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Gershowitz et al.

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(54) **LED ARRAY MEMBER AND THERMALLY DECOUPLED INTEGRATED CONTROL MODULE ASSEMBLY**

(71) Applicant: **Bridgelux, Inc.**, Livermore, CA (US)

(72) Inventors: **Michael Neal Gershowitz**, San Jose, CA (US); **R. Scott West**, Pleasanton, CA (US); **Babak Imangholi**, Livermore, CA (US)

(73) Assignee: **Bridgelux, Inc.**, Livermore, CA (US)

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H05B 33/08 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H05B 33/0815*** (2013.01); ***F21K 9/30*** (2013.01); ***F21V 23/006*** (2013.01); ***F21V 29/22*** (2013.01); ***F21V 29/70*** (2015.01); ***H05B 33/0824*** (2013.01); ***H05B 33/0827*** (2013.01); ***H05B 33/0842*** (2013.01); ***H05B 33/0845*** (2013.01); ***H05B 33/0884*** (2013.01); *F21V 23/02* (2013.01); *F21Y 2101/02* (2013.01);
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(58) **Field of Classification Search**
CPC F21K 9/30; F21K 9/1375; F21V 23/006; F21V 15/01; F21V 19/003
See application file for complete search history.

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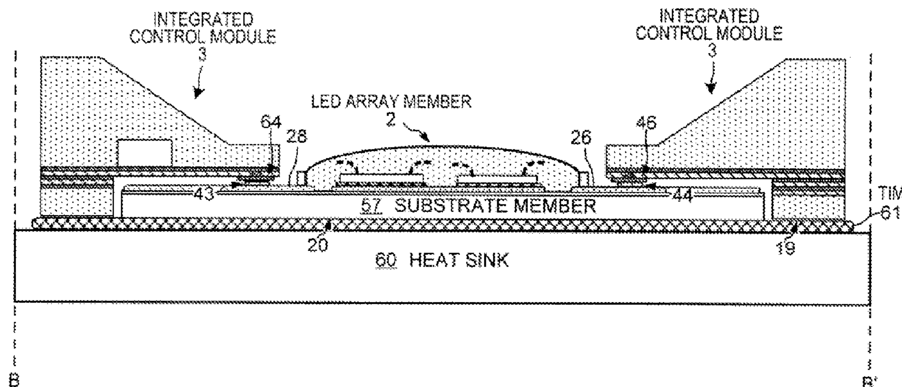
Primary Examiner — Evan Dzierzynski
(74) *Attorney, Agent, or Firm* — Imperium Patent Works; Darien K. Wallace

(57) **ABSTRACT**

A LAM/ICM assembly comprises an integrated control module (ICM) and an LED array member (LAM). In a first aspect, active circuitry is embedded in the ICM. The circuitry monitors LED operation, controls and supplies power to the LEDs, and communicates information into and out of the assembly. A thermal insulator is disposed between the ICM and a heat sink outside the lateral boundary of the LAM. In a second aspect, a lighting system comprises an AC-to-DC converter and a LAM/ICM assembly. The AC-to-DC converter outputs a substantially constant current or voltage. The magnitude of the current or voltage is adjusted by a signal output from the LAM/ICM. In a third aspect, the ICM includes a built-in switching DC-to-DC converter. An AC-to-DC power supply supplies a roughly regulated supply voltage. The switching converter within the LAM/ICM receives the roughly regulated voltage and supplies a regulated LED drive current to its LEDs.

20 Claims, 17 Drawing Sheets



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

(51) **Int. Cl.**

F21K 99/00	(2010.01)
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F21V 29/70	(2015.01)
H01L 25/16	(2006.01)
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F21Y 101/02	(2006.01)
F21Y 105/00	(2006.01)
H05K 1/14	(2006.01)
H05K 3/00	(2006.01)

(52) **U.S. Cl.**

CPC *F21Y2105/001* (2013.01); *H01L 25/167* (2013.01); *H01L 2224/48091* (2013.01); *H01L 2224/48137* (2013.01); *H01L 2224/73265* (2013.01); *H05B 37/0272* (2013.01); *H05K 1/142* (2013.01); *H05K 3/0061* (2013.01); *H05K 2201/10106* (2013.01)

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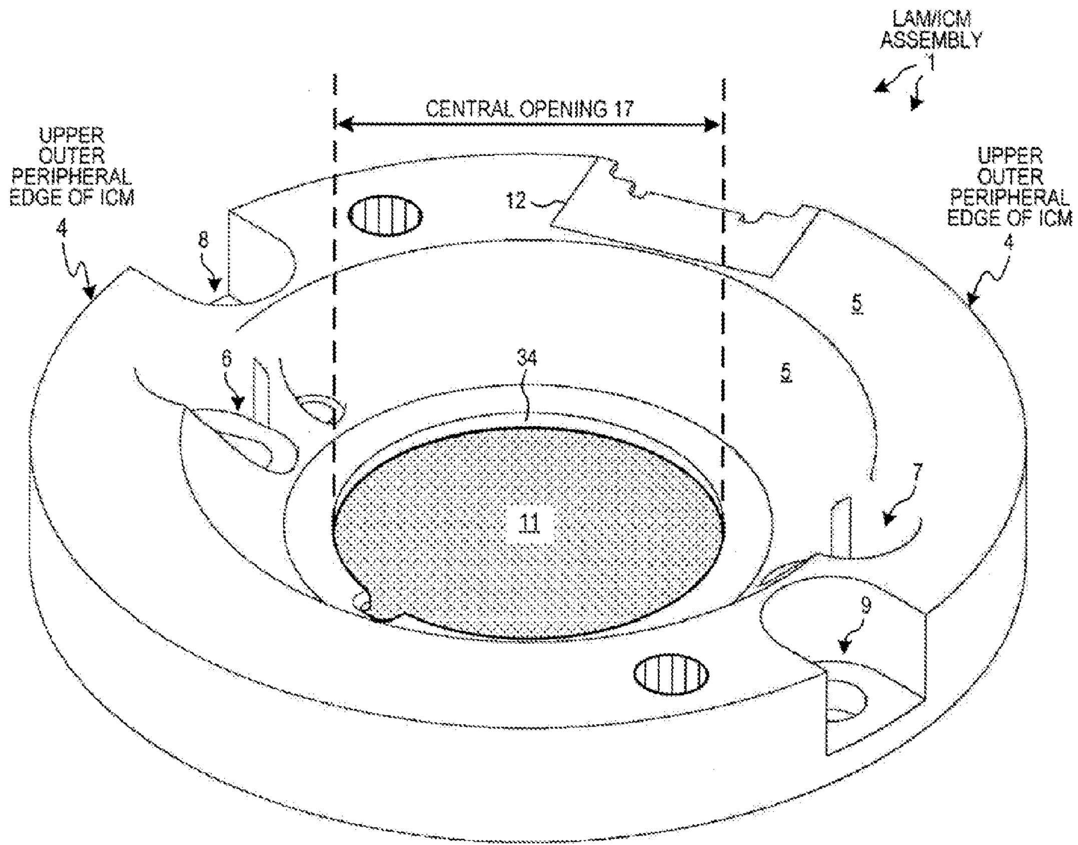
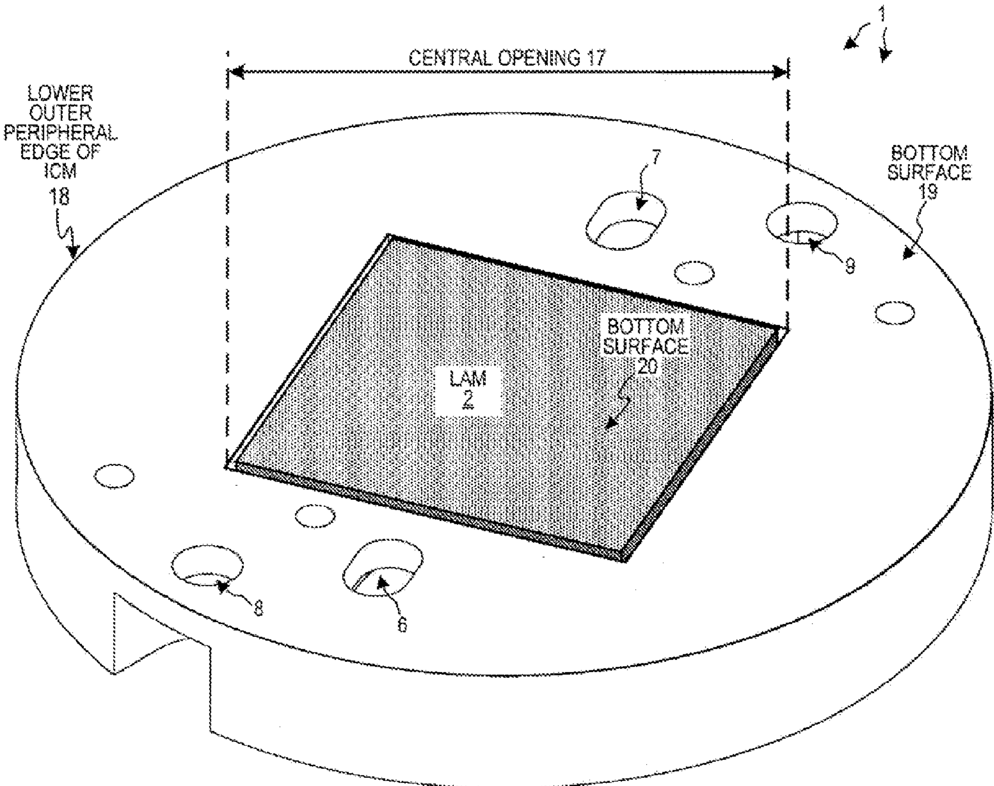
VIEW OF TOP OF LAM/ICM ASSEMBLY
(PERSPECTIVE TOP VIEW)

