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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY. DOCKET NO	TOT CLAIMS	IND CLAIMS
61/427,411	12/27/2010		110	ITMX-00318US0		

CONFIRMATION NO. 2477

23910
FLIESLER MEYER LLP
650 CALIFORNIA STREET
14TH FLOOR
SAN FRANCISCO, CA 94108

FILING RECEIPT



OC000000045551966

Date Mailed: 01/24/2011

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If Required, Foreign Filing License Granted: 01/19/2011

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 61/427,411**

Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No

**** SMALL ENTITY ****

Title

SOLID-STATE LIGHT EMITTING DEVICES WITH REMOTE PHOSPHOR WAVELENGTH
CONVERSION COMPONENT

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SOLID-STATE LIGHT EMITTING DEVICES WITH REMOTE PHOSPHOR WAVELENGTH CONVERSION COMPONENT

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BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] This invention relates to solid-state light emitting devices that use a remotely positioned phosphor wavelength conversion component to generate a desired color of light. More particularly, though not exclusively, the invention concerns solid-state devices based on LEDs (light emitting diodes) and in particular wavelength conversion components having improved emission color uniformity with emission angle.

[0003] 2. Description of the Related Art

[0004] White light emitting LEDs (“white LEDs”) are known and are a relatively recent innovation. It was not until LEDs emitting in the blue/ultraviolet part of the electromagnetic spectrum were developed that it became practical to develop white light sources based on LEDs. As taught, for example in US 5,998,925, white LEDs include one or more phosphor materials, that is photo luminescent materials, which absorb a portion of the radiation emitted by the LED and re-emit light of a different color (wavelength). Typically, the LED chip or die generates blue light and the phosphor(s) absorbs a percentage of the blue light and re-emits yellow light or a combination of green and red light, green and yellow light, green and orange or yellow and red light. The portion of the blue light generated by the LED that is not absorbed by the phosphor material combined with the light emitted by the phosphor provides light which appears to the eye as being nearly white in color.

[0005] Due to their long operating life expectancy (>50,000 hours) and high luminous efficacy (70 lumens per watt and higher) high brightness white LEDs are increasingly being used to replace conventional fluorescent, compact fluorescent and incandescent light sources.

[0006] Typically the phosphor material is mixed with a silicone or epoxy material and the mixture applied to the light emitting surface of the LED die. It is also known to provide the phosphor material as a layer on, or incorporate the phosphor material within, an optical component, a phosphor wavelength conversion component, that is located remotely to the LED

die. A problem with such devices can be the variation in color of emitted light with emission angle.

SUMMARY OF THE INVENTION

[0007] Embodiments of the invention concern light emitting devices comprising one or more solid-state light sources, typically LEDs, that are operable to generate blue light and a remote wavelength conversion component, containing one or more blue light excitable phosphor materials, that is operable to convert at least a portion of the blue light to light of a different wavelength. The emission product of the device comprises the combined light generated by the source and the wavelength conversion component and is typically configured to appear white in color. The wavelength conversion component comprises a light transmissive substrate such as a polymer or glass having a wavelength conversion layer comprising particles of the blue light excitable phosphor material and a light diffusing layer comprising particles of a light diffractive material such as titanium dioxide. In accordance with the invention the wavelength conversion and light diffusing layers are in direct contact with each other and are preferably deposited by screen printing or slot die coating. In this patent specification “direct contact” means that there are no intervening layers or air gaps. One benefit of the invention is that by selecting an appropriate particle size and concentration per unit area of the light diffractive material, it is possible to make a device having an emission product color that is virtually uniform with emission angle over a $\pm 60^\circ$ range from the emission axis. Moreover the use of a light diffusing layer can substantially reduce the quantity of phosphor material required to generate a selected color of emitted light. It is believed that the light diffusing layer increases the probability that a photon will result in the generation of photoluminescence light by directing light back into the wavelength conversion layer. Preliminary tests indicate that inclusion of a diffusing layer in direct contact with the wavelength conversion layer can reduce, by up to 40%, the quantity of phosphor material required to generate a given color emission product.

[0008] In one embodiment the particle size of the light diffractive material is selected such that blue light generated by the source is scattered more than light generated by the one or more phosphor materials.

[0009] According to the invention a wavelength conversion component for a light emitting device comprising at least one blue light emitting solid-state light source, comprises a light

transmissive substrate having a wavelength conversion layer comprising particles of at least one blue light excitable phosphor material and a light diffusing layer comprising particles of a light diffractive material; and wherein the layers are in direct contact with each other.

[0010] Preferably the wavelength conversion layer comprises a mixture of the at least one phosphor material and a light transmissive binder while the light diffusing layer comprises a mixture of the light diffractive material and a light transmissive binder. To minimize optical losses at the interface of the layers it is preferred that the layers comprise the same transmissive binder. The binder can comprise a curable liquid polymer such as a polymer resin, a monomer resin, an acrylic, an epoxy, a silicone or a fluorinated polymer. The binder is preferably UV or thermally curable.

[0011] To reduce the variation in emitted light color with emission angle the weight loading of light diffractive material to binder is in a range 7% to 35% and more preferably in a range 10% to 20%.

[0012] The wavelength conversion and light diffusing layers are preferably deposited by screen printing though they can be deposited using other deposition techniques such as spin coating or doctor blading.

[0013] The light diffractive material preferably comprises titanium dioxide (TiO_2) though it can comprise other materials such as barium sulfate (BaSO_4), magnesium oxide (MgO), silicon dioxide (SiO_2) or aluminum oxide (Al_2O_3).

[0014] In one arrangement the light diffractive material has an average particle size in a range $1\mu\text{m}$ to $50\mu\text{m}$ and more preferably in a range $10\mu\text{m}$ to $20\mu\text{m}$.

[0015] In other arrangements the light diffractive material has a particle size that is selected such that the particles will scatter blue light relatively more than they will scatter light generated by the at least one phosphor material. Typically the light diffractive particle size is selected such that the particles will scatter blue light relatively at least twice as much as they will scatter light generated by the at least one phosphor material. Such a light diffusing layer ensures that a higher proportion of the blue light emitted from the wavelength conversion layer will be scattered and directed by the light diffractive material back into the wavelength conversion layer increasing the probability of the photon interacting with a phosphor material particle and resulting in the generation of photoluminescent light. At the same time phosphor generated light can pass through the diffusing layer with a lower probability of being scattered. Since the diffusing layer

increases the probability of blue photons interacting with a phosphor material particle, less phosphor material can be used to generate a selected emission color. Initial tests further indicate that such an arrangement can also increase luminous efficacy of the wavelength conversion component/device. Preferably the light diffractive material has an average particle size of less than about 150nm.

[0016] The light transmissive substrate can comprise any material that is substantially transmissive to visible light (380nm to 740nm) and typically comprises a polymer material such as a polycarbonate or an acrylic. Alternatively the substrate can comprise a glass.

[0017] The concept of a wavelength conversion component having a light diffusing layer composed of light diffractive particles that preferentially scatter light corresponding to wavelengths generated by the LEDs compared with light of wavelengths generated by the phosphor material is considered inventive in its own right. According to a further aspect of the invention a wavelength conversion component for a light emitting device comprising at least one blue light emitting solid-state light source, comprises a wavelength layer comprising particles of at least one blue light excitable phosphor material and a light diffusing layer comprising particles of a light diffractive material; wherein the light diffractive particle size is selected such that the particles will scatter blue light relatively more than they will scatter light generated by the at least one phosphor material. Preferably the light diffractive material has an average particle size less than 150nm.

[0018] According to another aspect of the invention a light emitting device comprises: at least one solid-state light source operable to generate blue light and a wavelength conversion component located remotely to the at least one source and operable to convert at least a portion of the blue light to light of a different wavelength, wherein the emission product of the device comprises the combined light generated by the at least one source and the wavelength conversion component; wherein the wavelength conversion component comprises a light transmissive substrate having a wavelength conversion layer comprising particles of at least one blue light excitable phosphor material and a light diffusing layer comprising particles of a light diffractive material; and wherein the layers are in direct contact with each other. Preferably the wavelength conversion layer comprises a mixture of the at least one phosphor material and a light transmissive binder whilst the light diffusing layer comprises a mixture of the light diffractive material and a light transmissive binder. To minimize optical losses between the layers, the

layers preferably comprise the same transmissive binder. The binder can comprise a curable liquid polymer such as a polymer resin, a monomer resin, an acrylic, an epoxy, a silicone or a fluorinated polymer. The binder is preferably UV or thermally curable.

[0019] To reduce the variation in emitted light color with emission angle, the weight loading of light diffractive material to binder is in a range 7% to 35% and more preferably in a range 10% to 20%.

[0020] The wavelength conversion and light diffusing layers are preferably deposited by screen printing though they can be deposited using other deposition techniques such as spin coating, slot die coating, roller coating, drawdown coating or doctor blading.

[0021] The light diffractive material preferably comprises titanium dioxide though it can comprise other materials such as barium sulfate, magnesium oxide, silicon dioxide or aluminum oxide.

[0022] In one arrangement the light diffractive particle size is selected such that the particles will scatter blue light relatively more than they will scatter light generated by the at least one phosphor material. Preferably the light diffractive material has an average particle size of less than about 150nm.

[0023] The light transmissive substrate can comprise any material that is substantially transmissive to visible light (380nm to 740nm) and typically comprises a polymer material such as a polycarbonate or an acrylic. Alternatively the substrate can comprise a glass.

[0024] To reduce the transfer of heat from the light source to the wavelength conversion component and thereby damaging the phosphor material, the wavelength conversion component is separated from the at least one source by a distance of at least 1cm.

