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Declarations under Rule 4.17:

- as to the identity of the inventor (Rule 4.17(i))
- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))

[Continued on next page]

(54) Title: LASER-ACTIVATED REMOTE PHOSPHOR TARGET AND SYSTEM

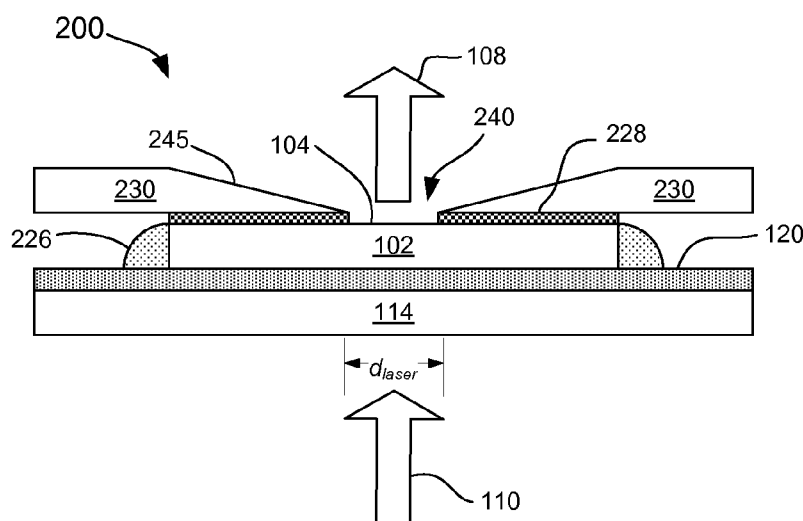


FIG. 2

(57) Abstract: A laser-activated remote phosphor (LARP) target comprising a substrate 8114, a dichroic filter (120) disposed on the substrate, a phosphor converter (102) disposed on the dichroic filter, and an aperture structure (230) disposed on the phosphor converter. The phosphor converter comprises a luminescent material that at least partially converts a primary laser pump light (110) into a secondary light (108) having a different peak wavelength. The dichroic filter substantially transmits the primary laser pump light and substantially reflects the secondary light. The aperture structure covers the lighting emitting surface except for an aperture (240) in the aperture structure whereby a substantial portion of secondary light passes through the aperture in the aperture structure for coupling into an optical system.



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- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*
- *of inventorship (Rule 4.17(iv))*
- Published:**
- *with international search report (Art. 21(3))*

LASER-ACTIVATED REMOTE PHOSPHOR TARGET AND SYSTEM

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application is an international application of and claims the benefit of United States Provisional Application No. 62/211,347, filed August 28, 2015, the entire contents of which are hereby incorporated by reference.

TECHNICAL FIELD

[0002] The present invention relates to lighting, and more specifically, to light source including a laser-activated remote phosphor.

BACKGROUND

[0003] Projection and display optics applications usually require light sources with low etendue to efficiently couple into a given optical system or provide a specified beam pattern. One way to accomplish this is by utilizing a laser in combination with a photoluminescent phosphor. This approach may be referred to as laser-activated remote phosphor (LARP) technology. The shorter wavelength primary light from the laser excites (pumps) the phosphor to emit a longer wavelength secondary light (wavelength conversion.) A significant advantage of using wavelength conversion is that the phosphor composition can be chosen so that the system emits a white light. Moreover, such a system can have a much lower etendue than incoherent sources such as high-power light emitting diodes (LEDs).

[0004] In LARP applications, the high pump fluxes that are needed to attain a high radiance of converted light from the phosphor have the unintended consequence of locally heating the phosphor in the pump region. This heating reduces the quantum efficiency of the phosphor, and thereby places severe limits on the final radiance of converted light. To address this problem, several approaches have been used. One solution is to use a wavelength converter in the form of a high thermal conductivity ceramic in combination with a high thermal conductivity substrate. Ceramic wavelength converters are formed by sintering a mass of inorganic phosphor

particles at high temperature until the particles diffuse and stick together to form a monolithic piece. Typically, the sintered piece has a density that approaches the theoretical density for the material although in some applications it is desirable to maintain some porosity to enhance scattering. Ceramic wavelength converters have a thermal conductivity that is much greater than wavelength converters formed by dispersing individual phosphor particles in a silicone resin.

SUMMARY

[0005] A reflective aperture structure is formed on the light-emitting surface of a phosphor converter to form a target for a laser-activated remote phosphor (LARP) system. The reflective aperture structure increases radiance and produces an emission spot with a sharp cutoff. In a preferred embodiment, this is accomplished by bonding the phosphor converter to an aperture structure comprised of a high-scattering, high thermal conductivity material, e.g., polycrystalline alumina. Alternatively, the aperture may be formed using high-reflectivity thin-films or applying a filled silicone ring. The aperture structure may also comprise a cavity formed in the light-emitting surface of the phosphor converter. All of these approaches produce a source of high radiance and low étendue.

