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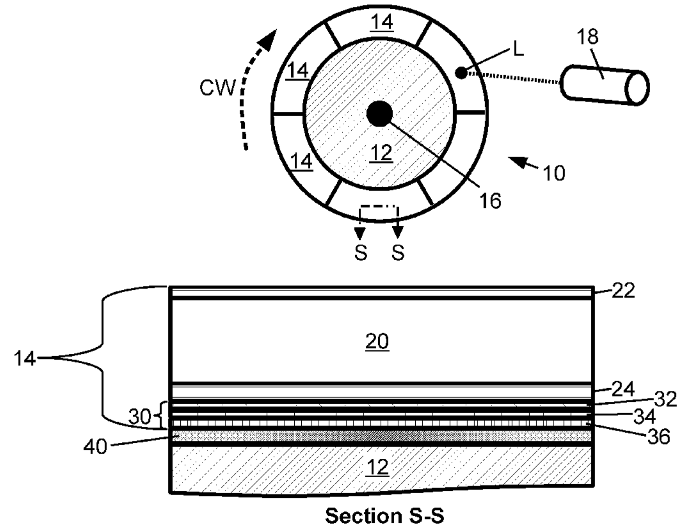
(54) Title: HIGH OPTICAL POWER LIGHT CONVERSION DEVICE USING A PHOSPHOR ELEMENT WITH SOLDER ATTACHMENT



Section S-S

Fig. 1

(57) Abstract: A light generator comprises a light conversion device (10) and a light source (18) arranged to apply a light beam (L) to a light conversion element (20). The light conversion device (10) includes: an optoceramic (20) or other solid phosphor element comprising one or more phosphors embedded in a ceramic, glass, or other host; a metal heat sink (12); and a solder bond (40) attaching the optoceramic phosphor element (20) to the metal heat sink (12). The optoceramic phosphor element (20) does not undergo cracking in response to the light source (18) applying a light beam (L) of beam energy effective to heat the optoceramic phosphor element (20) to the phosphor quenching point.

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HIGH OPTICAL POWER LIGHT CONVERSION DEVICE USING A PHOSPHOR ELEMENT WITH SOLDER ATTACHMENT

[0001] This application claims the benefit of U.S. Provisional Application No. 62/265,117 filed December 9, 2015 and titled "HIGH OPTICAL POWER LIGHT CONVERSION DEVICE USING A PHOSPHOR ELEMENT WITH GLASS HOST". U.S. Provisional Application No. 62/265,117 filed December 9, 2015 is incorporated herein by reference in its entirety.

[0002] This application claims the benefit of U.S. Provisional Application No. 62/232,702 filed September 25, 2015 and titled "HIGH OPTICAL POWER LIGHT CONVERSION DEVICE USING AN OPTOCERAMIC PHOSPHOR ELEMENT WITH SOLDER ATTACHMENT". U.S. Provisional Application No. 62/232,702 filed September 25, 2015 is incorporated herein by reference in its entirety.

[0003]

BACKGROUND

[0004] The following relates to the optical arts, phosphor arts, wavelength conversion arts, and related arts, and to optoelectronic, photonic, and like applications using same such as (but not limited to) projection displays (e.g. digital light processing, DLP), automotive lighting, and so forth.

[0005] Phosphor devices are known for converting light wavelength, usually down-converting from a shorter wavelength to one or more longer wavelengths. In a common approach, phosphor materials are dispersed in a transparent or translucent binder material such as epoxy, silicone, or so forth. The phosphor is energized, or "pumped" by a laser or other pump light source to emit phosphorescence. The phosphor device may be static, or may be configured as a phosphor wheel in which the phosphor is disposed near the outer rim of a rotating wheel. The phosphor wheel design advantageously can provide a time sequence of different colors (or more generally different spectra) by using different phosphors in different phosphor arc segments. Periods of zero emission can also be provided by leaving arced gaps between phosphor arc segments. Such a wheel can be used, for example, to provide sequential red, green, and blue light for a Digital Light Processing (DLP) projector or other DLP display device.

[0006] A problem arises for high optical power applications in that binder materials typically used in phosphors are susceptible to thermal damage due to heating by a high power pump laser. For example, in a typical down-conversion task in which a blue or ultraviolet laser is converted to white light (or to yellowish light that blends with blue pump laser light to form white light), the laser power may be on the order of 25 watts or higher, leading to significant heating.

[0007] A solution to this problem is to replace the binder material with a ceramic material, i.e. using an optoceramic phosphor. Typical ceramic materials are manufactured by sintering a mixture of powdered base material, binder, and stabilizer at elevated temperature, and optionally under elevated pressure. Other manufacturing processes such as chemical vapor deposition (CVD) or chemical reactions may be incorporated into the ceramic manufacturing process. For an optoceramic phosphor, the base material is chosen to include the desired phosphor component(s), and the mixture and sintering are designed to produce host material that is optically transmissive over the operational spectrum (including both the pump light and the phosphorescence). Ceramic materials are denser than a conventional phosphor binder material such as epoxy or silicone, and an optoceramic phosphor is typically thermally resistant at least up to the sintering temperature which is usually at least several hundred degrees Celsius, and may be as high as 1000°C or more depending upon the sintering process. Consequently, optoceramic phosphors are expected to be thermally stable when pumped by a high power laser.

