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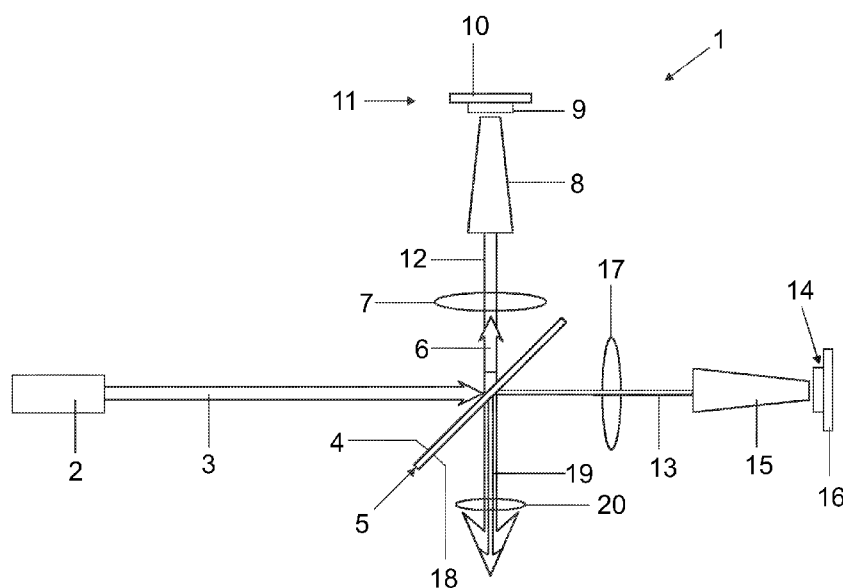
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(54) **Title:** LIGHTING APPARATUS WITH PHOSPHOR ELEMENT



(57) **Abstract:** The invention relates to a lighting apparatus (1) comprising an exciting light source (2), e.g. a blue laser diode array, for emitting exciting light (3, 6); a phosphor element (11) comprising a phosphor (9) for converting at least partially the exciting light into yellow light (12); a solid state light source (14), e.g. a blue LED, for emitting blue light (13); an optical system for guiding the exciting light onto the phosphor element and guiding and mixing the converted yellow light (12) and the blue light (13). The optical system may comprise a dichroic mirror (5) for reflecting blue light (3; 13) and transmitting yellow light (12).

Description

Lighting apparatus with phosphor element

Technical Field

The invention relates to a lighting apparatus comprising a phosphor element for converting exciting light into converted light.

Background of the Invention

5 For numerous lighting applications utilizing light guides, in particular for endoscopy, microscopy and medical headlamps, light sources with high colour rendering index (CRI) and high lumen output as well as high brightness are necessary. Traditionally, Xenon short-arc discharge lamps (e.g. OSRAM XBO®) with power input of several 10 100 W, embedded in optical reflectors, have been used. Due to the relatively high input power, limited lifetime with shifting luminous properties and adverse thermal impact on illuminated targets, there has been growing demand for alternative, more energy efficient 15 light sources. Solid state light sources such as light emitting diodes (LED) are becoming increasingly popular for general lighting applications. However, white LEDs do still not provide the high lumen output and brightness 20 needed for special lighting applications.

US 7,494,228 B2 discloses a light generating system for mixing different light colours from different LEDs or energized phosphors. Fig. 7 shows a system comprising an array of blue or UV LEDs 76 energizing a green phosphor 25 74 through a dichroic mirror 82. The converted green light is reflected by the dichroic mirror into a mixing

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tunnel 90. Furthermore, blue light emitted by an array of blue LEDs 92 and red light emitted by an array of red LEDs 98 are reflected by respective dichroic mirrors 96, 102 into the mixing tunnel 90. Accordingly, the green
5 light, blue light and red light are mixed in the mixing tunnel 90 and directed to the output port 104 of the mixing tunnel 90. The output port opening is matched to a light guide 52.

Description of the Invention

It is an object of the present invention to provide a
10 lighting apparatus, based on at least one solid state light source, suitable for lighting applications that require white light of high brightness.

It is also an aspect of the present invention to provide a solid state lighting apparatus suitable for technical
15 and medical light guide applications.