[0025] To increase the CRI (Color Rendering Index) of light generated by the device the device can further comprise at least one solid-state light source operable to generate red light.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] In order that the present invention is better understood LED-based light emitting devices and phosphor wavelength conversion components in accordance with the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

[0027] FIG. 1 shows schematic partial cutaway plan and sectional views of a solid-state light

emitting device in accordance with an embodiment of the invention;

[0028] FIG. 2 is a schematic of a phosphor wavelength conversion component in accordance with an embodiment of the invention;

[0029] FIG. 3 is a schematic of a phosphor wavelength conversion component in accordance with another embodiment of the invention;

[0030] FIG. 4 shows plots of emission color change versus emission angle for the device of FIG. 1 for phosphor wavelength conversion components containing 0%, 7%, 12%, 16%, 23% and 35% weight loadings of light diffractive material;

[0031] FIG. 5 is a plot of luminous efficacy (normalized) versus emission color change at an emission angle $\theta=60^\circ$ for the device of FIG. 1;

[0032] FIG. 6 shows plots of emission color change versus emission angle for a warm white ($\approx 3000\text{K}$) solid-state light emitting device in accordance with the invention for wavelength conversion components containing different 0%, 10%, 15% and 20% weight loadings of light diffractive material;

[0033] FIG. 7 is a plot of luminous efficacy (normalized) versus emission color change at an emission angle $\theta=60^\circ$ for the warm white light emitting device for wavelength conversion components containing different 0%, 10%, 15% and 20% weight loadings of light diffractive material;

[0034] FIG. 8 is a 1931 C.I.E. (Commission Internationale de l'Eclairage) chromaticity diagram showing emission color at emission angles $\theta=0^\circ, 15^\circ, 30^\circ, 45^\circ$ and 60° for the warm white light emitting device for wavelength conversion components containing 0%, 10%, 15% and 20% weight loadings of light diffractive material;

[0035] FIG. 9 shows schematic partial cutaway plan and sectional views of a high CRI solid-state light emitting device in accordance with another embodiment of the invention; and

[0036] FIG. 10 shows plots of relative light scattering versus light diffractive particle size (nm) for red, green and blue light.

DETAILED DESCRIPTION OF THE INVENTION

[0037] Throughout this patent specification like reference numerals are used to denote like parts.

[0038] A solid-state light emitting device **10** in accordance with an embodiment of the

invention will now be described with reference to FIG. 1 which shows schematic partial cutaway plan and sectional views of the device. The device **10** is configured to generate warm white light with a CCT (Correlated Color Temperature) of approximately 3000K and a luminous flux of approximately 1000 lumens.

[0039] The device **10** comprises a hollow cylindrical body **12** composed of a circular disc-shaped base **14**, a hollow cylindrical wall portion **16** and a detachable annular top **18**. To aid in the dissipation of heat the base **14** is preferably fabricated from aluminum, an alloy of aluminum or any material with a high thermal conductivity (preferably $\geq 200 \text{Wm}^{-1}\text{K}^{-1}$) such as for example copper, a magnesium alloy or a metal loaded plastics material. For low cost production the wall **16** and top **18** are preferably fabricated from a thermoplastics material such as HDPP (High Density Polypropylene), nylon or PMA (polymethyl acrylate). Alternatively they can be fabricated from a thermally conductive material such as aluminum or an aluminum alloy. As indicated in FIG. 1 the base **14** can be attached to the wall portion **16** by screws or bolts **20** or by other fasteners or by means of an adhesive. As further shown in FIG. 1 the top **18** can be detachably mounted to the wall portion **16** using a bayonet-type mount in which radially extending tabs **22** engage in a corresponding annular groove in the top **18**.

[0040] The device **10** further comprises a plurality (four in the example illustrated) of blue light emitting LEDs **24** (blue LEDs) that are mounted in thermal communication with a circular-shaped MCPCB (metal core printed circuit board) **26**. The blue LEDs **24** can comprise 4.8W CetusTM C1109 chip on ceramic devices from Intematix Corporation of Fremont, California in which each device comprises a ceramic packaged array of twelve 0.4W GaN-based (gallium nitride-based) blue LED chips that are configured as a rectangular array 3 rows by 4 columns. Each blue LED **24** is operable to generate blue light **28** having a peak wavelength λ_1 in a wavelength range 400nm to 480nm (typically 450nm to 470nm). As is known an MCPCB comprises a layered structure composed of a metal core base, typically aluminum, a thermally conductive/electrically insulating dielectric layer and a copper circuit layer for electrically connecting electrical components in a desired circuit configuration. The metal core base of the MCPCB **26** is mounted in thermal communication with the base **14** with the aid of a thermally conductive compound such as for example an adhesive containing a standard heat sink compound containing beryllium oxide or aluminum nitride. As shown in FIG. 1 the MCPCB can be attached to the base using screws or bolts **30**.

[0041] To maximize the emission of light, the device **10** can further comprise light reflective surfaces **32**, **34** that respectively cover the face of the MCPCB **26** and the inner curved surface of the top **18**. Typically the light reflective surfaces **32**, **34** can comprise a highly light reflective sheet material such as WhiteOptics™ “White 97” (A high-density polyethylene fiberbased composite film) from A.L.P. lighting Components, Inc of Niles, Illinois, USA. As indicated in FIG. **1** a circular disc **32** of the material can be used to cover the face of the MCPCB and a strip of the light reflective material configured as a cylindrical sleeve **34** that is inserted in the housing and is configured to cover the inner surface of the housing wall portion **16**.

[0042] The device **10** further comprises a phosphor wavelength conversion component **36** that is operable to absorb a proportion of the blue light **28** (λ_1) generated by the LEDs **24** and convert it to light **38** of a different wavelength (λ_2) by a process of photoluminescence **36**. The emission product **40** of the device **10** comprises the combined light of wavelengths λ_1 , λ_2 generated by the LEDs **24** and the phosphor wavelength conversion component **36**. The wavelength conversion component is positioned remotely to the LEDs **24** and is spatially separated from the LEDs a distance **d** that is typically at least 1cm. In this patent specification “remotely” and “remote” means in a spaced or separated relationship. The wavelength conversion component **36** is configured to completely cover the housing **12** opening such that all light emitted by the lamp passes through the component **36**. As shown the wavelength conversion component **36** can be detachably mounted to the top of the wall portion **16** using the top **18** enabling the component and emission color of the lamp to be readily changed.

[0043] In accordance with the invention and as shown in FIG. **2** the wavelength conversion component **36** comprises, in order, a light transmissive substrate **42**, a light diffusing layer **44** containing light diffractive particles and a wavelength conversion layer **46** containing one or more phosphor (photoluminescent) materials. As can be seen in FIG. **2** the wavelength conversion component **36** is configured such that in operation the wavelength conversion layer **46** faces the LEDs.

[0044] The light transmissive substrate **42** can be any material that is substantially transmissive to light in a wavelength range 380nm to 740nm and can comprise a light transmissive polymer such as a polycarbonate or acrylic or a glass such as a borosilicate glass. For the lamp **10** of FIG. **1** the substrate **42** comprises a planar circular disc of diameter $\phi = 62\text{mm}$ and thickness **t₁** which is typically 0.5mm to 3mm. In other embodiments the substrate can

comprise other geometries such as being convex or concave in form such as for example being dome shaped or cylindrical.

[0045] The diffusing layer **44** comprises a uniform thickness layer of particles of a light diffractive material, preferably titanium dioxide (TiO_2). In alternative arrangements the light diffractive material can comprise barium sulfate (BaSO_4), magnesium oxide (MgO), silicon dioxide (SiO_2), aluminum oxide (Al_2O_3) or a powdered material with as high a reflectivity as possible, typically a reflectance of 0.9 or higher. The light diffractive material powder is thoroughly mixed in known proportions with a light transmissive liquid binder material to form a suspension and the resulting mixture deposited onto the face of the substrate **42** preferably by screen printing to form a uniform layer of thickness t_2 (typically in a range $10\mu\text{m}$ to $75\mu\text{m}$) that covers the entire face of the substrate. The quantity of light diffracting material per unit area in the light diffusing layer **44** will typically in a range $10\mu\text{g.cm}^{-2}$ to 5mg.cm^{-2} .

[0046] Whilst screen printing is a preferred method for depositing the light diffractive diffusing layer **44**, it can be deposited using other techniques such as for example slot die coating, spin coating, roller coating, drawdown coating or doctor blading. The binder material can comprise a curable liquid polymer such as a polymer resin, a monomer resin, an acrylic, an epoxy (polyepoxide), a silicone or a fluorinated polymer. It is important that the binder material is, in its cured state, substantially transmissive to all wavelengths of light generated by the phosphor material(s) and the LEDs **24** and preferably has a transmittance of at least 0.9 over the visible spectrum (380nm to 800nm). The binder material is preferably U.V. curable though it can be thermally curable, solvent based or a combination thereof. U.V. or thermally curable binders can be preferable because, unlike solvent-based materials, they do not “outgas” during polymerization. In one arrangement the average particle size of the light diffractive material is in a range $5\mu\text{m}$ to $15\mu\text{m}$ though as will be described it can be in a nanometer range (nm) and is advantageously in a range 100nm to 150nm. The weight percent loading of light diffractive material to liquid binder is typically in a range 7% to 35%.

[0047] The wavelength conversion layer **46** is deposited in direct contact with the light diffusing layer **44** that is without any intervening layers or air gaps. The phosphor material, which is in powder form, is thoroughly mixed in known proportions with a liquid light transmissive binder material to form a suspension and the resulting phosphor composition, “phosphor ink”, deposited directly onto the diffusing layer **44**. The wavelength conversion layer

is preferably deposited by screen printing though other deposition techniques such as slot die coating, spin coating or doctor blading can be used. To eliminate an optical interface between the wavelength conversion and diffusing layers **46**, **44** and to maximize the transmission of light between layers, the same liquid binder material is preferably used to fabricate both layers; that is, a polymer resin, a monomer resin, an acrylic, an epoxy, a silicone or a fluorinated polymer.