[0008] Some commercially available optoceramic phosphors include yttrium aluminum garnet (YAG), cerium-doped YAG (YAG:Ce), lutetium YAG (LuYAG), silicate-based phosphors, silicon-aluminum-oxynitride (SiAlON) phosphors, or so forth embedded in a ceramic host such as such as polycrystalline alumina (Al_2O_3, PCA), lanthana-doped yttria (Y_2O_3-La_2O_3), yttrium aluminum garnet ($Y_3Al_5O_{12}$), magnesium aluminate spinel ($MgAl_2O_4$), dysprosia (Dy_2O_3), aluminum oxynitride ($Al_{23}O_{27}N_5$), aluminum nitride (AlN), or so forth. *See*, *e.g.* Raukas et al., "Ceramic Phosphors for Light Conversion in LEDs", ECS Journal of Solid State Science and Technology, vol. 2 no. 2, pages R3168-76 (2013).

[0009] Some improvements are disclosed herein.

BRIEF DESCRIPTION

[0010] In accordance with some disclosed embodiments, a light conversion device comprises: an optoceramic phosphor element comprising one or more phosphors embedded in a ceramic host; a metal heat sink; and a solder bond attaching the optoceramic phosphor element to the metal heat sink.

[0011] In accordance with some disclosed embodiments, a light conversion device comprises a phosphor element comprising one or more phosphors embedded in a solid host element, a metal heat sink, and a solder bond attaching the phosphor element to the metal heat sink. In some embodiments the phosphor element comprises one or more phosphors embedded in a solid glass host element.

[0012] In accordance with some disclosed aspects, a light generator comprises a light conversion device as set forth in one of the two immediately preceding paragraphs, and a light source arranged to apply a light beam to the light conversion element. The optoceramic phosphor element does not undergo cracking in response to the light source applying a light beam of beam energy effective to heat the optoceramic phosphor element to the phosphor quenching point.

[0013] In accordance with some disclosed embodiments, a method of fabricating a light conversion device comprises: depositing a solderable metal stack on a back side of an optoceramic phosphor element comprising one or more phosphors embedded in a ceramic host; and attaching the optoceramic phosphor element to a metal heat sink by soldering the solderable metal stack to the heat sink.

[0014] In accordance with some disclosed embodiments, a method is disclosed of fabricating a light conversion device. The method comprises depositing a solderable metal stack on a back side of a phosphor element comprising one or more phosphors embedded in a solid host element, and attaching the phosphor element to a metal heat sink by soldering the solderable metal stack to the heat sink.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIGURE 1 illustrates a phosphor wheel including six phosphor arc segments. Section S-S of FIGURE 1 shows a cross-section of a portion of one of the phosphor elements and its solder attachment to the metal wheel.

[0016] FIGURE 2 shows an exploded view of Section S-S of FIGURE 1 (left side) and a flow chart diagrammatically indicating principal manufacturing operations (right side).

[0017] FIGURE 3 shows a variant embodiment in which the heat sink (e.g. metal wheel of FIGURE 1) has a recess shaped and sized to receive at least the solder attachment and optionally a lower portion of the phosphor element.

DETAILED DESCRIPTION

[0018] As used herein, and as is conventional in the art, terms such as “optical spectrum”, “optical”, “wavelength”, “frequency”, “light”, “light beam”, and so forth are not limited to the visible spectrum but rather for a given filter may extend into, or reside entirely within, the infrared and/or ultraviolet spectral regions.

[0019] Contrary to the expectation that optoceramic phosphors are expected to be thermally stable when pumped by a high power laser, the inventors have found that in practice an optoceramic phosphor undergoes destructive failure as the output of the high-power pump laser is ramped up. Specifically, a static optoceramic phosphor element mounted on a heat sink using adhesive or thermal paste undergoes destructive cracking during high power pump laser ramp-up.

[0020] As disclosed herein, the inventors have found that this catastrophic cracking failure mode can be overcome by employing a solder connection of the optoceramic phosphor to a heat sink (e.g. Al or Cu). With the solder attachment, the pump laser power could be ramped up to pump power high enough to produce phosphor quenching without cracking the optoceramic phosphor element. Without being limited to any particular theory of operation, it is believed that the catastrophic failure mode is due to insufficient heat transfer out of the optoceramic phosphor, either in terms of the thermal resistance of the attachment or in terms of thermal reactance of the attachment (i.e. delay before heat transfer ramps up), and the solder attachment improves the heat transfer through the attachment sufficiently to overcome the catastrophic cracking failure mode. In view of this, it is contemplated to employ other attachment bonds, besides a solder bond, that provide the requisite heat transfer properties. For example, it is contemplated to replace the solder bond with a bond formed by sintering a powder or paste of silver (Ag) nanoparticles in an organic thinner (to provide uniform dispersion). The sintering is suitably performed at a temperature below the silver melting temperature, e.g. at ~250 °C in some embodiments although the optimal process temperature depends on factors such as Ag nanoparticle size, density, and average surface area. While the sintering is occurring, slight pressure may optionally be applied, and/or the sintering may optionally be performed in a controlled atmosphere. After sintering, the silver will be operable to a much higher temperature than the sintering temperature. Without being limited to any particular theory of operation, the bonding process in this approach is believed to be attributable to an atomic diffusion mechanism.

[0021] More generally, as disclosed herein a solder connection is used to attach a solid phosphor element to a heat sink (e.g. Al or Cu). The solder attachment is expected to improve the heat transfer through the attachment sufficiently to overcome the catastrophic cracking or other thermal failure mode. In view of this, it is contemplated to employ other attachment bonds, besides a solder bond, that provide the requisite heat transfer properties.

[0022] The solder bond approach disclosed herein is expected to provide benefits for various types of high-temperature phosphor elements, such as single-crystal or polycrystalline phosphor elements, glass phosphor elements, or so forth, in which the phosphor is incorporated into a crystal, glass, or other solid host material. The solder bond approach disclosed herein is expected to provide similar benefits for other types of high-temperature phosphor elements, such as single-crystal or polycrystalline phosphor elements in which the phosphor is incorporated into a crystal having high thermal stability during the crystal growth process.

