

(43) International Publication Date
18 September 2014 (18.09.2014)

(51) International Patent Classification:

G03B 21/20 (2006.01) H04N 9/31 (2006.01)
G03B 33/12 (2006.01) G03B 21/56 (2006.01)

(21) International Application Number:

PCT/US2013/063032

(22) International Filing Date:

2 October 2013 (02.10.2013)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

PCT/IB2013/000374 13 March 2013 (13.03.2013) IB

(71) Applicant: PANASONIC CORPORATION [JP/JP];
1006 Oaza Kadoma, Kadoma-shi, Osaka, 571-8501 (JP).(72) Inventors: LETO, Riccardo; 2 Wells Avenue, Newton,
MA 02459 (US). MIZUYAMA, Yosuke; 2 Wells Avenue,
Newton, MA 02459 (US). LU, Zhou; 2 Wells Avenue,
Newton, MA 02459 (US).(74) Agent: ASHERY, Lawrence, E.; RatnerPrestia, P.O. Box
980, Valley Forge, PA 19482 (US).(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, BN, 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, 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, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
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, RW, SD, SL, SZ, TZ,
UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, 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,
KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report (Art. 21(3))

(54) Title: MICRO PHOSPHOR ELEMENTS AND METHODS FOR MANUFACTURING THE SAME

100

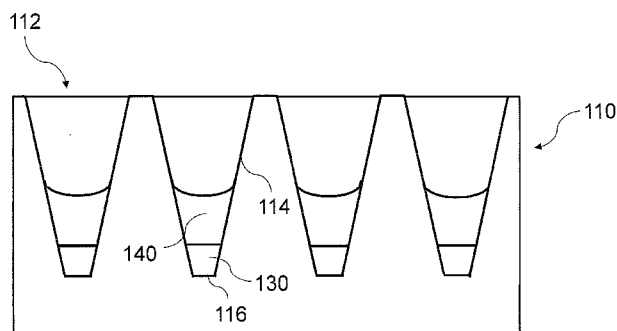


FIG. 1B

(57) Abstract: Phosphor elements for a projection light source and methods of manufacturing phosphor elements are disclosed. A phosphor element (100) comprises a substrate (110) and a layer of phosphor material (130). The substrate has an array of blind microholes (112) in a surface thereof. The layer of phosphor material (130) is provided on a bottom surface (116) of each of the microholes (112). The layer of phosphor material (130) is formed such that no phosphor material is deposited on a wall (114) of the respective microhole (112) above an uppermost continuous surface of the respective layer of phosphor material. The phosphor element is manufactured by fabricating a substrate having an array of blind microholes in a surface thereof, and depositing a layer of phosphor material on a bottom surface of each of the microholes such that no phosphor material is deposited on a wall of the respective microhole above an uppermost continuous surface of the respective layer of phosphor material.

~ 1 ~

MICRO PHOSPHOR ELEMENTS AND FABRICATION METHODS OF MICRO PHOSPHOR
ELEMENTS

FIELD OF THE INVENTION

The invention relates generally to phosphor elements for use in
5 projection light sources of image projectors or headlamps.

BACKGROUND OF THE INVENTION

In recent years, there has been a desire to create more compact image
projectors. Commonly, image projectors have been used only in a limited number of
applications (cinema, business presentation meetings, lectures etc...) because of their
10 size and power requirements. Due to these requirements, it is generally practical to
use image projectors only in fixed configurations (on a ceiling shelf, on a separate
projection room etc...).

The recent interest in more compact image projectors has resulted in
projectors that use non-traditional sources of illumination, such as LED or laser
15 sources. These relatively newer illumination sources bring with them a whole new set
of problems. For example, projectors utilizing laser illumination sources may create an
optical effect called "speckle" which is annoying/disturbing to the human eye.

One way to overcome the problems deriving from these newer light
sources is to obtain the necessary colors (red, green, and blue) by illuminating three
20 different types of phosphors with laser light. This phosphor emission does not create
speckle, and allows the use of a single high power laser. Due to the potential for the
use of phosphor emission in newer image projectors, improvements in phosphor
elements for use in image projectors are desired.

SUMMARY OF THE INVENTION

25 Aspects of the present invention are directed to phosphor elements and
methods of manufacturing phosphor elements.

In accordance with one aspect of the present invention, a method of
manufacturing a phosphor element for a projection light source is disclosed. The
method comprises fabricating a substrate having an array of blind microholes in a
30 surface thereof, and depositing a layer of phosphor material on a bottom surface of
each of the microholes such that no phosphor material is deposited on a wall of the
respective microhole above an uppermost continuous surface of the respective layer of
phosphor material.

In accordance with another aspect of the present invention, a phosphor
35 element for a projection light source is disclosed. The phosphor element comprises a
substrate and a layer of phosphor material. The substrate has an array of blind

~ - 2 - ~

microholes in a surface thereof. The layer of phosphor material is provided on a bottom surface of each of the microholes. The layer of phosphor material is formed such that no phosphor material is deposited on a wall of the respective microhole above an uppermost continuous surface of the respective layer of phosphor material.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is best understood from the following detailed description when read in connection with the accompanying drawings, with like elements having the same reference numerals. When a plurality of similar elements are present, a single reference numeral may be assigned to the plurality of similar elements with a small letter designation referring to specific elements. When referring to the elements collectively or to a non-specific one or more of the elements, the small letter designation may be dropped. According to common practice, the various features of the drawings are not drawn to scale unless otherwise indicated. To the contrary, the dimensions of the various features may be expanded or reduced for clarity. Included in the drawings are the following figures:

FIG. 1A is a diagram illustrating a top view of an exemplary phosphor element in accordance with aspects of the present invention;

FIG. 1B is a diagram illustrating a cross-sectional side view of the exemplary phosphor element of FIG. 1A;

FIG. 2 is a diagram illustrating an exploded cross-sectional side view of an alternative embodiment of the phosphor element of FIG. 1A;

FIG. 3 is a diagram illustrating an exemplary method for manufacturing a phosphor element in accordance with aspects of the present invention;

FIGS. 4A-4C are diagrams illustrating one process for depositing a layer of phosphor material in accordance with aspects of the present invention;

FIGS. 5A-5C are diagrams illustrating another process for depositing a layer of phosphor material in accordance with aspects of the present invention; and

FIGS. 6A-6B are diagrams illustrating yet another process for depositing a layer of phosphor material in accordance with aspects of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The embodiments of the invention described herein relate to improved phosphor elements for use in projection light sources. These phosphor elements include phosphor material that is used to create a full color spectrum during projection of an image. While the embodiments of the present invention are described herein with respect to use in image projectors, other uses for the disclosed phosphor elements like headlamps and headlights will be readily apparent to those of ordinary skill in the art.