The object of the present invention is achieved by a lighting apparatus comprising: an exciting light source for emitting exciting light; a phosphor element comprising a phosphor for converting at least partially the exciting light into yellow light; a solid state light
20 source for emitting blue light; an optical system for guiding the exciting light onto the phosphor element and guiding and mixing the converted yellow light and the blue light.

25 Additional features of preferred embodiments are defined in the dependent claims.

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According to the present invention, converted yellow light, emitted by a phosphor layer when excited by exciting light, is mixed with blue light, emitted by at least one solid state light source, e.g. a laser diode or a
5 light emitting diode (LED) such as a blue high-power multi-chip LED, resulting in white light.

In the context of the present invention the term phosphor means any wavelength-converting substance such as a fluorescent or phosphorescent material. Furthermore, the
10 phosphor may also comprise more than one phosphor component, i.e. may be a mixture of two or more phosphor components.

To achieve lumen output as high as possible, the exciting light source may comprise at least one laser light
15 source, preferably a laser diode, a laser diode stack or an array of laser diodes. In the case of multiple laser light sources, each one may emit laser light having the same specific centre wavelength (for example 450 nm, 445 nm or 405 nm), i.e. all of the laser light sources are of
20 the same type. Alternatively, the exciting light may comprise a mixture of different centre wavelengths, i.e. multiple laser light sources of different type may be used.

Depending on the type of phosphor used, the exciting
25 light may be blue or violet or even ultraviolet light being converted to yellow light, i.e. light of longer wavelength ("down-converting"). According to a preferred embodiment, an array of laser diodes emits exciting light with wavelength of about 450 nm (blue light). The blue
30 laser light is at least partially wavelength-converted by

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a suitable phosphor, e.g. YAG:Ce or $(Y_{0.96}Ce_{0.04})_3 Al_{3.75} Ga_{1.25} O_{12}$, to yellow light having a broad spectral distribution with a peak at approximately 570 nm. Any other suitable phosphor emitting yellow light may be used or
5 even a mixture of two or more phosphor components, which as a whole emits yellow light. The wavelength-converted yellow light is mixed with blue LED light, e.g. with a wavelength of approximately 470 nm, resulting in white light.

10 The luminous properties, particularly the CRI, of the mixed light emanating from the lighting apparatus may be further improved by adding red and/or green light to the yellow and blue light. For this purpose the lighting apparatus may further comprise a red and/or green light
15 emitting LED and/or a supplemental phosphor element comprising a red light emitting phosphor, e.g. $(Sr,Ba,Ca)_2Si_5N_8$ or $CaAlSiN_3:Eu$, and/or green light emitting phosphor, e.g. $(Ba_{0.40}Eu_{0.60}Mn_{0.30})MgAl_{10}O_{17}$. The supplemental red and/or green light emitting phosphors may be
20 mixed with the yellow light emitting phosphor for emitting a converted mixed light, comprising yellow and red and/or green light. Finally, the converted mixed light is mixed with the blue light, emitted by the at least one solid state light source, resulting in mixed white light
25 with improved CRI.

Preferably, pre-adjusted values of the corresponding colour temperature (CCT), e.g. 5000 or 6000 K, and colour rendering index (CRI), e.g. min. 60, preferred min. 70, more preferred min. 80, of the mixed white light may be
30 achieved by adjusting and controlling the respective out-

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put powers of the exciting light source and the at least one blue LED.

According to a preferred embodiment, the phosphor element comprises a carrier member having a front face, whereby
5 the phosphor is arranged on the front face of the carrier member, e.g. as a phosphor layer. Advantageously, the carrier member is made from a material with suitable cooling properties, e.g. a metal such as copper, aluminium or the like, facilitating dissipation of the heat
10 generated by the exciting light when impinging on the phosphor layer. For further improved cooling the phosphor element may also be arranged on a rotating device. If the carrier member comprises a solid body, the wavelength-converted light is reflected off the phosphor element and
15 collected and mixed by an optical system ("reflective mode"). However, the carrier member may also comprise a light-transmissive sheet for transmitting the wavelength-converted light ("transmissive mode").