[0048] The phosphor wavelength conversion layer **46** is preferably deposited by screen printing though other deposition techniques such as for example slot die coating, spin coating, roller coating, drawdown coating or doctor blading can be used. The binder material is preferably U.V. or thermally curable rather than being solvent-based. When a solvent evaporates the volume and viscosity of the composition will change and this can result in a higher concentration of phosphor material which will affect the emission product color of the device. With U.V. curable polymers, the viscosity and solids ratios are more stable during the deposition process with U.V. curing being used to polymerize and solidify the layer after deposition is completed. Moreover since in the case of screen printing of the phosphor ink multiple-pass printing may be required to achieve a required layer thickness, the use of a U.V. curable binder is preferred since each layer can be cured virtually immediately after printing prior to printing of the next layer.

[0049] The color of the emission product produced by the wavelength conversion component will depend on the phosphor material composition and the quantity of phosphor material per unit area in the wavelength conversion layer **46**. It will be appreciated that the quantity of phosphor material per unit area is dependent on the thickness t_3 of the wavelength conversion layer **46** and the weight loading of phosphor material to binder in the phosphor ink. In applications in which the emission product is white or in applications in which the emission product has a high saturation color (i.e. the emission product comprises substantially all photoluminescence generated light) the quantity of phosphor material per unit area in the wavelength conversion layer **46** will typically be between 10mg.cm^{-2} and 40mg.cm^{-2} . To enable printing of the wavelength conversion layer **46** in a minimum number of print passes the phosphor ink preferably has as high a solids loading of phosphor material to binder material as possible and preferably has a weight loading of phosphor material to binder in a range 40% to 75%. For weight loadings below about 40% it is found that five or more print passes may be necessary to achieve a required phosphor material per unit area. The phosphor material comprises particles with an average particle size of $10\mu\text{m}$ to $20\mu\text{m}$ and typically of order $15\mu\text{m}$.

[0050] In general lighting applications the emission product **40** will typically be white light and the phosphor material can comprise one or more blue light excitable phosphor materials that emit green (510nm to 550 nm), yellow-green (550nm to 570nm), yellow (570nm to 590nm), orange (590nm to 630nm) or red (630nm to 740nm) light. The thickness t_3 of the wavelength conversion layer, phosphor material composition and the density (weight loading) of phosphor material per unit area will determine the color of light emitted by the lamp.

[0051] The phosphor material can comprise an inorganic or organic phosphor such as for example silicate-based phosphor of a general composition $A_3Si(O,D)_5$ or $A_2Si(O,D)_4$ in which Si is silicon, O is oxygen, A comprises strontium (Sr), barium (Ba), magnesium (Mg) or calcium (Ca) and D comprises chlorine (Cl), fluorine (F), nitrogen (N) or sulfur (S). Examples of silicate-based phosphors are disclosed in United States patents US 7,575,697 B2 “*Silicate-based green phosphors*” (assigned to Intematix Corp.), US 7,601,276 B2 “*Two phase silicate-based yellow phosphors*” (assigned to Intematix Corp.), US 7,655,156 B2 “*Silicate-based orange phosphors*” (assigned to Intematix Corp.) and US 7,311,858 B2 “*Silicate-based yellow-green phosphors*” (assigned to Intematix Corp.). The phosphor can also comprise an aluminate-based material such as is taught in our co-pending patent application US2006/0158090 A1 “*Novel aluminate-based green phosphors*” and patent US 7,390,437 B2 “*Aluminate-based blue phosphors*” (assigned to Intematix Corp.), an aluminum-silicate phosphor as taught in co-pending application US2008/0111472 A1 “*Aluminum-silicate orange-red phosphor*” or a nitride-based red phosphor material such as is taught in our co-pending United States patent application US2009/0283721 A1 “*Nitride-based red phosphors*” and International patent application WO2010/074963 A1 “*Nitride-based red-emitting in RGB (red-green-blue) lighting systems*”. It will be appreciated that the phosphor material is not limited to the examples described and can comprise any phosphor material including nitride and/or sulfate phosphor materials, oxy-nitrides and oxy-sulfate phosphors or garnet materials (YAG).

[0052] A further example of a phosphor wavelength conversion component **36** in accordance with the invention is illustrated in FIG. 3. In common with the wavelength conversion component of FIG. 2 the component comprises a light transmissive substrate **42**, a light diffusing layer **44** and a wavelength conversion layer **46**. In accordance with the invention the light diffusing and wavelength conversion layers **44**, **46** are deposited in direct contact with one another. Again in operation the component is configured such that the wavelength conversion

component is configured such that the light diffusing layer **44** faces the LEDs **24**.

[0053] In operation blue light **28** generated by the LEDs **24** travels through the wavelength conversion layer **46** until it strikes a particle of phosphor material. It is believed that on average as little as 1 in 1000 interactions of a photon with a phosphor material particle results in absorption and generation of photo luminescence light **38**. The majority, about 99.9%, of interactions of photons with a phosphor particle result in scattering of the photon. Due to the isotropic nature of the scattering process on average half of the photons will be scattered in a direction back towards the LEDs. Tests indicate that typically about 10% of the total incident blue light **28** is scattered and emitted from the wavelength conversion component **36** in a direction back towards the LEDs. For a cool white light emitting device the amount of phosphor material is selected to allow approximately 10% of the total incident blue light to be emitted from the wavelength conversion component and contribute to the emission product **40**. The majority, approximately 80%, of the incident light is absorbed by the phosphor material and re-emitted as photo luminescence light **38**. Due to the isotropic nature of photo luminescence light generation, approximately half of the light **38** generated by the phosphor material will be emitted in a direction towards the LED. As a result only up to about 40% of the total incident light will be emitted as light **38** of wavelength λ_2 and contributes to the emission product **38** with the remaining (up to about 40%) of the total incident light being emitted as light **38** of wavelength λ_2 in a direction back towards the LED. Light emitted towards the LEDs from the wavelength conversion component **36** is re-directed by the light diffractive surfaces **32**, **34** to contribute to the emission product and to increase the overall efficiency of the device.

[0054] The inventors have discovered that the addition of a light diffusing layer **44** composed of particles of a light diffractive material can substantially reduce the quantity of phosphor material required to generate a selected color of emitted light. It is believed that the diffusing layer **44** increases the probability that a photon will result in the generation of photoluminescence light by reflecting light back into the wavelength conversion layer **46**. Preliminary tests indicate that inclusion of a diffusing layer in direct contact with the wavelength conversion layer can reduce, by up to 40%, the quantity of phosphor material required to generate a given color emission product.

[0055] Moreover the inventors have further discovered that as well as providing a substantial saving in phosphor material usage, the addition of a light diffusing layer **44** in direct contact with

the wavelength conversion layer **46** significantly increases the uniformity of color of emitted light with emission angle θ . The emission angle θ is measured with respect to an emission axis **48** (FIG. 1). FIG. 4 shows plots of measured CIE color change versus emission angle θ for the lamp of FIG. 1 for wavelength conversion components **36** comprising diffusing layer **44** with percentage (%) weight loadings of light diffractive material to binder material of 0%, 7%, 12%, 16%, 23% and 35%. All emission color measurements were measured at a distance of 10m from the lamp **10** for wavelength conversion components in which the light diffusing layer comprises light diffractive particles of TiO_2 with an average particle size $\approx 5\mu\text{m}$. For comparison the data for a 0% percentage loading of TiO_2 correspond to a wavelength conversion component that does not include a light diffusing layer.

[0056] The measured color change is derived from the relationship:

[0057]
$$\text{CIE change} = \sqrt{(\text{CIE } x_{\theta^\circ} - \text{CIE } x_{0^\circ})^2 + (\text{CIE } y_{\theta^\circ} - \text{CIE } y_{0^\circ})^2}$$

[0058] where $\text{CIE } x_{\theta^\circ}$ is the measured CIE chromaticity x value at an emission angle of θ° , $\text{CIE } x_{0^\circ}$ is the measured CIE chromaticity x value for an emission angle of $\theta=0^\circ$, $\text{CIE } y_{\theta^\circ}$ is the measured CIE chromaticity y value at an emission angle of θ° and $\text{CIE } y_{0^\circ}$ is the measured CIE chromaticity y value at an emission angle of $\theta=0^\circ$. It will be appreciated that the CIE change is normalized to the light color at an emission angle $\theta=0^\circ$ (i.e. the CIE change is always 0 for $\theta=0^\circ$).