~ - 3 - ~

The embodiments of the invention described herein are particularly advantageous due to their precise localization of the phosphor material. The disclosed phosphor elements comprise an array of microholes in which the phosphor materials may be precisely placed. Additionally, the disclosed embodiments are particularly
5 advantageous due to their ability to precisely focus the light from the phosphor material using reflective material on the walls of the microholes. The disclosed methods also enable simple and cost-effective processes for fabricating the phosphor elements described herein.

Referring now to the drawings, FIGS. 1A and 1B illustrate an exemplary
10 phosphor element 100 in accordance with aspects of the present invention. Phosphor element 100 may be usable in an projection light source. As a general overview, phosphor element 100 includes a substrate 110 and a layer of phosphor material 130. Additional details of phosphor element 100 are described herein.

Substrate 110 forms the basis of phosphor element 100. As shown in
15 FIGS. 1A and 1B, substrate 110 has an array of blind microholes 112 formed in an upper surface thereof. It will be understood by one of ordinary skill in the art that the number and layout of microholes 112 shown in FIG. 1A is for the purpose of illustration, and is not intended to be limiting. Substrate 110 may include any number and layout of microholes 112 as necessary to produce a desired light emission using phosphor
20 element 100.

Preferably, substrate 110 comprises a material that effectively dissipates/transmits heat, and is a good reflector. Accordingly, substrate 110 may comprise a metallic, reflective material. In one exemplary embodiment, all or a portion of substrate 110 is formed from reflective material. Where only a portion of substrate
25 110 is formed from reflective material, it is desirable that the portion of substrate 110 forming walls 114 of microholes 112 be formed from the reflective material. In another exemplary embodiment, substrate 110 is formed from a non-reflective material that is at least partially coated with a reflective material. Where substrate 110 is only partially coated with reflective material, it is desirable that the parts of substrate 110 forming
30 walls 114 of microholes 112 be coated with the reflective material. Suitable reflective materials for use with the present invention include, for example, silver, aluminum, stainless steel, and/or alloys or combinations thereof. Suitable non-reflective materials for forming an inner portion of substrate 110 include, for example, nickel and/or nickel alloys. Other suitable reflective and non-reflective materials will be known to one of
35 ordinary skill in the art from the description herein.

Microholes 112 are shaped and sized to promote the emission of light from the phosphor material in a given direction away from substrate 110. In an

~ - 4 - ~

exemplary embodiment, the diameter at the top of each microhole 112 is larger than the diameter along the bottom surface 116 of each microhole 112, as shown in FIG. 1B. For example, microholes 112 may have a conical shape, a pyramidal shape, a tetrahedral shape, or a combination of such shapes. The diameter at the top of each
5 microhole 112 may be between approximately 300-600 microns. The diameter at the bottom of each microhole 112 may be approximately 100 microns. Microholes 112 may be approximately 1-2 mm deep in substrate 110, and may be spaced such that there are between approximately 10-100 microns between each microhole 112.

Substrate 110 may be formed from one or more separate pieces. In one
10 exemplary embodiment, substrate 110 comprises a unitary piece of material, as shown in FIG. 1B (e.g., a single piece of reflective material). In another exemplary embodiment, substrate 110 comprises two or more pieces of material attached via an adhesive. A substrate formed from two or more pieces of material is shown in FIG. 2. As shown in FIG. 2, substrate 110 comprises a frame portion 118 in which the array of
15 microholes 112 are formed. Substrate 110 also comprises a base portion 120 which is formed as a flat piece of material. Base portion 120 may then be adhered to frame portion 118 such that an upper surface of base portion 120 forms the bottom surface 116 of each of the microholes 112. Base portion 120 may be adhered to frame portion 118 with a layer of adhesive (not shown). Suitable adhesives for attaching base
20 portion 120 to frame portion 118 will be known to one of ordinary skill in the art from the description herein.

In one exemplary embodiment of substrate 110, frame portion 118 and base portion 120 are formed from different materials. For example, frame portion 118 comprises a reflective material (such as any of the reflective materials set forth above),
25 and base portion 120 comprises either the same reflective material or a transmissive material. Suitable optically transmissive materials for use as base portion 120 include, for example, glass. Other suitable transmissive materials will be known to one of ordinary skill in the art from the description herein. This embodiment of phosphor
30 element 100 may be particularly desirable in order to allow excitation of the phosphor material in microholes 112 by a laser positioned below the bottom surface of substrate 110 (i.e., in order to allow excitation of the phosphor material by transmitting the laser beam through base portion 120).

In the above-described embodiment, base portion 120 may further comprise a dichroic mirror layer 122 formed on the surface of base portion 120 forming
35 the bottom surface 116 of each microhole 112 (i.e., the upper surface of base portion 120, as shown in FIG. 2). The use of dichroic mirror layer 122 may be particularly desirable to allow transmission of the laser beam through base portion 120 to the

~ - 5 - ~

phosphor material in microholes 112, while reflecting light emitted by the phosphor material out toward the top of microholes 112.

The layer of phosphor material 130 is provided on the bottom surface 116 of each microhole 112. The layer of phosphor material 130 includes a plurality of nano- or micro-scale phosphor grains that are configured to absorb light from an illumination source (e.g., a laser) and re-emit light at optical wavelengths (e.g., red, green, or blue light). As shown in FIG. 1B, the layer of phosphor material 130 in each of the microholes 112 may have a substantially uniform height and volume. The layer of phosphor material may have a height of approximately 100 microns. The layer of phosphor material 130 is formed in each microhole 112 such that no phosphor material is deposited on walls 114 of the respective microhole 112 above an uppermost continuous surface of the layer of phosphor material 130. In other words, no phosphor material contacts the walls 114 of the microholes 112 except the material forming part of the layer 130. Processes for forming the layer of phosphor material 130 such that no phosphor material is deposited on walls 114 are described in greater detail herein.

