US008668361B2

(12) **United States Patent**
Hasnain et al.

(10) **Patent No.: US 8,668,361 B2**
(45) **Date of Patent: Mar. 11, 2014**

(54) **LED-BASED REPLACEMENT FOR FLUORESCENT LIGHT SOURCE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/888,111**

(22) Filed: **Sep. 22, 2010**

(65) **Prior Publication Data**

US 2012/0068604 A1 Mar. 22, 2012

(51) **Int. Cl.**
H01R 33/00 (2006.01)
F25D 27/00 (2006.01)

(52) **U.S. Cl.**
USPC **362/294**; 362/126

(58) **Field of Classification Search**
USPC ..... 315/185 S, 312, 324, 291; 362/294, 218, 362/373, 249.02, 311.02, 800, 126
See application file for complete search history.

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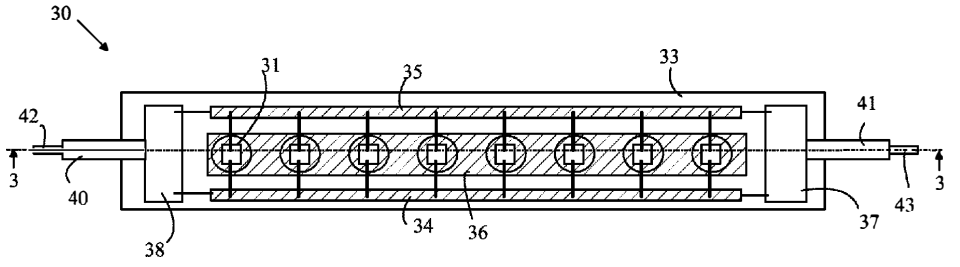
(57) **ABSTRACT**

A light source that is adapted to replace existing fluorescent tubes in an existing fluorescent light fixture is disclosed. The light source includes a plurality of LEDs mounted on a heat-dissipating structure, first and second plug adapters that mate with the florescent tube connectors of the fluorescent tube the light source is to replace, and a power adapter that converts power from a fluorescent tube ballast presented on the first and second plug adapters to DC power that powers the LEDs. The light source is powered from the output of the existing fluorescent ballast. The light source can utilize the existing metallic enclosure as a heat-radiating surface and/or direct air heat transfer from the surface of the heat-dissipating structure.

17 Claims, 7 Drawing Sheets



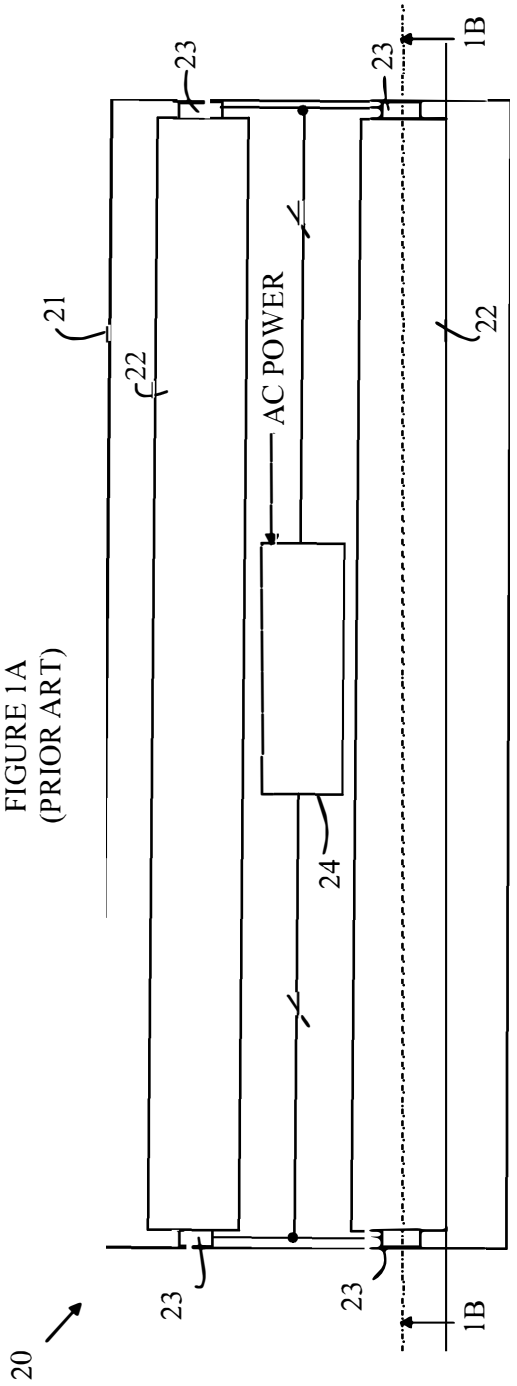


FIGURE 1A
(PRIOR ART)

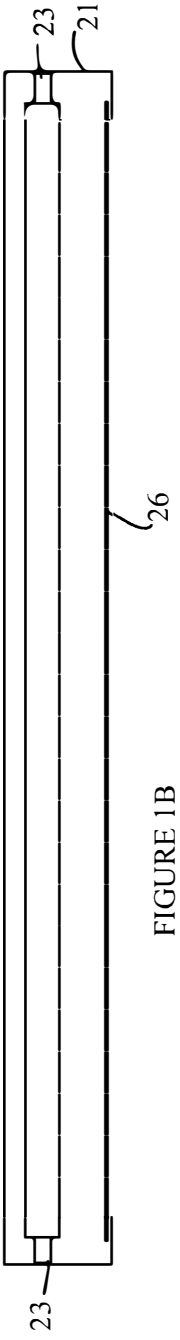


FIGURE 1B
(PRIOR ART)

