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Dated: March 5, 2015

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Operations Manager, Legal Translations
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Sworn to and signed before me, this 5th day of March 2015

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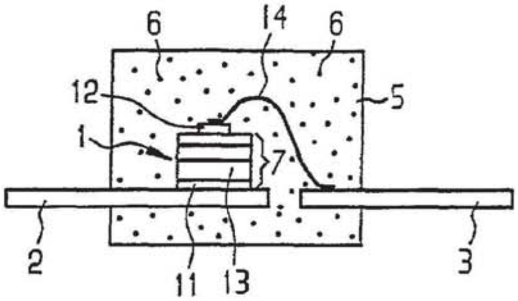
(54) Light-emitting semiconductor element with a luminescence-converting element

(57) A blended color light-emitting semiconductor element with radiation emitting semiconductor body (1) and a luminescence-converting element (4, 5). The semiconductor body (1) emits radiation having a wavelength $\lambda \leq 520$ nm and the luminescence-converting element (4, 5) converts a part of this radiation into radiation having a higher wavelength. This makes it possible to produce light emitting diodes that emit multicolored light, in particular white light. The luminescence-converting element (4, 5) contains a luminescent organic substance



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Description

The invention concerns a semiconductor element that emits a mixture of colors, in particular, white light.

There is an increasing demand in many potential areas of application for light emitting diodes with which it is possible to produce multicolored light, particularly white light, such as, for example, in display elements, vehicle dashboards, illumination in airplanes and cars and in full color LED displays. So far it has only been possible to produce white "LED" light with so-called multi LEDs, in which three light emitting diodes emitting different colors (in general a red, a green and a blue one) or two complementary-colored light emitting diodes (e.g., a blue and a yellow one) are used. Aside from increased assembly costs, such multi-LEDs require expensive control electronics, since the different types of diodes require different driving voltages. Long-term stability regarding the wavelength and intensity is additionally impacted by the different aging behavior of the different light emitting diodes and also because of the different driving voltages and the operating currents resulting therefrom. An additional disadvantage of the Multi-LEDs is that component miniaturization is strongly limited.

It is the task of the present invention to develop a semiconductor element of the aforesaid kind, by means of which, in a technically simple manner and with as little use of components as possible, multicolored light, in particular white light, can be produced.

This task is accomplished by means of a semiconductor element according to Claim 1. Additional advantageous embodiments are the objects of the dependent claims 2 to 30. The dependent Claims 31 to 34 disclose possible preferred applications of the semiconductor element of this invention.

According to this invention, a radiation-emitting semiconductor body is provided with at least a first and at least a second electrical contact, which is electrically connected to the semiconductor body, to which a luminescence-converting element is attached. The semiconductor has a layer sequence which emits electromagnetic radiation at wavelengths $\lambda \leq 520$ nm. It particularly has a layer sequence with an active layer of $Ga_xIn_{1-x}N$ or $Ga_xAl_{1-x}N$. The luminescence-converting element transforms radiation in a first wavelength range of the radiation out of a first wavelength range emitted by the semiconductor body into a second wavelength range such that the semiconductor component emits in at least a second spectral subrange of the first wavelength range and radiation in the second wavelength range. The luminescence-converting element is, for this purpose, provided with an inorganic luminescent compound, in particular a phosphor. This means, for example, that the luminescence-converting element selectively spectrally absorbs a part of the radiation emitted by the semiconductor body and emits it in a longer wavelength range (in the second wavelength range). The radiation emitted by the semiconductor body ideally has a wavelength $\lambda \leq 520$ nm at an intensity maximum.

In an advantageous additional configuration of the semiconductor element according to this invention, the luminescence-converting element consists at least in part of a transparent epoxy resin to which the organic luminescent material is added. It is in fact advantageously possible to incorporate inorganic luminescent substances, in particular phosphors, such as YAG: Ce ($Y_3Al_5O_{12}$:Ce^{+3}) in the epoxy resin in a simple manner. Other suitable luminescent substances are other garnets doped with rare earths, such as $Y_3Ga_5O_{12}$:Ce^{+3}, as well as alkali earth sulfides doped with rare earths, such as SrS:Ce^{+3}, Na, SrS:Ce^{+3}, Cl, SrS:$CeCl_3$, CaS:Ce^{+3} and SrSe:Ce^{+3}.