FIG. 1



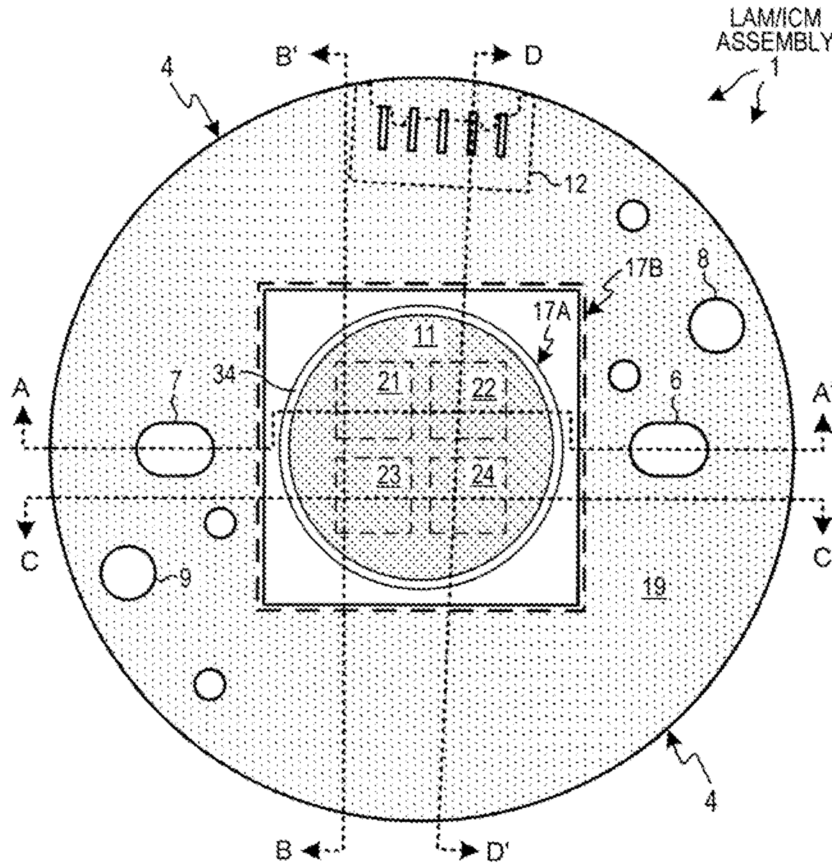
VIEW OF TOP OF LAM/ICM ASSEMBLY
(PERSPECTIVE TOP VIEW)

FIG. 2



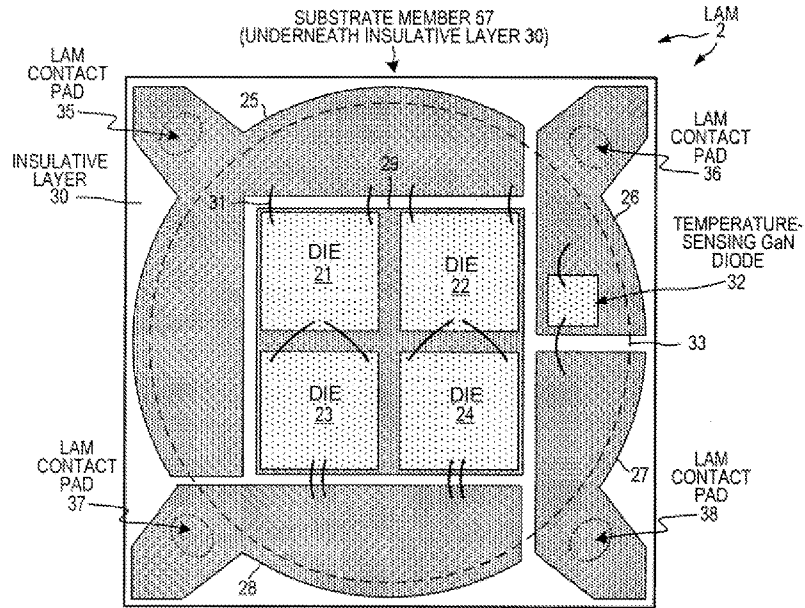
VIEW OF BOTTOM OF LAM/ICM ASSEMBLY
(PERSPECTIVE VIEW)

FIG. 3



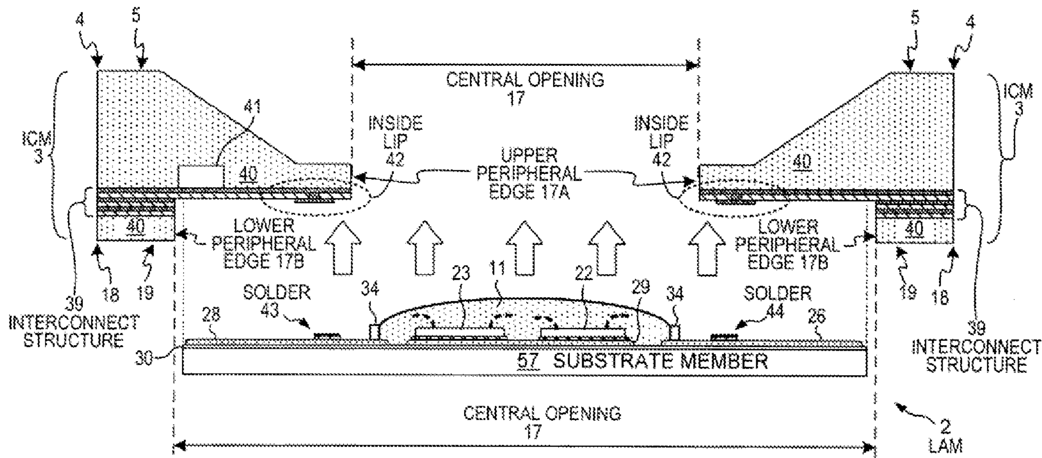
TOP-DOWN VIEW OF LAM/ICM ASSEMBLY
(TOP-DOWN VIEW)

FIG. 4



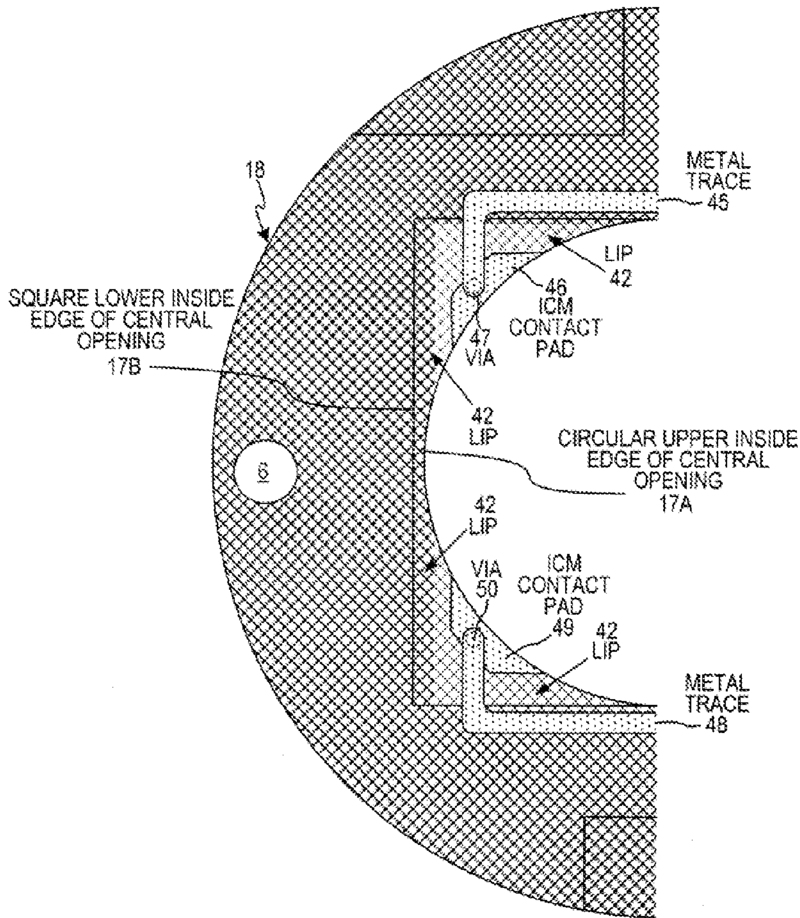
TOP-DOWN VIEW OF ONE EXAMPLE OF A LAM
(SHOWN WITHOUT PHOSPHOR LAYER)

FIG. 5



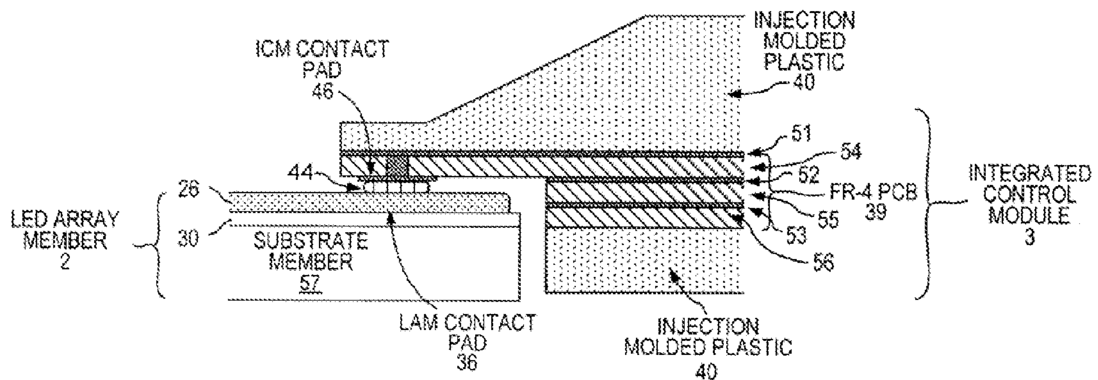
THE LAM FITS UP INTO THE CENTRAL OPENING IN THE BOTTOM OF THE ICM AND IS FIXED IN PLACE
(CROSS-SECTIONAL SIDE VIEW OF ASSEMBLY)

FIG. 6



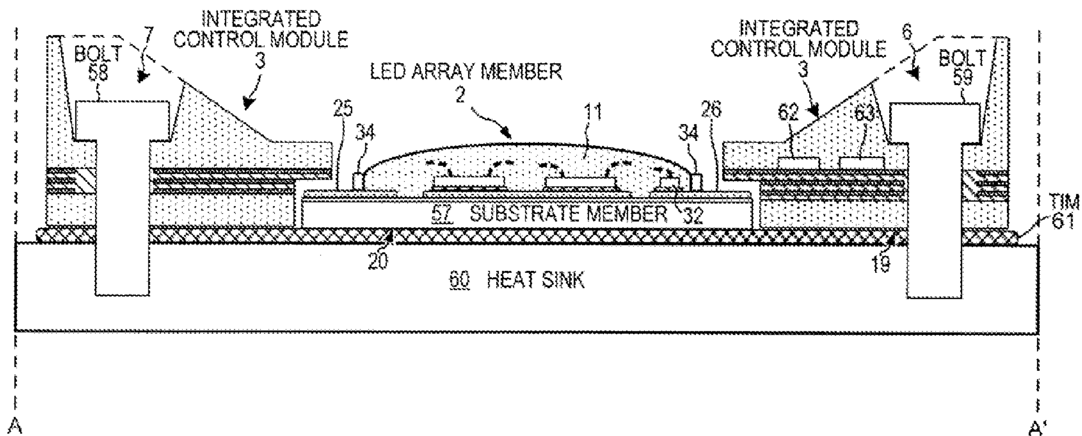
BOTTOM-UP VIEW OF ICM SHOWING CONTACT PADS ON THE INSIDE LIP OF THE ICM

FIG. 7



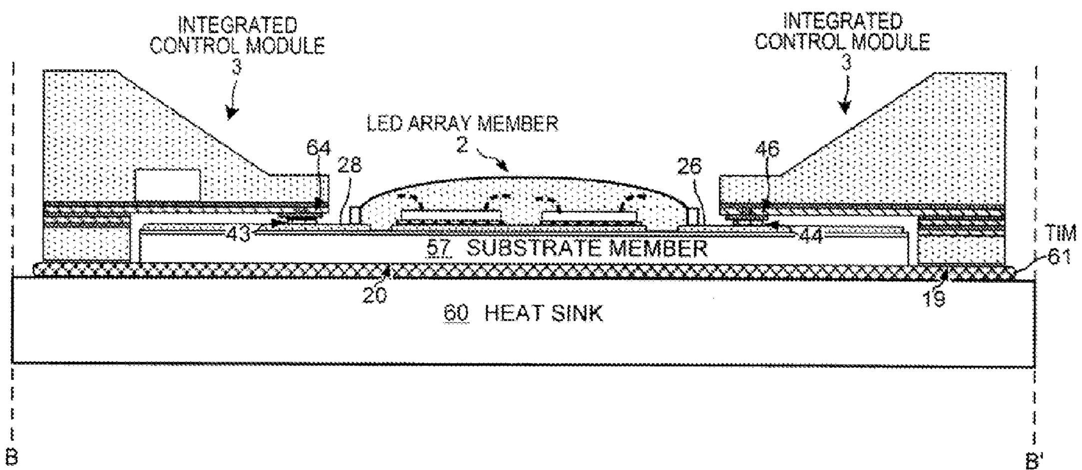
DETAIL OF A CONTACT PAD OF THE LAM MAKING CONTACT WITH A CONTACT PAD ON THE BOTTOM OF THE INSIDE LIP OF THE ICM

