat exchanger. The fluid is configured to absorb heat at the LED assembly and generated by the LED assembly, and the heat exchanger is configured to cool the fluid and remove the heat absorbed by the fluid at the LED assembly.

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(1 of 16 Drawing Sheet(s) Filed in Color)

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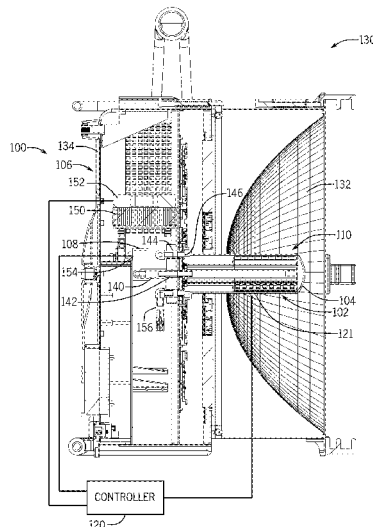
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F21V 29/61 (2015.01)
F21Y 115/10 (2016.01)

(52) **U.S. Cl.**
CPC **F21V 29/58** (2015.01); **F21V 29/59** (2015.01); **F21V 29/61** (2015.01); **F21Y 2115/10** (2016.08)

(58) **Field of Classification Search**
CPC F21V 29/59; F21V 29/61; F21Y 2115/10
USPC 165/287
See application file for complete search history.



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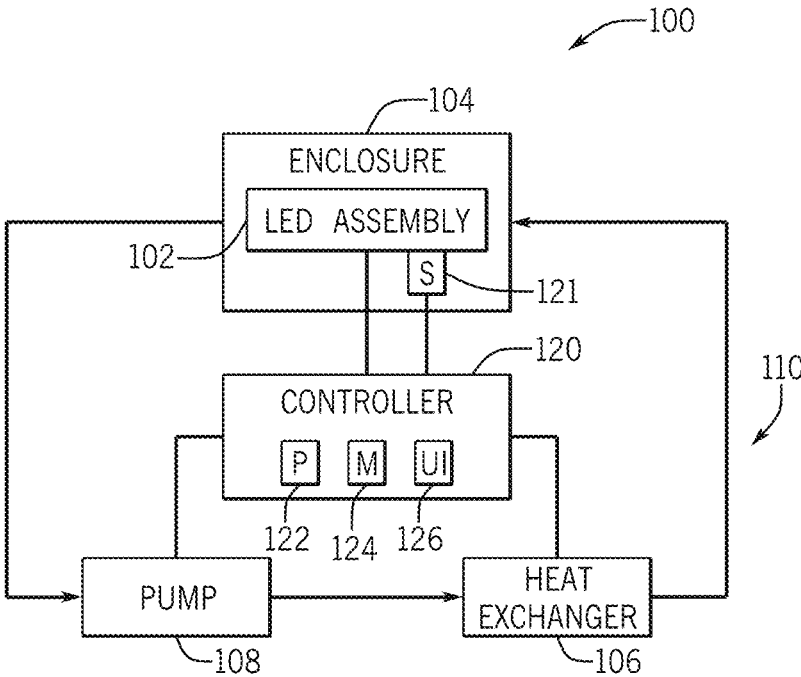