The optical system may comprise a dichroic mirror, having
20 a rear side and a front side, each of which, for example, may comprise interference layers. The rear side is adapted for reflecting the exciting light onto the phosphor element and transmitting the converted yellow light emerging from the phosphor element. The front side is
25 adapted for reflecting the blue LED light and transmitting the converted yellow light. Therefore, the converted yellow light is transmitted by the dichroic mirror, but the exciting light is blocked. This is particularly advantageous when using laser light for exciting the phosphor, because the resulting mixed white light is laser-
30 light-free, which may be relevant for certain applica-

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tions, particularly medical applications. Preferably, all the elements of the lighting apparatus are arranged and adjusted in such a way that the transmitted yellow light and the reflected blue LED light exit the lighting apparatus in the same direction, resulting in mixed white light, for further utilization, e.g. coupling into a light guide such as a glass fibre.

The optical system may further comprise a first optical element, arranged in front of the phosphor element, for guiding the exciting light onto the phosphor layer. This may help to avoid hot-spots on the phosphor layer, particularly when using high power laser light for exciting the phosphor. The converted yellow light is collected and guided by the first optical element in the direction of the rear side of the dichroic mirror. Furthermore, a second optical element may be arranged in front of the blue LED for guiding the blue LED light in the direction of the front side of the dichroic mirror. Each of the optical elements may be elongated and designed to transmit light by way of total internal reflection (TIR) along its longitudinal axis. Further optical elements, e.g. collimating lenses, may be beneficial for shaping the various light beams of the lighting apparatus. Further details will be explained in the description of the drawing.

Furthermore, two or more mixed white light beams, each emanating from separate lighting apparatus according to the invention, may be mixed in a modular manner to enhance lumen output.

Brief Description of the Drawing

A preferred embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawing in which:

Fig. shows a schematic top view of an embodiment of a
5 lighting apparatus according to the present invention.
tion.

Preferred Embodiment of the Invention

The only Fig. schematically shows a preferred embodiment of a lighting apparatus 1 according to the invention, designed for substituting a 300 W Xenon lamp in lighting
10 applications such as endoscopy, microscopy and medical headlamps.

A laser diode array 2, comprising 6 times 7 individual blue laser diodes (not shown), delivers a total laser output power of approximately 42 W. The blue laser beam
15 3, comprising 42 individual laser beams (not shown), which are arranged to form a 6 times 7 matrix array of laser beams, is being reflected by the rear side 4 of a dichroic mirror 5. For this purpose the rear side 4 of the dichroic mirror 5 comprises an interference coating
20 for reflecting blue light, but transmitting yellow light. The dichroic mirror 5 is tilted such that the angle of incidence of the incident blue collective laser beam 3 is approximately 45°. Therefore, the angle between the incident collective laser beam 3 and the reflected collective
25 laser beam 6 is approximately 90°. The reflected collective laser beam 6 passes a lens 7, which focuses the 42 individual laser beams on the 4 mm² entrance of a first

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TIR-optic 8. The first TIR-optic 8 guides the individual laser beams onto a phosphor layer 9 by virtue of total internal reflection, thus avoiding hot-spots on the phosphor layer 9. The TIR-optic 8 is of elongated and tapered shape, whereby the smaller end of the TIR-optic 8 faces the phosphor layer 9. The phosphor layer 9 is coated on a carrier member 10, constituting a phosphor element 11. The carrier member 10 is made of aluminium, because of its proper thermal properties. The phosphor layer 9 has a thickness of approximately 40 μm and consists of the yellow light emitting phosphor $(\text{Y}_{0.96}\text{Ce}_{0.04})_3 \text{Al}_{3.75} \text{Ga}_{1.25} \text{O}_{12}$. The phosphor layer 9 converts almost all (more than 95%) of the impinging blue collective laser beam 6 to yellow light, the latter of which is collected and guided by the TIR-optic 8. Beyond the TIR-optic 8 the yellow light beam 12 passes through and is being parallelized by the lens 7, thereby avoiding unacceptable deviations from the designated incidence angle of the dichroic mirror 5 and, hence, ensuring maximal transmission through its interference coating. The small unconverted remainder of the blue laser beam 6, which is scattered back is blocked by the rear side 4 of the dichroic mirror 5, thus avoiding risk to the human eye. Furthermore, a blue light beam 13, emerging from a blue LED 14 (LE B Q6WP from the company OSRAM Opto Semiconductor), is guided through a second TIR-optic 15, which is similar to the first one. The blue LED 14 is mounted on a cooling plate 16. After passing through and being parallelized by a second lens 17 the blue light beam 13 is reflected by the front side 18 of the dichroic mirror 5. For this purpose the front side 18 of the dichroic mirror 5 comprises an interference coating for transmitting the yellow light beam 12, but re-

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flecting the blue LED light 13. The LED light branch, comprising the blue LED 14, the second TIR-optic 15 and the second lens 17, is aligned with respect to the tilted dichroic mirror 5 such that the blue light beam 13 is re-
5 flected in the direction of the transmitted yellow light beam 12, resulting in a mixed white light beam 19. The mixed white light beam 19 is focused on the entrance aperture of a light guide (not shown) via a third lens 20. The lumen output achieved with the lighting apparatus 1
10 is approximately 2,600 lm.