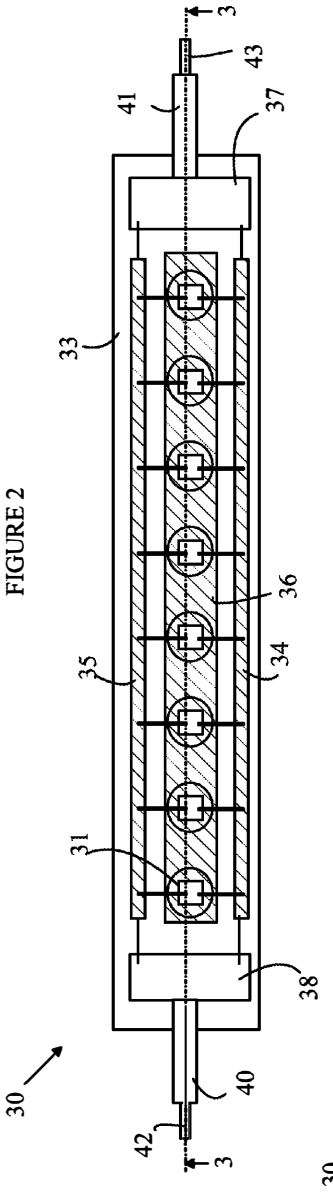


FIGURE 2

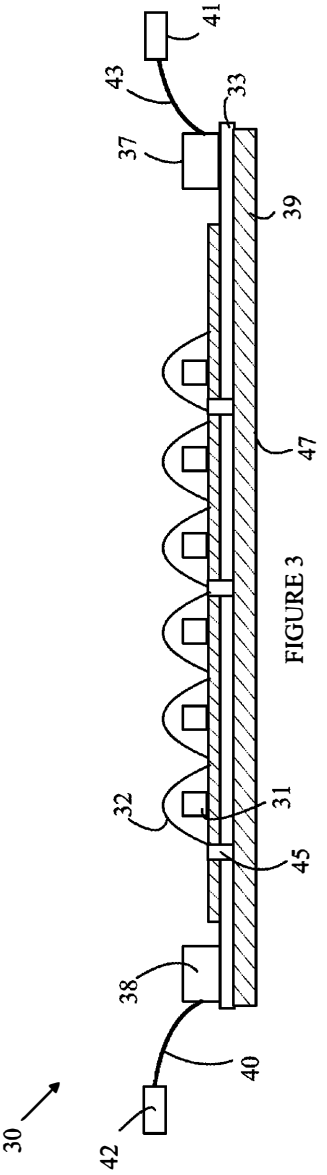


FIGURE 3

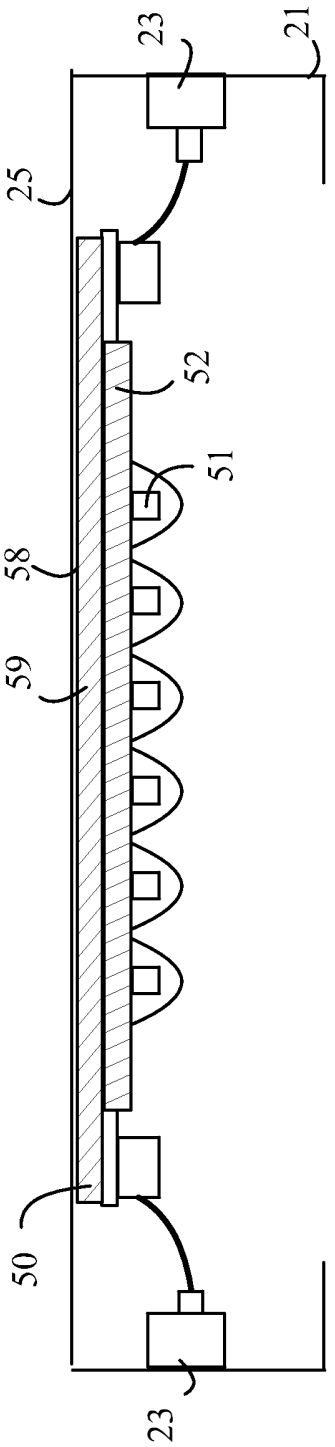


FIGURE 4

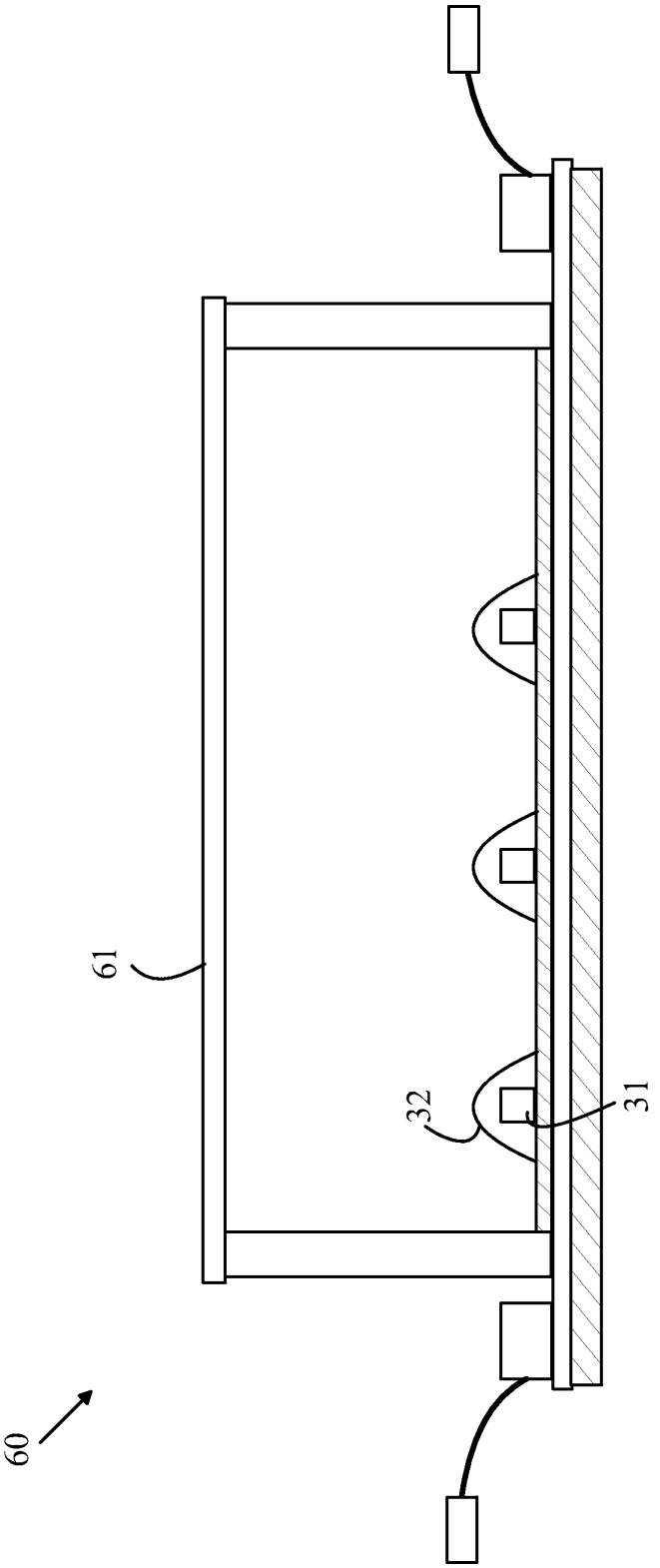


FIGURE 5

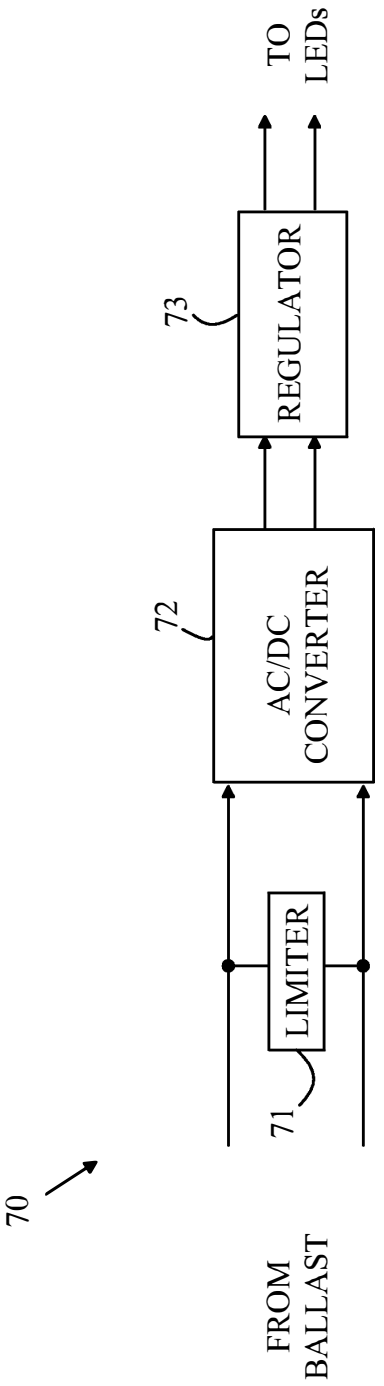

70
FROM BALLAST
71
LIMITER
72
AC/DC CONVERTER
73
REGULATOR
TO LEDs

FIGURE 6

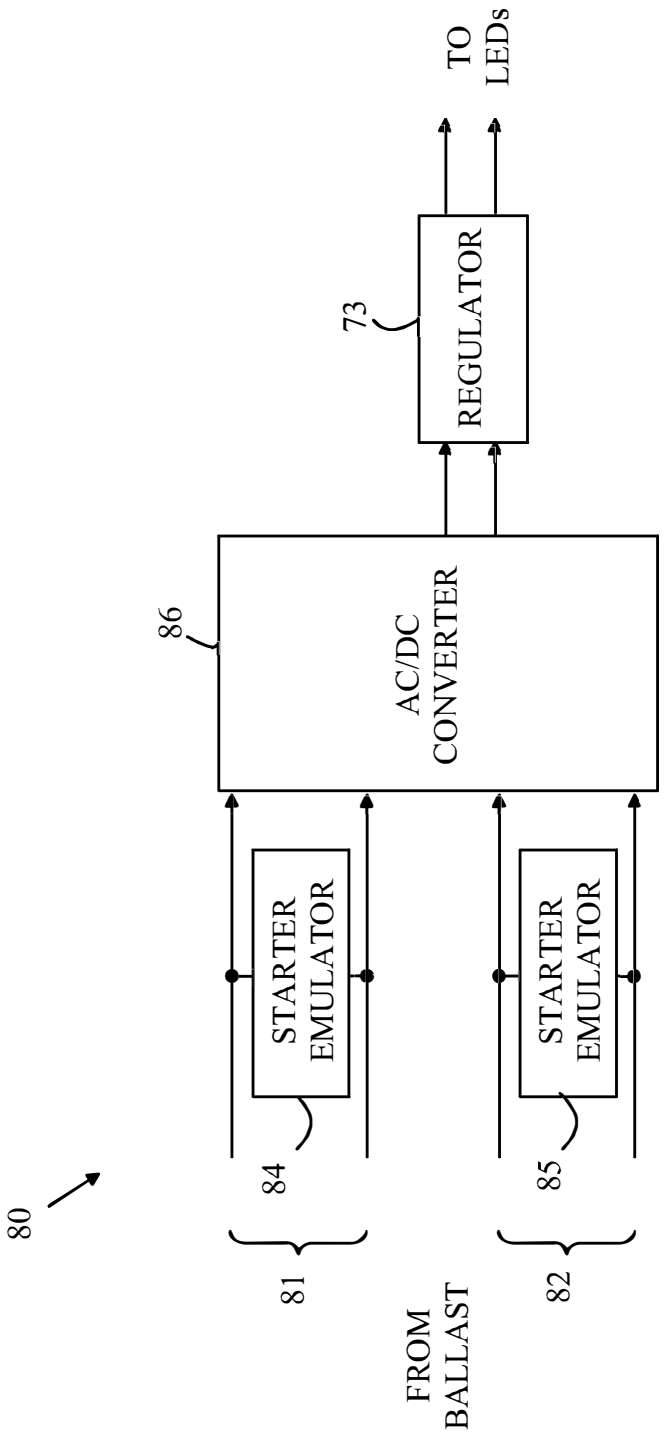

TO LEDs
73
REGULATOR
86
AC/DC CONVERTER
STARTER EMULATOR
STARTER EMULATOR
84
85
80
81
82
FROM BALLAST

FIGURE 7

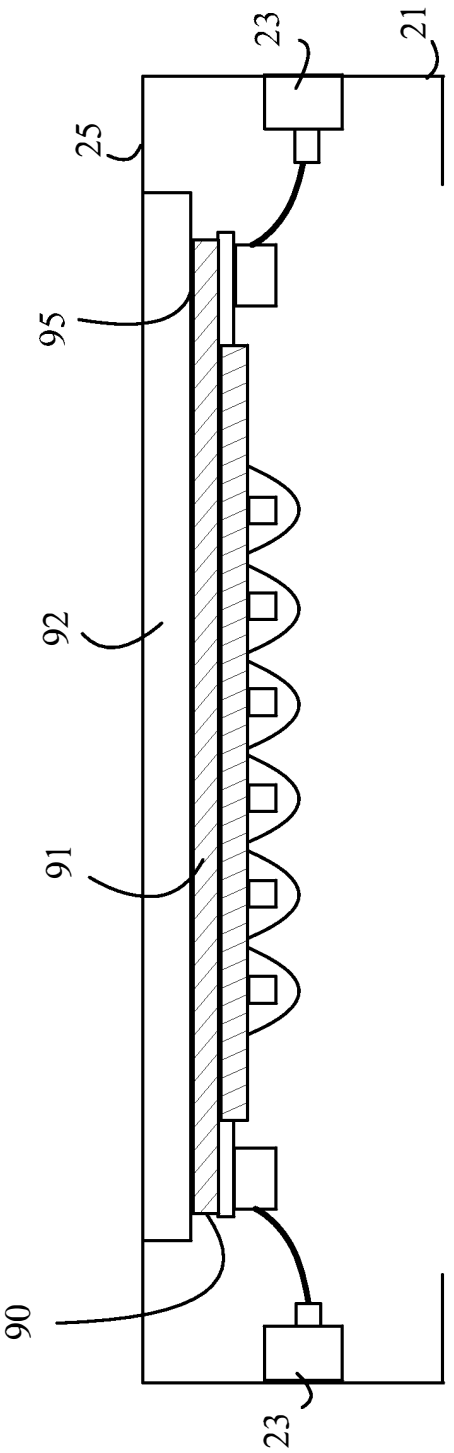


FIGURE 8

LED-BASED REPLACEMENT FOR FLUORESCENT LIGHT SOURCE

BACKGROUND OF THE INVENTION

Light emitting diodes (LEDs) are an important class of solid-state devices that convert electric energy to light. Improvements in these devices have resulted in their use in light fixtures designed to replace conventional incandescent and fluorescent light sources. The LEDs have significantly longer lifetimes than both incandescent bulbs and fluorescent tubes. In addition, the efficiency of conversion of electricity to light has now reached the same levels as obtained in fluorescent light fixtures.

In many applications, the cost of replacing a fluorescent tube and disposing of the defective tube is much greater than the cost of the tube itself. In commercial settings, the labor cost inherent in stocking and replacing tubes is high. In addition, the cost of disposal of fluorescent tubes further increases the cost of replacing the tubes, since fluorescent tubes utilize mercury to generate the underlying UV light that is then converted to visible light by the phosphors in the tubes, which are also hazardous materials that present a separate health hazard. Hence, care must be taken in handling the tubes and moving them to the disposal site to prevent breakage and the subsequent release of the toxic materials. Finally, the cost of the tubes themselves over the lifetime of the light fixture is also significant. Thus, there has been some interest in replacing existing fluorescent tubes with LED-based lighting elements.

