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(54) **MICRO-LED BASED HIGH VOLTAGE AC/DC INDICATOR LAMP**

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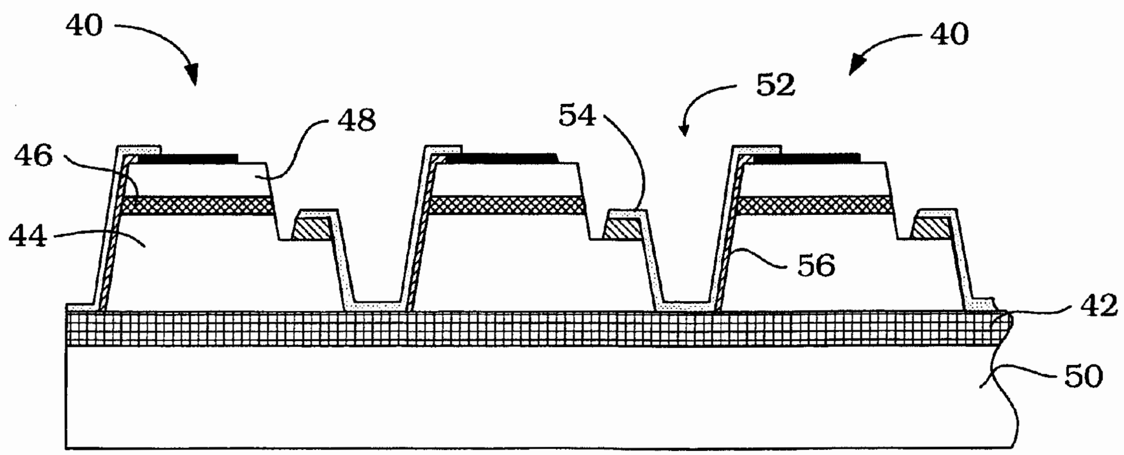
(57) **ABSTRACT**

An AC/DC indicator lamp based on an array of micro-LEDs may be powered by a standard high voltage AC or DC power source. The indicator lamp has a low power consumption. The micro-LEDs are serially connected on a substrate with the total device area and power consumption compatible with a standard DC low voltage LED. A plurality of indicator lamps may be connected together in parallel to present a string of indicator lamps.



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Samsung Electronics Co., Ltd. v. Sinotechnix, LLC.
Samsung's Exhibit 1008
EX1008, Page 1