FIG. 1

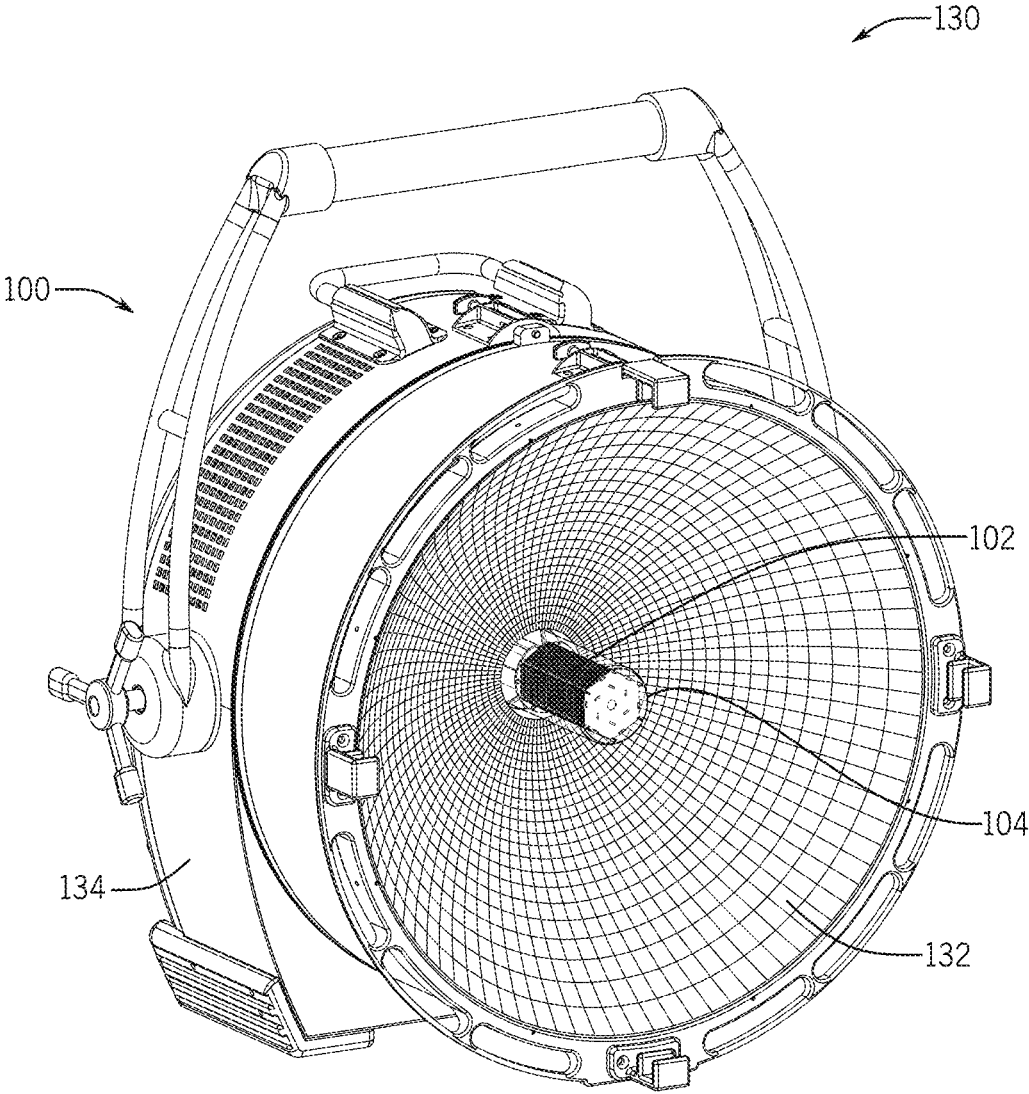


FIG. 2

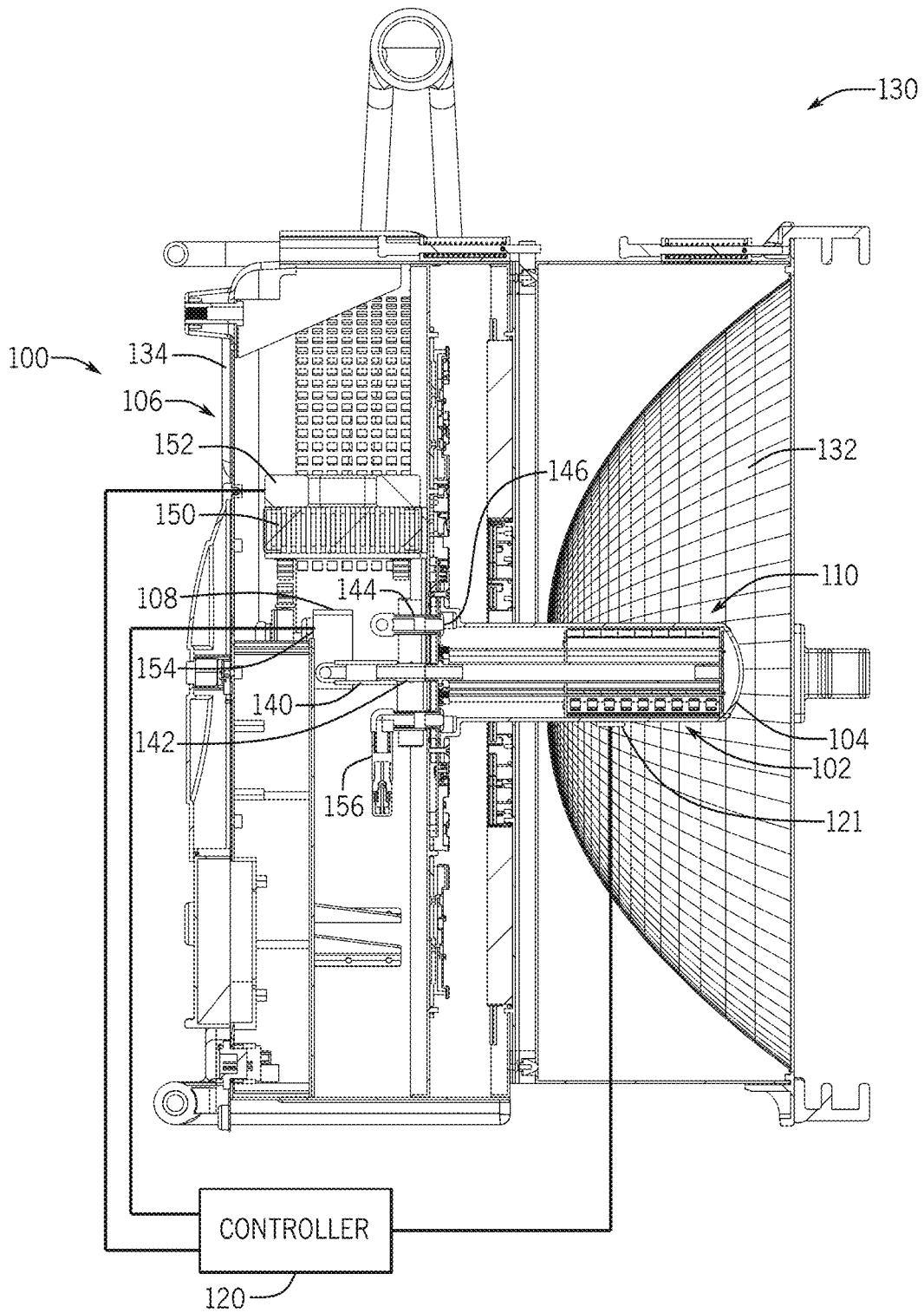


FIG. 3

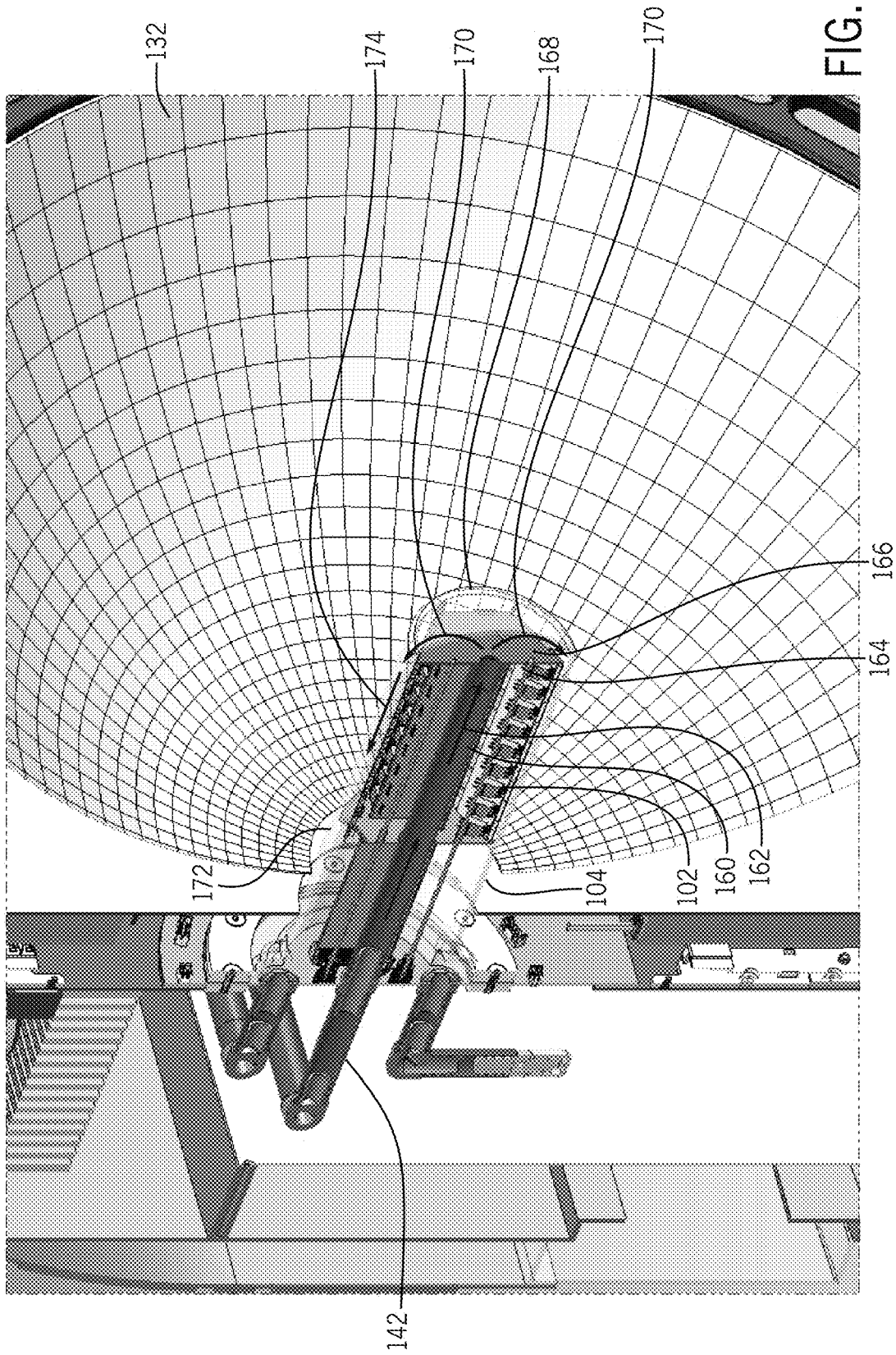


FIG. 4

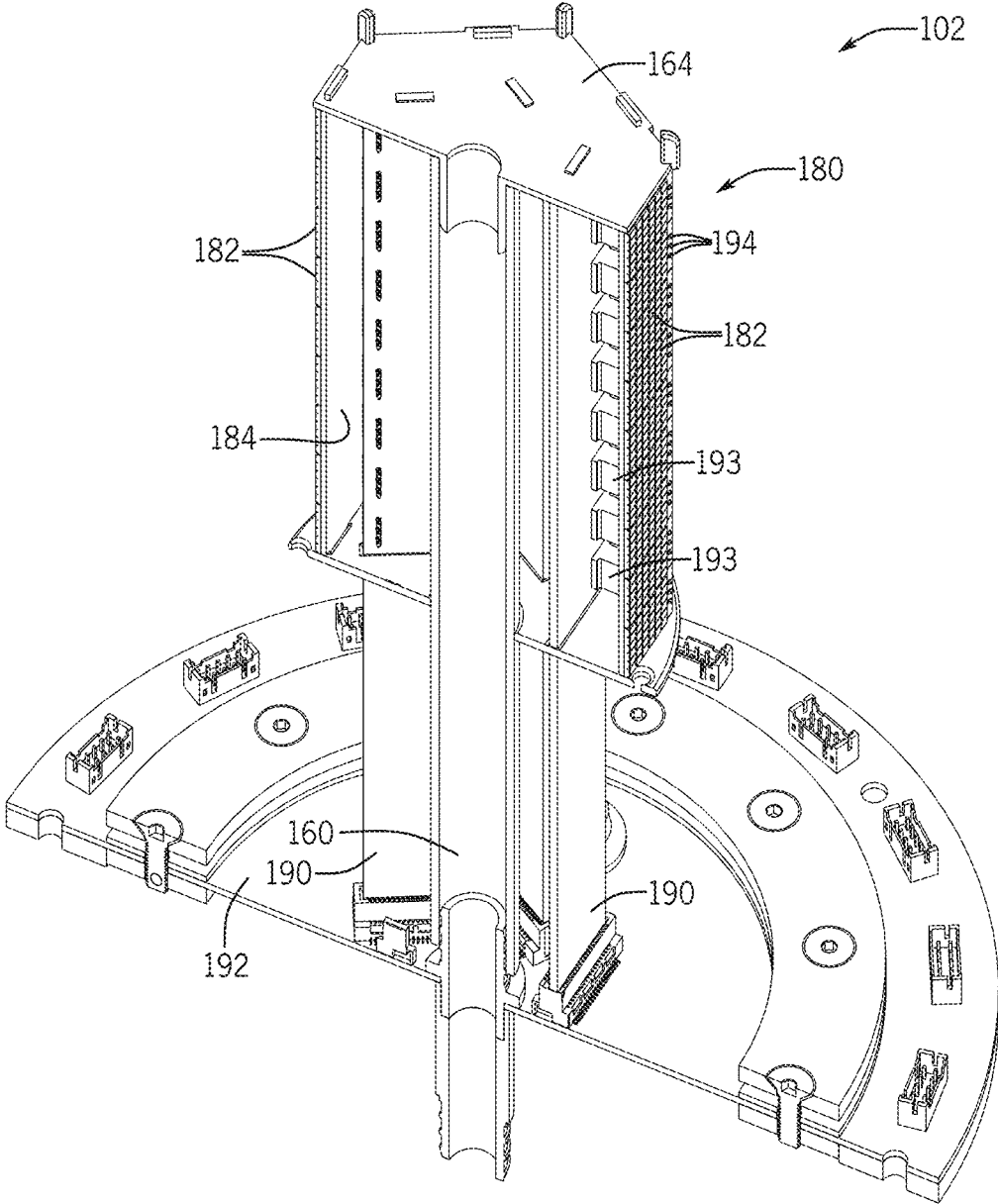


FIG. 5

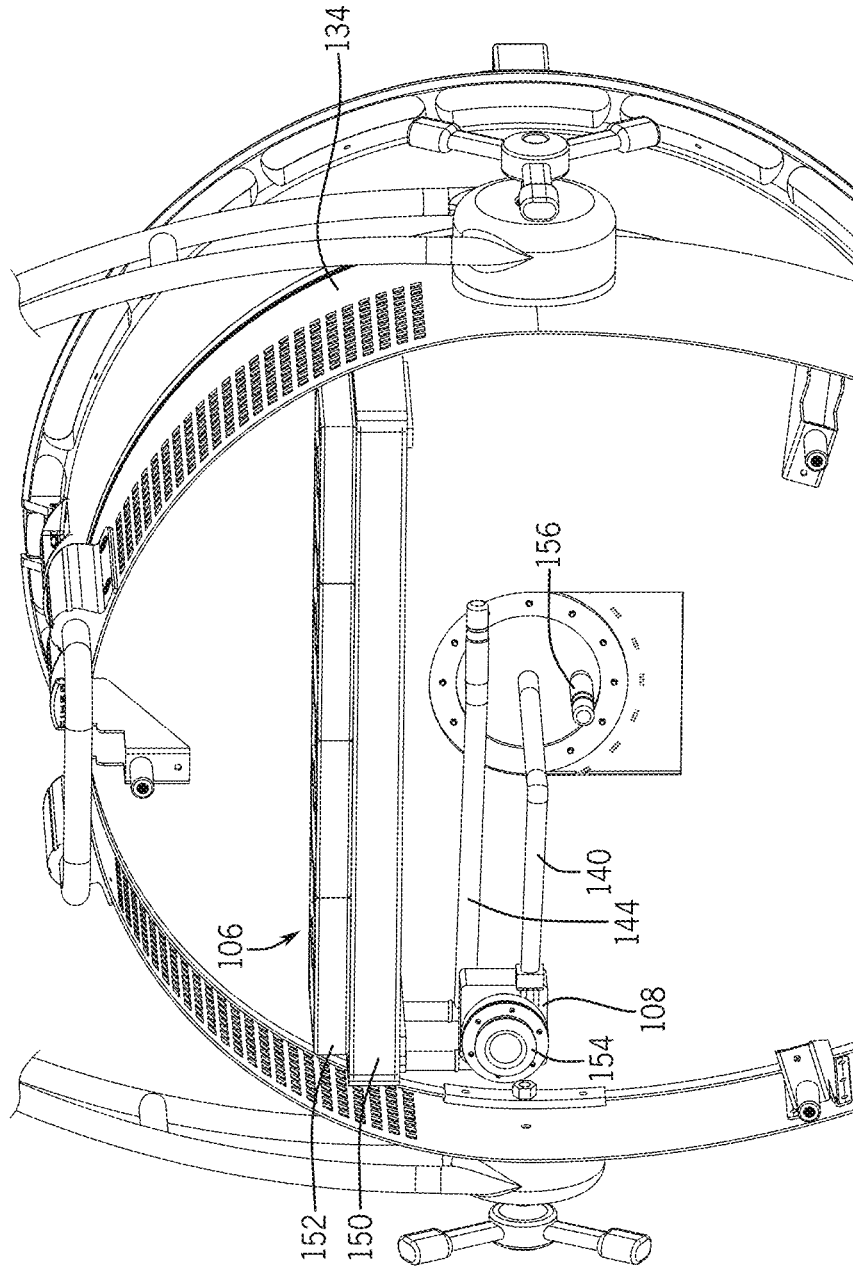


FIG. 6A

