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(54) **CURRENT STEERING AND DIMMING CONTROL OF A LIGHT EMITTER**

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H05B 33/08 (2006.01)

(52) **U.S. Cl.**
CPC ***H05B 37/0272*** (2013.01); ***H05B 33/0803*** (2013.01); ***H05B 33/0857*** (2013.01)

(58) **Field of Classification Search**
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USPC 315/149, 291, 307, 224, 246, 312, 158, 315/287; 323/212, 300
See application file for complete search history.

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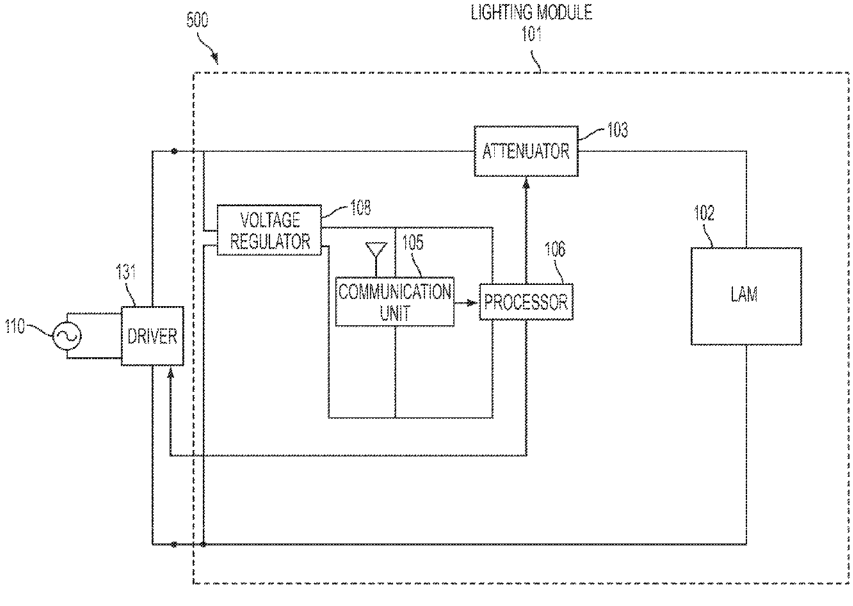
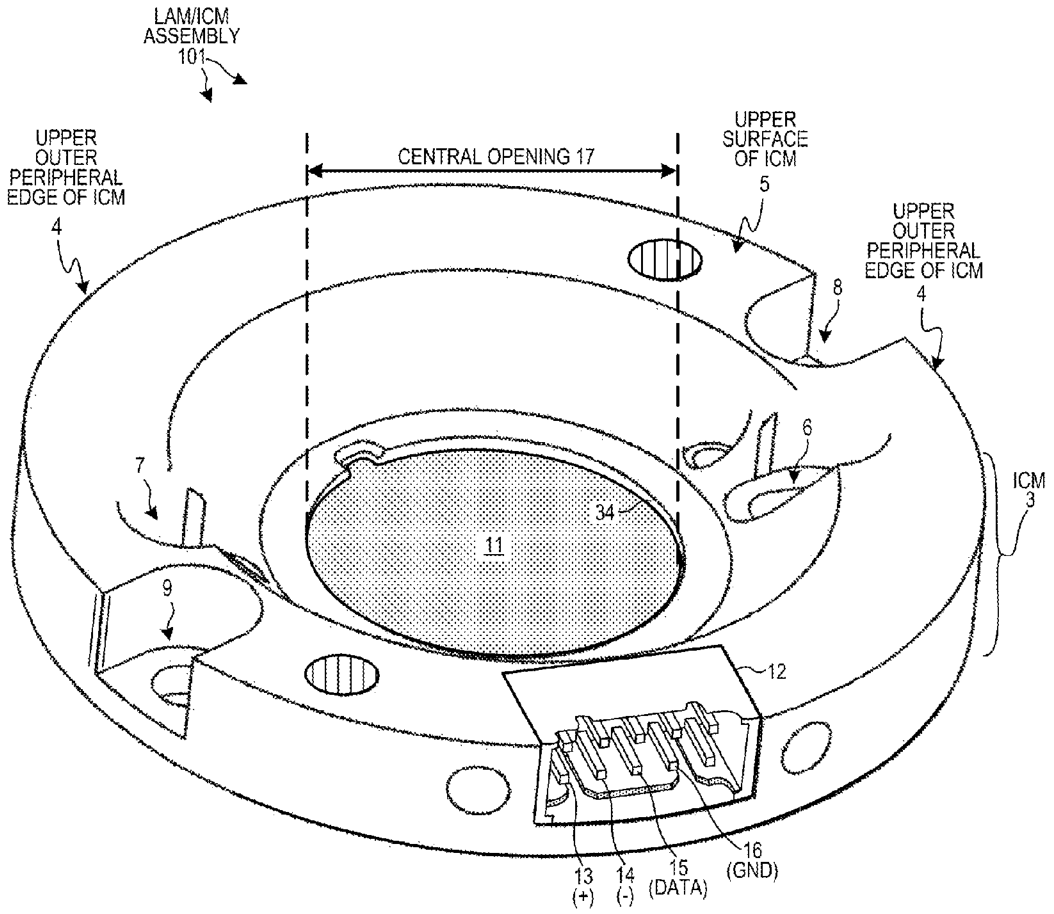
(74) *Attorney, Agent, or Firm* — Arent Fox LLP

(57) **ABSTRACT**

A lighting module includes a light emitting diode (LED) array and a dimming circuit configured to control current applied to the LED array to control luminance of light emitted from the lighting module.

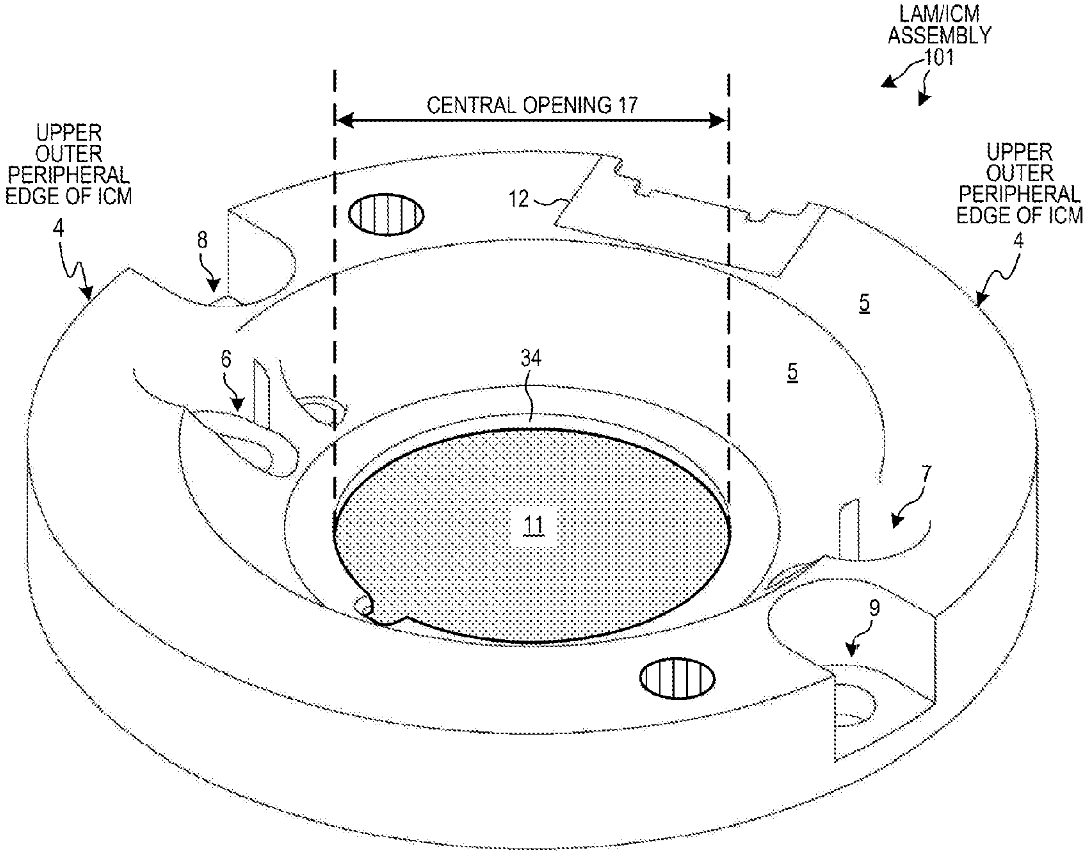
17 Claims, 14 Drawing Sheets





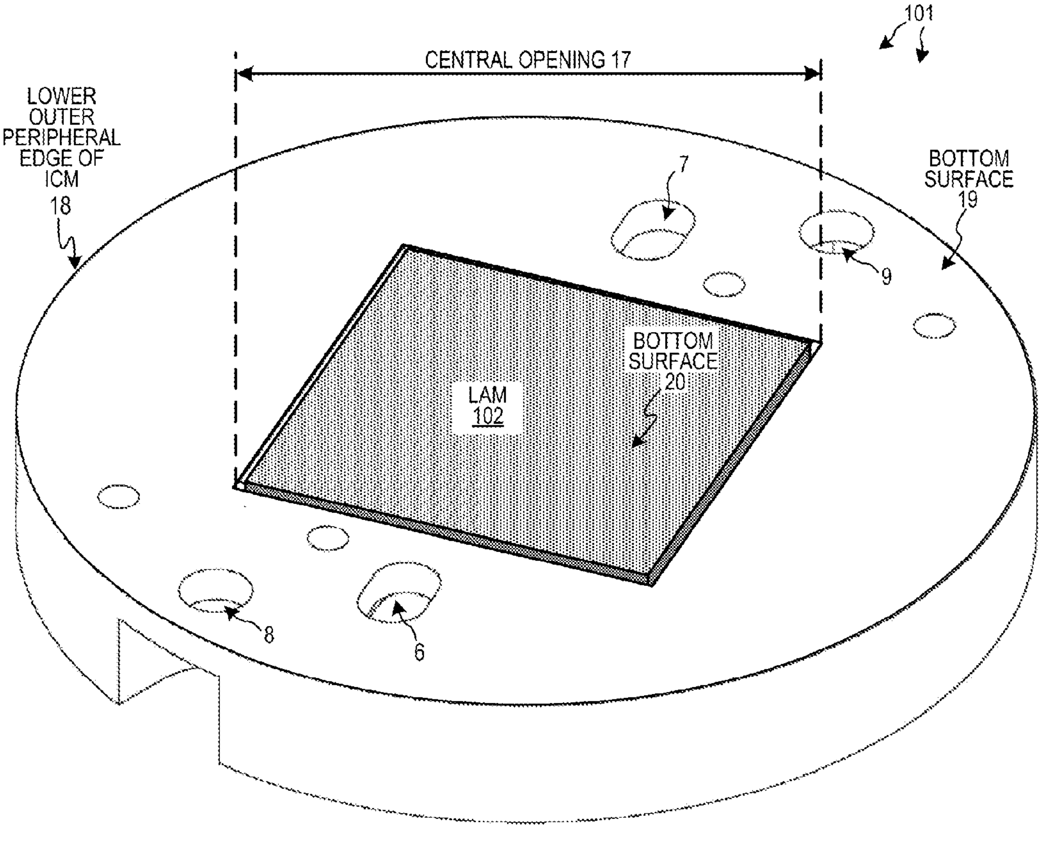
VIEW OF TOP OF LAM/ICM ASSEMBLY
(PERSPECTIVE TOP VIEW)