[0006] In an embodiment, there is provided a laser-activated remote phosphor target. The laser-activated remote phosphor includes: a substrate; a dichroic filter disposed on the substrate; a phosphor converter disposed on the dichroic filter, the phosphor converter comprising a luminescent material that at least partially converts a primary laser pump light into a secondary light having a different peak wavelength, the dichroic filter substantially transmitting the primary laser pump light and substantially reflecting the secondary light; and an aperture structure disposed on a light emitting surface of the phosphor converter, the aperture structure covering the lighting emitting surface except for an aperture in the aperture structure whereby a substantial portion of secondary light passes through the aperture in the aperture structure for coupling into an optical system.

[0007] In a related embodiment, the aperture structure may include a polycrystalline ceramic. In a further related embodiment, the polycrystalline ceramic may be

polycrystalline alumina. In a further related embodiment, a scattering length of the aperture structure may be less than 10 μm .

[0008] In another related embodiment, the aperture structure may be a reflective metal coating. In a further related embodiment, the reflective metal coating may further cover the sides of the phosphor converter.

[0009] In still another related embodiment, the aperture may be beveled. In yet another related embodiment, the aperture structure may be a cavity formed in the light emitting surface of the phosphor converter. In a further related embodiment, the phosphor converter may be a monolithic, polycrystalline ceramic. In a further related embodiment, the phosphor converter may have a scattering gradient wherein scattering of the laser pump light is lower in a region below the cavity.

[0010] In still yet another related embodiment, the aperture may have a diameter D and a scattering length l_s and the phosphor converter may have a thickness t , and the scattering length l_s may be greater than the thickness divided by fifty. In a further related embodiment, the thickness may be greater than the scattering length l_s which may be greater than the thickness divided by five. In another further related embodiment, the aperture may be cylindrical and have a depth less than twice the diameter. In yet another further related embodiment, the phosphor converter may have an absorption length of the primary laser pump light that is less than the thickness of the phosphor converter.

[0011] In another embodiment, there is provided a laser-activated remote phosphor system. The laser-activated remote phosphor system includes: a laser to generate a beam of a primary laser pump light, a target, and an optical system. The target includes: a substrate; a dichroic filter disposed on the substrate; a phosphor converter disposed on the dichroic filter, the phosphor converter comprising a luminescent material that at least partially converts the primary laser pump light into a secondary light having a different peak wavelength, the dichroic filter substantially transmitting the primary laser pump light and substantially reflecting the secondary light; and an aperture structure disposed on a light emitting surface of the phosphor converter, the aperture structure covering the lighting emitting surface except for an aperture in the aperture structure whereby a substantial portion of

secondary light passes through the aperture in the aperture structure for coupling into the optical system.

[0012] In a related embodiment, a diameter of the beam may be greater than a diameter of the aperture. In another related embodiment, the optical system may include an optical fiber.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] The foregoing and other objects, features and advantages disclosed herein will be apparent from the following description of particular embodiments disclosed herein, as illustrated in the accompanying drawings in which like reference characters refer to the same parts throughout the different views. The drawings are not necessarily to scale, emphasis instead being placed upon illustrating the principles disclosed herein.

[0014] FIG. 1 illustrates a transmissive LARP system and target without an aperture structure, according to embodiments disclosed herein.

[0015] FIG. 2 illustrates a transmissive LARP target having a beveled aperture structure, according to embodiments disclosed herein.

[0016] FIG. 3 illustrates a transmissive LARP target having an aperture structure comprised of a polycrystalline ceramic, according to embodiments disclosed herein.

[0017] FIG. 4 illustrates a transmissive LARP target having an aperture structure comprised of a reflective coating, according to embodiments disclosed herein.

[0018] FIG. 5 illustrates a transmissive LARP target having an aperture structure comprised of a polycrystalline ceramic, according to embodiments disclosed herein.

[0019] FIG. 6 illustrates a transmissive LARP target having an aperture structure comprised of cavity formed in the light-emitting surface of the phosphor converter, according to embodiments disclosed herein.

DETAILED DESCRIPTION

[0020] Laser-activated remote phosphor (LARP) sources have the advantage over conventional light sources by providing a very low étendue. This is needed for

many applications, including projection, automotive forward lighting, and other display optic applications. One of the challenges with LARP sources is that while the pump laser may have a very small beam waist at the phosphor converter, the converted emission spot may have a considerably larger area as a result of total-internal reflection (TIR) or scattering within the converter. This effect is especially difficult to control in transmissive LARP applications, where the primary laser pump light impinges on one side of the converter and the converted secondary light is emitted from the opposite side. While high scattering in the converter may help to confine the emission spot, it also reduces efficiency due to backscattering of the primary laser pump light. More importantly, emission spot expansion increases étendue and therefore lessens the usefulness of this approach.

