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Li

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(54) **LASER/PHOSPHOR, LED AND/OR DIFFUSER LIGHT SOURCES WITH LIGHT RECYCLING**

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§ 371 (c)(1),
(2) Date: **Jan. 6, 2022**

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Publication Classification

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F21V 7/04	(2006.01)
F21V 29/70	(2006.01)
F21V 8/00	(2006.01)

(52) **U.S. Cl.**

CPC ***F21V 9/40*** (2018.02); ***F21V 7/00*** (2013.01); ***F21V 7/04*** (2013.01); ***F21V 7/0033*** (2013.01); ***F21V 29/70*** (2015.01); ***G02B 6/0008*** (2013.01)

(57) **ABSTRACT**

Apparatus and method using a recycling light source. The source includes: a laser, a phosphor plate and/or diffuser plate that receives laser light and outputs wavelength-converted and/or diffused light, curved reflective surface(s) that collect the output light and reflect the light back to the plate to increase brightness of output light. An optional heatsink and vibrator can be used. Some embodiments include a plurality of parabolic reflectors to image the plate to an output aperture in one of the parabolic reflectors. Some embodiments include a diffuser arranged to diffuse laser light at the diffuser, and a first curved reflector located and configured to reflect diffused light back toward the diffuser in order to preserve a brightness of the laser light. Some embodiments include a laser-excited phosphor light source and method with light recycling.

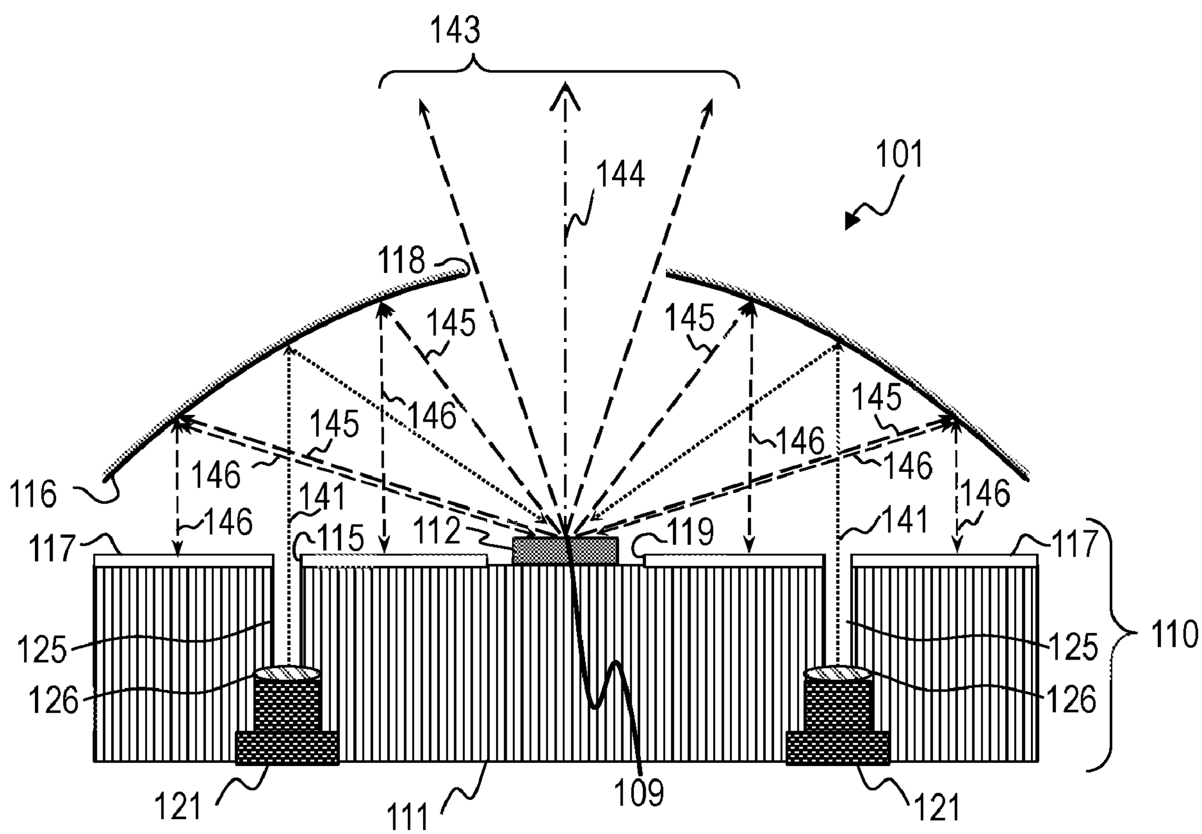

FIG. 1A

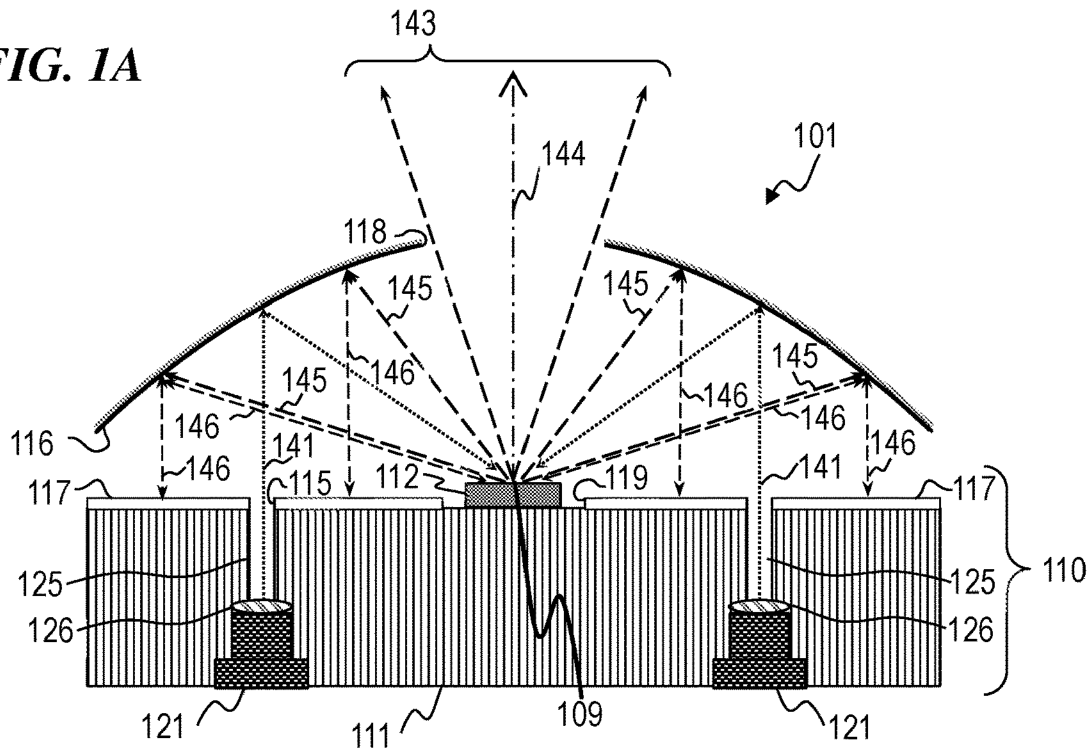
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FIG. 1B

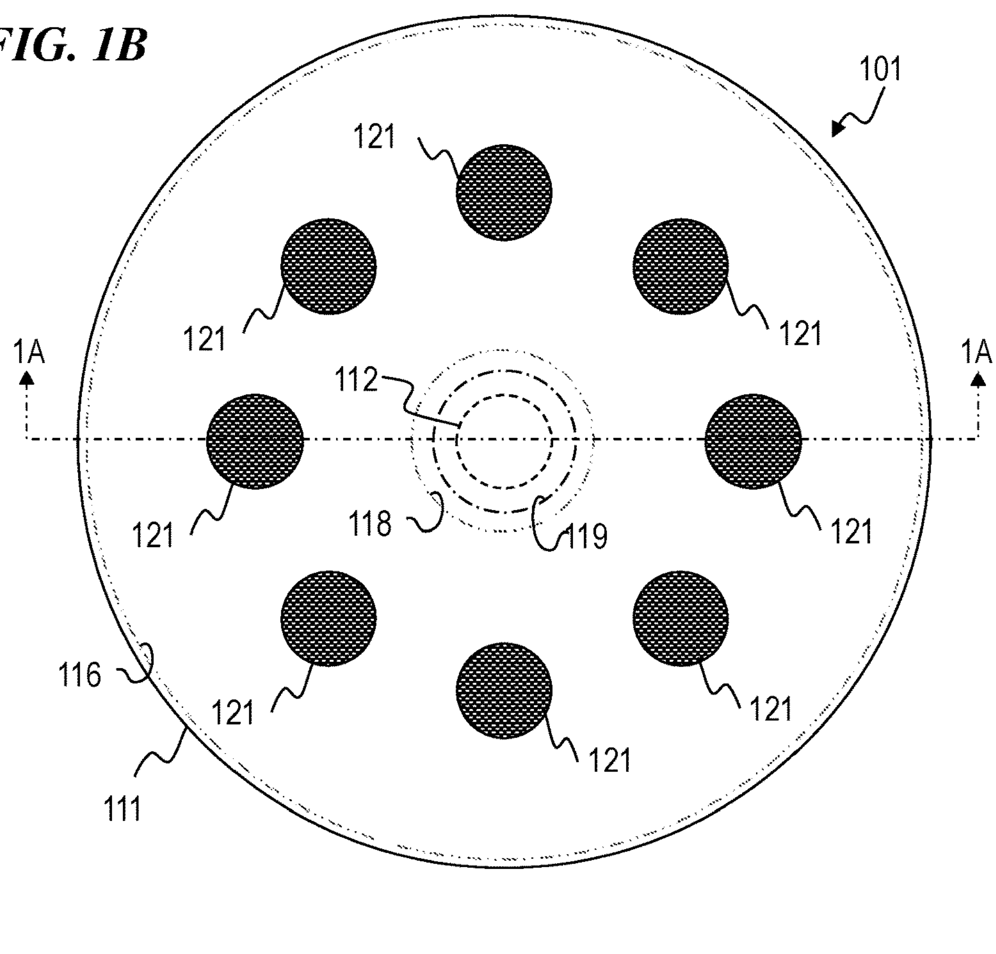
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FIG. 1C

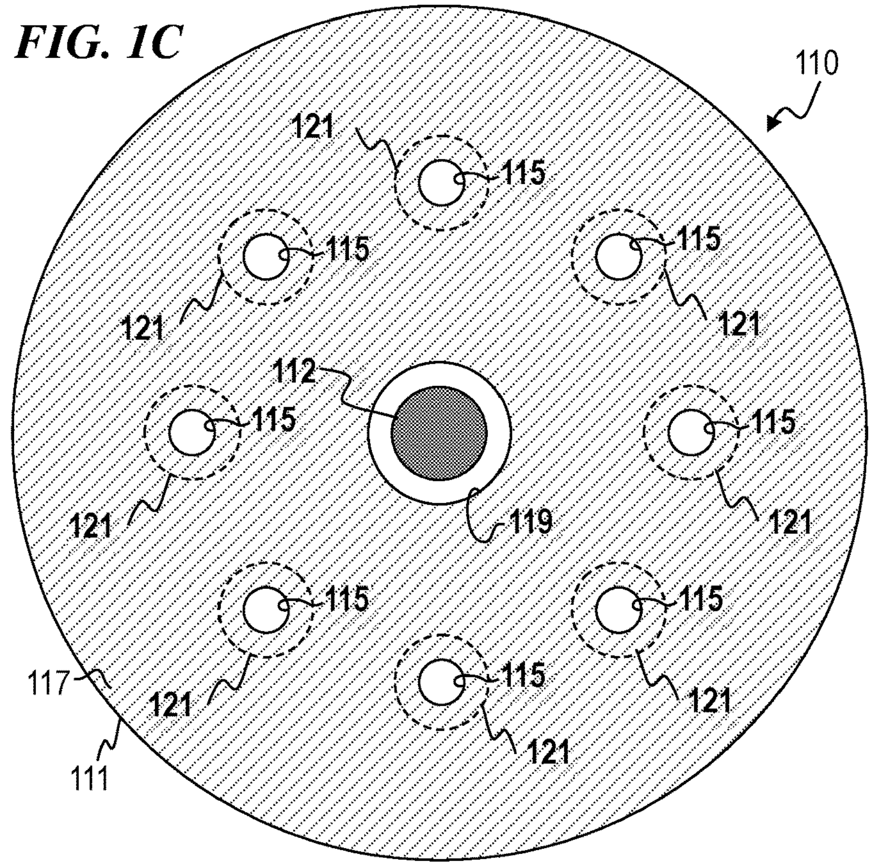
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FIG. 1D

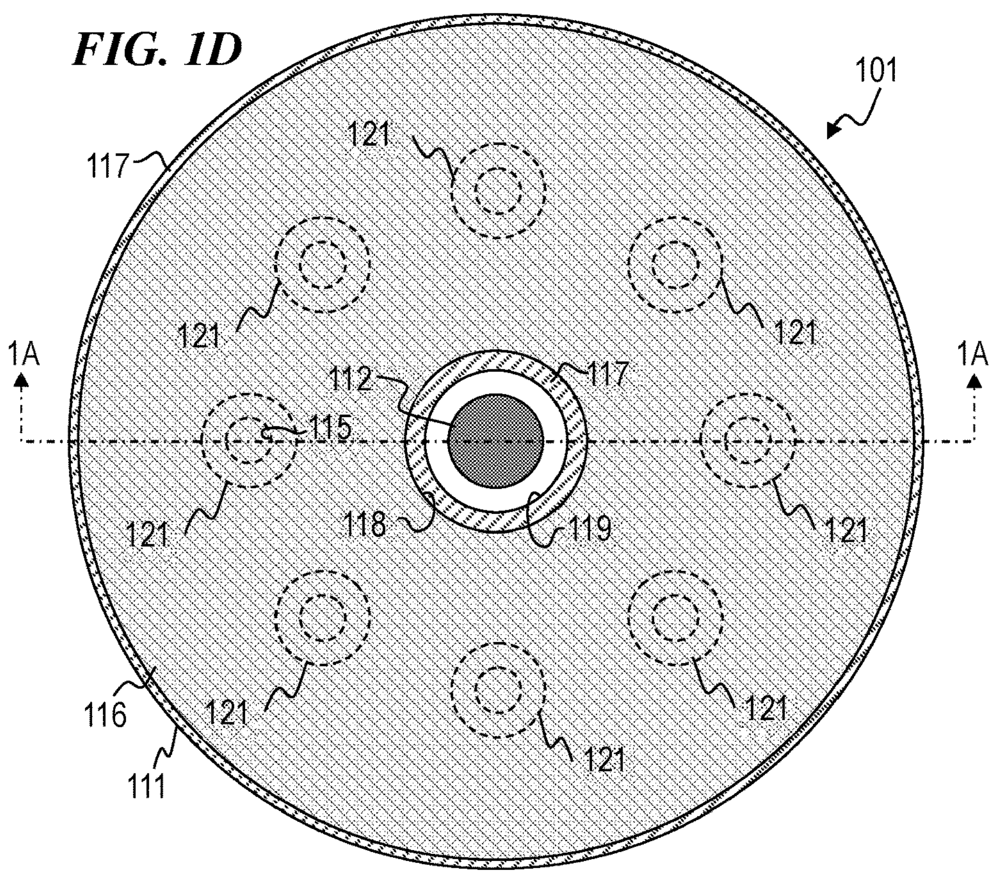
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FIG. 1E