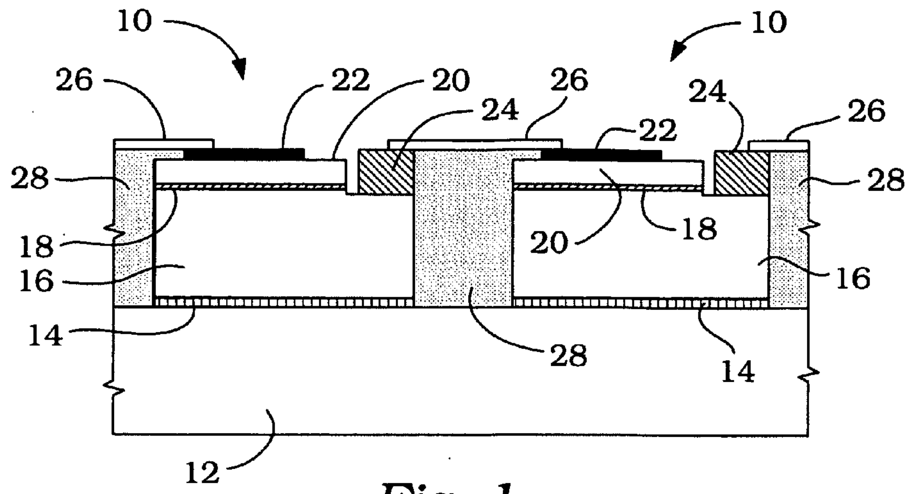

Fig. 1

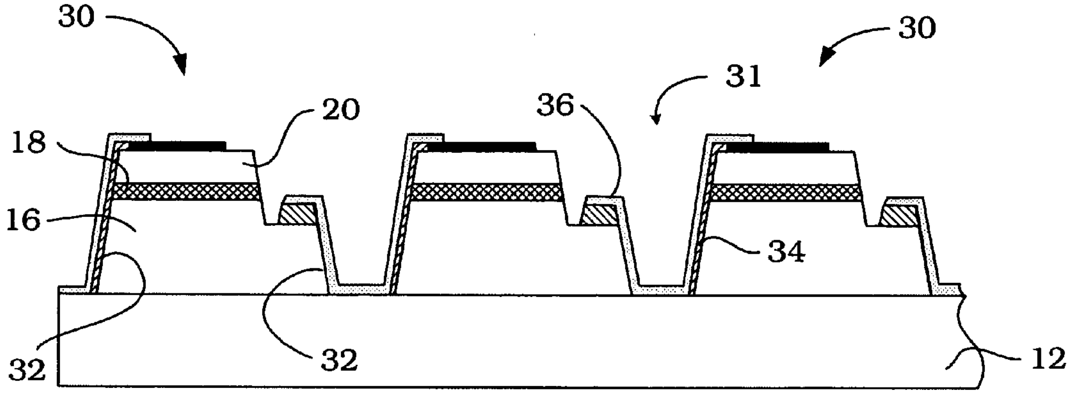

Fig. 2

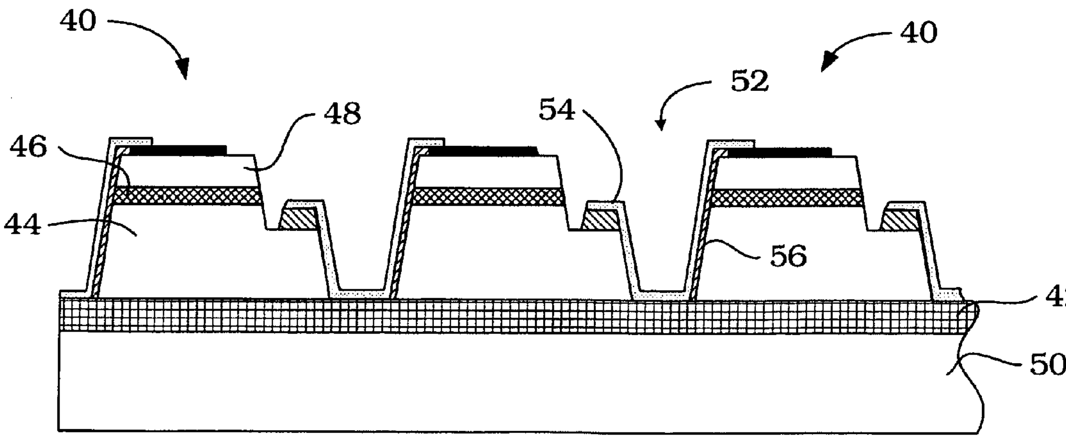

Fig. 3

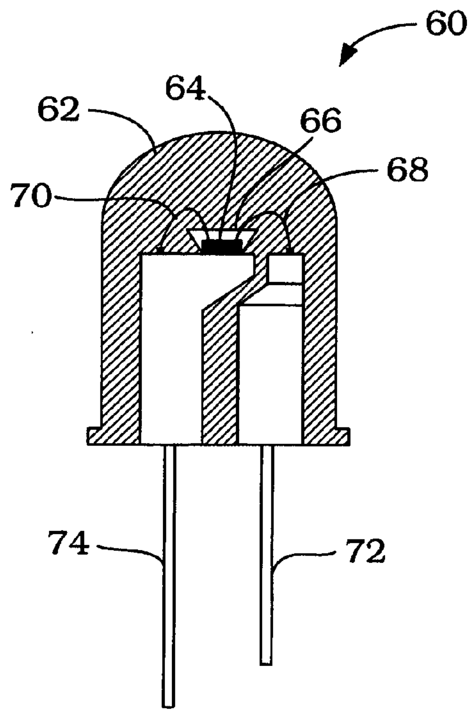

Fig. 4

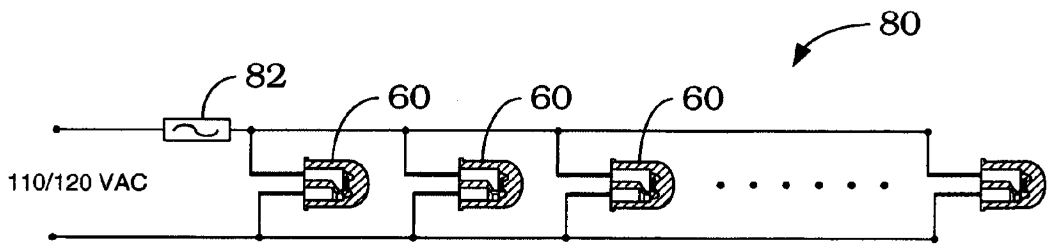

Fig. 5

MICRO-LED BASED HIGH VOLTAGE AC/DC INDICATOR LAMP

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefit of provisional application Ser. No. 60/649827, filed Feb. 3, 2005, which is hereby incorporated into the present application by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to a light emitting diode (LED), and more particularly, to an indicator lamp, which includes serially interconnected micro-size LEDs (Micro-LEDs) integrated on a single chip. The resulting indicator lamp may be directly powered by an AC voltage (i.e., 110/120V or 220/240V power grid) or a high DC voltage without a power transformer.

BACKGROUND OF THE INVENTION

[0003] Tiny LED indicator lamps have been widely used in electronics, toys, decorations and displays. These standard or conventional LEDs based on AlInGaN or AlInGaP have a typical chip area (or die size) of approximately 0.3 mm by 0.3 mm. These LED lamps typically operate with a DC current of 20 milliamps and a corresponding DC voltage between 2 volts and 4 volts, depending on the LED semiconductor materials. The standard indicator lamp with a T1 or T1-¾ package may have a maximum input power of about 0.1 watt.

[0004] Although the intrinsic low voltage and DC current nature of the standard LED lamp makes it very convenient to be incorporated in electronics design, it may also be an inconvenience in other applications. For example, in order to use these standard indicator lamps for Christmas tree decorations, the LED-based light strings must employ parallel wiring of individual LEDs, a bulky step-down transformer and rectifier conversion scheme. LED light strings may also employ serial wiring of individual LED lamps with the number of LED lamps dependant on the AC supply voltage. In the serially connected string, the number of LED lamps cannot easily be changed, and further, if one lamp fails and leads to an open circuit, the entire string will not work.

