(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
18 October 2012 (18.10.2012)

WIPO | PCT

(10) International Publication Number
WO 2012/139644 A1

(51) International Patent Classification: *F21K 99/00* (2010.01)

(21) International Application Number: PCT/EP2011/055851

(22) International Filing Date: 13 April 2011 (13.04.2011)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant (*for all designated States except US*): **OSRAM AG** [DE/DE]; Hellabrunner Str. 1, 81543 München (DE).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **BERBEN, Dirk** [DE/DE]; Hochstr. 48B, 86399 Bobingen (DE). **MORGENBROD, Nico** [DE/DE]; Wulfsheinstr. 2, 10585 Berlin (DE). **HARTWIG, Ulrich** [DE/DE]; Driesener Str. 6, 10439 Berlin (DE).

(74) Common Representative: **OSRAM AG**; Intellectual Property IP, Postfach 22 13 17, 80503 München (DE).

(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) Title: METHOD FOR MANUFACTURING A PHOSPHOR DEVICE AND LIGHTING APPARATUS COMPRISING SUCH PHOSPHOR DEVICE

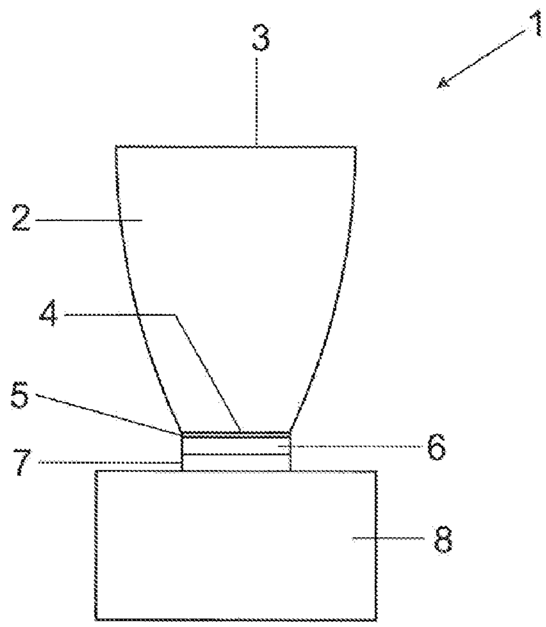

FIG 1

(57) Abstract: According to the present invention, the phosphor layer (6) of a phosphor device (1) is deposited on a coating electrode (5), attached to its optical transmitting member (2), by virtue of electrophoretic deposition (EPD). Due to EPD, the thickness of the phosphor layer can be controlled precisely which is relevant to the efficiency of the phosphor device. The optical transmitting member (2) is designed for receiving exciting light, e.g. laser light, through its first end face (3), guiding it to the phosphor layer (6). The exciting light is being converted by the phosphor layer (6) to wavelength-converted light. The converted light is collected and guided by the transmitting member (2), finally leaving its first end face (3) for further use. The optical transmitting member (2) is made of optically transparent material with good thermal properties to facilitate heat transfer from the phosphor layer (6). The heat transfer may be further improved by attaching a heat sink (8) to the phosphor layer (6) by way of heat transfer paste (7).

WO 2012/139644 A1

Description

Method for manufacturing a phosphor device and lighting apparatus comprising such phosphor device

Technical Field

The invention relates to a phosphor device, particularly to a method for manufacturing a phosphor device. Furthermore, the invention relates to a lighting apparatus comprising such phosphor device.

Background of the Invention

Phosphor devices are used in lighting apparatus wherein the phosphor (component or mixture), i.e. a substance with wavelength-converting properties, e.g. a fluorescent or luminescent substance, is remote from the exciting light source. Therefore, they are also called remote phosphor devices. Remote phosphor devices can be used in various lighting applications, e.g. in RGB projection equipment, generating red (R), green (G) and blue (B) light for coloured video projection. Other possible lighting applications comprise medical, architectural or entertainment lighting with coloured or white light.

In prior art remote phosphor devices, such as phosphor wheels or LED based illumination devices, a carrier plate or an optical transmitting member is coated with phosphor. The phosphor is excited by exciting light, e.g. visible blue laser light (450 nm), impinging on the phosphor layer. The exciting laser light is wavelength-converted by the phosphor to generate light with longer wavelengths (e.g. broad spectral distribution with a peak at approximately 520 nm for green light).