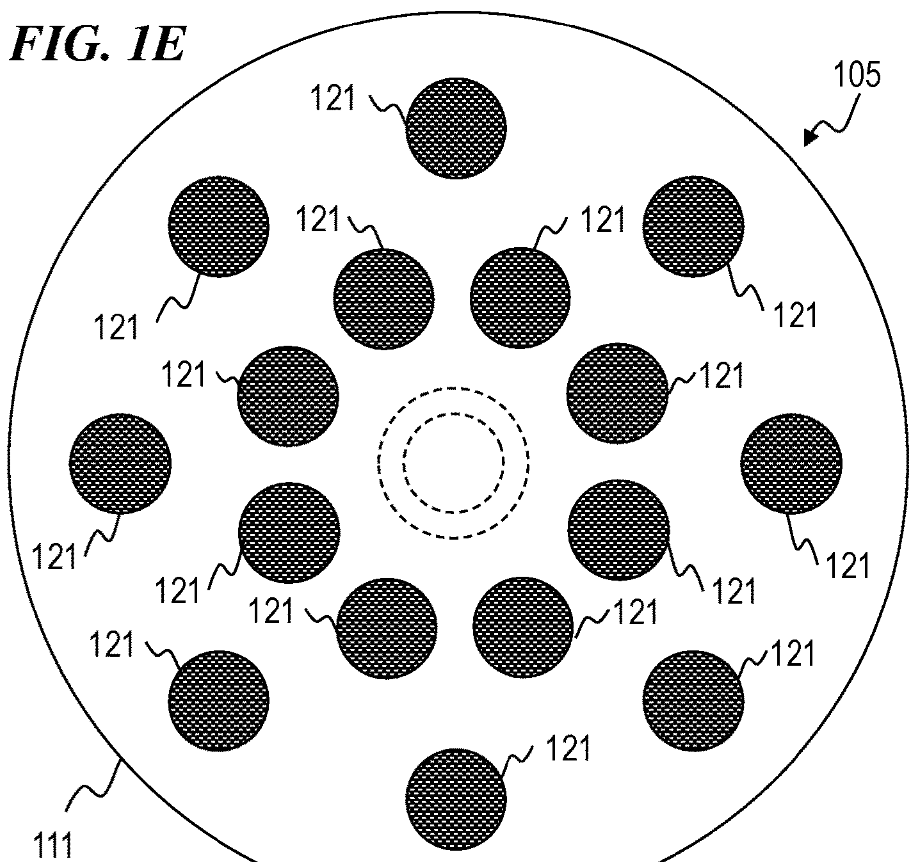
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FIG. 1F

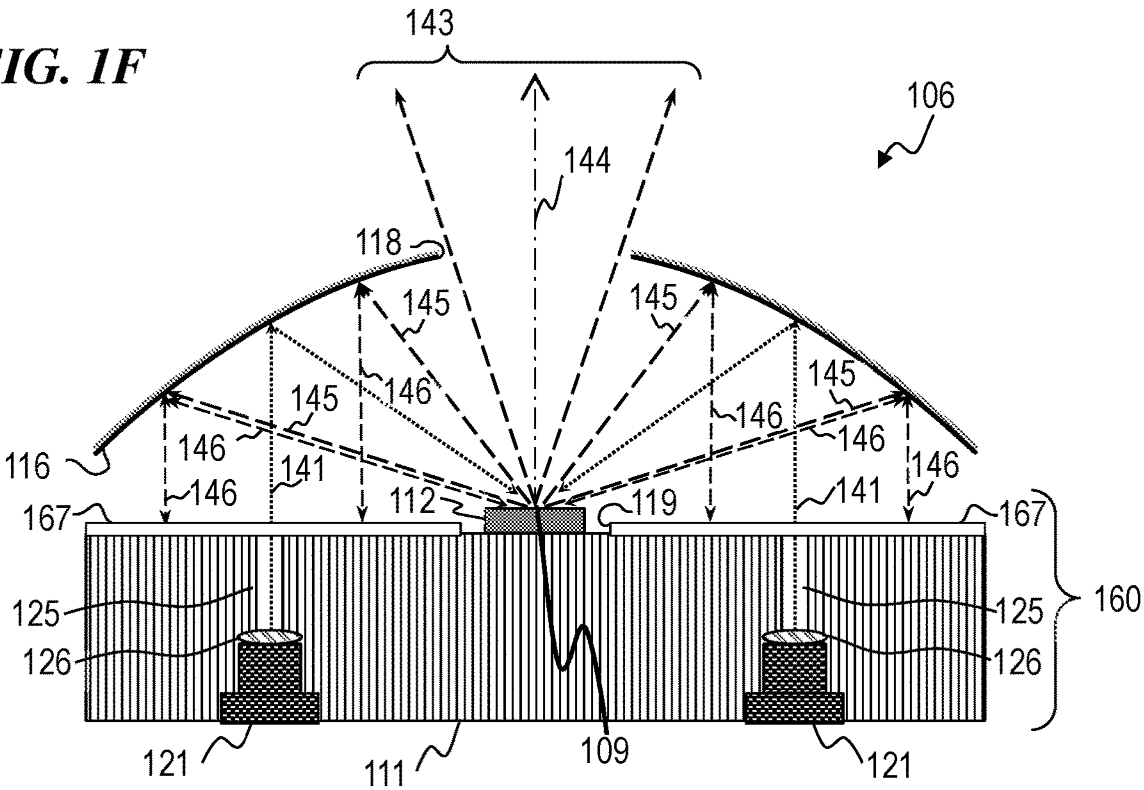
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FIG. 1G

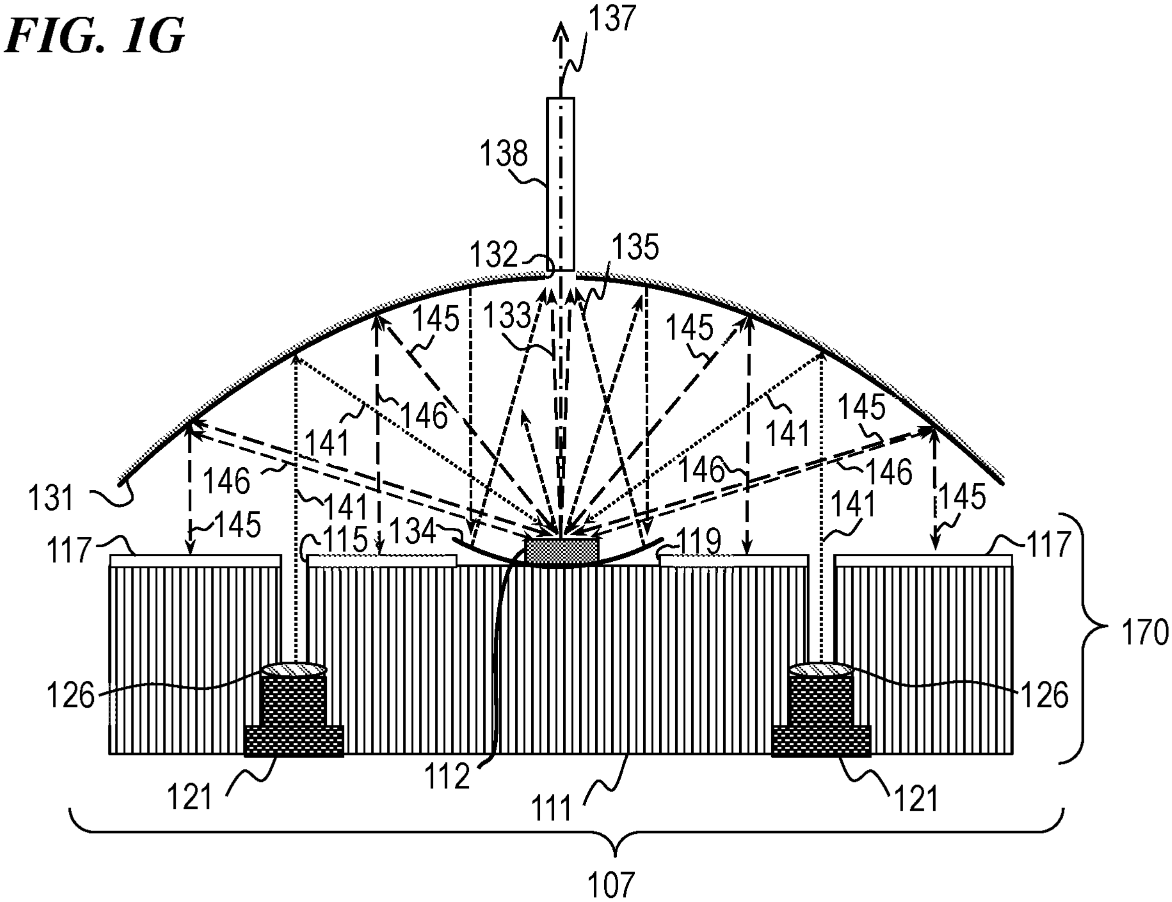
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FIG. 2A