[0059] As can be seen for FIG. 4 for a wavelength conversion component with no light diffusing layer (i.e. 0% TiO_2 loading) the color of light generated by such a lamp can alter by a CIE change of nearly 0.07 for emission angles up to $\theta=60^\circ$. In comparison for a wavelength conversion component **36** in accordance with the invention that includes a light diffusing layer **44** with a percentage weight loading of TiO_2 of only 7% the change in emission color over a 60° range drops to about 0.045. As can be seen from the Figure increasing the percentage weight loading of TiO_2 decreases the change in emission color over a 60° angular range. For example for a 35% TiO_2 percentage weight loading the CIE color change is less than 0.001. Although the change in emission color with emission angle decreases with increasing TiO_2 loading the total emission intensity will also decrease. FIG. 5 shows measured luminous efficacy versus CIE color change at an emission angle $\theta=60^\circ$ for wavelength conversion components **36** comprising diffusing layer **44** with percentage (%) weight loadings of TiO_2 to binder material of 0%, 7%, 12%, 16%, 23% and 35%. The luminous efficacy values are normalized relative to a lamp that does not include a light diffusing layer (i.e. 0% TiO_2 loading). The CIE color change @ $\theta=60^\circ$ is

determined from the relationship:

$$[0060] \quad \sqrt{(CIE\ x_{60^\circ} - CIE\ x_{0^\circ})^2 + (CIE\ y_{60^\circ} - CIE\ y_{0^\circ})^2}$$

[0061] where CIE x_{60° is the measured CIE chromaticity x value at an emission angle of 60° , CIE x_{0° is the measured CIE chromaticity x value for an emission angle of 0° , CIE y_{60° is the measured CIE chromaticity y value at an emission angle of 60° and CIE y_{0° is the measured CIE chromaticity y value at an emission angle of 0° . As can be seen from FIG. 5 there can be as much as a 25% decrease in luminous efficacy for a wavelength conversion component with a light diffusing layer containing a 35% weight loading of TiO_2 . It will be appreciated when selecting the weight loading of light diffractive material in light diffusing layer a balance needs to be struck between improving emission color uniformity with emission angle and the decrease in luminous efficacy of the lamp. Initial test results suggest that a wavelength conversion component in accordance with the invention preferably has a light diffusing layer with percentage weight loading of light diffractive material to binder material in a range 10% to 20%.

[0062] FIG. 6 shows plots of measured CIE color change versus emission angle θ for a 3000K white light emitting lamp 10 for conversion components 36 comprising diffusing layer 44 with percentage (%) weight loadings of TiO_2 to binder material of 0%, 10%, 15% and 20% whilst FIG. 7 shows corresponding measured luminous efficacy versus CIE color change at an emission angle $\theta=60^\circ$. FIG. 8 is a 1931 chromaticity diagram showing the color CIE x, CIE y) of emitted light at emission angles $\theta=0^\circ$, 15° , 30° , 45° and 60° for a 3000K white light emitting LED-based lamp in accordance with the invention for wavelength conversion components containing 0%, 10%, 15% and 20% weight loadings of TiO_2 . For comparison FIG. 8 also includes the black body radiation curve and ANSI C78.377A “Specification for chromaticity of white solid state lighting products” S and R quadrangles for white light of 3500K and 3000K respectively. Each quadrangle is equivalent to approximately seven MacAdam ellipses whilst each sub quadrangle (S02, S03, S06, S07, R02, R03, R06, R07) is equivalent to approximately four McAdam ellipses. As is known a MacAdam ellipse is a region on a chromaticity diagram which contains all colors which are indistinguishable, to the average human eye, from the color at the center of the ellipse. As can be seen from FIG. 8 for a lamp without a light diffusing layer (0% TiO_2) the variation in emission color for emission angles of over a range $\theta=0^\circ$ to 60° is approximately three MacAdam ellipses. For a lamp including a light diffusing layer with a 10%

weight loading of TiO_2 the variation in emission color with emission angle is less than two MacAdam ellipses with a corresponding decrease in luminous efficacy of about 2% (FIG. 7). For a lamp including a light diffusing layer with a 15% weight loading of TiO_2 the variation in emission color with emission angle is approximately one MacAdam ellipse with a corresponding decrease in luminous efficacy of about 5% (FIG. 7). For such a lamp an average person would be unable to perceive the variation in emission color with emission angle. For a lamp including a light diffusing layer with a 20% weight loading of TiO_2 the variation in emission color with emission angle is less than one MacAdam ellipse with a corresponding decrease in luminous efficacy of about 9% (FIG. 7). It will be appreciated the inclusion of a light diffusing layer **44** in accordance with the invention can virtually eliminate the effects of emission color variation with emission angle whilst maintaining an acceptable luminous efficacy.

[0063] As well as reducing phosphor material usage and improving angular emission color uniformity the inclusion of a light diffusing layer **44** provides the additional benefit of improving the visual appearance of the device in an “off” state. In the known devices the phosphor material, which is typically yellow appearance, is visible when the device is in an “off” state and this is considered by many to be undesirable. In contrast in the devices of the invention the light it is the diffusing layer that is visible in an “off” state and this can significantly reduce the yellow appearance.

[0064] A high CRI solid-state light emitting device **10** in accordance with another embodiment of the invention will now be described with reference to FIG. 9 which shows schematic partial cutaway plan and sectional views of the device. The device **10** is configured to generate warm white light with a CCT of $\approx 3000\text{K}$, a luminous flux of about 1100 lumens and a CRI (Color Rendering Index) greater than 90. The device **10** is essentially the same as that of FIG. 1 and additionally comprises one or more red light emitting LEDs (red LEDs) **50**. As shown in FIG. 9 the red LED(s) can comprise a packaged array of red LED chips. The red LED chips can comprise AlGaAs (aluminum gallium arsenic), GaAsP (gallium arsenic phosphide), AlGaInP (aluminum gallium indium phosphide) or GaP (gallium phosphide) LED that are operable to generate red light **52** having a peak wavelength λ_3 in a wavelength range 610nm to 670nm. The emission product **38** of the device **10** comprises the combined blue **28** (λ_1) and red **52** (λ_3) light by generated by the LEDs **24**, **50** and photoluminescence light **38** generated by the phosphor wavelength conversion component **36**. Operation of the device **10** of FIG. 9 is analogous to that

of the device of FIG. 1 and is not described further. Initial tests of the device of FIG. 9 indicate that the light diffusing layer 44 increases the angular emission color uniformity of the device by blending the red, blue and phosphor generated light.

[0065] In further embodiments it is envisioned to configure the light diffusing layer such that it selectively scatters blue light generated by the LEDs more than it scatters light generated by the phosphor material. Such a light diffusing layer ensures that a higher proportion of the blue light emitted from the wavelength conversion layer will be scattered and directed by the light diffractive material back into the wavelength conversion layer increasing the probability of the photon interacting with a phosphor material particle and resulting in the generation of photoluminescence light. At the same time phosphor generated light can pass through the diffusing layer with a lower probability of being scattered. Since the diffusing layer increases the probability of blue photons interacting with a phosphor material particle less phosphor material can be used to generate a selected emission color. Initial tests further indicate that such an arrangement can also increase luminous efficacy of the wavelength conversion component/device. The inventors have appreciated that by appropriate selection of the average particle size of the light scattering material it is possible to configure the light diffusing layer such that it scatters blue light more readily than other colors, namely green and red. FIG. 10 shows plots of relative light scattering versus TiO₂ average particle size (nm) for red, green and blue light. As can be seen from FIG. 10 TiO₂ particles with an average particle size of 100nm to 150nm are more than twice as likely to scatter blue light (450nm to 480nm) than they will scatter green light (510nm to 550nm) or red light (630nm to 740nm). For example TiO₂ particles with an average particle size of 100nm will scatter blue light nearly three times ($2.9=0.97/0.33$) more than it will scatter green or red light. For TiO₂ particles with an average particle size of 200nm these will scatter blue light over twice ($2.3=1.6/0.7$) as much as they will scatter green or red light. In accordance with the invention the light diffractive particle size is preferably selected such that the particles will scatter blue light relatively at least twice as much as light generated by the phosphor material(s). The concept of a wavelength conversion component including a light diffusing layer comprised of light diffractive particles that preferentially scatter light corresponding to wavelengths generated by the LEDs compared with light of wavelengths generated by the phosphor material is considered inventive in its own right.

[0066] It will be appreciated that the invention is not limited to the exemplary embodiments

described and that variations can be made within the scope of the invention. For example whilst the devices of the invention have been described as comprising one or more LEDs the devices can comprise other solid-state light sources such as a laser diode or laser.

CLAIMS

What is claimed is:

1. A wavelength conversion component for a light emitting device comprising at least one blue light emitting solid-state light source, the component comprising: a light transmissive substrate having a wavelength conversion layer comprising particles of at least one blue light excitable phosphor material and a light diffusing layer comprising particles of a light diffractive material; wherein the layers are in direct contact with each other.
2. The component of Claim 1, wherein the wavelength layer comprises a mixture of the at least one phosphor material and a light transmissive binder and the light diffusing layer comprises a mixture of the light diffractive material and the light transmissive binder.
3. The component of Claim 2, wherein the light transmissive binder comprises a curable liquid polymer selected from the group consisting of: a polymer resin, a monomer resin, an acrylic, an epoxy, a silicone and a fluorinated polymer.
4. The component of Claim 1, wherein the light diffractive material has an average particle size in a range selected from the group consisting of: 1 μ m to 50 μ m and 10 μ m to 20 μ m.
5. The component of Claim 2, wherein the weight loading of light diffractive material to binder selected from the group consisting of: 7% to 35% and 10% to 20%.
6. The component of Claim 1, wherein the wavelength conversion and light diffusing layers are deposited using a method selected from the group consisting of: screen printing, slot die coating, spin coating, roller coating, drawdown coating and doctor blading.
7. The component of Claim 1, wherein the light diffractive material is selected from the group consisting of: titanium dioxide, barium sulfate, magnesium oxide, silicon dioxide and aluminum oxide.

