Thus, a light emitting arrangement adapted to provide a total light output spectrum is provided, comprising: a solid state light source adapted to emit primary light; and a wavelength converting member comprising multiple types of quantum dots adapted to convert said primary light into secondary light, each type of quantum dot having a secondary light emission wavelength range providing a sub-range of the total light output spectrum, wherein a first type of quantum dot (Q1) is positioned to receive secondary light emitted by a second type of quantum dot (Q2), and wherein said first type of quantum dot has a large stokes shift. Thus, re-absorption of secondary emission originating from one type of quantum dot by another type of quantum dot can be avoided or at least considerably reduced.
— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))
Light emitting arrangement comprising quantum dots

FIELD OF THE INVENTION

The present invention relates to solid state light emitting arrangements comprising using quantum dots as wavelength conversion materials.

BACKGROUND OF THE INVENTION

In the development of new products within the field of lighting much effort is made to design light sources producing a full spectrum, i.e. a light output including all wavelengths of visible light. There is also a demand for light sources with a continuous spectrum showing black body emission at various correlated color temperatures (CCTs).

Such full spectrum lighting is white light having a smooth intensity spectrum without sharp spikes or dips. This demand is based on the insight that while daylight is the best light, a continuous full spectrum artificial light is the second best. There are many claimed benefits of a continuous full spectrum, for examples that full spectrum lighting improves color perception, improves visual clarity, improves mood, improves productivity, improves mental awareness, increases retail sales, improves plant growth, improves results of light therapy in treating seasonal affective disorder (SAD) and sleep disorders, improves scholastic performance of students, improves vitamin D synthesis in the body, and reduces incidence of dental decay.

Various incandescent claimed full-spectrum lamps are commercially available such as a fluorescent T12 lamp. However, the spectra of these incandescent lamps are still showing spikes and/or dips. In addition, incandescent claimed full-spectrum lamps are also relatively energy-consuming.

LEDs emitting different colors (without phosphors) can be used to obtain desirable CCT and CRI. However, the spectrum obtained with such direct emitters is very peaked with large dips, see Fig. 12. Curve "B" represents the black body line. Using direct LEDs no full spectrum lighting can be made. Another drawback of using different direct LEDs is that each LED needs a different driving current. Furthermore, due to different temperature dependencies of different LEDs would require the current for at least some of the LEDs to be adjusted as a function of the temperature).
Using phosphor-converted light emitting diodes (LEDs) it is also difficult to obtain full spectrum lighting without spikes and/or dips in the spectrum. In phosphor-converted LEDs blue light is partially converted to yellow/orange/red light in order to obtain white light. However, the spectrum with such phosphor converted LEDs always show a peaked spectrum with dips. Fig. 11 shows a spectrum of blue LED which is partially converted to yellow and red light by a yellow and red phosphor, respectively, in order to obtain white light having CCT of 3000K and a color rendering index (CRI) of 90. Curve "B" represents the black body line. It is difficult to fill in the gaps of this spectrum using conventional organic and inorganic phosphors, which are broad band emitters, to obtain continuous full back body emission.

US 2005/0135079 suggests an LED device for a flash module which produces white light with a higher CRI than prior flash modules. The device comprises a light source producing primary light and a wavelength converting overlay including a plurality of quantum dots dispersed in a matrix material. The quantum dots may be selected to have different secondary emission wavelengths to produce a broad emission from the light emitting device. In some embodiments, quantum dots are combined with conventional phosphor material. However, a drawback of the device described in this document is that re-absorption of the secondary light may lead to reduced efficiency and it becomes difficult to make a fine tuning of a desired spectrum.

Hence, there remains a need in the art for improved full-spectrum light sources.

SUMMARY OF THE INVENTION

It is an object of the present invention to overcome this problem, and to provide a light emitting arrangement which produces a continuous spectrum light output.