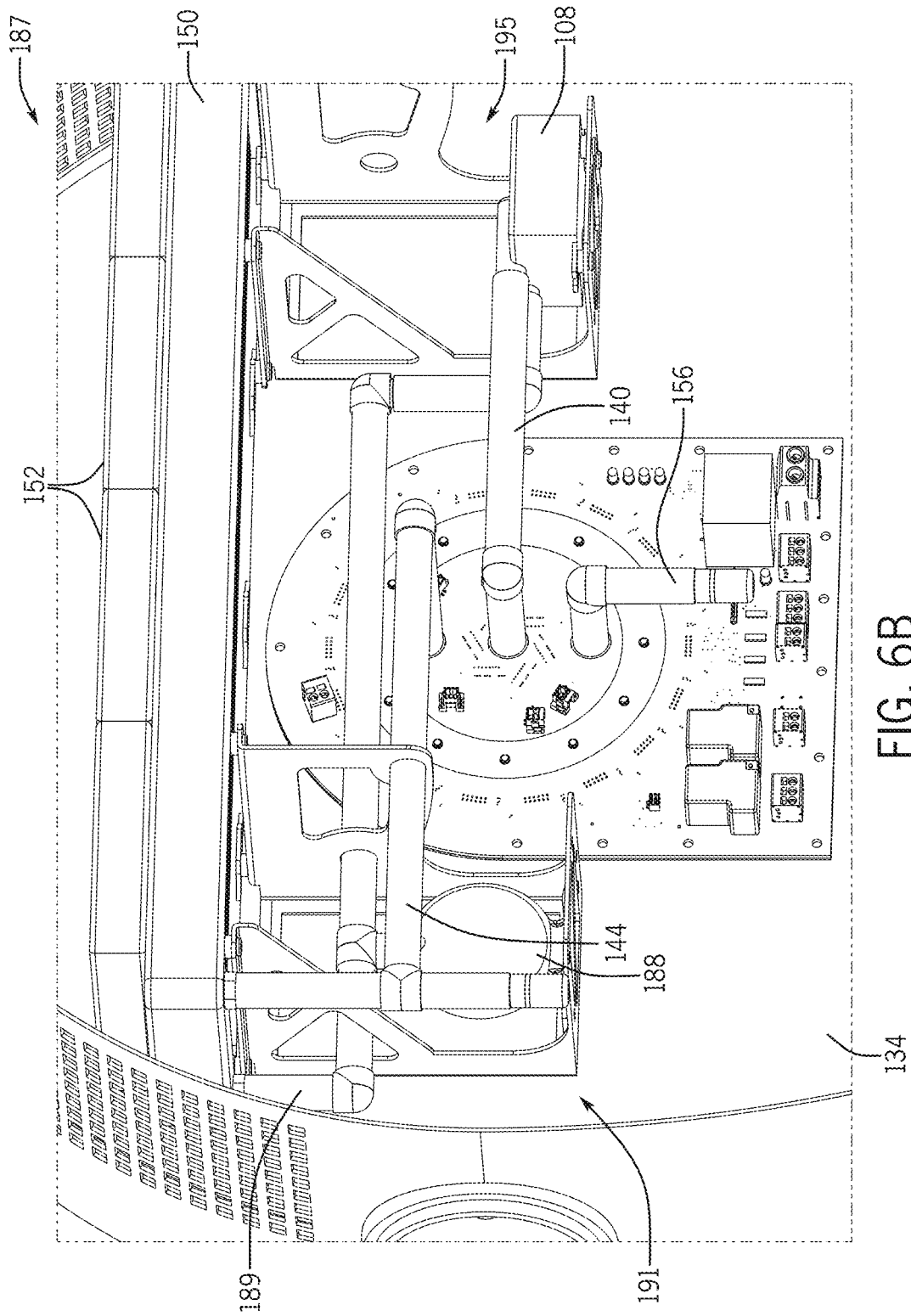


FIG. 6B

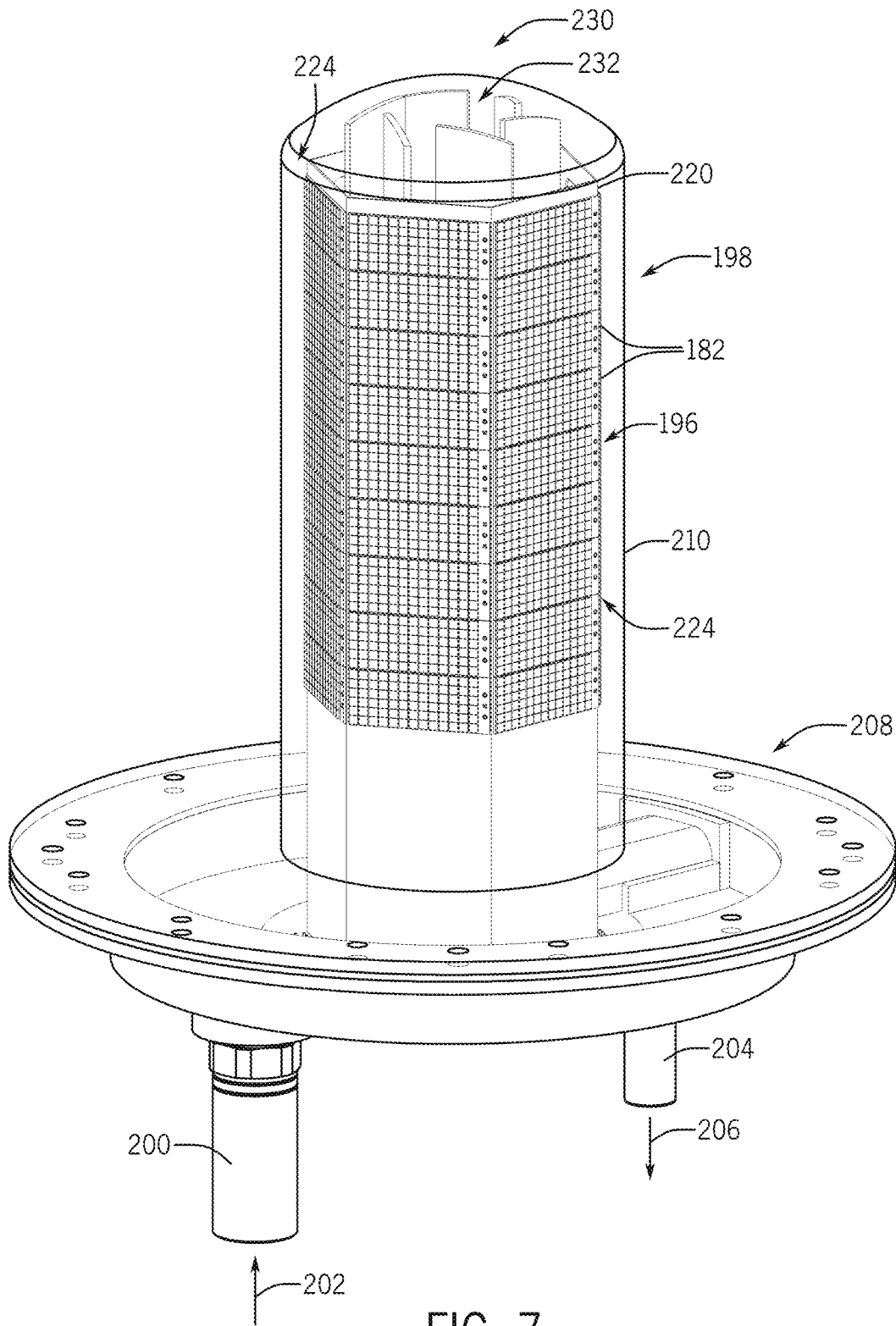


FIG. 7

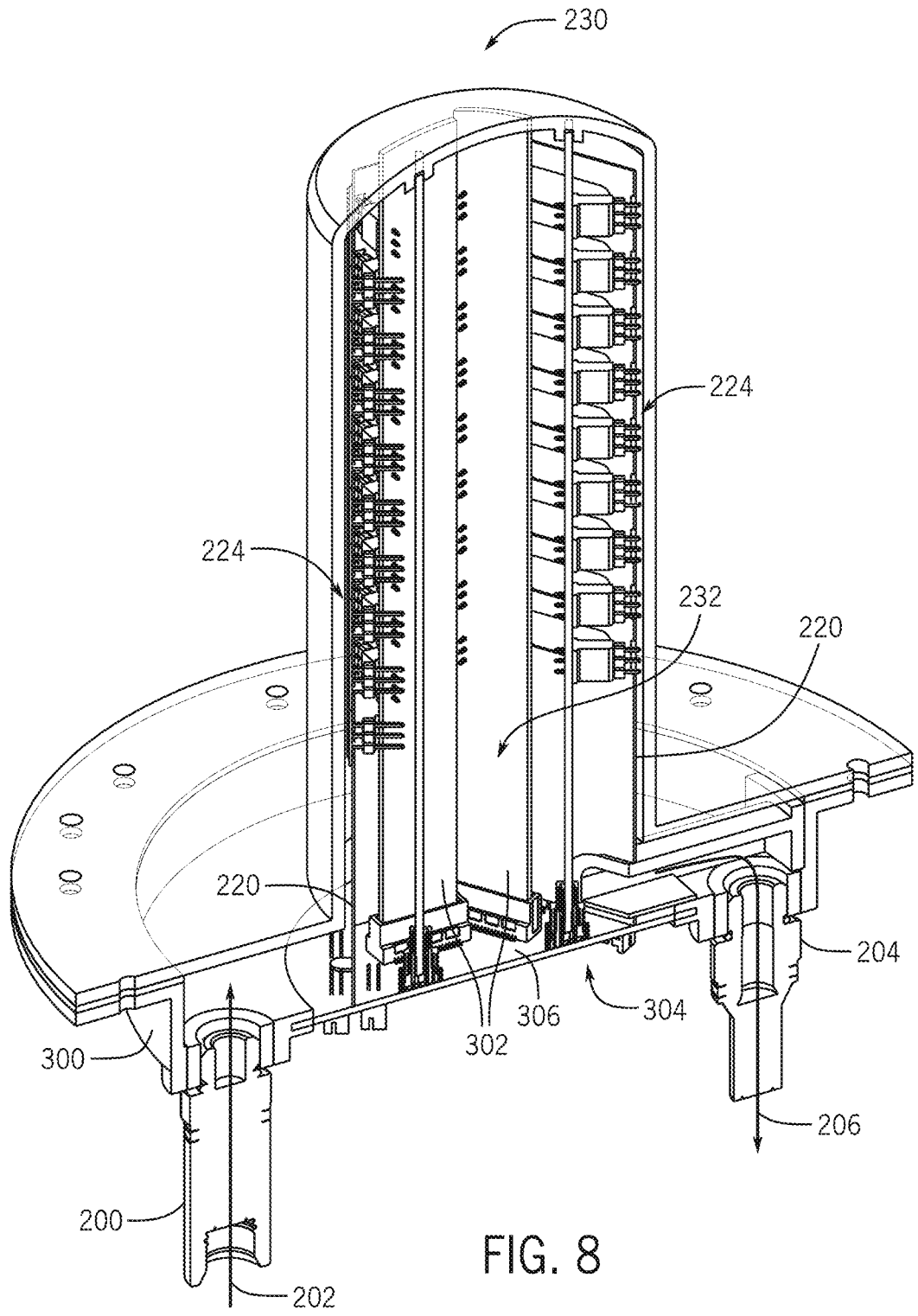


FIG. 8

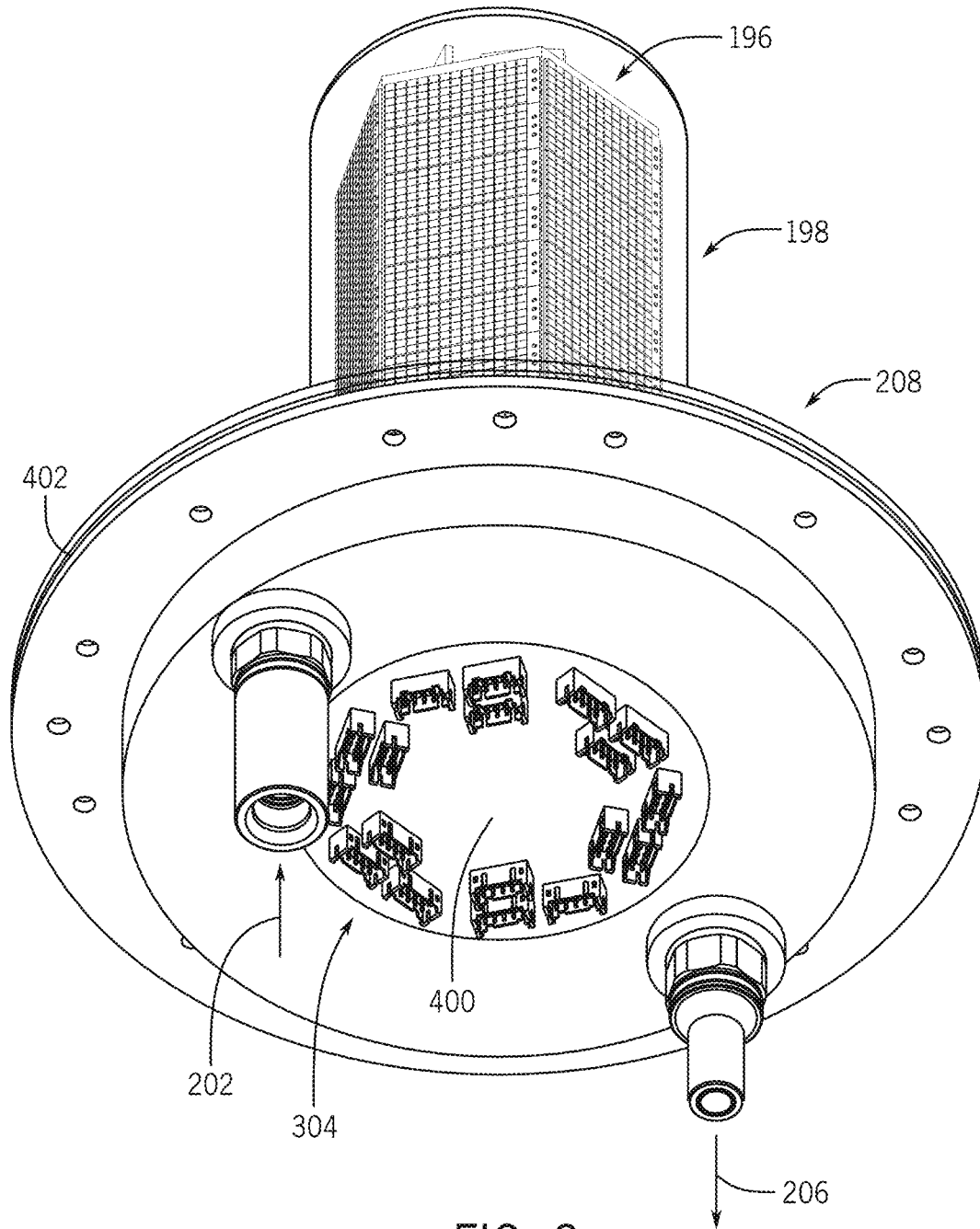


FIG. 9

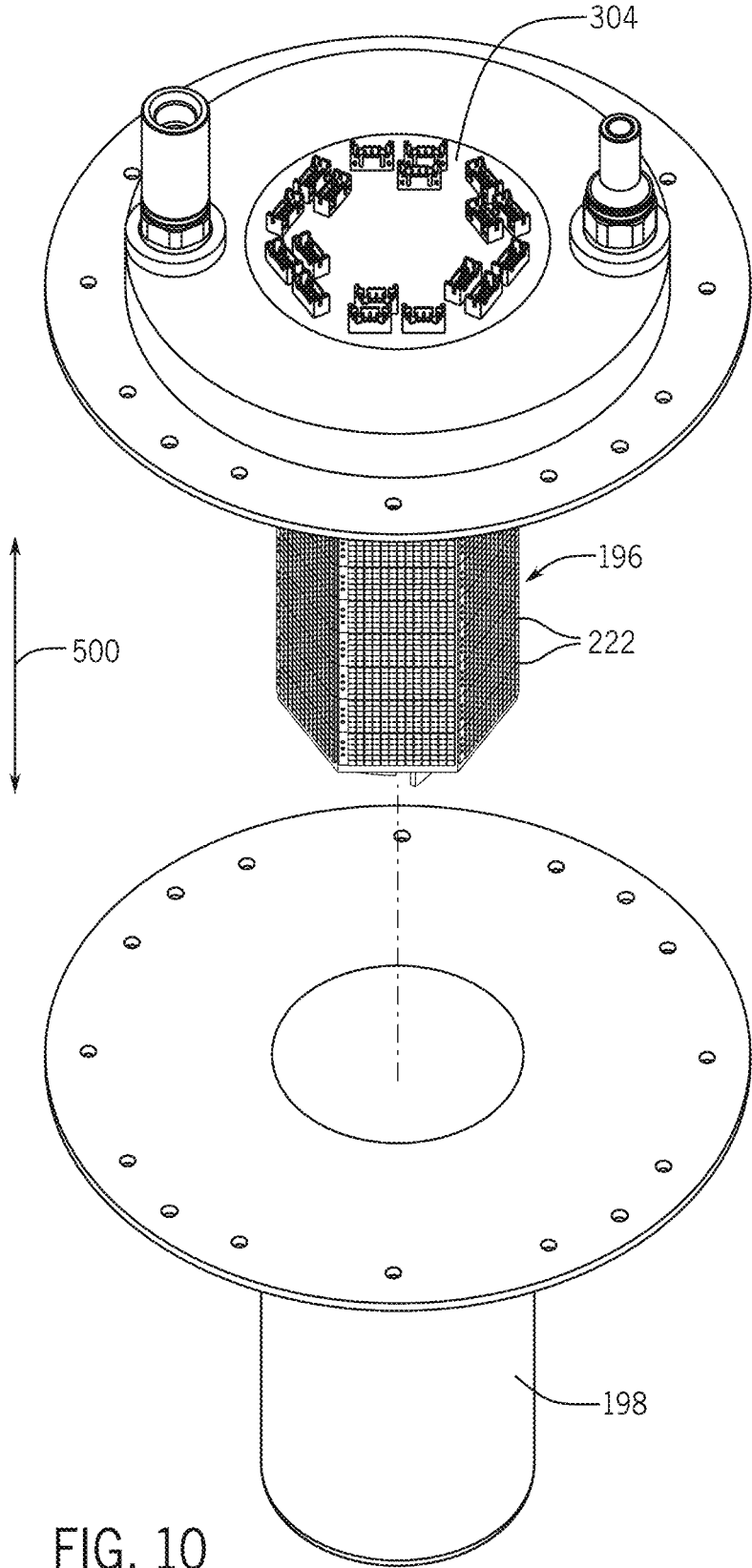
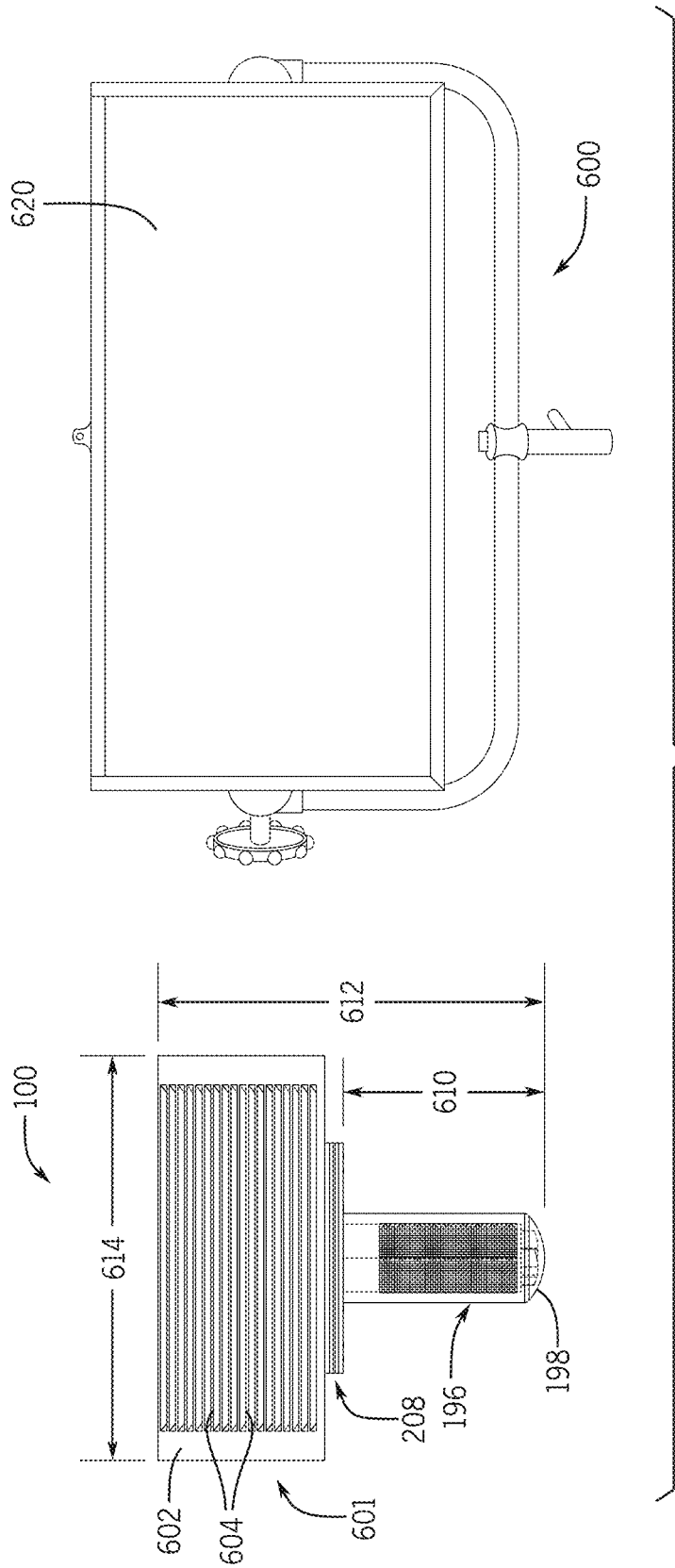