Phosphor element 100 is not limited to the above-described features, but may include alternative or additional features that would be understood to those of ordinary skill in the art.

For example, phosphor element 100 may further comprise a plurality of optical elements 140. Optical elements 140 may be provided in each of the microholes 112 on top of the layer of phosphor material 130. In an exemplary embodiment, optical elements 140 comprise refractive lenses. Other suitable optical elements will be known to one of ordinary skill in the art from the description herein. Optical elements 140 may be provided in phosphor element 100 in order to further promote the emission of light from the phosphor material in a given direction away from substrate 110.

FIG. 3 illustrates an exemplary method 200 for manufacturing a phosphor element in accordance with aspects of the present invention. The manufactured phosphor element may be usable in a projection light source. As a general overview, method 200 includes fabricating a substrate and depositing a layer of phosphor material. Additional details of method 200 are described herein with respect to the components of phosphor element 100.

In step 210, a substrate is fabricated. In an exemplary embodiment, substrate 110 is fabricated. As set forth above, substrate 110 has an array of blind microholes 112 formed in a surface thereof. Microholes 112 are shaped and sized to promote the emission of light from the phosphor material in a given direction away from substrate 110. The array of blind microholes 112 may be formed using any of the processes described below.

~ - 6 - ~

In an exemplary embodiment, step 210 comprises electroforming the substrate on a negative mold. In this embodiment, a mold may be provided having a surface corresponding to a negative of the upper surface of substrate 110. The mold can be prefabricated (e.g. from brass) using vibration assisted machining or other conventional micromachining techniques. The mold surface includes an array of micro-projections corresponding in shape and size to the array of microholes 112 to be formed in substrate 110. Substrate 110 may then be fabricated on the surface of the mold using a conventional electroforming process. This process may be particularly suitable for forming microholes having a pyramidal or tetrahedral shape.

In another exemplary embodiment, step 210 comprises drilling the array of microholes 112. In this embodiment, a piece of material is selected to be used as substrate 110 (e.g., a piece of reflective material such as aluminum or stainless steel). The array of blind microholes 112 are then drilled in the surface of the piece of material. Microholes 112 may be drilled, for example, by a laser milling/ablation process with a pico-second pulsed laser. Multiple microholes 112 may be drilled simultaneously by using a laser with parallel beam-splitting. When the holes are formed in this manner, it may be desirable to smooth the walls 114 of microholes 112 via an electropolishing process. This process may be particularly suitable for forming microholes having a conical shape.

Step 210 may further comprise coating the walls of the microholes with a layer of reflective material. As set forth above, substrate 110 may be formed from reflective material. Where substrate 110 is not formed from reflective material, it may nonetheless be coated with reflective material. In an exemplary embodiment, step 210 comprises coating the walls 114 of microholes 112 with a layer of reflective material. The reflective material may be coated on substrate 110, for example, by an electroplating process. Alternatively, the reflective material may be coated on substrate 110 by first coating a negative mold with a layer of reflective material, and then electroforming substrate 110 on the mold (and on the layer of reflective material). Suitable materials for use as the reflective material are set forth above in the description of substrate 110.

It will be understood by one of ordinary skill in the art that the processes for fabricating a substrate are described above for the purposes of illustration, and are not intended to be limiting. Substrate 110 may be fabricated using any other suitable process known to one of ordinary skill in the art.

In step 220, a layer of phosphor material is deposited on a bottom surface of each of the microholes. In an exemplary embodiment, the layer of phosphor material 130 is deposited on the bottom surface 116 of each of the microholes 112.

~ - 7 - ~

The layer of phosphor material 130 may be deposited such that the layer of phosphor material 130 in each of the microholes 112 has a substantially uniform height and volume.

As set forth above, the layer of phosphor material 130 is deposited in
5 each microhole 112 such that no phosphor material is deposited on walls 114 of the respective microhole 112 above an uppermost continuous surface of the layer of phosphor material 130. In other words, following deposition of the layer of phosphor material 130, no phosphor material contacts the walls 114 of the microholes 112 except the material forming part of the layer 130. The layer of phosphor material 130 may be
10 formed using any of the processes described below.

Prior to step 220, it may be desirable to create a slurry of the phosphor material in order to ease the deposition of the phosphor material at the bottom of microholes 112. The slurry may be formed using an optically transparent carrier which offers good thermal conductivity and is optochemically stable under illumination by the
15 light used to excite the phosphor particles. In an exemplary embodiment, the carrier comprises a combination of silicone (e.g., Dow Corning EG6301) and photoresist (e.g., Micro-Chem SU8). The phosphor slurry can be prepared in the desired weight ratio (or phosphor density) using a lab mixer.

In an exemplary embodiment, step 220 comprises depositing phosphor
20 material in each of the microholes 112, and spinning substrate 110 such that the phosphor material is forced into a layer on the bottom surface 116 of each of the microholes 112. In this embodiment, a suitable amount of phosphor material is deposited on top of substrate 110 such that it seeps into each of the microholes 112 (though not in a layer on the bottoms thereof). After the phosphor material is
25 deposited, air may desirably be removed from the phosphor material, for example, by exposing substrate 110 with the phosphor material to a vacuum. After the air has been removed from the phosphor material, excess phosphor material is scraped from the top of substrate 110, and substrate 110 is spun around a preselected axis. Spinning substrate 110 subjects the phosphor material in microholes 112 to a centrifugal force,
30 which forces the phosphor material into a layer of phosphor material 130 at the bottom of each microhole 112. Because the phosphor particles are heavier than the material of the slurry, the phosphor materials move toward the bottom surfaces 116 of microholes 112. This spinning continues until no phosphor material is left on the walls 114 of the microholes 112 above the uppermost continuous surface of the layer of phosphor
35 material 130. After the above spinning step, it may be desirable to briefly spin substrate 110 in an opposite direction in order to homogenize the layer of phosphor material 130.