According to a first aspect of the invention, this and other objects are achieved by a light emitting arrangement adapted to provide a total light output spectrum, comprising:
- a solid state light source adapted to emit primary light; and
- a wavelength converting member arranged to receive said primary light and comprising multiple types of quantum dots adapted to convert said primary light into secondary light, each type of quantum dot having a secondary light emission wavelength range providing a sub-range of the total light output spectrum, wherein a first type of quantum dot is positioned to receive secondary light emitted by a second type of quantum dot, wherein said first type of quantum dot has an absorbance in its absorption wavelength
range which is at least 10 times larger than the absorbance in the secondary light emission wavelength range of said second type of quantum dot. Due to the difference in absorbance level at different wavelengths, re-absorption of secondary emission originating from one type of quantum dot by another type of quantum dot is avoided or at least considerably reduced. Hence, the invention allows different types of quantum dots to be mixed within a single layer or region, or provided as a layer stack.

Optionally also said second type of quantum dot has an absorbance in its absorption wavelength range which is at least 10 times larger than the absorbance in the secondary light emission wavelength range, or the secondary light emission wavelength range of another type of quantum dot comprised in the wavelength converting member. Preferably, said first and/or second type of quantum dot(s) has an absorbance in its absorption wavelength range which is at least 50 times, more preferably at least 100 times, larger than the absorbance in the secondary light emission wavelength range of another type (e.g., first or second type, respectively) of quantum dot.

In embodiments of the invention, the wavelength converting member comprises said first type of quantum dot and said second type of quantum dot mixed within a single layer or comprised within different layers of a multilayer stack. In one embodiment, multiple types of quantum dots may be mixed within a single layer, wherein each type of quantum dot has an absorbance in its respective absorption wavelength range which is at least 10 times larger than the absorbance in the secondary light emission wavelength range of another type of quantum dot, and typically all other types of quantum dots, comprised within the wavelength converting member. Alternatively, the wavelength converting member may comprise a plurality of layers stacked in a light output direction from the solid state light source, wherein each layer comprises at least one type of quantum dot and wherein at least one distal layer with respect to the solid state light source comprises a type of quantum dot having an absorbance in its absorption wavelength range which is at least 10 times larger than the absorbance in the secondary light emission wavelength range of at least one type of quantum dot contained in a more proximal layer with respect to the light source. The quantum dots may have negligible absorption in the wavelength range above 500 nm.

In embodiments of the invention, at least one type of quantum dots, and possibly all types of quantum dots used, may have a size in the range of from 1 to 10 nm in at least one direction.

In embodiments of the invention, the emission sub-range provided by a type of quantum dot does not overlap with any other sub-range provided by another type of quantum
dot. In other embodiments, the emission sub-range provided by each type of quantum dot overlaps with at least one other sub-range provided by another of said types of quantum dots. Hence, the invention provides a versatile tool for accurately designing the emission spectrum for any desired application, for example full spectrum illumination or color enhancement.

In some embodiments, the wavelength converting member may further comprise a broad band emitting phosphor arranged to receive said primary light and capable of converting said primary light into secondary light, thereby providing a broad sub-range of the total light output spectrum. The sub-range provided by a type of quantum dot may partially or completely overlap with at least part of the sub-range provided by the broad band emitting phosphor. Said quantum dots may, within said sub-range, provide secondary light of a higher intensity than the broad band emitting phosphor. The overlap may be in a region of low emission intensity of the broad band emitting phosphor, resulting in a boost of the phosphor emission spectrum. Alternatively, the overlap may be in a region of high emission intensity of the broad band emitting wavelength phosphor, thus further enhancing a color produced by the broad band emitting phosphor.

In embodiments of the invention the total light output spectrum provided by the light emitting arrangement includes all wavelengths of the range from 400 nm to 800 nm. Hence, a full spectrum light emitting arrangement is provided.

In embodiments of the invention, the intensity of the total light output spectrum does not deviate at any wavelength by more than 20 %, preferably not more than 10 %, from the corresponding black body emission spectrum, said black body emission spectrum corresponding to a black body temperature in the range of from 500 K to 10 000 K. This means that the total light output spectrum closely resembles the black body emission spectrum, which is desirable for many different applications.