8. The component of Claim 1, wherein the light diffractive material has an average particle size that is selected such that the particles will scatter blue light relatively more than they will scatter light generated by the at least one phosphor material.
9. The component of Claim 8, wherein the light diffractive material will scatter blue light at least twice as much as it will scatter light generated by the at least one phosphor material.
10. The component of Claim 8, wherein the light diffractive material has an average particle size that is less than about 150nm.
11. The component of Claim 1, wherein the light transmissive substrate is selected from the group consisting of: a polycarbonate, an acrylic and a glass.
12. A wavelength conversion component for a light emitting device comprising at least one blue light emitting solid-state light source, the component comprising: a wavelength conversion layer comprising particles of at least one blue light excitable phosphor material and a light diffusing layer comprising particles of a light diffractive material; wherein the light diffractive particle size is selected such that the particles will scatter blue light relatively more than they will scatter light generated by the at least one phosphor material.
13. The component of Claim 12, wherein the light diffractive particle size is selected such that the particles will scatter blue light relatively at least twice as much as they will scatter light generated by the at least one phosphor material.
14. The component of Claim 12, wherein the light diffractive material has an average particle size that is less than about 150nm.
15. A light emitting device comprising:
at least one solid-state light source operable to generate blue light and
a wavelength conversion component located remotely to the at least one source and operable to convert at least a portion of the blue light to light of a different wavelength, wherein

the emission product of the device comprises the combined light generated by the at least one source and the wavelength conversion component;

wherein the wavelength conversion component comprises

a light transmissive substrate having a wavelength conversion layer comprising particles of at least one blue light excitable phosphor material and

a light diffusing layer comprising particles of a light diffractive material; and wherein the layers are in direct contact with each other.

16. The device of Claim 15, wherein the wavelength conversion layer comprises a mixture of the at least one phosphor material and a light transmissive binder and the light diffusing layer comprises a mixture of the light diffractive material and the light transmissive binder.

17. The device of Claim 16, wherein the light transmissive binder comprises a curable liquid polymer selected from the group consisting of: a polymer resin, a monomer resin, an acrylic, an epoxy, a silicone and a fluorinated polymer.

18. The device of Claim 15, wherein the light diffractive material has an average particle size in a range selected from the group consisting of: 1 μ m to 50 μ m and 10 μ m to 20 μ m.

19. The device of Claim 16, wherein the weight loading of light diffractive material to binder selected from the group consisting of: 7% to 35% and 10% to 20%.

20. The device of Claim 15, wherein the first and second layers are deposited using a method selected from the group consisting of: screen printing, slot die coating, spin coating, roller coating, drawdown coating and doctor blading.

21. The device of Claim 15, wherein the light diffractive material is selected from the group consisting of: titanium dioxide, barium sulfate, magnesium oxide, silicon dioxide and aluminum oxide.

22. The device of Claim 15, wherein the light diffractive particle size is selected such that the

particles will scatter blue light generated by the at least one source relatively more than they will scatter light generated by the at least one phosphor material.

23. The device of Claim 22, wherein the light diffractive particle size is selected such that the particles will scatter blue light relatively at least twice as much as they will scatter light generated by the at least one phosphor material.

24. The device of Claim 22, wherein the light diffractive material has an average particle size that is less than about 150nm.

25. The device of Claim 15, wherein the light transmissive substrate is selected from the group consisting of: a polycarbonate, an acrylic and a glass.

26. The device of Claim 15, wherein the wavelength conversion component is separated from the at least one light source by a distance of at least 1cm.

27. The device of Claim 15, and further comprising at least one solid-state light source operable to generate red light.

ABSTRACT

A light emitting device comprises at least one solid-state light source (LED) operable to generate blue light and a wavelength conversion component located remotely to the at least one source and operable to convert at least a portion of the blue light to light of a different wavelength, wherein the emission product of the device comprises the combined light generated by the LED and the wavelength conversion component. The wavelength conversion component comprises a light transmissive substrate having a wavelength conversion layer comprising particles of at least one blue light excitable phosphor material and a light diffusing layer comprising particles of a light diffractive material (e.g. TiO_2). The component is characterized in that the layers are in direct contact with each other. The light diffractive particle size can be selected such that the particles will scatter blue light generated by the LED relatively more than they will scatter light generated by the wavelength conversion component. In such an arrangement the particles have an average particle size that is less than about 150nm.