Converting existing fluorescent fixtures to LED-based light sources presents a number of challenges. Existing fluorescent fixtures typically include an enclosure that holds one or more tubes and a ballast that converts the 50 or 60 cycle building power to the voltages and frequencies utilized by the tubes. A fluorescent tube typically has a startup phase in which a discharge is initiated in the gas. Once the discharge is established, a different voltage is applied to the fluorescent tube to maintain the discharge. The ballast provides the driving voltages and manages the startup phase. The voltages used to start and drive the fluorescent tube are typically AC voltages.

LEDs are typically driven with a DC voltage at a constant current. Hence, an LED light source typically requires a power supply that converts the conventional building power to a DC source that supplies a constant current to the LEDs in the light source. Accordingly, when an existing fluorescent tube light source is converted to an LED-based light source, all of the fluorescent tubes are typically removed and the fluorescent tube ballast is replaced with a LED power source.

This conversion can impose a significant cost and require a significant downtime for the lighting fixtures. The retired fluorescent tubes that are still functioning represent a significant capital investment that is lost when the fixture is replaced. In addition, specialized personnel are needed to remove the old ballast and install the new LED power supply. Accordingly, a switchover to LED-based tube replacements can require a significant level of organization and planning as well as cost.

The electrical conversion efficiency and lifetime of LEDs depend on the operating temperature of the LEDs. Increases in temperature lead to a loss in conversion efficiency and a lowering of the LED lifetime. Transferring the heat from the LEDs to the surrounding air is, hence, an important consideration in replacing existing fluorescent