[0023] FIGURE 1 diagrammatically shows a phosphor wheel **10** including a metal disk or “wheel” **12** made of copper, a copper alloy, an aluminum alloy, or so forth. One or more optoceramic phosphor elements, e.g. arc segments **14**, are attached to an outer perimeter of the wheel **12**, that is, are attached at or near the outer rim of the wheel **12**. The metal disk or wheel **12** thus serves as both a carrying component and as a heat sink for the optoceramic phosphor arc segments **14**. The illustrative optoceramic phosphor arc segments **14** are geometrically advantageous design that minimizes the amount of optoceramic phosphor material while enabling phosphor coverage of the entire wheel circumference. The illustrative phosphor wheel **10** includes six optoceramic phosphor arc segments **14** of equal size; however, more or fewer phosphor arc segments can be employed (including as few as a single optoceramic phosphor arc segment forming a complete 360° circle). While the illustrative six optoceramic phosphor arc segments **14** are commonly illustrated and labeled, it will be appreciated that different optoceramic phosphor arc segments can include different phosphors (for example, to emit phosphorescence of different colors), and/or there may be gaps between neighboring optoceramic phosphor arc segments. In operation the metal wheel **12** is rotated about a central axis **16**, for example, by connecting a motor shaft of a motor (not shown) to the central axis **16** and operating the motor to rotate the phosphor wheel **10** in an illustrated clockwise direction **CW** (counterclockwise rotation is also contemplated). Simultaneously with the rotation, pump light is applied to a local region – this is diagrammatically indicated in FIGURE 1 by a laser **18** applying an illustrative pump laser beam spot **L**. As the metal wheel **12** rotates it carries the optoceramic phosphor arc segments **14** in sequence into contact with the laser beam **L** to emit phosphorescence. It will be readily appreciated that by suitable selection of the phosphors of the various optoceramic phosphor arc segments **14**, various color time sequences can be generated, such as red-green-blue-red-green-blue as may be appropriate in a DLP display application.

[0024] With continuing reference to FIGURE 1 and with further reference to FIGURE 2, Section S-S diagrammatically illustrates a cross-section of a portion of one optoceramic phosphor arc segment **14** and its solder attachment to the metal wheel **12**. FIGURE 2 shows an exploded view of Section S-S (left side) and a flow chart diagrammatically indicating principal manufacturing operations (right side). It is noted that layer thicknesses are not drawn to scale in diagrammatic Section S-S of FIGURE 1 and its exploded view shown in FIGURE 2. The optoceramic phosphor arc segment **14** includes an optoceramic phosphor element **20** which may, by way of non-limiting illustration, comprise a phosphor such as yttrium aluminum garnet (YAG), cerium-doped YAG (YAG:Ce), lutetium YAG (LuYAG), silicate-based phosphors, silicon-aluminum-oxynitride (SiAlON) phosphors, or so forth embedded in a ceramic material that is optically transmissive in the visible spectrum, such as polycrystalline alumina (Al_2O_3, PCA), lanthana-doped yttria (Y_2O_3-La_2O_3), yttrium aluminum garnet ($Y_3Al_5O_{12}$), magnesium aluminate spinel ($MgAl_2O_4$), dysprosia (Dy_2O_3), aluminum oxynitride ($Al_{23}O_{27}N_5$), aluminum nitride (AlN), or so forth. *See*, *e.g.* Raukas et al., “Ceramic Phosphors for Light Conversion in LEDs”, ECS Journal of Solid State Science and

Technology, vol. 2 no. 2, pages R3168-76 (2013). In other embodiments, the phosphor element arc segment **14** includes a phosphor element **20** which may, by way of non-limiting illustration, comprise a phosphor such as yttrium aluminum garnet (YAG), cerium-doped YAG (YAG:Ce), lutetium YAG (LuYAG), silicate-based phosphors, silicon-aluminum-oxynitride (SiAlON) phosphors, or so forth embedded in a crystalline, glass, or other solid host material that is optically transmissive in the visible spectrum. For example, the host material can be a glass such as B270, BK7, P-SF68, P-SK57Q1, P-SK58A, P-BK7, or so forth.

[0025] The phosphor or phosphor dopant may be suitably chosen to emit the desired emission light, e.g. green, yellow, red, or light combination such as a white phosphor blend. The optoceramic phosphor element **20** may be manufactured using any suitable process such as (by way of non-limiting illustration) sintering a mixture of powdered base material, binder, and stabilizer at elevated temperature. In other embodiments, e.g. using a glass host material, the phosphor element **20** may be manufactured using a suitable process such as (by way of non-limiting illustration) melting, molding, sintering or so forth.

[0026] In the illustrative examples, an optoceramic phosphor element is assumed for illustration. Optionally, one or more optical coatings may be applied to one or more surfaces of the optoceramic phosphor element **20**. For illustrative purposes, the optoceramic phosphor arc segment **14** includes a front-side anti-reflection (AR) coating **22** and a back-side dielectric or metal or hybrid dielectric/metal mirror coating **24**. (The term “front-side” as used herein denotes the side of the optoceramic phosphor element **20** at which the beam from the pump laser **18** or other pump light beam impinges; while the term “back-side” as used herein denotes the side of the optoceramic phosphor element **20** which is attached to the heat sink **12** (where, again, in the illustrative example the metal wheel **12** of the phosphor wheel **10** serves as the heat sink for the optoceramic phosphor element **20**). The AR coating **22** is designed to minimize reflection of the pump laser light impinging on the optoceramic phosphor element **20** while not impeding emission of the phosphorescence. The dielectric mirror coating **24** is designed to reflect the phosphorescence, and optionally is also designed to reflect the pump laser light. As indicated in FIGURE 2, these coatings may be applied by sputter deposition **S1**, although any other deposition technique suitable for depositing the materials that make up these coatings **22**, **24** can be used to perform the deposition(s) **S1**. It will also be appreciated that either one, or both, of the optical coatings **22**, **24** may be omitted, and/or other optical coatings can be provided such as a wavelength-selective filter coating, a light-scattering coating, a deposited Fresnel lens, or so forth.