In another aspect, the invention relates to a luminaire comprising a light emitting arrangement as described herein. Such a luminaire may be adapted for any desired application, for example general illumination for home or professional indoor environments, decorative illumination, or light therapy applications.

In a further aspect, the invention provides the use of multiple types of quantum dots having different secondary light emission ranges for providing a continuous light output spectrum, wherein each type of quantum dot has an absorbance in its respective absorption wavelength range which is at least 10 times larger than the absorbance in its respective secondary light emission wavelength range.
It is noted that the invention relates to all possible combinations of features recited in the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

This and other aspects of the present invention will now be described in more detail, with reference to the appended drawings showing embodiment(s) of the invention.

Fig. 1a is a graph illustrating an exemplary emission spectrum of a light emitting arrangement according to embodiments of the invention, and the black body emission spectrum (denoted B).

Fig. 1b is a graph illustrating the total output spectrum (S) of a light emitting arrangement according to the invention, and the black body emission spectrum (denoted B).

Fig. 2 is a graph showing the absorption spectra of the quantum dots of a light emitting arrangement according to embodiments of the invention.

Fig. 3 is a schematic side view of a light emitting arrangement according to embodiments of the invention.

Fig. 4 is a schematic side view of a light emitting arrangement according to embodiments of the invention comprising a single-layer wavelength converting member.

Fig. 5 is a schematic side view of a light emitting arrangement according to embodiments of the invention comprising a multi-layer wavelength converting member.

Fig. 6 is a graph showing the total emission spectra of quantum dots, according to embodiments of the light emitting arrangement.

Fig. 7 is a schematic side view of a light emitting arrangement according to embodiments of the invention.

Fig. 8 is a graph showing the emission spectrum of a light emitting arrangement according to embodiments of the invention comprising both quantum dots and broad band emitting phosphors.

Fig. 9 is a schematic side view of a light emitting arrangement according to embodiments of the invention comprising a pixilated wavelength converting member.

Fig. 10 is a cross-sectional side view of a light emitting arrangement comprising a light mixing chamber.

Fig. 11 is a graph showing a typical output spectrum of a conventional phosphor-converted LED.

Fig. 12 is a graph showing a typical output spectrum of a conventional light emitting arrangement comprising a plurality of differently colored LEDs.
As illustrated in the figures, the sizes of layers and regions are exaggerated for illustrative purposes and, thus, are provided to illustrate the general structures of embodiments of the present invention. Like reference numerals refer to like elements throughout.

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DETAILED DESCRIPTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which currently preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided for thoroughness and completeness, and fully convey the scope of the invention to the skilled person.

The present inventors have found that a light emitting arrangement using a solid state light source, e.g. a UV, violet or blue LED, and a plurality of quantum dots, a continuous, full black body emission spectrum can be obtained.

Fig. 1 schematically illustrates a spectrum that can be obtained by a light emitting arrangement according to embodiments of the invention. The graph shows intensity as a function of wavelength (λ). The first peak (to the left) represents the shortest visible wavelength, violet light, which may originate from the light source (primary light) or from quantum dots. The further peaks are the result of quantum dot emission (secondary light). The emission band width of each quantum dot is narrow, showing as the distinct peaks in Fig. 1. In order to achieve continuous full black body emission using only quantum dots, multiple types of quantum dots having partly overlapping emission bands are used.

Fig. 1b illustrates an example of a total light output spectrum S of a light emitting arrangement according to the invention. The spectrum also shows the black body emission spectrum B. As can be seen, the total output spectrum of the light emitting arrangement closely resembles the black body emission over a broad wavelength range, typically from 400 to 800 nm. At a given wavelength λ₂, the black body emission has intensity I₂ and the emission from the light emitting arrangement has intensity I₂. Typically, I₂ does not deviate (up or down) from L by more than 20 %, that is 0.8*I₂ ≥ I₂ ≥ 1.2*I₂. Hence, large intensity dips in the emission spectrum of the light emitting arrangement are avoided and the emission thus closely resembles full, black body emission.