The wavelength-converted light from the phosphor is collected by an optical transmitting member, e.g. an optical collimator such as a lens made of glass or a compound parabolic concentrator (CPC) or a compound elliptical concentrator (CEC) etc., arranged in front of the phosphor.

In U.S. Patent No. 7,543,959 an illumination system comprising a light source and an optical concentrator coated with phosphor is disclosed. Exiting light from the light source, e.g. a light emitting diode (LED), enters the optical concentrator on its larger end face and is concentrated towards its smaller end face. The smaller end face is coated with a phosphor layer, which is exited by the concentrated exiting light. The exiting light is wavelength-converted by and transmitted through the phosphor layer ("transmissive mode" phosphor device).

Description of the Invention

It is an object of the present invention to provide a method for manufacturing a phosphor device.

The object of the present invention is achieved by a method for manufacturing a phosphor device comprising the steps: providing an optical transmitting member having a first end face and a second end face, whereby the optical transmitting member is designed for guiding exciting light entering through the first end face onto a phosphor layer arranged on the second end face, whereby at least a part of the exciting light is being wavelength-converted by the phosphor layer, and whereby the optical transmitting member is further designed for at least partially collecting and guiding the light converted by the phosphor layer; attaching an optically transparent electrode on the second end face of the optical transmitting member; providing a phosphor and a counter-electrode designed for electrophoretic deposition of the phosphor; depositing a phosphor layer on the optically transparent electrode by means of electrophoretic deposition (EPD), thereby using the optically transparent electrode as a coating electrode.

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

Furthermore, protection is sought for a lighting apparatus comprising the phosphor device manufactured according to the present invention.

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

According to the present invention, the phosphor layer of a phosphor device is deposited on the coating electrode attached to its optical transmitting member by virtue of electrophoretic deposition (EPD). The thickness of the phosphor layer, which is relevant to the efficiency of the phosphor device, can be controlled precisely by the EPD process. The concept of coating the phosphor directly onto a coating electrode of the optical transmitting member facilitates dissipation of the heat generated by the exciting light when impinging on the phosphor layer, because there is no air gap preventing the effective transfer of heat to the optical transmitting member. For improved heat dissipation the optical transmitting member may preferably comprise a thermally conductive though optically transparent material, e.g. Al_2O_3, YVO_4, YLF or sapphire.

The coating electrode for depositing the phosphor layer must be transparent for the exciting light in order to enable the exciting light, guided by and leaving the optical transmitting member through its second end face, to pass the coating electrode and impinge on the phosphor layer. An appropriate coating electrode may be achieved by coating a transparent, electrically conductive layer on the outer surface of the second end face of the optical transmitting member. The electrically conductive layer may comprise tin oxide (TO), indium tin oxide (ITO), aluminium zinc oxide, a metal mono layer or graphene. Since very small current densities, typically several mA/mm^2 are sufficient for the deposition of the phosphor layer, the thickness of the electrically conductive layer may typically be in the range of several nm to several tenth of nm. Alternatively, an appropriate optically transparent electrode may be achieved by placing a wire mesh on the second end face of the optical transmitting member. Because the coating electrode has to support only small currents during deposition of the phosphor, the wire diameter can be sufficiently small to facilitate appropriate mesh size and, hence, transparency.

The optically transparent coating electrode may also be separated into adjacent, separately controllable coating electrode zones, resulting in separated, adjacent phosphor zones. By virtue of this measure, different phosphor components, e.g. a red (R), a green (G) and a blue (B) light emitting phosphor may be subsequently deposited on respective electrode zones. When excited with ultraviolet (UV) radiation, for example, the converted red, green and blue light fractions may be collected and mixed by the optical transmitting member, resulting in mixed white light.

The phosphor may be deposited on the transparent coating electrode by standard aqueous EPD with the phosphor suspended in water. This coating bath may be hold in a container also serving as the counter-electrode. By applying a DC voltage between the coating electrode and the counter-electrode, a phosphor layer is deposited on the transparent coating electrode while being submerged into the coating bath.

The optical transmitting member may be designed for transmitting light and, as the case may be, for mixing fractions of light of different colour by way of total internal reflection (TIR) between its first end face and second end face. For this purpose, the optical transmitting member may be elongated and have a polygonal cross section, particularly a triangular, rectangular or hexagonal cross section.