FIG. 8



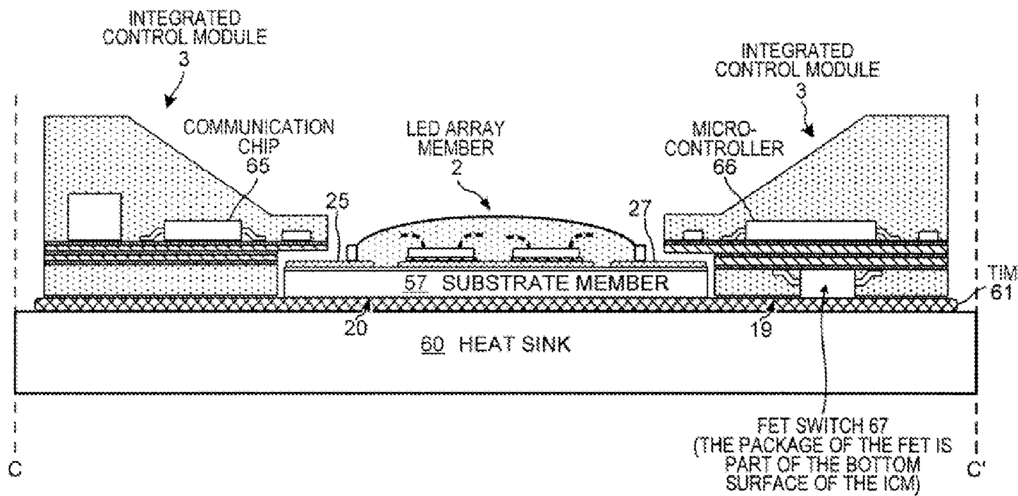
CROSS-SECTIONAL VIEW TAKEN ALONG LINE A-A'
(SHOWN ON A HEAT SINK)

FIG. 9



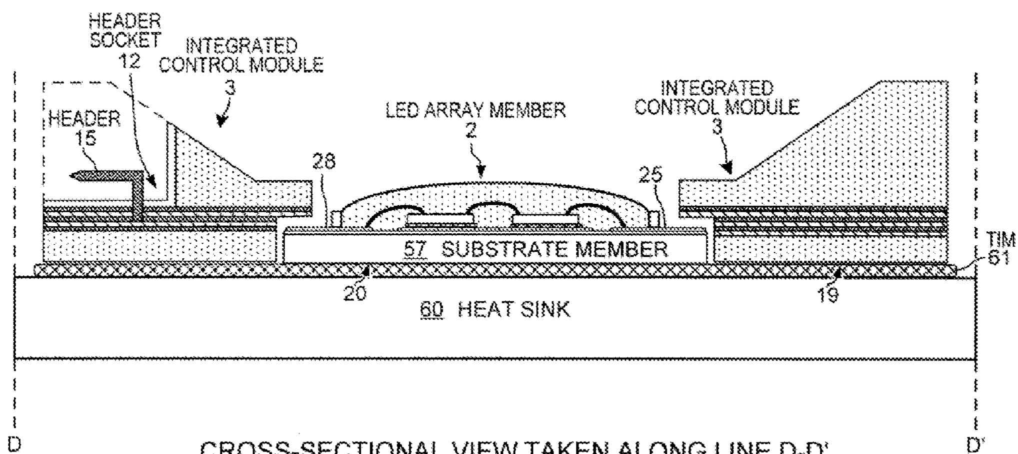
CROSS-SECTIONAL VIEW TAKEN ALONG LINE B-B'
(SHOWN ON A HEAT SINK)

FIG. 10



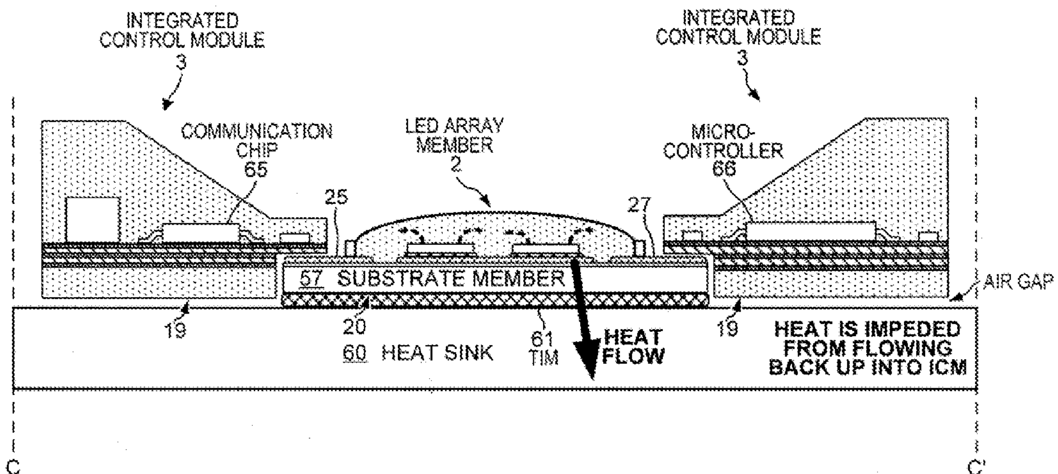
CROSS-SECTIONAL VIEW TAKEN ALONG LINE C-C'
(SHOWN ON A HEAT SINK)

FIG. 11



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

FIG. 12



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

FIG. 13

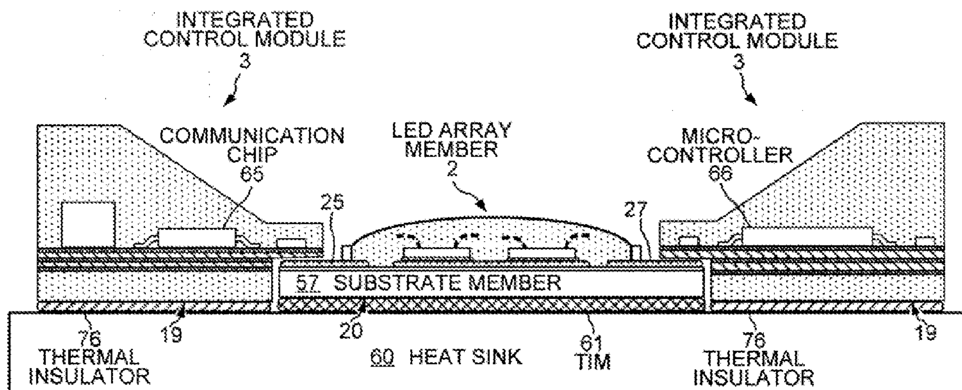
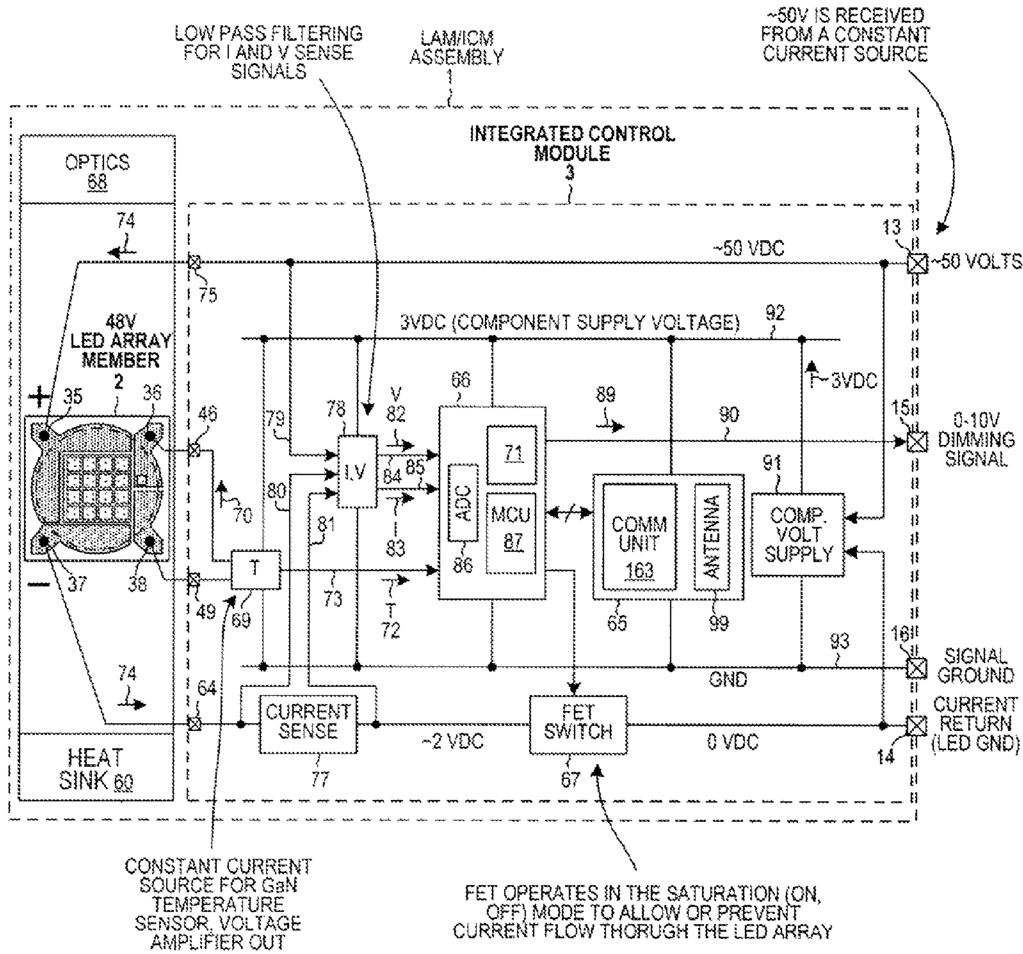
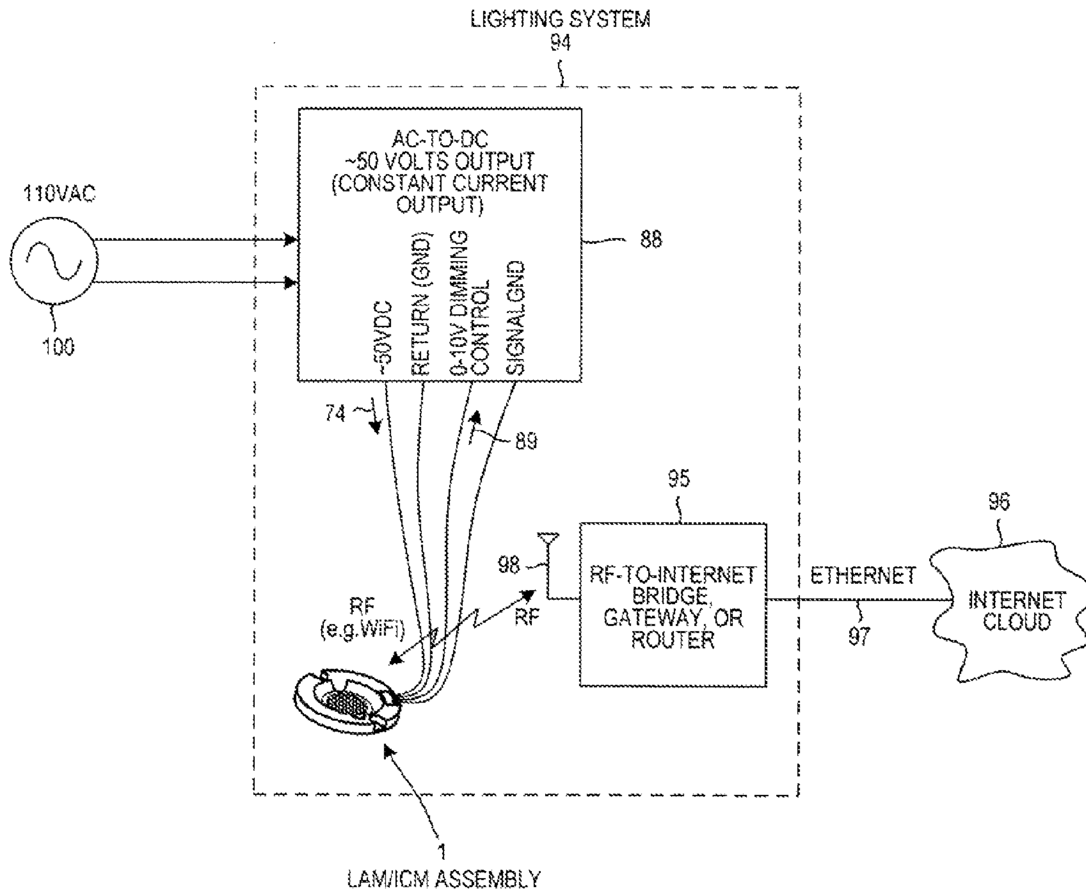