As used herein, the expressions "continuous spectrum" refers to an emission spectrum which resembles the emission spectrum (intensity as a function of wavelength) of a
black body radiator. The black body spectrum for a given black body temperature is a smooth line. "Resembles" here means that for a spectrum superimposed on the black body line the intensity should not deviate at any wavelength by more than 20 %, and preferably by not more than 10 %. Such a spectrum is thus referred to as a "continuous spectrum", and do not have any strong dips or peaks.

The amount of wavelength converting material may be adapted to produce a light intensity such that sum of the emission peaks mimics the black body radiation of a desired black body temperature.

Although Fig. 1 shows only eight emission peaks originating from quantum dots (or seven peaks, if the first peak should originate from the light source), is it envisaged that in embodiments of the invention the light output spectrum may contain a lower or higher number of quantum dot emission peaks. Quantum dots of any specific size typically have a light distribution with a full width at half maximum (FWHM) in the range of 30-60 nm. The position of each emission maximum can be anywhere in the electromagnetic spectrum but preferably somewhere between 400 nm and 800 nm. In order to provide a continuous emission spectrum, typically at least 8 emission peaks are used, but in embodiments of the invention there may be for example 10 emission peaks or more, such as 12 emission peaks or more. A higher number of emission peaks produces a more continuous spectrum, that is a spectrum that is even closer to the black body line.

In embodiments of the invention, fewer than 8 emission peaks may still provide a continuous spectrum, for example where the desired spectrum is not required to cover the whole range from 400 to 800 nm, but should only cover a portion thereof, one example being embodiments in which quantum dots are combined with a broad band emitting phosphor.

"Full width at half maximum" or "FWHM", refers to the width of the wavelength range at the half of the peak intensity of a plot of intensity as a function of wavelength.

As used herein, by "broad band emitting wavelength converting material" or "broad band emitting phosphor material" is meant a wavelength converting material which has an emission spectrum having a FWHM of more than 100 nm.

In contrast, to broad band emitting materials, quantum dots of any specific size typically have a light distribution with a full width at half maximum (FWHM) in the range of 30-60 nm, for example 30-50 nm. As an example a green quantum dot emitter may emit light with a FWHM of <50 nm, more preferably <40 nm, and most preferably <30 nm (FWHM).
In embodiments of the invention however it is possible to use at least some quantum dots which do not have overlapping emission peaks.

Quantum dots and quantum rods are small crystals of semiconducting material generally having a width or diameter of only a few nanometers. When excited by incident light, a quantum dot emits light of a color determined by the size and material of the crystal. Light of a particular color can therefore be produced by adapting the size of the dots. In embodiments of the present invention, the quantum dots may for example have a size in the range of from 1 to 10 nm in at least one direction. As an alternative to quantum dots, quantum rods may be used, which may have a width in the range of from 1 to 10 nm and a length of up to 1 mm or more.

The present invention utilizes quantum dots having a large stokes shift. As used herein, a material having a "large stokes shift" is a material whose absorbance in the absorption wavelength range (i.e., at the excitation wavelength) is at least 10 times larger than the absorbance in the emission wavelength range. Preferably the invention uses quantum dots having an absorbance in the absorption wavelength range (i.e., at the excitation wavelength) is at least 50 times, more preferably at least 100 times, larger than the absorbance in the emission wavelength range.

Thus, the types of quantum dots used in the present invention may have high absorption in the range of from e.g. 200 to about 500 nm, and no or negligible absorption in the range above about 500 nm, including quantum dots having emission in the range of from about 500 nm to 750 nm and higher. Fig. 2 is a graph schematically showing the absorption spectra of various quantum dots that may be used in the present invention.