The method for manufacturing a phosphor device according to the present invention may further comprise the step of arranging a reflective means on the back side of the phosphor layer, i.e. reverse to the side facing the optically transparent electrode and, likewise, reverse to the side facing the impinging exciting light. Preferably, the reflective means comprises TiO_2, because its reflectivity for light is approximately 98%, which is remarkably high compared to 88-90% of a typical aluminium mirror. Due to this measure the light converted by the phosphor layer is effectively reflected towards the optically transparent electrode and, hence, the second end face of the optical transmitting member. The optical transmitting member collects the converted light through its second end face and guides it to its first end face for further use.

To further improve heat dissipation a heat sink may be attached to the back side of the phosphor layer by virtue of a heat transfer paste. Preferably, the heat transfer paste may contain TiO_2 as filler to add diffuse reflective properties to the paste.

The phosphor device manufactured according to the present invention may be part of a lighting apparatus, further comprising at least one exciting light source, e.g. a laser, preferably a laser diode or a laser diode array, for emitting exciting light. The phosphor device and the exciting light source are arranged such that the exciting light is enabled to enter the phosphor device through the first end face of the optical transmitting member. After passing through the second end face of the optical transmitting member and the optically transparent electrode, the exciting light impinges on the phosphor layer where it is at least partially being wavelength-converted by the phosphor. The wavelength-converted light is collected and mixed (spatially and, as the case may be, in terms of colours) by the optical transmitting member after entering its second end face. Finally, the mixed light leaves the optical transmitting member through the first end face. The mixed light may be guided and shaped by additional optical devices for further use in various applications. Further details will be explained in the description of the drawings.

Brief Description of the Drawings

Embodiments of the present invention will now be described, by way of example, with reference to the accompanying drawings in which:

Fig. 1 is a side view of an embodiment of a phosphor device manufactured according to the present invention;

Fig. 2a is a side view of an optical transmitting member comprising an optically transparent electrode;

Fig. 2b is a schematic view of the optical transmitting member shown in Fig. 1a and submerged into an EPD bath;

Fig. 2c shows the optical transmitting member after the phosphor layer is applied by means of EPD;

Fig. 3 shows a lighting apparatus comprising a phosphor device as shown in Fig. 1.

Preferred Embodiments of the Invention

Fig. 1 schematically shows an embodiment of a phosphor device 1 manufactured according to the present invention. The phosphor device comprises an elongated optical transmitting member 2 having a first end face 3 and a second end face 4, a transparent coating electrode 5 attached on the outer surface of the second end face 4, a phosphor layer 6 deposited on the transparent electrode 5, a reflective means 7 attached on the back side of the phosphor layer 6 and a heat sink 8 coupled to the reflective means 7.

The manufacturing of the phosphor device shown in Fig. 1 is explained with reference to the Figs. 2a-2c, showing different steps of the manufacturing. The same reference numerals are used for the same or similar features.

In Fig. 2a the optical transmitting member 2 is shown. It is formed as a CPC with a hexagonal cross section and is made of solid YVO_4, because of its superior optical as well as thermal properties. The thermal properties of YVO_4facilitate heat transfer from the phosphor layer while being excited by exciting light. Of course, other material with similar optical and thermal properties could be used. The second end face 4 of the optical transmitting member 2 is being coated with a transparent indium tin oxide (ITO) layer 5 of less than 100 nm thickness.

Next, the electrophoretic deposition (EPD) of the phosphor layer is explained. As schematically shown in Fig. 2b the second end face 4 of the optical transmitting member 2 is submerged into a coating bath 9 held by a container 10. The coating bath 9 comprises a suspension of a phosphor, e.g. the yellow light emitting phosphor $(Y_{0.96}Ce_{0.04})_3 Al_{3.75} Ga_{1.25} O_{12}$. The ITO layer 5 is connected to a DC voltage source U designed for generating an electrical field of typically several V/mm to several hundred V/mm, thereby serving as the transparent coating electrode of the EPD process. A counter-electrode 11 submerged into the coating bath 9 and arranged opposite to the coating electrode 5 is also connected to the DC voltage source U. The counter-electrode 11 has the same shape as the coating electrode 5, but is of smaller size to reduce inhomogeneity of the electrical field and, hence, avoid increased phosphor deposition at the edge of the coating electrode. After the EPD process is complete, the phosphor layer 6 is deposited on the ITO layer 5 (Fig. 2c). The thickness of the phosphor layer 6 is approximately 40 μm, but may differ for other phosphors.