[0005] A standard-size LED array may be integrated on the same substrate with a total device size from around 1 mm by 1 mm to 2 mm by 2 mm or even larger for 120 VAC supply. The device runs under a current of approximately 20 mA or higher to achieve a high brightness for applications such as household lighting purpose. Such an AC-LED needs special packaging and heat dissipation scheme because of the relatively large chip size and high thermal production, which is not compatible with packaging requirements of low power indicator lamps. These power AC-LEDs are not suitable to replace the standard tiny LED indicator lamps.

[0006] In U.S. Pat. No. 6,410,940, a micro-size LED (micro-LED) array is disclosed, which is arranged in matrix format to be individually addressed for applications such as a micro-size display, or the array may be arranged in a parallel format to enhance the light output compared with the standard broad area LED. Basically, these micro-LED arrays still work under a low DC voltage (several volts) with a typical current level of tens of mA.

[0007] An individual micro-LED has a typical size of hundreds times smaller than the standard LED, and its area is even smaller than the contacts area of the standard LED, therefore, the device geometry layout design and fabrication process are considerably different from each other. The micro-LED array for high voltage AC/DC application is also different from that of the standard-size LED array. A need remains for a micro-size light emitting diode array, which may be powered by standard high voltage AC/DC power and may be used to replace the conventional low DC voltage indicator lamps.

SUMMARY OF THE INVENTION

[0008] The present invention provides a micro-LED array which is serially interconnected with two outlet leads for connection with a high voltage AC/DC power supply. The array has a comparable total chip size and power consumption to those of the conventional LED indicator lamps, so that the micro-LED array may be directly packaged in a housing used for a standard LED indicator lamp. The result is a high voltage AC/DC indicator lamp with the same or similar outside physical features as the standard LED indicator lamp. Depending on the detailed design, the supplied power to the high voltage AC/DC indictor lamp may be 12 volts, 24 volts, 36 volts, 48 volts, and other DC voltages, or it may be an AC voltage such as 110/120 volts or 220/240 volts.