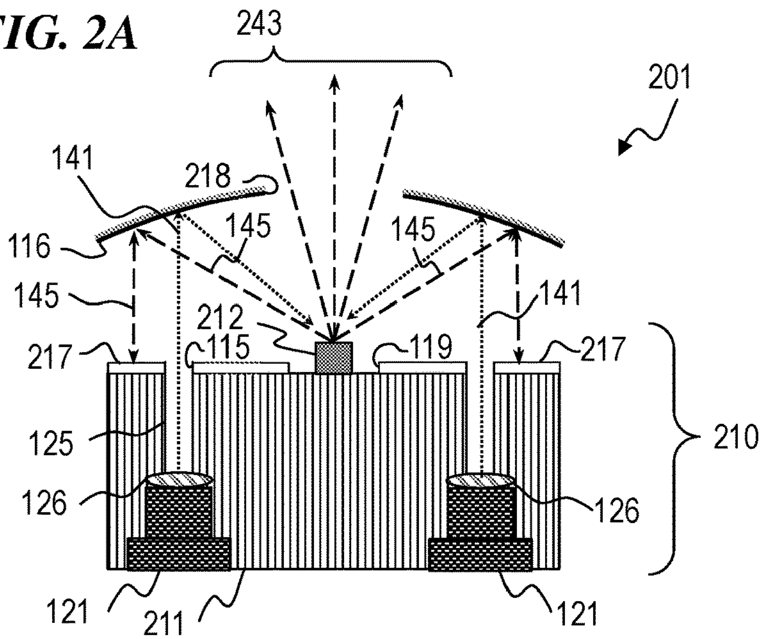


FIG. 2B

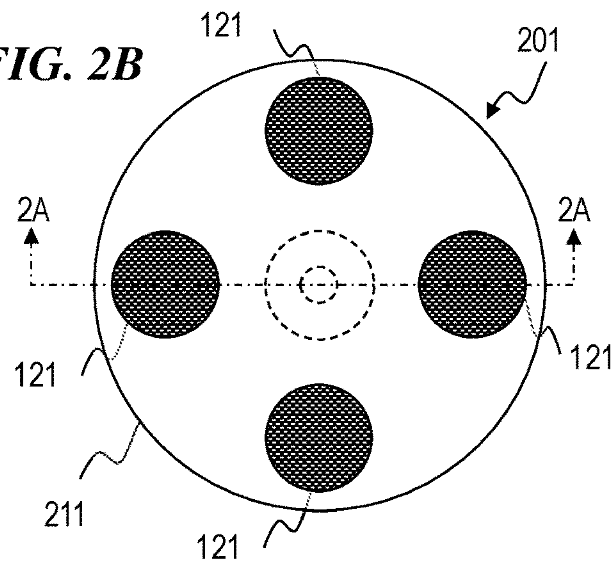


FIG. 2C

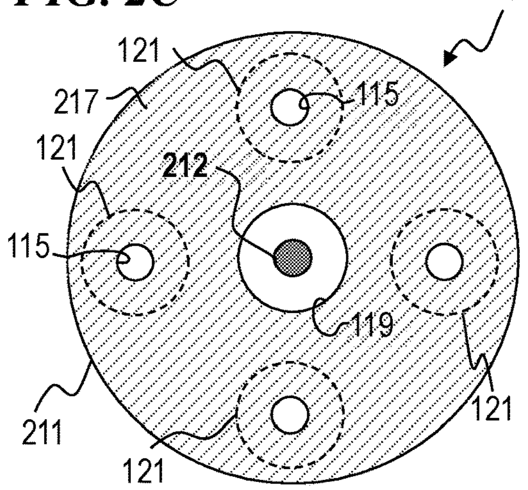


FIG. 2D

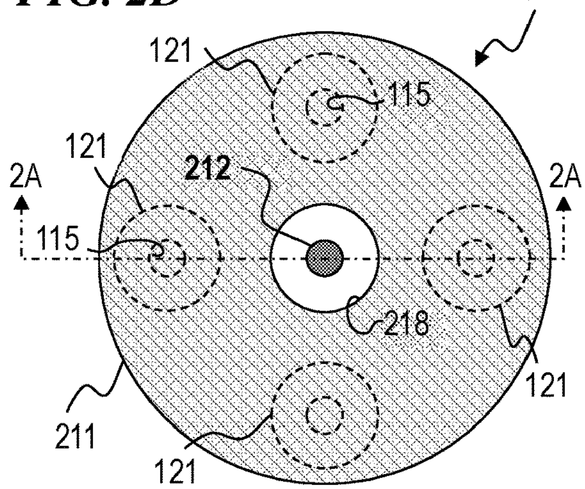


FIG. 3A

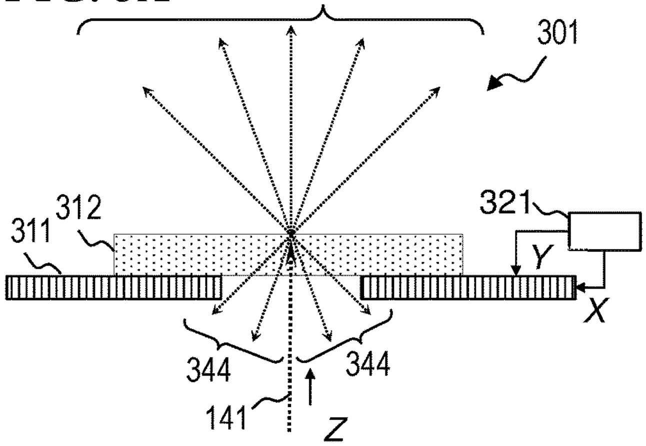


FIG. 3B

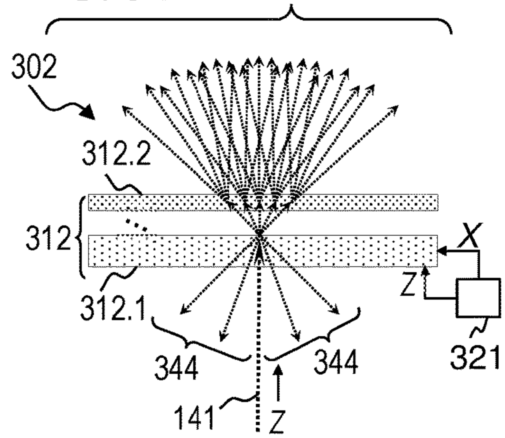


FIG. 4A

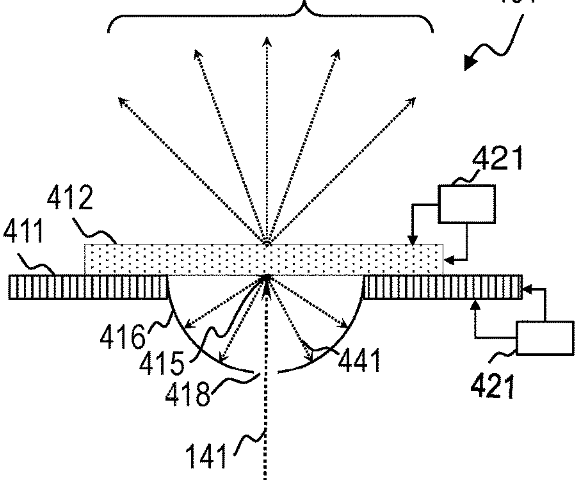


FIG. 4C

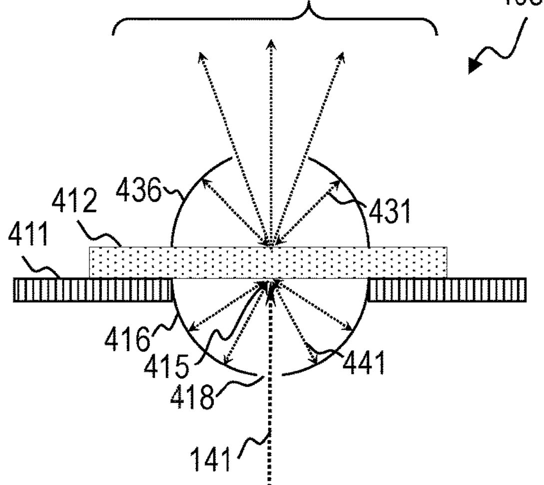


FIG. 4B

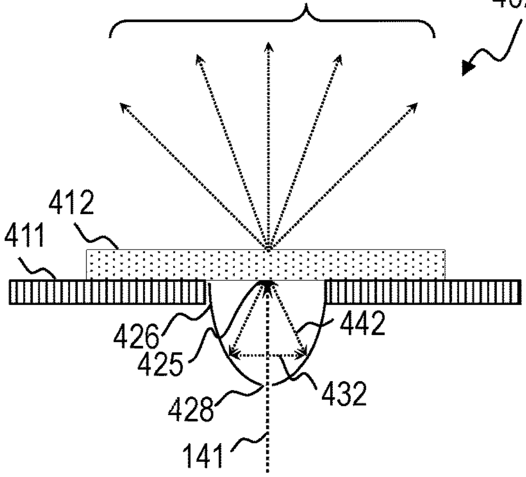


FIG. 4D

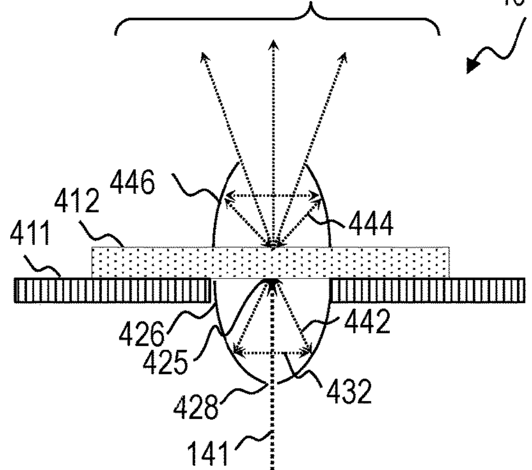


FIG. 5A

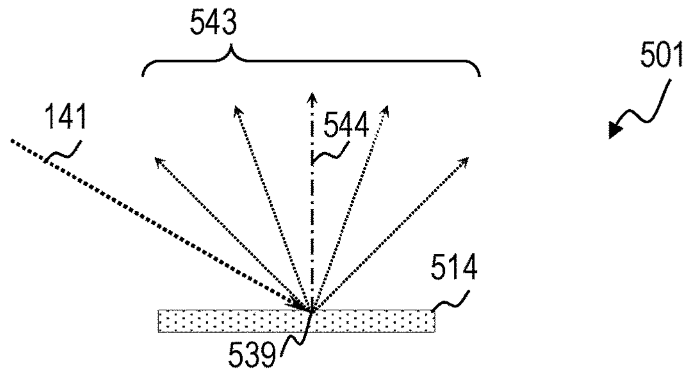


FIG. 5B

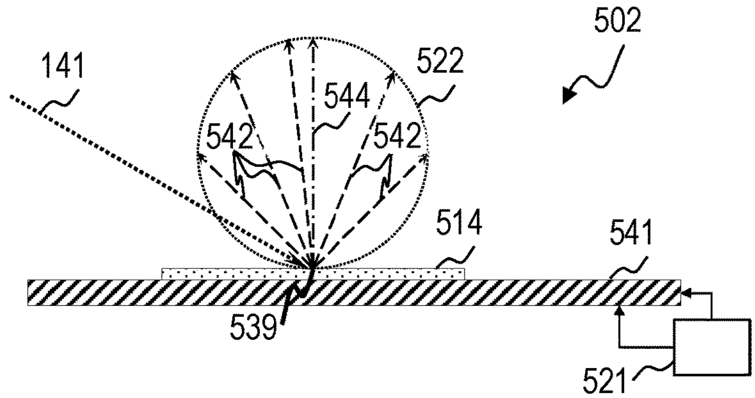


FIG. 5C1

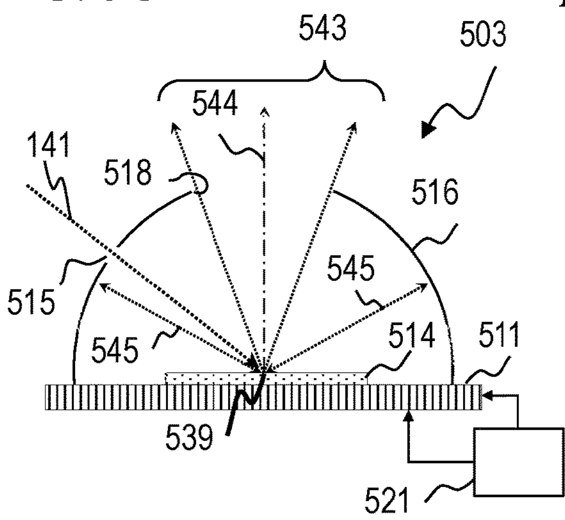


FIG. 5C2

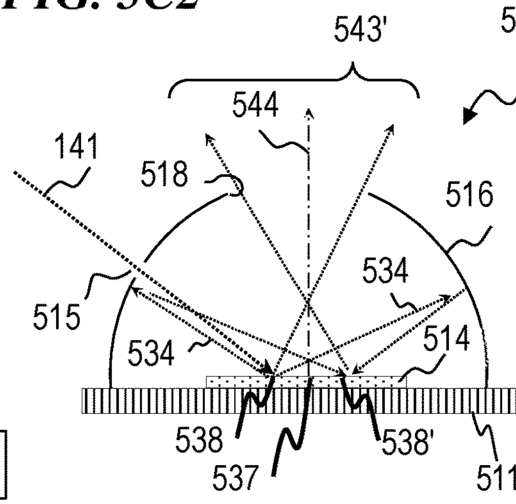


FIG. 5D1

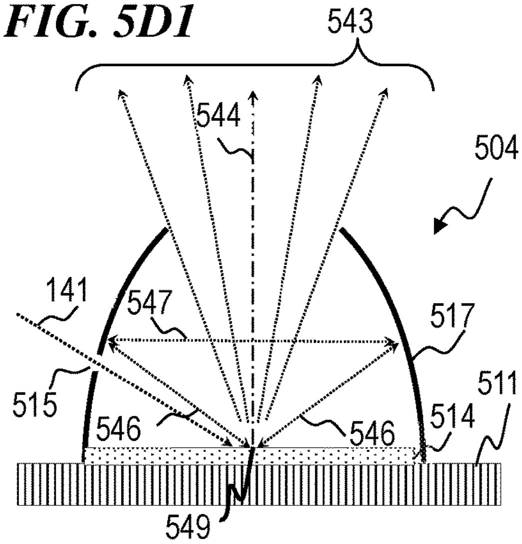


FIG. 5D2

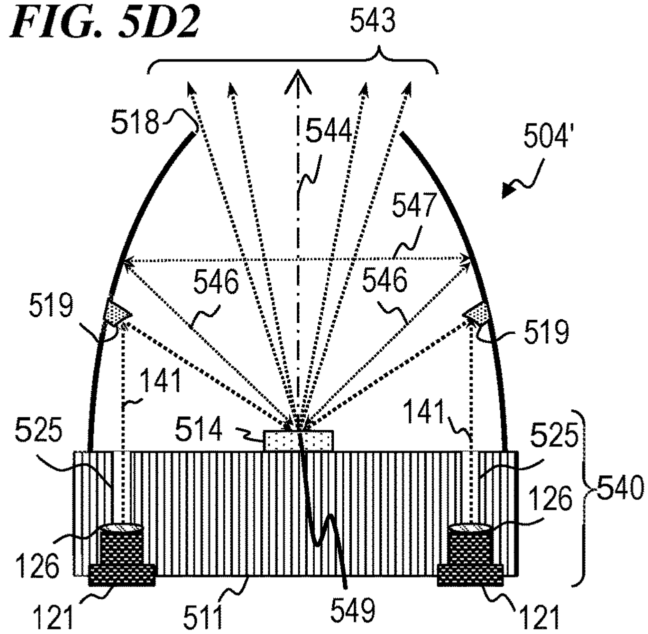


FIG. 5E

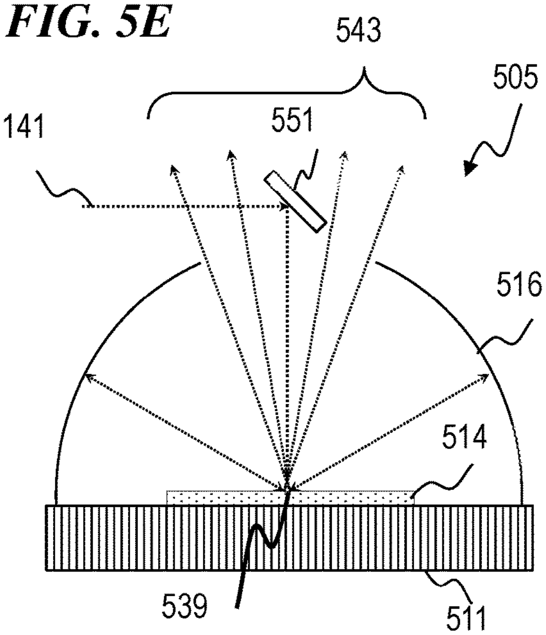


FIG. 5F

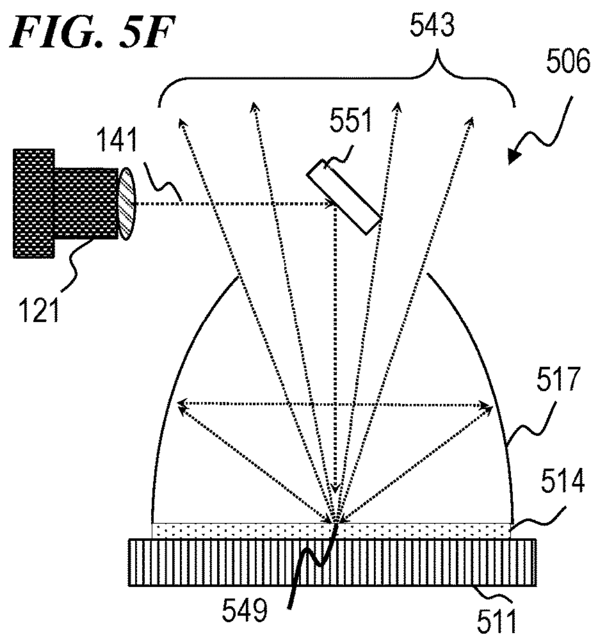
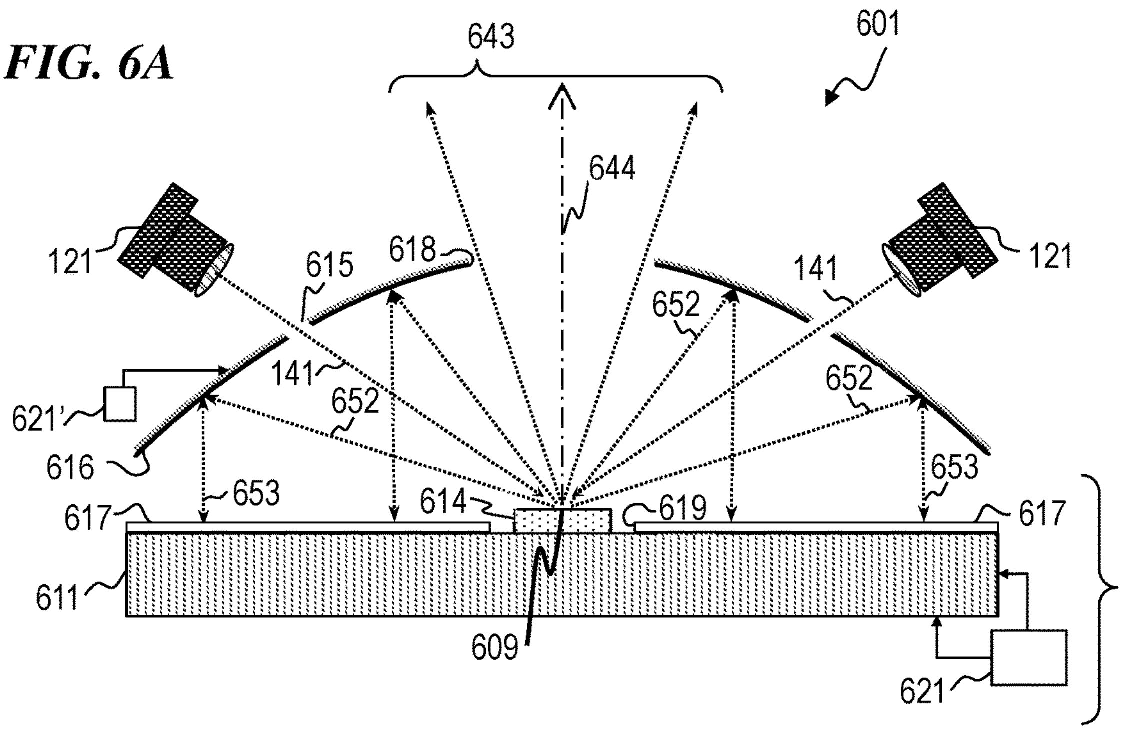