[0021] Embodiments as disclosed throughout provide a laser exciting a remote phosphor converter with a small beam area without expanding the emission spot, especially in a transmissive mode of operation. Since the pump spot is, in some embodiments, actually be larger than the emission area in the invention, the input power may be, and in some embodiments is, spread over a larger area, thereby reducing peak phosphor temperatures. This permits higher radiance emission because thermal quenching of the phosphor is reduced for a given pump power. Furthermore, embodiments are disclosed that improve heat dissipation over prior methods, further increasing radiance by permitting even higher pump powers and intensities.

[0022] A transmissive LARP configuration is illustrated in FIG. 1 without an aperture structure. The system comprises target 100, a laser light source (not shown) and optical system 122. The primary laser pump light 110 is incident on a sapphire or other transparent, high thermal conductivity substrate 114. The pump light 110 has a spot size of diameter d_{laser} . A dichroic filter 120 is applied to the opposite side of the substrate to retro-reflect back-directed emission from the phosphor converter into the desired forward direction as indicated by arrow 106. Primary laser pump light 110 passes through transparent substrate 114 and dichroic filter 120 and into phosphor converter 102 where it is at least partially converted to secondary light 108 having a different peak wavelength. To achieve a small emission spot, the incident

laser beam must have an intensity distribution that is narrower than the desired emission spot radiance distribution. If the phosphor converter 102 has strong scattering, such that the scattering length, l_s , in the phosphor converter at emission wavelengths is much smaller than the diameter of the pump beam, the scattering may confine the emission spot to perhaps within a factor of two of the pump spot size. However, the emission spot will have an intensity distribution which, if imaged into an optical system with a well-defined étendue, will generally result in coupling losses. Furthermore, the strong scattering will enhance the amount of luminescence directed in the backward direction and backscatter more pump light, decreasing the amount of pump light that can be converted to luminescence. Both of these effects will reduce forward-directed conversion efficiency.

[0023] In accordance with embodiments of the present invention, it has been found that integrating the transmissive LARP approach with an aperture structure provides a target that can produce a well-defined emission spot equal or even smaller than the laser pump spot size. This decreases étendue and increases coupling efficiency into an optical system. Furthermore, using polycrystalline alumina (PCA) or other high-scattering, high-thermal conductivity materials for the aperture structure greatly improves heat dissipation of the device, permitting even higher pump intensities and emission radiance.

[0024] FIG. 2 illustrates an embodiment of a LARP target. Focused or collimated primary laser pump light 110 is incident on a transparent substrate 114 of target 200. A wavelength-selective dichroic filter 120, which passes the pump light 110 but reflects the converted secondary light 108 generated by the phosphor converter 102, is applied to the opposite side of substrate 114. Depending on the details of the configuration, the dichroic filter 120 may be bonded directly to the phosphor converter 102 or separated by an air gap whose distance is much less than the desired spot size, typically less than 100 μm . Bonding of the dichroic filter to the phosphor can be accomplished by a number of methods including silicones and thermally-enhanced silicones with appropriate fillers. In some embodiments, if the converter 102 does not have enough scattering to eliminate leakage of emission out

of the sides of the converter, an additional reflecting material 226 is applied to the sides, such as a TiO₂-filled silicone or a reflective metal coating.

[0025] The light-emitting surface 104 of the converter is covered with an aperture structure 230 comprising a highly reflective material with an aperture 240 over the region of strongest luminescence. The aperture structure 230 may be bonded to the light-emitting surface 104 of converter 102 with a layer of a bonding material 228, e.g., a silicone glue or metal solder. Preferably, aperture 240 is square or circular, with dimensions defined by the source étendue requirements. More preferably, aperture 240 is circular with a diameter D. However, there are no particular constraints on the shape and it may be adjusted to suit a particular application. For a circular aperture, the diameter D would generally be on the order of the pump beam diameter, preferably from 10 μm – 5 mm, depending on the optical application. The aperture structure 230 itself may be formed by several methods, including direct application of optical coatings using a masking procedure to produce the aperture 240, bonding of highly-reflective ceramics such as porous polycrystalline alumina (Al₂O₃) (PCA), and application of a TiO₂ (or other high refractive index filler) in silicone. Certain materials for the aperture structure 230 may also function to conduct heat away from the phosphor converter which is heated by non-radiative losses generated during laser pumping. For example, reflective metal coatings may be soldered to a heat sink. PCA aperture structures have high thermal conductivity and can be applied to a heat sink either by mechanical mounting with appropriate thermal greases or metallization and soldering. In this case, the metallization used to bond the aperture structure to the heat sink is not required to have high optical reflectivity.