Furthermore, means for adjusting and controlling the respective output powers of the laser diode array 2 and the blue LED 14 may be provided (not shown) for adjusting and controlling the corresponding colour temperature (CCT)
15 and colour rendering index (CRI) of the mixed white light beam. To this end, sensor elements (not shown) may be arranged for detecting light scattered from both TIR-optics. The signals of the sensors may be used for adjusting the input power of the laser diode array 2 and
20 the blue LED 14, respectively.

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Claims

1. A lighting apparatus (1) comprising:
 - an exciting light source (2) for emitting exciting light (3, 6);
 - a phosphor element (11) comprising a phosphor for
5 converting the exciting light (2) at least partially into yellow light (12);
 - a solid state light source (14) for emitting blue light (13);
 - an optical system for guiding the exciting light (3,
10 6) onto the phosphor element (11) and guiding and mixing the converted yellow light (12) and the blue light (13).
2. The lighting apparatus according to claim 1, wherein the optical system comprises a dichroic mirror (5)
15 having a rear side (4) and a front side (18), the rear side (4) being adapted for reflecting the exciting light (3) onto the phosphor element (11) and transmitting the converted yellow light (12) emerging from the phosphor element (11), the front side (18)
20 being adapted for reflecting the blue light (13) emanating from the solid state light source (14) and transmitting the converted yellow light (12).
3. The lighting apparatus according to claim 2, wherein the optical system further comprises a first optical
25 element (8), arranged in front of the phosphor element (11), for guiding the exciting light (6) onto the phosphor element (11) and collecting and guiding

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the converted yellow light (12) in the direction of the rear side (4) of the dichroic mirror (5).

4. The lighting apparatus according to claim 2 or 3, wherein the optical system further comprises a second optical element (15), arranged in front of the solid state light source (14), for guiding the blue light (13), emanating from the solid state light source, in the direction of the front side (18) of the dichroic mirror (5).
5. The lighting apparatus according to claim 3 or 4, wherein the optical element (8; 15) is elongated and designed to transmit light by way of total internal reflection (TIR) along its longitudinal axis.
6. The lighting apparatus according to any of the preceding claims, wherein the phosphor of the phosphor element (11) comprises $(Y_{0.96}Ce_{0.04})_3 Al_{3.75} Ga_{1.25} O_{12}$.
7. The lighting apparatus according to any of the preceding claims, wherein the phosphor of the phosphor element further comprises a red and/or green light emitting phosphor.
8. The lighting apparatus according to any of the preceding claims, wherein the exciting light is blue light (3, 6).
9. The lighting apparatus according to any of the preceding claims, wherein the exciting light source (2)