FIG. 6A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621

FIG. 6B

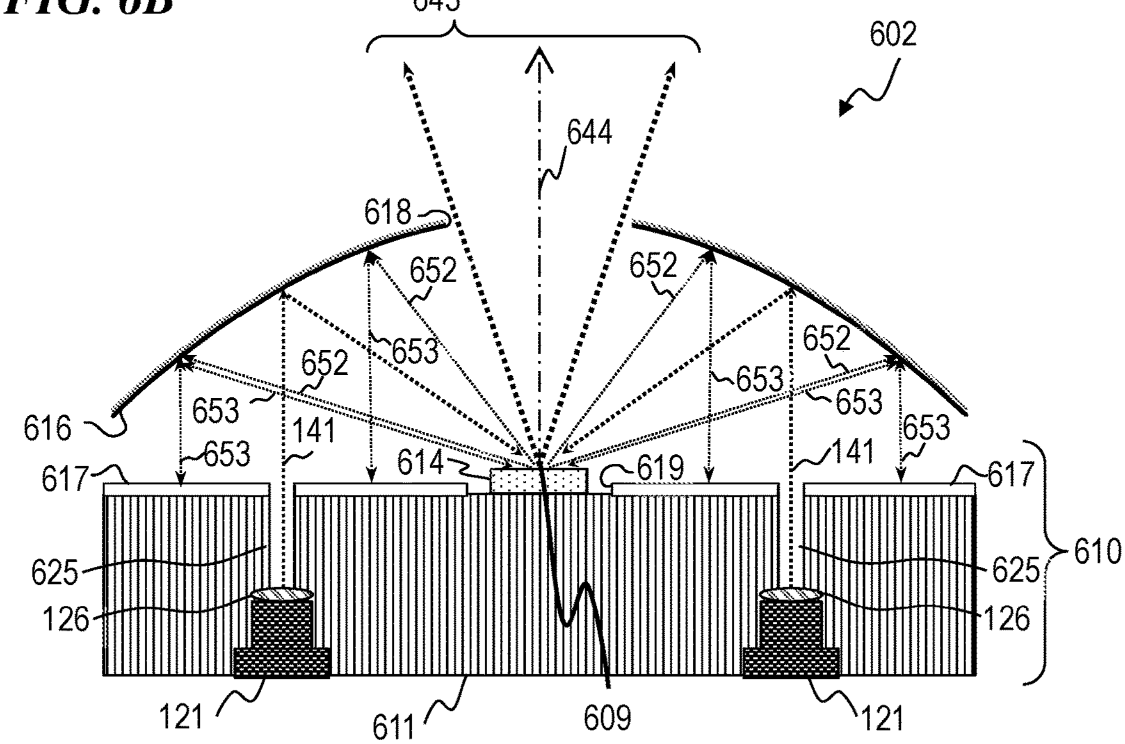
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FIG. 6C

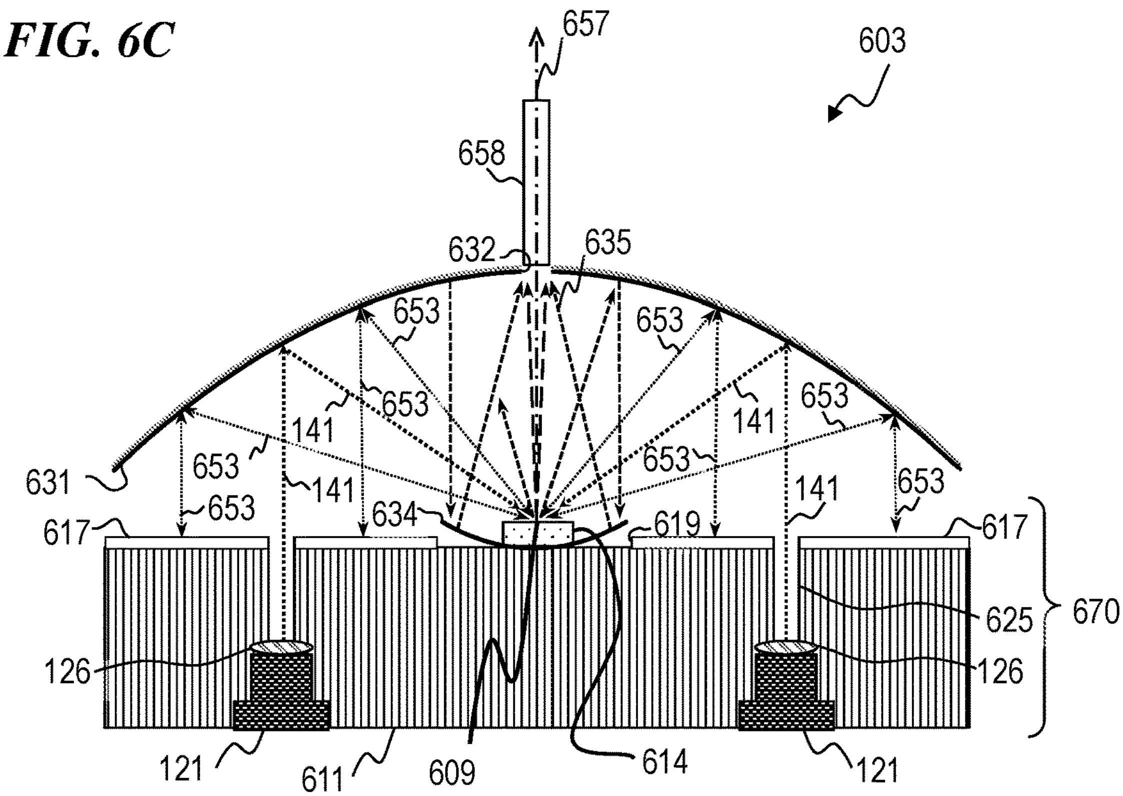
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FIG. 6D

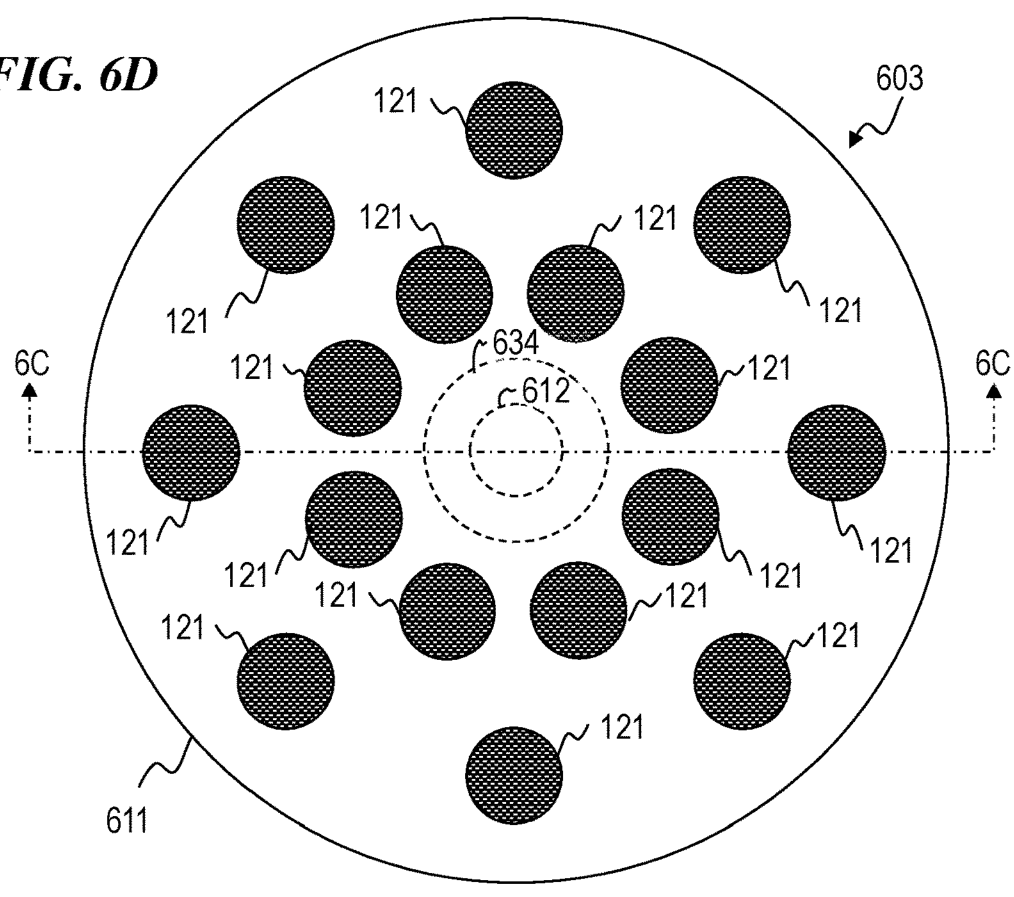
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FIG. 7A

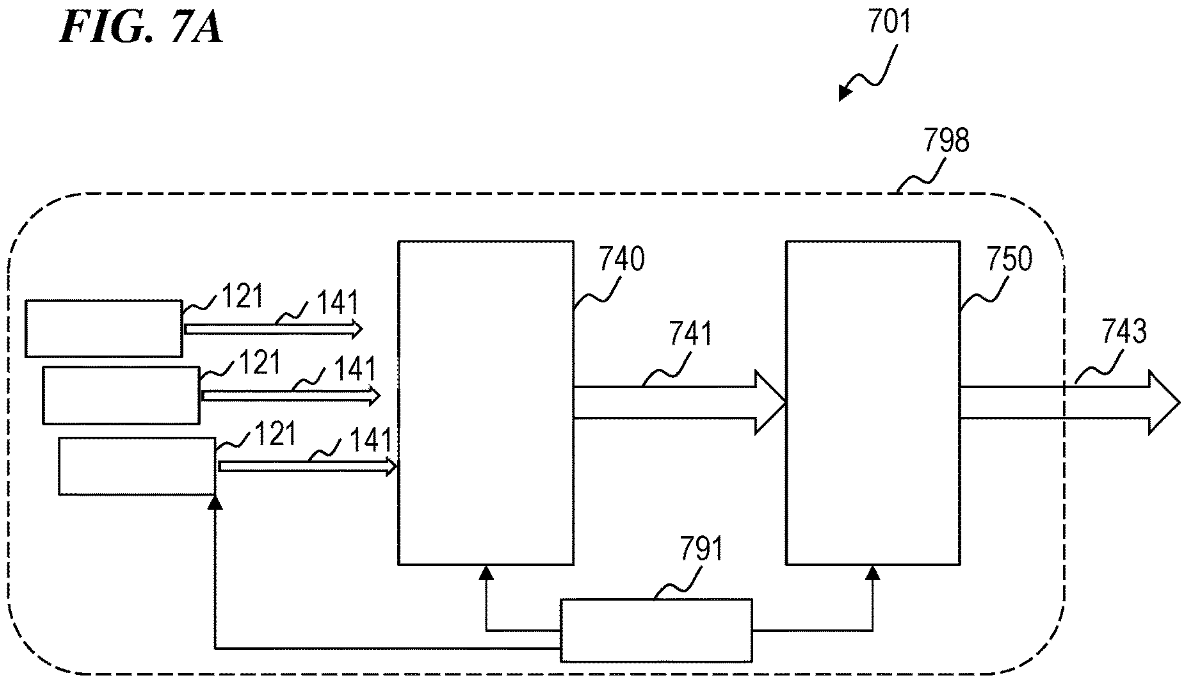
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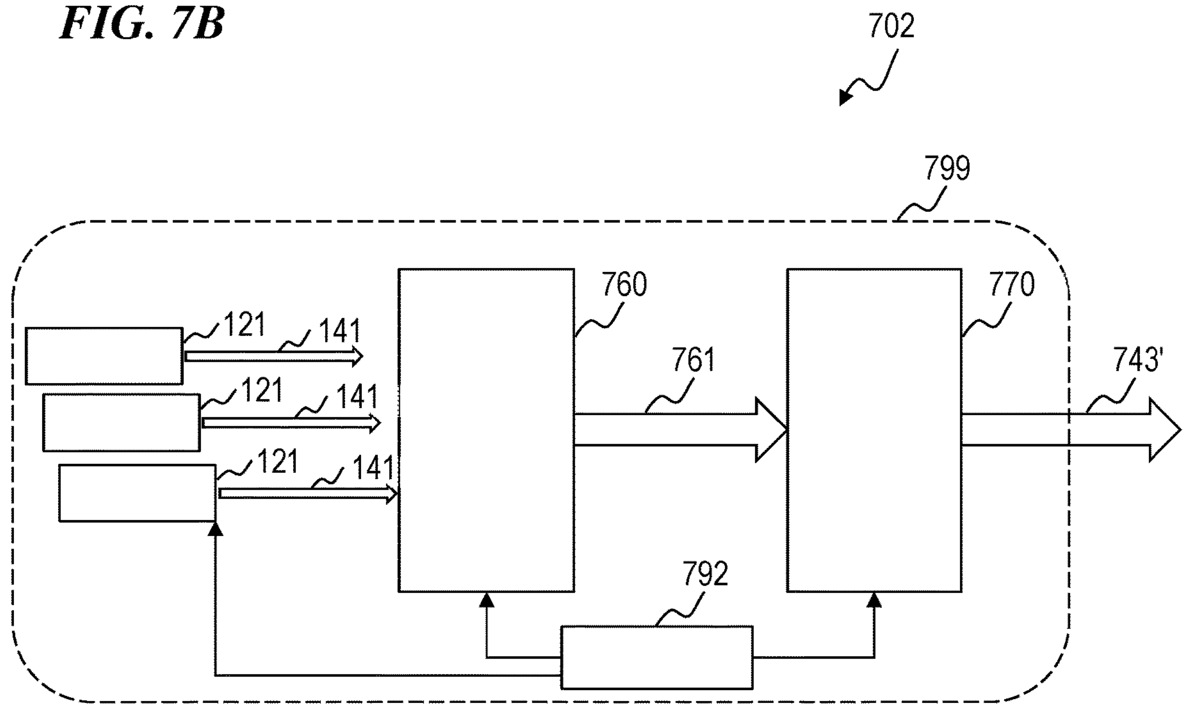
FIG. 7B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743'
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FIG. 8A