[0026] The phosphor converter may be a number of known phosphor conversion materials, including powder phosphors in various host matrices such as low melting point temperature glass or polymers (e.g., silicones), monolithic ceramic phosphors such as polycrystalline cerium-activated garnets, such as Y₃Al₅O₁₂:Ce (YAG:Ce) and Lu₃Al₅O₁₂:Ce (LuAG:Ce), two-phase monolithic ceramics such as YAG:Ce-Al₂O₃, and other phosphor systems known in the art. The converter should have high thermal conductivity for LARP applications of at least 1W/m/K, and

preferably at least 5W/m/K . Additionally, the converter should contain sufficient volume scattering to confine the luminescence. For example, the scattering length $l_s \ll D$, the diameter of the aperture as indicated in FIG. 3; however to avoid strong backscattering, $l_s > t/100$, where t is the phosphor converter thickness. More preferably, $l_s > t/50$ to $l_s > t/5$. In some embodiments, $t > l_s > t/5$, if reflective surfaces have very high reflectivity ($> 97\%$). If strong surface scattering is not present, one cannot have $l_s > t$ because extraction losses will become large. Scattering may be induced through powder phosphor particles embedded in a lower index matrix, pores, grain boundaries (anisotropic materials only), or second phases in the case of monolithic ceramic converters, or the incorporation of other benign scattering particles whose index is different than the matrix. Preferably, a combination of highly reflective surfaces at the sides 109 of the converter 102 completely confines the luminescence (except at the aperture region).

[0027] The method by which the aperture source functions is similar to how the extraction process for a luminescent source of higher refractive index couples light efficiently into a lower index medium. Referring again to FIG. 3, primary laser pump light 110 excites a region in the phosphor converter 102 of target 300 which produces a secondary wavelength-converted light 108. The luminescence region 350 is confined by volume scattering from the phosphor converter 102. The dichroic filter 120 and reflective surfaces 334 of aperture structure 330 further confine the luminescence in three-dimensions. If the reflectivity of all confining regions/surfaces is high, at least 90%, and preferably greater than 95%, then the trapped radiation power density will increase due to the partial cavity effect. Because of the scattering, some fraction of this otherwise trapped radiation will be coupled to the aperture 340. As a consequence, the radiance of the light emitted from aperture 340 will exceed the radiance of the light that would be directly emitted into the aperture alone, without the cavity contribution. In the case of no losses (perfect reflectivity), then all the radiation generated by the entire luminescent region 350 will be coupled into aperture 340, effectively decreasing the étendue of the LARP source.

[0028] In one set of samples that were fabricated, 2.0 mm diameter x 100 μ m thick monolithic polycrystalline ceramic converters of 0.5% Ce in (Y,Gd)₃Al₅O₁₂:Ce (GdYAG:Ce) were coated with a multilayer enhanced silver reflective thin film. Porosity of the GdYAG:Ce samples is expected to be on the order of 1%, providing a large amount of volume scattering within the converter. The other silver side was coated with Cr (50 nm), Ni (500 nm), Au (200nm) to form an appropriate bonding-soldering layer. Samples were glued onto dichroic coated sapphire substrates which have above 95% reflectivity at nearly all angles for wavelengths above 500 nm and transmit light below 480 nm on the order of 98% transmission. The gluing was done using ZnO-filled silicone to provide thermal conductivity of 0.6 W/m/K. The sides of the samples were also coated with the filled silicone to provide extra reflectivity on the sides. This embodiment is illustrated in FIG. 4. In particular, target 400 is shown with an aperture structure 430 which is comprised of a reflective metal coating that has been applied to the light-emitting surface 104 and sides of phosphor converter 104, except in the region of aperture 440.

[0029] In another embodiment illustrated in FIG. 5, the metal coating is replaced by highly reflective PCA or other highly reflective polycrystalline ceramic material to form aperture structure 530 of target 500. The ceramic reflective material should have a thermal conductivity of at least 10W/m/K, and preferably greater than the thermal conductivity of the phosphor converter 102. The aperture 540 is cylindrical and preferably should have a depth not exceeding twice the diameter. Depending on the location of the heat sink, lateral thermal conduction through the aperture structure may be important, requiring a minimum thickness for effective heat transfer. Also, mechanical limits can limit the minimum thickness of the aperture structure. For high reflectivity, the aperture structure material must be highly scattering. To ensure good confinement of radiation the scattering length of the aperture structure material (PCA for example) $l_{\text{aperture}} \ll D$; preferably, l_a should be considerably less than 10 μ m. With PCA, this can readily be achieved through reduced sintering temperatures and/or times to increase porosity. This may be reached for pore diameters in the range of 200 – 400 nm and volume porosities exceeding 1 – 2%. Most preferably, the PCA aperture structure is bonded to a

monolithic ceramic phosphor using the high-temperature ceramic joining techniques described in International Patent Application No. PCT/US2015/036256.