[0027] With continuing reference to FIGURES 1 and 2, the optoceramic phosphor element **20** and the dielectric or metal mirror coating **24** (if present) typically are not materials that are well-suited to solder bonding. To facilitate attachment of the optoceramic phosphor arc segment **14** to the metal wheel **12** by way of soldering, the optoceramic phosphor arc segment **14** further includes a solderable metal stack **30** is deposited on the back side of the optoceramic phosphor element **20** (or, more particularly in the illustrative example, on the back side of the dielectric mirror coating **24**). The solderable metal stack **30** can include as few as a single metal layer; in the illustrative embodiment, the solderable metal stack **30** includes: an adhesion layer **32** adjacent the element **20** of (by way of non-limiting illustrative example) chromium or titanium or a titanium-tungsten (TiW) alloy; a diffusion barrier layer **34** of (by way of non-limiting illustrative example) nickel; and a solderable metal layer **36** of (by way of non-limiting illustrative example) gold. This is merely an illustrative example, and numerous solderable solder stacks known in the art for facilitating soldering of non-metallic elements to a metal element can be employed. By way of some further non-limiting illustrative examples: the solderable metal layer **36** could be silver, platinum, or another solder-compatible metal or metal sub-stack rather than gold; the nickel diffusion barrier layer can include a few percent (e.g. 5%) vanadium to reduce its magnetic properties so as to facilitate deposition by magnetron sputtering; the diffusion barrier layer **34** can be omitted entirely and/or the adhesion layer **32** can be omitted entirely; and so forth. As indicated in FIGURE 2, the solderable metal stack **30** may, for example, be deposited on the back side of the optoceramic phosphor element **20** (or, more particularly in the illustrative example, on the back side of the dielectric mirror coating **24**) in a metal deposition operation **S2** by sputtering, plating, vacuum metal evaporation (e.g. using electron beam evaporation, thermal evaporation), or so forth, although any other deposition technique suitable for depositing the materials that make up these solderable metal stack **30** can be used to perform the deposition(s) **S1**.

[0028] With continuing reference to FIGURES 1 and 2, the optoceramic phosphor arc segment **14** including the optoceramic phosphor element **20**, the optional optical coatings **22**, **24**, and the solderable metal stack **30** is attached to the metal substrate **12** (the metal wheel **12** in the illustrative example of FIGURE 1) by a solder operation **S3** which forms a solder bond **40**. In one suitable approach diagrammatically illustrated in FIGURE 2, the solder operation **S3** entails placing the optoceramic phosphor arc segment **14** onto the metal heat sink **12** with a solder preform **40_1** coated with solder flux **40_2** interposed between the optoceramic phosphor arc segment **14** and the metal heat sink **12**. In another contemplated embodiment, the solder flux is mixed into the solder preform rather than being coated on the solder preform. A wide range of solder alloys can be used for the solder preform **40_1** such as, by way of non-limiting example, a lead/indium/silver solder alloy, a gold/tin solder alloy, a gold-silicon (AuSi) alloy, or so forth. This assembly is then heated to a soldering temperature which is effective to cause the solder **40_1**, **40_2** to form the solder bond **40** between the solderable metal stack **30** and the metal heat sink **12**. Other approaches are contemplated for performing the solder operation **S3**, such as employing a solder gun to dispose pre-mixed solder material and flux onto one or both of the surfaces to be soldered together and then pressing them together. For commercial manufacturing, the solder bonding operation **S3** should be an automated process with high throughput.

[0029] With brief reference to FIGURE 3, in a variant embodiment the heat sink substrate **12** to which the solder attachment is to be made includes a recess **44** shaped and of sufficient depth to receive the solder preform **40_1** coated with solder flux **40_2**, so as to facilitate the solder operation **S3**. The resulting device will then have the solder bond **40** disposed in the recess **44**. Optionally, the recess **44** may be deep enough to receive a lower portion of the optoceramic phosphor arc segment **14** as well, so that the resulting device has the solder bond **40** and a lower portion of the optoceramic phosphor element **20** disposed in the recess **44**.

[0030] The illustrative embodiment pertains to the phosphor wheel **10** of FIGURE 1. However, it will be appreciated that the disclosed approach for solder attachment of the optoceramic phosphor element **20** to a metal heat sink **12** is equally applicable for attaching static phosphor elements to a heat sink. For example, in one application, the optoceramic phosphor element **20** contains one or more phosphors that generate yellow or yellowish phosphorescence, and the pump laser beam is a blue laser beam. By appropriate tuning of the phosphor concentration in the optoceramic phosphor element **20** and the blue pump beam power, a mixture of blue pump light and yellow or yellowish phosphorescence is generated that approximates white light. The optoceramic phosphor element may be employed in any desired optical system. As one non-limiting example, a static optoceramic phosphor element soldered to a heat sink as disclosed herein may be employed in conjunction with a light tunnel, where the high optical power in the light tunnel is accommodated by efficient heat transfer from the optoceramic phosphor element to the heat sink via the solder bond as disclosed herein.