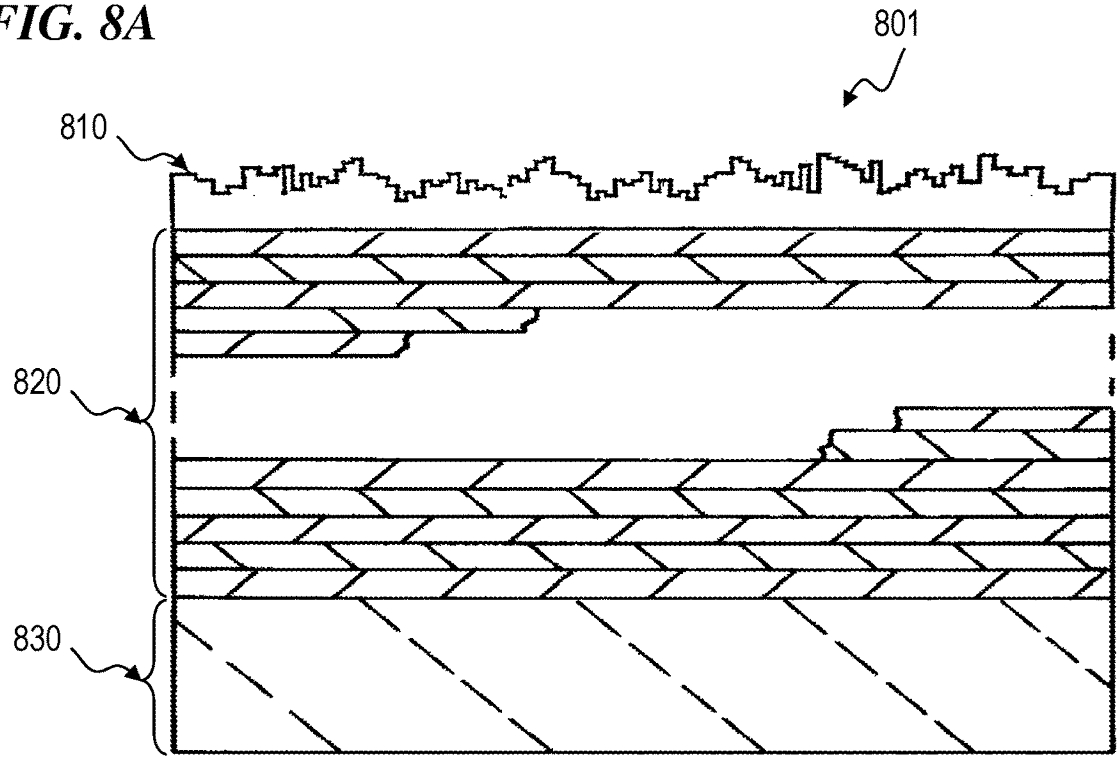

FIG. 8B

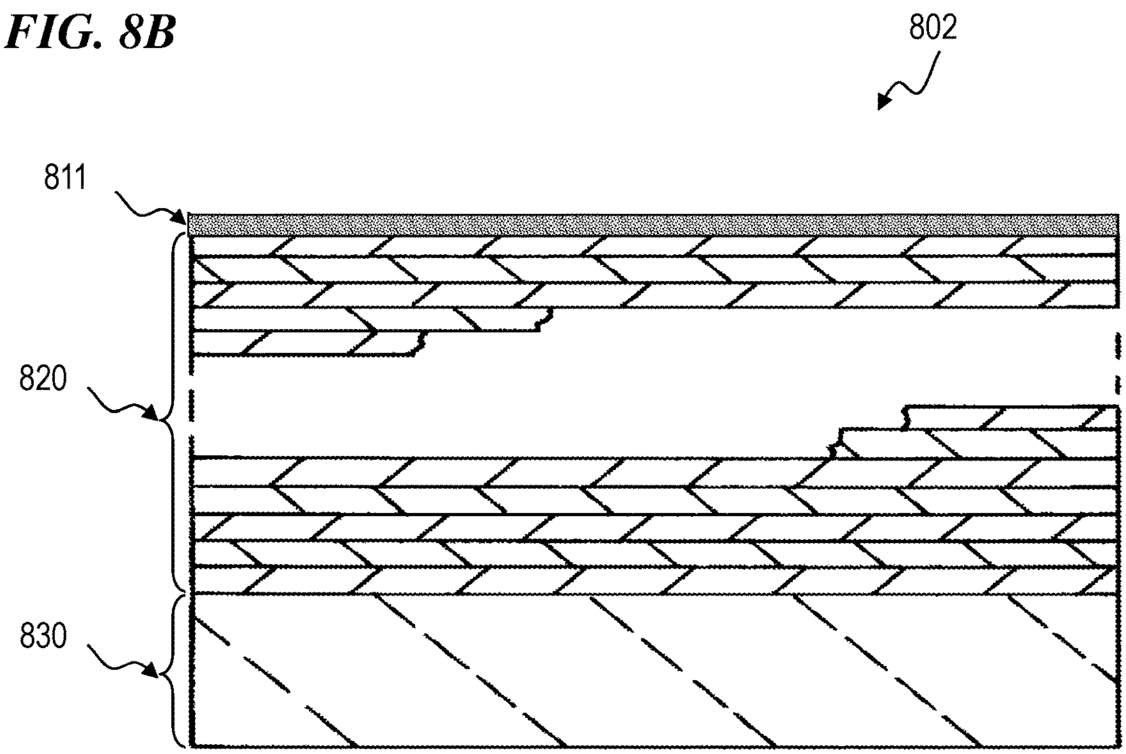

FIG. 9A

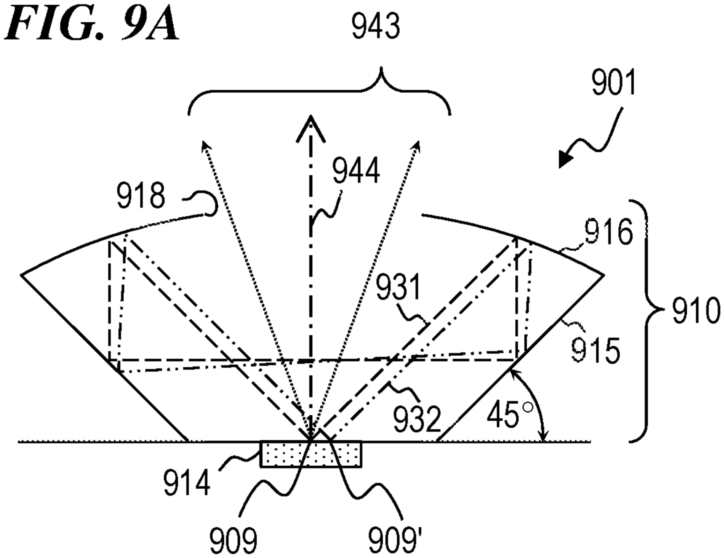
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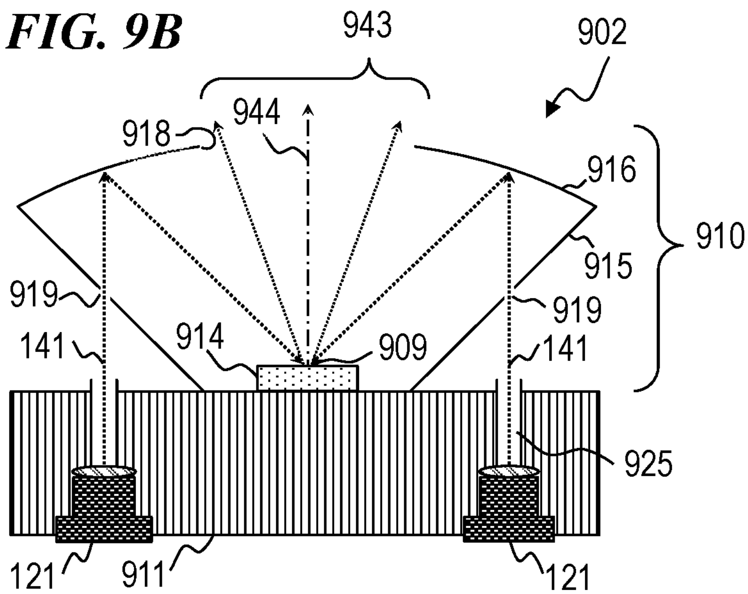
FIG. 9B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911
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FIG. 9C

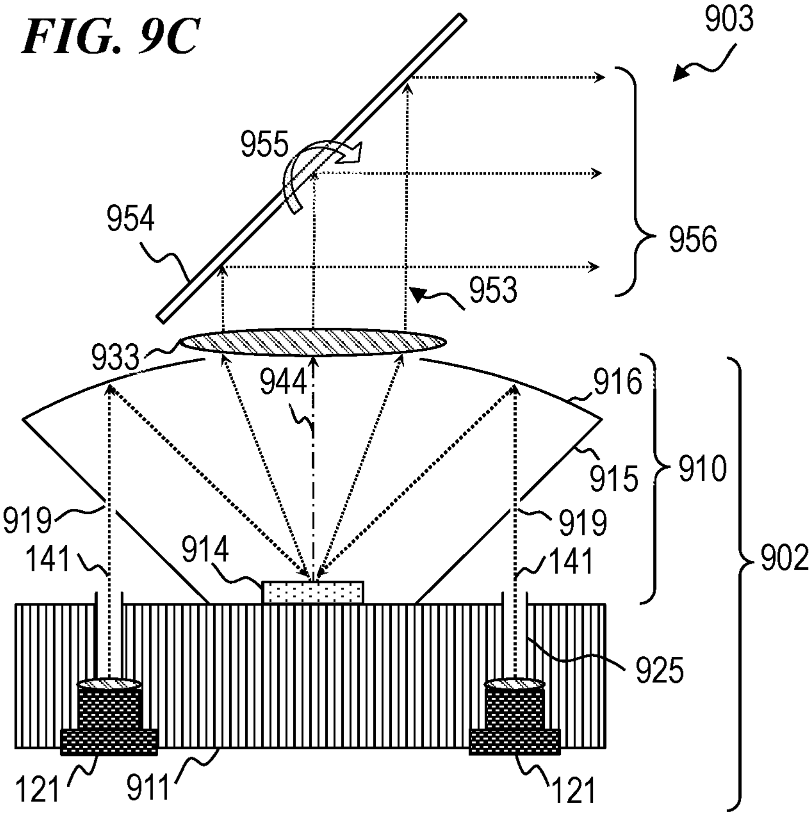
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FIG. 9D

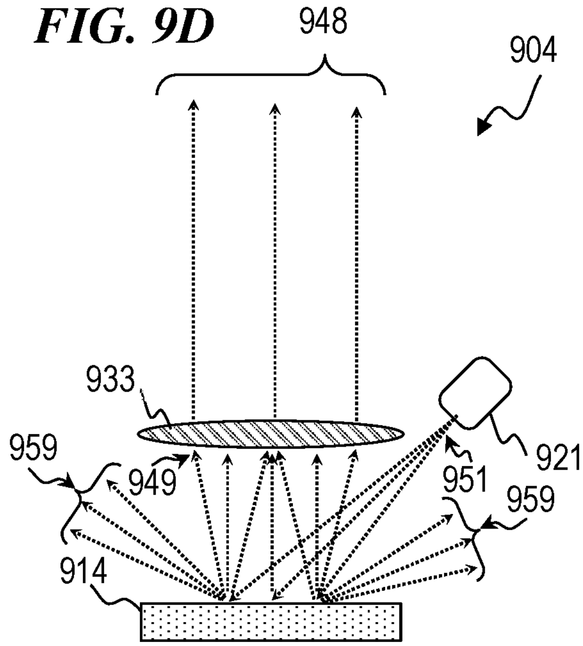
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FIG. 9E

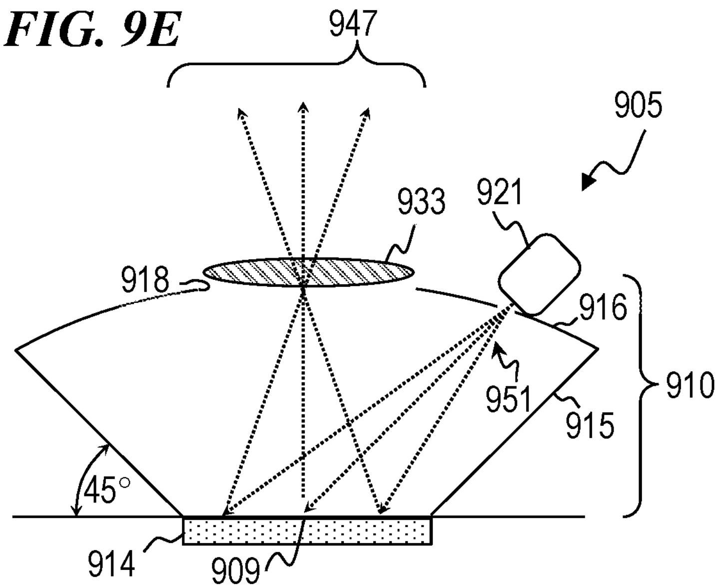

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FIG. 9F

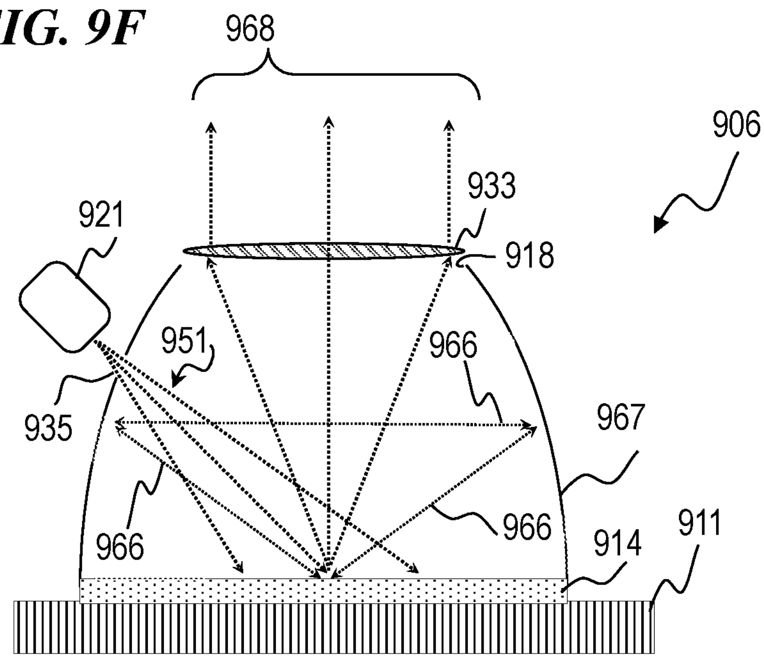

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FIG. 9G

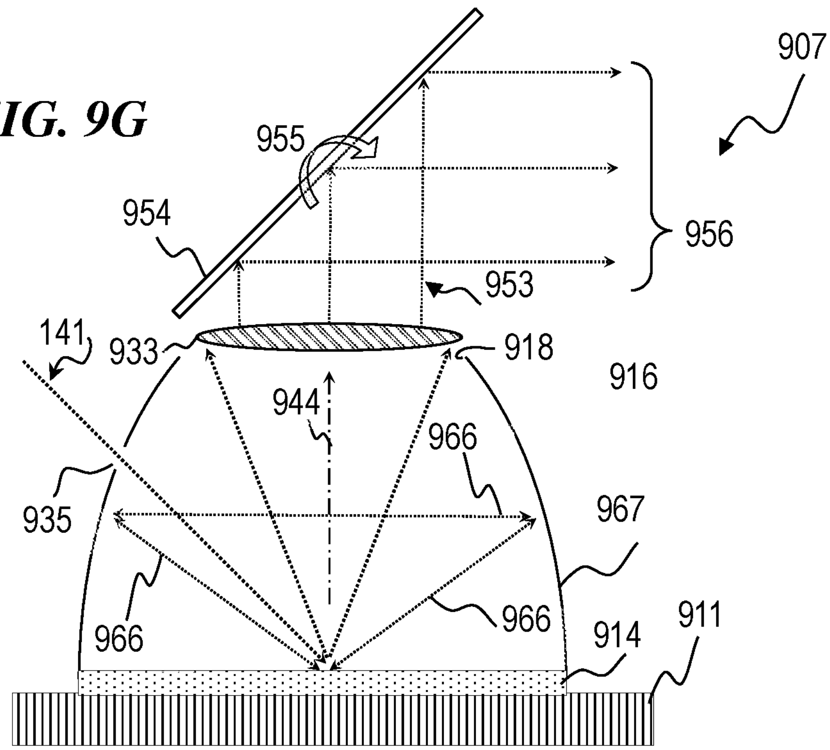
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FIG. 9H