FIG. 1



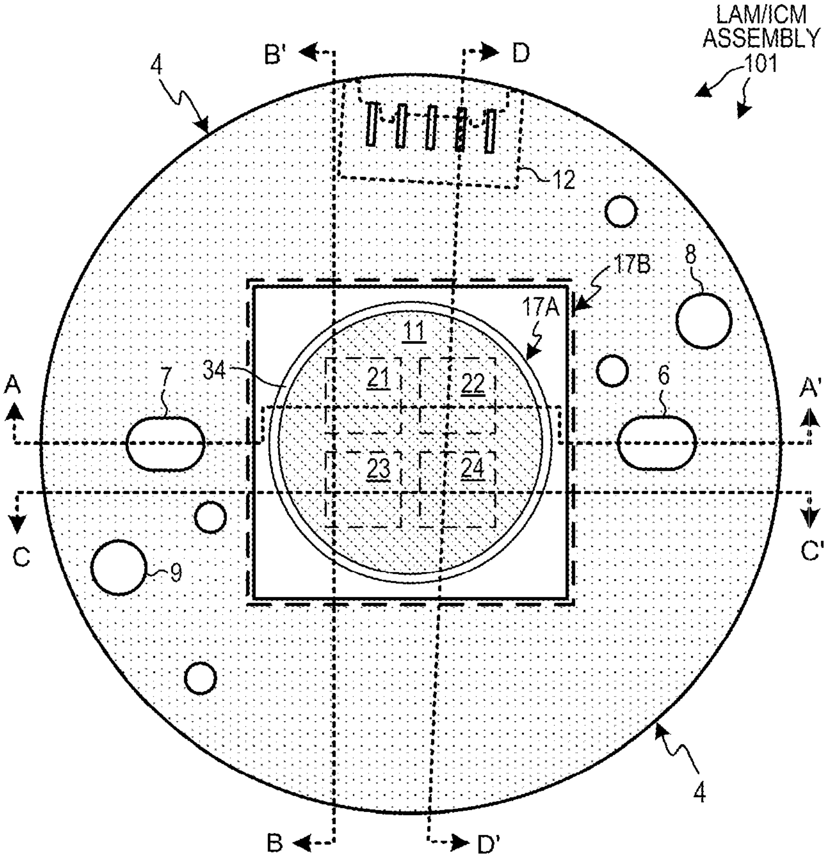
VIEW OF TOP OF LAM/ICM ASSEMBLY
(PERSPECTIVE TOP VIEW)

FIG. 2



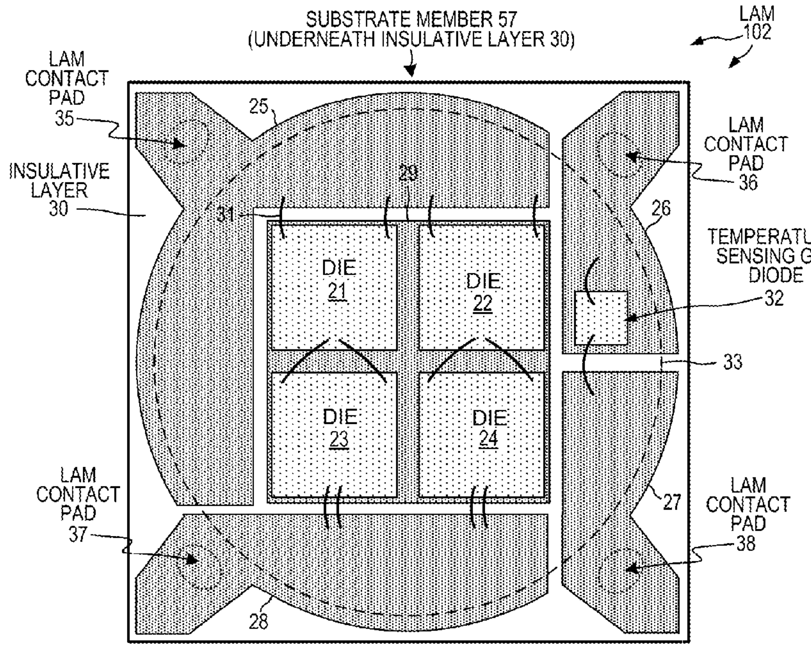
VIEW OF BOTTOM OF LAM/ICM ASSEMBLY
(PERSPECTIVE VIEW)

FIG. 3



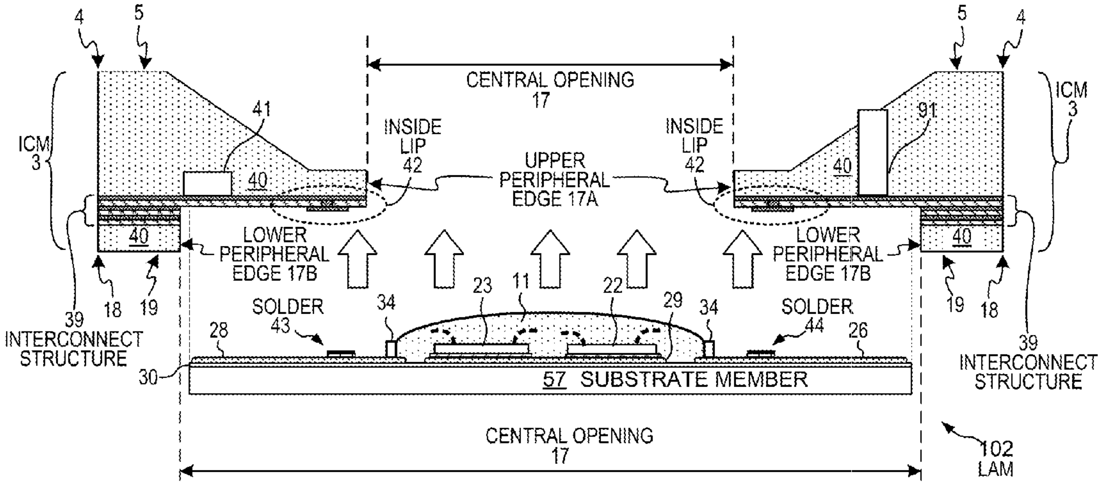
TOP-DOWN VIEW OF LAM/ICM ASSEMBLY
(TOP-DOWN VIEW)

FIG. 4



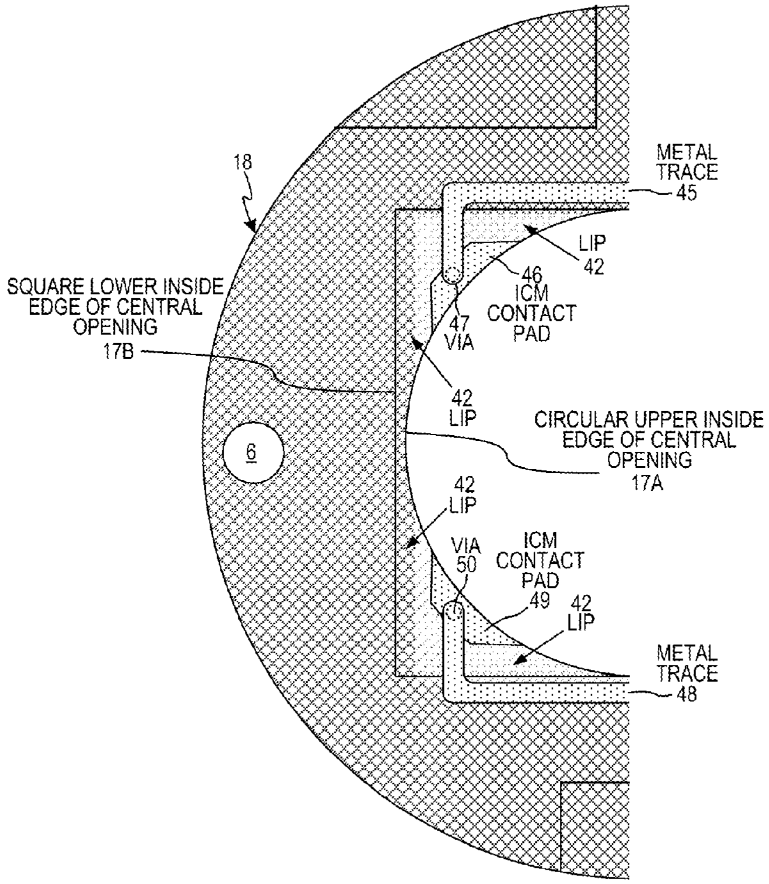
TOP-DOWN VIEW OF ONE EXAMPLE OF A LAM
(SHOWN WITHOUT PHOSPHOR LAYER)

FIG. 5



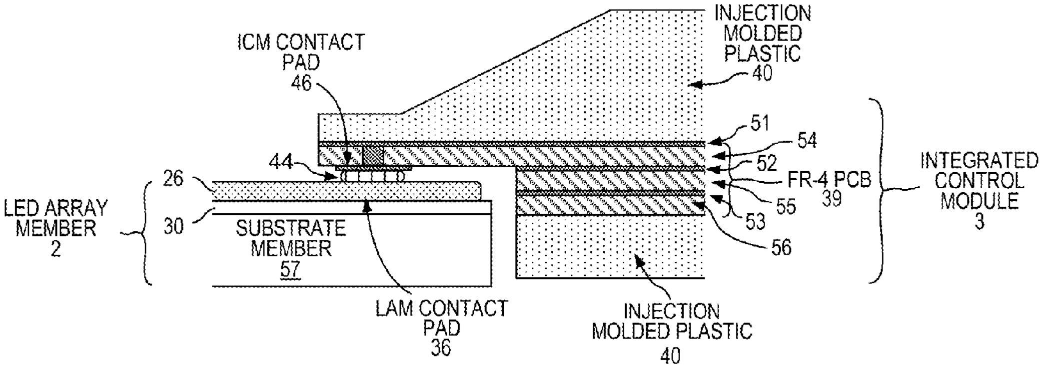
THE LAM FITS UP INTO THE CENTRAL OPENING IN THE
BOTTOM OF THE ICM AND IS FIXED IN PLACE
(CROSS-SECTIONAL SIDE VIEW OF ASSEMBLY)