FIG. 14



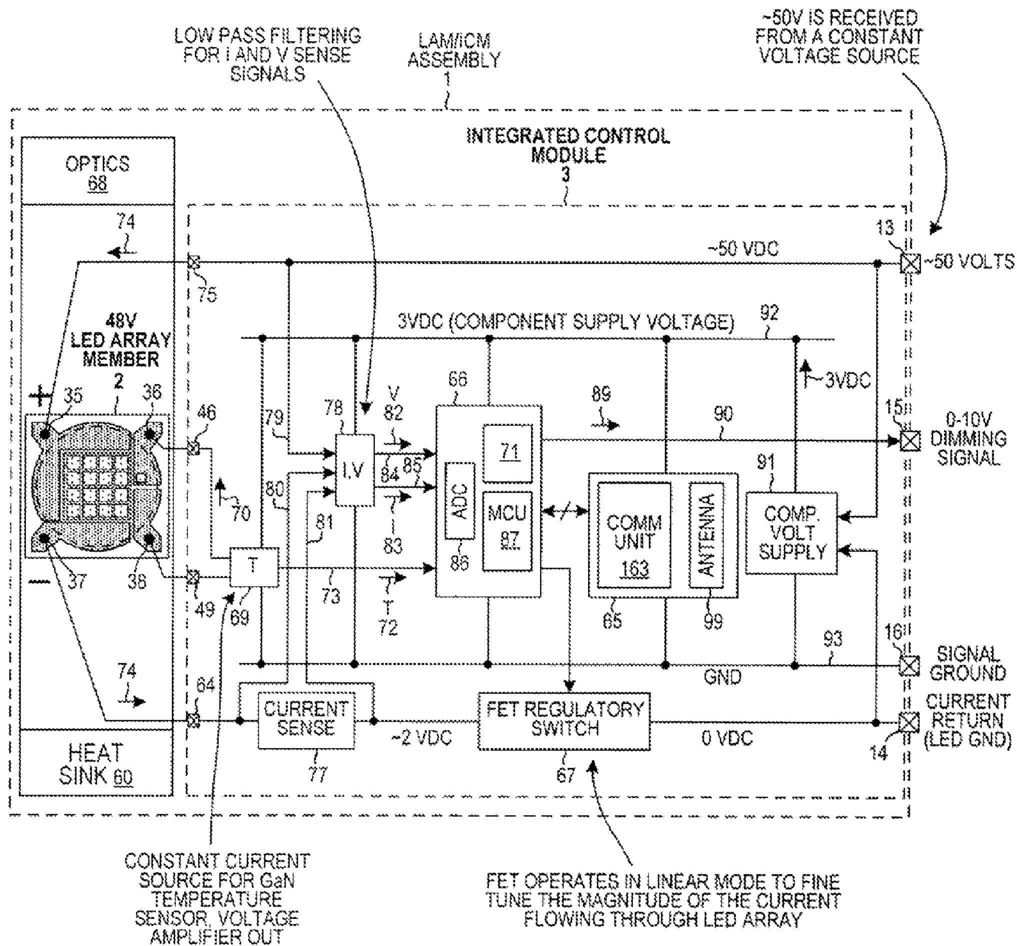
SCHEMATIC OF THE LED ARRAY MEMBER/ INTEGRATED CONTROL MODULE ASSEMBLY

FIG. 15



LIGHTING SYSTEM INVOLVING THE LED ARRAY MEMBER/
INTEGRATED CONTROL MODULE ASSEMBLY OF FIG. 13

FIG. 16



SCHEMATIC OF THE LED ARRAY MEMBER/ INTEGRATED CONTROL MODULE ASSEMBLY

FIG. 17

MULTIPLE CONTACT PADS IN THE CORNER OF THE LED ARRAY

MULTIPLE CONTACT PADS IN THE CORNER OF THE LED ARRAY

TEMPERATURE SENSING GaN LED AND LANDING PADS

TEMPERATURE SENSING GaN LED DIE IS IDENTICAL TO OTHER LED DICE THAT EMIT LIGHT

MULTIPLE CONTACT PADS IN THE CORNER OF THE LED ARRAY

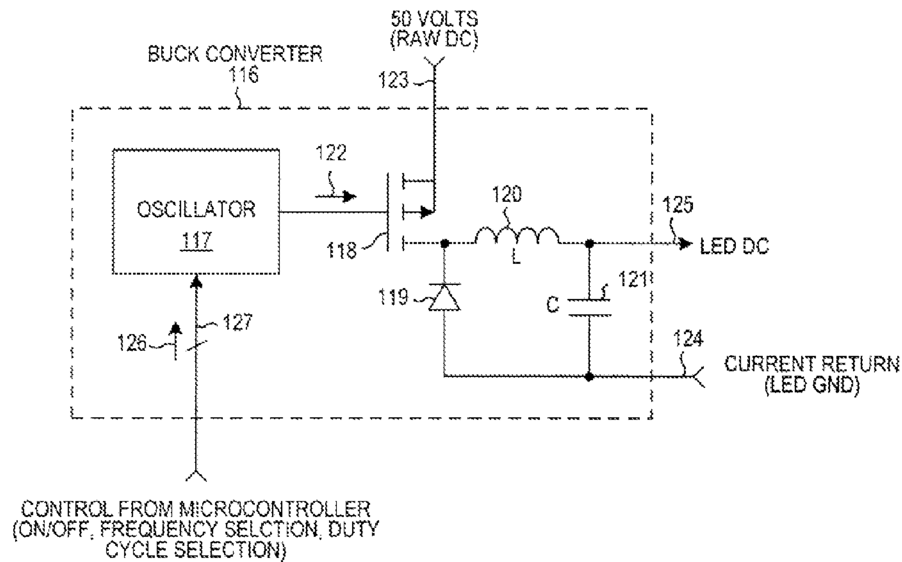
MULTIPLE CONTACT PADS IN THE CORNER OF THE LED ARRAY

ANOTHER EXAMPLE OF AN LED ARRAY MEMBER USABLE WITH AN INTEGRATED CONTROL MODULE

FIG. 18

DIAGRAM OF THE LAM/ICM ASSEMBLY WITH AN INTEGRATED BUCK CONVERTER

FIG. 19



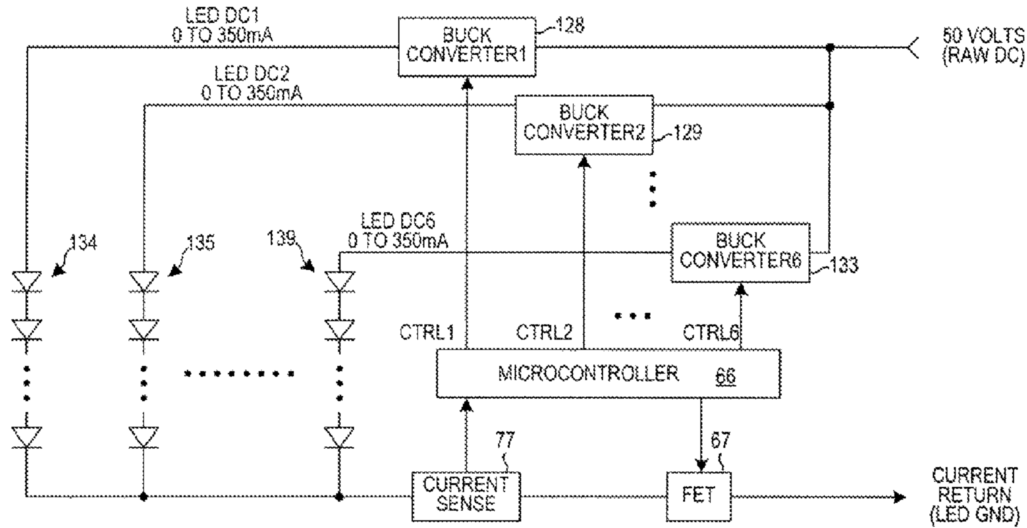
BUCK CONVERTER

FIG. 20

	ONE BUCK CONVERTER DRIVING ALL LEDS	SIX BUCK CONVERTERS, EACH DRIVING ONE STRING OF LEDS
NOMINAL "LED DC" OUTPUT CURRENT	3.5 AMPS	0.6 AMPS
NOMINAL "LED DC" OUTPUT VOLTAGE	48 VOLTS	48 VOLTS
NOMINAL RIPPLE	75%	75%
NOMINAL SWITCHING FREQUENCY	10 MHZ	10 MHZ
INDUCTANCE L	70nH	1uH
APPROX SIZE OF INDUCTOR	7mm x 7mm x 7mm	2.5mm x 2.5mm x 1mm
CAPACITANCE C	10nF	1nF