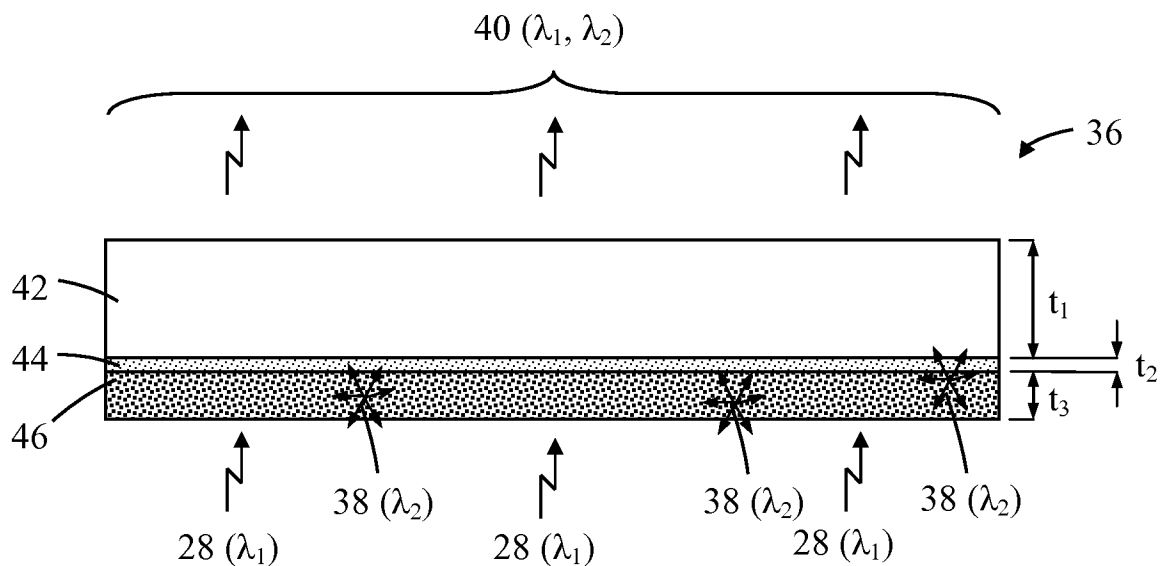


FIG. 2

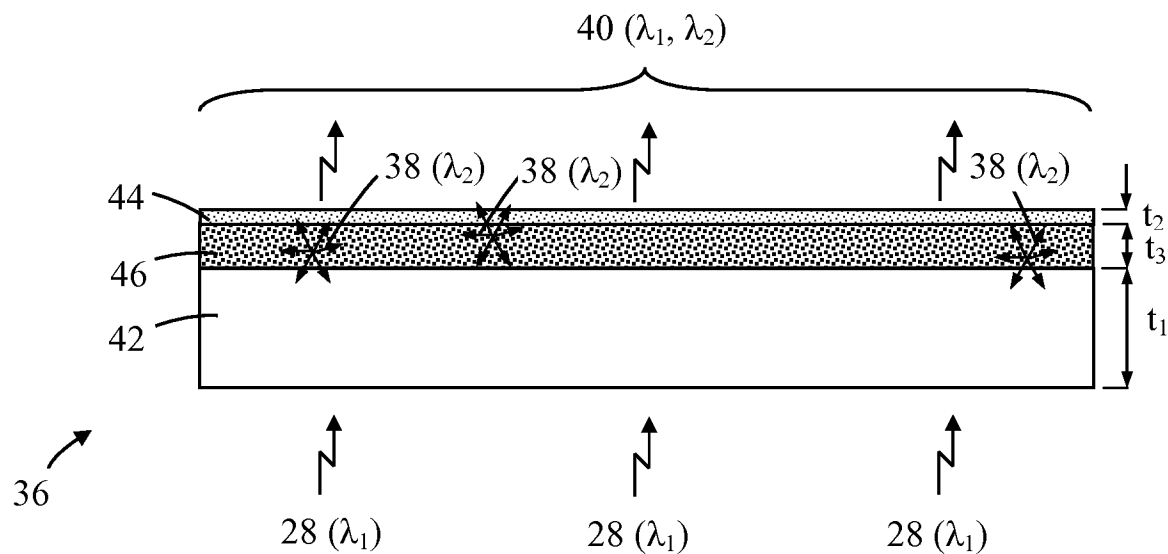


FIG. 3

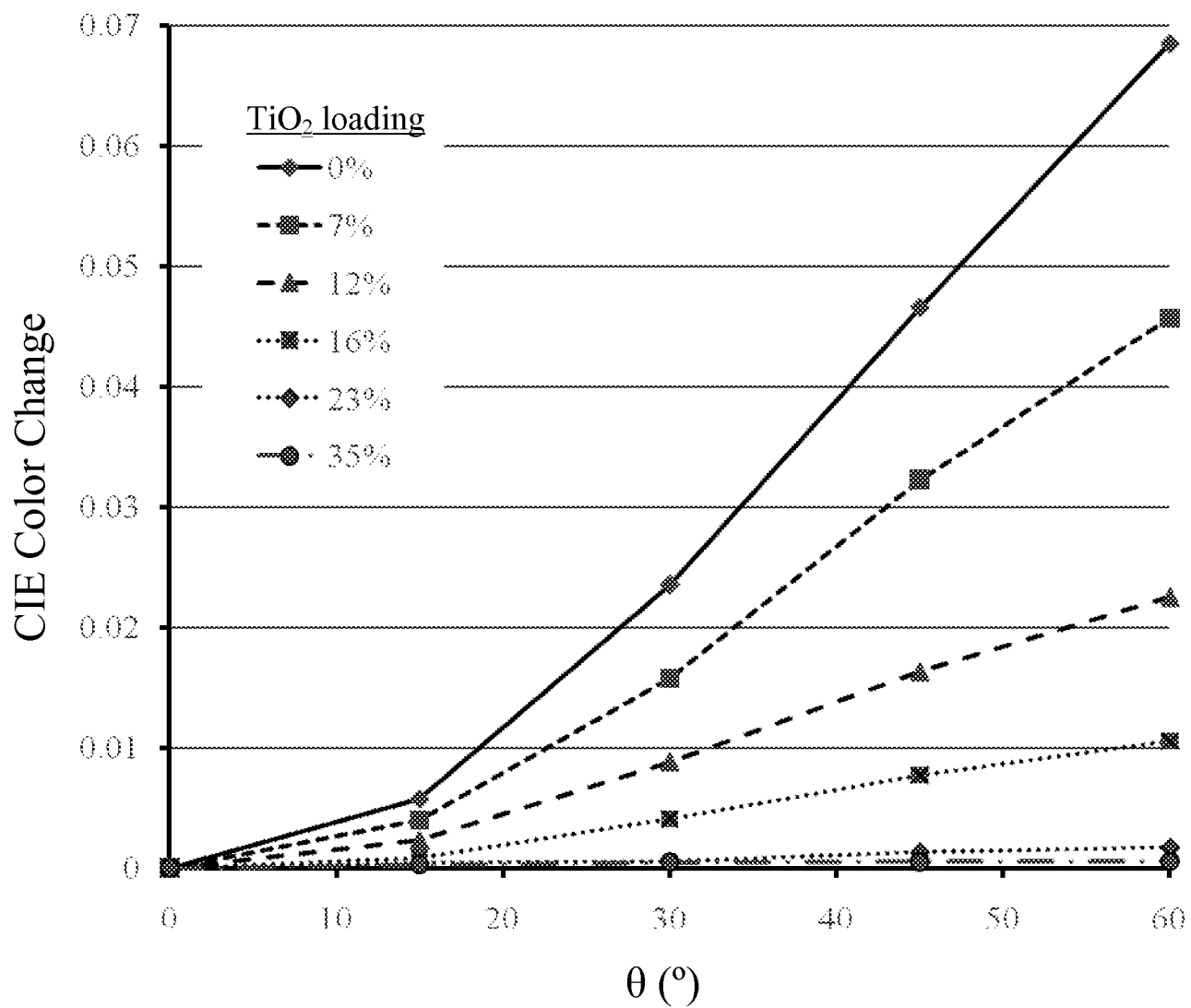


FIG. 4

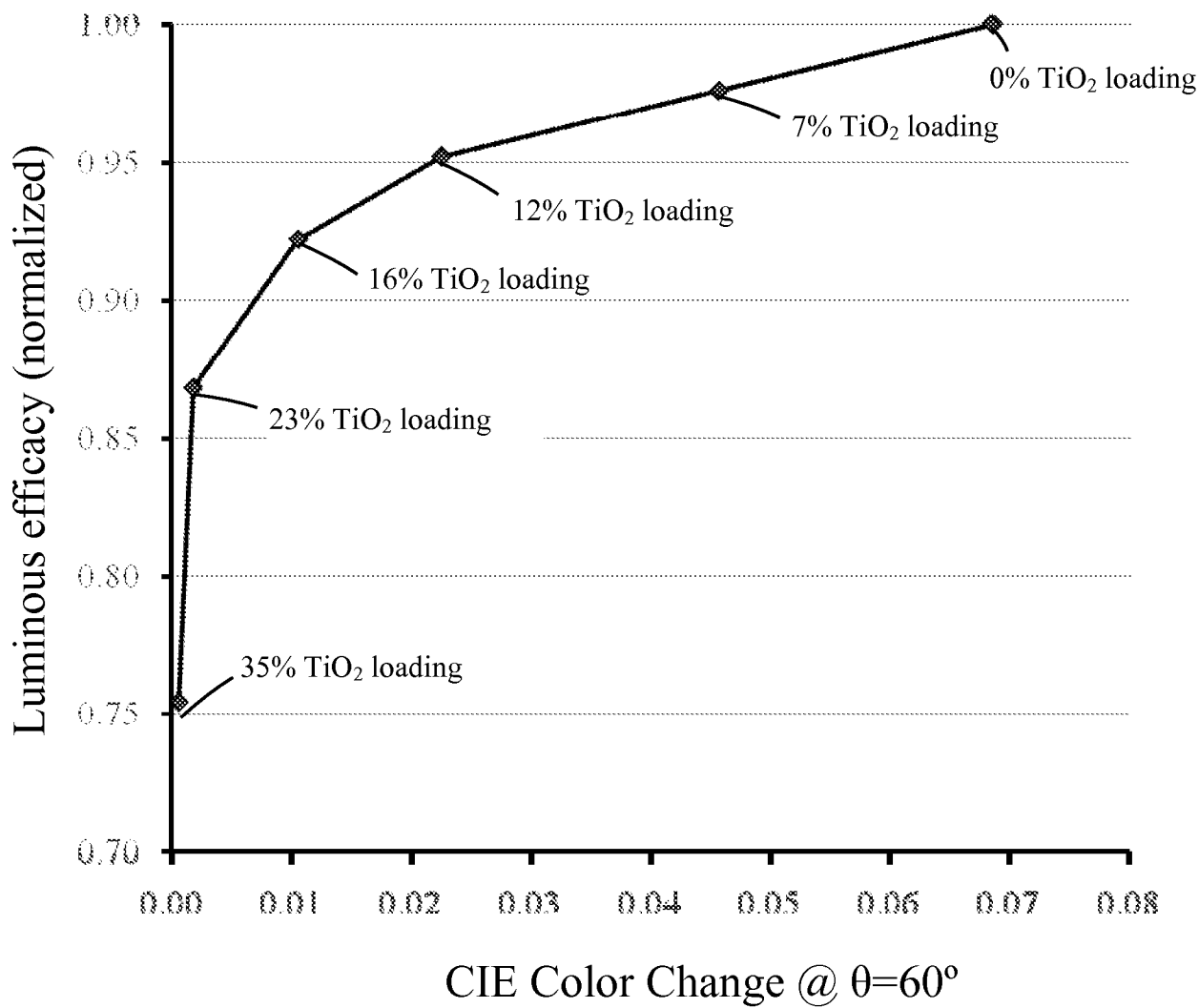


FIG. 5

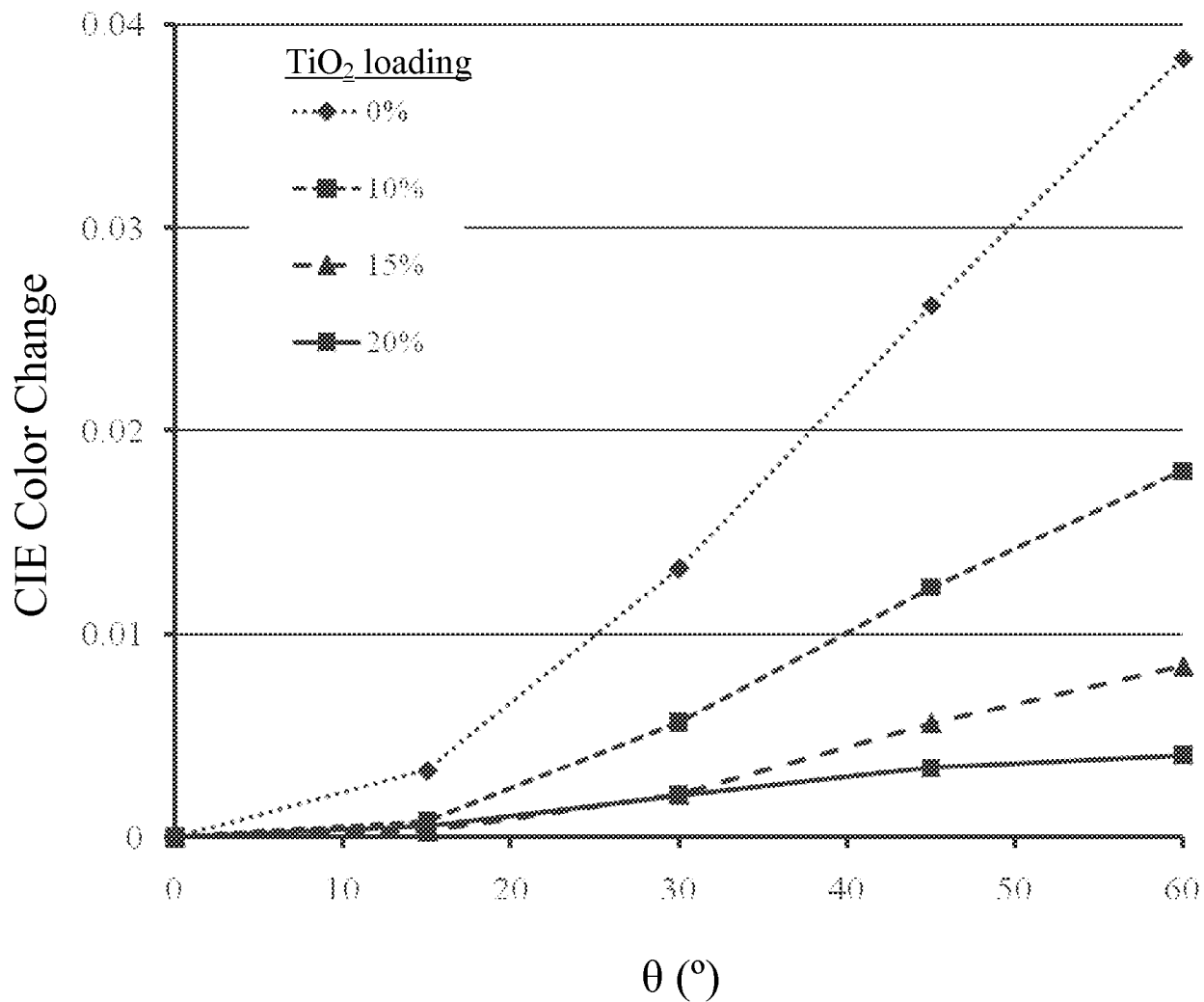


FIG. 6

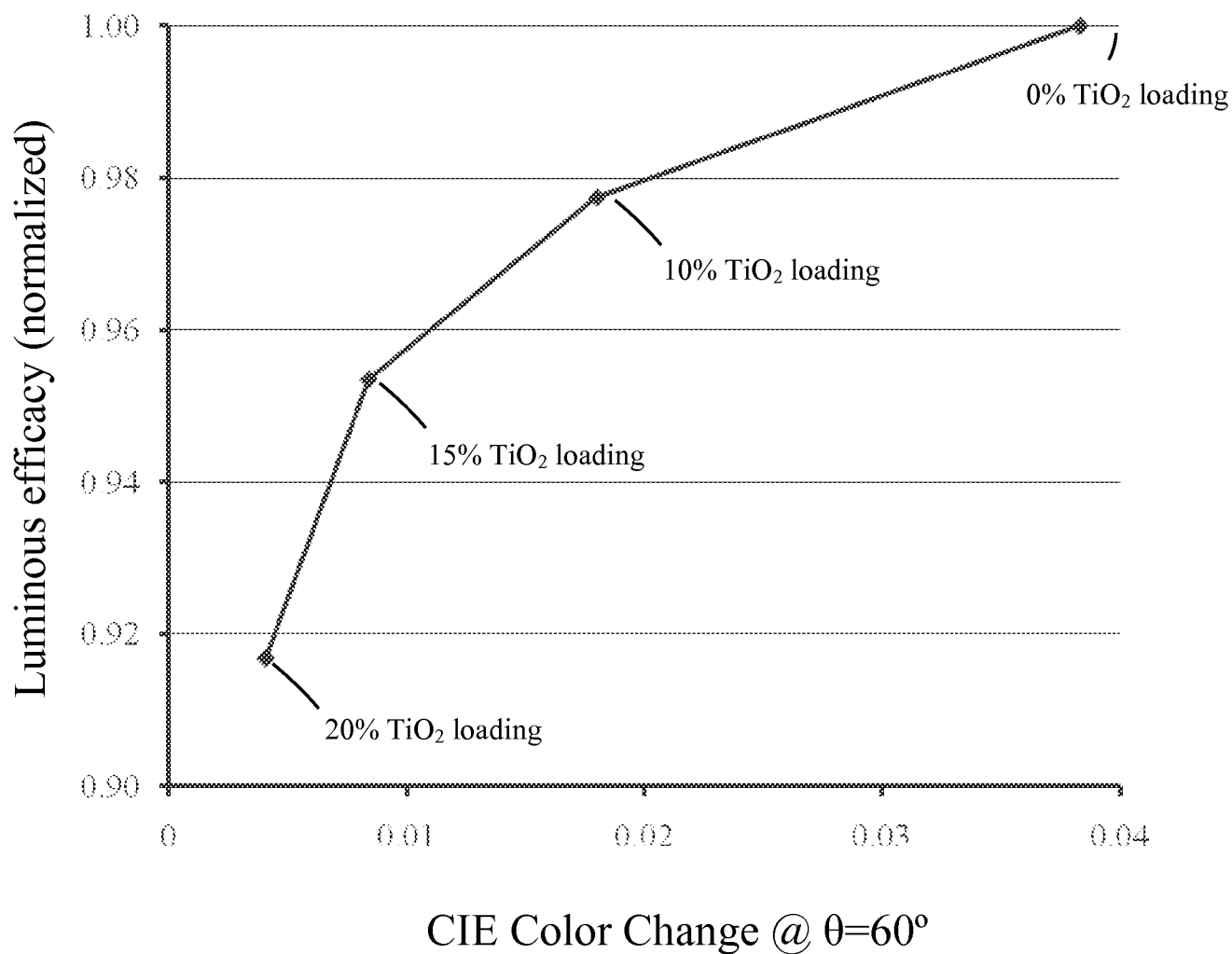


FIG. 7

CIE 1931 Chromaticity Diagram

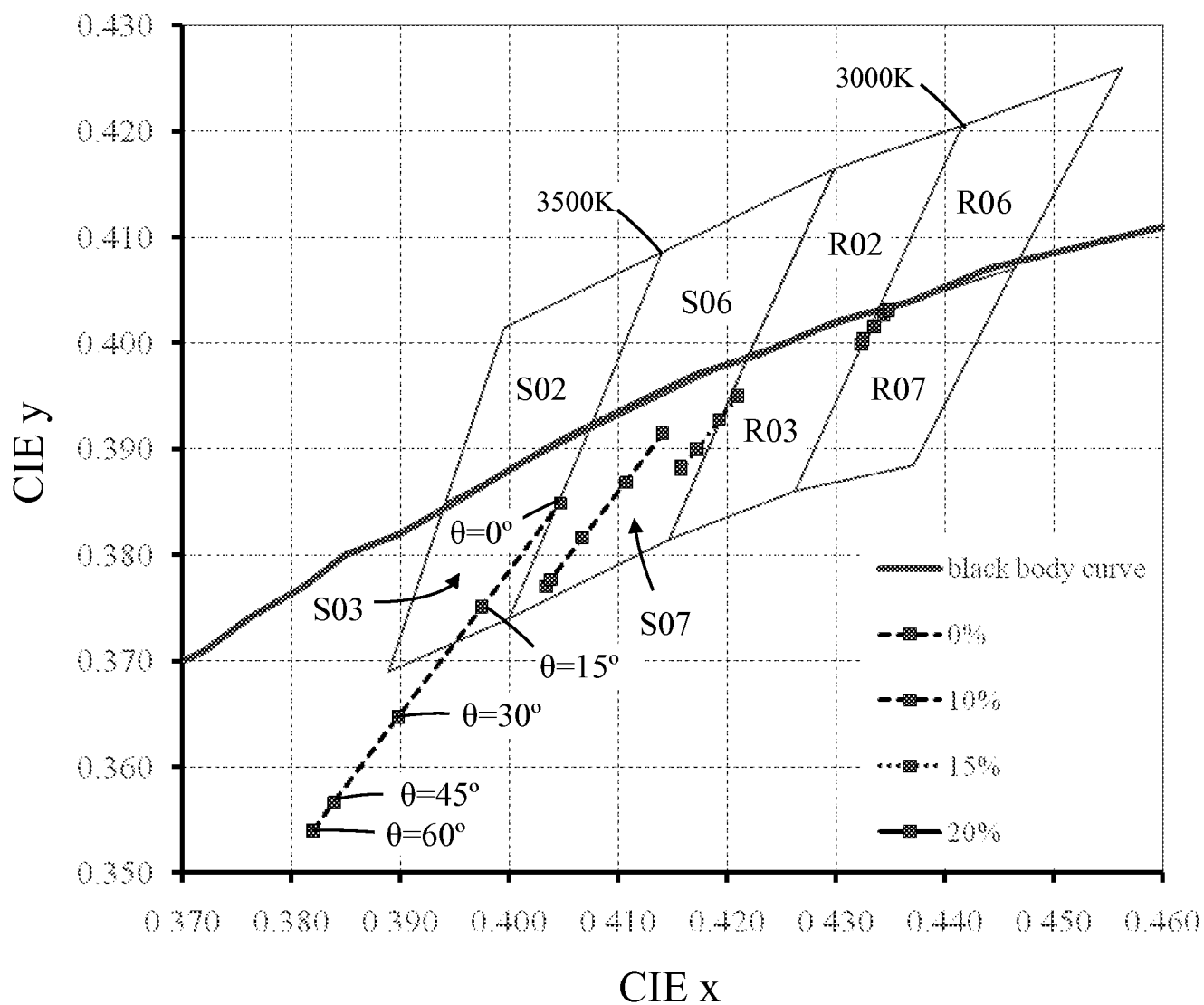


FIG. 8

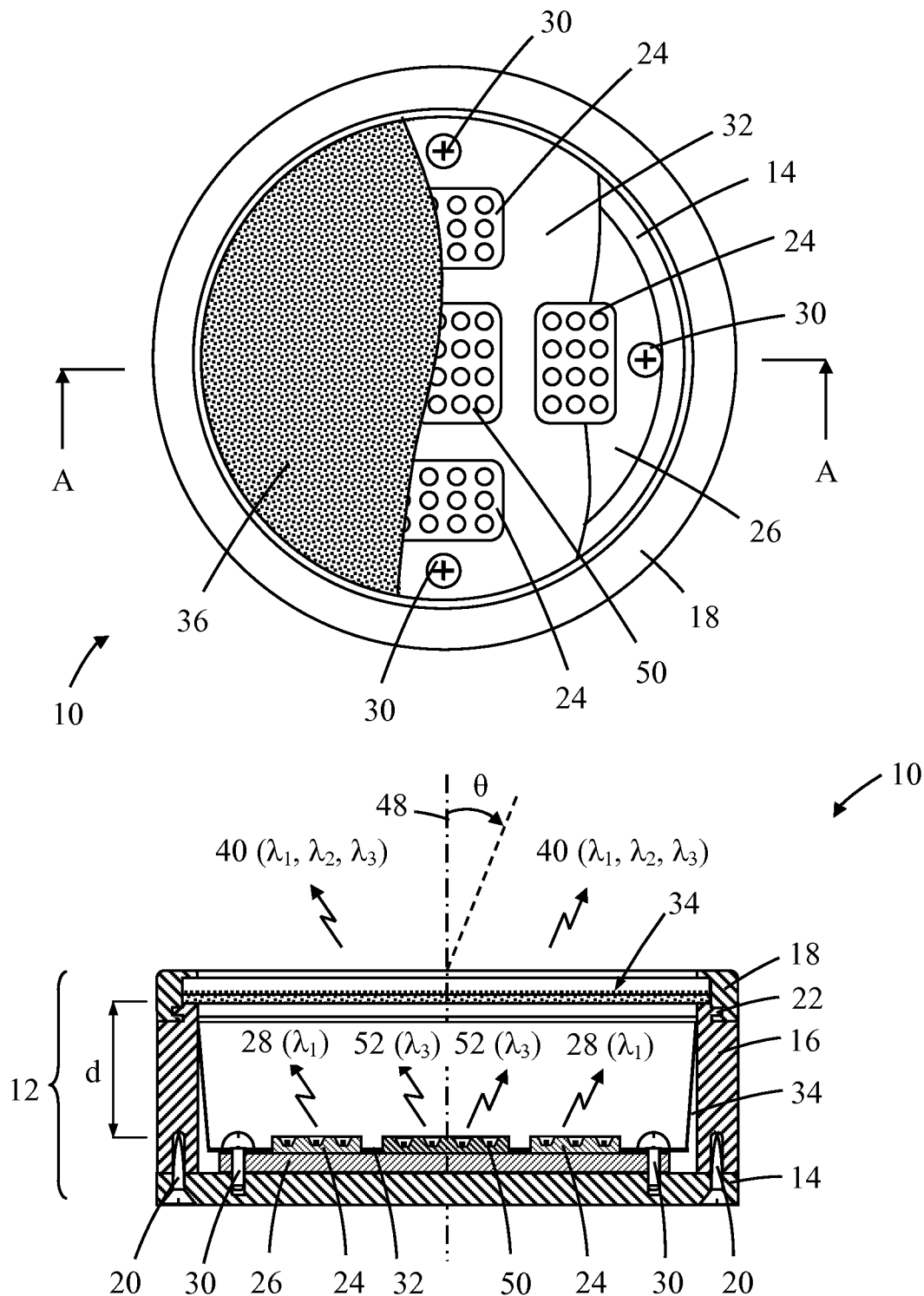


FIG. 9

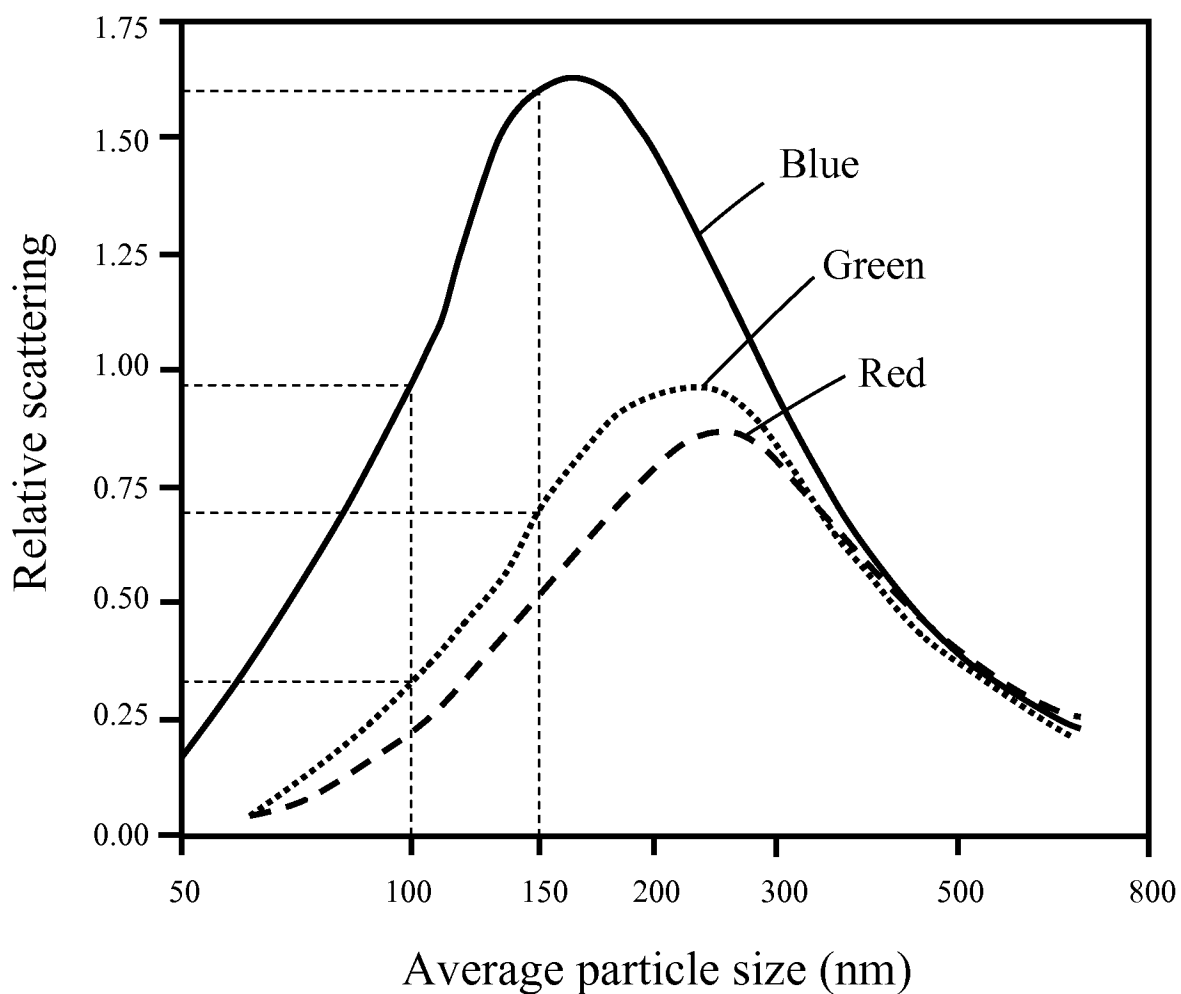


FIG. 10

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	ITMX-00318US0
		Application Number	
Title of Invention	SOLID-STATE LIGHT EMITTING DEVICES WITH REMOTE PHOSPHOR WAVELENGTH CONVERSION COMPONENT		
The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76. This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.			

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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	ITMX-00318US0
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Title of Invention	SOLID-STATE LIGHT EMITTING DEVICES WITH REMOTE PHOSPHOR WAVELENGTH CONVERSION COMPONENT		

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Title of the Invention	SOLID-STATE LIGHT EMITTING DEVICES WITH REMOTE PHOSPHOR WAVELENGTH CONVERSION COMPONENT		
Attorney Docket Number	ITMX-00318US0	Small Entity Status Claimed ☒	
Application Type	Provisional		
Subject Matter	Utility		
Suggested Class (if any)		Sub Class (if any)	
Suggested Technology Center (if any)			
Total Number of Drawing Sheets (if any)	9	Suggested Figure for Publication (if any)	

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	ITMX-00318US0
	Application Number	