FIG. 10



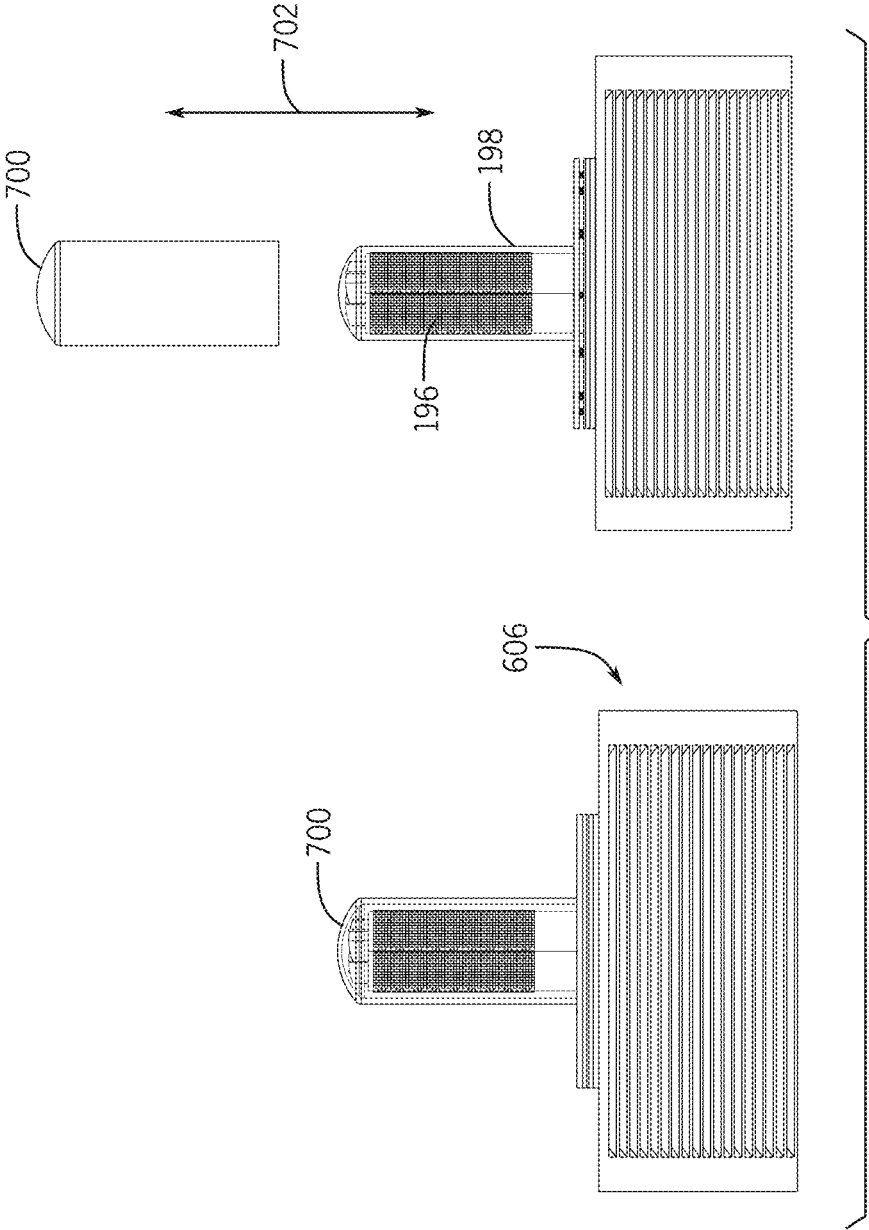
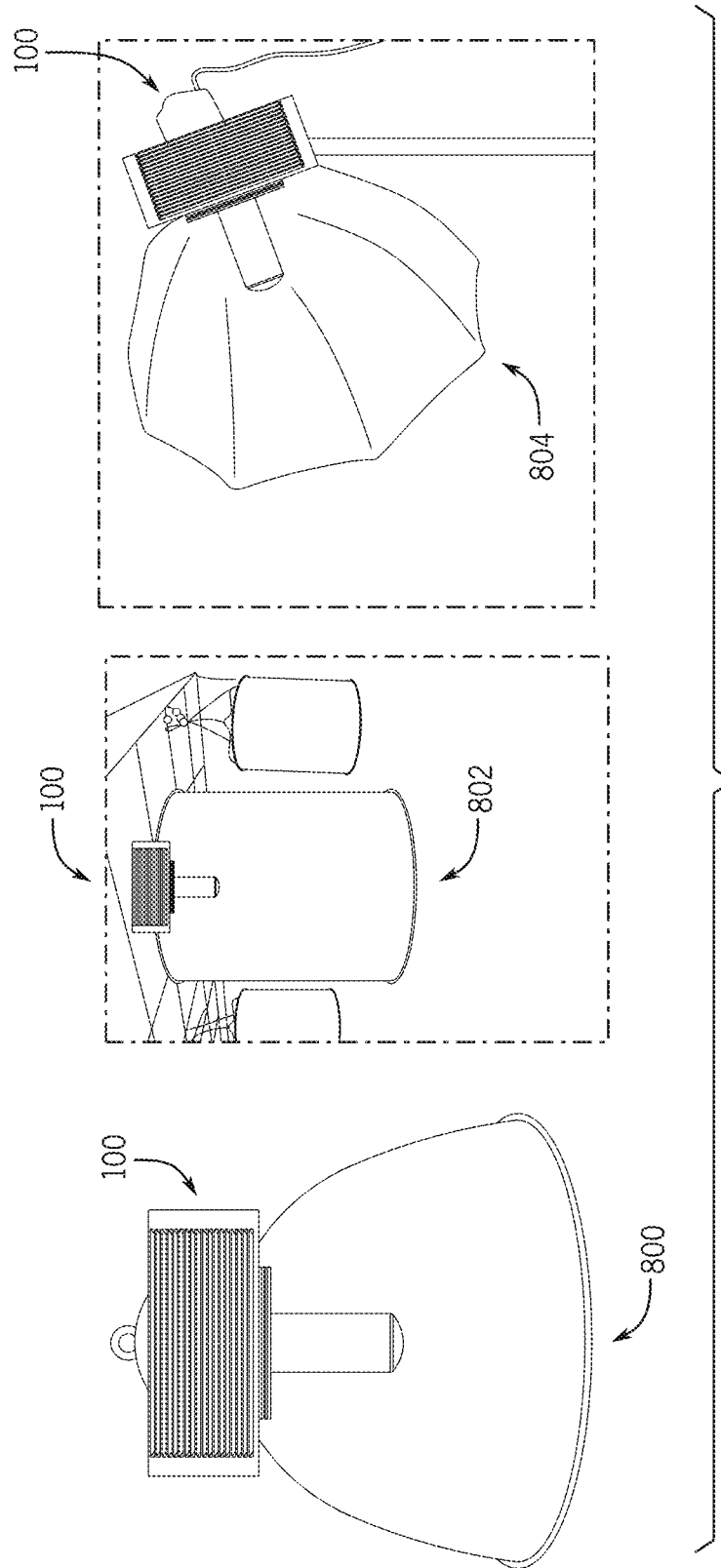
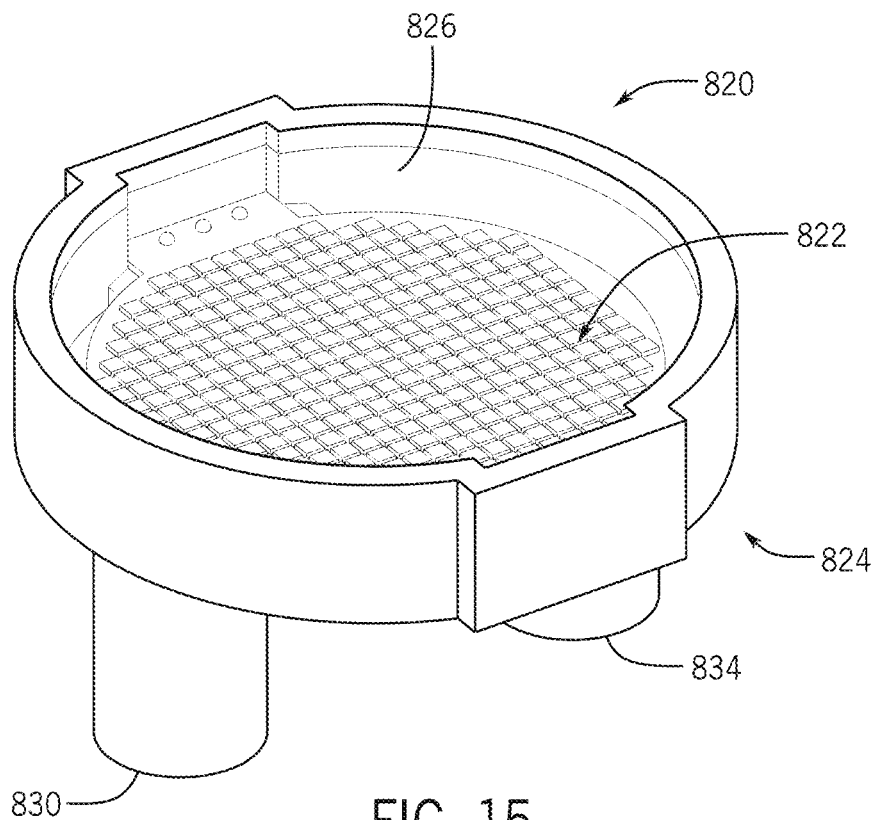
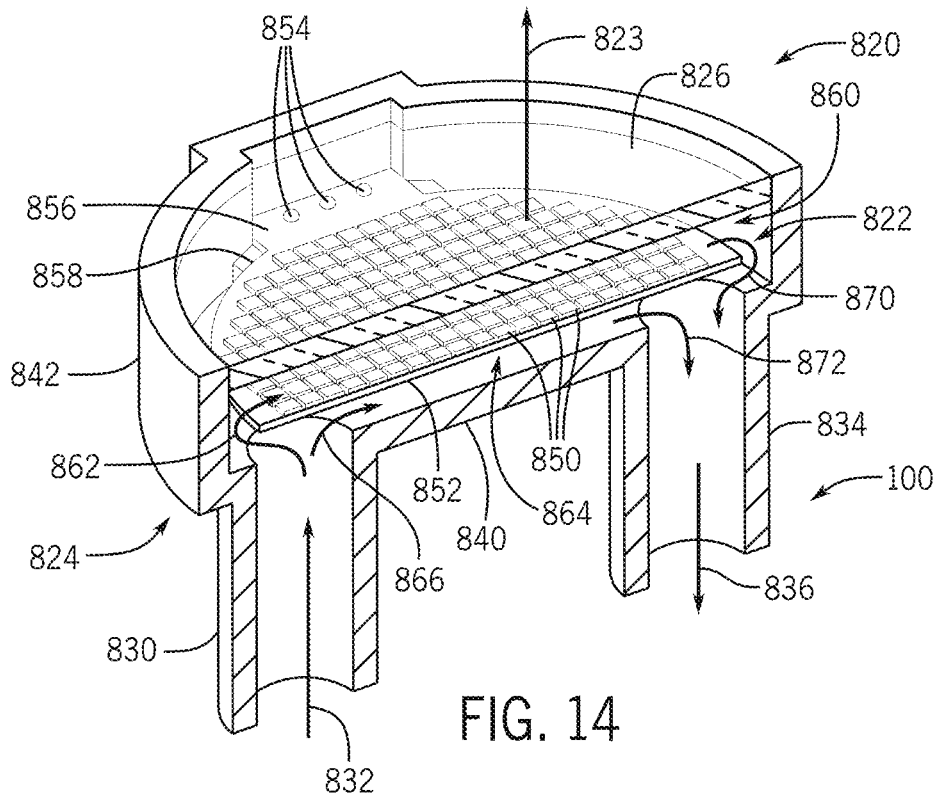


FIG. 12





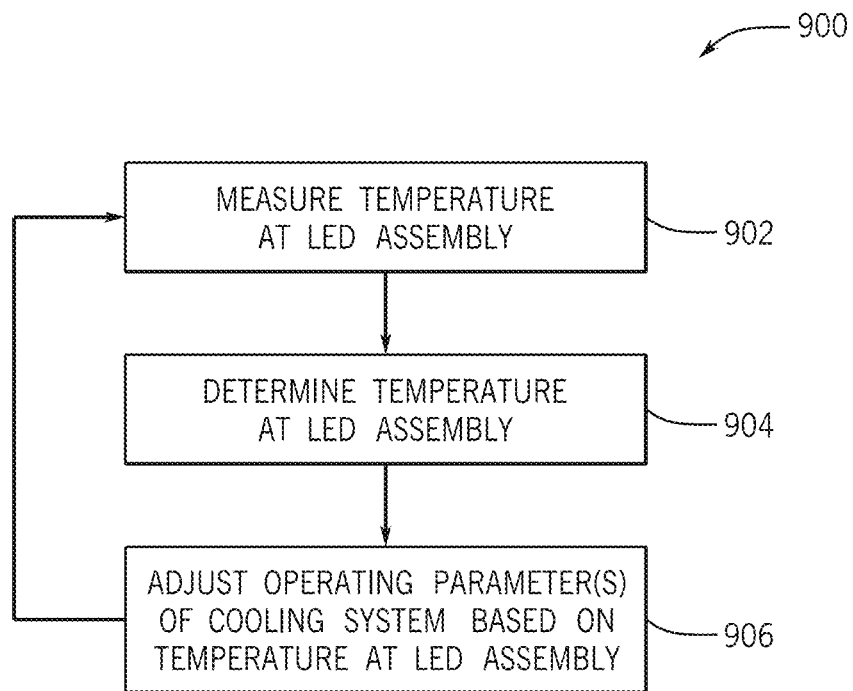


FIG. 16

1

LIGHT EMITTING DIODE COOLING SYSTEMS AND METHODS**CROSS-REFERENCE TO RELATED APPLICATIONS**

This application is a Continuation of U.S. Non-Provisional patent application Ser. No. 16/731,619, entitled "LIGHT EMITTING DIODE COOLING SYSTEMS AND METHODS," filed Dec. 31, 2019, and U.S. Provisional Patent Application Ser. No. 62/854,161, entitled "LIGHT EMITTING DIODE COOLING SYSTEMS AND METHODS", filed May 29, 2019, which are hereby incorporated by reference.