[0031] In experimental tests, optoceramic phosphor elements soldered to a copper heat sink have been tested, along with optoceramic phosphor elements attached to a copper heat sink by thermal paste for comparison. Some tested optoceramic phosphor elements included the front side AR coating **22** and the back side dielectric mirror coating **24**, with the latter designed for a backside air interface. In tests, no cracking of optoceramic phosphor elements secured to the heat sink by soldering was observed for beam energies effective to heat the optoceramic phosphor element up to and beyond the phosphor quenching point. By contrast, optoceramic phosphor elements secured to the heat sink by thermal paste exhibited catastrophic cracking as pump laser power was increased, and this cracking occurred well before the phosphor quenching point was reached so that it limited thermal range of the device. Damage to the AR coating **22** was also observed in the optoceramic phosphor elements mounted using thermal paste, leading to a reduced laser induced damage (LITD) threshold as compared with optoceramic phosphor elements mounted using the disclosed solder bond. It was also surprisingly observed that the back side dielectric mirror coating **24** designed for a backside air interface provides substantial light output improvement in spite of the fact that the backside interface was to the solder bond **40**, rather than to the design-basis air (refractive index n=1). Without being limited to any particular theory of operation, it is believed that this may be due to the multiple layers of the stack providing significant reflection such that the fraction of light reaching the backside mirror/solder interface is low.

[0032] These results demonstrate that the disclosed solder attachment approach enables construction of a passive light conversion device comprising an optoceramic phosphor element **20** comprising one or more phosphors embedded in a ceramic host, a metal heat sink **12**, and a solder bond **40** attaching the optoceramic phosphor element **20** to the metal heat sink **12**, which can operate with a pump beam energy of any value up to the phosphor quenching point without the optoceramic phosphor element **20** undergoing cracking. By contrast, the conventional thermal paste attachment resulted in catastrophic cracking well below the phosphor quenching point thereby limiting device performance. It is noted that the disclosed solder bond is providing improved device performance for passive optical elements which in many embodiments include no electrical or electronic components.

[0033] It will be appreciated that various of the above-disclosed and other features and functions, or alternatives thereof, may be desirably combined into many other different systems or applications. It will be further appreciated that various presently unforeseen or unanticipated alternatives, modifications, variations or improvements therein may be subsequently made by those skilled in the art which are also intended to be encompassed by the following claims.

CLAIMS:

1. A light conversion device comprising:

an optoceramic phosphor element comprising one or more phosphors embedded in a ceramic host;

a metal heat sink; and

a solder bond attaching the optoceramic phosphor element to the metal heat sink.

2. The light conversion device of claim 1 wherein the light conversion device is a static light conversion device or a phosphor wheel.

3. The light conversion device of any one of claims 1-2 further comprising:

a mirror coating disposed on a back side of the optoceramic phosphor element between the optoceramic phosphor element and the solder bond.

4. The light conversion device of claim 3 wherein the mirror is a dielectric mirror designed to operate with a backside air interface.

5. The light conversion device of any one of claims 3-4 further comprising:

a solderable metal stack including one or more metal layers disposed on the mirror coating between the mirror coating and the solder bond;

wherein the solder bond attaches to the solderable metal stack.

6. The light conversion device of any one of claims 1-2 further comprising:

a solderable metal stack including one or more metal layers disposed on a back side of the optoceramic phosphor element between the optoceramic phosphor element and the solder bond;

wherein the solder bond attaches to the solderable metal stack.

7. The light conversion device of any one of claims 5-6 wherein the solderable metal stack comprises one of:

a chromium/nickel/gold layer stack in which the solder bond attaches to the gold layer;

a titanium/nickel/gold layer stack in which the solder bond attaches to the gold layer;

a chromium/nickel/silver layer stack in which the solder bond attaches to the silver layer; and

a titanium/nickel/silver layer stack in which the solder bond attaches to the silver layer.

8. The light conversion device of claim 7 wherein the nickel layer of the solderable metal stack includes vanadium.

9. The light conversion device of any one of claims 1-8 wherein the metal heat sink includes a recess within which the solder bond is disposed.

10. The light conversion device of claim 9 wherein a lower portion of the optoceramic phosphor element is also disposed within the recess of the heat sink.

11. The light conversion device of any one of claims 1-10 wherein the optoceramic phosphor element does not undergo cracking in response to an applied light beam with beam energy effective to heat the optoceramic phosphor element to the phosphor quenching point.

12. A light generator comprising:

a light conversion device as set forth in any one of claims 1-11; and

a light source arranged to apply a light beam to the light conversion element;

wherein the optoceramic phosphor element does not undergo cracking in response to the light source applying a light beam of beam energy effective to heat the optoceramic phosphor element to the phosphor quenching point.

13. A light conversion device comprising:

a phosphor element comprising one or more phosphors embedded in a solid host element;

a metal heat sink; and

a solder bond attaching the phosphor element to the metal heat sink.

14. The light conversion device of claim 13 wherein the light conversion device is a static light conversion device or a phosphor wheel.

15. The light conversion device of any one of claims 13-14 further comprising:

a mirror coating disposed on a back side of the phosphor element between the phosphor element and the solder bond.

16. The light conversion device of claim 15 wherein the mirror is a dielectric mirror designed to operate with a backside air interface.

17. The light conversion device of any one of claims 15-16 further comprising:

a solderable metal stack including one or more metal layers disposed on the mirror coating between the mirror coating and the solder bond;

wherein the solder bond attaches to the solderable metal stack.

18. The light conversion device of any one of claims 13-14 further comprising:

a solderable metal stack including one or more metal layers disposed on a back side of the phosphor element between the phosphor element and the solder bond;

wherein the solder bond attaches to the solderable metal stack.