FIG. 6



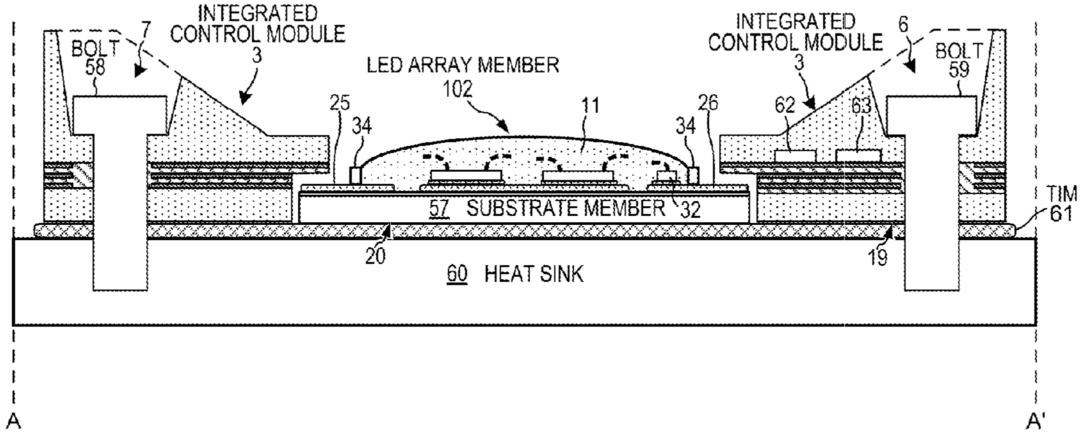
BOTTOM-UP VIEW OF ICM SHOWING CONTACT PADS ON THE INSIDE LIP OF THE ICM

FIG. 7



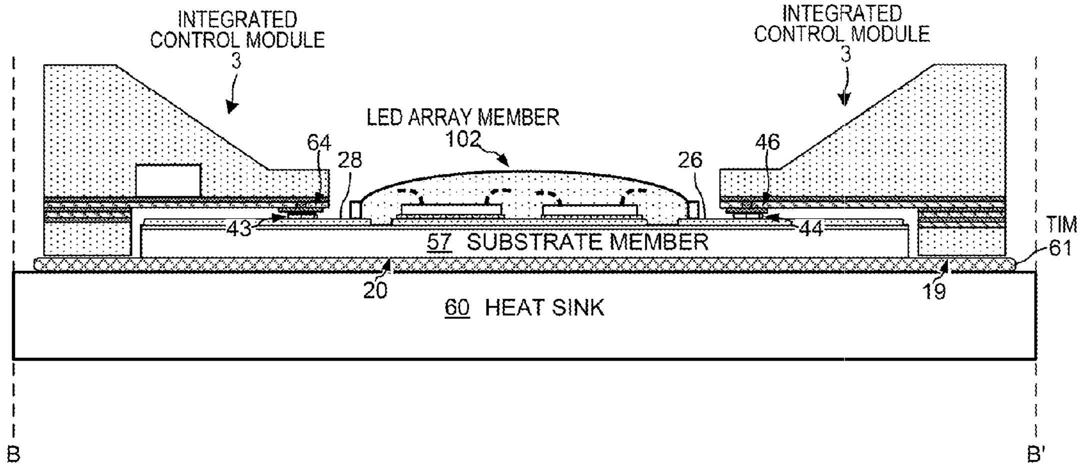
DETAIL OF A CONTACT PAD OF THE LAM MAKING CONTACT WITH A CONTACT PAD ON THE BOTTOM OF THE INSIDE LIP OF THE ICM

FIG. 8



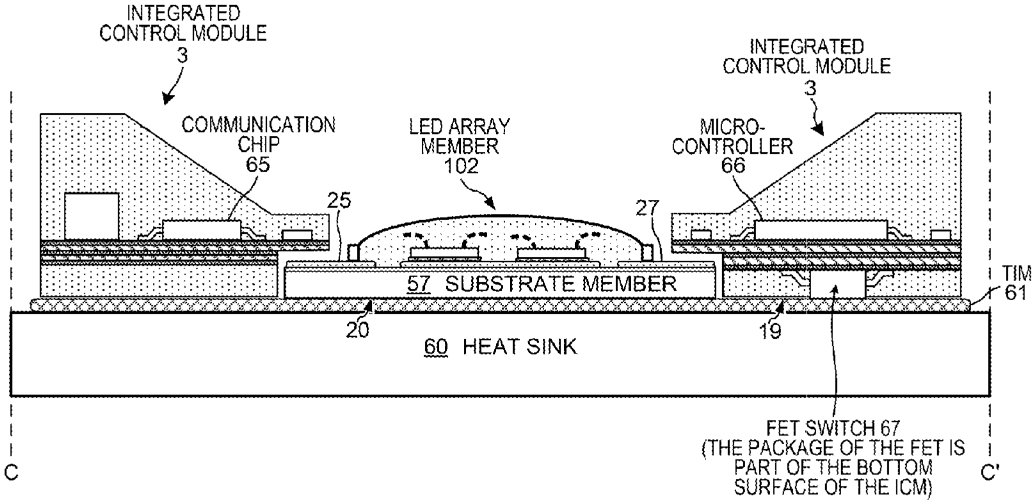
CROSS-SECTIONAL VIEW TAKEN ALONG LINE A-A'
(SHOWN ON A HEAT SINK)

FIG. 9



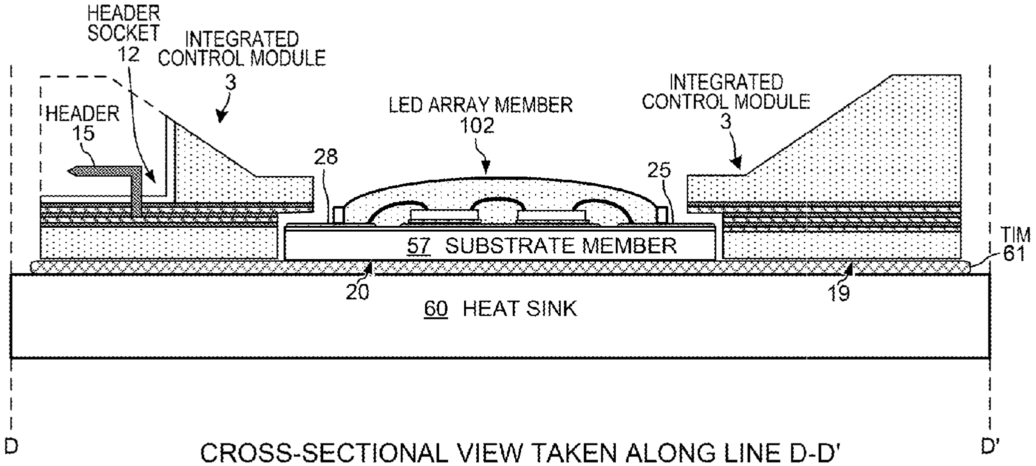
CROSS-SECTIONAL VIEW TAKEN ALONG LINE B-B'
(SHOWN ON A HEAT SINK)

FIG. 10



CROSS-SECTIONAL VIEW TAKEN ALONG LINE C-C'
(SHOWN ON A HEAT SINK)

FIG. 11



CROSS-SECTIONAL VIEW TAKEN ALONG LINE D-D'
(SHOWN ON A HEAT SINK)