BACKGROUND

The present disclosure relates generally to light cooling systems.

This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present techniques, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

Generally, LED lighting instruments provide lighting for a variety of applications. In some applications, high intensity lighting from LED lighting instruments may be desirable. For example, LED lighting instruments may provide high intensity lighting for motion picture and television sets and studios. To provide such high intensity lighting (e.g., lighting consuming 500 W-1500 W of total power), an arrangement of LEDs within the lighting instruments may be relatively dense and numerous. As the density of LEDs in a given space increase, an amount of heat produced by the LEDs and a temperature of the LEDs may generally increase. Typical Wall Plug Efficiency ("WPE") of blue LEDs used to make white light is 50% such that only 50% of the energy will be converted into photons and the other 50% will be lost as heat. There may be an additional loss when the light is converted from blue light to white by the phosphors. As such, about half of the electrical power provided to LEDs is converted into heat.

Conventional cooling techniques for lighting systems may not sufficiently cool such high intensity LED lighting instruments. Additionally, Chip Scale Packaging ("CSP") technology and Chip on Board ("COB") arrays provide the ability to directly attach LED die to a printed circuit board ("PCB") without a package. Typical LED die are only 1 mm in size (e.g., a length of the die) or less. The LED die are packaged separately, which makes them easier to handle in manufacturing and increases the available area for dissipating heat (e.g., 3 mm×3 mm is a common package for example). In COB and/or CSP technology, an array of LED dies is attached directly to a high-resolution PCB which can dramatically increase the power density. LED arrays with power densities of 80 watts per square inch and higher are produced today with these CSP and COB technologies with higher power densities constantly being developed. LEDs may typically require being maintained at a junction temperature of less than 125 degrees Celsius or they will be damaged. Due to the heat restrictions, the packing density of LEDs in system designs is effectively limited by heat. Traditional air cooling techniques, such as via heat sinks,

2

may not sufficiently cool the LED lighting instruments. Even adding fans to increase airflow over metal heat sinks provides limited heat dissipation. Although the following description describes cooling systems used in LED lighting systems, the cooling systems may be deployed in other lighting systems.

BRIEF DESCRIPTION

The light cooling systems and methods disclosed herein provide cooling for an LED assembly. The light cooling systems include a fluid configured to flow over the LED assembly to cool LEDs emitting light and to remove heat produced by the LEDs. A pump of the cooling system may circulate the fluid from the LED assembly to a heat exchanger, configured to remove the heat from the fluid, and back to the LED assembly to continue cooling and removing heat from the LED assembly. Additionally, light cooling methods include controlling the pump to control the flowrate of the fluid through the heat exchanger and over/through the LED assembly.

DRAWINGS

These and other features, aspects, and advantages of the present disclosure will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings. 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.

FIG. 1 is a schematic diagram of an embodiment of a cooling system configured to immersively and actively cool a light emitting diode (LED) assembly, in accordance with one or more current embodiments;

FIG. 2 is a perspective view of an embodiment of a lighting assembly having the LED assembly and the cooling system of FIG. 1, in accordance with one or more current embodiments;

FIG. 3 is a cross-sectional view of the lighting assembly of FIG. 2 having the cooling system and the LED assembly, in accordance with one or more current embodiments;

FIG. 4 is a perspective cross-sectional view of the lighting assembly of FIG. 2 having the cooling system and the LED assembly, in accordance with one or more current embodiments;

FIG. 5 is a perspective view of the LED assembly of FIG. 2, in accordance with one or more current embodiments;

FIG. 6A is a rear perspective view of the lighting assembly of FIG. 2 having the cooling system and the LED assembly, in accordance with one or more current embodiments;

FIG. 6B is a rear perspective view of another embodiment of a lighting assembly having the cooling system of FIG. 1, in accordance with one or more current embodiments;

FIG. 7 is a perspective view of another embodiment of the cooling system and the LED assembly of FIG. 1 including a transparent enclosure, in accordance with one or more current embodiments;

FIG. 8 is a perspective cross-sectional view of the LED assembly and the transparent enclosure of FIG. 7, in accordance with one or more current embodiments;

FIG. 9 is a bottom perspective view of the LED assembly and the transparent enclosure of FIG. 7, in accordance with one or more current embodiments;

FIG. 10 is a partially exploded view of the LED assembly and the transparent enclosure of FIG. 7, in accordance with one or more current embodiments;

FIG. 11 is a side view of the cooling system of FIG. 7 and a side view of an embodiment of a lighting assembly, in accordance with one or more current embodiments;

FIG. 12 includes side views of the cooling system of FIG. 7, in accordance with one or more current embodiments;

FIG. 13 includes perspective views of the cooling system of FIG. 7 coupled to light directing assemblies, in accordance with one or more current embodiments;

FIG. 14 is a perspective cross-sectional view of another embodiment of a lighting assembly having the LED assembly and the cooling system of FIG. 1, in accordance with one or more current embodiments;

FIG. 15 is a perspective view of the lighting assembly of FIG. 14, in accordance with one or more current embodiments; and

FIG. 16 is a flow diagram of an embodiment of a method for controlling the cooling system of FIGS. 1-15, in accordance with one or more current embodiments.

DETAILED DESCRIPTION

One or more specific embodiments of the present disclosure will be described below. These described embodiments are only examples of the presently disclosed techniques. Additionally, in an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but may nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

When introducing elements of various embodiments of the present disclosure, the articles "a," "an," and "the" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to "one embodiment" or "an embodiment" of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

Turning now to the drawings, FIG. 1 is a schematic diagram of a cooling system 100 configured to actively cool an LED assembly 102. The cooling system 100 includes an enclosure 104 configured to at least partially enclose and/or house the LED assembly 102 and a heat exchanger 106 fluidly coupled to the enclosure 104. The cooling system 100 also includes a pump 108 configured to circulate fluid (e.g., coolant, mineral oil, water, a hydrocarbon fluid, a silicon fluid, or a combination thereof) along a cooling circuit 110 through the heat exchanger 106, through the enclosure 104, through and/or over the LED assembly 102, and back to the pump 108. In certain embodiments, the cooling system 100 may include the LED assembly 102 or a portion thereof.

The LED assembly 102 may be any assembly including one or more LEDs. For example, to provide lighting for

applications such as television and theater sets, film sets, tradeshows, and any one of the range of permanent, semi-permanent, and temporary settings, the LED assembly 102 may include multiple LEDs configured to emit light. While emitting light, the LEDs may produce heat and a temperature of a surrounding area (e.g., an area adjacent to the LED assembly 102 and/or within/adjacent to the enclosure 104) may generally increase.

During operation, the cooling system 100 is configured to absorb the heat generated by the LED assembly 102 and to transfer the heat to ambient air. For example, as the pump 108 circulates the fluid through the enclosure 104 and/or through the LED assembly 102, the fluid may absorb the heat generated by the LED assembly 102. The heat exchanger 106 may include a radiator and/or fan(s) configured to actively draw ambient air toward/across the heat exchanger 106 to cool the fluid traveling through the heat exchanger 106 and along the cooling circuit 110. In certain embodiments, the heat exchanger 106 may include a second fluid (e.g., in addition to or in place of the ambient air) configured to exchange heat with the fluid flowing along the cooling circuit 110.

The pump 108 may be a variable speed pump configured to circulate the fluid through the cooling circuit 110. In certain embodiments, a housing of the pump 108 may include a flexible diaphragm configured to expand and/or retract based on a volume of the fluid flowing along the cooling circuit 110. For example, as the fluid absorbs heat at and from the LED assembly 102, the fluid may expand (e.g., thermal expansion). As the fluid flows from the LED assembly 102 and the enclosure 104, the flexible diaphragm of the pump 108 may expand to allow of the increased volume of fluid to pass through the pump without affecting the flowrate of the fluid through the pump 108 and along the cooling circuit 110. In some embodiments, the flexible diaphragm of the pump 108 may be a service panel configured to allow access to internal portions of the pump 108. As described in greater detail below, in certain embodiments, the flexible diaphragm may be located elsewhere along the cooling circuit 110 (e.g., in addition to or in place of being located at the pump 108) to facilitate thermal expansion of the fluid in the cooling circuit 110.

The LED assembly 102 is configured to emit light, which may pass through the fluid circulating between the LED assembly 102 and the enclosure 104 and through the enclosure 104. As such, the LED assembly 102 is configured to provide lighting for the various applications described herein (e.g., motion picture and television lighting and other applications that may benefit from high intensity lighting) while being cooled by the cooling system 100. The LEDs of the LED assembly 102 may include varied/multiple configurations. For example, the LED assembly 102 may include chip scale packaging (CSP) arrays (e.g., bi-color CSP arrays). CSP technology may benefit from very high density of LED chips in a specified area (e.g., per square inch/centimeter), and CSP technology may utilize different colors of individual LEDs. For example, CSP technology may include a five color configuration (e.g., warm white, cool white, red, green, and blue), a four color configuration (e.g., white, red, green, and blue), a three color configuration (e.g., red, green, and blue), a bi-color white configuration (e.g., warm white and cool white), a single white configuration, and/or a single color configuration.

In some embodiments, the LED assembly 102 may include single color chip on board ("COB") arrays. The COB arrays may include a relatively large number of LEDs bonded to a single substrate and a layer of phosphor placed

over the entire array. An advantage of COB technology is very high LED density per specified area (e.g., per square inch/centimeter). Additionally or alternatively, the LED assembly 102 may include discrete LEDs.

The cooling system 100 includes a controller 120 configured to control the LED assembly 102, the heat exchanger 106, the pump 108, or a combination thereof. For example, the controller 120 may control some or all LEDs of the LED assembly 102 to cause the LEDs to emit light. Additionally or alternatively, the controller 120 may control operation of the heat exchanger 106 to cause the heat exchanger 106 to exchange more or less heat between the fluid and the ambient air. For example, the controller 120 may control fans of the heat exchanger 106 to control an air flow rate through/over the heat exchanger 106. In certain embodiments, the fans of the heat exchanger 106 may be controlled via pulse width modulated (PWM) power. The fans may be controlled based on the temperature at the LED assembly 102. In some embodiments, to reduce a noise output of the fans of the heat exchanger 106, the controller 120 may operate the fans only when cooling of the fluid by other means (e.g., via the radiator without active airflow) is insufficient.

As illustrated, the cooling system 100 may include a sensor 121 disposed at the LED assembly 102 and configured to output a signal (e.g., an input signal) indicative of the temperature at the LED assembly 102 and/or a temperature of the fluid adjacent to the LED assembly 102. The sensor 121 may be any suitable temperature/thermal sensor, such as a thermocouple. In certain embodiments, the cooling system 100 may include other thermal sensor(s) disposed within the fluid and configured to output a signal indicative of a temperature of the fluid (e.g., within the enclosure 104) and/or disposed at the enclosure 104 and configured to output a signal indicative of a temperature at the enclosure 104.

Further, the controller 120 may control operation of the pump 108 to cause the pump 108 to circulate the fluid along the cooling circuit 110 at particular flowrates. For example, based on the temperature at the LED assembly 102 and/or at the enclosure 104 (e.g., based on the signal indicative of the temperature at the LED assembly 102 received from the sensor 121), the controller 120 may be configured to output a signal (e.g., an output signal) to the pump 108 indicative of instructions to adjust the flowrate of the fluid flowing through the cooling circuit 110.

As illustrated, the controller 120 includes a processor 122 and a memory 124. The processor 122 (e.g., a microprocessor) may be used to execute software, such as software stored in the memory 124 for controlling the cooling system 100 (e.g., for controller operation of the pump 108 to control the flowrate of fluid through the cooling circuit 110). Moreover, the processor 122 may include multiple microprocessors, one or more "general-purpose" microprocessors, one or more special-purpose microprocessors, and/or one or more application specific integrated circuits (ASICs), or some combination thereof. For example, the processor 122 may include one or more reduced instruction set (RISC) or complex instruction set (CISC) processors.

The memory device 124 may include a volatile memory, such as random-access memory (RAM), and/or a nonvolatile memory, such as read-only memory (ROM). The memory device 124 may store a variety of information and may be used for various purposes. For example, the memory device 124 may store processor-executable instructions (e.g., firmware or software) for the processor 122 to execute, such as instructions for controlling the cooling system 100.

In certain embodiments, the controller 120 may also include one or more storage devices and/or other suitable components. The storage device(s) (e.g., nonvolatile storage) may include ROM, flash memory, a hard drive, or any other suitable optical, magnetic, or solid-state storage medium, or a combination thereof. The storage device(s) may store data (e.g., measured temperatures at the LED assembly 102), instructions (e.g., software or firmware for controlling the cooling system 100), and any other suitable data. The processor 122 and/or the memory device 124, and/or an additional processor and/or memory device, may be located in any suitable portion of the system. For example, a memory device for storing instructions (e.g., software or firmware for controlling portions of the cooling system 100) may be located in or associated with the cooling system 100.

Additionally, the controller 120 includes a user interface 126 configured to inform an operator of the temperature at the LED assembly 102 and/or of the flowrate of the fluid through the cooling circuit 110. For example, the user interface 126 may include a display and/or other user interaction devices (e.g., buttons) configured to enable operator interactions.

FIG. 2 is a perspective view of an embodiment of a lighting assembly 130 having the cooling system 100 and the LED assembly 102 of FIG. 1. The lighting assembly 130 includes a reflector 132 (e.g., a parabolic reflector) configured to reflect light emitted by the LED assembly 102. For example, the light emitted by the LED assembly 102 may pass through the fluid disposed between the LED assembly 102 and the enclosure 104, through the enclosure 104, and may be reflected by the reflector 132 outwardly. The reflector 132 is coupled to a chassis 134 (e.g., a housing) of the lighting assembly 130. In certain embodiments, the LED assembly 102, the enclosure 104, and/or other portions of the cooling system 100 may be coupled to the chassis 134. For example, as described in greater detail below, the heat exchanger 106 and/or the pump 108 of the cooling system 100 may be coupled to the chassis 134.