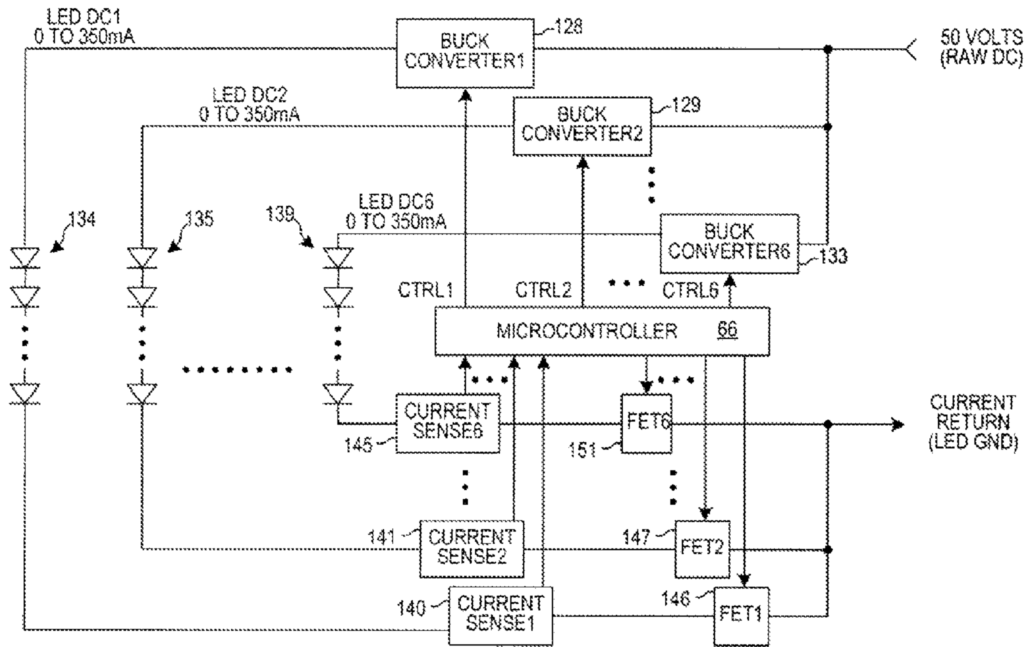
PARAMETERS AND COMPONENTS OF THE BUCK CONVERTER(S) OFTHE LAM/ICM

FIG. 21



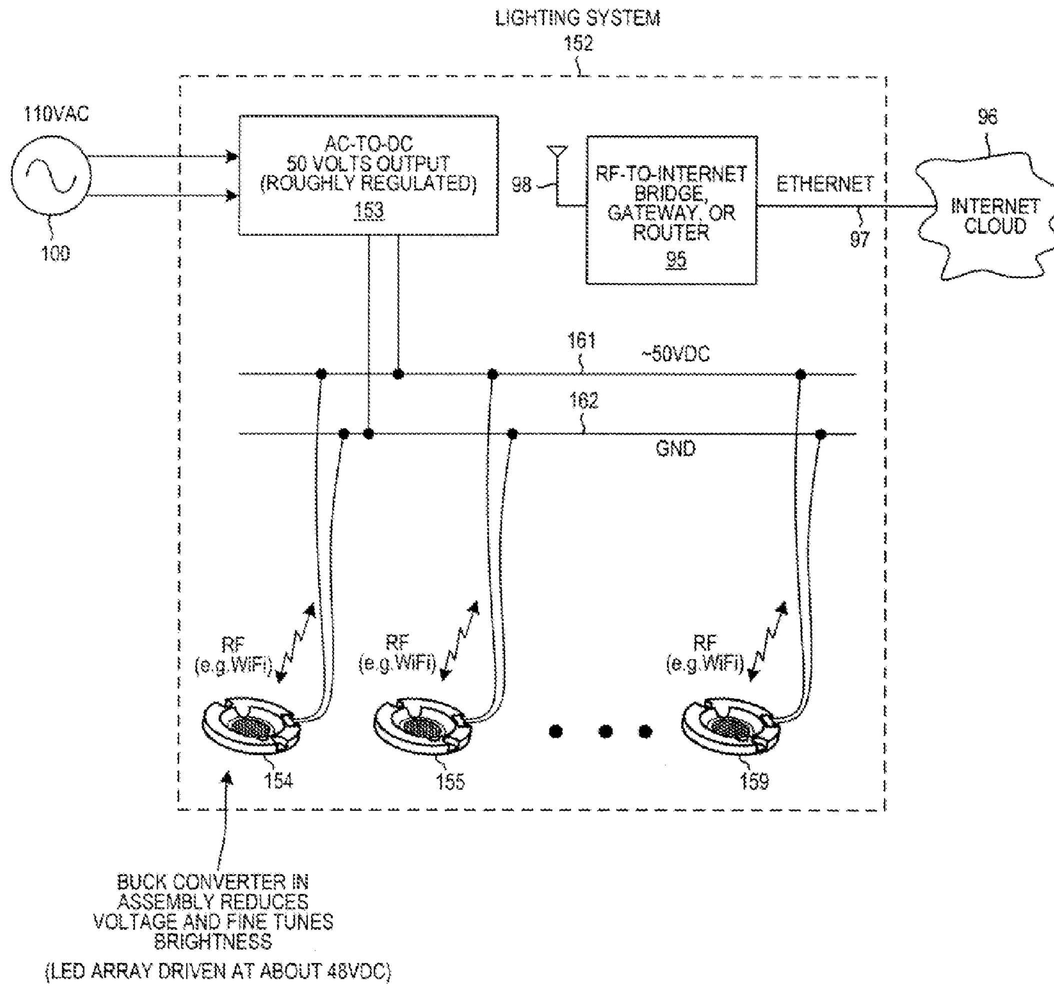
ONE WAY TO DRIVE MULTIPLE LED STRINGS WITH MULTIPLE BUCK CONVERTERS

FIG. 22



ANOTHER WAY TO DRIVE MULTIPLE LED STRINGS WITH MULTIPLE BUCK CONVERTERS

FIG. 23



LIGHTING SYSTEM INVOLVING MULTIPLE 48V LED ARRAY MEMBER/
INTEGRATED CONTROL MODULE ASSEMBLIES OF FIG. 16

FIG. 24

LED ARRAY MEMBER AND THERMALLY DECOUPLED INTEGRATED CONTROL MODULE ASSEMBLY

CROSS REFERENCE TO RELATED APPLICATIONS

This application claims priority under 35 U.S.C. §119 from U.S. Provisional Application No. 61/856,552, entitled "LED Array Member and Integrated Control Module Assembly," filed on Jul. 19, 2013, the subject matter of which is incorporated herein by reference.

TECHNICAL FIELD

The present invention relates generally to packaging of light-emitting diodes.

BACKGROUND INFORMATION

A light emitting diode (LED) is a solid state device that 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. Making a light fixture or a "luminaire" out of such an LED array, however, typically involves other components. The LED array generates heat when used. If the temperature of the LED array is allowed to get too high, performance of the LED array may suffer and the LED array may actually fail. In order to remove enough heat from the LED array so as to keep the LED array adequately cool, the LED array is typically fixed in some way to a heat sink. In addition, power must somehow be supplied to the LED array. Power supply circuitry is typically required to supply current to the LED array in a desired and suitable fashion. Optical components are also generally employed to direct and focus the emitted light in a desired fashion. There are many considerations involved in packaging an LED array so that it the array can be used effectively in an overall luminaire. Ways of packaging LED arrays for use in luminaires are sought.

SUMMARY

An LAM/ICM assembly comprises an integrated control module (ICM) and an LED array member (LAM). In one example, the ICM is a thick, washer-shaped, molded plastic member that fits over an upper surface of the LAM and holds the LAM so that a bottom surface of the LAM is held in good thermal contact against a heat sink. A thermal interface material thermally couples the bottom surface of the LAM and the heat sink. The ICM has holes through which threaded screws or bolts can extend. The screws or bolts extend through the holes in the ICM and engage corresponding threaded holes in the heat sink, thereby pulling the washer-shaped ICM toward the heat sink. The ICM in turn presses downward on the top of

the LAM and causes the bottom surface of the LAM to be pressed against a layer of thermal interface material on the heat sink. There is no thermal interface material laterally outside the LAM between the heat sink and the bottom surface of the ICM. In one embodiment, a thermal insulator is disposed between the heat sink and the bottom surface of the ICM laterally outside the LAM.

In addition, the ICM includes terminals and an interconnect layer through which power from outside the assembly is received onto the assembly and is supplied through the ICM, and through mating sets of contact pads of the ICM and LAM, and to the LAM so that the LEDs of the LAM can be powered and emit light. The ICM does not cover the LEDs of the LAM, but rather a central circular opening in the washer-shaped ICM allows light emitted from the LEDs to pass upward through the central opening and away from the heat sink.

In accordance with a first novel aspect, the washer-shaped ICM includes circuitry involving active electronic components. The circuitry monitors LAM operation, controls and supplies power to the LAM, and communicates information into and out of the assembly. In one example, the circuitry monitors the voltage disposed across a string of LEDs of the LAM, monitors the current flowing through the string of LEDs of the LAM, and monitors the temperature of the LED array. In one example, the ICM includes a printed circuit board to which this circuitry is mounted. The circuitry and the printed circuit board are encapsulated in injection molded plastic. Injection molded plastic overmolds almost all of the printed circuit board including the periphery of the printed circuit board, the upper surface of the printed circuit board, and the lower surface of the printed circuit board. There are, however, exposed contacts on the bottom of the printed circuit board that extend around in the bottom of the inside lip of the central opening in the ICM. When the LAM is fitted up into place into the central opening in the ICM, LAM contact pads on the peripheral edge of upper surface of the LAM make electrical contact with corresponding ICM contact pads on the bottom of the inside lip of the ICM. Power is supplied through the ICM and to the LAM through these contacts, and LAM operation is monitored by the ICM through these contacts.