Alternatively, it may be joined using low-temperature glass bonding; however, this approach leaves a bond line of lower thermal conductivity which may compromise the heat transfer to the aperture structure.

[0030] In another embodiment, the cylindrical aperture may be replaced by a broad beveled aperture structure 230 as shown in FIG. 2. This may be useful if the aperture structure is required to be relatively thick compared to the aperture size. However, high-angle radiation emitted from the aperture 240 may scatter off the beveled sides 245. Because strong scattering produces nearly Lambertian radiation, scattering from the beveled area will effectively increase the aperture size, albeit, the radiance in the bevel region is much lower than in the aperture.

[0031] In another embodiment illustrated in FIG. 6, the aperture structure of target 600 comprises a cavity 644 formed in the light-emitting surface 104 of phosphor converter 102. As with the previous embodiments, the cavity effect will enhance the radiance in the aperture 640. This can be accomplished with laser drilling in the green, pre-fired, or fully sintered state of monolithic ceramic phosphors or other LARP phosphor materials. Other methods can also be used including injection molding and punching. The phosphor converter 102 should again have a scattering length $l_s \ll D$, the diameter of the aperture 640. In such embodiments, the intrinsic scattering of the phosphor converter 102 acts as the reflecting surfaces to confine radiation in luminescence region 650. To take full advantage of the étendue decreasing functionality of the aperture, the phosphor converter thickness t should be greater than the pump absorption length l_{abs} so that the luminescence produced along the sides of the aperture does not extend to the surface. Otherwise, the source area would extend beyond the aperture, reducing the desired radiance increase.

[0032] In another embodiment, the PCA aperture structure material described in the embodiments described with regards to FIGs. 2 and 5 may be replaced by alternative composites in which pore scattering is replaced or enhanced by addition of high-index filler particles in the PCA matrix. These composite materials include PCA-TiO₂, PCA-ZrO₂, and other materials. One may also apply a glaze to the PCA

surface bonded to the monolithic ceramic phosphor. This can aid bonding and produces a more specular reflectance which may further improve confinement and increase overall reflectivity in some applications.

[0033] In another embodiment, fillers may also be incorporated into the polycrystalline ceramic phosphor material in the embodiment shown in FIG. 5, providing greater control and possibly reflectivity in the cavity. In such embodiments, one could also apply a scatter gradient such that stronger scattering of the primary laser pump light occurs in the thicker parts of the ceramic while being reduced in the volume directly behind the aperture to reduce backscattering losses.

[0034] The phosphor material is not limited to polycrystalline ceramics, but may and in some embodiments does include phosphor glasses, single-crystal ceramics such as YAG:Ce, and others. In low scattering materials such as single-crystal YAG:Ce ceramics or highly sintered polycrystalline ceramics, additional surface structuring (photonic lattice, strong random surface scatterers) could be applied to the aperture region 102 in FIG. 2 to provide light extraction in lieu of volume scattering. This may further reduce backscattering losses for the transmissive geometry.

Additionally, reflective LARP geometries may also make use of the aperture configuration, by shining the primary laser pump light directly through the aperture.

[0035] Unless otherwise stated, use of the word "substantially" may be construed to include a precise relationship, condition, arrangement, orientation, and/or other characteristic, and deviations thereof as understood by one of ordinary skill in the art, to the extent that such deviations do not materially affect the disclosed methods and systems.

[0036] Throughout the entirety of the present disclosure, use of the articles "a" and/or "an" and/or "the" to modify a noun may be understood to be used for convenience and to include one, or more than one, of the modified noun, unless otherwise specifically stated. The terms "comprising", "including" and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0037] Elements, components, modules, and/or parts thereof that are described and/or otherwise portrayed through the figures to communicate with, be associated with, and/or be based on, something else, may be understood to so communicate, be associated with, and or be based on in a direct and/or indirect manner, unless otherwise stipulated herein.

[0038] Although the methods and systems have been described relative to a specific embodiment thereof, they are not so limited. Obviously many modifications and variations may become apparent in light of the above teachings. Many additional changes in the details, materials, and arrangement of parts, herein described and illustrated, may be made by those skilled in the art.

What is claimed is:

1. A laser-activated remote phosphor target comprising:
 - a substrate;
 - a dichroic filter disposed on the substrate;
 - a phosphor converter disposed on the dichroic filter, the phosphor converter comprising a luminescent material that at least partially converts a primary laser pump light into a secondary light having a different peak wavelength, the dichroic filter substantially transmitting the primary laser pump light and substantially reflecting the secondary light; and
 - an aperture structure disposed on a light emitting surface of the phosphor converter, the aperture structure covering the lighting emitting surface except for an aperture in the aperture structure whereby a substantial portion of secondary light passes through the aperture in the aperture structure for coupling into an optical system.
2. The laser-activated remote phosphor target of claim 1, wherein the aperture structure is comprised of a polycrystalline ceramic.
3. The laser-activated remote phosphor target of claim 2, wherein the polycrystalline ceramic is polycrystalline alumina.
4. The laser-activated remote phosphor target of claim 3, wherein a scattering length of the aperture structure is less than 10 μm .
5. The laser-activated remote phosphor target of claim 1, wherein the aperture structure is comprised of a reflective metal coating.
6. The laser-activated remote phosphor target of claim 5, wherein the reflective metal coating further covers the sides of the phosphor converter.