~ - 8 - ~

Step 220 may utilize a different process when substrate 110 is formed from more than one separate piece. In an exemplary embodiment, step 210 comprises forming substrate 110 from two separate pieces. In this embodiment, step 210 comprises forming an array of microholes 112 in frame portion 118. The array of
5 microholes 112 may be formed in frame portion 118 by either electroforming frame portion 118 or by drilling holes in frame portion 118, substantially as described above. Step 210 then further comprises adhering base portion 120 to frame portion 118 such that a surface of base portion 120 forms the bottom surface 116 of each microhole 112. Where base portion 120 includes a dichroic mirror layer 122, step 210 may comprise
10 the step of forming the dichroic mirror layer 122 on the surface of base portion 120 prior to adhering base portion 120 to frame portion 118. Suitable processes for forming dichroic mirror layer 122 on a piece of material will be known to one of ordinary skill in the art from the description herein.

In this embodiment, step 220 comprises depositing the layer of phosphor
15 material 130 on base portion 120 (or dichroic mirror layer 122 of base portion 120) before adhering frame portion 118 to base portion 120. A number of different processes may be utilized for depositing the layer of phosphor material 130 on base portion 120.

In one process 300 for depositing the layer of phosphor material 130, a
20 plurality of dots of phosphor material are lithographically deposited on base portion 120 in an array corresponding to the positions of the bottoms of microholes 112. As shown in FIG. 4A, a mixture of phosphorus material and curable materials 302 is deposited on base portion 120. The curable materials may be light-curable materials (such as SU-8 photoresist) or thermal-curable materials (such as EG-6301 encapsulant provided by
25 Dow Corning of Midland, Michigan, USA). In FIG. 4B, a photomask 304 is positioned above the phosphorous mixture 302. The phosphorous mixture 302 is cured by exposure to a light source positioned above photomask 304 (as illustrated by arrows in FIG. 4B). After the exposed portions of the phosphorous mixture 302 are cured, the uncured portions are dissolved, resulting in a plurality of dots of phosphor material
30 corresponding to the layers of phosphor material 130, as shown in FIG. 4C.

In another process 310 for depositing the layer of phosphor material 130, a plurality of dots of phosphor material are deposited by imprinting a mold having a plurality of recesses in an array corresponding to the positions of the bottoms of microholes 112. As shown in FIG. 5A, a mixture of phosphorus material and curable
35 materials 312 is deposited on base portion 120. In FIG. 5B, a mold 314 is pressed into the phosphorous mixture 312. The phosphorous mixture 312 within mold 314 is cured by exposure to pressure from mold 314 and a heat source (illustrated by arrows in

~ - 9 - ~

FIG. 5B. After curing, mold 314 is removed, resulting in a plurality of dots of phosphor material corresponding to the layers of phosphor material 130, as shown in FIG. 5C.

In yet another process 320 for depositing the layer of phosphor material 130, a plurality of dots of phosphor material are provided within a thin metal sheet (or foil) having a plurality of holes in an array corresponding to the positions of the bottoms of microholes 112. As shown in FIG. 6A, a plurality of holes are formed in a thin sheet of metal foil 322, the holes corresponding to the positions of the bottoms of microholes 112. The sheet of metal foil 322 is then provided on base portion 120. In FIG. 6B, phosphor material is forced into the holes in foil 322. The phosphor material may be forced into the holes by scraping an excess amount of phosphor over the holes and along the surface of foil 322. The resulting plurality of dots of phosphor material correspond to the layers of phosphor material 130. Foil 322 may or may not be removed prior to adhering frame portion 118 to base portion 120.

After any of the above processes is implemented, frame portion 118 is adhered to base portion 120 (as similarly shown in FIG. 2).

Method 200 is not limited to the above described steps, but may include alternative or additional steps, as would be understood by one of ordinary skill in the art.

For example, method 200 may further include the step of curing the layer of phosphor material. In an exemplary embodiment, phosphor element 100 including the layer of phosphor material 130 may be subjected to high temperatures sufficient to cure the phosphor material.

For another example, method 200 may further include the step of forming an optical element in each of the microholes on top of the layer of phosphor material. In an exemplary embodiment, optical element 140 is formed in each of the microholes 112 on top of the layer of phosphor material 130. Optical element 140 may be formed, for example, from the material provided in the slurry of phosphor material. In other words, during spinning of the substrate with the phosphor material, as the layer of phosphor material forms on the bottom of microholes 112, the remainder of the slurry (e.g., silicone) forms a layer on top of the phosphor material. This layer may function as a refractive lens based on the materials used for the phosphor material slurry and the speed of spinning of substrate 110.

In another exemplary embodiment, a separate optical element is formed in each microhole 112 by adding a preselected material to each hole after formation of the layer of phosphor material 130. The optical element may be, for example, a positive lens. The preselected material may be, for example, silicone or epoxy. The preselected material may be provided on top of optical element 140; in other words,

~ - 10 - ~

the preselected material may form a separate optical element on top of the optical element 140 formed by the material in the phosphor slurry. In this embodiment, the material from the phosphor slurry (e.g. silicone) is hardened before the preselected material is added. After being added, any excess of the preselected material may be removed (e.g., by scraping), and the material may be hardened (e.g. by curing). The preselected material may be selected to have a higher refractive index than the material from the phosphor slurry, in order to converge the light emitted by the layer of phosphor material 130. This embodiment may be particularly suitable for forming an effective positive microlens array on system 100 that is intrinsically aligned with the phosphor materials in microholes 112.

Although the invention is illustrated and described herein with reference to specific embodiments, the invention is not intended to be limited to the details shown. Rather, various modifications may be made in the details within the scope and range of equivalents of the claims and without departing from the invention.

What is Claimed:

1. A method of manufacturing a phosphor element for a projection light source, the method comprising:

fabricating a substrate having an array of blind microholes in a surface thereof; and

depositing a layer of phosphor material on a bottom surface of each of the microholes such that no phosphor material is deposited on a wall of the respective microhole above an uppermost continuous surface of the respective layer of phosphor material.

2. The method of claim 1, wherein the fabricating step comprises electroforming the substrate on a negative mold.

3. The method of claim 1, wherein the fabricating step comprises drilling the array of microholes in a piece of material.

4. The method of claim 1, wherein the substrate comprises a reflective material.

5. The method of claim 1, wherein the fabricating step comprises coating the walls of the microholes with a layer of reflective material.