In accordance with a second novel aspect, a lighting system comprises an AC-to-DC converter and a LAM/ICM assembly, where the LAM/ICM supplies a control signal back to the AC-to-DC converter. The AC-to-DC converter receives a supply voltage from an AC voltage source, such as a 110 VAC voltage source. The AC-to-DC converter outputs a substantially constant and regulated current or voltage, where the substantially constant current or voltage has an adjustable magnitude. The level to which the current or voltage is regulated can be changed by appropriate control of the control signal (for example, a zero volts to ten-volt control input signal) to the AC-to-DC converter. If the ICM determines that more power should be received, then the ICM increases the level of the zero-to-ten-volt control signal. If the ICM determines that less power should be received, then the ICM decreases the level of the zero-to-ten-volt control signal. The AC-to-DC converter responds by increasing or decreasing the current or voltage level to which it regulates, as instructed by the control signal.

In the case where the adjustable AC-to-DC converter outputs a regulated constant current, a FET of the LAM/ICM assembly simply turns on or off current flow through the LAM. If LAM current flow is on, then the magnitude of the current flowing from the AC-to-DC converter is determined by the feedback zero-to-ten-volt control signal that the LAM/ICM supplies back to the AC-to-DC converter. Because the

AC-to-DC converter output cannot normally be turned fully off by the zero-to-ten-volt control signal, and because the circuitry of the ICM requires a supply voltage at all times to operate, the ICM includes a semiconductor switch that is operable in the saturated mode as an "on-off" switch to the LAM. The ICM also includes circuitry that controls the semiconductor switch so that when it is desired to have the LAM produce no light whatsoever, the switch is turned "off" interrupting all current flow to the LAM, but leaving voltage output from the AC-to-DC converter at the ICM which can be used to continue to power the circuitry of the ICM while the LAM is "off".

In the case where the adjustable AC-to-DC converter outputs a regulated constant voltage, the ICM of the LAM/ICM assembly receives power from the AC-to-DC converter and supplies power to the LEDs of the LAM. The ICM includes a semiconductor switch that is operable in the linear mode. The ICM also includes circuitry that controls the semiconductor switch in the linear mode such that the ICM receives the substantially constant voltage from the AC-to-DC converter and causes a controlled DC current to flow through the LAM. Linear operation of the semiconductor switch is controlled to fine tune the magnitude of the DC current flowing through the LEDs. The circuitry also outputs a control signal that is supplied out of the LAM/ICM assembly and back to the AC-to-DC converter. This control signal is the zero-volt to ten-volt control input signal that controls the AC-to-DC converter. Using this control signal, the circuitry of the LAM/ICM assembly controls the AC-to-DC converter so that the LED voltage at which the LEDs of the LAM are driven is close to (for example, within ten percent of) the voltage at which the constant current is supplied by the AC-to-DC converter to the LAM/ICM assembly. Because the voltages are close, power dissipation of the semiconductor switch in the ICM is low enough so that it can perform its regulating function without overheating. In one example, the semiconductor switch is disposed in a semiconductor package, where the semiconductor package of the switch extends from a bottom surface of the ICM and is a good thermal contact with the heat sink.

In accordance with a third novel aspect, a lighting system comprises an AC-to-DC converter and a LAM/ICM assembly. The AC-to-DC converter receives a supply voltage from an AC voltage source, such as a 110 VAC voltage source. The AC-to-DC converter in the third novel aspect outputs a substantially constant voltage. The ICM of the LAM/ICM assembly includes a switching DC-to-DC converter. The switching DC-to-DC converter of the ICM receives the substantially constant DC voltage from the AC-to-DC converter and supplies a substantially constant and regulated LED DC drive current to the LAM.

The switching DC-to-DC converter that is embedded in the ICM may be a step down converter whose input voltage is higher than its output voltage. Or the switching DC-to-DC converter that is embedded in ICM may be a step up converter whose input voltage is lower than its output voltage. Or the switching DC-to-DC converter that is embedded in the ICM may be a combination converter whose incoming input voltage can be higher or lower than the converter output voltage. In one specific example, the switching DC-to-DC converter of the ICM is a step-down buck converter that is switched at about 10 MHz. In other examples, the switching DC-to-DC converter of the ICM is one of a step-up boost converter, a SEPIC converter, and a boost/buck combination converter operating at switching frequencies that may be substantially higher than 10 MHz to keep the physical size of electronic components small.

In one example, the LAM includes a plurality of strings of LEDs. The ICM includes a plurality of buck converters, all of which are controlled by a common microcontroller that is a part of the ICM. Each string of LEDs is supplied with an independently controlled LED drive current by a corresponding one of the plurality of buck converters. In some embodiments, multiple such LAM/ICM assemblies are driven in parallel by the same AC-to-DC converter, where the AC-to-DC converter outputs only a roughly regulated constant voltage. Within each LAM/ICM, the microcontroller monitors the voltage supplied to each LED string, monitors the current flowing through each LED string, and monitors the temperature of the LED array. The microcontroller controls the current supplied to each string independently of the currents supplied to the other strings. The microcontroller may control the current supplied to each string of LEDs by controlling the switching DC-to-DC converter or converters of the ICM that supply the drive currents to the strings of LEDs. In some examples, the ICM includes an RF (Radio Frequency) transceiver that the microcontroller uses to communicate information to and from other RF transceivers located outside the LAM/ICM assembly. The ICM also includes a terminal through which the microcontroller can communicate digital information into and out of the LAM/ICM assembly. The communication interface can be a wired one through this terminal, or the communication interface can be a wireless one provided by the RF communication link.

Further details and embodiments and techniques are described in the detailed description below. This summary does not purport to define the invention. The invention is defined by the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, where like numerals indicate like components, illustrate embodiments of the invention.

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

FIG. **2** is a perspective view of the top of an 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 LAM/ICM of FIGS. **1** and **2**.

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

FIG. **5** is top-down view of one example of a LAM usable with the ICM of FIGS. **1** and **2**.

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

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

FIG. **8** is a more detailed diagram showing how a LAM contact pad on the peripheral edge of upper surface of the LAM makes contact with a corresponding ICM contact pad in the bottom of the inside lip of the ICM.

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

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

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

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

FIG. **13** is a view of an alternative embodiment of the LAM/ICM of FIG. **4** taken along sectional line C-C' with an

air gap between the heat sink and the ICM outside the lateral boundary of the substrate member of the LAM.

FIG. **14** is a view of yet another alternative embodiment of the LAM/ICM of FIG. **4** taken along sectional line C-C' with a thermal insulator between the heat sink and the ICM outside the lateral boundary of the substrate member of the LAM.

FIG. **15** is a circuit diagram of the LAM/ICM assembly in accordance with a second novel aspect, in an example in which the AC-to-DC converter outputs a regulated constant current and the AC-to-DC converter receives a control signal back from the LAM/ICM assembly.

FIG. **16** is a diagram of a lighting system that includes the LAM/ICM assembly of FIG. **15**.

FIG. **17** is a circuit diagram of the LAM/ICM assembly in accordance with the second novel aspect, in an example in which the AC-to-DC converter outputs a regulated constant voltage.

FIG. **18** is a top-down diagram of another example of a LAM that can be used with the ICM of FIGS. **1** and **2**.

FIG. **19** is a circuit diagram of the LAM/ICM assembly in accordance with a third novel aspect.

FIG. **20** is a circuit diagram of a buck converter suitable for use in the LAM/ICM assembly of FIG. **19**.

FIG. **21** is a table that sets forth parameters and components characteristics of the buck converter of FIG. **20**.

FIG. **22** is a diagram illustrating a first way to drive multiple LED strings with multiple buck converters, where the multiple buck converters are parts of the ICM.

FIG. **23** is a diagram illustrating a second way to drive multiple LED strings with multiple buck converters, where the multiple buck converters are parts of the ICM.

FIG. **24** is a diagram of a lighting system that includes the LAM/ICM assembly of FIG. **19**.

DETAILED DESCRIPTION

Reference will now be made in detail to background examples and some embodiments of the invention, examples of which are illustrated in the accompanying drawings.

FIG. **1** is a perspective view of the top of an LED assembly member/integrated control module assembly (LAM/ICM assembly) **1**. There are two parts of the LAM/ICM assembly: a LED assembly member **2** (FIG. **3**) and an integrated control module **3**. The LED assembly member **2** 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 **1** is a disk-shaped structure that has a circular upper outer peripheral edge **4**. Reference numeral **5** identifies the upper surface of the LAM/ICM assembly **1**. The upper surface **5** is a surface 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 **1** 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 **1** 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 **1**. 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 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 **1**.

FIG. **2** is a perspective view of the top of the LAM/ICM assembly, taken from the other side of the LAM/ICM assembly opposite header socket **12**.

FIG. **3** is a perspective view of the bottom of the LAM/ICM assembly **1**. Reference numeral **18** identifies the circular lower outer peripheral edge of the LAM ICM assembly. 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 **2** is disposed in the central opening **17** so that the bottom surface **20** of the LAM **2** 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 **1**. 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 **2**, 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 **2** 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. The outwardly extending portions of the metal areas at the corners of the LAM of FIG. **5** are referred to as LAM contact pads because these areas of metal are exposed, and are not covered

with soldermask. Reference numerals **35-38** identify these LAM contact pads in the illustration of FIG. **5**.

FIG. **6** is a cross-sectional diagram that shows how the LAM **2** 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 and the electronic components. In the illustrated example, the interconnect structure **39** is a multi-layer printed circuit board (PCB). One of the electronic components **41** of the circuitry is seen in cross-section as a rectangle. Not all of the printed circuit board is actually encapsulated, but rather the bottom of the inside lip **42** of the central opening **17** is not covered 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 **2** 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 **2** 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** contacts ICM contact pad **46** through conductive via **47**. Trace **48** contacts ICM contact pad **49** through conductive via **50**.

FIG. **8** is a view that shows how LAM contact pad **36** is 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 **2** is covered by insulative layer **30**. Electrical contact is made from metal area **26**, a part of which is LAM contact pad **36**, up through solder **44**, to ICM contact pad **46**, 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 can also be used for this interconnect structure.

FIG. **9** is a cross-sectional view of the LAM/ICM assembly **1** 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 **2** 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. Reference numerals **62** and **63** identify additional electronic components of the circuitry mounted on PCB **39**. The circuitry is overmolded by the injection molded plastic encapsulant **40**.

FIG. **10** is a cross-sectional view of the LAM/ICM assembly **1** of FIG. **4** taken along sectional line B-B' (shown on a heat sink). Solder **43** couples LAM contact pad **37** to ICM contact pad **64**. Solder **44** couples LAM contact pad **36** to ICM contact pad **46**.