FIG. 3 is a cross-sectional view of the lighting assembly 130 of FIG. 2 having the cooling system 100. As illustrated, the cooling system 100 includes the enclosure 104, the LED assembly 102 disposed in the enclosure 104, the heat exchanger 106 configured to exchange heat with the fluid, and the pump 108 configured to drive circulation of the fluid. Additionally, the cooling system 100 includes an inlet pipe 140 coupled to the pump 108 and to a fluid inlet 142 of the enclosure 104. Further, the cooling system 100 includes an outlet pipe 144 coupled to a fluid outlet 146 of the enclosure 104 and to the heat exchanger 106. In certain embodiments, the inlet pipe 140 and/or the outlet pipe 144 may extend into the LED assembly 102 and/or into the enclosure 104.

As illustrated, the fluid inlet 142 is disposed generally along a centerline of the enclosure 104 and the LED assembly 102. The pump 108 is configured to drive the fluid from the inlet pipe 140, into the fluid inlet 142, generally along the centerline of the LED assembly 102 and the enclosure 104, into and along a gap between the LED assembly 102 and the enclosure (e.g., a gap where the fluid absorbs heat generated by the LED assembly 102), out of the fluid outlet 146, and into the outlet pipe 144 (e.g., along the cooling circuit 110). After absorbing heat at the LED assembly 102, the fluid circulates through the heat exchanger 106 and returns to the pump 108. At the heat exchanger 106, the fluid rejects the heat absorbed at the LED assembly 102. For example, the heat exchanger 106 includes a radiator 150 and fans 152 configured to draw air (e.g., ambient air) across the radiator 150. The air drawn across the radiator 150 may absorb heat

from the fluid flowing through the radiator **150** (e.g., heat transferred from the fluid to the radiator **150**), thereby cooling the fluid for subsequent circulation along the cooling circuit **110** and back through the LED assembly **102** and the enclosure **104**.

Additionally, in certain embodiments, the heat exchanger **106** may not reject all the heat absorbed by the fluid at the LED assembly **102**, such that the fluid retains at least some of the heat absorbed at the LED assembly **102**. As such, a temperature of the fluid along the cooling circuit **110** (e.g., an average temperature) may increase, thereby increasing a volume of the fluid. The cooling system **100** includes a flexible membrane **154** at the pump **108** configured to expand due to heating of the fluid and to retract due to cooling of the fluid (e.g., to accommodate volumetric changes of the fluid along the cooling circuit **110**). In certain embodiments, the flexible membrane **154** may be included elsewhere within the cooling system **100**.

The cooling system **100** includes a valve **156** fluidly coupled to the cooling circuit **110**. The valve **156** may be configured to bleed air and/or fluid from the cooling circuit **110**, such as when fluid is added to the cooling circuit **110** (e.g., the valve **156** may be a bleed valve). Additionally or alternatively, fluid may be added to the cooling circuit **110** via the valve **156** (e.g., the valve **156** may be a fill valve). In certain embodiments, the cooling system **100** may include multiple valves **156** with a first valve **156** being a bleed valve and a second valve **156** being a fill valve.

As described above, the controller **120** may be configured to control the LED assembly **102**, the heat exchanger **106**, the pump **108**, or a combination thereof. For example, the controller **120** may control some or all LEDs of the LED assembly **102** to cause the LEDs to emit light. Additionally, the controller **120** may control a rotation rate of the fans **152** and/or a flow rate of the fluid along the cooling circuit **110**. For example, based on feedback received from the sensor **121** at the LED assembly **102** (e.g., the temperature at the LED assembly **102**), the controller **120** may control the rotation rate of the fans **152** and/or the flow rate of the fluid. More specifically, in response the temperature at the LED assembly **102** being greater than a target temperature and a difference between the temperature at the LED assembly **102** and the target temperature exceeding a threshold value, the controller may increase the rotation rate of the fans **152** and/or may increase the flow rate of the fluid. In response the temperature at the LED assembly **102** being less than the target temperature and the difference between the temperature at the LED assembly **102** and the target temperature exceeding a threshold value, the controller may decrease the rotation rate of the fans **152** and/or may decrease the flow rate of the fluid.

FIG. 4 is a perspective cross-sectional view of the lighting assembly **130** of FIG. 2 having the cooling system **100**. As illustrated, the fluid of the cooling system **100** is configured to flow from the inlet pipe **140**, through the fluid inlet **142**, and through an inner annular passage **160** formed within the LED assembly **102** (e.g., in a direction **162**). As such, the fluid enters the LED assembly **102** as a chilled fluid. The inner annular passage **160** is coupled to the fluid inlet **142** and to an end **164** of the LED assembly **102**. From the inner annular passage **160**, the fluid circulates through an end passage **166** formed between the end **164** of the LED assembly **102** and an end **168** of the enclosure **104**, as indicated by arrows **170**. From the end passage **166**, the fluid circulates into an outer annular passage **172** formed between the LED assembly **102** and the enclosure **104**, as indicated by arrow **174**. As the fluid flows through the outer annular

passage **172**, the fluid absorbs heat generated by the LED assembly **102**. From the outer annular passage **172**, the fluid exits the enclosure **104** through the fluid outlet **146** and flows into the outlet pipe **144**. As such, the fluid exits the enclosure **104** as a heated fluid. After passing through the heat exchanger **106** and the pump **108** of the cooling system **100**, the fluid circulates back to through the LED assembly **102** and the enclosure **104** to continue cooling the LED assembly **102**.

The lighting assembly **130** is a side emission configuration of the lighting assembly, such that the lighting assembly **130** is configured to emit light radially outwardly (e.g., from sides of the lighting assembly **130**) and through the fluid and the enclosure **104**. As described in greater detail below in reference to FIGS. 14 and 15, the cooling system **100** may include a front emission configuration of the lighting assembly, such as in place of or in addition to the side emission configuration of FIGS. 2-5.

FIG. 5 is a perspective view of the LED assembly **102** of FIG. 2. As illustrated, the LED assembly **102** includes a tower **180** and LED arrays **182** mounted to the tower **180**. As illustrated, the tower **180** is a hexagonal structure formed by panels **184** (e.g., six panels **184**) with nine LED arrays **182** mounted on each panel **184**. In certain embodiments, the tower may include more or fewer panels **184** (e.g., three panels **184**, four panels **184**, eight panels **184**, etc.) and/or each panel **184** may include more or fewer LED arrays **182** (e.g., one LED array **182**, two LED arrays **182**, five LED arrays **182**, twenty LED arrays **182**, etc.). In some embodiments, the tower **180** may be shaped differently in other embodiments and/or may be omitted. For example, the LED arrays **182** may be mounted directly to the enclosure **104** in some embodiments. In certain embodiments, the LED assembly **102** may include other LED configurations in addition to or in place of the LED arrays **182**.

The LED arrays **182** of the LED assembly **102** are configured to emit light outwardly through the fluid flowing between the LED assembly **102** and the enclosure **104** (e.g., through the outer annular passage **172** formed between the LED assembly **102** and the enclosure **104**) and through the enclosure **104**. The fluid may be transparent or semi-transparent such that the fluid is configured to allow the light to pass through the fluid toward the enclosure **104**. For example, the fluid may be a dielectric and/or electrically insulating fluid having a refractive index of between 1.4 and 1.6. In some embodiments, the enclosure **104** enclosing the fluid may be acrylic, polycarbonate, glass (e.g., borosilicate glass), or another material having a refractive index between about 1.44-1.5. In certain embodiments, the LEDs of the LED arrays **182** may include silicone (e.g., a silicone layer) through which light emitted by the LEDs passes. The silicone may have a refractive index of about 1.38-1.6. As such, a type of fluid (e.g., the fluids having the refractive indices recited above) may facilitate light passage from the LEDs, through the fluid, and toward the enclosure **104**. Additionally, the refractive index of the layer of the LED (e.g., the silicone), the fluid, and/or the enclosure **104** may generally be matched (e.g., within a difference threshold). In some embodiments, the fluid and/or the enclosure **104** may behave as lens configured to optically shape light provided by the LED assembly **102**. For example, the fluid and/or the enclosure **104** having the specific refractive indices described above may allow the fluid and/or the enclosure to shape the light in a desirable manner.

Additionally or alternatively, the fluid may include a mineral oil having a relatively long shelf life (e.g., about twenty-five years) or a fluid having properties similar to

mineral oil. The fluids may be non-corrosive such that the fluids facilitate pumping along the cooling circuit 110 by the pump 108 and compatible with plastics and other system materials. Further, such fluids may generally have a relatively low viscosity, which may allow directly cooling the electronics of the LED assembly 102 (e.g., the LED arrays 182, wiring coupled to the LED arrays 182 and to printed circuit boards (“PCB’s”), and other electronic components of the LED assembly 102) without affecting the performance/functionality of the electronics. In certain embodiments, the type of the fluid included in the cooling circuit 110 may depend on an amount of LED arrays 182 and/or an amount of LEDs generally included in the LED assembly 102, a structure/geometry of the LED assembly 102, a density of LEDs of the LED assembly 102, an amount of heat generated by the LED assembly 102, or a combination thereof. During operation, the LED arrays 182 of the LED assembly 102 may have a power density of between 20 W-300 W per square inch, between 50 W-250 W per square inch, and other suitable power densities. In an aspect, each LED array 182 may have a surface area of 4 square inches or less. Due to the cooling systems mentioned herein, the LED arrays 182 may be operated at the aforementioned power densities for longer than 30 seconds, 1 minute, 1 hour, and 100 hours. In some embodiments, the LED assembly 102 may have a total power of 400 W-5000 W.

In some embodiments, the refractive index of the fluid disposed between the LED arrays 182 and the enclosure 104 may cause light to more easily leave the LED arrays 182 compared to an embodiment in which the LED arrays 182 are exposed to air. This may result in a color shift of the light emitted from the LED arrays 182. The controller 120 may control the LED arrays 182 (e.g., the colors and/or color temperatures of the LED arrays 182) based on the potential color shift of the emitted light.

The enclosure 104 may include clear, transparent, and/or semi-transparent materials such that the light emitted by the LED assembly 102 may pass through the enclosure 104 (e.g., after passing through the fluid disposed within and/or flowing through the outer annular passage 172) and outwardly from the enclosure 104. For example, the enclosure 104 may be formed of a clear plastic and/or glass (e.g., borosilicate glass). In certain embodiments, the enclosure 104 may include poly(methyl methacrylate) (“PMMA”) and/or other acrylics.

As illustrated, the LED assembly 102 includes printed circuit boards (“PCBs”) 190 coupled to a base PCB 192, the LED arrays 182, and the end 164 (e.g., end plate) of the LED assembly 102. For example, each PCB 190 extends generally along a respective panel 184 and is coupled (e.g., physically and electrically coupled via connectors 193) to the LED arrays 182 coupled to the respective panel 184. Each connector 193 is coupled to a respective LED array 182 at connections 194. In certain embodiments, each LED array 182 may be configured to snap/click into place on the panel 184. For example, each panel 184 may include features configured to receive the LED arrays 182 via a snap or click mechanism to facilitate assembly of the LED assembly 102.

FIG. 6A is a rear perspective view of the lighting assembly 130 of FIG. 2 having the cooling system 100. As generally described above, the cooling system 100 includes the inlet pipe 140 configured to flow fluid (e.g., chilled fluid) into the LED assembly 102 and the enclosure 104 and the outlet pipe 144 configured to receive fluid (e.g., heated fluid) from the LED assembly 102 and the enclosure 104. The fluid circulates from the outlet pipe 144, through the radiator 150

of the heat exchanger 106, through the pump 108, and back to the inlet pipe 140. As illustrated, the cooling system includes four fans 152 configured to draw air across the radiator 150 to cool the fluid passing through the radiator 150. In certain embodiments, the cooling system may include more or fewer fans 152 (e.g., one fan 152, two fans 152, three fans 152, five fans 152, ten fans 152, etc.). The fans 152 are positioned above the radiator 150, such that the heat transferred from the fluid passing through the radiator 150 moves generally upwardly toward through the fans 152. Additionally, the heat exchanger 106 and the pump 108 are mounted to the chassis 134 of the lighting assembly 130.

FIG. 6B is a rear perspective view of an embodiment of a lighting assembly 187 having the cooling system 100 of FIG. 1. The lighting assembly 187 includes the inlet pipe 140 configured to flow fluid (e.g., chilled fluid) into the LED assembly 102 and the enclosure 104 and the outlet pipe 144 configured to receive fluid (e.g., heated fluid) from the LED assembly 102 and the enclosure 104. The fluid circulates from the outlet pipe 144 to the radiator 150, through the radiator 150, to an intermediate pipe 189, through an expansion chamber 188 coupled to the intermediate pipe 189, and back to the inlet pipe 140 via the pump 108. The expansion chamber 188 is configured to expand due to heating of the fluid and to retract due to cooling of the fluid (e.g., to accommodate volumetric changes of the fluid along the cooling circuit 110). In certain embodiments, the expansion chamber 188 may be included elsewhere along the cooling circuit 110, such as along the inlet pipe 140 and/or along the outlet pipe 144.

As illustrated, the lighting assembly 187 includes a first bracket 191 coupled to the radiator 150 and the expansion chamber 188 and a second bracket 195 coupled to the radiator 150 and the pump 108. The radiator 150 and the expansion chamber 188 are mounted to the first bracket 191, and the first bracket 191 is mounted to the chassis 134, such that the first bracket 191 is configured to support a weight of the expansion chamber 188 and/or at least a portion of a weight of the radiator 150 (e.g., to transfer forces associated with the weight(s) to the chassis 134). Additionally, the radiator 150 and the pump 108 are mounted to the second bracket 195, and the second bracket 195 is mounted to the chassis 134, such that the second bracket 195 is configured to support a weight of the pump 108 and/or at least a portion of the weight of the radiator 150 (e.g., to transfer forces associated with the weight(s) to the chassis 134).

FIG. 7 is a perspective view of an LED assembly 196 and an enclosure 198 that may be included the cooling system 100 of FIG. 1. As illustrated, the LED assembly 196 is disposed within the enclosure 198. The LED assembly 196 includes a fluid inlet 200 configured to receive the fluid flowing along the cooling circuit 110 (e.g., as indicated by arrow 202) and a fluid outlet 204 configured to flow the fluid from the enclosure and the LED assembly 196 to the cooling circuit 110 (e.g., as indicated by arrow 206) (although the fluid direction may be reversed such that the fluid enters through the fluid outlet 204, for example, and exits through the fluid inlet 200). Additionally, the enclosure 198 includes a base 208 and a cylinder 210 extending from the base 208. In certain embodiments, the LED assembly 196 and/or the enclosure 198 of the cooling system 100 may be included in the lighting assembly of FIGS. 2-6.