Quantum dots with a large stokes shift can be obtained by using quantum dots having a thick layer of cadmium sulfide (CdS) shell. Increasing the thickness of a CdS shell relative to the core, for example CdSe, may increase the absorption below about 500 nm, whereas the absorption at wavelengths higher than 500 nm, and especially in the secondary emission wavelength range of quantum dots having an emission range above 500 nm, shows almost no change. Another way of obtaining large stokes shift is by using so called doped quantum dots. For example, Mn doped nanoparticles of ZnSe may be used.

A light emitting arrangement according to the invention is illustrated schematically in Fig. 3. The light emitting arrangement 100 comprises a solid state light source 101 for emitting primary light L1 and a wavelength converting member 102, arranged in the light output direction from the light source so as to receive the primary light L1 and convert at least part of it into secondary light L2.
In an embodiment of the light emitting arrangement shown in Fig. 4, different types of quantum dots, denoted Q1, Q2, Q3, Q4, Q5 etc having different secondary emission ranges, may be contained in a single wavelength converting layer of the wavelength converting member. Hence, different types of quantum dots may be mixed within a single layer or region. Re-absorption of secondary emission of some of the quantum dots, e.g. green light, by other quantum dots emitting e.g. yellow light, can be avoided by using quantum dots having a large stokes shift as described above.

Optionally, the wavelength converting layer comprising the quantum dots may additionally comprise a broad band emitting phosphor material.

In another embodiment of the light emitting arrangement illustrated in Fig. 5, different types of quantum dots Q1, Q2, Q3, Q4, Q5, etc having different secondary emission ranges, may be contained in separate wavelength converting layers of the wavelength converting member 102. However, due to the large stokes shift of the quantum dots, the layers may be stacked in the light output direction, which is practical during production and allows a compact, efficient arrangement. Optionally, a broad band emitting phosphor material may be contained in a further layer, or in a layer comprising quantum dots.

In an exemplary embodiment, the light emitting arrangement comprises eight different types of quantum dots. The light source may be an UV LED. A first type of quantum dot Q1 may convert the primary UV light emitted by the light source into secondary light of 400-440 nm (violet), a second type of quantum dot Q2 may convert primary light into 440-460 nm (violet blue), a third type of quantum dot Q3 may convert primary light into 460-480 nm (blue), a fourth type of quantum dot Q4 may convert primary light into 490-530 nm (blue green), a fifth type of quantum dot Q5 may convert primary light into 530-560 nm (yellow green), sixth type of quantum dot Q6 may converting primary light into 570-620 nm (yellow/orange), a seventh type of quantum dot Q7 may convert primary light into 620-700 nm (orange) and a eighth type of quantum dot Q8 may convert primary light into 700-750 nm (red).

Another exemplary embodiment uses 16 different types of quantum dots emitting light of different sub-ranges as indicated in Table 1.
Table 1. Example embodiment sub-ranges

<table>
<thead>
<tr>
<th>Quantum dot type</th>
<th>Emission wavelengths (converted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>400 - 440 nm – blue violet (BV) light</td>
</tr>
<tr>
<td>Q2</td>
<td>440 - 460 nm – violet blue (VB) light</td>
</tr>
<tr>
<td>Q3</td>
<td>460 - 480 nm – blue (B) light</td>
</tr>
<tr>
<td>Q4</td>
<td>480 - 490 nm – green blue (GB) light</td>
</tr>
<tr>
<td>Q5</td>
<td>490 - 500 nm – blue green (BG) light</td>
</tr>
<tr>
<td>Q6</td>
<td>500 - 530 nm – green (G) light</td>
</tr>
<tr>
<td>Q7</td>
<td>530 - 560 nm – yellow green (YG) light</td>
</tr>
<tr>
<td>Q8</td>
<td>560 - 570 nm – green yellow (GY) light</td>
</tr>
<tr>
<td>Q9</td>
<td>570 - 580 nm – yellow light</td>
</tr>
<tr>
<td>Q10</td>
<td>580 - 590 nm – orange yellow (OY) light</td>
</tr>
<tr>
<td>Q11</td>
<td>590 - 600 nm – yellow orange (YO) light</td>
</tr>
<tr>
<td>Q12</td>
<td>600 - 620 nm – orange (O) light</td>
</tr>
<tr>
<td>Q13</td>
<td>620 - 640 nm – red orange (RO) light</td>
</tr>
<tr>
<td>Q14</td>
<td>640 - 700 nm – orange red (OR) light</td>
</tr>
<tr>
<td>Q15</td>
<td>700 - 750 nm – red (R) light</td>
</tr>
<tr>
<td>Q16</td>
<td>750 - 800 nm – near infrared (NIR) light</td>
</tr>
</tbody>
</table>