6. The method of claim 1, wherein a diameter at a top of each of the microholes is larger than a diameter at a bottom of each of the microholes.

7. The method of claim 6, wherein the microholes have a conical shape.

8. The method of claim 6, wherein the microholes have a pyramidal or tetrahedral shape.

9. The method of claim 6, wherein the diameter at the top of each of the microholes is between approximately 300 microns and 600 microns.

10. The method of claim 1, wherein the depositing step comprises depositing the phosphor material in each of the microholes, and spinning the substrate such that the phosphor material is forced into a layer on the bottom surface of each of the microholes.

11. The method of claim 10, further comprising the step of removing air from the phosphor material after the depositing of the phosphor material and before the spinning of the substrate.

12. The method of claim 1, wherein the fabricating step comprises forming the array of microholes in a frame portion, and adhering the frame portion to a base portion such that a surface of the base portion forms the bottom surface of each of the microholes.

~ 12 ~

13. The method of claim 12, wherein the frame portion comprises a reflective material, and the base portion comprises a transmissive material.

14. The method of claim 13, wherein the base portion further comprises a dichroic mirror on the surface of the base portion forming the bottom surface of each of the microholes.

15. The method of claim 12, wherein the depositing step comprises depositing the layer of phosphor material on the base portion before the adhering of the frame portion to the base portion.

16. The method of claim 15, wherein the depositing step comprises lithographically depositing a plurality of dots of phosphor material.

17. The method of claim 1, wherein the layer of phosphor material in each of the microholes has a substantially uniform height and volume.

18. The method of claim 1, further comprising the step of curing the layer of phosphor material.

19. The method of claim 1, further comprising forming a lens in each of the microholes on top of the layer of phosphor material.

20. A phosphor element for a projection light source comprising:
a substrate having an array of blind microholes in a surface thereof; and
a layer of phosphor material on a bottom surface of each of the microholes, the layer of phosphor material formed such that no phosphor material is deposited on a wall of the respective microhole above an uppermost continuous surface of the respective layer of phosphor material.

21. The phosphor element of claim 20, wherein the substrate comprises a reflective material.

22. The phosphor element of claim 20, wherein the substrate comprises a layer of reflective material coating the walls of the microholes.

23. The phosphor element of claim 20, wherein a diameter at a top of each of the microholes is larger than a diameter at a bottom of each of the microholes.

24. The phosphor element of claim 23, wherein the microholes have a conical shape.

25. The phosphor element of claim 23, wherein the microholes have a pyramidal or tetrahedral shape.

26. The phosphor element of claim 23, wherein the diameter at the top of each of the microholes is between approximately 300 microns and 600 microns.

27. The phosphor element of claim 20, wherein the substrate comprises a frame portion in which the array of microholes are formed, and a base

portion adhered to the frame portion such that a surface of the base portion forms the bottom surface of each of the microholes.

28. The phosphor element of claim 27, wherein the frame portion comprises a reflective material, and the base portion comprises a transmissive
5 material.

29. The phosphor element of claim 28, wherein the base portion further comprises a dichroic mirror on the surface of the base portion forming the bottom surface of each of the microholes.

30. The phosphor element of claim 20, wherein the layer of phosphor
10 material in each of the microholes has a substantially uniform height and volume.

31. The phosphor element of claim 20, further comprising a lens in each of the microholes on top of the layer of phosphor material.