The LED assembly 196 includes a tower 220 and the LED arrays 182 mounted to the tower 220. As illustrated, the tower 220 is a hexagonal structure with nine LED arrays 182 mounted on each of the six sides of the hexagonal structure. In certain embodiments, the tower 220 may include more or

fewer sides (e.g., three sides, four sides, eight sides, etc.) and/or each side may include more or fewer LED arrays **182** (e.g., one LED array **182**, two LED arrays **182**, five LED arrays **182**, twenty LED arrays **182**, etc.). In some embodiments, the tower **220** may be shaped differently in other embodiments and/or may be omitted. For example, the LED arrays **182** may be mounted directly to the enclosure **198** in some embodiments. In certain embodiments, the LED assembly **196** may include other LED configurations in addition to or in place of the LED arrays **182**.

The LED arrays **182** of the LED assembly **196** are configured to emit light outwardly through the fluid flowing between the LED assembly **196** and the enclosure **198** (e.g., through an outer annular passage **224** of the cooling system **100**) and through the enclosure **198**. In some embodiments, the enclosure **198** enclosing the fluid may be acrylic, polycarbonate, glass (e.g., borosilicate glass), or another material having a refractive index between about 1.44-1.5. Additionally, the refractive index of the layer of the LED (e.g., the silicone), the fluid, and/or the enclosure **198** may generally be matched (e.g., within a difference threshold).

The enclosure **198** may include clear, transparent, and/or semi-transparent materials such that the light emitted by the LED assembly **196** may pass through the enclosure **198** (e.g., after passing through the fluid disposed within and/or flowing through the outer annular passage **224**) and outwardly from the enclosure **198**. For example, the enclosure **198** may be formed of a clear plastic and/or glass (e.g., borosilicate glass). In certain embodiments, the enclosure **198** may include poly(methyl methacrylate) (“PMMA”) and/or other acrylics.

The cooling system **100** is configured to flow the fluid into the fluid inlet **200**, through the outer annular passage **224** between the LED assembly **196** and the enclosure **198**, and toward an end **230** of the tower **220**. The end **230** is disposed generally opposite of the base **208**. The tower **220** includes an inner annular passage **232** extending from the end **230** to the base **208**. As illustrated, the inner annular passage **232** is fluidly coupled to the outer annular passage **224** at the end **230** of the tower **220**. The cooling system **100** is configured to flow the fluid from the outer annular passage **224** and into the inner annular passage **232** via the end **230**. The inner annular passage **232** is fluidly coupled to the fluid outlet **204** such that the fluid may pass through the tower **220**, via the inner annular passage **232**, and out of the tower **220** and the enclosure **198** at the fluid outlet **204**.

As the fluid passes over and through the LED assembly **196** (e.g., over the LED arrays **182** and through the tower **220**), the fluid is configured to absorb heat generated by operation of the LED arrays **182**. For example, because the fluid is configured to absorb heat generated by the LED arrays **182** while flowing through both the outer annular passage **224** and the inner annular passage **232**, the cooling system **100** is configured to significantly increase an amount of heat that may be absorbed compared to embodiments of cooling systems that extract heat only from an interior or exterior of a light source. Additionally, because the fluid is generally transparent and/or semi-transparent (e.g., the fluid has a refractive index generally between 1.4-1.5), the fluid may have minimal/no effects on the light emitted from the LED assembly **196** and through the fluid. As such, the fluid may actively cool the LED assembly **196** during operation of the LED assembly **196** with little to no effect on a quality of light emitted from the LED assembly **196**.

The LED assembly **196** is a side emission configuration of a lighting assembly, such that the LED assembly **196** is configured to emit light radially outwardly (e.g., from sides

of the LED assembly **196**) and through the fluid and the enclosure **198**. As described in greater detail below in reference to FIGS. **14** and **15**, the cooling system **100** may also include a front emission configuration of the lighting assembly, such as in place of or in addition to the side emission configuration of FIGS. **7-10**.

FIG. **8** is a perspective cross-sectional view of the LED assembly **196** and the enclosure **198** of FIG. **7**. As described above, the enclosure **198** is configured to receive the fluid from the pump **108** through the fluid inlet **200**. The fluid is then configured to contact the tower **220** and a base **300** of the LED assembly **196** coupled to the tower **220**. The tower **220** and the base **300** are configured to direct the fluid upwardly along the outer annular passage **224**. The fluid is then configured to flow through the end **230** and into the inner annular passage **232**. As illustrated, the inner annular passage **232** is formed between and by the tower **220** and PCBs **302** of the LED assembly **196**. The fluid is configured to flow downwardly within the inner annular passage **232** toward a base PCB **304** electrically coupled to the PCBs **302**. After passing over the PCBs **302** and/or the base PCB **304**, the fluid is configured to exit the tower **220** and the enclosure **198** at the fluid outlet **204**. As mentioned with respect to FIG. **7**, the fluid direction may be reversed such that the fluid may be configured to flow in through the fluid outlet **204**, up through the inner annular passage **232**, through the end **230**, and down the outer annular passage **224**, and out the fluid inlet **200**.

The PCBs **302** may be electrically coupled to the LED arrays **182** such that the PCBs **302** may provide power and/or communication with the LED arrays **182**. For example, the LED assembly **196** may include wiring extending outwardly between the PCBs **302** and the LED arrays **182**. As such, the fluid may flow over the PCBs **302** and the wiring extending between the PCBs **302** and the LED arrays **182** to cool and absorb heat from the tower **220** (e.g., heat generated by the LED arrays **182** that is transferred to/absorbed by the tower **220**), from the PCBs **302**, and/or from the wiring. Additionally, the fluid may flow over the base PCB **304** and may absorb heat from the base PCB **304**. For example, the base PCB **304** includes a wet side **306** configured to contact the fluid and a dry side generally opposite the wet side **306** that is configured to remain dry (e.g., to not contact the fluid). As generally described above, the fluid may be dielectric and/or electrically insulating such that the fluid may have minimal/no electrical effects on the LED arrays **182**, the PCBs **302**, the base PCB **304**, and the wiring of the LED assembly **196**.

FIG. **9** is a bottom perspective view of the LED assembly **196** and the enclosure **198** of FIG. **7**. As illustrated, the base PCB **304** includes a dry side **400** configured to remain generally dry (e.g., to not contact the fluid during operation of the cooling system **100**). The LED assembly **196** includes a gasket **402** configured to form a seal between the enclosure **198** and the LED assembly **196** (e.g., between the base **208** of the enclosure **198** and the base PCB **304** of the LED assembly **196**). As such, the LED assembly **196** may remain dry at the dry side **400** of the base PCB **304**, and the cooling system **100** may be configured to flow the fluid through the enclosure **198** and the tower **220** without leaking fluid.

FIG. **10** is a partially exploded view of the LED assembly **196** and the enclosure **198** of FIG. **7**. The LED assembly **196** is configured to insert into and to be removed from the enclosure **198** as generally indicated by arrow **500**. For example, to replace portions of the LED assembly **196** (e.g., the LED arrays **182**, the PCBs **302**, the base PCB **304**,

wiring, etc.), the LED assembly 196 and the enclosure 198 may be disassembled by removing the LED assembly 196 from the enclosure 198 along an axis generally parallel to arrow 500. Additionally, while the LED assembly 196 and the enclosure 198 are disposed in the illustrated positions (e.g., with the LED assembly 196 and the enclosure 198 extending downwardly), the LED assembly 196 may be removed from the enclosure 198 with a minimal loss and/or splashing of the fluid using threaded enclosures, a gasket, a latch, and/or other securing mechanisms. To assemble/reassemble the LED assembly 196 into the enclosure 198, the LED assembly 196 may be inserted into the enclosure 198 along the axis generally parallel to the arrow 500. Thus, the configuration and coupling of the LED assembly 196 and the enclosure 198 described herein may facilitate quick and easy maintenance of the LED assembly 196.

FIG. 11 is a side view of the cooling system 100 of FIG. 7 and a side view of a lighting assembly 600. As illustrated, the base 208 of the enclosure 198 is coupled to a heat exchanger 601. After absorbing heat from and at the LED assembly 196, the fluid is configured to flow into and through the heat exchanger 601. The heat exchanger 601 includes a radiator 602 configured to exchange heat from the fluid to ambient air adjacent to the heat exchanger 601. The heat exchanger 601 may include the radiator 602 on each of four sides of the heat exchanger 601 (e.g., four radiators 602). In certain embodiments, the heat exchanger 601 may include more of fewer sides with each side having the radiator 602. The radiator 602 includes fins 604 configured to transfer heat from the fluid (e.g., to absorb heat from the fluid) to the ambient air. In some embodiments, the heat exchanger 601 may include other shapes configured to cool the fluid (e.g., a sphere, a cylinder, etc.).

The LED arrays 182 of the LED assembly 196 extend outwardly from the base 208 of the enclosure 198 a distance 610. In certain embodiments, the distance 610 may be between about three inches and about nine inches. In some embodiments, the distance 610 may be about five and one-half inches. Additionally, the cooling system 100 extends a generally vertical distance 612 and a generally horizontal distance 614. In certain embodiments, the generally vertical distance 612 may be between about ten inches and about twenty inches, and/or the generally horizontal distance 614 may be between about seven inches and about seventeen inches. In some embodiments, the generally vertical distance 612 may be fourteen inches, and/or the generally horizontal distance 614 may be twelve inches.

The lighting assembly 600 is a prior art lighting assembly having a lighting area 620 configured to emit light. A back portion of the lighting area 620 may be a heat sink configured to absorb/transfer heat from the lighting area 620. As illustrated, the cooling system 100 is generally smaller and more compact than the lighting area 620 and the heat sink of the lighting assembly 600. Additionally, as generally described above, the cooling system 100 is configured to provide sufficient cooling for the LED assembly 196 as the LED assembly 196 operates at 1500 W. The lighting assembly 600 may be configured to provide cooling for lights of the lighting area 620 operating at 400 W. As such, the cooling system 100 may be more versatile than the lighting assembly 600, and prior art lighting assemblies generally, by providing a more compact design configured to operate at significantly higher powers. In certain embodiments, the LED assembly 102 and/or the enclosure 104 of the cooling system 100 may be coupled to the heat exchanger 601, such

that the heat exchanger 601 is configured to exchange heat with the fluid circulating through the LED assembly 102 and the enclosure 104.

FIG. 12 includes side views of the cooling system 100 of FIG. 7. The cooling system 100 includes a cover 700 configured to fit over/onto the enclosure 198. The cover 700 includes materials configured to convert a color correlated temperature ("CCT") of light emitted by the LED assembly 196. For example, the cover 700 may include and/or be formed of phosphor and may be configured to convert a cool white CCT of about 5600K to a warmer white CCT of about 4300K, about 3200K, and other CCT's. In certain embodiments, the cover 700 may be injection molded plastic, silicone, coated glass, or a combination thereof. In certain embodiments, the cover 700 may fit over/onto the enclosure 104, such that the cover 700 converts a CCT of light emitted by the LED assembly 102 through the enclosure 104.

The cover 700 is configured to slide onto and off of the enclosure 198, as generally noted by arrow 702. For example, the cover 700 may be easily field changeable such that an operator may slide the cover 700 onto and off of the enclosure 198. Additionally, light produced by a low cost single color version of the LED assembly 196 may easily be converted to any CCT with the addition of the cover 700, which may be of relatively low cost. Further, the cover 700 may be significantly more power efficient compared to traditional embodiments, because the cover 700 is not a filter removing a portion of light emitted by the LED assembly 196. Instead, the cover 700 is configured to convert light to a desired color and CCT.

In certain embodiments, the LED assembly 196 may be configured to emit a blue light, cool white light (e.g., 5000K or higher), or other colors. The cover 700 may be adapted for any suitable color and/or white such that light emitted from a single-color version of the LED assembly 196 (e.g., a blue light LED assembly 196 or a cool white light LED assembly 196) may be converted into any CCT and/or any color with no change to the LED assembly 196 or other electronics of the cooling system 100.

As illustrated, the cover 700 is configured to contact the enclosure 198 while the cover 700 is disposed on the enclosure 198. The contact between enclosure 198 and the cover 700 may allow the enclosure 198 to transfer heat to the cover 700. The fluid flowing within the enclosure 198 may be configured to cool both enclosure 198 and the cover 700 (e.g., the fluid may absorb heat from the enclosure 198 to facilitate cooling of the cover 700).

FIG. 13 includes perspective views of the cooling system 100 of FIG. 7 coupled to light directing assemblies 800, 802, and 804 configured to direct light emitted by the LED assembly 102 of the cooling system 100. For example, the light directing assembly 800 is a high bay assembly configured to be disposed in building setting and to direct light emitted by the LED assembly 102 downwardly. The light directly assembly 802 is a space light directing assembly configured to be disposed in a studio to provide environment lighting. Additionally, the light directly assembly 804 is an umbrella assembly configured to be disposed in a studio and to generally focus light emitted by the LED assembly 102.

FIG. 14 is a perspective cross-sectional view of another embodiment of a lighting assembly 820 having an LED assembly 822 and the cooling system 100 of FIG. 1. The lighting assembly 820 is a front emission configuration of a lighting assembly that may be included in the cooling system 100, such that the lighting assembly 820 is configured to emit light outwardly through a front portion of the lighting assembly 820, as indicated by arrow 823, rather

than through side of a lighting assembly (e.g., as in lighting assembly embodiments of FIGS. 2-13). Accordingly, the cooling system 100 may include a lighting assembly having a side emission configuration, a front emission configuration, and/or others.

The lighting assembly 820 includes a chassis 824 configured to receive and flow the fluid to cool the LED assembly 822. As illustrated, the LED assembly 822 is disposed within and mounted to the chassis 824. Additionally, the lighting assembly 820 includes a cover 826 coupled to the chassis 824. The cover 826 is configured to at least partially enclose the lighting assembly 820, such that the cover 826 directs the fluid through the lighting assembly 820 and over the LED assembly 822. Additionally, the cover 826 may include clear, transparent, and/or semi-transparent materials such that the light emitted by the LED assembly 822 may pass through the cover 826 (e.g., after passing through the fluid) and outwardly from the cover 826. For example, the cover 826 may be formed of a clear plastic and/or glass (e.g., borosilicate glass). In certain embodiments, the cover 826 may include poly(methyl methacrylate) (“PMMA”) and/or other acrylics and/or other materials described herein.