FIG. 12

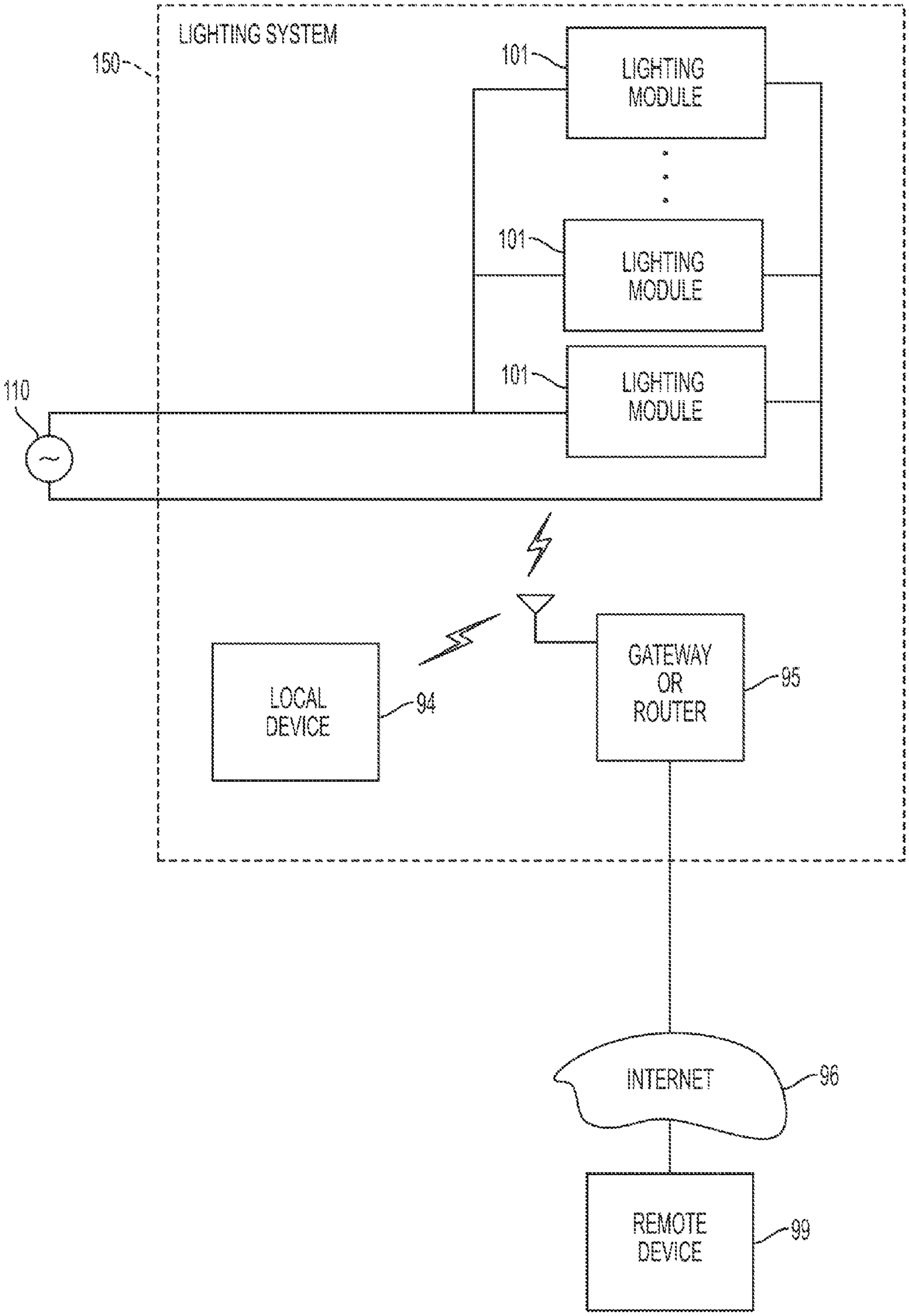

LIGHTING SYSTEM
150
101
LIGHTING MODULE
101
LIGHTING MODULE
101
LIGHTING MODULE
110
~
LOCAL DEVICE
94
GATEWAY OR ROUTER
95
INTERNET
96
REMOTE DEVICE
99

FIG. 13

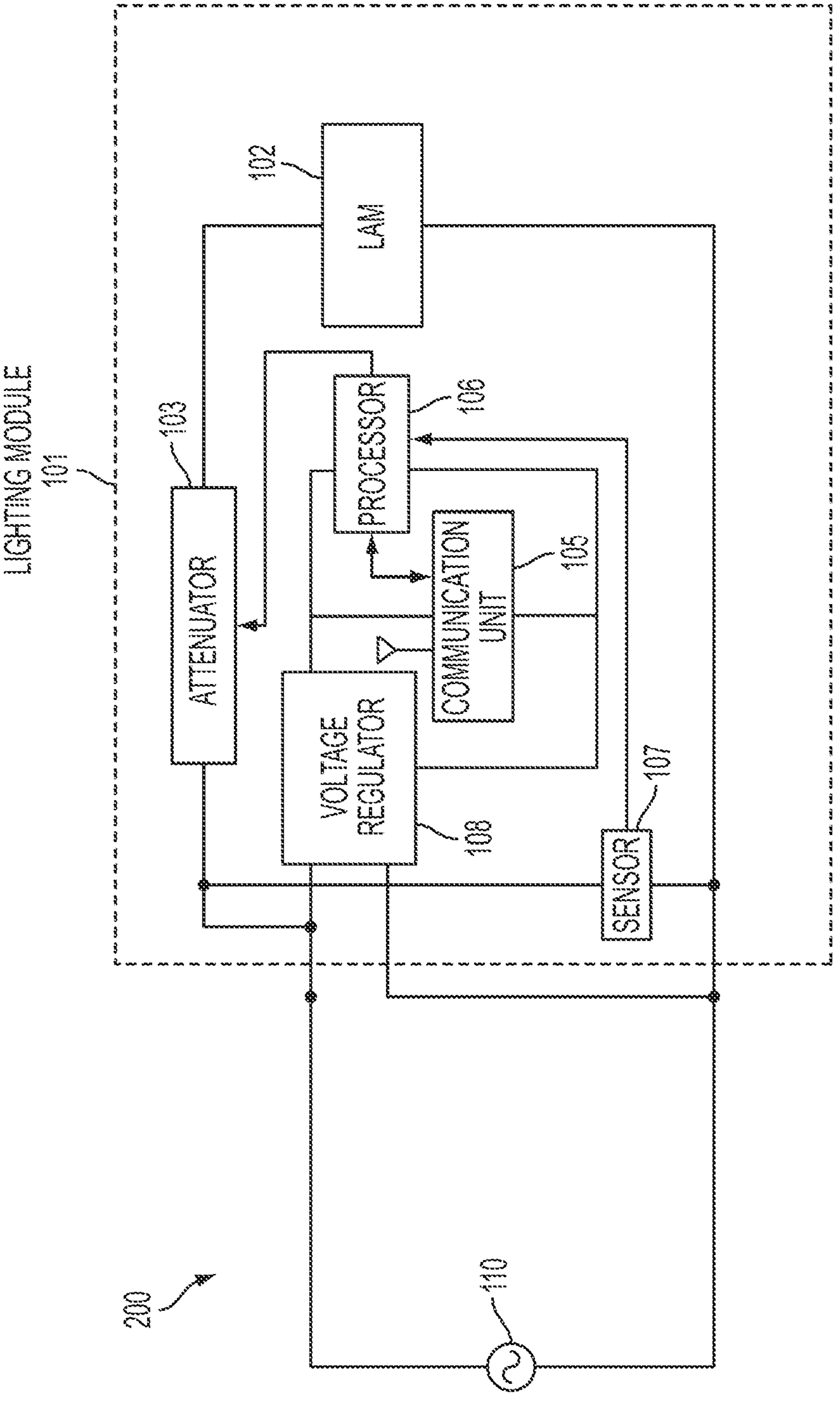

LIGHTING MODULE
101
102
LAM
103
ATTENUATOR
PROCESSOR
106
COMMUNICATION UNIT
105
VOLTAGE REGULATOR
108
SENSOR
107
200
110

FIG. 14

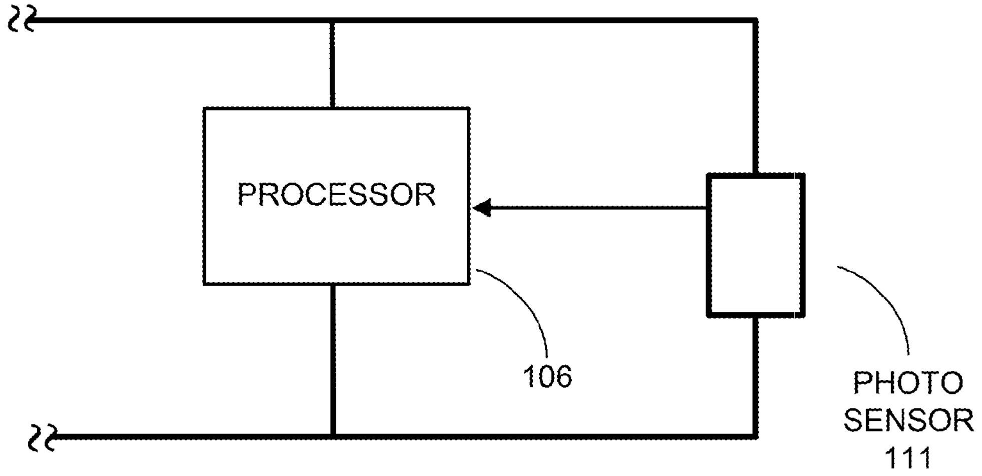


FIG. 14A

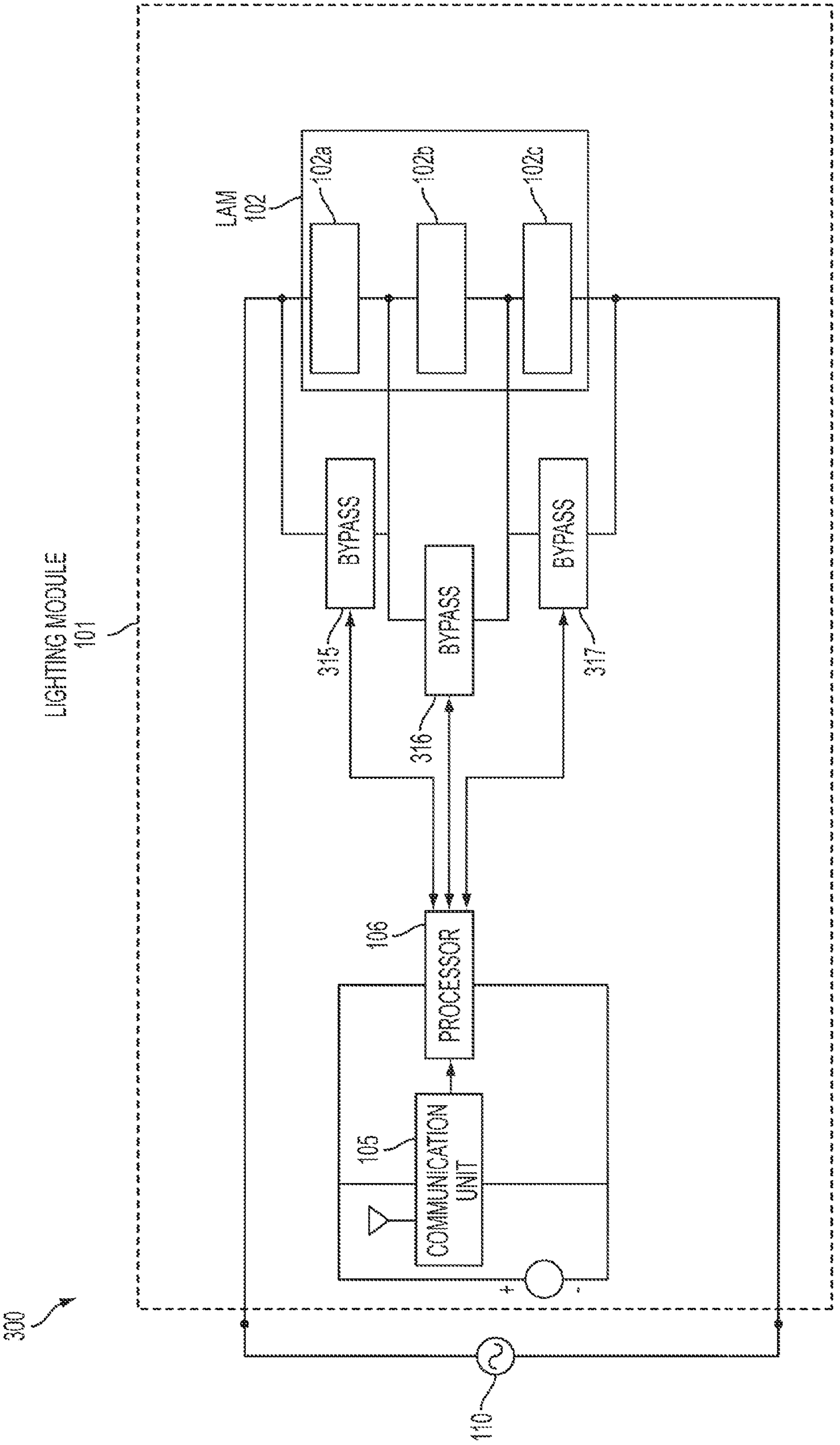

LIGHTING MODULE
101
LAM
102
102a
102b
102c
BYPASS
BYPASS
BYPASS
315
316
317
106
PROCESSOR
105
COMMUNICATION
UNIT
+
-
300
110