In embodiments of the invention, all light emitted by the solid state light source 101 may be converted by the wavelength converting member 102. In alternative embodiment, only part of the primary light emitted by the light source is converted.

In some embodiments of the present invention it is not necessary that the different emission peaks of the quantum dots overlap as illustrated in Fig. 1 above. Thus, in some embodiments, the secondary emission peaks P1-P7 of the different types of quantum dots, may be distinct from each other, i.e. not overlapping, as illustrated in Fig. 6. Optionally however the secondary emission range provided by one or more types of quantum dots may overlap with the secondary emission range of a broad band emitting phosphor described below.

In embodiments of the invention the wavelength converting member may comprise at least one conventional phosphor material, providing secondary emission of a broad wavelength range. Such as phosphor material may be referred to a broad band emitting phosphor within the context of the present invention. A broad band emitting phosphor
material may be provided as a separate layer or even a separate body, optionally forming a separate, second wavelength converting member.

An example of a light emitting arrangement having a wavelength converting member comprising quantum dots as well as a conventional phosphor material is schematically illustrated in Fig. 7. The wavelength converting member 102 comprises a layer 102' comprising quantum dots as described above, and a layer 102'' comprising a conventional organic or inorganic phosphor material. Alternatively, the quantum dots and the broad band emitting phosphor material may be provided in a single layer.

Fig. 8 shows an example of the output spectrum of a light emitting arrangement in which the wavelength converting member 102 comprises a first broad band emitting phosphor providing secondary emission L2' having typically an FWHM of 150 nm, e.g. 510-660 nm, and a second broad band emitting phosphor L2'' providing secondary emission typically having an FWHM of 120 nm, e.g. 590-710 nm. The emission peak originating from the light source primary light is denoted L1 (typically having FWHM of 50 nm, e.g. 380-430 nm). In order to fill in the gaps of the combined output spectrum of the first and the second phosphors and the light source, the wavelength converting member further comprises quantum dots providing emission peaks P1, P2, P3 and P4 at for example at 430-470 nm, 470-510 nm, 590-630 nm and 630-660 nm, respectively.

The wavelength converting member may be arranged at a remote position with respect to the light source, i.e., the wavelength converting member and the light source may be mutually spaced apart, as illustrated in Figs. 3-5. Alternatively, the wavelength converting member may be arranged in the vicinity of the light source, at a small distance therefrom. In other embodiments, the wavelength converting member may be arranged directly on the light source, e.g. as illustrated in Fig. 7.

In embodiments of the invention, the wavelength converting member 102 may comprise a plurality of in-plane domains 102a, 102b, 102c, 102d etc, as illustrated in Fig. 9. At least some of these domains 102a, 102b, 102c contain quantum dots and form distinct, in-plane regions, arranged in an array. The array may be two-dimensional, forming a matrix. An array arrangement of domains may be referred to as a "pixel arrangement" or pixilated arrangement" within the context of the present invention. Accordingly, the individual domains 102a, 102b, etc of such an arrangement may be referred to as "quantum dot pixels". Typically, one quantum dot pixel contains a one or more types of quantum dot. For example, domain 102a may contain quantum dots Q1, domain 102b may contain quantum dots Q2, domain 102c may contain quantum dots Q3 etc. The quantum dot pixels may be arranged in
any suitable pattern, for example a triangular, hexagonal or checkerboard pattern. The pattern may be repetitive or periodic.