7. The laser-activated remote phosphor target of claim 1, wherein the aperture is beveled.
8. The laser-activated remote phosphor target of claim 1, wherein the aperture structure is a cavity formed in the light emitting surface of the phosphor converter.
9. The laser-activated remote phosphor target of claim 8, wherein the phosphor converter is a monolithic, polycrystalline ceramic.
10. The laser-activated remote phosphor target of claim 8, wherein the phosphor converter has a scattering gradient wherein scattering of the laser pump light is lower in a region below the cavity.
11. The laser-activated remote phosphor target of claim 1, wherein the aperture has a diameter D and a scattering length l_s and the phosphor converter has a thickness t , wherein $l_s > t/50$.
12. The laser-activated remote phosphor target of claim 11, wherein $t > l_s > t/5$.
13. The laser-activated remote phosphor target of claim 11, wherein the aperture is cylindrical and has a depth less than twice the diameter.
14. The laser-activated remote phosphor target of claim 11, wherein the phosphor converter has an absorption length of the primary laser pump light that is less than the thickness of the phosphor converter.
15. A laser-activated remote phosphor system, comprising:
 - a laser to generate a beam of a primary laser pump light, a target, and an optical system;
 - wherein the target comprises:
 - a substrate;

a dichroic filter disposed on the substrate;

a phosphor converter disposed on the dichroic filter, the phosphor converter comprising a luminescent material that at least partially converts the primary laser pump light into a secondary light having a different peak wavelength, the dichroic filter substantially transmitting the primary laser pump light and substantially reflecting the secondary light; and

an aperture structure disposed on a light emitting surface of the phosphor converter, the aperture structure covering the lighting emitting surface except for an aperture in the aperture structure whereby a substantial portion of secondary light passes through the aperture in the aperture structure for coupling into the optical system.

16. The laser-activated remote phosphor system of claim 15, wherein a diameter of the beam is greater than a diameter of the aperture.