19. The light conversion device of any one of claims 17-18 wherein the solderable metal stack comprises one of:

a chromium/nickel/gold layer stack in which the solder bond attaches to the gold layer;

a titanium/nickel/gold layer stack in which the solder bond attaches to the gold layer;

a chromium/nickel/silver layer stack in which the solder bond attaches to the silver layer; and

a titanium/nickel/silver layer stack in which the solder bond attaches to the silver layer.

20. The light conversion device of claim 19 wherein the nickel layer of the solderable metal stack includes vanadium.

21. The light conversion device of any one of claims 13-20 wherein the metal heat sink includes a recess within which the solder bond is disposed.

22. The light conversion device of claim 21 wherein a lower portion of the phosphor element is also disposed within the recess of the heat sink.

23. The light conversion device of any one of claims 13-22 wherein the phosphor element comprises one or more phosphors embedded in a solid glass host element.

24. The light conversion device of claim 23 wherein the solid glass host element comprises B270, BK7, P-SF68, P-SK57Q1, P-SK58A, or P-BK7.

25. A light generator comprising:

a light conversion device as set forth in any one of claims 13-24; and

a light source arranged to apply a light beam to the light conversion element;

wherein the optoceramic phosphor element does not undergo cracking in response to the light source applying a light beam of beam energy effective to heat the optoceramic phosphor element to the phosphor quenching point.

26. A method of fabricating a light conversion device comprising:

depositing a solderable metal stack on a back side of an optoceramic phosphor element comprising one or more phosphors embedded in a ceramic host; and

attaching the optoceramic phosphor element to a metal heat sink by soldering the solderable metal stack to the heat sink.

27. The method of claim 26 further comprising:

prior to depositing the solderable metal stack on the back side of the optoceramic phosphor element, depositing a dielectric mirror coating on the back side of the optoceramic phosphor element whereby the solderable metal stack is deposited on the dielectric mirror coating.

28. The method of any one of claims 26-27 wherein the depositing of the solderable metal stack on the back side of the optoceramic phosphor element includes:

depositing a chromium or titanium layer onto the back side of the optoceramic phosphor element or onto a dielectric mirror coating disposed on the back side of the optoceramic phosphor element;

depositing a nickel layer on the chromium or titanium layer; and

depositing a silver, platinum, or gold layer on the nickel layer.

29. The method of claim 28 wherein the nickel layer includes vanadium.

30. The method of any one of claims 26-27 wherein the depositing of the solderable metal stack on the back side of the optoceramic phosphor element includes:

depositing a solderable silver, platinum, or gold layer on the nickel layer;

wherein the soldering comprises soldering the solderable silver, platinum, or gold layer to the heat sink.

31. The method of any one of claims 26-28 wherein the attaching comprises:

disposing the optoceramic phosphor element onto the metal heat sink with a solder preform interposed between the optoceramic phosphor element and the metal heat sink to create an assembly; and

heating the assembly to a soldering temperature which is effective to cause the solder preform to form a solder bond between the solderable metal stack and the metal heat sink.

32. The method of claim 31 wherein the solder preform includes solder flux coated onto or mixed into the solder preform.

33. The method of any one of claims 31-32 wherein the solder preform comprises a lead/indium/silver solder alloy or a gold/tin solder alloy.

34. A method of fabricating a light conversion device comprising:

depositing a solderable metal stack on a back side of a phosphor element comprising one or more phosphors embedded in a solid host element; and

attaching the phosphor element to a metal heat sink by soldering the solderable metal stack to the heat sink.

35. The method of claim 34 further comprising:

prior to depositing the solderable metal stack on the back side of the phosphor element, depositing a dielectric mirror coating on the back side of the phosphor element whereby the solderable metal stack is deposited on the dielectric mirror coating.

36. The method of any one of claims 34-35 wherein the depositing of the solderable metal stack on the back side of the phosphor element includes:

depositing a chromium or titanium layer onto the back side of the phosphor element or onto a dielectric mirror coating disposed on the back side of the phosphor element;

depositing a nickel layer on the chromium or titanium layer; and

depositing a silver, platinum, or gold layer on the nickel layer.

37. The method of any one of claims 33-34 wherein the depositing of the solderable metal stack on the back side of the phosphor element includes:

depositing a solderable silver, platinum, or gold layer on the nickel layer;