Thiogsallates doped with with rare earths, such as $CaGa_2S_4$:Ce^{+3} and $SrGa_2S_4$:Ce^{+3} as well as aluminates doped with rare earths, such as $YAlO_3$:Ce^{+3}, $YGaO_3$:Ce^{+3}, and orthosilicates doped with rare earths, such as M_2SiO_5:Ce^{+3} (M: Sc, Y, Sc), such as Y_2SiO_5:Ce^{+3}, are capable of producing light of blended colors. The yttrium in all of the yttrium compounds can in principle be replaced by scandium or lanthanum.

It is likewise advantageously possible, in the case of the semiconductor component according to this invention, to convert a number (one or more) of first spectral ranges deriving from the first spectral range into several second wavelength ranges. It is thus advantageously possible to produce various color mixtures and color temperatures.

The semiconductor element of this invention has the particular advantage that the wavelength spectrum produced by wavelength conversion and thus the resulting color of the emitted light does not depend on the magnitude of the operating current passing through the semiconductor body. This is of particularly great importance if the ambient temperature of the semiconductor element, and thus, as is well-known, the operating current, varies considerably. Light emitting diodes with a semiconductor body based on GaN are particularly sensitive in this regard.

Contrary to the multi-LEDs mentioned above, the semiconductor element of this invention additionally needs only one driving voltage and thus only one control circuit, whereby the component cost can be kept very low.

A particularly preferred embodiment of the invention makes use of a partially transparent, i.e., partially transparent to the radiation emitted by the radiation-emitting semiconductor body, luminescence-converting element. To ensure a uniform color of the emitted light, the luminescence-converting layer can advantageously be designed so that it has a constant thickness throughout. According to this additional improvement, it is a particular advantage of the semiconductor element according to this invention that a high reproducibility can be achieved in a simple manner, which is of great significance for mass production. A lacquer or synthetic resin layer can, for instance, be used as a luminescence-converting layer.

Another preferred embodiment of the semiconductor element of this invention has a partially transparent luminescence-converting casing as a luminescence-converting element, which casing encloses at least a part of the semiconductor body (and possibly portions of the electrical connectors) and can be used as a component casing (housing) at the same time. The advantage of a semiconductor element according to this embodiment is essentially that it is possible to use production lines that are conventionally used for producing conventional light emitting diodes (e.g., radial light emitting diodes) to produce it. The material of the luminescence conversion casing is used as the component casing in place of the transparent plastic used for conventional light emitting diodes.

In advantageous implementations of the semiconductor element of this invention and of aforementioned preferred embodiments, the luminescence-converting layer or the luminescence-converting casing consists of a transparent material (e.g., a polymer such as an epoxy resin) to which at least one luminescent dye is added (examples of suitable polymers are provided below). Luminescence-converting elements can be produced particularly economically in this way. The process steps needed for this can in fact be integrated into conventional production lines for light emitting diodes without much expense.

In a particularly preferred other implementation of this invention and/or of the aforesaid embodiments, the second wavelength range(s) are at least partly at a longer wavelength than the first wavelength range.

It is in particular ensured that a second spectral subrange of the first wavelength range and the second wavelength range are complementary to each other. This particularly makes it possible to produce multicolored light, in particular white light, by means of a single-color light source, particularly by way of a light emitting diode with a light-emitting semiconductor that only emits blue or green light. For example, to produce white light with a light emitting semiconductor body that only emits blue light, a portion of the spectral range emitted by the semiconductor body is converted into the yellow spectral range. In the process, the color temperature of the white light can be varied by way of a suitable selection of the luminescent substance and a suitable design of the luminescence-converting element (e.g., concerning its thickness and the concentration of the luminescent substance). In addition, these structures advantageously also offer the possibility of using luminescent dye mixtures whereby the desired color tone can be readily adjusted in a very precise manner.