tubes with LED-based light sources. Typically, LED light sources in the power range of existing fluorescent tube light sources require a large heat transfer surface and good air circulation. If the fluorescent tubes are in a closed fixture that has poor air circulation, the transfer of the heat to the air presents additional challenges.

SUMMARY OF THE INVENTION

The present invention includes a light source that is adapted to replace existing fluorescent tubes in an existing fluorescent light fixture. The light source includes a plurality of LEDs mounted on a heat-dissipating structure, first and second plug adapters that mate with the florescent tube connectors of the fluorescent tube the light source is to replace, and a power adapter that converts power from a fluorescent tube ballast presented on the first and second plug adapters to DC power that powers the LEDs. The light source is powered from the output of the existing fluorescent ballast. The light source can utilize the existing metallic enclosure as a heat-radiating surface and/or direct air heat transfer from the surface of the heat-dissipating structure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A is a view from underneath a typical prior art fluorescent tube lighting assembly, and FIG. **1**B is a cross-sectional view of lighting assembly **20** through line **1**B-**1**B.

FIGS. **2** and **3** illustrate one embodiment of an LED-based light source that is configured as a replacement for a conventional fluorescent tube.

FIG. **4** is a cross-sectional view of another embodiment of a light source according to the present invention mounted against the back wall of enclosure **21** shown in FIGS. **1**A and **1**B.

FIG. **5** is a cross-sectional view of another embodiment of a light source according to the present invention.

FIG. **6** illustrates one embodiment of a power adapter according to the present invention.

FIG. **7** illustrates another embodiment of a power adapter according to the present invention.