FIG. 15

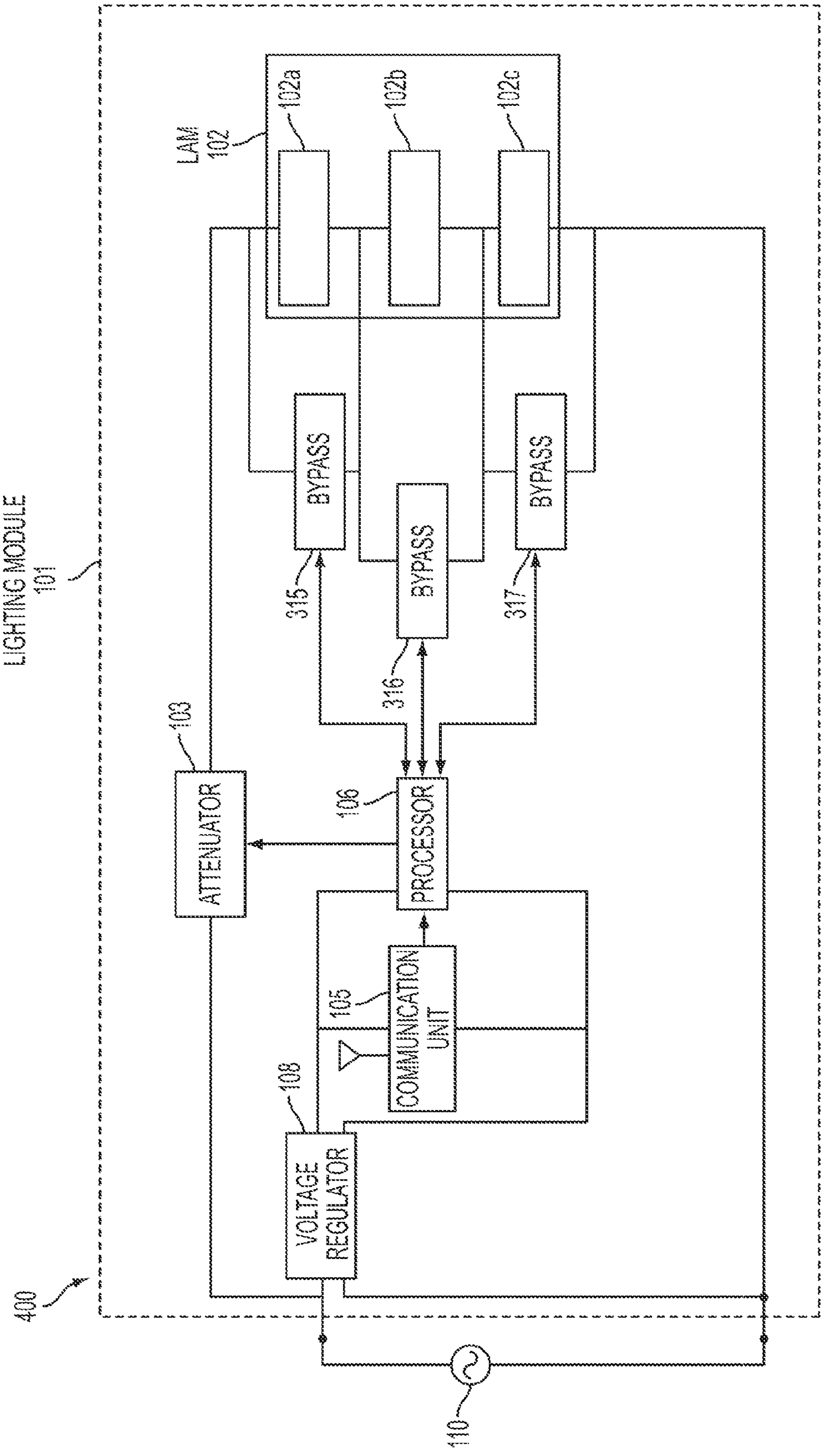

LIGHTING MODULE
101
400
LAM
102
102a
102b
102c
BYPASS
BYPASS
BYPASS
315
316
317
ATTENUATOR
103
PROCESSOR
106
COMMUNICATION UNIT
105
VOLTAGE REGULATOR
108
110

FIG. 16

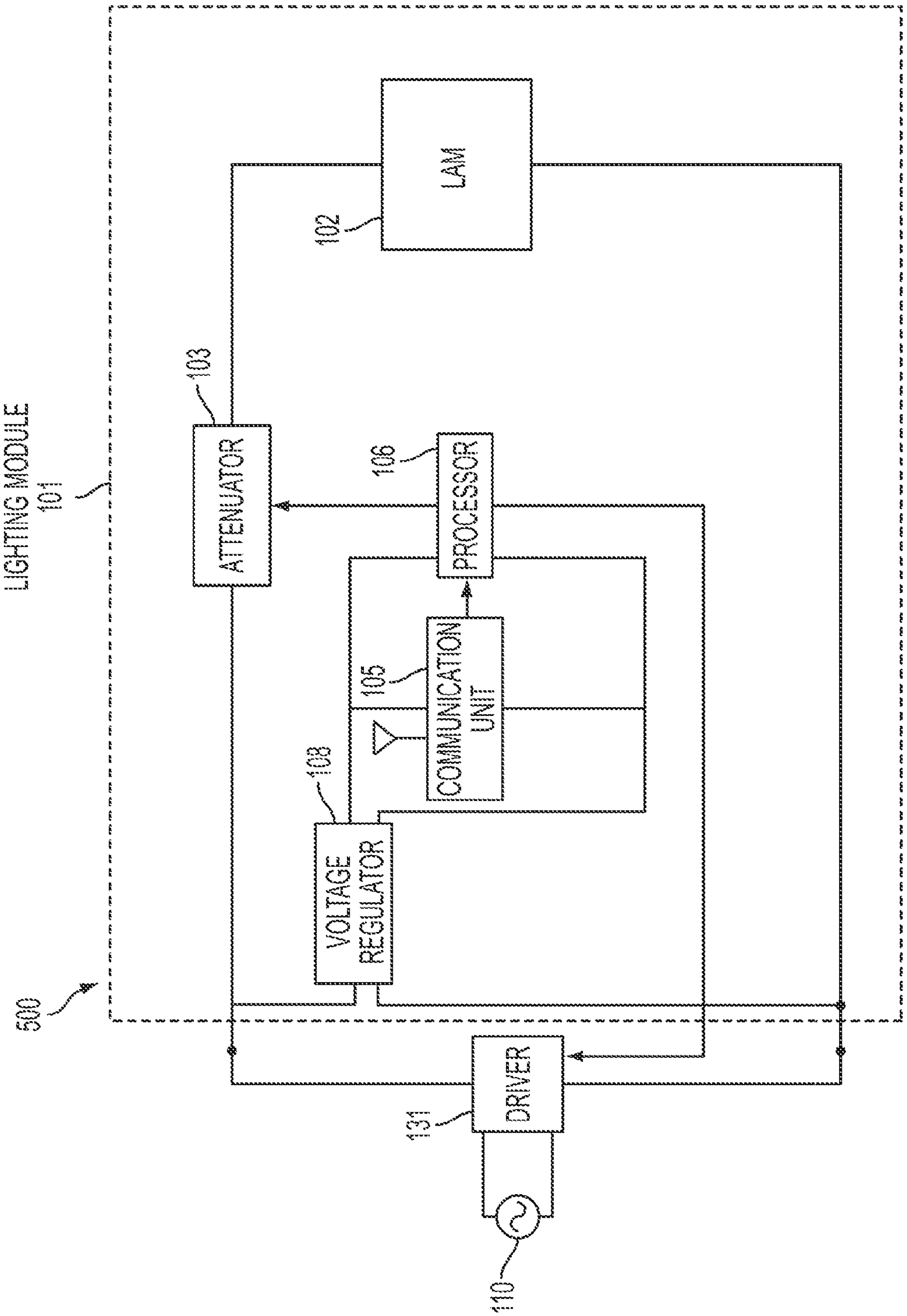

LIGHTING MODULE
101
500
ATTENUATOR
103
LAM
102
PROCESSOR
106
COMMUNICATION UNIT
105
VOLTAGE REGULATOR
108
DRIVER
131
110

FIG. 17

CURRENT STEERING AND DIMMING CONTROL OF A LIGHT EMITTER

BACKGROUND

Field

The present disclosure relates generally to solid state light emitters, and more particularly, to dimming control of the solid state light emitter.

Background

Solid state light emitters, such as light emitting diodes (LEDs), are becoming the favored choice for general lighting applications over incandescent lamps and fluorescent fixtures for their lower power demand. An LED converts electrical energy to light. Light is emitted from active layers of semiconductor material sandwiched between oppositely doped layers when a voltage is applied across the doped layers. In order to use an LED chip, the chip is typically enclosed along with other LED chips in a package. In one example, the packaged device is referred to as an LED array. The LED array includes an array of LED chips mounted onto a heat conducting substrate. A layer of silicone in which phosphor particles is embedded is typically disposed over the LED chips. Electrical contact pads are provided for supplying current into the LED array and through the LED chips so that the LED chips can be made to emit light. Light emitted from the LED chips is absorbed by the phosphor particles, and is re-emitted by the phosphor particles so that the re-emitted light has a wider band of wavelengths.