Title of Invention	SOLID-STATE LIGHT EMITTING DEVICES WITH REMOTE PHOSPHOR WAVELENGTH CONVERSION COMPONENT	

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Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
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Application Data Sheet 37 CFR 1.76		Attorney Docket Number	ITMX-00318US0
		Application Number	
Title of Invention	SOLID-STATE LIGHT EMITTING DEVICES WITH REMOTE PHOSPHOR WAVELENGTH CONVERSION COMPONENT		

If the Assignee is an Organization check here. ☒			
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Mailing Address Information:			
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City	Fremont	State/Province	CA
Country i	US	Postal Code	94538
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A signature of the applicant or representative is required in accordance with 37 CFR 1.33 and 10.18. Please see 37 CFR 1.4(d) for the form of the signature.					
Signature	/Martin C. Fliesler/			Date (YYYY-MM-DD)	2010-12-27
First Name	Martin	Last Name	Fliesler	Registration Number	25656

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Electronic Patent Application Fee Transmittal				
Application Number:				
Filing Date:				
Title of Invention:		SOLID-STATE LIGHT EMITTING DEVICES WITH REMOTE PHOSPHOR WAVELENGTH CONVERSION COMPONENT		
First Named Inventor/Applicant Name:		Bing Dai		
Filer:		Martin Charles Fliesler/Michelle Calavita		
Attorney Docket Number:		ITMX-00318US0		
Filed as Small Entity				
Provisional Filing Fees				
Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Basic Filing:				
Provisional Application filing fee	2005	1	110	110
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Miscellaneous:				
Total in USD (\$)				110