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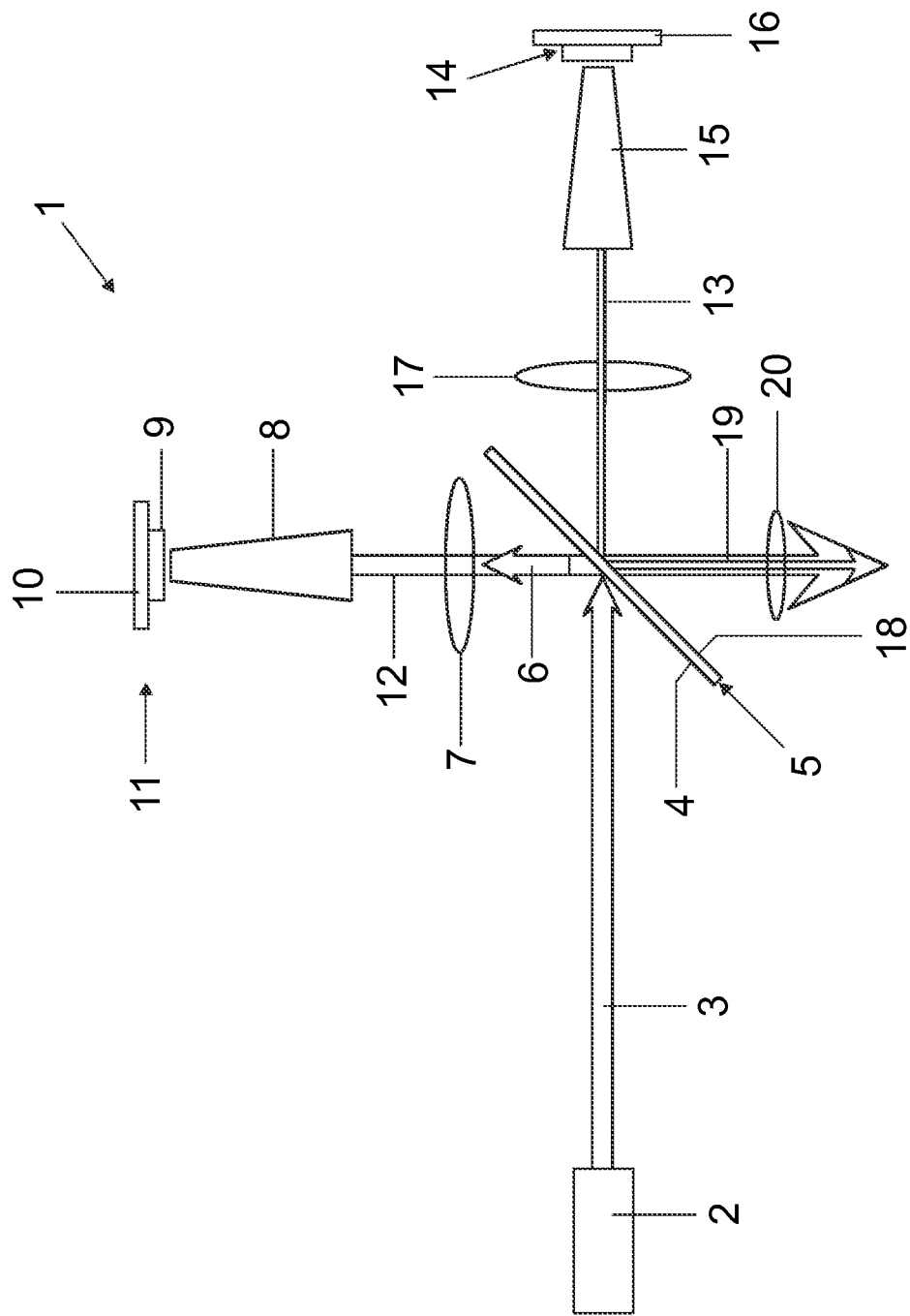
comprises a laser light source, particularly a laser diode, a laser diode bulk or a laser diode array.

10. The lighting apparatus according to any of the preceding claims, wherein the solid state light source
5 comprises a blue light emitting diode (LED).

11. The lighting apparatus according to any of the preceding claims, wherein the phosphor element (11) comprises a carrier member (10) having a front face, whereby the phosphor is arranged on the front face of
10 the carrier member (10).

12. The lighting apparatus according to claim 11, wherein carrier member comprises a rotating device.

13. The lighting apparatus according to any of the preceding claims, further comprising a control system
15 for achieving a pre-adjusted CRI by controlling and adjusting the respective output powers of the exciting light source and the solid state light source.



INTERNATIONAL SEARCH REPORT

International application No

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A. CLASSIFICATION OF SUBJECT MATTER

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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)

G03B H04N 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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/239717 A1 (CHEN HUI-PING [TW] ET AL) 2 October 2008 (2008-10-02) paragraph [0035] figure 8	1,6-13
X	----- EP 1 605 199 A2 (LUMILEDS LIGHTING LLC [US] PHILIPS LUMILEDS LIGHTING CO [US]) 14 December 2005 (2005-12-14) paragraph [0028] - paragraph [0036] figures 5,6	1,6,8-13
X	----- US 2006/227302 A1 (HARBERS GERARD [US] ET AL) 12 October 2006 (2006-10-12) paragraph [0048] - paragraph [0054] figures 6-10 -----	1,6,8-13



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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