In embodiments of the invention the light emitting arrangement comprises a light mixing chamber, in which the light source is arranged. Typically the light mixing chamber is defined by at least one side wall which may be reflective, and a light exit window. In some embodiments, wavelength converting member may be arranged in the light exit window. Fig. 10 illustrates a light emitting arrangement comprising a light mixing chamber defined by a base portion and at least one side wall. The solid state light source may be provided on the base portion. In the case of a single light source, the light source is typically positioned centrally on the base portion. In the case of two or more light sources, the light sources may be arranged symmetrically around a center of the base portion. It is however contemplated the light sources may be provided on a side wall or at any other suitable location in the light mixing chamber.

The at least one side wall provides surrounds the chamber and defines a light exit window in which the wavelength converting member is positioned, at a location remote from the light source. In other embodiments, the wavelength converting member may instead be provided within the light mixing chamber. The surface of the at least one side wall facing the interior of the chamber may be reflective, e.g. provided with a layer of reflective material, in order to provide homogeneous distribution of the light to be received by the wavelength converting member, and/or to provide a more homogeneous distribution on secondary light from the wavelength converting member and good mixing with primary light. The reflectivity of the reflective side wall is preferably at least 80%, more preferably at least 90%, and even more preferably at least 95%. Typically the reflective layer may be diffuse reflective.

Optionally, the light emitting arrangement may further comprise a diffuser arranged on a side of the wavelength converting member facing towards the light output direction (i.e. not facing towards the light source). Such a diffuser may be provided in the light exit window or outside of the light mixing chamber.

In embodiments of the invention, the solid state light source emits primary light of from 200 to 460 nm, corresponding to UV, violet light and blue light. Typically the primary light may be in the range of 440 to 460 nm. Thus, in embodiments where the solid-state light source is an LED, it may be a UV, violet or blue emitting LED such as GaN or InGaN based LED. Organic light emitting diodes (OLEDs) or laser diodes emitting primary light of suitable wavelength range may also be used.
The broad band emitting phosphor material may be an inorganic material or an organic material. Examples of inorganic wavelength converting materials may include, but are not limited to, cerium (Ce) doped YAG (Y3Al5O12) or LuAG (Lu3Al5O12). Ce doped YAG emits yellowish light, whereas Ce doped LuAG emits yellow-greenish light. Examples of other inorganic phosphors which emit red light may include, but are not limited to, ECAS (ECAS, which is Ca_{x}Al_{1-x}SiN_{3}:Eu where 0<x<1; preferably 0<x<0.2) and BSSN (BSSNE, which is Ba_{2-x}Sr_{x}Al_{2-y}Si_{5-y}O_{8+y}:Eu_{y} wherein M represents Sr or Ca, 0<x<1 and preferably 0<x<0.2, 0<y<4, and 0.0005<z<0.05).

Examples of suitable organic phosphor materials are organic luminescent materials based on perylene derivatives, for example compounds sold under the name Lumogen® by BASF. Examples of suitable compounds include, but are not limited to, Lumogen® Red F305, Lumogen® Orange F240, Lumogen® Yellow F083, and Lumogen® F170. Advantageously, a layer comprising organic luminescent material may be transparent and non-scattering.

Optionally the wavelength converting member, for example a region or layer comprising a broad band emitting phosphor material, may comprise scattering elements. Examples of scattering elements include pores and scattering particles, such as particles of TiO_{2} or Al_{2}O_{3}.

The person skilled in the art realizes that the present invention by no means is limited to the preferred embodiments described above. On the contrary, many modifications and variations are possible within the scope of the appended claims.

Additionally, variations to the disclosed embodiments can be understood and effected by the skilled person in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measured cannot be used to advantage.
CLAIMS:

1. A light emitting arrangement (100) adapted to provide a total light output spectrum, comprising:
   - a solid state light source (101) adapted to emit primary light; and
   - a wavelength converting member (102) arranged to receive said primary light and comprising multiple types of quantum dots adapted to convert said primary light into secondary light, each type of quantum dot having a secondary light emission wavelength range providing a sub-range of the total light output spectrum,
     wherein a first type of quantum dot (Q1) is positioned to receive secondary light emitted by a second type of quantum dot (Q2), wherein said first type of quantum dot has an absorbance in its absorption wavelength range which is at least 10 times larger than the absorbance in the secondary light emission wavelength range of said second type of quantum dot.