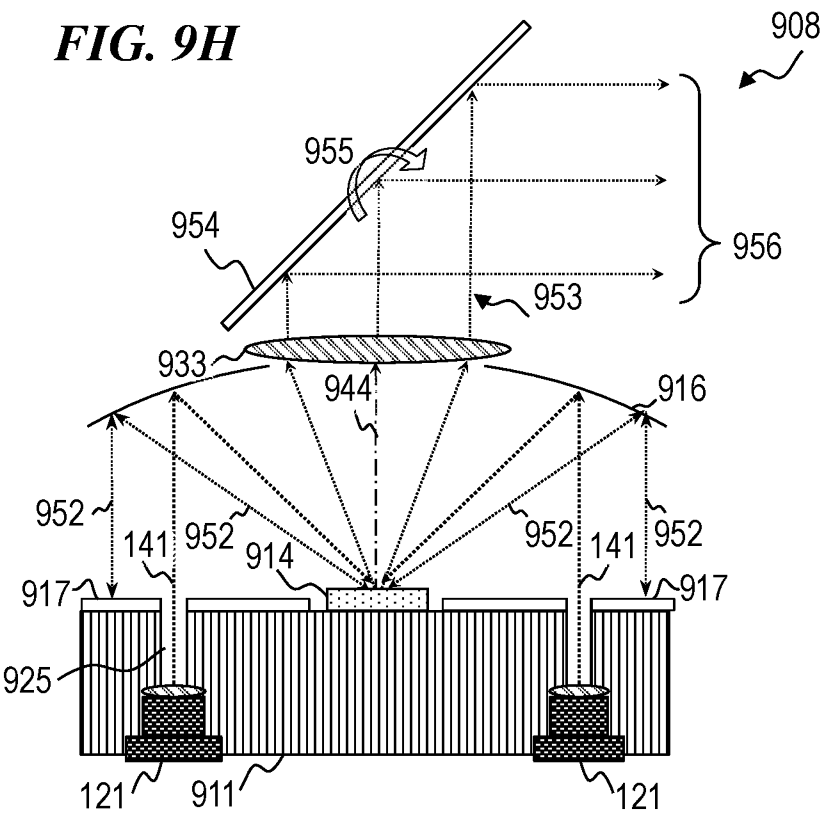
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FIG. 10A