Compact lighting fixtures or modules with solid state light emitters do not contain AC/DC conversion, DC driver, and dimming control circuits due to the heat generated by the light emitter, which can compromise the performance of heat sensitive electronics. Instead, the power and control components are typically arranged externally to the lighting fixture. Installation of solid state light emitters using several external power and control components can complicate the physical installation surrounding the lighting fixture and require added labor. Allowing several light emitters to share power and control components may reduce the number of components to install, but at the cost of surrendering individual power and control to each emitter. In particular, for large lighting installations where remote power control of many lighting fixtures is sought from a central location, maintaining individualized control capability is desirable for flexibility of the lighting system operation.

Designing a solid state lighting module with an AC voltage input can eliminate some of the external components, such as the DC driver. A solid state attenuator or rectifier may be used as a driver for the lighting element. For dimming control, passive control circuit devices (e.g., resistive/capacitive (RC) devices) can be used for dimming the lighting element by detection of the zero crossing points of the VAC input which can then be applied in phase-cut techniques. However, such control circuits are typically installed externally to the lighting fixture, and thus have the same drawback as with DC driven light emitters. In addition, due to minimum current flow requirements of the solid state attenuator, complete dimming may not be achievable. Typical circuits of this type are limited to dimming only down to about 5-10% of the light output before the light emitter simply cuts out because of the minimum current parameters of the attenuator. A dimming control circuit for solid state light emitters that can be contained within the lighting fixture with remote control network capability and that can allow deep dimming between 0 and 10% luminance is needed.

SUMMARY

In an aspect of the disclosure, a lighting module includes a light emitting diode (LED) array and a dimming circuit configured to control current applied to the LED array to control luminance of light emitted from the lighting module.

In another aspect of the disclosure, a lighting module includes an LED array arranged in a plurality of sections and a plurality of bypass circuits, each of the bypass circuits being configured to bypass a corresponding one of the sections of the LED array to control the luminance of light emitted from the lighting module.

In another aspect of the disclosure, a lighting module configured to be coupled to an external driver includes an LED array and a dimming circuit configured to control current applied to the LED array to control the luminance emitted from the lighting module. The dimming circuit includes a processor configured to receive a dimming input signal and to send a first control signal to an external driver and a second control signal to the dimming circuit in response to the dimming input signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of the connector side of the top of an exemplary LED array member (LAM)/integrated control module (ICM) assembly.

FIG. **2** is a perspective view of the top of an exemplary LED array member (LAM)/integrated control module (ICM) assembly from the side opposite the connector.

FIG. **3** is a perspective view of the bottom of the exemplary LAM/ICM of FIGS. **1** and **2**.

FIG. **4** is a cross-sectional, top-down view of the exemplary LAM/ICM assembly of FIGS. **1** and **2**.

FIG. **5** is top-down view of an exemplary LAM usable with the ICM of FIGS. **1** and **2**.

FIG. **6** is cross-sectional view showing how the exemplary LAM fits up and into the central opening in the ICM.

FIG. **7** is a diagram showing an exemplary ICM contact pad disposed on the inside lip of the ICM.

FIG. **8** is a more detailed diagram showing an exemplary LAM contact pad on the peripheral edge of upper surface of the LAM making contact with a corresponding ICM contact pad.

FIG. **9** is a cross-sectional view taken along line A-A' of the exemplary LAM/ICM of FIG. **4**.

FIG. **10** is a cross-sectional view taken along line B-B' of the exemplary LAM/ICM of FIG. **4**.

FIG. **11** is a cross-sectional view taken along line C-C' of the exemplary LAM/ICM of FIG. **4**.

FIG. **12** is a cross-sectional view taken along line D-D' of the exemplary LAM/ICM of FIG. **4**.

FIG. **13** shows a block diagram of an exemplary lighting system having remote dimming control of multiple lighting modules.

FIG. **14** shows a block diagram of an exemplary lighting module including a local dimming control circuit for a solid state light emitter.

FIG. **14**A shows an example of a photo sensor used to detect ambient luminance for controlling dimming of a solid state light emitter.

FIG. **15** shows a block diagram of an exemplary lighting module including a local dimming control circuit for LED array sections.

FIG. **16** shows block diagram of an exemplary lighting module including a local dimming control circuit for multiple solid state light emitters combining primary dimming control and deep dimming control.

FIG. **17** shows a block diagram of an exemplary lighting module including a local dimming control circuit for deep dimming of multiple solid state light emitters powered by a DC driver.

DETAILED DESCRIPTION

The detailed description set forth below in connection with the appended drawings is intended as a description of various configurations and is not intended to represent the only configurations in which the concepts described herein may be practiced. The detailed description includes specific details for the purpose of providing a thorough understanding of various concepts. However, it will be apparent to those skilled in the art that these concepts may be practiced without these specific details. In some instances, well known structures and components are shown in block diagram form in order to avoid obscuring such concepts.

The word “exemplary” is used herein to mean serving as an example, instance, or illustration. Any embodiment described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments. Likewise, the term “embodiment” of an apparatus, method or article of manufacture does not require that all embodiments of the invention include the described components, structure, features, functionality, processes, advantages, benefits, or modes of operation. The phrase “coupled to” used herein relates to an electrical connection between two elements, and not necessarily a mechanical connection.

FIGS. **1-2** show perspective views of the top of an LED assembly member/integrated control module assembly (LAM/ICM assembly) **101**. There are two parts of the LAM/ICM assembly: a LED assembly member **102** (FIG. **3**) and an integrated control module **3**. The LED assembly member **102** is hereinafter referred to as the LAM. The integrated control module **3** is hereinafter referred to as the ICM. As illustrated in the diagram, the LAM/ICM assembly **101** is a disk-shaped structure that has a circular upper outer peripheral edge **4**.

LAM/ICM assembly **101** includes an upper surface **5** of a molded plastic encapsulant **40** (FIG. **6**). Two sets of two holes **6-9** are provided through which threaded screws or bolts (not shown) can extend to fix the LAM/ICM assembly **101** to a heat sink. The disk-shaped shaded object in the center in the illustration is a disk-shaped amount of silicone **11**. The silicone **11** has phosphor particles embedded in it. This silicone with the embedded phosphor particles overlies an array of light emitting diodes (LEDs). The LEDs are not seen in the diagram because they are disposed under the silicone. The LAM/ICM assembly **101** further includes a header socket **12** and ten header pins, such as pins **13**, **14**, **15** and **16**. Pin **13** is a power terminal through which a supply voltage or a supply current is received into the LAM/ICM assembly **101**. Pin **14** is a power terminal through which the current returns and passes out of the LAM/ICM assembly. Pin **14** is a ground terminal with respect to the power terminal **13**. Pin **15** is a data signal terminal through which digital signals are communicated into and/or out of the LAM/ICM assembly. Pin **16** is a signal ground for the data signals communicated on pin **15**. The illustrated example of the LAM/ICM assembly **101** that has ten header pins is but one example. In other examples, fewer or more header pins are provided in the header socket **12**, and assignment of power or signals to the pins can be on different positions than illustrated herein. If the LEDs underneath silicone **11** are powered and emitting light, then the light passes upward through the central circular opening **17** in upper surface **5**, and is transmitted upward and away from the LAM/ICM assembly **101**.

FIG. **3** is a perspective view of the bottom of the LAM/ICM assembly **101**, showing a circular lower outer peripheral edge **18** of the LAM ICM assembly **101**. Whereas the shape of central opening **17** at the upper surface **5** of the ICM is circular as pictured in FIG. **1**, the shape of the central opening **17** at the bottom surface **19** of the ICM as pictured in FIG. **3** is square. The LAM **102** is disposed in the central opening **17** so that the bottom surface **20** of the LAM **102** protrudes just slightly from the plane of the bottom surface **19** of the ICM **3**. From the perspective of the illustration of FIG. **3**, the bottom surface **20** of the LAM is slightly higher than is the bottom surface **19** of the ICM. The bottom surface **20** of the LAM is actually the bottom surface of a substrate member **57** of the LAM (FIG. **6**).

FIG. **4** is a cross-sectional, top-down diagram of the LAM/ICM assembly **101**. The round circle identified by reference numeral **17**A is the edge of circular central opening **17** at the upper surface of the ICM. The dashed square identified by reference numeral **17**B is the edge of the square-shaped central opening **17** at the bottom surface of the ICM. The four dashed squares **21-24** identify where four LED dice are disposed underneath the silicone **11**.

FIG. **5** is a simplified top-down diagram of one example of LAM **102**, where the silicone and solder mask layers are not shown so that the metallization patterns of die attachment of LED dice **21-24** can be seen. There are five areas of metal **25-29** disposed on an insulative layer **30**, where the insulative layer **30** in turn is disposed on the substrate member **57**. The insulative layer **30** insulates each of the metal areas from the substrate member **57** of the LAM. The substrate member **57** in this case is a square piece of aluminum sheet. The four LED dice **21-24** are lateral LED dice that are die-attached to the central metal area **29**. The LED dice are wire bonded to form two parallel strings. An LED drive current can flow through the first string by flowing from metal area **25**, through LED die **21**, through LED die **23**, and to metal area **28**. An LED drive current can flow through the second string by flowing from metal area **25**, through LED die **22**, through LED die **24**, and to metal area **28**. Reference numeral **31** identifies one of the bond wires. In addition to LED dice **21-24**, LAM **102** includes a temperature sensing GaN diode die **32**. In one example, this GaN diode die **32** is of identical construction to the LED dice. In the illustrated example, it is of identical construction except for the fact that it is a smaller die. The anode of GaN diode **32** is coupled via a bond wire to metal area **26**. The cathode of GaN diode **32** is coupled via another bond wire to metal area **27**. The dashed line **33** identifies the circular outer periphery of a rim **34** that retains the silicone **11**. As can be seen from FIGS. **1**, **2** and **4**, this rim **34** is of a diameter that is just smaller than the inside diameter of the central opening **17** in the upper surface of the ICM. LAM contact pads **35-38** are shown as outwardly extending portions of the metal areas at the corners of the LAM **102**. In this example, the LAM contact pads **35-38** have areas of metal that are exposed, and are not covered with soldermask.

FIG. **6** is a cross-sectional diagram that shows how the LAM **102** fits up into the central opening **17** in the ICM **3**. ICM **3** includes an interconnect structure **39**, a plurality of electronic components that are mounted to the interconnect structure, and the amount of insulative molded plastic encapsulant **40** that encases and encapsulates the interconnect structure **39** and one or more electronic components **41**.