2. A light emitting arrangement according to claim 1, wherein said wavelength converting member comprises said first type of quantum dot and said second type of quantum dot mixed within a single layer or comprised within different layers of a multi-layer stack.

3. A light emitting arrangement according to claim 1, wherein multiple types of quantum dots are mixed within a single layer, wherein each type of quantum dots has an absorbance in its respective absorption wavelength range which is at least 10 times larger than the absorbance in the secondary light emission wavelength range of another type of quantum dot.

4. A light emitting arrangement according to claim 1, wherein the wavelength converting member comprises a plurality of layers stacked in a light output direction from the solid state light source, wherein each layer comprises at least one type of quantum dot and wherein at least one distal layer with respect to the solid state light source comprises a type of quantum dot having an absorbance in its absorption wavelength range which is at least 10
times larger than the absorbance in the secondary light emission wavelength range of a type of quantum dot contained in a more proximal layer with respect to the light source.

5. A light emitting arrangement according to claim 1, wherein at least said first type of quantum dot has an absorbance in its absorption wavelength range which is at least 100 times larger than the absorbance in the secondary light emission wavelength range of said second type of quantum dot.

6. A light emitting arrangement according to claim 1, wherein the sub-range provided by a type of quantum dot does not overlap with any other sub-range provided by another type of quantum dot.

7. A light emitting arrangement according to claim 1, wherein the sub-range provided by each type of quantum dot overlaps with at least one other sub-range provided by another of said types of quantum dots.

8. A light emitting arrangement according to claim 1, further comprising a broad band emitting phosphor arranged to receive said primary light and capable of converting said primary light into secondary light, thereby providing a broad sub-range of the total light output spectrum.

9. A light emitting arrangement according to claim 8, wherein a sub-range provided by a type of quantum dot partially or completely overlaps with at least part of a sub-range provided by the broad band emitting phosphor, and said quantum dots within said sub-range provides secondary light of a higher intensity than the broad band emitting phosphor.

10. A light emitting arrangement according to claim 9, wherein the overlap is in a region of low emission intensity of the broad band emitting phosphor.

11. A light emitting arrangement according to claim 1, wherein the total light output spectrum includes all wavelengths of the range from 400 nm to 800 nm.

12. A light emitting arrangement according to claim 1, wherein said quantum dots have negligible absorption in the wavelength range above 500 nm.
13. A light emitting arrangement according to claim 1, wherein at least one type of quantum dots have a size in the range of from 1 to 10 nm in at least one direction.

14. A luminaire comprising a light emitting arrangement according to claim 1.

15. Use of multiple types of quantum dots having different secondary light emission ranges, each type of quantum dot having an absorbance in its respective absorption wavelength range which is at least 10 times larger than the absorbance in its respective secondary light emission wavelength range, for providing a continuous light output spectrum.
Fig. 1a

Fig. 1b
Fig. 2

Absorption vs. wavelength ($\lambda$) graph

Fig. 3

Diagram showing components labeled 100, 101, 102, L1, L2

Fig. 4

Diagram with labels Q1, Q2, Q3, Q4, Q5, L2, 101, 102
**INTERNATIONAL SEARCH REPORT**

**International application No**
PCT/IB2013/05238O

**A. CLASSIFICATION OF SUBJECT MATTER**

INV. H01L33/50

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

H01L F21K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

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<td>WO 2011/002509 AI (QIAO TIECHENG ALEX [US]; BATTAGLIA DAVID [US]; SUNDERRAJAN SURESH [US]) 6 January 2011 (2011-01-06) pages 5-11,20; claims 1-5</td>
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See patent family annex.

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**Date of the actual completion of the international search**
31 July 2013

**Date of mailing of the international search report**
08/08/2013

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