FIG. **11** is a cross-sectional view of the LAM/ICM assembly **1** of FIG. **4** taken along sectional line C-C' (shown on heat sink **60**). Electronic components of the circuit as seen in cross-section include a communication integrated circuit **65**, a microcontroller integrated circuit **66**, and a FET switch **67**. Each of these three components is a packaged device that is in turn overmolded by the plastic encapsulant **40** of the ICM. In the case of the FET switch **67**, a surface of the package forms a part of the bottom surface of the ICM so that when the ICM is pressed against the heat sink **60** (with the TIM **61** in between), the bottom surface of the FET switch package makes good thermal contact with the heat sink **60**. The FET switch package 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 **1** of FIG. **4** taken along sectional line D-D' (shown on a heat sink).

FIG. **13** shows an alternative embodiment of the LAM/ICM assembly **1** of FIG. **4** taken along sectional line C-C'. In the embodiment of FIG. **11**, it was advantageous to form a good thermal contact between heat sink **60** and electronic components whose heat generating surface is facing towards the bottom surface of ICM **3**, such as FET switch **67**. In the embodiment of FIG. **11**, heat generated by FET switch **67** is dissipated through thermal interface material **61** into heat sink **60**. In the embodiment of FIG. **13**, however, thermal contact between heat sink **60** and the bottom surface **19** of ICM **3** is avoided so as to impede heat that flows from substrate member **57** into heat sink **60** from flowing back up into ICM **3**. The embodiment of FIG. **13** is used when the light emitting diodes mounted on the upper surface of substrate member **57** generate such large amounts of heat that the heat sink **60** cannot dissipate that heat before the temperature of the heat sink increases to a degree that would be hotter than the electronic components in ICM **3** under the same operating conditions. If the heat sink becomes hotter than the electronic components and there is a strong thermal path between the heat sink and the electronic components, then the temperature of the electronic components would increase more than they would in a configuration that does not include a heat sink. In some further embodiments of FIG. **13**, electronic components are not placed towards the bottom surface of ICM **3**. However, in some embodiments it may be advantageous to place the electronic components towards the bottom surface of ICM **3**, such as for electronic reasons (e.g. component placement, wire routing, etc.) In addition, the thermal interface material **61** is deposited laterally and only beneath substrate member **57** such that only substrate member **57** is thermally coupled to heat sink **60**. A gap remains between the bottom surface **19** of ICM **3** and the upper surface of heat sink **60** outside the lateral boundary of substrate member **57**. The layer of air between heat sink **60** and ICM **3** provides some degree of thermal insulation that impedes heat from the heat sink from flowing back up into ICM **3** and overheating the electronic components.

FIG. **14** shows yet another alternative embodiment of the LAM/ICM assembly **1** of FIG. **4** taken along sectional line C-C'. The air gap of the embodiment of FIG. **13** between heat sink **60** and ICM **3** has been filled with a thermal insulator **76**. Thermal insulator **76** impedes heat that is generated by the light emitting diodes and that flows into heat sink **60** from flowing back up through the bottom surface **19** of ICM **3** and into the electronic components. Before the LAM/ICM assembly **1** is mounted on heat sink **60**, thermal insulator **76** is deposited as a layer over bottom surface **19** of ICM **3**, and the thermal interface material **61** is deposited over bottom surface **20** of LAM **2**. In some embodiments, thermal insulator **76** is a ceramic or fibrous material.

FIG. **15** is a diagram of the LAM/ICM assembly **1** in accordance with a second novel aspect. The LAM/ICM assembly **1** is illustrated with the heat sink **60** and with optics **68** denoted as blocks. The microcontroller **66** monitors the

temperature of the LAM **2** via a temperature interface circuit **69**. Temperature interface circuit **69** includes a constant current source that supplies a constant current **70** to the temperature sensing GaN die **32** via ICM contact pad **46**, LAM contact pad **36**, LAM contact pad **38** and ICM contact pad **49**. The temperature interface circuit **69** also includes a voltage amplifier that amplifies the sensed voltage across LAM contact pads **36** and **38** and supplies the resulting amplified voltage signal T **72** to the microcontroller **66** via conductor **73**. In addition, microcontroller **66** monitors the voltage V with which the LEDs of LAM **2** are driven. This LED drive voltage is the voltage between LAM contact pads **35** and **37**. A current and voltage measuring interface circuit **78** measures this voltage via conductors **79** and **80**. In addition, microcontroller **66** monitors the LED drive current **74** flowing through the LEDs of the LAM **2**. This current **74** flows from pin **13**, through ICM contact pad **75**, through LAM contact pad **35**, through the LEDs, through LAM contact pad **37**, through ICM contact pad **64**, through current sense resistor **77**, through FET switch **67**, out of the LAM/ICM assembly via pin **14**. The current and voltage measuring interface circuit **78** detects the LED drive current **74** as the voltage dropped across the current sense resistor **77**. This voltage is detected across conductors **80** and **81**. The voltage and current measuring interface circuit **78** receives the voltage sense and current sense signals, low pass filters them, amplifies them, and performs level shifting and scaling to generate a voltage sense signal V **82** and a current sense signal I **83**. The voltage and current sense signals **82** and **83** are supplied to the microcontroller **66** via conductors **84** and **85**, respectively.

The T signal **72**, the V signal **82**, and the I signal **83** are converted into digital values by the analog-to-digital converter (ADC) **86** of the microcontroller. A main control unit (MCU) **87** of the microcontroller executes a program **71** of processor-executable instructions. The I, V and T signals, as well as information received from communication integrated circuit **65**, are used by the MCU **87** to determine how to control FET switch **67**. In the present example, the MCU **87** can control the FET switch to be nonconductive, thereby turning off the LEDs. The MCU **87** can control the FET switch to be fully conductive, thereby turning on the LEDs to a brightness proportional to the current supplied by the AC-DC converter as controlled by the zero to ten volt signal also produced by the MCU as directed by the control program. As explained in further detail below, the ICM **3** receives a substantially constant current via pins **13** and **14** from an AC-to-DC power supply circuit **88** (see FIG. **16**). The AC-to-DC power supply circuit **88** has a constant current output, the magnitude of the constant current being controllable by a zero to ten volt signal received by the AC-to-DC power supply circuit. The voltage that results across pins **13** and **14** when this constant current is being supplied to the LAM/ICM assembly **1** is about 50 volts. The microcontroller **66** controls the FET switch **67** to be fully on with nearly zero voltage across it when the LAM is to be illuminated. To accomplish control for a desired LED brightness (desired amount of current flow through the LEDs of the LAM), the microcontroller **66** sends a zero to ten voltage dimming control signal **89** back to the AC-to-DC power supply circuit **88** via conductor **90**, and data terminal **15**. The microcontroller **66** uses this control signal **89** to increase and to decrease the magnitude of the constant current **74** being output by the AC-to-DC power supply circuit **88**. The circuit components **69**, **78**, **66** and **65** are powered from a low DC supply voltage such as 3 volts DC. A component voltage supply circuit **91** generates this 3 volt supply voltage from the 50 volts across pins **13** and **14**. The 3 volt supply voltage is supplied onto voltage supply conductor **90**. Conductor **93** is the ground reference conductor for the component supply voltage. Because only a small amount of power is required to power the circuitry embedded in the ICM, the component voltage supply circuit **91** may be a simple linear voltage regulator.

FIG. **16** is a system level diagram of a lighting system **94**. Lighting system **94** includes the power supply circuit **88**, the LAM/ICM assembly **1**, and internet connectivity circuitry **95**. The LEDs of the LAM can be monitored and controlled remotely by communicating across the internet **96**. Information can be communicated from the internet **96**, across an ethernet connection **97**, through the internet connectivity circuitry **95**, from antenna **98** of the internet connectivity circuitry **95** to the antenna **98** of the LAM/ICM assembly **1** in the form of an RF transmission, through transceiver **163** of the communication integrated circuit **65**, and to the MCU **87** of the microcontroller **66**. Information can also be communicated in the opposite direction from the MCU **87** of the microcontroller **66**, through the transceiver **163** of the communication integrated circuit **65**, from antenna **99** in the form of an RF transmission to antenna **98**, through the internet connectivity circuitry **95**, across ethernet connection **97**, to the internet **96**. The lighting system **94** is typically part of a luminaire (light fixture) that is powered by ordinary 110 VAC wall power. Symbol **100** represents a source of 110 VAC wall power for the luminaire.

FIG. **16** shows that if the AC-to-DC supply is a constant voltage supply, the MCU **87** can control the FET switch to operate in the FET's linear mode in order to control the magnitude of the constant current **74** supplied to the LEDs of the LAM, thereby adjusting the brightness of the LEDs. When operating in this linear mode way, the voltage drop across the FET switch should be about two volts. As explained in further detail below, the ICM **3** receives a substantially constant voltage via pins **13** and **14** from an AC-to-DC power supply circuit that has a constant voltage output, the magnitude of the constant voltage being controllable by a zero-to-ten-volt signal received by the AC-to-DC power supply circuit. The voltage that results across pins **13** and **14** when this constant current is being supplied to the LAM/ICM assembly **1** is about 50 volts (or more accurately about 2 volts greater than the forward voltage of the LAM). The microcontroller **66** controls the FET switch **67** to fine tune the amount of current supplied to the LEDs of the LAM by adjusting the voltage drop across the FET switch to that amount required to achieve the necessary current flow. The voltage drop across FET switch **67** is about two volts or less depending on the current required, it will be nearest zero when maximum current is flowing and nearest 2 volts when minimum current is flowing. Note that to turn the LEDs off, the FET switch will be turned off, and the voltage across it will be much greater than 2 volts, but since no current is flowing through the FET, no power will be generated within the FET. To prevent excessive power dissipation by the FET when operating in the linear region, the voltage applied to the ICM must be within two volts of the forward voltage required to illuminate the LED. To accomplish this for a desired LED brightness (desired amount of current flow through the LEDs of the LAM), the microcontroller **66** sends a zero to ten voltage dimming control signal **89** back to the AC-to-DC power supply circuit **88** via conductor **90**, and data terminal **15**. The microcontroller **66** uses this control signal **89** to increase and to decrease the magnitude of the constant voltage being output by the AC-to-DC power supply circuit **88**. The circuit components **69**, **78**, **66** and **65** are powered from a low DC supply voltage such as 3 volts DC. A component voltage supply circuit **91** generates this 3 volt supply voltage from the 50 volts across pins **13** and

14. The 3 volt supply voltage is supplied onto voltage supply conductor **90**. Conductor **93** is the ground reference conductor for the component supply voltage. Because only a small amount of power is required to power the circuitry embedded in the ICM, the component voltage supply circuit **91** may be a simple linear voltage regulator.

FIG. **18** is a top-down diagram of another example of a LAM usable with the ICM. In this example, there are multiple LAM contact pads in each corner of the LAM, and there are multiple separately controllable strings of LED dice. One of these strings includes LED dice **101-110**. An LED drive current can be supplied to this string via LAM contact pad **111** and LAM contact pad **112**. There are six such separately controllable strings of the LED dice. The GaN temperature sensing diode is identified by reference numeral **32**. The LAM contact pads through which the GaN temperature sensing diode **32** is driven and monitored are LAM contact pads **113** and **114**. Reference numeral **34** identifies the rim that retains the silicone that covers the LED dice. The silicone is not illustrated in FIG. **18** so that the LED dice disposed under it can be seen in the illustration.