In the illustrated example, the interconnect structure **39** is a multi-layer printed circuit board (PCB). The entire printed circuit board may not be completely encapsulated. For example, the bottom of the inside lip **42** of the central opening **17** may be uncovered with encapsulant so that portions of metallization on this lip **42** can serve as ICM contact pads. Each of the LAM contact pads on the top of the LAM **102** is soldered to corresponding one of the ICM contact pads on the downward facing inside lip **42** of the ICM. In this example, amounts **43** and **44** of solder paste are disposed on the LAM contact pads, and the LAM **102** is moved up and into contact with the ICM **3**, and then the assembly is heated in a reflow soldering process to solder the LAM contact pads to the ICM contact pads. Other soldering and mechanical/electrical interface methods such as conductive adhesives could be used instead of reflow soldering with solder paste as described herein.

FIG. **7** is a view of the bottom of the ICM **3**. Metal traces of the printed circuit board **39** extend to the inside lip **42** and connect to ICM contact pads through conductive vias. For example, trace **45** may contact ICM contact pad **46** through conductive via **47**. Trace **48** may contact ICM contact pad **49** through conductive via **50**.

FIG. **8** is a view that shows how LAM contact pad **36** may be coupled via solder **44** to the corresponding ICM contact pad **46** on the inside lip of the ICM. The PCB **39** includes three metal layers **51**, **52** and **53** and three fiberglass layers **54**, **55** and **56**. The substrate member **57** of the LAM **102** may be covered by insulative layer **30**. The metal area **26**, a part of which is LAM contact pad **36**, may be electrically coupled to ICM contact pad **46**, up through solder **44** and through a conductive via in the PCB, and to metal interconnect layer **51** of the PCB **39**. The interconnect structure described herein is that of a conventional FR-4 PCB; however, other structures such as Kapton “flex circuit” or metal clad PCB circuits may also be used for this interconnect structure.

FIG. **9** is a cross-sectional view of the LAM/ICM assembly **101** of FIG. **4** taken along sectional line A-A' (shown on a heat sink **60**). Bolts **58** and **59** extend through holes **6-7**, and hold the bottom surface **20** of LAM **102** in good thermal contact with the heat sink **60** through a layer **61** of a thermal interface material (TIM). There are no LAM contact pads or ICM contact pads in the cross-section illustrated. Electronic components **62** and **63** of control circuitry are mounted on PCB **39**. The circuitry may be overmolded by the injection molded plastic encapsulant **40**.

FIG. **10** is a cross-sectional view of the LAM/ICM assembly **101** of FIG. **4** taken along sectional line B-B' (shown on a heat sink). Solder **43** may electrically couple LAM contact pad **37** to ICM contact pad **64**. Solder **44** may electrically couple LAM contact pad **36** to ICM contact pad **46**.

FIG. **11** is a cross-sectional view of the LAM/ICM assembly **101** of FIG. **4** taken along sectional line C-C' (shown on heat sink **60**). Electronic components **65**, **66** and **67** of a control circuit are mounted on PCB **39**. Each of these three components **65-67** may be a packaged device that is in turn overmolded by the plastic encapsulant **40** of the ICM **3**. In the case of component **67**, a surface of the package forms a part of the bottom surface of the ICM **3** so that when the ICM **3** is pressed against the heat sink **60** (with the TIM **61** in between), the bottom surface of the packaged device makes good thermal contact with the heat sink **60**. The component **67** may, for example, be a DCB-isolated SMPD (direct copper bonded isolated surface mount power device) package whose downward facing surface is a heat-dissipating substrate that is intended to be pressed against a heat sink.

FIG. **12** is a cross-sectional view of the LAM/ICM assembly **101** of FIG. **4** taken along sectional line D-D' (shown on a heat sink).

The LAM/ICM assembly **101** may be implemented as a lighting module within a lighting system of multiple lighting modules that are interconnected. Each lighting module may be controllable for ON/OFF control, as well as dimming and monitoring of LED parameters (e.g., surface temperature) to maintain the lighting module within acceptable operating ranges to minimize aging and degradation and to optimize performance. For example, since each lighting module includes an ICM **3** having a processor **66** and communication unit **65**, each lighting module may be individually controlled within the lighting system using a communication network.

FIG. **13** shows a lighting system **150** that includes multiple lighting modules **101**. Each lighting module **101** may implemented as the LAM/ICM assembly **1** as shown in FIGS. **1-12**. A standard AC line voltage source **110** (e.g., 110 VAC) supplies the light emitter module **101**. Power control, (i.e., ON/OFF switching) and dimming control to each lighting module **101** may be sent wirelessly via a control signal using antenna **98** of a gateway or router **95**. In this example, the gateway or router **95** may receive a control signal from a remote device **99** over the Internet **96** for delivery to the gateway or router **95** via an Ethernet connection or some other suitable connection **97**. Alternatively, a local device **94** may send a control signal directly to the gateway or router **95** via a wired or wireless local area network. Alternatively, the local device **94** may be hardwired to the gateway or router **95**. This modular arrangement of lighting modules **101** allows a local device **94** or remote device **99** to control each lighting module **101** individually within the entire lighting system **150** from a single location or control point. Also, the modular configuration allows for easy expansion of the lighting system **150** as each lighting module **101** contains its own dimming control circuitry.

FIG. **14** shows an exemplary power and dimming control circuit **200** for the lighting module **101**. An attenuator **103** is connected between the AC power source **110** and the LAM **102** to attenuate the voltage applied to the LAM **102** between full voltage and 0 voltage for dimming functionality. A voltage regulator **108** is arranged to convert the AC voltage to a DC voltage (e.g., 110VAC/3VDC) for the dimming control circuit contained internally within the lighting module **101**, which includes a communication unit **105** and a processor **106**.

The communication unit **105** is configured to receive a remote wireless control signal from the local device **94** or the remote device **99** (see FIG. **13**). The processor **106** is configured to control the attenuator **103** by sending a dimming control signal based on the remote control signal. The attenuator **103** may be configured as a phase cutting device that can be switched in a modulated manner to phase-cut the sinusoidal AC voltage to the LAM **102**, which controls the luminance of the light output of the LAM **102** in response to the dimming control signal from the processor **106**. For example, the attenuator **103** may be configured as a triac. As another example, the attenuator **103** may be configured as a phase cutting transistor.

The processor **106** may monitor the zero crossing points of the AC voltage via sensor **107**, and execute an algorithm to determine a phase angle for the phase cut to achieve the desired dimming level. The processor **106** may then send the dimming control signal to trigger the attenuator **103** according to the phase cut. By triggering the attenuator **103** at some phase angle greater than the zero crossing point, a fraction of the supply voltage sinusoidal wave is supplied to the LAM **102**, which provides the desired dimming effect.

In the example of the dimming control circuit **200** implemented within the ICM **3** shown in FIGS. **1-12**, the attenuator **103** may be arranged on the PCB **39** as component **67**, the processor **106** may be arranged on the PCB **39** as component **66**, and the communication unit **105** may be arranged as component **65** on the PCB **39** as shown in FIG. **11**.

FIG. **14**A shows an optional photo sensor **111** that senses ambient light and provides feedback to the processor **106**, which may control dimming based on ambient light conditions and settings according to user preference. In some embodiments, the photo sensor **111** may measure the ambient luminance at the sensor location and provide that information to the processor **106**. The processor **106** may use the information to adjust the luminance of the light output from the LAM **102** by adjusting the power being delivered to the light source at the attenuator **103**.

The photo sensor **111** may be arranged on the PCB as device **91** as shown in FIG. **6**. Alternatively, the photo sensor **111** may be disposed separate from the lighting module **101**. Alternatively the photo sensor **111** may be disposed in a different part of a room and configured to communicate the information regarding ambient lighting at that part of the room back to the processor **106**. In this example, the photo sensor **111** may be local devices **94** which may communicate either directly with processor **106** or indirectly with processor **106** via gateway or router **95**. The processor **106** may control the light output of the LAM **102** by using the information received from the sensor to determine the ambient light in the room and either increase or decrease the power being delivered to the light source depending on determined ambient light. For example, if the processor **106** determines that the luminance of light in the room is lower than a predetermined level, then the power to the LAM **102** may be increased by adjustment to the attenuator **103**. Similarly, if the processor **106** determines from the information received from the sensor that the luminance of light in the room is higher than a predetermined level, then the power to the LAM **102** may be decreased.

The predetermined level of light in the room may be set by a user and include factors such as a predetermined level based on day of week or time of day. The predetermined level of light in the room may also be adjusted based on factors such as occupancy input. For example, a motion sensor may provide information to the processor **106** that the room has a person in it, then the predetermined level may be adjusted accordingly. The predetermined level may also be adjusted based on inputs such as whether the television is ON or OFF. For example if the television is ON, the predetermined level may be lower than when the television is OFF. In one embodiment, the predetermined level of luminance in the room when the television is ON may be set to 75% lower than when the television is OFF.

In another embodiment, the photo sensor **111** may be configured to determine a sudden change in ambient luminance (e.g., when the blinds in a room are opened). Here, the predetermined level may be set to very low or zero. If the predetermined level is set to zero when the blinds are determined to be open, then the processor **106** may control the attenuator **103** to dim the LAM **102** to zero.

FIG. **15** shows an exemplary power and dimming control circuit **300** for the lighting module **101** to control the LAM **102**. In this example, the LAM **102** is arranged having multiple LED sections **102***a*, **102***b*, **102***c*. The LAM **102** may include more or less than three LED sections. Each LED section **102***a*, **102***b*, **102***c* may include one or more LEDs, LED pairs, or strings of LEDs, LED pairs. LED pairs may be connected in parallel with opposite polarity to allow AC supply current to drive each LED in an alternating pattern. Likewise, LED strings may be connected in parallel pairs with opposite polarity. For multiple strings of LEDs, each string may be connected in series, in parallel, or combinations of both. Alternatively, the LEDs of LED sections **102***a*, **102***b*, **102***c* may be arranged for DC operation, such as in series for example. To drive the LEDs for DC operation, a full wave bridge rectifier may be included in the control circuit to convert the AC voltage from supply **110** to a DC voltage.

A processor **106** may be programmed with software to steer the current to each LED section, or around each LED section of LAM **102**. For example, to control dimming of the LAM **102**, one or more LED sections may be shunted in a controlled manner to achieve the desired dimming. As shown in FIG. **15**, bypass circuits **315**, **316**, and **317** shunt the LED sections **102***a*, **102***b*, and **102***c* respectively.