Electronic Acknowledgement Receipt

EFS ID:	9119387
Application Number:	61427411
International Application Number:	
Confirmation Number:	2477
Title of Invention:	SOLID-STATE LIGHT EMITTING DEVICES WITH REMOTE PHOSPHOR WAVELENGTH CONVERSION COMPONENT
First Named Inventor/Applicant Name:	Bing Dai
Customer Number:	23910
Filer:	Martin Charles Fliesler/Michelle Calavita
Filer Authorized By:	Martin Charles Fliesler
Attorney Docket Number:	ITMX-00318US0
Receipt Date:	27-DEC-2010
Filing Date:	
Time Stamp:	17:28:57
Application Type:	Provisional

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	\$ 110
RAM confirmation Number	2575
Deposit Account	061325
Authorized User	

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File Listing:

Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		Application_and_Drawings.pdf	446721 3c547b7a7a0a02a90d65107901e579ef11a d1502	yes	31
	Multipart Description/PDF files in .zip description				
	Document Description		Start	End	
	Specification		1	17	
	Claims		18	21	
	Abstract		22	22	
	Drawings-only black and white line drawings		23	31	
Warnings:					
Information:					
2	Application Data Sheet	ADS.pdf	1344917 0714d5db9f7b947f88f7cb47b52b7d6581e d9e95	no	5
Warnings:					
Information:					
3	Fee Worksheet (PTO-875)	fee-info.pdf	29727 bdbf40c5792fa6d76ba56d2d6857a88f9f5f 4bba	no	2
Warnings:					
Information:					
Total Files Size (in bytes):			1821365		

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If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371

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New International Application Filed with the USPTO as a Receiving Office

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