100

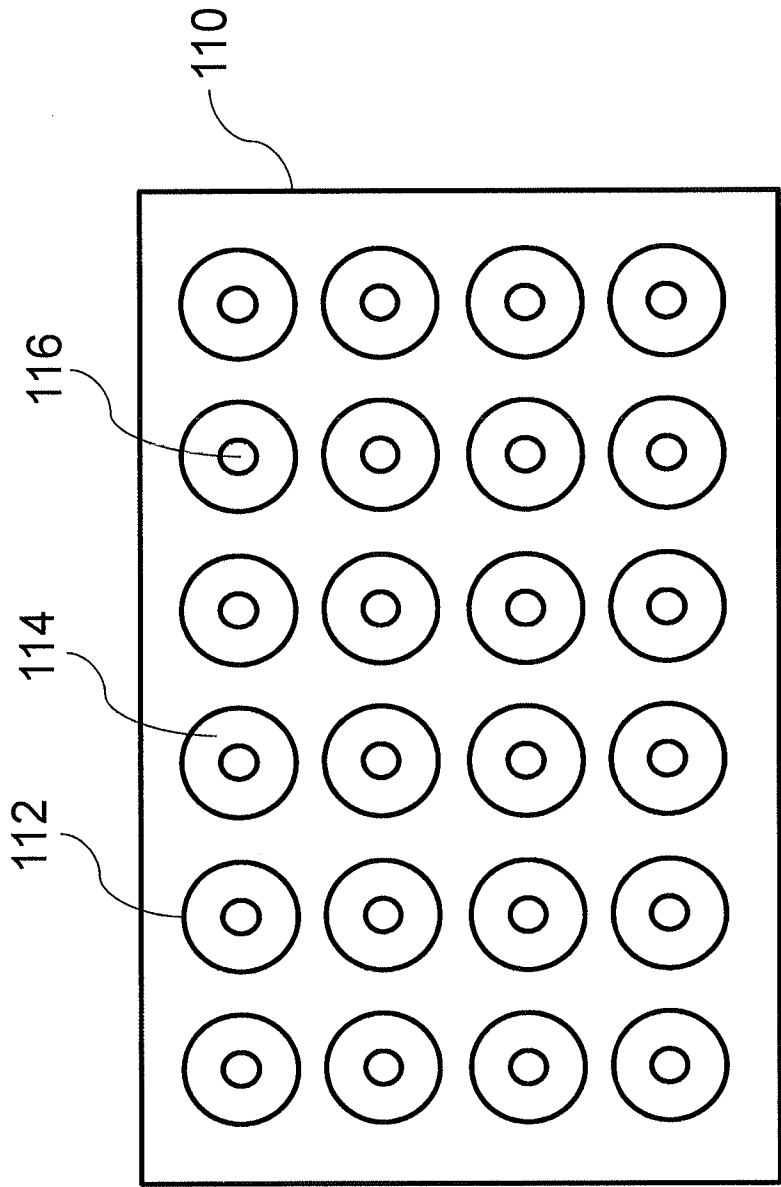


FIG. 1A

100

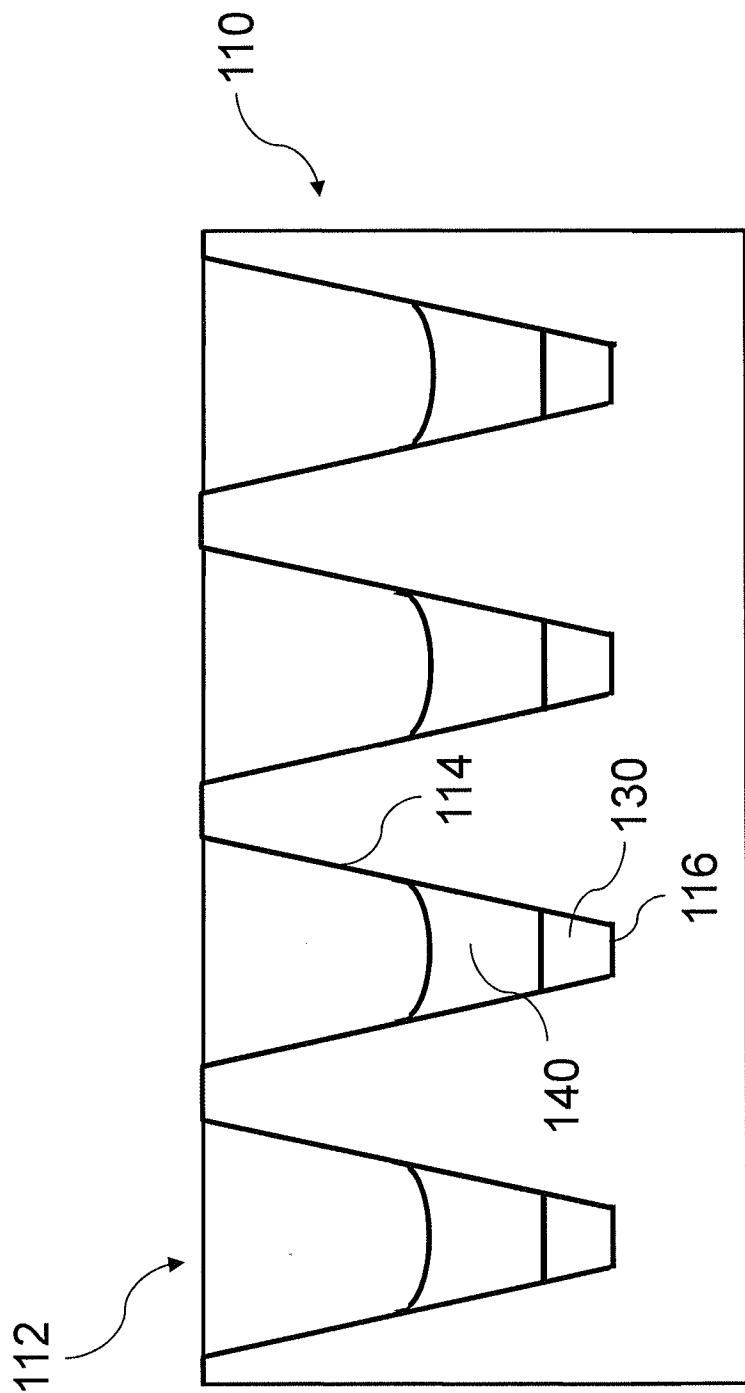


FIG. 1B

200

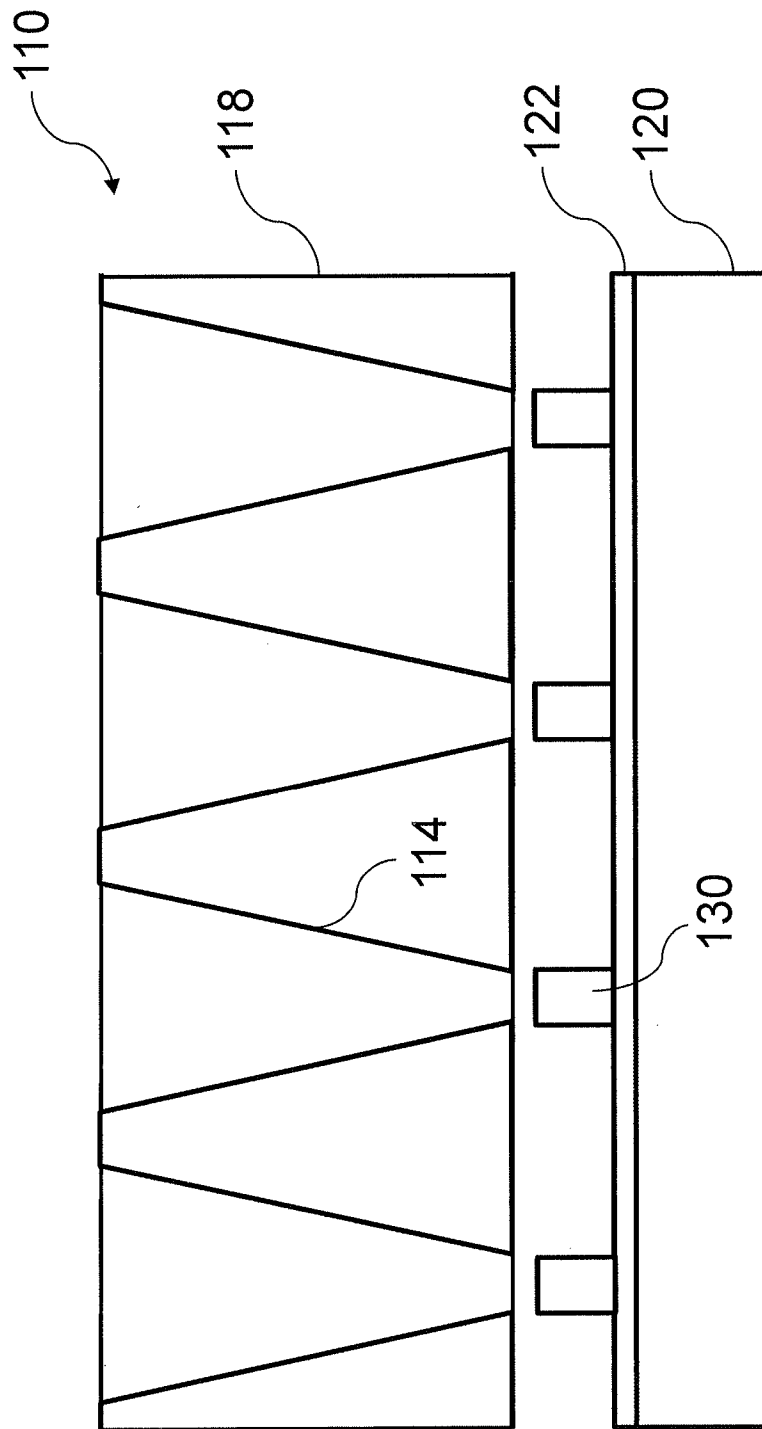


FIG. 2

200