Finally, the heat sink 8 is attached to the coated optical transmitting member 2 using a heat transfer paste 7 which results in the finished phosphor device 1 shown in Fig. 1. The paste 7 contains TiO_2 as filler to add diffuse reflectivity to the thermal properties. For certain applications the phosphor device 1 shown in Fig. 1 but without heat sink or even without reflective means may be appropriate.

Fig. 3 shows a schematic view of a lighting apparatus 20 comprising a phosphor device 1 as shown in Fig. 1. The lighting apparatus 20 further comprises at least one laser diode 22, emitting exciting light 23 of a wavelength of about 450 nm, and a dichroitic mirror 24 arranged on the optical axis between the laser diodes 22 and the phosphor device 1. For high power applications, the exciting light source may be a laser array with more than 1 W of laser beam power for each laser diode. The exciting light 23 passes through the dichroitic mirror 24, enters the phosphor device 1 through the first end face 3 of the optical transmitting member 2 and is received by the phosphor layer (not shown) EPD-coated on its second face. The light wavelength-converted by the excited phosphor layer is collected and mixed by the optical transmitting member 2. The mixed light exits the first end face 3 of the optical transmitting member 3 and is transmitted to the dichroitic mirror 24. The dichroitic mirror 24 is tilted to reflect the mixed wavelength-converted light off the optical axis defined by the beam of the diode laser 22. Depending on the specific application, e.g. entertainment lighting with coloured, further optical elements may be involved.

Claims

1. Method for manufacturing a phosphor device (1) comprising the steps:

   providing an optical transmitting member (2) having a first end face (3) and a second end face (4), whereby the optical transmitting member (2) is designed for guiding exciting light entering through the first end face (3) onto a phosphor layer (6) arranged on the second end face (4), whereby at least a part of the exciting light is being wavelength-converted by the phosphor layer (6), and whereby the optical transmitting member (2) is further designed for at least partially collecting and guiding the light converted by the phosphor layer (6);

   attaching an optically transparent electrode (5) on the second end face (4) of the optical transmitting member (2);

   providing a phosphor (9) and a counter-electrode (10) designed for electrophoretic deposition of the phosphor (9);

   depositing a phosphor layer (6) on the optically transparent electrode (5) by means of electrophoretic deposition, thereby using the optically transparent electrode (5) as a coating electrode.

2. The method according to claim 1, wherein the attaching of the optically transparent coating electrode (5) is performed by coating an optically transparent,

electrically conductive layer on the second end face (4) of the optical transmitting member (2).

3. The method according to claim 1, wherein the thickness of the electrically conductive layer (5) is in the range of several nm to several tenth of nm.

4. The method according to claim 2 or 3, wherein the layer (5) comprises tin oxide (TO), indium tin oxide (ITO), aluminium zinc oxide, a metal mono layer or graphene.

5. The method according to claim 1, wherein the attaching of the optically transparent electrode is performed by placing a wire mesh on the second end face of the optical transmitting member.

6. The method according to any of the preceding claims, further comprising the step of submerging the optical transmitting member (2) with the coating electrode (5) and additionally a counter-electrode (11) into a coating bath (9), and the latter comprising the phosphor for the phosphor layer (6).

7. The method according to any of the preceding claims, wherein the optical transmitting member (2) comprises an optically transparent and thermally conductive material, particularly Al_2O_3, YVO_4, YLF or sapphire.

8. The method according to any of the preceding claims, wherein the optical transmitting member (2) is de-

signed to transmit light by way of total internal reflection (TIR) between its first end face (3) and second end face (4).

9. The method according to any of the preceding claims, wherein the optical transmitting member (2) is elongated and has a polygonal cross section, particularly a triangular, a rectangular or a hexagonal cross section.

10. The method according to any of the preceding claims, wherein the phosphor comprises a phosphor component or a phosphor mixture.

11. The method according to any of the preceding claims, wherein the optically transparent coating electrode is being separated into adjacent, separately controllable electrode zones, resulting in separated adjacent phosphor zones.

12. The method according to any of the preceding claims, further comprising the step of arranging a reflective means (7) on the side of the phosphor layer (6) reverse to the side facing the optically transparent electrode (5).