It is also possible to produce luminescence-converting elements in an inhomogeneous way, e.g., with an inhomogeneous luminescent dye distribution. In the process, different wavelengths of the light produced by the luminescence-converting element can be compensated for in an advantageous manner.

In a further preferred embodiment of the luminescence-converting semiconductor of this invention, the luminescence-converting element or another component casing contains one or more dyes that do not perform any wavelength conversion. Dyes used for the production of conventional light emitting diodes, e.g., azo, anthraquinone or perinone dyes can be used for this purpose as usual.

In an advantageous further improvement of the semiconductor element according to this invention, at least a part of the surface of the semiconductor body is covered with a first transparent coating, e.g., made of a polymer, to which the luminescence-converting layer is applied. This reduces the radiation intensity in the luminescence-converting element and thus its radiation exposure, which has a positive effect on the life span of the luminescence-converting element depending on the materials used.

A particularly preferred further improvement of the invention as well as the aforementioned embodiments make use of a semiconductor body, e.g., a light emitting or a laser diode, in which the spectrum of the emitted radiation has a luminescence maximum at a wavelength between 420 nm and 460 nm, in particular at 430 nm (e.g., semiconductor bodies based on $Ga_xAl_{1-x}N$) or 450 nm. (e.g., semiconductor bodies based on $Ga_xIn_{1-x}N$). By using such a semiconductor element according to this invention it is possible to produce nearly all colors and color combinations of the CIE color palette.

In another particularly preferred implementation of the invention and its embodiments, the luminescence -converting casing and/or the luminescence-converting layer consists of a lacquer or a polymer, such as silicone, thermoplastic or thermosetting material (epoxy and acrylate resins) used as the casing of optoelectronic elements. It is furthermore possible to use covering elements, e.g., made of thermoplastic, as a luminescence-converting layer. All aforementioned materials can be added to one or more luminescing materials in a simple manner.

A semiconductor element according to this invention can be realized in a particularly simple manner if the semiconductor body is placed in a recess of a possibly prefabricated housing according to a preferred implementation and if the recess is equipped with a covering element with a luminescence-converting layer. Such a semiconductor element can be mass produced in large numbers in conventional production lines. To accomplish this, it is simply necessary for the covering element, e.g., a layer of lacquer or casting resin or a prefabricated covering made of a thermoplastic, to be mounted on the housing after the semiconductor body is installed. The recess in the housing can optionally be filled with a transparent material, for example, a transparent polymer, which, e.g., does not alter the wavelength of the light emitted by the semiconductor body or else can, if desired, be designed to be luminescence converting. In the latter case, the covering element can also be omitted.

Advantageous materials for producing the aforesaid luminescence-converting layer and/or the luminescence-converting casing are, for example, polymethylmethacrylate (PMMA) or an epoxy resin to which one or more luminescing materials are added.

In a particularly advantageous embodiment of the semiconductor element according to this invention, at least all of the components of the casing through which light passes, i.e., the luminescence converting casing or layer as well, are made of purely inorganic materials. The luminescence converting element thus consists of an inorganic luminescent material, which is embedded in an inorganic material that is temperature-stable, transparent or partially transparent. The luminescence converting element particularly consists of an inorganic phosphor which is embedded in a preferably inorganic glass that melts at a low temperature (e.g., a silicate glass). A preferred method for producing such a luminescence converting layer is the sol-gel method, by means of which the entire luminescence converting layer, i.e., both the inorganic luminescent material and the material in which it is embedded, can be produced in one production step.

To improve the mixing of the radiation of the first wavelength range emitted by the semiconductor body with the radiation of the second wavelength range obtained by luminescence conversion and thus the color constancy of the emitted light, it is possible, in an advantageous development of the semiconductor element according to the invention, to also add to the luminescence casing and/or the luminescence conversion layer a dye that luminesces in the blue, which weakens the so-called directionality of the radiation emitted by the semiconductor body. Directionality is understood to signify that the radiation emitted by the semiconductor body has a preferred beam direction.