[0009] A conventional LED indicator lamp may be replaced with an array of micro-LEDs connected in a serial mode, that is the p-contact (anode) of one micro-LED is connected with the n-contact (cathode) of its neighboring micro-LED, the result is that the applied voltage to the array equals to the sum of the voltage drop on each micro-LED. If each micro-LED works under 3 volts, for example, then for a 120V power supply, the array will have 40 serially connected micro-LEDs. Since the diode has current flow and light emission only when the voltage drop between its anode and cathode is positive, for an AC power supply, the above array will only have light emission in the positive half cycle of the AC power. A second array may be used, which is connected in parallel with the first array, but this second array is arranged to have a reversed current flow direction, so that in each half cycle, there is one array emitting light. In this scheme, a conventional LED with a size 0.3 mm by 0.3 mm may be replaced by an array consisting of 80 micro-LEDs with a size of less than 25 μm by 25 μm, considering that extra space is required for isolation and interconnection.

[0010] The micro-LED array may be integrated on the same substrate, and the isolation between each micro-LED is accomplished through trench etching to remove the conductive materials down to the insulating substrate, or to an insulating layer sandwiched between the micro-LED structure and the conductive or insulting substrate. This insulating layer may be epitaxially grown on the substrate and its composition and thickness should be selected so that the subsequent micro-LED material structure is thin enough (less than 2.5 μm, for example), to ensure that the isolation trench etching and the metalization interconnection between the neighboring micro-LEDs may be easily accomplished. Another approach based on surface planarization with spin-on polymers or deposited insulators is also presented.

[0011] The integrated micro-LED array with a size comparable to the standard DC LED indicators, may have a similar package as the standard indictor lamp, and have similar power consumption. Since the input voltage is much higher, the indictor lamp in this invention runs under a current much smaller than the standard indicator lamp. For a 120 VAC design, the indicator lamp may be directly run with the standard household power. Many indicator lamps may be connected in parallel to construct an LED string with high reliability.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] **FIG. 1** is an enlarged cross sectional view of a micro-LED based AC/DC indicator lamp with polymer planarization.

[0013] **FIG. 2** is an enlarged sectional view of a micro-LED AC/DC indicator lamp with sloped side walls.

[0014] **FIG. 3** is an enlarged cross sectional view of a micro-LED based AC/DC indicator lamp on a conductive substrate with an insulation epitaxial layer and a thin LED structure.

[0015] **FIG. 4** is an enlarged cross sectional view of a packaging of a micro-LED based AC/DC indicator lamp.

[0016] **FIG. 5** is an illustration of a parallel micro-LED based AC lamp string.

DETAILED DESCRIPTION

[0017] Referring to **FIG. 1**, an embodiment of a micro-LED of the present invention based on AlInGaN semiconductor materials is generally indicated by reference numeral **10**. Micro-LED **10** may be grown on an insulating sapphire substrate **12** and include a buffer layer **14**, n-type semiconductor layer **16**, an activation region layer **18** and a p-type semiconductor layer **20**. For 120 VAC applications, each micro-LED **10** may have dimensions of approximately 25 μm by 25 μm or similar size, formed by plasma etching down to the insulating substrate **12**. A p-contact (anode) **22** and an n-contact (cathode) **24** are formed on the p-type layer **20** and n-type layer **16** separately. A current spreading layer used for the standard broad area LED is generally not required for the micro-LED **10** of the present invention because of the very small size of micro-LED, although its incorporation is also an option.

[0018] The anode and cathode are formed by depositing different metals and then thermally annealing in a different temperature and ambient environment. For example, the anode is formed by a Ni and Au metal stack annealed in an oxygen-containing environment, while the cathode is formed by a Ti and Al metal stack annealed in a nitrogen environment. To reduce the number of manufacture steps, a tunneling junction consisting of heavily doped n^+ semiconductor and p^+ semiconductor layers on the p-type semiconductor layer **20** may also be used. In this case, both the anode and cathode are formed in the same process step by the same Ti and Al metal stack on the n^+ and n semiconductors respectively.