13. The method according to claim 11, wherein the reflective means (7) comprises TiO_2.

14. The method according to any of the preceding claims, further comprising the step of arranging a heat sink

(8) on the side of the phosphor layer (6) reverse to the side facing the optically transparent coating electrode (5).

15. A Lighting apparatus (20) comprising:

a phosphor device (1) manufactured according to any of the preceding claims;

an exciting light source (22) for emitting exciting light (23);

whereby the phosphor device (1) and the exciting light source (22) are designed and arranged such that the exciting light (23) is enabled to enter the phosphor device (1) through the first end face (3) of the optical transmitting member (4).

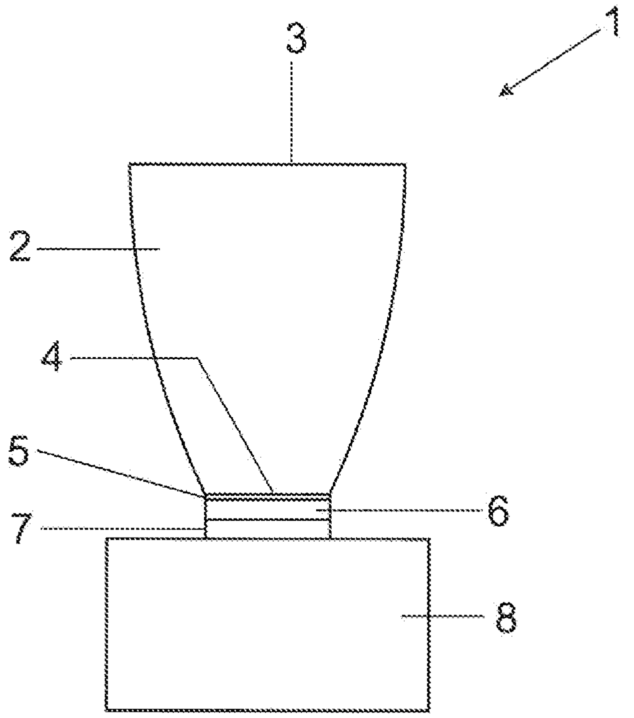

FIG 1

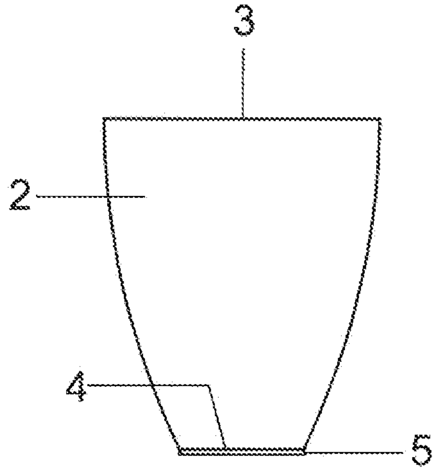

FIG 2a

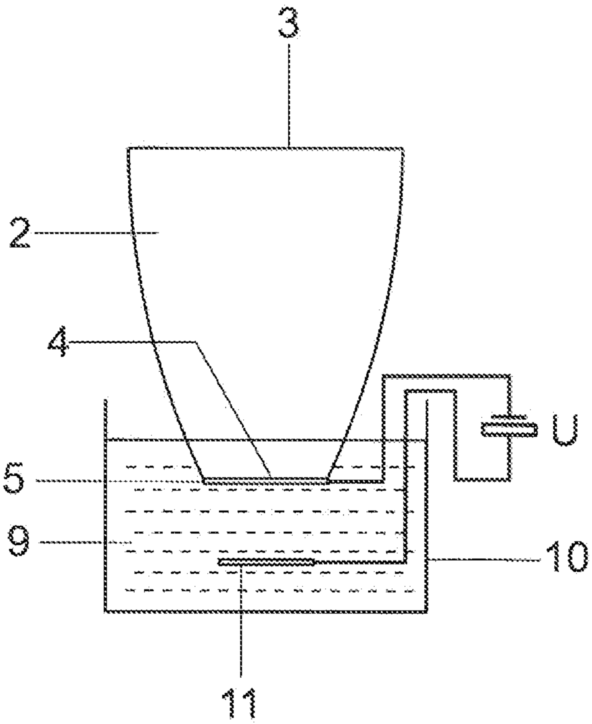

FIG 2b

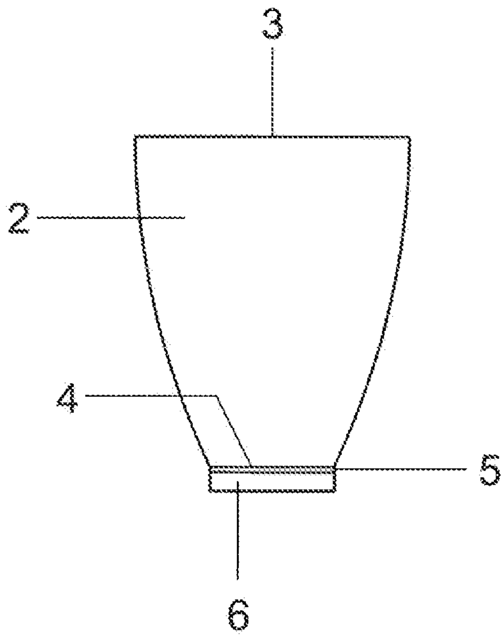

FIG 2c

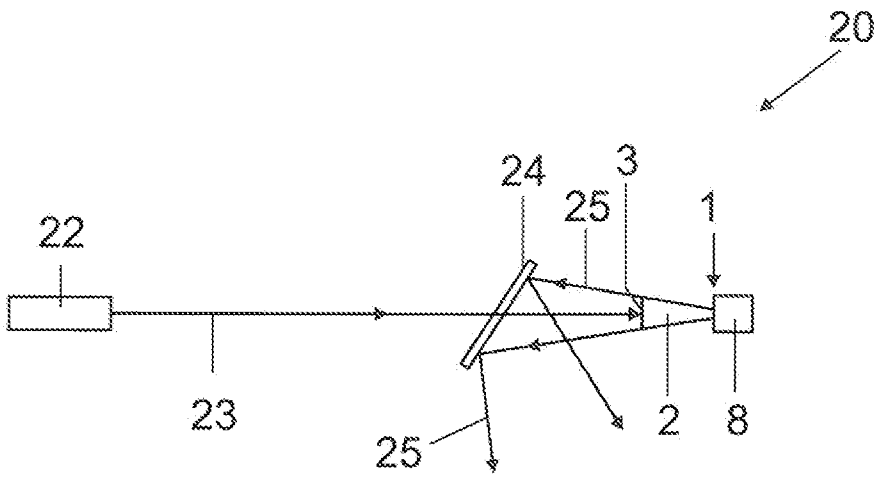

FIG 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/055851

A. CLASSIFICATION OF SUBJECT MATTER
INV. F21K99/00
ADD.

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)
F21K H04N

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.
Y	US 2007/146639 A1 (CONNER ARLIE R [US]) 28 June 2007 (2007-06-28) paragraphs [0041], [0072]; figure 3 -----	1-15