FIG. **8** is a cross-sectional view of another embodiment of a light source according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

The manner in which the present invention provides its advantages can be more easily understood with reference to FIGS. **1**A and **1**B. FIG. **1**A is a view from underneath a typical prior art fluorescent tube lighting assembly, and FIG. **1**B is a cross-sectional view of lighting assembly **20** through line **1**B-**1**B. Light source **20** includes an enclosure **21** that houses two fluorescent tubes shown at **22** and a ballast **24** for powering the fluorescent tubes. Light source **20** also includes a diffuser plate **26** that is not shown in FIG. **1**A. The fluorescent tubes are inserted into connectors **23** that are connected to ballast **24** and provide the power for operating the fluorescent tubes.

The specific electrical connections and type of connector utilized depends on the type of fluorescent tube for which light source **20** is designed. For example, some designs utilize fluorescent tubes that have filaments within the tubes that are used for starting the discharge in the tube; while other designs utilize a high voltage startup phase to start the discharge. The first type of fluorescent tube utilizes a connector that mates with two pins on each end of the fluorescent tube. The second type of fluorescent tube has only one pin on each end of the fluorescent tube. The details of the ballast operation will be discussed in more detail below. For the purposes of the present discussion, it is sufficient to note that ballast **24** typi-

cally provides a first power pattern used to start the fluorescent tube and a second power pattern used to maintain the discharge during operation.

Conversion systems for converting fluorescent tube lighting to LED lighting are available commercially. In one scheme, the ballast is replaced by a power supply for providing a constant current source to the LEDs. This procedure requires the conversion to be carried out by someone with significantly more expertise than that required to replace a burnt-out fluorescent tube. In addition, the investment in the ballast is lost. In this regard, it should be noted that some of the circuitry in the ballast could, in principle, be utilized to simplify the circuitry needed to construct the constant current source for the LEDs.

Commercial lighting elements based on LEDs that emulate a conventional fluorescent tube are also available. These replacement tubes plug into the same connectors as the fluorescent tubes that they replace after the ballast has been replaced or the ballast has been removed and the connectors wired directly to the AC power lines. Since these replacements have the same form factor as the fluorescent tubes that they replace, heat dissipation presents challenges that significantly increase the cost of the replacements.

The present invention is based on the observation that a replacement LED light source for fluorescent tube **22** should plug into the same connectors and operate from the voltage patterns generated by the ballasts. Such a replacement would permit the conversion from fluorescent tubes to LED light sources to take place gradually as the fluorescent tubes burn out and are replaced. Furthermore, the upgrade could be carried out by the same personnel who are presently employed to change fluorescent tubes when those fluorescent tubes burn out. In addition, as will be discussed in more detail below, the power supply on the LED light source can advantageously use the output waveforms of the ballast for a number of different types of ballasts that are currently in use.

Refer now to FIGS. **2** and **3**, which illustrate one embodiment of an LED-based light source that is configured as a replacement for a conventional fluorescent tube. FIG. **2** is a top view of light source **30**, and FIG. **3** is a cross-sectional view of light source **30** through line **3-3**. Light source **30** is constructed from a plurality of LEDs of which LED **31** is typical. In this embodiment, the dies emit blue light and are covered with a layer of phosphor **32** that converts a portion of the light generated by the corresponding die to light in the yellow region of the spectrum such that the light that leaves the phosphor layer is perceived as being white light of predetermined color temperature by a human observer. In this embodiment, the LEDs are connected in parallel utilizing traces **34** and **35**, which are formed on an insulating layer **33**. However, embodiments in which the LEDs are connected in series or more complex circuit patterns can also be accommodated. Each LED is also mounted on a heat-dissipating structure **36** that aids in the transfer of the heat generated by the LEDs to the ambient environment. The manner in which the heat is dissipated will be discussed in more detail below.

Traces **33** and **34** are powered from an interface circuit having components shown at **37** and **38**. The interface circuit is connected to the connectors used to power the existing fluorescent tube via cables **40** and **43** that have connectors shown at **42** and **41**, respectively. Connectors **42** and **41** have ends that match the ends of the fluorescent tube that light source **30** replaces.

As noted above, heat dissipation is an important consideration with high power LED light sources. A T12 or T8 fluorescent tube typically generates 70 to 100 lumens per inch of tube while consuming approximately 0.9 watts of power per inch of tube. Hence, an LED replacement light source needs to generate 70 to 100 lumens per inch of light source. In addition, the LED replacement light source must have a "footprint" that is no wider than the fluorescent tube. Currently, white light sources based on GaN blue emitting LEDs generate 70 to 100 lumens per watt. Hence, the LED replacement source will generate about 1 watt/sec of heat for each inch along the light source to provide a replacement for the higher efficiency fluorescent tubes. If a lower efficiency fluorescent tube is being replaced, the heat that must be dissipated could be as low as 0.5 watts/sec. On the other hand, an LED replacement light source could provide more light than existing fluorescent tubes of the length being replaced, and hence, heat dissipations in excess of 2 watts/sec/inch of fluorescent tube could be required.

This heat needs to be dissipated without raising the temperature of the LEDs beyond the point at which an unacceptable decrease in the electrical conversion efficiency of the LEDs is incurred or a temperature at which the life of the LED is reduced. The operating temperature of the LEDs depends on the power being dissipated in the LEDs, the efficiency with which that heat is transferred to the ambient environment, and the temperature of the ambient environment. Typically, a maximum temperature of 70° C. is the operating limit; however, higher temperatures could be utilized with some LEDs, for example limits of 100° C. or 150° C. could be utilized.

In one aspect of the present invention, the LEDs are distributed on heat-dissipating structure **36** such that the surface area presented by the heat-dissipating structure is sufficient to dissipate a significant fraction of the heat of each LED to the surrounding air without the use of finned heat radiators or direct connections to larger heat-radiating surfaces. In one embodiment, the LEDs are distributed such that the heat generated on heat-dissipating structure **36** is less than 1 watt per square inch of surface area on the top surface of heat-dissipating structure **36**. As noted above, this arrangement is well matched to existing fluorescent tubes. It should be noted that T12 fluorescent tubes have a diameter of 1.5 inches; hence, a heat-radiating surface of about 1.5 square inches per inch of fluorescent tube being replaced could be made available. It has been determined experimentally, that if the LEDs are spaced apart along the length of heat-dissipating structure **36**, between 0.5 and 1 watt of heat per square inch of surface area can be dissipated without raising the temperature of the LEDs by more than 30° C. above ambient.