FIG. **19** is a diagram of an LAM/ICM assembly **115** in accordance with a third novel aspect. The LAM/ICM assembly **115** is similar to the LAM/ICM assembly **1** of FIG. **15** explained above, except that: 1) the LAM/ICM assembly **115** of FIG. **19** does not output a 0-10 volt dimming control signal, and 2) the LAM/ICM assembly **115** includes a switching DC-to-DC converter **116**. In the example of FIG. **19**, the switching DC-to-DC converter is a buck converter.

FIG. **20** is a more detailed diagram of the buck converter **116**. The buck converter **116** includes a programmable oscillator **117**, a switch **118**, a diode **119**, and inductor **120**, and a capacitor **121**. Programmable oscillator **117** supplies a rectangular wave digital drive signal **122** to the switch **118**. This drive signal causes the switch to turn on and off in a cyclical fashion. The 50-volt supply voltage from pin **13** is received between conductor **123** and conductor **124**. From this 50 volts supply voltage, the buck converter **116** generates and outputs the LED drive current **74** at about 48 volts to the LAM via conductor **125**. Microcontroller **66** adjusts the frequency and/or duty cycle of signal **112** by sending multi-bit digital control information **126** to the oscillator **116** across conductors **127**. By adjusting the frequency and/or duty cycle of signal **112**, the microcontroller **66** controls the magnitude of the nominal output current **74** that the buck converter **116** supplies on conductor **125** to the LEDs of the LAM.

FIG. **21** is a table that sets forth parameters of operation for the buck converter **116** using 10 MHz nominal switching frequency for the purpose of this explanation. The switching frequency can be substantially higher, as required by the voltages and currents of a particular LAM.

FIG. **22** is a diagram illustrating a first way to drive multiple LED strings with multiple buck converters, where the multiple buck converters are parts of the ICM. In the example of FIG. **22**, the buck converter block **116** of FIG. **19** actually includes multiple buck converters **128-133**. In addition, the LAM includes multiple strings **134-139** of LEDs that can be driven independently. Microcontroller **66** controls each of the buck converters separately by sending each buck converter different digital control information across different control lines. The microcontroller **66** controls the frequency and/or duty cycle output by each buck converter's programmable oscillator **117** separately. The microcontroller **66** monitors current flow through each string of LEDs one at a time using the same single current sense resistor **77**. Providing multiple buck converters in this way reduces the physical size of the inductors of the buck converters as indicated in the right column of FIG. **21**. Where six LED strings are separately driven, each by a separate buck converter, the approximate physical size of the inductor of each buck converter is 2.5 mm by 2.5 mm by 1.0 mm. This small inductor size facilitates encapsulation in a slim ICM profile. While it has been illustrated that each buck converter could be controlled by individual control signals, it is equally possible to implement the system where a single oscillator is used to drive multiple buck converter circuits composed only of the switch **118**, diode **119**, inductor **120** and capacitor **121**, thus further saving on the amount of components required while keeping the physical size of the components as small as possible.

FIG. **23** is a diagram illustrating a second way to drive multiple LED strings with multiple buck converters, where the multiple buck converters are parts of the ICM. In this case, each string of LEDs has a corresponding dedicated current sense resistor and FET switch. Current sense resistor **140** and FET switch **146** are for the first LED string **134**. Current sense resistor **141** and FET switch **147** are for the second LED string **135**. Current sense resistor **145** and FET switch **151** are for the sixth LED string **139**.

FIG. **24** is a diagram of a lighting system **152** that includes multiple instances of the LAM/ICM assembly **115** of FIG. **19** in accordance with the third novel aspect. Lighting system **152** includes an AC-to-DC power supply **153**, multiple LAM/ICM assemblies **154-159** of the type shown in FIG. **19**, and internet connectivity circuitry **95**. Bidirectional communication between each of the LAM/ICM assemblies and the internet **96** via internet connectivity circuitry **95** is the same as described above in connection with FIG. **16**. Unlike the AC-to-DC power supply **88** of the embodiment of FIG. **16** that outputs a regulated substantially constant current (the magnitude of which is adjustable), the AC-to-DC power supply **153** of the embodiment of FIG. **24** outputs a substantially constant voltage that is only roughly regulated. This roughly regulated voltage, in the example of FIG. **24**, is 50 volts. This roughly regulated voltage is supplied in parallel to the many LAM/ICM assemblies via conductors **161** and **162** as shown. The control of the amount of LED drive current supplied to the LEDs of an individual LAM/ICM assembly is controlled by the switching DC-to-DC converter (for example, a buck converter) within the LAM/ICM assembly itself. Each LAM/ICM assembly controls the amount of LED drive current being supplied to its own LEDs. The AC-to-DC power supply **153** therefore can output a supply voltage that is only roughly regulated. The AC-to-DC power supply **153** need not receive any 0-10 volt control signal to control its output.

Although an ICM having an embedded DC-to-DC converter is described above in connection with a specific example in which the switching DC-to-DC converter embedded in the ICM is a step-down buck converter, this is but one example. In other examples, the embedded switching DC-to-DC converter is a boost converter whose input voltage is lower than its output voltage. The voltage as received by the embedded boost converter is lower than the voltage (LEDDC) at which the LED array is driven. In other examples, the embedded switching DC-to-DC converter is a combination boost/buck converter whose incoming input voltage can be either higher or lower than the converter output voltage. The voltage as received by the embedded boost/buck converter may be higher or lower than the voltage (LEDDC) at which the LED array is driven. The embedded switching DC-to-DC converter may also be a Single-Ended Primary-Inductor Converter) SEPIC converter whose output voltage can be less than, equal to, or greater than its input voltage. Any DC-to-DC converter topology whose characteristics are suitable for the ICM application can be employed.

Although certain specific embodiments are described above for instructional purposes, the teachings of this patent document have general applicability and are not limited to the specific embodiments described above. Accordingly, various modifications, adaptations, and combinations of various features of the described embodiments can be practiced without departing from the scope of the invention as set forth in the claims.

What is claimed is:

1. An assembly comprising:

an LED (Light Emitting Diode) array member (LAM) comprising a plurality of LED dice disposed on a substrate member;

an integrated control module (ICM) through which power is supplied to the LAM, wherein the ICM defines a central opening, wherein the LAM fits up into the central opening in the ICM and is attached to the ICM, and wherein an electrical contact is made between an upper surface of the LAM and a bottom surface of the ICM adjacent to the central opening; and

a heat sink thermally coupled through a thermal interface material to a bottom surface of the substrate member of the LAM, wherein the heat sink is not thermally coupled through the thermal interface material to the ICM.

2. The assembly of claim **1**, wherein the central opening has a substantially circular upper peripheral edge and a substantially rectangular lower peripheral edge, wherein the substantially circular upper peripheral edge has a smaller periphery than the substantially rectangular lower peripheral edge, wherein the substrate member is rectangular, and wherein the rectangular substrate member fits up inside the substantially rectangular lower peripheral edge of the central opening.

3. The assembly of claim **1**, wherein the LAM is attached to the ICM in such a way that light emitted from the plurality of LED dice passes up through the central opening in a direction away from the heat sink.

4. The assembly of claim **1**, wherein the ICM presses the LAM against the thermal interface material.

5. The assembly of claim **1**, wherein the ICM comprises no LEDs.

6. The assembly of claim **1**, wherein the LAM includes a plurality of strings of LEDs, wherein the ICM comprises a plurality of switching DC-to-DC converters, and wherein each of the plurality of switching DC-to-DC converters drives a corresponding one of the plurality of strings of LEDs.

7. The assembly of claim **6**, wherein the ICM includes an amount of injection molded plastic that overmolds and encapsulates the switching DC-to-DC converters.

8. The assembly of claim **1**, wherein the LAM includes a temperature sensing GaN diode, and wherein the ICM includes circuitry that monitors the temperature sensing GaN diode.

9. The assembly of claim **8**, wherein the ICM includes an amount of injection molded plastic that overmolds and encapsulates the circuitry that monitors the temperature sensing GaN diode.

10. An assembly comprising:

an LED (Light Emitting Diode) array member (LAM) comprising a plurality of LED dice disposed on a substrate member;

an integrated control module (ICM) through which power is supplied to the LAM, wherein the ICM defines a central opening, wherein the LAM fits up into the central opening, and wherein an electrical contact is made between an upper surface of the LAM and a bottom surface of the ICM adjacent to the central opening; and

a thermal interface material disposed between a bottom surface of the substrate member of the LAM and a heat sink, wherein no thermal interface material is disposed between the heat sink and the bottom surface of the ICM.

11. The assembly of claim **10**, wherein a thermal insulator material is disposed between the heat sink and the bottom surface of the ICM.

12. The assembly of claim **10**, wherein the ICM includes an active electronic component, and wherein the LED dice are controlled by the active electronic component.

13. The assembly of claim **12**, wherein the ICM includes an amount of encapsulant that forms an upper surface of the ICM, and wherein the amount of encapsulant covers the active electronic component.

14. The assembly of claim **10**, wherein the ICM includes an active electronic component, and wherein power is supplied to the LED dice through the active electronic component.

15. The assembly of claim **10**, wherein the central opening has a substantially circular upper peripheral edge and a substantially rectangular lower peripheral edge, wherein the substantially circular upper peripheral edge has a smaller periphery than the substantially rectangular lower peripheral edge, wherein the substrate member is rectangular, and wherein the rectangular substrate member fits up inside the substantially rectangular lower peripheral edge of the central opening.

16. The assembly of claim **10**, wherein the ICM has holes through which threaded members engage the heat sink and pull the ICM towards the heat sink and thereby press the substrate member against the thermal interface material.

17. An assembly comprising:

a substrate member upon which light emitting diodes are mounted;

an integrated control module (ICM) through which power is supplied to the light emitting diodes, wherein the ICM has a central opening, wherein the central opening has a substantially circular upper peripheral edge and a substantially rectangular lower peripheral edge, wherein the substrate member fits up into the central opening in the ICM, wherein an electrical contact is made between an upper surface of the substrate member and a bottom surface of the ICM adjacent to the central opening, wherein the ICM includes an active electronic component, and wherein the light emitting diodes are controlled by the active electronic component; and

a thermal interface material disposed between a bottom surface of the substrate member and a heat sink, wherein no thermal interface material is disposed between the ICM and the heat sink adjacent to the bottom surface of the ICM.

18. The assembly of claim **17**, further comprising:

a thermal insulator material disposed between the ICM and the heat sink adjacent to the bottom surface of the ICM.

19. The assembly of claim **17**, wherein a temperature sensing GaN diode is mounted on the substrate member, and wherein the ICM includes circuitry that monitors the temperature sensing GaN diode.

20. The assembly of claim **19**, wherein the ICM includes an amount of injection molded plastic that overmolds and encapsulates the circuitry that monitors the temperature sensing GaN diode.

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