17. The laser-activated remote phosphor system of claim 15, wherein the optical system comprises an optical fiber.

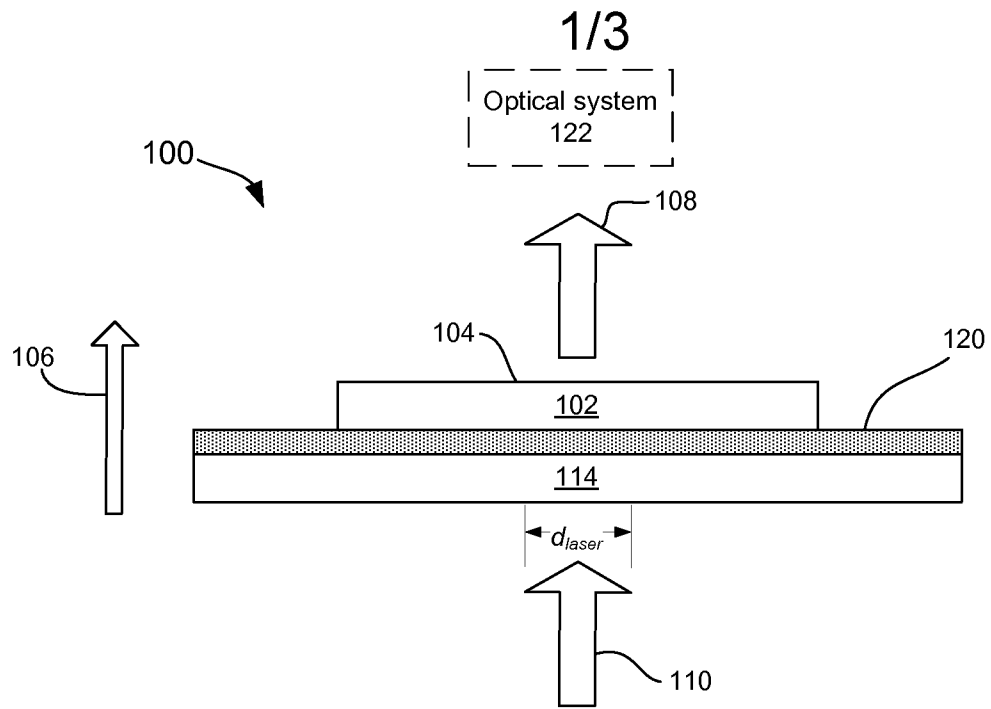


FIG. 1

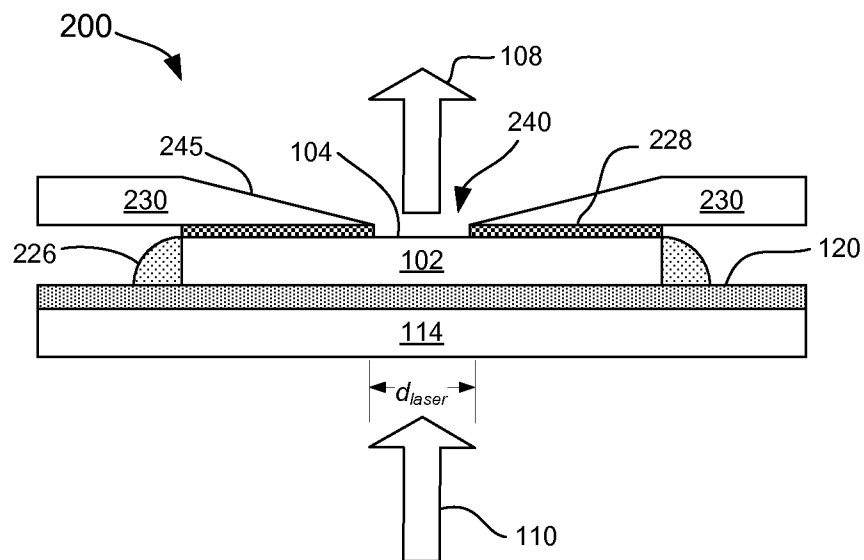


FIG. 2

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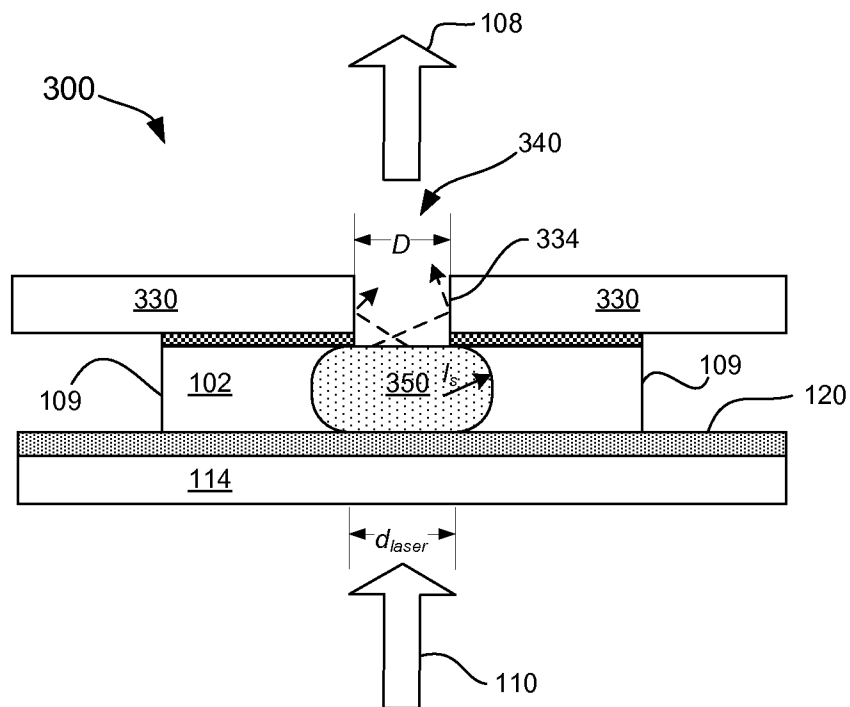