Referring to FIG. **3**, if additional heat dissipation is required, an additional heat-dissipating surface **47** on the backside of the light source can be utilized. In one aspect of the present invention, light source **30** includes a metallic layer **39** that is separated from heat-dissipating structure **36** by insulating layer **33**. In one aspect of the invention, a metal layer is connected to heat-dissipating structure **36** by vertical heat-conducting areas such as the metal filled via shown at **45**. In another aspect of the invention, heat-dissipating structure **36** is part of metal layer **39**. In this case, insulating layer **33** is absent from the area under heat-dissipating structure **36**.

It should be noted that heat-dissipating structure **47** can transfer heat to the air if light source **30** is suspended above the back wall **25** of enclosure **21** shown in FIGS. **1**A and **1**B. In this case, cables **40** and **41** shown in FIGS. **2** and **3** could be replaced by rigid members such that light source **30** would be suspended within the enclosure in the same manner as the fluorescent tube that it replaces.

However, more effective heat transfer can be provided by mounting light source **30** such that surface **47** is in thermal contact with the back wall of the existing fluorescent tube enclosure. Refer now to FIG. **4**, which is a cross-sectional view of another embodiment of a light source according to the present invention mounted against the back wall of enclosure **21** shown in FIGS. **1**A and **1**B. Light source **50** utilizes a heat-dissipating structure **52** that is part of heat-dissipating structure **59** and has a sufficient contact area with heat-dissipating structure **59** to assure that the thermal resistance

between heat-dissipating structure **52** and heat-dissipating structure **59** is much less than the thermal resistance between the LEDs **51** and heat-dissipating structure **52**. Heat-dissipating structure **59** has a surface **58** that is in thermal contact with wall **25** of enclosure **21** when light source **50** is mounted in enclosure **21**. The electrical contacts used to power the LEDs are on separate traces on the surface of heat-dissipating structure **52**. These traces cover a portion of the surface of heat-dissipating structure **52**; however, the fraction of the surface so covered is small compared to the area of heat-dissipating structure **52** that is exposed to the air.

Light source **50** can be attached to surface **25** by a variety of methods. As noted above, one important goal of the present invention is to provide a replacement light source that can be installed by the same person who would normally replace a defective fluorescent tube in the same enclosure. For example, light source **50** could be bolted to surface **25**. However, attachment methods that require that the new light source be bolted to enclosure **21** are not preferred, since such schemes can require that new holes be drilled in enclosure **21**.

Light source **50** could also be supplied with a heat-conducting adhesive that is applied prior to making the attachment of light source **50** to surface **25**. The adhesive is applied over a significant area, and hence, the thermal resistance of the adhesive is less of an issue. To simplify the attachment, light source **50** could be supplied with the adhesive already applied to surface **58** and protected by a peal-off strip. While this method can be practiced by low-skilled personnel, the method presents problems if the light source must be removed at a future date due to failure or the desire to further upgrade the light source. In addition, the coefficient of thermal expansion of the material from which heat-dissipating structure **59** is constructed will, in general, be different from that of the material from which enclosure **21** is constructed; hence, the thermal cycling of the light source can weaken the attachment bond over time leading to a bond failure or loss of thermal conductivity when gaps form between surfaces **25** and **58**.

In one aspect of the present invention, the attachment mechanism makes use of the observation that existing enclosures are often constructed from steel. Hence, if heat-dissipating structure **59** is constructed from a material that is magnetized, such as iron, light source **50** can be attached magnetically to surface **25**. In another aspect of the invention, a heat-conducting grease is applied to surface **59** to assure good thermal contact between the two surfaces. This grease also facilitates the movement of light source **50** on surface **25** during the positioning of light source **50** on the surface. Since the surface area of enclosure **21** is much greater than the area available on the heat-dissipating surface of the replacement light source, considerably higher power dissipation levels can be accommodated. As a result, a replacement light source that is significantly brighter than the fluorescent tube being replaced can be provided.

In one aspect of the present invention, the replacement LED light source has a plurality of LEDs mounted on a heat-dissipating substrate that has a width that is less than or equal to the diameter of the fluorescent tube that the light source is designed to replace. The substrates are metal clad printed circuit boards in which the metal cladding provides the heat-radiating surface. The LEDs are mounted in a spaced apart arrangement such that the heat generated on any 1 square inch section of the substrate is less than a predetermined design power value that depends on the manner in which the substrate dissipates the heat to the surrounding environment. The goal of the LED placement is to provide sufficient heat dissipation to limit the temperature of the LEDs to less than 75° C. above ambient.

Refer again to FIG. **2**. For example, if the substrate has a heat-radiating surface that dissipates the heat to the surrounding air such as the surface of heat-dissipating structure **36**, the present invention limits the LED density such that the heat generated on each square inch of heat-dissipating surface is less than 2 watts and preferably less than 1 watt; while accommodating LEDs that dissipate at least 0.5 watts of heat per second. It should be noted that the relative sizes of heat-dissipating structure **36** and traces **33** and **34** are not shown to scale. In practice, the width of heat-dissipating structure **36** is substantially equal to the width of the light source. Hence, if LEDs having a power dissipation of 1.5 watts each are mounted at one inch spacing on heat-dissipating structure **36** and heat-dissipating structure **36** is 1.5 inches wide, each LED will be surrounded by an area of 1.5 square inches of heat-dissipating surface. This maintains the power density at a level of 1 watt per square inch.

If the heat-dissipating surface is increased by utilizing the surface **47** shown in FIG. **3** in addition to the surface of heat-dissipating structure **36** then the density of LEDs can be increased further. For example, if light source **30** were mounted such that air circulated on both sides of light source **30**, this additional surface area could be utilized to dissipate heat thereby doubling the power density on the substrate.

Finally, if the arrangement shown in FIG. **4** is utilized, then the effective heat-dissipating surface is still greater. The effective size depends on the thermal resistance between surfaces **25** and **58**. In this regard, it should be noted that enclosure **21** is often painted. The paint layer limits the thermal conductance of the interface between surfaces **25** and **58**.