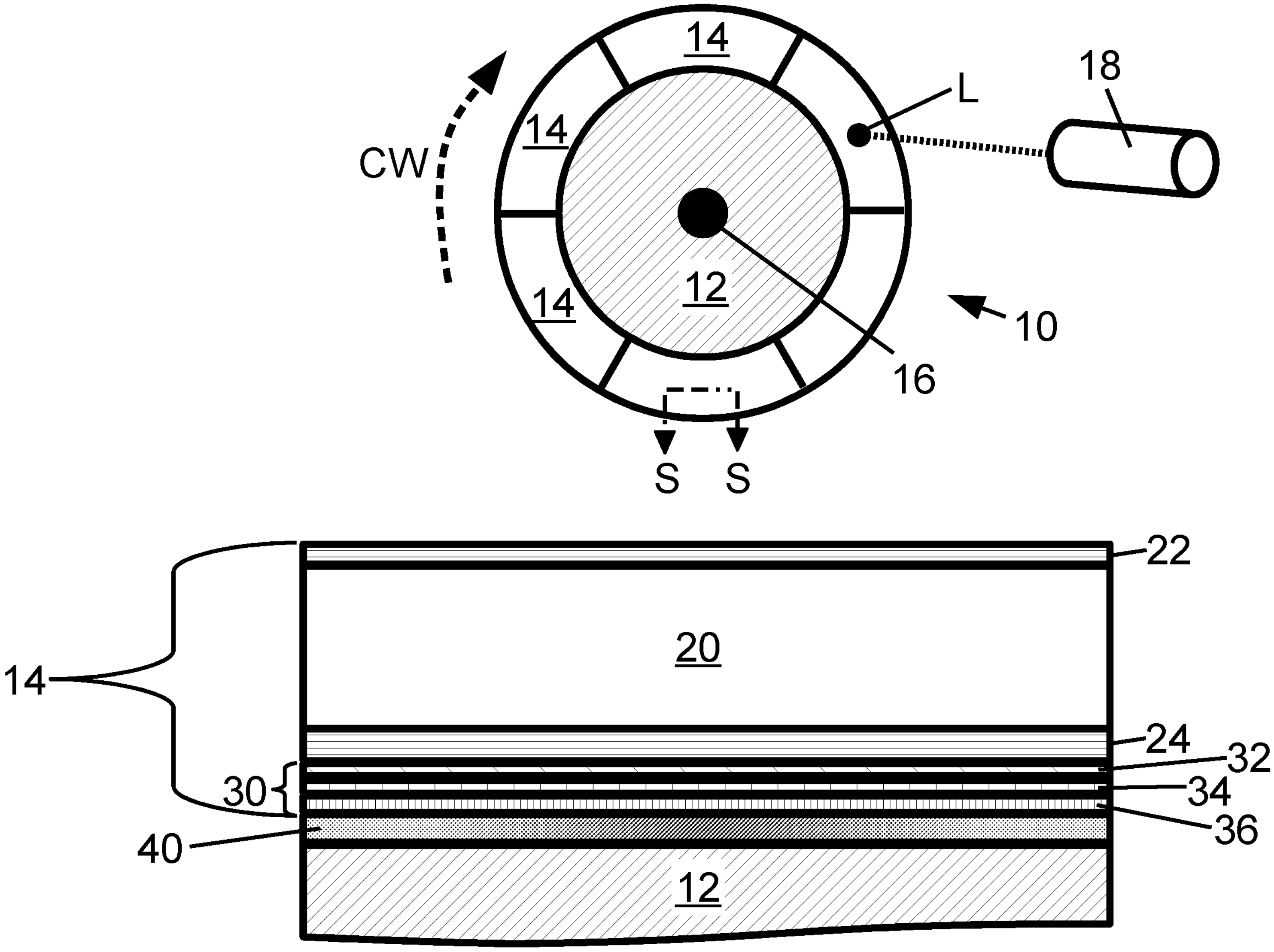
wherein the soldering comprises soldering the solderable silver, platinum, or gold layer to the heat sink.

38. The method of any one of claims 33-34 wherein the attaching comprises:

disposing the phosphor element onto the metal heat sink with a solder preform interposed between the phosphor element and the metal heat sink to create an assembly; and

heating the assembly to a soldering temperature which is effective to cause the solder preform to form a solder bond between the solderable metal stack and the metal heat sink.