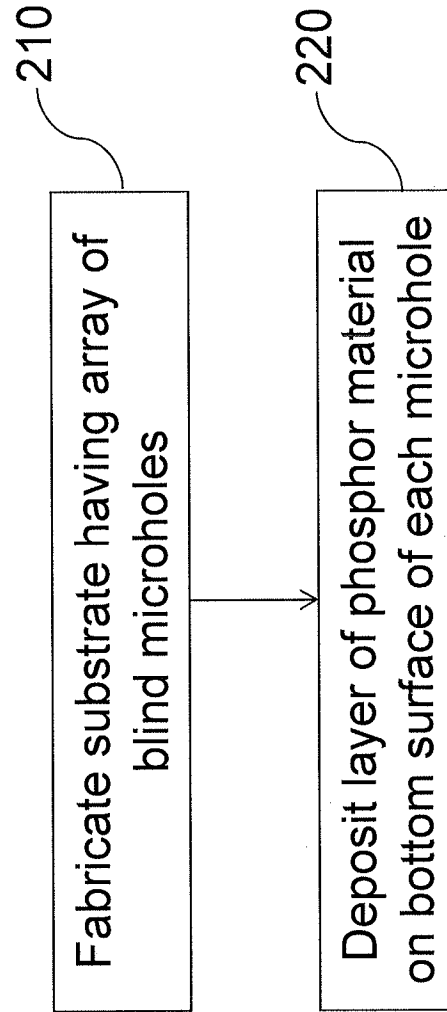


FIG. 3

300

302

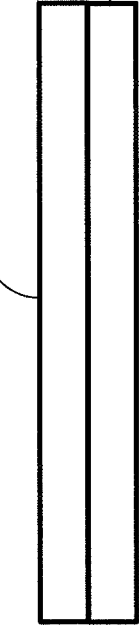
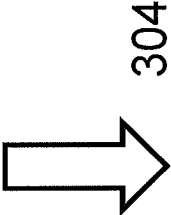
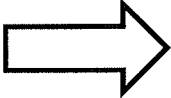