In one embodiment, each bypass circuit **315**, **316**, and **317** includes a field effect transistor (FET) having the gate voltage controlled by the processor **106** to switch the FET on, so that the processor **106** controls current steering away from the shunted LED section. For example, bypass circuit **315** may operate a FET in an energized state, which completely diverts the current through the FET and bypasses LED section **102***a*. The bypass circuits **316** and **317** may maintain the FET in a deenergized state and effectively an open switch, allowing the LED sections **102***b* and **102***c* to receive full current. The luminance level of LAM **102** is then dimmer by approximately one third.

The processor **106** may also control the gate voltage of the FET to operate in a linear mode which provides a shunt resistance to the respective light emitter. For example, the FET in bypass circuit **315** may have its gate voltage controlled by processor **106** within a range to operate the FET in linear mode, so that drain to source current is controlled in a way to divert some current away from the light emitter. The FET may operate effectively as a variable resistor in this linear mode, and the LED section **102***a* may be dimmed according to the current steering. Alternatively, the bypass circuits **315**, **316**, **317** may include variable resistors controlled by the processor **106** to variably shunt the LED sections **102***a*, **102***b*, **102***c*.

In one example, the processor **106** may execute a software program that can control dimming of the LAM **102** according to one or more dimming curves to dim faster or slower, which may be adapted to user preference. The dimming curves may include linear and logarithmic profiles to expand dimming of the light emitters across the full range of a controller for fuller resolution. For example, a dimming controller in the local device **94** or the remote device **99** (see FIG. **13**) with a luminance level range **1** to **10** can operate the LAM **102** with a sliding scale of luminance levels for even and proportional dimming at each discrete level within the full range. In contrast, conventional dimming controllers may affect the dimming only within a subrange, such as between settings **3** and **8**, effectively half of the available resolution for the full range **1** to **10**.

In another example, the processor **106** may be programmed to control the color temperature of the LAM **102** during dimming. This may be implemented by steering current using the bypass circuits **315**, **316**, **317** to each LED section according to the color characteristics of the LEDs (e.g., depending on the phosphors of the LED). For example, if LED section **102***a* is configured to emit red light, and the LED sections **102***b* and **102***c* emit blue or green light, the processor **106** may steer the current away from the LED sections **102***b* and **102***c* to achieve warmer color effect, predominantly from the red LED section **102***a*.

Each of the bypass circuits **315**, **316**, **317** may include a sensor to detect the amount of current being diverted from each respective LAM section **102***a*, **102***b*, **102***c* so that the processor **106** can selectively adjust dimming control and the current steering according to the methods described above.

FIG. **16** shows an exemplary dimming control circuit **400** for the lighting module **101** to control triggering of the attenuator **103** and to control a plurality of LED sections **102***a*, **102***b*, **102***c*. The processor **106** is configured to receive a dimming input signal from the receiver **105** and to send a control signal to the attenuator **103** to dim the light emitters **102***a*, **102***b*, **102***c*. In this example, the attenuator **103** may be controlled to reduce the luminance by phase cutting as described above with respect to FIG. **14**. For an embodiment in which the attenuator **103** is implemented as a triac, the dimming control may be limited to between 100% luminance and about 5-10% luminance due to minimum current parameters to operate the triac. To complete the dimming control for full dimming down to 0% luminance, the processor **106** may be configured to send deep dimming control signals to bypass circuits **315**, **316** and **317** for shunting the light emitters **102***a*, **102***b* and **102***c* respectively. Because the attenuator **103** may significantly reduce the operating current of the light emitter array **102** to a low level (i.e., near 5-10% of the full current), the heat dissipation by the bypass circuits **315**, **316**, **317** is limited to low levels during deep dimming, which allows the dimming control circuit **400** to be contained locally within the light emitter module **101**. In alternative variations, the processor **106** may be programmed to control the attenuator **103** for a different dimming control range, for example between 100% and 30% luminance, and to control the bypass circuits **315**, **316**, **317** for the reminder dimming control range between 0% and 29% luminance. The dimming control circuit **400** is not limited to these combined dimming ranges, as the processor **106** may combine other ranges according to the operation parameters of the attenuator **103** and the bypass circuits **315**, **316**, and **317**.

FIG. **17** shows an exemplary dimming control circuit **500** to control dimming of an LAM **102**. In this example, an external constant current DC driver **131** is powered by the AC power source **110**. The processor **106** may perform a primary dimming control of the LAM **102** by sending a dimming control signal back to the driver **131** to increase and to decrease the magnitude of the constant current being output by the driver **131**. However, the driver **131** may only be controlled to a level of current that dims the LAM **102** down to about 10% of luminance. To achieve deep dimming, the processor **106** may send a control signal to an attenuator **103** in series with the LAM **102** to provide a variable resistance. For example, the attenuator **103** may be configured as a field effect transistor (FET), controlled by the processor **106** to operate in a linear mode. The processor **106** may control the attenuator **103** to fine tune the amount of current supplied to LAM **102** by adjusting the voltage drop across the FET in linear mode to an amount required to achieve the necessary current flow. Alternatively, the attenuator **103** may be configured as a variable resistor controllable by the processor **106**.

As shown in FIG. **17**, the attenuator **103** is coupled to the LAM **102** in series. In an alternative example, the attenuator **103** may be coupled to the LAM **102** in parallel to variably shunt the current to the LAM **102** to achieve the deep dimming control in response to the control signal from the processor **106**. The LAM **102** may be configured as multiple LED sections as shown in FIG. **15** and FIG. **16**, with an attenuator **103** arranged in series or in parallel with each LED section to achieve the deep dimming.

The optional photo sensor **111** shown in FIG. **14**A may be combined with any of the above embodiments, such as shown in FIGS. **14-17** and described above.

With respect to the processor **106**, examples of processors include microprocessors, microcontrollers, digital signal processors (DSPs), field programmable gate arrays (FPGAs), programmable logic devices (PLDs), state machines, gated logic, discrete hardware circuits, and other suitable hardware configured to perform the various functionality described throughout this disclosure. The processor may execute software. Software shall be construed broadly to mean instructions, instruction sets, code, code segments, program code, programs, subprograms, software modules, applications, software applications, software packages, routines, subroutines, objects, executables, threads of execution, procedures, functions, etc., whether referred to as software, firmware, middleware, microcode, hardware description language, or otherwise.

Aspects may also be implemented using a combination of both hardware and software. Accordingly, in one or more example aspects, the functions described may be implemented in hardware, software, firmware, or any combination thereof, depending upon the particular application and design constraints imposed on the overall system.

While aspects have been described in conjunction with the example implementations outlined above, various alternatives, modifications, variations, improvements, and/or substantial equivalents, whether known or that are or may be presently unforeseen, may become apparent to those having at least ordinary skill in the art. Accordingly, the example implementations of the invention, as set forth above, are intended to be illustrative, not limiting. Various changes may be made without departing from the spirit and scope of the aspects. Therefore, the aspects are intended to embrace all known or later-developed alternatives, modifications, variations, improvements, and/or substantial equivalents.

Thus, the claims are not intended to be limited to the aspects shown herein, but is to be accorded the full scope consistent with the language claims, wherein reference to an element in the singular is not intended to mean "one and only one" unless specifically so stated, but rather "one or more." Unless specifically stated otherwise, the term "some" refers to one or more. All structural and functional equivalents to the elements of the various aspects described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under 35 USC 112(f) unless the element is expressly recited using the phrase "means for" or "step for."

What is claimed is:

1. A lighting module comprising:

a light emitting diode (LED) array; and

a dimming circuit configured to control current applied to the LED array to control luminance of light emitted from the lighting module, the dimming circuit comprising:

a triac configured to provide current from an AC power source to the LED array; and

a processor configured to:

determine a phase angle for phase cutting the triac;

send a control signal to trigger a switching operation of the triac based on the phase angle;

monitor zero crossing points for the AC voltage input; and

determine the phase angle based on the zero crossing points.

2. The lighting module of claim **1**, wherein the lighting module is configured to be connected to an AC power source.

3. The lighting module of claim **1**, wherein the

processor is further configured to receive a dimming input signal and to provide a control signal to the dimming circuit in response to the dimming input signal.

4. The lighting module of claim **3** wherein information associated with ambient luminance is provided to the processor.

5. The lighting module of claim **4** wherein the processor determines the luminance, compares the determined luminance with a predetermined level, and determines the control signal for dimming based on the comparison.

6. The lighting module of claim **5** wherein the predetermined level is based on the day of week or time of day or both.

7. The lighting module of claim **5** wherein the predetermined level is based on information received by the processor that a television is ON based on detected ambient luminance.

8. The lighting module of claim **1**, further comprising a bypass circuit arranged with the LED array,

wherein the processor is configured to provide a bypass control signal to the bypass circuit for current steering to the LED array to control the luminance of light emitted from the lighting module.

9. The lighting module of claim **8**, wherein the bypass circuit comprises a plurality of variable resistors, with at least one resistor being arranged to shunt a corresponding one of the LEDs and to variably divert an amount of current from the corresponding one of the light emitters based on the control signal.

10. The lighting module of claim **1**, wherein the dimming circuit further comprises a sensor configured to determine the zero crossing points for the AC voltage input and to send zero crossing point information to the processor.

11. The lighting module of claim **1**, wherein the dimming circuit further comprises:

a communication unit configured to receive the dimming input signal wirelessly and to provide the dimming input signal to the processor.

12. The lighting module of claim **8**, wherein the bypass circuit comprises a plurality of transistors, with at least one transistor being arranged to shunt a corresponding one of the LEDs.

13. The lighting module of claim **8**,

wherein at least a first portion of the LED array is configured to emit a first light color and at least a second portion of the LED array is configured to emit a second light color different that the first light color, and

wherein the processor is further configured to provide a bypass control signal to control color temperature of the light emitted from the lighting module.

14. A lighting module configured to be coupled to an external driver, comprising:

a LED array; and

a dimming circuit configured to control current applied to the LED array to control luminance emitted from the lighting module, the dimming circuit comprising:

a processor configured to receive a dimming input signal and to send a first control signal to an external driver and a second control signal to the dimming circuit in response to the dimming input signal.

15. The lighting module of claim **14**, a dimming circuit, wherein the dimming circuit further comprises:

a communication unit configured to receive the dimming input signal wirelessly and to provide the dimming input signal to a processor.

16. The lighting module of claim **14**, wherein the dimming circuit further comprises an attenuator configured to receive constant current from the driver and the processor is further configured to determine a variable resistance for the attenuator, and wherein the second control signal controls the variable resistance.

17. The lighting module of claim **14**, wherein the dimming circuit further comprises:

a communication unit configured to receive the dimming input signal wirelessly and to provide the dimming input signal to the processor.

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