The above-described embodiments of the present invention have utilized a design requirement that the temperature rise of the LEDs is held to less than 75° C. over ambient. However, embodiments in which the design criterion is greater or less than this amount could also be utilized. For example, the replacement light sources could be constructed such that the maximum increase in temperature over ambient is 20° C., 30° C., 40° C., 50° C., 60° C., or 70° C.

Typically, the LED dies are of order 1 to 2 mm and dissipate between 1 and 2 watts. In one aspect of the present invention, the dies are mounted directly on the heat-dissipating structure, as opposed to mounting packaged LED dies on the heat-dissipating structure. In one aspect of the present invention, the dies are separated by one to two inches on the light source and the width of the heat-radiating surface is chosen such that the area surrounding each die has sufficient surface area radiating heat to the environment to assure that the temperature of the die remains less than 75° C. above ambient when the die is powered. Even with the phosphor layer over the dies, the light source appears to be discrete point emitters from the point of view of an observer in the area illuminated by the final light source. Fluorescent tubes, in contrast, are broad linear sources. Hence, in some applications, additional optics may be necessary to give the appearance of a fluorescent tube-like light source. Since the individual LEDs are of order 2 or 3 mm, a cylindrical lens that is located one or two inches above the LEDs can transform the collection of point sources into a linear source that is collimated or that diverges at a predetermined angle. Such an arrangement is shown in FIG. **5**, which is a cross-sectional view of another embodiment of a light source according to the present invention. In light source **60** a cylindrical lens **61** is mounted above the LEDs. It should be noted that most fluorescent tube enclosures have a depth of a few inches, since the enclosures must accommodate fluorescent tubes that are typically 1.5 inches in diameter. Hence, the LEDs appear as point sources at the lens.

Alternatively, the diffuser **26** shown in FIG. **1**B could be replaced by a diffuser having a cylindrical lens stamped on the diffuser. This arrangement, however, requires the user to change the diffuser, and forecloses the user from changing a single fluorescent tube and leaving the remaining tubes in place until they fail.

The above-described embodiments of the present invention utilize a power adapter system that connects to the existing fluorescent tube connectors in the light fixture and powers the LEDs on the light source. Consider a lighting fixture that has 4 fluorescent tubes powered from a common ballast. This light fixture could be converted to LED-based lighting by replacing all of the fluorescent tubes at once and changing the ballast to one that accepts AC and outputs DC of the desired voltage and current to run the LEDs. However, as noted above, this operation requires a skilled tradesman. Alternatively, the fluorescent tubes could be replaced as they fail. Each time a fluorescent tube fails, the individual who is normally responsible for replacing dead tubes would replace the dead tube with a light source according to the present invention. When all of the fluorescent tubes have finally been replaced, the existing ballast could, in principle, also be replaced to provide higher overall power conversion efficiency.

In one aspect of the present invention, the power adapters shown at **37** and **38** in FIG. **2** convert the output of the fluorescent tube ballast to DC having the desired voltage and current needed to drive the LED light source. The remaining fluorescent tubes in the enclosure still receive the same power as before; hence, these fluorescent tubes do not need to be replaced until they fail. The form of the power adapter depends to some degree on the type of ballast that is employed in the light fixture at the start of the conversion process. However, in general, there is a startup phase in which the ballast applies signals needed to initiate the discharge in the tube and a maintenance phase in which the voltage pattern across the fluorescent tube is maintained at level that allows the discharge to continue. In one aspect of the present invention, the power adapters present loads to the fluorescent tube ballast at startup that mimic the current flows associated with the fluorescent tube having started while protecting the LEDs from any high voltages used in the startup phase. Once, the ballast switches to the maintenance voltage, the power adapters convert the AC voltage associated with this phase of operation to DC at the voltage and current required by the LED light source.

The AC output of conventional ballasts is either at the AC line frequency or an AC signal at frequencies in excess of 20 KHz, and preferably greater than 42 KHz. Older ballast designs utilize the line frequency. More modern "digital" ballasts utilize the high frequency output. Converting the high frequency output to DC with the desired characteristics, in general, requires small components and is more economical. However, either output voltage can be accommodated.

There are two general types of pin arrangements in fluorescent tubes. One type has one pin at each end and is run by applying the AC output of the ballast across those pins. To start the fluorescent tube, a higher voltage is initially applied across the tube until the discharge starts or some predetermined time has elapsed. Refer now to FIG. **6**, which illustrates one embodiment of a power adapter according to the present invention. Power adapter **70** is designed to adapt the output of a cold start ballast of the type used to power two-pin fluorescent tubes. A limiter **71** limits the starting voltage to prevent damage to AC/DC converter **72** and presents a load to the ballast that mimics the current drawn when the corresponding fluorescent tube starts. AC/DC converter **72** converts the AC generated by the ballast to a DC voltage that can be used by regulator **73** to generate a constant current power supply to power the LEDs.

The second type of pin arrangement consists of two pins at each end of the tube. Tubes of this type have some form of startup mode in which a current between the pins on the ends of the tube heats the gas or otherwise facilitates the initial gas breakdown prior to applying the discharge maintenance potential across one pin on each end of the tube. In this arrangement, the power adapter must mimic a tube that is starting up in terms of the power drain and loads across the pins at each end. Once the ballast perceives that the fluorescent tube has started, the two pins on each end of the fluorescent tube are driven with the same AC voltage to maintain the discharge. In this mode, the power adapter needs to rectify the supplied power in a manner to that analogous to that discussed above. Refer now to FIG. **7**, which illustrates another embodiment of a power adapter according to the present invention. Power adapter **80** operates with a 4-pin ballast that supplies separate power to the fluorescent tube's starter circuitry. The two pins **81** from one fluorescent tube connector power a starter emulator **84** that presents a load that mimics the starter circuit in the fluorescent tube for which the ballast was designed. Similarly, the two pins **82** from the other fluorescent tube connector power a second starter emulator **85**. Once the ballast supplies the fluorescent tube driving voltage on one pin from the set of pins shown at **81** and one pin from the set of pins shown at **82**, AC/DC converter **86** rectifies this AC signal and provides the DC power to regulator **73**.