[0019] An interconnection **26** between the neighboring micro-LEDs **10** may be accomplished in different ways. Preferably, the interconnection **26** is accomplished by a surface planarization, followed by metallization. A visible-light transparent, but deep ultraviolet (DUV) photon definable polymer **28** may be applied on the uneven surface of the micro-LEDs **10** by spin-coating. Then with DUV photolithography, part of the polymer **28** is removed to achieve a quasi-flat surface with the p-type **22** and n-type **24** contacts exposed, followed with thermal curing to form hard polymide. With surface planarization, the metal deposition for interconnection **26** may be easily accomplished. The polymer **28** also has the function to passivate the surface and etched side-walls of the micro-LEDs **10** to diminish the non-emission recombination rate and improve the device reliability. By selection of a polymer **28** with a high refractive index, light extraction from the device **10** may be enhanced. A substitute material which may be used for the polymer is an insulating dielectric material such as different oxides or nitrides materials. For example, thick silicon oxides or silicon nitrides may be deposited into the deep trench between micro-LEDs, so the trench can be filled up to achieve a quasi-flat surface.

[0020] Referring to **FIG. 2**, a micro-LED which does not incorporate the surface planarization step described hereinabove, is generally indicated by reference numeral **30**. The isolation of the micro-LEDs **30** is accomplished by etching a trench **31** to the insulating substrate **12** with an quasi-isotropic plasma etch so that the sidewalls **32** have a slope with an angle, generally between 40° and 80°. With the sloped sidewalls, a thin layer of insulating dielectric materials **34** may be deposited followed with the interconnection metal wire **36**. The insulating material **34**, which maybe silicon oxide, silicon nitride, or other insulators, isolates the metal wire **36** from the semiconductor sidewalls **32**, and passivates the dangling bonds on the sidewalls The sloped sidewalls **32** reduce the effective area of the micro-LED **30**. However, with the sloped sidewall profile, the insulating material **34** and the interconnecting metal wire **36** can be conformably deposited with a uniform thickness on the flat surface and on the sidewall; further, the sloped sidewalls **32** enhance the light extraction from the micro-LEDs **30**. Because semiconductors typically have a large index of refraction, most of the generated light is trapped in the semiconductors forming a guided wave, which cannot escape. With the sloped profile, the guided light waves have more opportunity to escape from the sidewalls **32** at the areas without metal wire **36**. Note on the sidewalls, only a small potion is covered with the interconnection metal wire **36**. The result is the micro-LED array **30** has more light efficiency.

[0021] Referring to **FIG. 3**, another embodiment of the micro-LED of the present invention based on AlInGaN semiconductor materials is generally indicated by reference numeral **40**. Micro-LED **40** may be grown on different substrates **42** such as silicon carbide (SiC), silicon (Si), gallium nitride (GaN), aluminum nitride (AlN), gallium arsenide (GaAs), indium phosphide (InP) and sapphire (Al_2O_3), for example. Without the typical low temperature buffer layer, the semiconductor growth starts from high temperature grown AlN with high resistivity. Other semiconductors such as AlGaN and AlInGaN may also be used. This insulating layer gradually transits to the n-type GaN semiconductor layer **44** by changing AlGaN or AlInGaN alloy composition. Next the activation layer **46** is grown followed by the p-type semiconductor layer **48**. A tunneling junction consisting of heavily doped n^+ semiconductor and p^+ semiconductor layers on the p-type semiconductor layer **48** may also be included, so the anode and cathode can be formed in one step.

[0022] Without sacrificing the final device performance, the micro-LED structure layers **44**, **46** and **48** (not include the insulating layer) are very thin, for example, less than 2.5 μm, instead of the typical thickness of more than 5 μm. The benefits of this thin structure plus the resistive layer **42** are that conductive or semi-conductive substrates **50**, such as SiC, Si, GaN, GaAs and InP, for example, may also be used for the high voltage AC/DC indicator lamp **40**. Furthermore, an isolation trench **52** may be only etched to the deposited insulating layer **42** with an quasi-isotropic etch, so the trench depth is shallow and with an inclination slope, and a conformal interconnection metallization wire **54** and a dielectric isolation layer **56** applied to the sidewalls may be easily formed without additional complex processing steps. The isolation layer **56** may consist of silicon oxide, silicon nitride, other oxide, nitride, or polymide, for example.