FIG. 4A



304

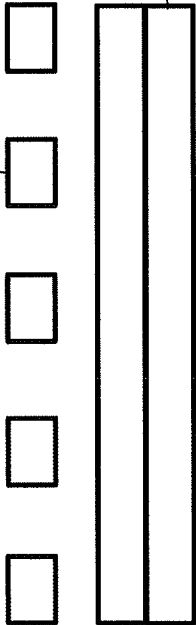


FIG. 4B

130

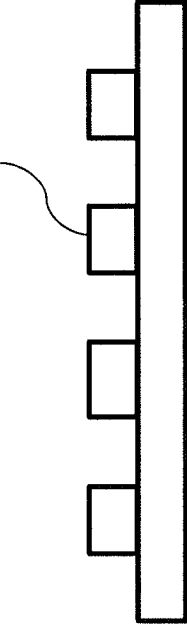


FIG. 4C

310

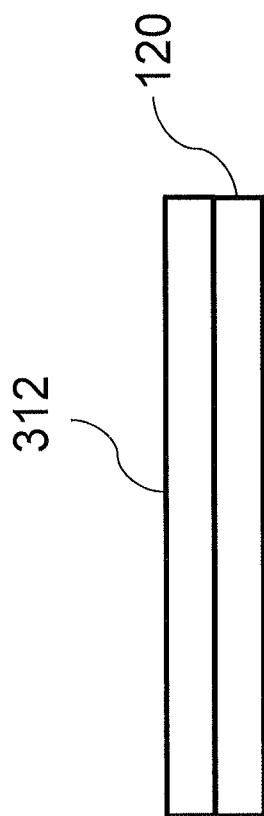


FIG. 5A

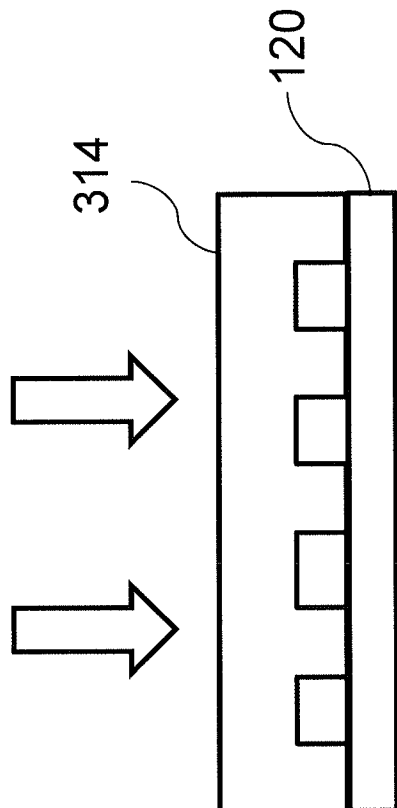


FIG. 5B

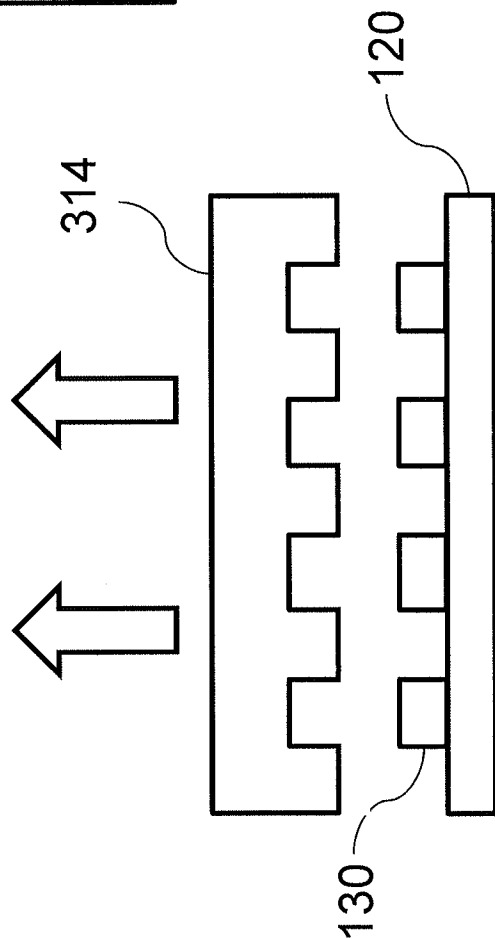


FIG. 5C

320

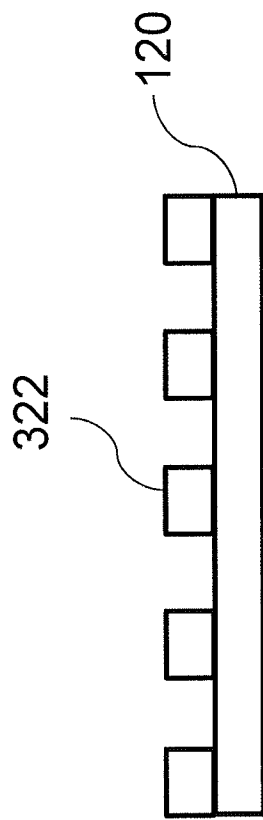


FIG. 6A

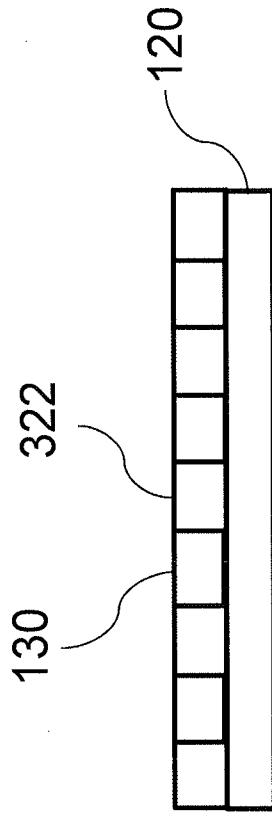


FIG. 6B

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/063032

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03B21/20 G03B33/12 H04N9/31 G03B21/56
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)
G03B 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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/116107 A1 (KINDLER DAVID [US] ET AL) 7 May 2009 (2009-05-07)	1,2,4-9, 12-31
Y	abstract; figures 4,5,11B,11D,13 paragraph [0002] - paragraph [0008] paragraphs [0034], [0064] paragraph [0057] - paragraph [0059] paragraph [0078] - paragraph [0093] -----	3,10,11
Y	WO 95/30236 A1 (MINNESOTA MINING & MFG [US]) 9 November 1995 (1995-11-09) abstract page 17, line 1 - line 5 -----	3
Y	US 2011/317396 A1 (EMTMAN CASEY EDWARD [US] ET AL) 29 December 2011 (2011-12-29) abstract; figures 9A,9B paragraphs [0071], [0074] ----- -/-	10



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 application or patent 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

11 November 2013

Date of mailing of the international search report

19/11/2013

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Tano, Valeria

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2013/063032

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2011/253298 A1 (TOMONO HARUO [JP]) 20 October 2011 (2011-10-20) abstract	11
A	----- US 2005/002096 A1 (YONEKUBO MASATOSHI [JP] ET AL) 6 January 2005 (2005-01-06) abstract; figures 1,2(a),4(a) paragraphs [0035], [0040]	1,20
A	----- US 2010/328617 A1 (MASUDA HIROKI [JP]) 30 December 2010 (2010-12-30) abstract; figures 1B,2-9 paragraph [0046]	1,20
A	----- US 2006/126023 A1 (TAN CHINH [US] ET AL) 15 June 2006 (2006-06-15) figures 8-11 paragraph [0055] - paragraph [0057] -----	1,20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2013/063032

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 2009116107	A1	07-05-2009	CN	101688979 A	31-03-2010
			CN	101950122 A	19-01-2011
			JP	2010527464 A	12-08-2010
			KR	20100024420 A	05-03-2010
			RU	2009146834 A	27-06-2011
			US	2009116107 A1	07-05-2009
			WO	2008144673 A2	27-11-2008

WO 9530236	A1	09-11-1995	CA	2186258 A1	09-11-1995
			EP	0797835 A1	01-10-1997
			JP	H09512636 A	16-12-1997
			WO	9530236 A1	09-11-1995

US 2011317396	A1	29-12-2011	CN	102313596 A	11-01-2012
			DE	102011077847 A1	29-12-2011
			JP	2012018162 A	26-01-2012
			US	2011317396 A1	29-12-2011

US 2011253298	A1	20-10-2011	JP	2011228051 A	10-11-2011
			US	2011253298 A1	20-10-2011

US 2005002096	A1	06-01-2005	CN	1573525 A	02-02-2005
			JP	2004354763 A	16-12-2004
			KR	20040103437 A	08-12-2004
			KR	20060090783 A	16-08-2006
			TW	I236545 B	21-07-2005
			US	2005002096 A1	06-01-2005

US 2010328617	A1	30-12-2010	CN	101936505 A	05-01-2011
			JP	4883376 B2	22-02-2012
			JP	2011013315 A	20-01-2011
			TW	201109722 A	16-03-2011
			US	2010328617 A1	30-12-2010

US 2006126023	A1	15-06-2006	CN	101263420 A	10-09-2008
			DE	112006000275 T5	13-12-2007
			JP	4671443 B2	20-04-2011
			JP	2008529070 A	31-07-2008
			US	2006126023 A1	15-06-2006
			WO	2006081297 A2	03-08-2006