As noted above, once all of the tubes in a light fixture have been replaced with LED-based alternatives, it may be advantageous to replace the old ballast with an AC/DC converter that is more power efficient than the combination of the old ballast and the power adapters in the LED-based light sources. If the old ballast is merely replaced, the input to the LED-based light sources will switch to a DC voltage that is typically much less than the amplitude of the AC voltages supplied by the ballast. In the case of a 4-wire output ballast, both pins in set **81** will be connected together, and both pins in set **82** will also be connected together. In one aspect of the present invention, the AC/DC converters used in power adapters **70** and **80** include a sensor that determines if the input to those converters is AC or DC. If the input is DC, the converter merely connects the DC lines to the power regulator. It should be noted the startup circuit emulators will, in general, not be activated by the lower DC voltages supplied by the new ballast.

In the embodiments discussed above with reference to FIG. **4**, one of the heat-dissipating surfaces was a magnet that provided an attachment mechanism and a heat path to a surface of the enclosure in which the light source is mounted. It should be noted that it is sufficient for structure **59** shown in FIG. **4** to be ferromagnetic to provide the benefits discussed above. Refer now to FIG. **8**, which is a cross-sectional view of another embodiment of a light source according to the present invention. Light source **90** includes a heat-dissipating structure **91** that is in thermal communication with the LEDs. Structure **91** includes a ferromagnetic material such as iron or nickel. A separate magnet **92** is interposed between surface **95** and structure **91**. Hence, structure **91** does not need to be a magnet; it is sufficient for structure **91** to have sufficient ferromagnetic material to assure that structure **91** binds to magnet **92** with sufficient force to hold light source **90** in place.

In the above-described embodiments, the light sources utilize individual LEDs that are distributed on the surface of the heat-dissipating structure. However, small clusters of LEDs could also be utilized provided the local heat generated is less than the power that would cause the area to increase in temperature to an unacceptable level.

The above-described embodiments of the present invention have been provided to illustrate various aspects of the invention. However, it is to be understood that different aspects of the present invention that are shown in different specific embodiments can be combined to provide other embodiments of the present invention. In addition, various modifications to the present invention will become apparent from the foregoing description and accompanying drawings.

Accordingly, the present invention is to be limited solely by the scope of the following claims.

What is claimed is:

1. A light source comprising:

a substrate having a first metallic surface, said first metallic surface characterized by a normal that points in a normal direction, said first metallic surface being in contact with air over said first metallic surface, said air being characterized by an air temperature; and

a plurality of component LED light generators mounted directly on said first metallic surface, each component LED light generator comprising an LED characterized by an operating temperature, said LEDs generating light that leaves said light source in said normal direction, wherein said component LED light generators are spaced apart on said first metallic surface such that heat dissipated in said normal direction to air adjacent to said metallic surface is sufficient to maintain said operating temperature at less than 75° C. above said air temperature.

2. The light source of claim **1** wherein said component LED light generators are spaced such that the heat generated on any square inch of said metallic surface is less than 2 watts.

3. The light source of claim **1** wherein said component LED light generators are spaced such that the heat generated on any square inch of said metallic surface is less than 1 watt.

4. The light source of claim **1** wherein said light source further comprises a second metallic surface in thermal communication with said first metallic surface and positioned to dissipate additional heat from said first metallic surface.

5. The light source of claim **4** wherein said second metallic surface comprises a ferromagnetic material.

6. The light source of claim **5** wherein said ferromagnetic material is magnetized.

7. The light source of claim **1** wherein said first metallic surface is planar.

8. A light source comprising:

a plurality of LEDs mounted on a heat-dissipating structure;

first and second plug adapters that mate with a fluorescent tube connector; and

a power adapter that converts power from a fluorescent tube ballast presented on said first and second plug adapters to DC power that powers said LEDs wherein said fluorescent tube ballast provides power in a first mode that starts a conventional fluorescent tube of a predetermined type and switches to provide power in a second mode that powers said conventional tube in a maintenance phase of operation, and wherein said power adapter presents a load to said ballast in said first mode, said load mimicking a load that would be provided by said fluorescent tube when said fluorescent tube commences operation.

9. The light source of claim **8** wherein said heat-dissipating structure comprises a substrate having a first metallic surface, said first metallic surface characterized by a normal that points in a normal direction, said first metallic surface being in contact with air over said first metallic surface, said air being characterized by an air temperature; each LED being characterized by an operating temperature, said LEDs generating light that leaves said light source in said normal direction, wherein said LEDs are spaced apart on said first metallic surface such that heat dissipated in said normal direction to air adjacent to said metallic surface is sufficient to maintain said operating temperature at less than 75° C. above said air temperature.

10. The light source of claim **9** wherein said heat-dissipating structure further comprises a second metallic surface in thermal communication with said first metallic surface and positioned to dissipate additional heat from said first metallic surface.

11. The light source of claim **8** wherein said LEDs are arranged in a linear array on said heat-dissipating substrate and wherein said light source further comprises a cylindrical lens for processing light from said LEDs.

12. A light source comprising:

a plurality of LEDs mounted on a heat-dissipating structure;

first and second plug adapters that mate with a fluorescent tube connector;

a power adapter that converts power from a fluorescent tube ballast presented on said first and second plug adapters to DC power that powers said LEDs; and

an attachment mechanism that bonds a surface of said heat-dissipating structure to a metallic wall of an enclosure in which said light source is to operate, said attachment mechanism transferring heat from said LEDs to said enclosure.

13. The light source of claim **12** wherein said attachment mechanism comprises a magnet that holds said heat-dissipating structure against said metallic wall.

14. A light source comprising:

a substrate having a first metallic surface, said first metallic surface characterized by a normal that points in a normal direction, said first metallic surface being in contact with air over said first metallic surface, said air being characterized by an air temperature; and

a plurality of component LED light generators mounted directly on said first metallic surface, each component LED light generator comprising an LED characterized by an operating temperature, said LEDs generating light that leaves said light source in said normal direction, wherein said component LED light generators are spaced apart on said first metallic surface such that heat dissipated in said normal direction to air adjacent to said metallic surface is sufficient to maintain said operating temperature such that the electrical conversion efficiency of the LED is not reduced.

15. The light source of claim **14** wherein said component LED light generators are spaced such that the heat generated on any square inch of said metallic surface is less than 2 watts.

16. The light source of claim **14** wherein said component LED light generators are spaced such that the heat generated on any square inch of said metallic surface is less than 1 watt.

17. The light source of claim **14** wherein said light source further comprises a second metallic surface in thermal communication with said first metallic surface and positioned to dissipate additional heat from said first metallic surface.

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