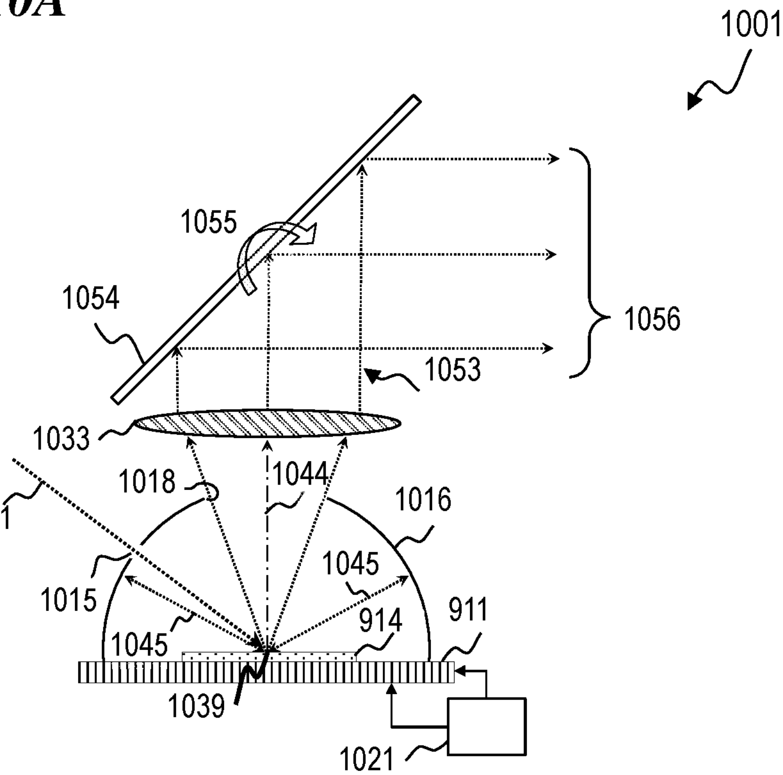


FIG. 10B

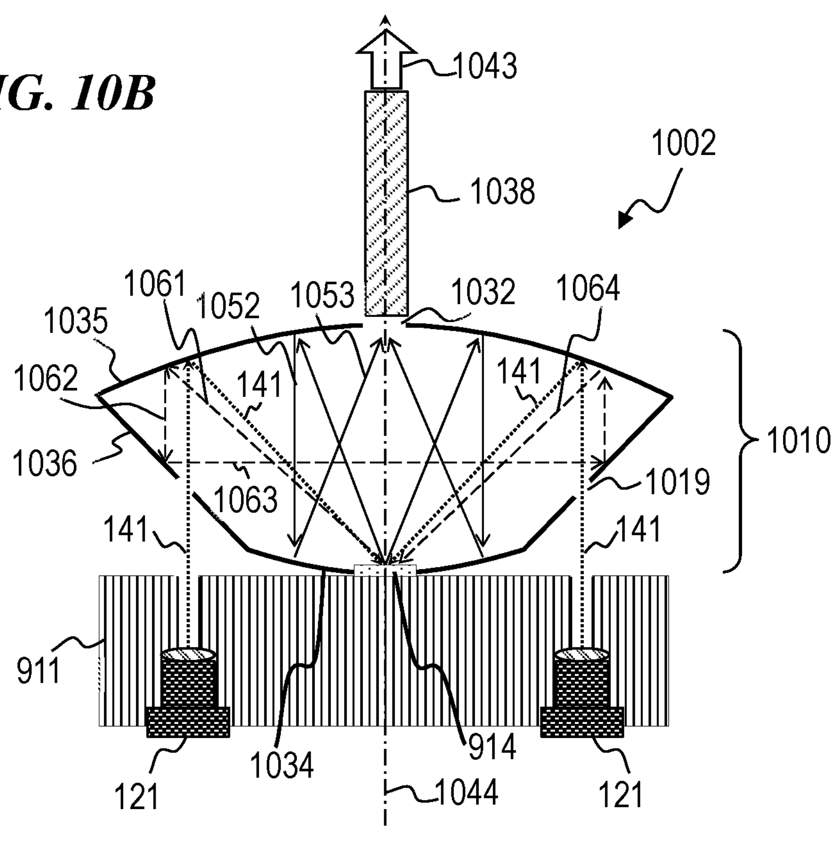


FIG. 11A

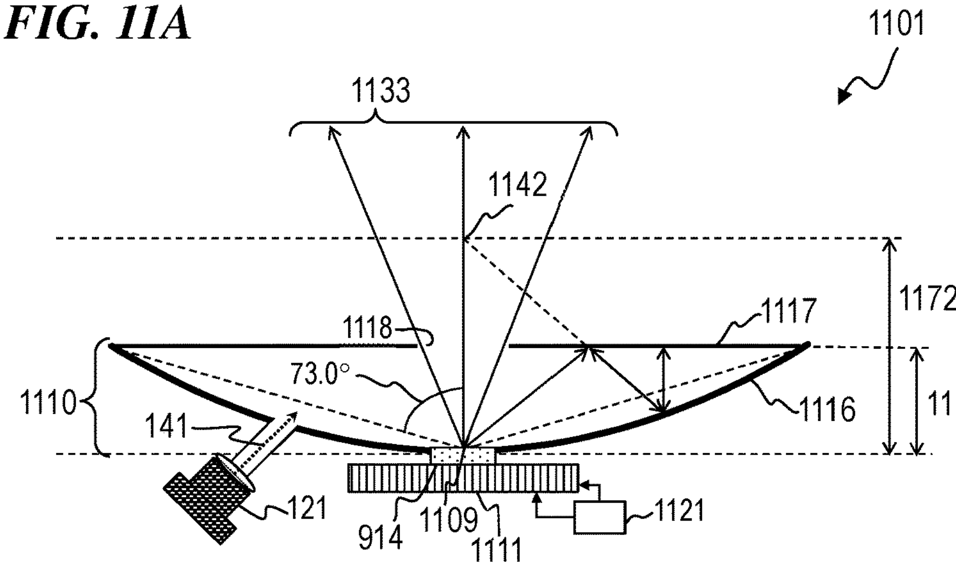


FIG. 11B

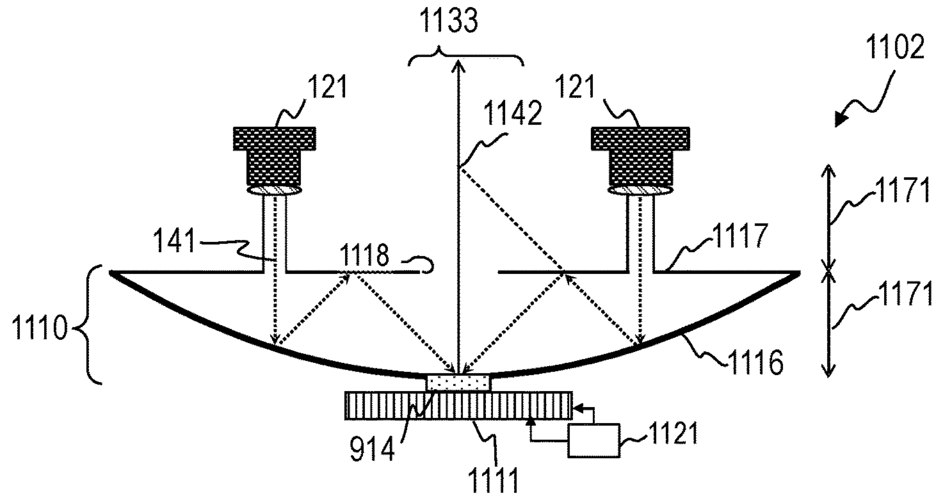


FIG. 11C

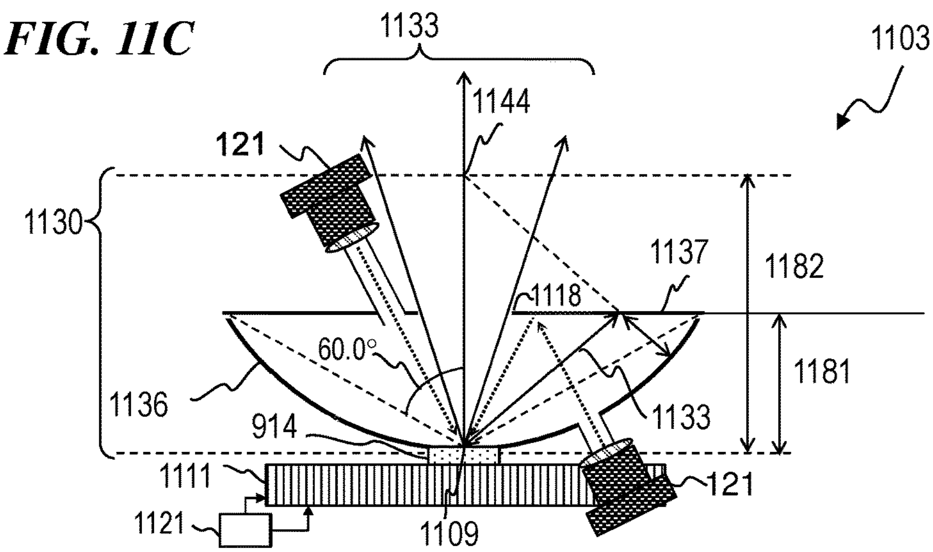


FIG. 12A

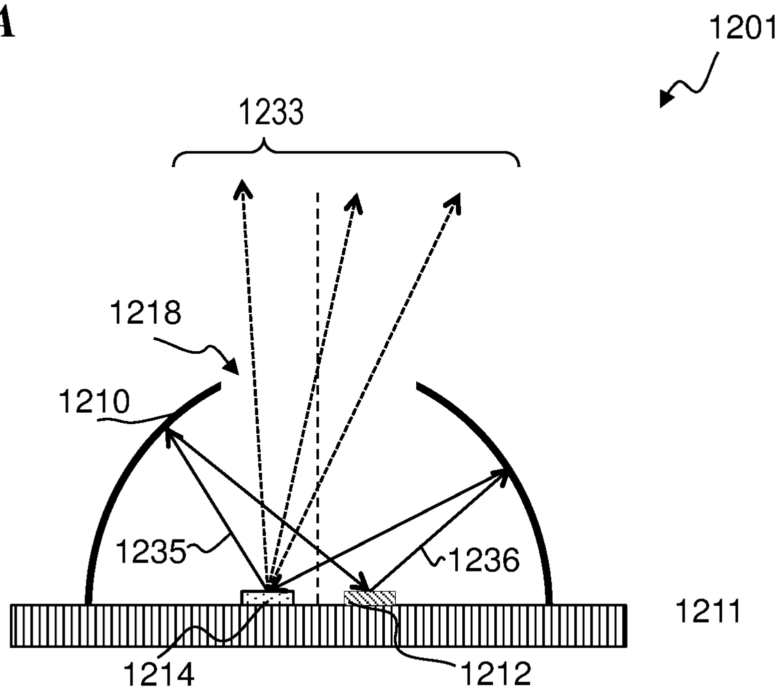


FIG. 12B

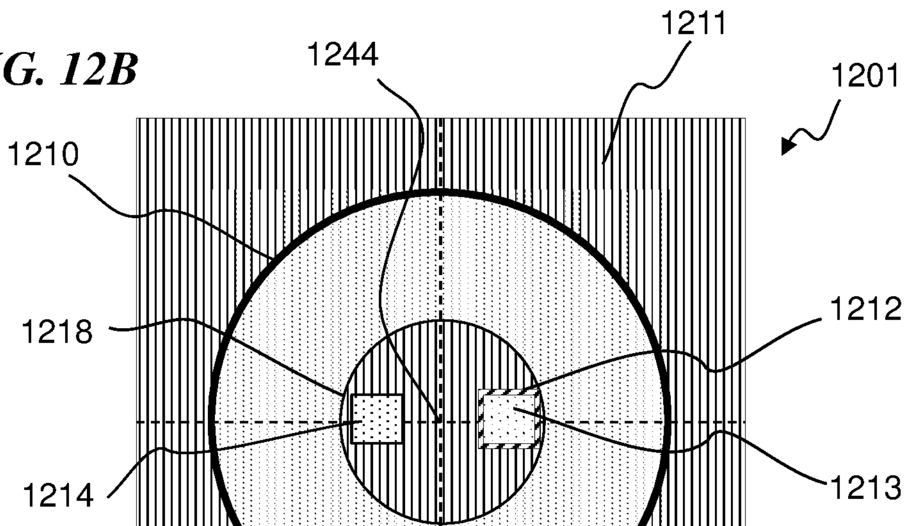


FIG. 12C

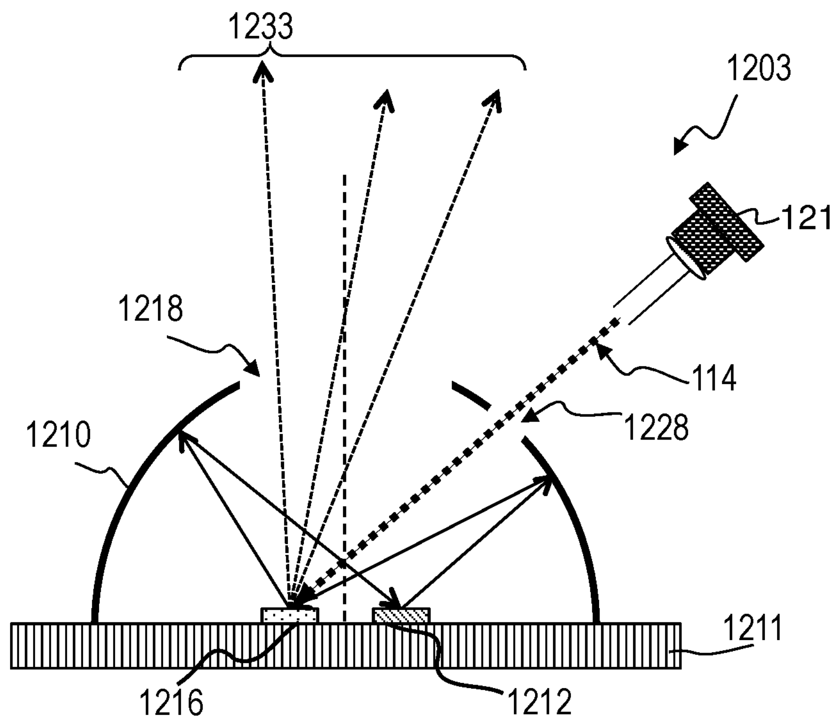


FIG. 12D

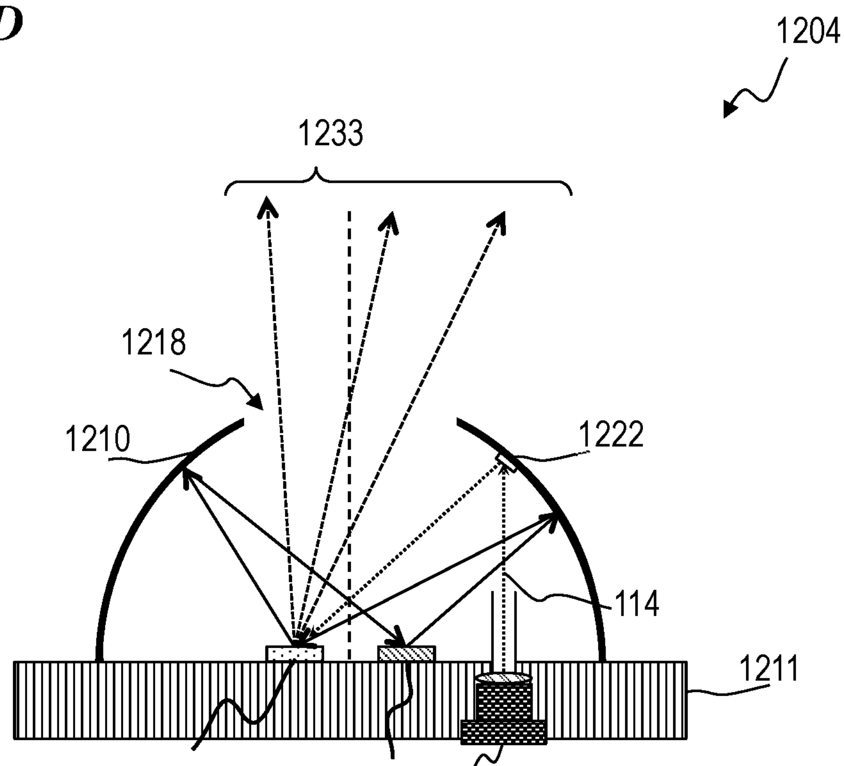


FIG. 12E

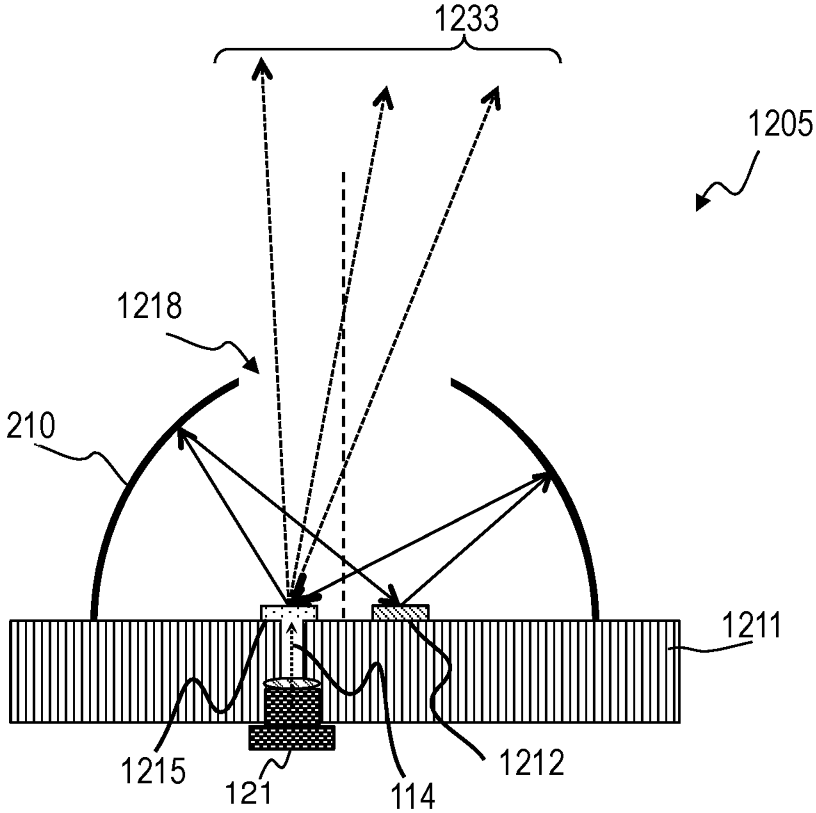


FIG. 12F

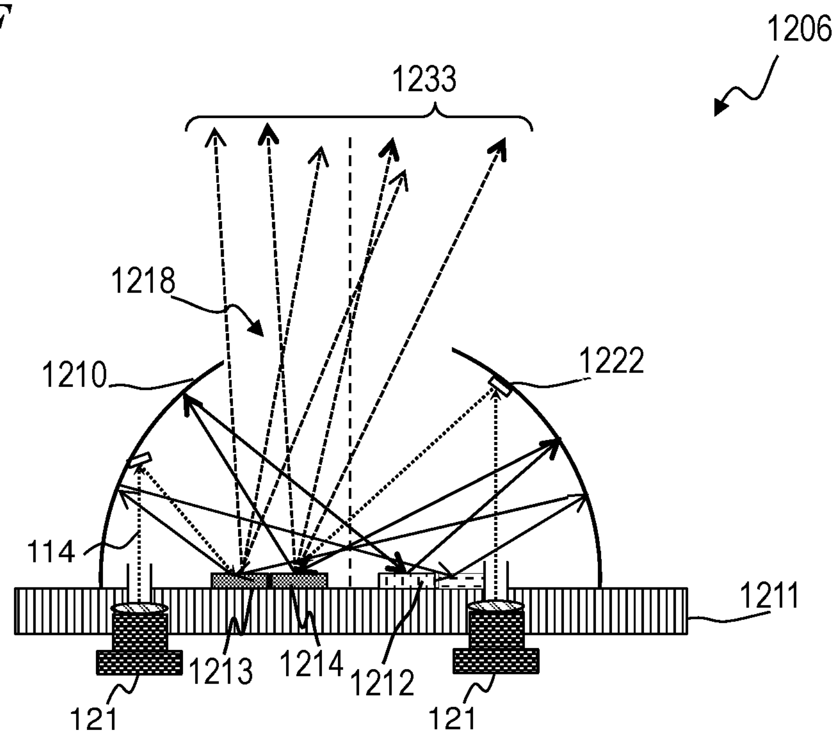


FIG. 13A

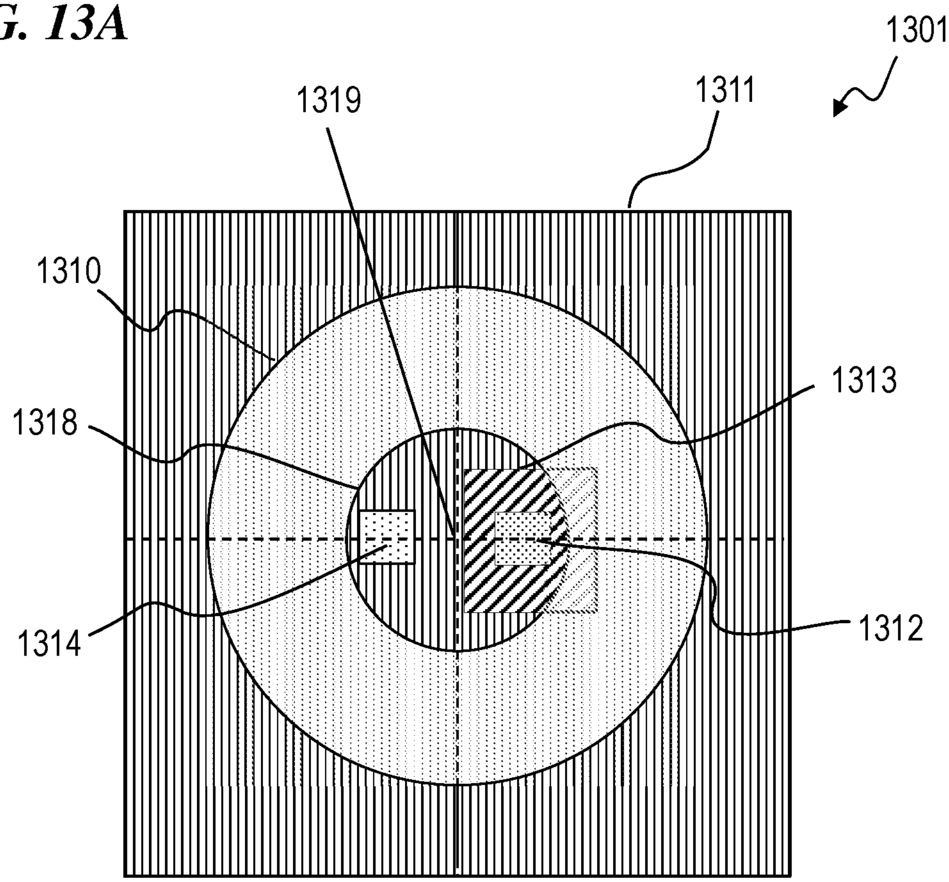


FIG. 13B

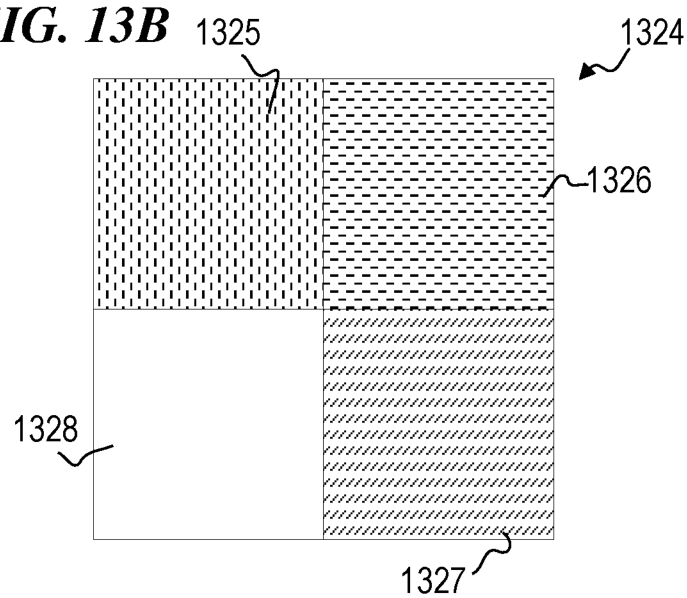


FIG. 14A

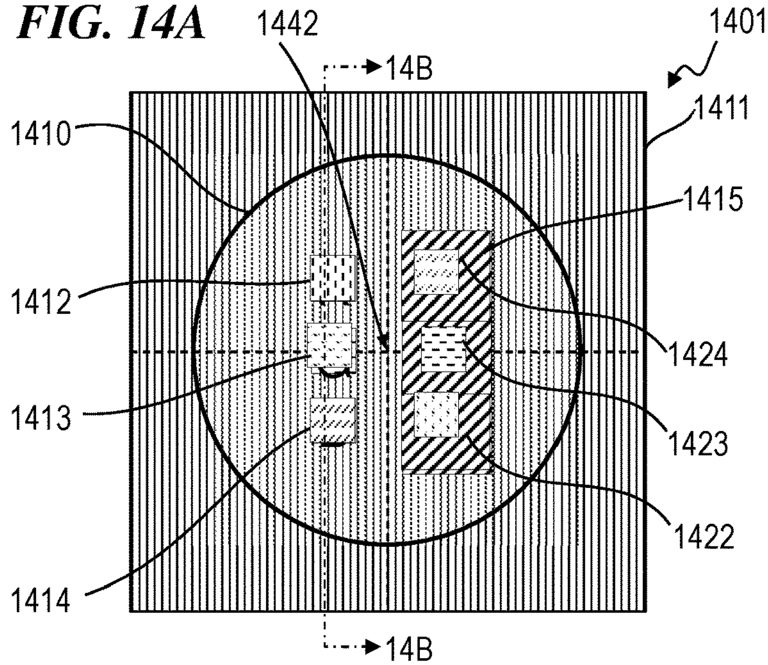


FIG. 14B

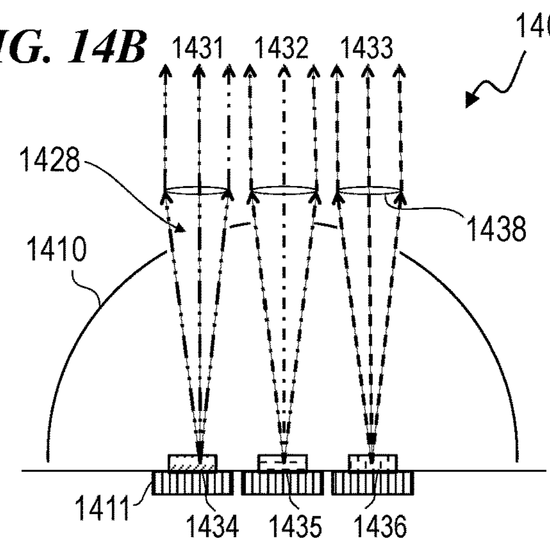


FIG. 14C

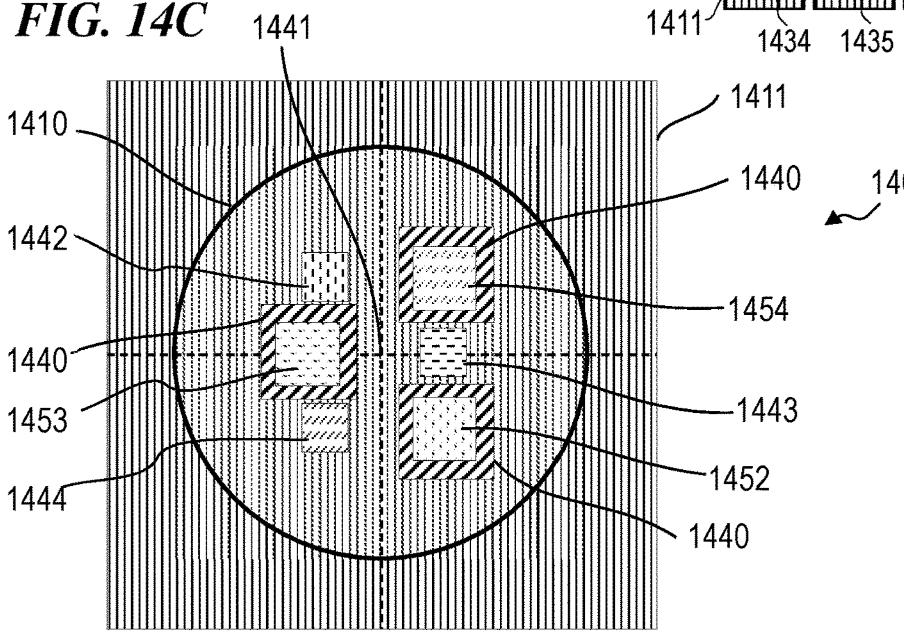


FIG. 15A

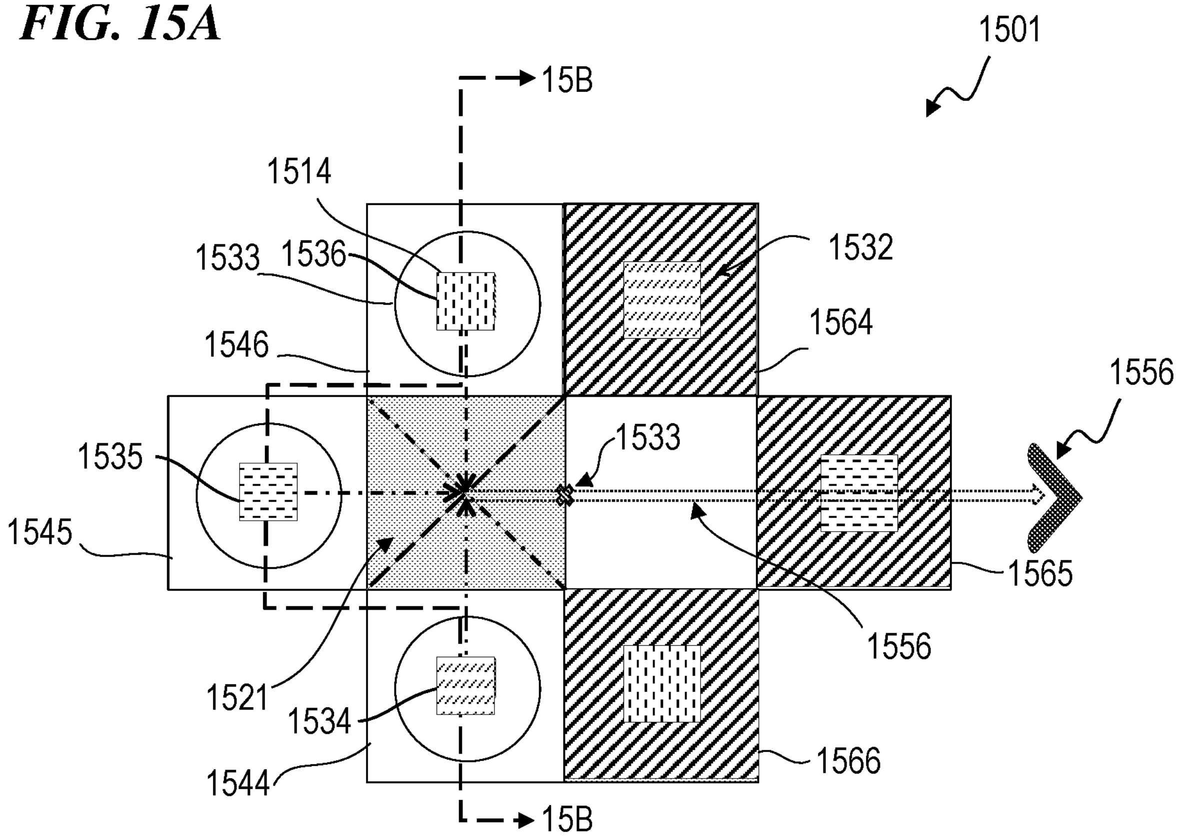


FIG. 15B

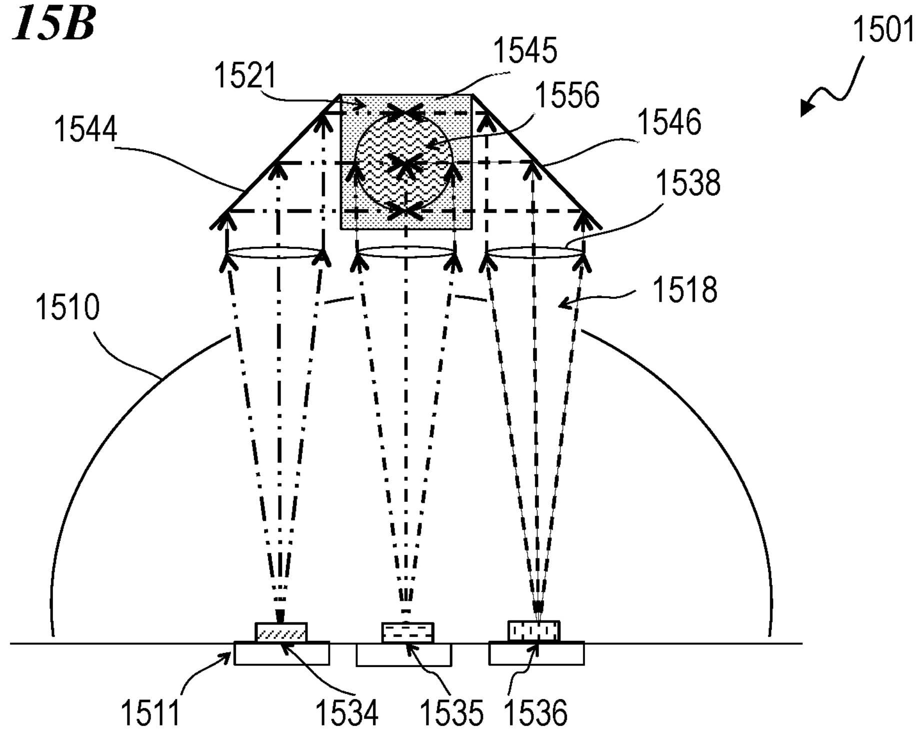


FIG. 16A

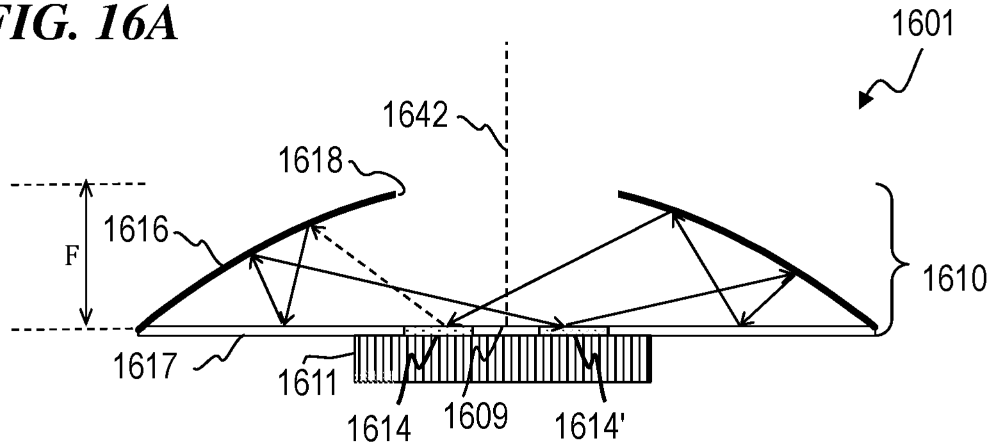


FIG. 16B

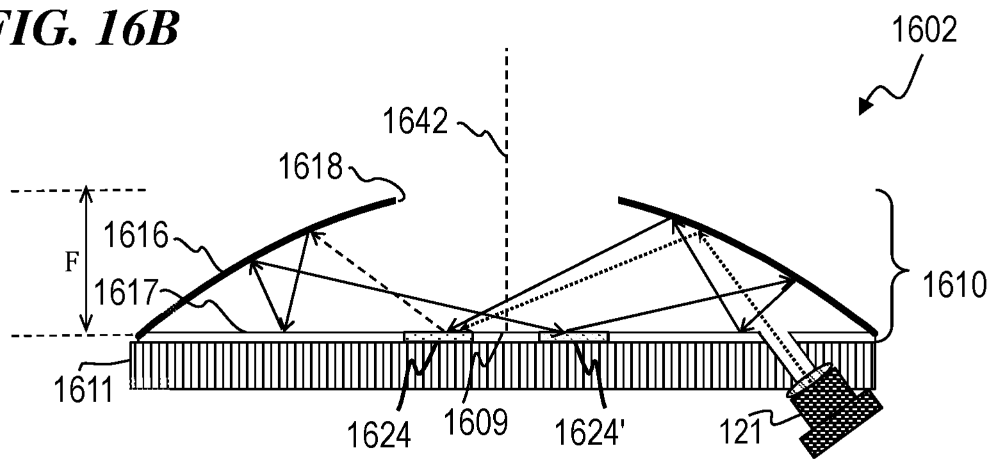


FIG. 17

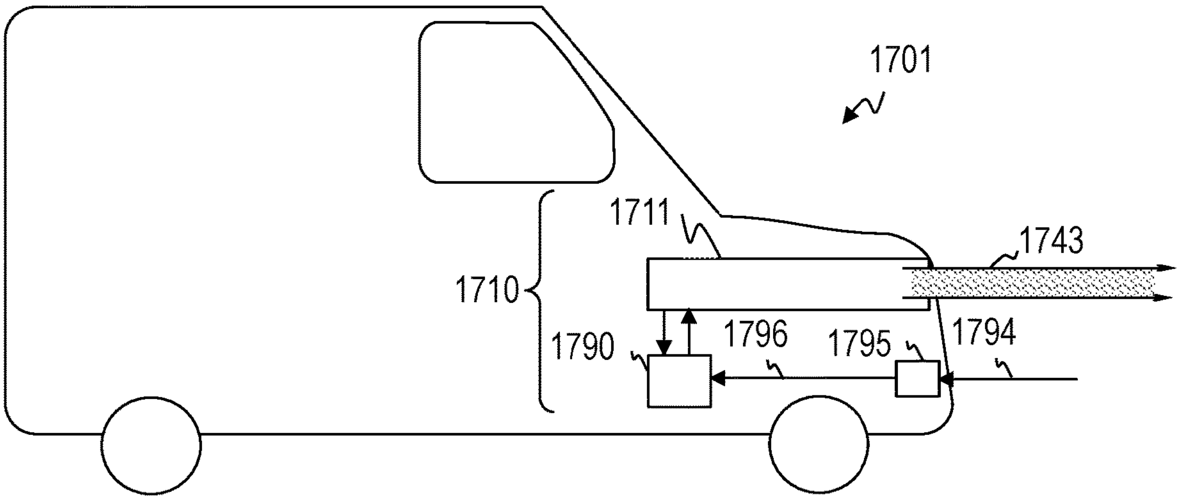


FIG. 18A

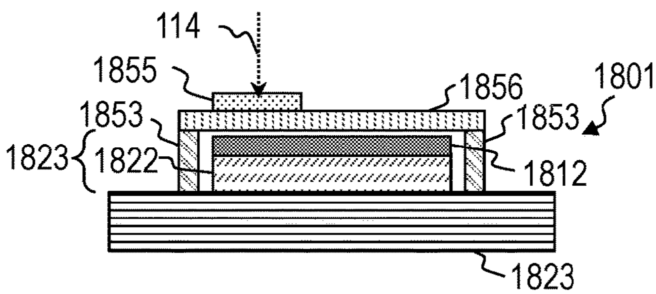
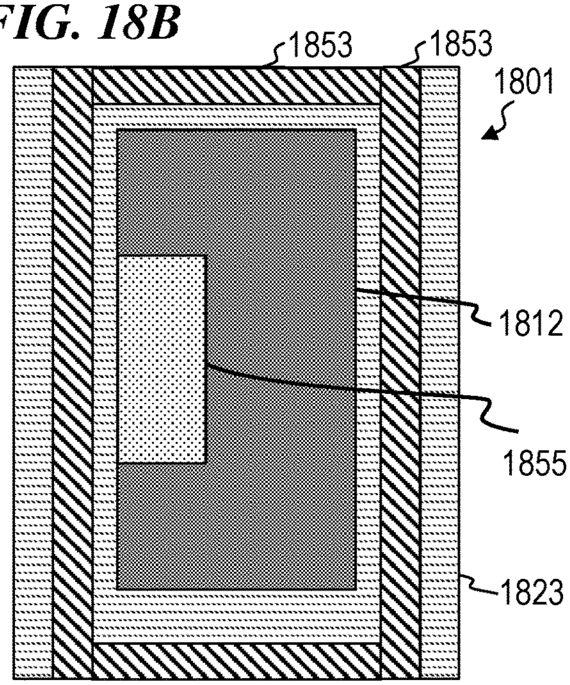


FIG. 18B



LASER/PHOSPHOR, LED AND/OR DIFFUSER LIGHT SOURCES WITH LIGHT RECYCLING

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority benefit, including under 35 U.S.C. § 119(e), of

[0002] U.S. Provisional Patent Application 62/871,498 titled "LASER-EXCITED PHOSPHOR LIGHT SOURCE AND METHOD WITH LIGHT RECYCLING," filed Jul. 8, 2019, by Kenneth Li;