[0023] Referring to **FIG. 4**, a device packaging **60** may include standard 3 mm, 5 mm, 10 mm, or other diameter lens sizes, known as T1, T1-¾, and T3-¼ package respectively. These are the packages which have been used for the standard LED indictor lamps. The device packaging **60** includes the epoxy lens or dome **62**, a micro-LED array **64**, a reflector cup **66**, wire bonds **68** and **70**, and two metal leads **72** and **74**. The thermal dissipation of these packages **60** is through the two thin metal leads **72** and **74**, leading to a high thermal resistance and limited thermal dissipation ability. Such a package has a maximum input power of around 0.1 W, or a maximum current of less than around 1 mA for a 120 VAC indictor lamp. Considering that the standard 0.3 mm×0.3 mm LED indicator lamp running under a current 20 mA with a current density of 22 A/cm^2, each micro-LED with an area of 25 μm×25 μm should run under a current density of 44A/cm^2, or a current 0.3 mA. Even considering there are two micro-LED arrays **64** connected in parallel and conducting in opposite directions, the total input power of the 120 VAC indicator lamp is still less than the maximum limitation, ensuring its reliability without over heating.

[0024] The indicator lamp **60** emits a light wavelength depending on the bandgap energy of the semiconductor at the device active region. For example, if InGaN is used at the active region, by changing indium composition in the InGaN alloy to change the bandgap energy, it can emit a light covering ultra-violet (UV), blue and green wavelength range. To achieve white light, phosphors may be used for color conversion. For example, Yttrium Aluminate yellow phosphor can absorb blue light and emit yellow light. After wire bonding, a phosphors slurry can be filled in the cup **66**, followed with encapsulation **62**. If micro-LED array **64** emits blue light and yellow phosphor is incorporated, the combination of the transmitted blue light from micro-LED array and the yellow light from the phosphor will produce white color.

[0025] Surface mounted packages may also be used for housing the micro-LED array. Furthermore, with a larger housing chamber, several micro-LED arrays with red, green, and blue colors fabricated from different semiconductors can be packaged in the same housing. With the red, green, and blue color mixing, a high voltage AC/DC white emitter is achieved.

[0026] The AC indicator lamp **60** may be easily used for indication and signaling purposes with a direct connection to the 110V/120V power supply. As an example, almost every machine or instrument powered by electricity incorporates a conventional LED beside (or inside) the power switch to indicate if the power is on. This standard indicator LED has to be driven by a low DC voltage. If the AC indicator **60** is substituted for the conventional LED, it will be directly driven by the 110V/120V power without extra circuit. As another example for Christmas tree decorations, a parallel AC-LED lamp string may be constructed generally indicated by reference numeral **80**, as illustrated in **FIG. 4**. Since each lamp **60** runs with a current of approximately 1 mA, there is almost no limitation on the number of lamps connected in the string **80**, and the string may be directly plugged into the house-hold AC power supply without any transformer or rectifier. For safety reasons, a fuse **82** may be serially connected with the lamp string **80** for over-current protection in case some lamps are destroyed and form a short circuit. In that case, the shorted lamp may be removed, and the fuse **82** replaced with a new fuse. If a bad lamp or a loose connection causes an open circuit, the parallel lamp string **80** will still work without any replacement. To avoid the damage caused by the power surge in the power grid, a varistor (not shown) may be connected between the terminals of the power supply. If a power surge occurs, the varistor is trigged and the surge current will by-passed by the varistor to protect the indicator lamps **60**.

[0027] Although an InGaAlN semiconductor emitter is used as examples in the invention description, it should be understood that a AC/DC light emitting device based on other semiconductor materials such as GaAs, InP, may be constructed. Depending on the bandgap energy of the semiconductor, the micro-LEDs may emit red, blue, green, yellow or white light, for example. White light may be created by color mixing red, blue and green light or by wavelength conversion with phosphor.

[0028] It should be understood that while a certain form of this invention has been illustrated and described, it is not limited thereto except insofar as such limitations are included in the following claims.

Having thus described the invention, what is claimed as new and desired to be secured by Letters Patent is:

1. A high voltage AD/DC indicator lamp comprising:

an array of series connected micro-LEDs having a direction of current flow and presenting positive and negative terminals, each of said micro-LEDs having an active region between a p-type semiconductor and a n-type semiconductor,

said array of series connected micro-LEDs grown on a substrate,

said terminals adapted to be connected across a power source to energize said array of series connected micro-LEDs.