Y	US 4 482 447 A (MIZUGUCHI JIN [JP] ET AL) 13 November 1984 (1984-11-13) column 3, line 19 - line 40 -----	1-15
A	WO 2009/105198 A2 (LIGHT PRESCRIPTIONS INNOVATORS [US]; FALICOFF WAQIDI [US]; CHAVES JULI) 27 August 2009 (2009-08-27) paragraphs [0021], [0022], [0027] -----	1-15

☐ 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
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"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

Date of the actual completion of the international search	Date of mailing of the international search report
17 October 2011	26/10/2011

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Pigniez, Thierry

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2011/055851

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2007146639 A1	28-06-2007	CN 101361022 A	04-02-2009
		EP 1963915 A1	03-09-2008
		JP 2009521786 A	04-06-2009
		KR 20080083180 A	16-09-2008
		WO 2007075661 A1	05-07-2007
US 4482447 A	13-11-1984	AU 568089 B2	17-12-1987
		AU 1903983 A	22-03-1984
		CA 1195809 A1	29-10-1985
		DE 3333251 A1	22-03-1984
		FR 2532957 A1	16-03-1984
		GB 2127850 A	18-04-1984
		JP 1287832 C	14-11-1985
		JP 59050200 A	23-03-1984
		JP 60010120 B	15-03-1985
WO 2009105198 A2	27-08-2009	CN 102016402 A	13-04-2011
		EP 2245364 A2	03-11-2010
		US 2009225529 A1	10-09-2009