In a further advantageous development of the semiconductor component according to this invention, an inorganic luminescent material in the form of a powder is used, which does not dissolve in the enveloping material (matrix). The inorganic luminescent material and the material in which it is enveloped also have different indexes of refraction. This advantageously causes a fraction of the light that is not absorbed by the luminescent material, depending on the grain size, to be scattered. This efficiently weakens the directionality of the radiation emitted by the semiconductor body so that unabsorbed radiation and the radiation deriving from luminescence conversion can be homogeneously blended, which leads to a spatially homogeneous color impression. This is, for example, the case when YAG:Ce having a grain size of 4 – 13 μm is embedded in epoxy resin.

A semiconductor element that emits white light can, for example, be made by mixing the inorganic luminescent material $Y_2Al_5O_{12}:Ce^{+3}$ into an epoxy resin used to produce the luminescence converting casing or layer. A portion of the blue radiation emitted by the semiconductor body is shifted to the yellow wavelength range by the inorganic luminescent material $Y_2Al_5O_{12}:Ce^{+3}$ and thus into a complimentary wavelength region. The color tone (chromaticity coordinate in the CIE Color Pallet) of the white light can then be varied through an appropriate choice of dye mixture and concentration.

The inorganic phosphor YAG:Ce has the particular advantage among others that this concerns insoluble pigments (a particle size of e.g., 10 μm) with an index of refraction of approx. 1.84. As a result a scattering effect takes place in addition to wave length conversion, which leads to a good blending of the blue diode emission and the yellow converter emission.

In a further preferred implementation of a semiconductor element of this invention and/or of the aforesaid advantageous embodiments, light scattering particles, so-called diffusers, are added to the luminescence converting element or some other light transmitting component of the component casing. This allows the color impression and the directional characteristics of the semiconductor element to be optimized in an advantageous way.

It is of particular advantage for the excitation efficiency of white light emitting semiconductor elements of this invention and/or of the aforesaid embodiments to be increased considerably, as compared with the excitation efficiency of a light bulb, by way of a blue light emitting semiconductor body essentially based on GaN. The reason for this is that, on the one hand, the external quantum yield of such semiconductor bodies is a few percent and, on the other hand, the luminescence yield of inorganic dye molecules is often about 90%. The semiconductor element of this invention furthermore has an extremely long lifespan in comparison with a light bulb, it is more robust and it operates at a lower voltage.

It is furthermore advantageous that the brightness of the semiconductor element of this invention that is perceptible to the human eye as compared with a semiconductor element that is not fitted with a luminescence converting element, but is otherwise identical, can be increased considerably because the eye's sensitivity increases at longer wavelengths. It is furthermore possible to convert ultraviolet light to visible light.

The concept of luminescence conversion with the blue light of a semiconductor body presented here can also be advantageously extended to multiple-stage luminescence conversion elements according to the scheme ultraviolet → blue → green → yellow → red. In this case a number of spectrally selectively emitting luminescence conversion elements are disposed one behind the other relative to the semiconductor body.

It is also advantageously possible to jointly embed several inorganic luminescent materials that emit in a spectrally selective manner in a transparent polymer of a luminescence-converting element. This makes it possible to produce a very wide color spectrum.

The semiconductor elements of this invention can be employed particularly advantageously in, e.g., full color LED displays or for purposes of illumination in airplanes, motor vehicles, etc.

A particular advantage of the white light emitting semiconductor elements of this invention based on Ce-doped phosphors, particularly Ce-doped garnets, such as YAG:CE, as luminescing materials is that, upon excitation with blue light, these luminescing materials effectuate a spectral shift of about 100 nm between absorption and emission. This leads to a considerable reduction in the reabsorption of the light emitted by the luminescent material and thus to a higher light yield. Such inorganic luminescing materials additionally, advantageously and generally have a higher thermal and photochemical (e.g., UV) stability (considerably higher than organic luminescent materials), so that it is possible to produce white light emitting diodes for exterior applications and/or higher temperature ranges.

Semiconductor elements of this invention can most advantageously be used for purposes of illuminating motor vehicle interiors and airplane cabins as well as for displays, such as such as motor vehicle dashboards or liquid crystal displays, particularly because of their low power consumption in full color LED displays.

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