The chassis 824 includes a fluid inlet 830 configured to receive the fluid flowing along the cooling circuit 110 (e.g., as indicated by arrow 832) and a fluid outlet 834 configured to flow the fluid from the chassis 823 to the cooling circuit 110 (e.g., as indicated by arrow 836) (although the fluid direction may be reversed such that the fluid enters through the fluid outlet 834, for example, and exits through the fluid inlet 832). Additionally, the chassis 824 includes a base 840 and a cylinder 842 extending from the base 840. The base 840 includes the fluid inlet 830 and the fluid outlet 834. In certain embodiments, the LED assembly 822 and/or the chassis 824 may be included in the lighting assembly and/or LED assembly of FIGS. 2-13.

The LED assembly 822 includes LEDs 850 mounted to a PCB 852. The PCB 852 is mounted to the chassis 824 via connections 854. For example, the PCB 852 includes a tab 856 extending over a ledge 858 of the chassis 824. The connections 854 secure the LED assembly 822 to the ledge 858. Additionally, the connections 854 may be electrical connections configured to provide power and/or electrical connections to the LEDs 850. In certain embodiments, the PCB 852 may include an additional tab 856 disposed generally opposite the illustrated tab 856 and configured to mount to an additional ledge 858 of the chassis 824. However, the additional tab 856 and the additional ledge 858 are omitted in FIG. 14 for purposes of clarity.

The LEDs 850 of the LED assembly 822 are configured to emit light outwardly through the fluid flowing between the LED assembly 822 and the cover 826 (e.g., through an upper passage 860 of the cooling system 100) and through the cover 826. In some embodiments, the cover 826 enclosing the fluid may be acrylic, polycarbonate, glass (e.g., borosilicate glass), or another material having a refractive index between about 1.44-1.5. Additionally, the refractive index of the LEDs 850 (e.g., the silicone), the fluid, and/or the cover 826 may generally be matched (e.g., within a difference threshold).

The cooling system 100 is configured to flow the fluid into the fluid inlet 832, into the upper passage 860 extending between the LED assembly 822 and the cover 826 (e.g., as indicated by arrow 862), and into a lower passage 864 extending between the LED assembly 822 and the base 840 of the chassis 824 (e.g., as indicated by arrow 866). The fluid is configured to absorb heat generated by the LED assembly 822 (e.g., due to operation of the LEDs 850 and the PCB 852

and the light emitted by the LEDs 850) as the fluid flow through the upper passage 860 and the lower passage 864. Additionally, because the fluid is generally transparent and/or semi-transparent (e.g., the fluid has a refractive index generally between 1.4-1.5), the fluid may have minimal/no effects on the light emitted from the LED assembly 822 and through the fluid. As such, the fluid may actively cool the LED assembly 822 during operation of the LED assembly 822 with little to no effect on a quality of light emitted from the LED assembly 822.

The cooling system 100 is configured to flow the fluid from the upper passage 860 and into the fluid outlet 834, as indicated by arrow 870, and from the lower passage 864 into the fluid outlet 834, as indicated by arrow 872. After flowing the fluid over the LED assembly 822 and into the fluid outlet 834, the pump 108 circulates the fluid through a heat exchanger 106 of the cooling system 100, for example, to cool the fluid.

FIG. 15 is a perspective view of the lighting assembly 820 of FIG. 14. As described above, the cooling system 100 is configured to circulate the fluid into the fluid inlet 830 of the chassis 824, over the LED assembly 822 of the lighting assembly 820, and through the fluid outlet 834, thereby cooling the LED assembly 822. Accordingly, the lighting assembly 820 of FIGS. 14 and 15 provides a front emission configuration of a lighting assembly and LED assembly that may be cooled via the cooling system 100.

FIG. 16 is a flow diagram of a method 900 for controlling the cooling system 100 of FIG. 1. For example, the method 900, or portions thereof, may be performed by the controller 120 of the cooling system 100. The method 900 begins at block 902, where the temperature at an LED assembly (e.g., the LED assembly 102/196) is measured. The sensor 121 may measure the temperature and output a signal (e.g., an input signal to the controller 120) indicative of the temperature at or adjacent to the LED assembly (e.g., a temperature at a surface of the LED assembly, a temperature of the fluid adjacent to and/or flowing over the LED assembly, a temperature at a surface of the enclosure 104/198, etc.). The controller 120 may receive the signal indicative of the temperature.

At block 904, the temperature at the LED assembly is determined. Block 904 may be performed in addition to or in place of block 902. For example, block 902 may be omitted from the method 900, and the sensor 121 may be omitted from the cooling system 100. The controller 120 may be configured to determine the temperature at the LED assembly based on whether the LED assembly, or portions thereof, are emitting light and based on an amount of time that the LED assembly, or the portions thereof, have been emitting light. As generally described above, the controller 120 may be configured to control the LED assembly (e.g., by controlling which LED arrays 182 are emitting light, a duration that the LED arrays 182 emit light, an intensity of the light emitted by the LED arrays 182, etc.). Based on the control actions, the controller 120 may determine/estimate the temperature at the LED assembly (e.g., the temperature at the surface of the LED assembly 102/196, the temperature of the fluid adjacent to and/or flowing over the LED assembly 102/196, the temperature at the surface of the enclosure 104/198, etc.).

At block 906, operating parameter(s) of the cooling system 100 are adjusted based on the temperature at the LED assembly (e.g., the temperature measured at block 902 and/or determined at block 904). For example, the controller 120 may output a signal (e.g., an output signal) to the pump 108 indicative of instructions to adjust the flowrate of fluid

17

through the cooling circuit 110. Additionally or alternatively, the controller 120 may output a signal to a heat exchanger (e.g., the heat exchanger 106/601) indicative of instructions to adjust a flow rate of air flowing over a radiator of the heat exchanger (e.g., by outputting a signal to fans of the heat exchanger 106/601 indicative of instructions to adjust a rotational speed of the fans to adjust the flow rate of air). In certain embodiments, the controller 120 may control the LED assembly based on the temperature at the LED assembly, such as by reducing a number of LED arrays emitting light and/or to prevent overheating of the LED assembly.

In certain embodiments, the controller 120 may compare the temperature at the LED assembly to a target temperature and determine whether a difference between the temperature (e.g., a measured and/or determined temperature at the LED assembly 102/196) and the target temperature is greater than a threshold value. Based on the difference exceeding the threshold value, the controller 120 may control the operating parameters of the cooling system 100 described above. As such, the controller 120 may reduce certain control actions performed by the cooling system 100 based on minor temperature fluctuations and/or may reduce an amount of air flow and/or power used by the heat exchanger to cool the fluid. The controller 120 may receive an input indicative of the target temperature (e.g., from an operator of the cooling system 100) and/or may determine the target temperature based on a type of LED included in the LED assembly, a type of fluid circulating through the cooling system 100, a material of the enclosure, a material of the tower of the LED assembly, a size of the LED assembly and/or the cooling system 100 generally, or a combination thereof.

After completing block 906, the method 900 returns to block 902 and the next temperature at the LED assembly is measured. Alternatively, the method 900 may return to block 904, and the next temperature at the LED assembly may be determined. As such, blocks 902-906 of the method 900 may be iteratively performed by the controller 120 and/or by the cooling system 100 generally to facilitate cooling of the LED assembly and the enclosure.

While only certain features of the disclosure have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the disclosure.

The techniques presented and claimed herein are referenced and applied to material objects and concrete examples of a practical nature that demonstrably improve the present technical field and, as such, are not abstract, intangible or purely theoretical. Further, if any claims appended to the end of this specification contain one or more elements designated as “means for [perform]ing [a function] . . .” or “step for [perform]ing [a function] . . .”, it is intended that such elements are to be interpreted under 35 U.S.C. 112(f). However, for any claims containing elements designated in any other manner, it is intended that such elements are not to be interpreted under 35 U.S.C. 112(f).

The invention claimed is:

1. A cooling system for a light emitting diode (“LED”) assembly, comprising:

a fluid configured to absorb heat at the LED assembly and generated by the LED assembly, wherein the fluid is transparent or semi-transparent, and wherein the fluid is configured to enable light emitted by the LED assembly to pass through the fluid;

18

a heat exchanger configured to remove heat absorbed by the fluid at the LED assembly and exchange heat from the fluid to ambient air;

an enclosure configured to house the LED assembly, wherein the enclosure is transparent or semi-transparent; and

a pump configured to circulate the fluid between the enclosure and the LED assembly and through the heat exchanger, wherein the LED assembly comprises at least one LED array configured to operate above a predetermined power density, and wherein the predetermined power density is between 50 watts per square inch and 250 watts per square inch.

2. The cooling system of claim 1, wherein the heat exchanger comprises a radiator configured to exchange heat with ambient air.

3. The cooling system of claim 1, wherein the heat exchanger comprises one or more fans configured to draw air across at least a portion of the heat exchanger to exchange heat from the heat exchanger to air.

4. The cooling system of claim 1, comprising the LED assembly, wherein the LED assembly is configured to transmit light through the enclosure in a front emission configuration or a side emission configuration.

5. The cooling system of claim 1, comprising the at least one LED array, wherein the at least one LED array comprises a plurality of LEDs configured to operate above the predetermined power density, and wherein the heat exchanger is configured to remove heat absorbed by the fluid at the at least one LED array while the plurality of LEDs operate above the predetermined power density.

6. The cooling system of claim 5, wherein the at least one LED array has a surface area equal to or less than 4 in², and wherein the at least one LED array is configured to operate at or above the predetermined power density for more than 1 minute.

7. The cooling system of claim 6, wherein the LED assembly is configured to operate above a total power of between 400 watts and 5000 watts.

8. The cooling system of claim 1, comprising a flexible diaphragm configured to expand, retract, or both, as a volume of the fluid increases, decreases, or both.

9. The cooling system of claim 1, wherein a first refractive index corresponding to the fluid and a second refractive index corresponding to the enclosure are matched.

10. The cooling system of claim 1, comprising the LED assembly, an inner annular passage formed within the LED assembly, and an outer annular passage formed between the LED assembly and the enclosure, wherein the pump is configured to circulate the fluid through the outer annular passage and the inner annular passage to absorb heat at the LED assembly.

11. The cooling system of claim 1, comprising: the LED assembly configured to emit light; and

a controller comprising a memory and a processor, wherein the processor is configured to: receive an input signal indicative of a temperature at the LED assembly;

determine whether a difference between the temperature at the LED assembly and a target temperature exceeds a threshold value; and

adjust operation of the heat exchanger, the pump, or both, based on the difference between the temperature at the LED assembly and the target temperature exceeding the threshold value.

12. The cooling system of claim 11, wherein adjusting operation of the heat exchanger, the pump, or both, com-

19

prises adjusting operation of fans of the heat exchanger configured to force air over the heat exchanger to cool the fluid circulating through the heat exchanger.

13. The cooling system of claim 12, wherein adjusting operation of the fans of the heat exchanger comprises:

causing the fans to increase an air flow over the heat exchanger in response to the temperature being greater than the target temperature and the difference between the temperature and the target temperature exceeding the threshold value; and

causing the fans to decrease the air flow over the heat exchanger in response to the temperature being less than the target temperature and the difference between the temperature and the target temperature exceeding the threshold value.

14. The cooling system of claim 1, wherein the enclosure comprises acrylic, polycarbonate, glass, or a combination thereof.

15. The cooling system of claim 1, wherein a refractive index of the fluid is between 1.4 and 1.6.

16. The cooling system of claim 1, wherein a refractive index of the enclosure is between 1.44 and 1.5.

17. The cooling system of claim 1, wherein the fluid is configured to contact the LED assembly.

18. A cooling system for a light emitting diode ("LED") assembly, comprising:

a fluid configured to absorb heat at the LED assembly and generated by the LED assembly, wherein the fluid is transparent or semi-transparent, and wherein the fluid is configured to enable light emitted by the LED assembly to pass through the fluid;

a heat exchanger configured to remove heat absorbed by the fluid at the LED assembly and exchange heat from the fluid to ambient air;

an enclosure configured to house the LED assembly, wherein the enclosure is transparent or semi-transparent;

a pump configured to circulate the fluid between the enclosure and the LED assembly and through the heat exchanger;

the LED assembly configured to emit light; and

a controller comprising a memory and a processor, wherein the processor is configured to:

receive an input signal indicative of a temperature at the LED assembly;

determine whether a difference between the temperature at the LED assembly and a target temperature exceeds a threshold value; and

adjust operation of the heat exchanger, the pump, or both, based on the difference between the temperature at the LED assembly and the target temperature

20

exceeding the threshold value, wherein adjusting operation of the heat exchanger, the pump, or both, comprises adjusting a flow rate of the fluid through the LED assembly, the enclosure, and the heat exchanger.

19. The cooling system of claim 18, wherein adjusting the flow rate of the fluid comprises:

causing the pump to increase the flow rate of the fluid in response to the temperature being greater than the target temperature and the difference between the temperature and the target temperature exceeding the threshold value; and

causing the pump to decrease the flow rate of the fluid in response to the temperature being less than the target temperature and the difference between the temperature and the target temperature exceeding the threshold value.

20. A cooling system for a light emitting diode ("LED") assembly, comprising:

a fluid configured to absorb heat at the LED assembly and generated by the LED assembly, wherein the fluid is transparent or semi-transparent, and wherein the fluid is configured to enable light emitted by the LED assembly to pass through the fluid;

a heat exchanger configured to remove heat absorbed by the fluid at the LED assembly and exchange heat from the fluid to ambient air;

an enclosure configured to house the LED assembly, wherein the enclosure is transparent or semi-transparent;

a pump configured to circulate the fluid between the enclosure and the LED assembly and through the heat exchanger;

the LED assembly configured to emit light; and

a controller comprising a memory and a processor, wherein the processor is configured to:

receive an input signal indicative of a temperature at the LED assembly;

determine a target temperature based on a type of LED of the LED assembly, a type of the fluid circulating through the cooling system, a material of the enclosure, a material of a tower of the LED assembly, a size of the LED assembly, or a combination thereof; determine whether a difference between the temperature at the LED assembly and the target temperature exceeds a threshold value; and

adjust operation of the heat exchanger, the pump, or both, based on the difference between the temperature at the LED assembly and the target temperature exceeding the threshold value.

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