2. The high voltage AD/DC indicator lamp as set forth in claim 1 wherein said power source includes a power source selected from the group consisting of **12** volts DC, 24 volts DC, 36 volts DC, 48 volts DC, 110 volts AC, 120 volts AC, 220 volts AC and 240 volts AC.

3. The high voltage AC/DC indicator lamp as set forth in claim 1 further comprising a tunneling junction consisting of heavily doped n$^+$ semiconductor and p$^+$ semiconductor layers on said p-type semiconductor layer.

4. The high voltage AC/DC indicator lamp as set forth in claim 1 wherein said micro-LEDs are isolated from each other by etched trenches, and wherein said trenches are filled with polymer, oxides, nitrides or other insulation materials to achieve a generally flat top surface.

5. The high voltage AC/DC indicator lamp as set forth in claim 1 wherein said micro-LEDs include etched trenches and sidewalls, said sidewalls coated with an insulation material.

6. The high voltage AC/DC indicator lamp as set forth in claim 5 wherein said insulation material includes an insulation material selected from the group consisting of silicon oxide, silicon nitride, oxides, nitrides and polymides.

7. The high voltage AC/DC indicator lamp as set forth in claim 5 wherein said sidewalls have a slope to enhance light extraction and conformal deposition of insulation material and interconnection metal wire.

8. The high voltage AC/DC indicator lamp as set forth in claim 1 further comprising a second array of series connected micro-LEDs grown on said substrate and connected in series or parallel to said array of series connected micro-LEDs.

9. The high voltage AC/DC indicator lamp as set forth in claim 1 wherein said substrate is an insulating substrate and includes a substrate material selected from the group consisting of sapphire, aluminum nitride, silicon carbide, silicon, gallium nitride, gallium arsenide and indium phosphide.

10. The high voltage AC/DC indicator lamp as set forth in claim 1 wherein said substrate is a conducting or semiconducting substrate and includes a substrate material selected from the group consisting of silicon carbide, silicon, gallium nitride, gallium arsenide and indium phosphide.

11. The high voltage AC/DC indicator lamp as set forth in claim 1 further comprising an insulating layer between said substrate and said n-type semiconductor.

12. The high voltage AC/DC indicator lamp as set forth in claim 11 wherein said insulating layer selected from the group consisting of aluminum nitride, aluminum gallium nitride, and aluminum indium gallium nitride.

13. The high voltage AC/DC indicator lamp as set forth in claim 11 further comprising a buffer layer between said insulating layer and said substrate.

14. The high voltage AC/DC indicator lamp as set forth in claim 13 wherein said buffer layer has a thickness between 0 and 10 μm.

15. The high voltage AC/DC indicator lamp as set forth in claim 1 further comprising a buffer layer between said substrate and said n-type semiconductor.

16. The high voltage AC/DC indicator lamp as set forth in claim 13 wherein said buffer layer has a thickness between 0 and 10 μm.

17. The high voltage AC/DC indicator lamp as set forth in claim 1 wherein said micro-LEDs are based on semiconductors selected from the group consisting of AlInGaN, AlInGaP and AlGaAs.

18. The high voltage AC/DC indicator lamp as set forth in claim 1 further comprising a package for housing said array.

19. The high voltage AC/DC indicator lamp as set forth in claim 18 wherein said package includes a package selected from the group consisting of T1, T1-¾ and T3-¼.

20. The high voltage AC/DC indicator lamp as set forth in claim 19 further comprising a plurality of said indicator lamps connected in parallel.

21. The high voltage AC/DC indicator lamp as set forth in claim 20 wherein said indicator lamps emit the same or different colors.

22. The high voltage AC/DC indicator lamp as set forth in claim 18 wherein said package is a surface mount package.

23. The high voltage AC/DC indicator lamp as set forth in claim 1 wherein said array of micro-LEDs emit white light by wavelength conversion with phosphor.

24. The high voltage AC/DC indicator lamp as set forth in claim 1 wherein said array of micro-LEDs emit white light by mixing red, blue and green light.

25. The high voltage AC/DC indicator lamp as set forth in claim 1 wherein said array of micro-LEDs has a die size of less than approximately 1 millimeter by 1 millimeter.

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