39. The method of claim 38 wherein the solder preform includes solder flux coated onto or mixed into the solder preform.



Section S-S

Fig. 1

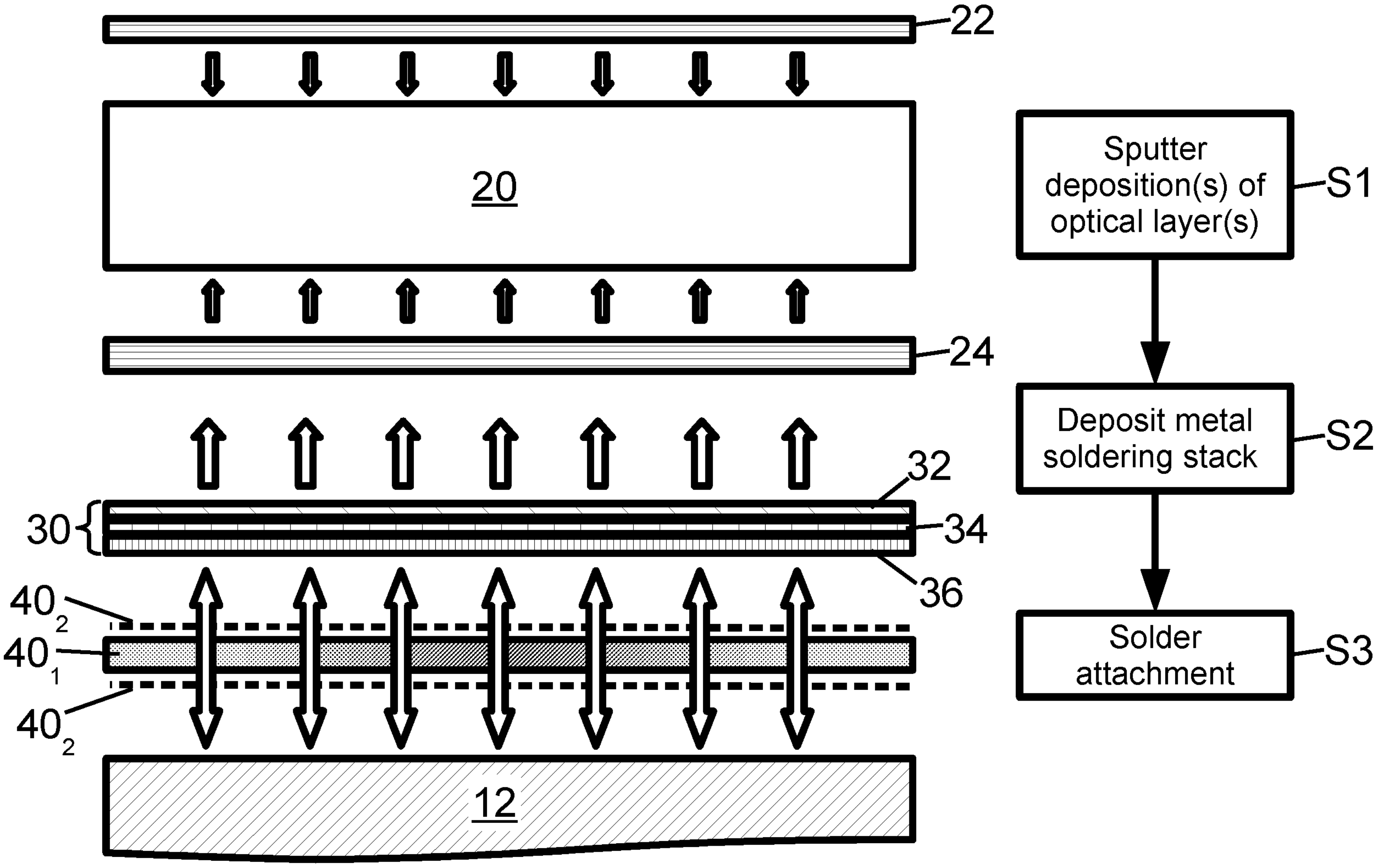

22
20
24
32
30
34
36
40_2
40_1
40_2
12
Sputter deposition(s) of optical layer(s)
S1
Deposit metal soldering stack
S2
Solder attachment
S3

Fig. 2

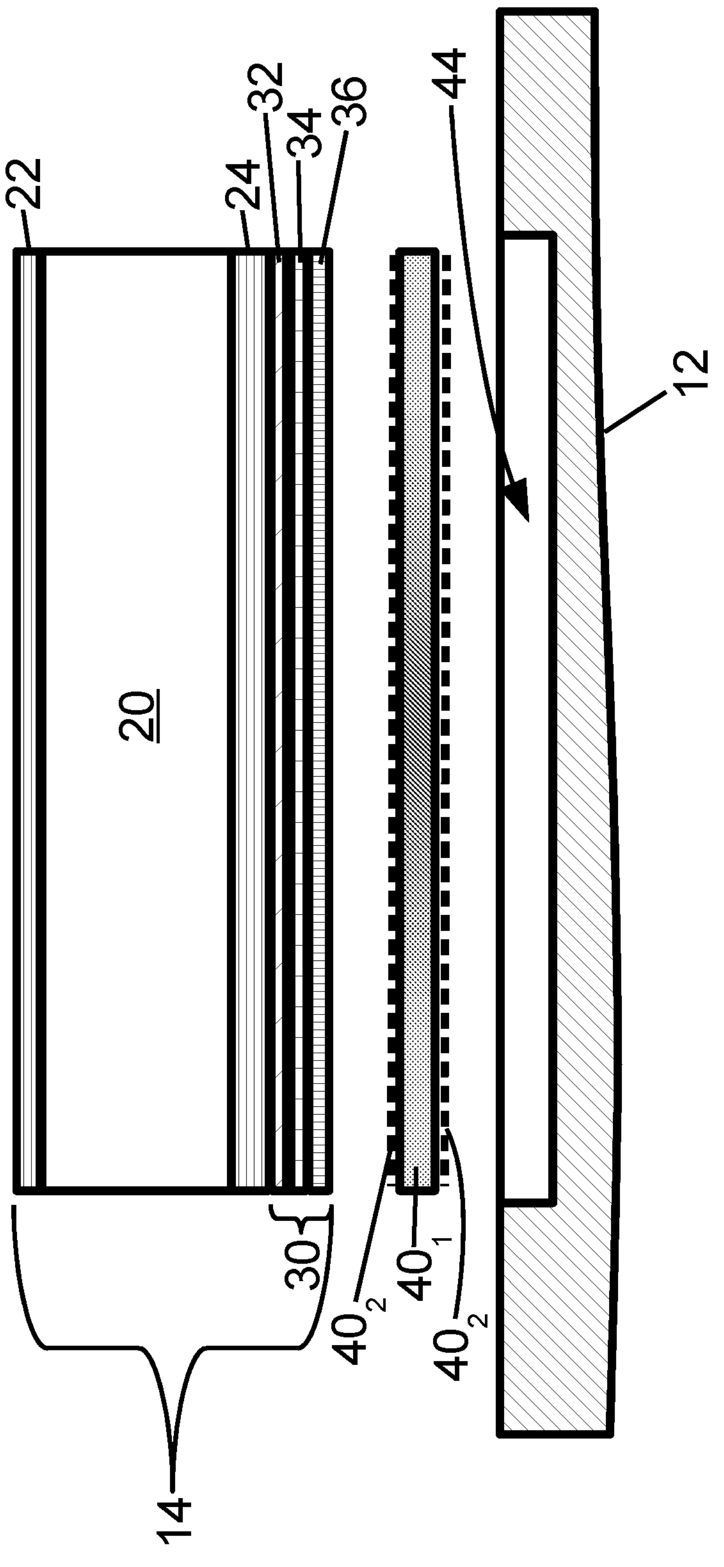


Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/053367

A. CLASSIFICATION OF SUBJECT MATTER
INV. C03C14/00 C04B37/02 G03B21/20
ADD. C09K11/02 H01L33/50 H01L33/64

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)
C03C C04B C09K H01L G03B

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, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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"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
24 November 2016

Date of mailing of the international search report
05/12/2016

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Tinjod, Frank

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