FIG. 3

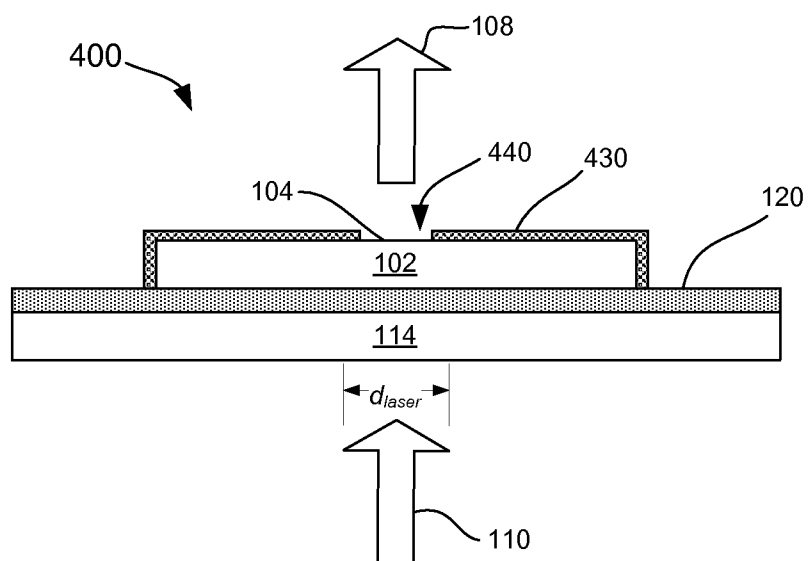


FIG. 4

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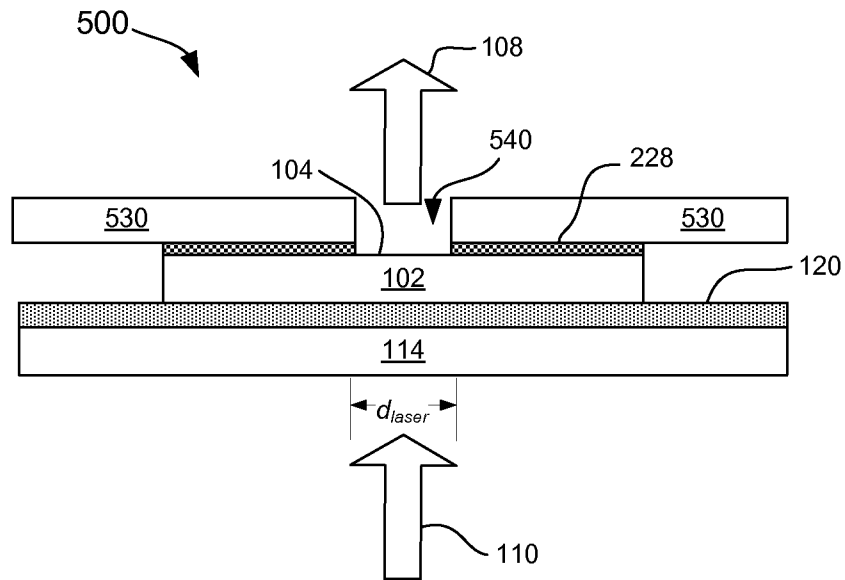


FIG. 5

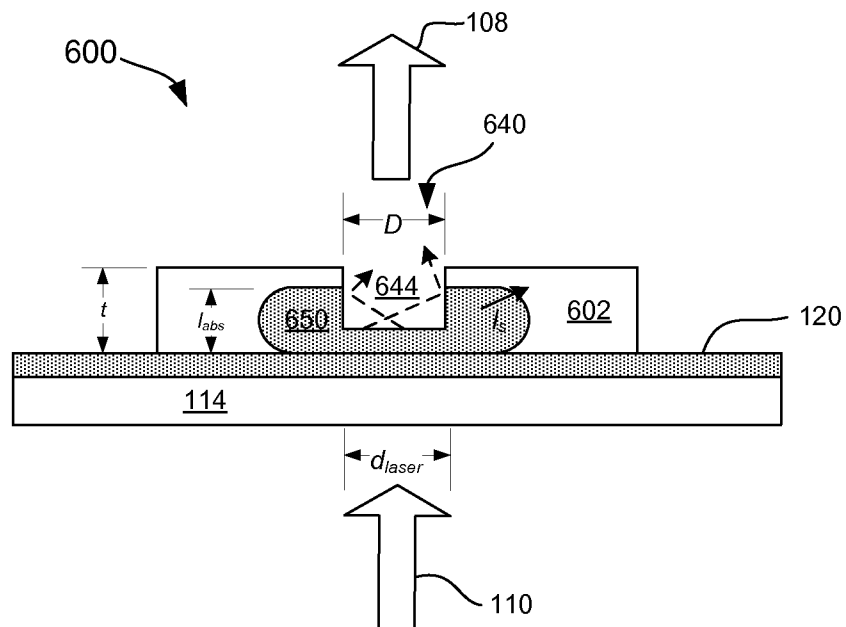


FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2016/049332

A. CLASSIFICATION OF SUBJECT MATTER
INV. G03B21/20
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

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	WO 2008/018002 A2 (KONINKL PHILIPS ELECTRONICS NV [NL]; PHILIPS LUMILEDS LIGHTING CO [US]) 14 February 2008 (2008-02-14) paragraph [0023] - paragraph [0048]; figures 1-3	1-17
A	----- WO 2015/112946 A1 (OSRAM SYLVANIA INC [US]) 30 July 2015 (2015-07-30) paragraph [0032] - paragraph [0042]; figures 1-2	1-17
A	----- US 2013/250544 A1 (ZINK NATHAN [US] ET AL) 26 September 2013 (2013-09-26) paragraph [0016] - paragraph [0084]; figures 1A-5	1-17
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Further documents are listed in the continuation of Box C.



See patent family annex.

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