[0003] U.S. Provisional Patent Application 62/881,927 titled "SYSTEM AND METHOD TO INCREASE BRIGHTNESS OF DIFFUSED LIGHT WITH FOCUSED RECYCLING," filed Aug. 1, 2019, by Kenneth Li;

[0004] U.S. Provisional Patent Application 62/895,367 titled "INCREASED BRIGHTNESS OF DIFFUSED LIGHT WITH FOCUSED RECYCLING," filed Sep. 3, 2019, by Kenneth Li;

[0005] U.S. Provisional Patent Application 62/911,937 titled "INCREASING THE BRIGHTNESS OF A LIGHT SOURCE BY LIGHT RECYCLING WITH OFFSET FOCUS REFLECTOR," filed Oct. 7, 2019, by Kenneth Li;

each of which is incorporated herein by reference in its entirety.

[0006] This application is related to:

[0007] P.C.T. Patent Application No. PCT/US2020/037669, filed Jun. 14, 2020 by Kenneth Li et al., titled "HYBRID LED/LASER LIGHT SOURCE FOR SMART HEADLIGHT APPLICATIONS,"

[0008] U.S. Provisional Patent Application 62/862,549 titled "ENHANCEMENT OF LED INTENSITY PROFILE USING LASER EXCITATION," filed Jun. 17, 2019, by Kenneth Li;

[0009] U.S. Provisional Patent Application 62/874,943 titled "ENHANCEMENT OF LED INTENSITY PROFILE USING LASER EXCITATION," filed Jul. 16, 2019, by Kenneth Li;

[0010] U.S. Provisional Patent Application 62/938,863 titled "DUAL LIGHT SOURCE FOR SMART HEADLIGHT APPLICATIONS," filed Nov. 21, 2019, by Y. P. Chang et al.;

[0011] U.S. Provisional Patent Application 62/954,337 titled "HYBRID LED/LASER LIGHT SOURCE FOR SMART HEADLIGHT APPLICATIONS," filed Dec. 27, 2019, by Kenneth Li;

[0012] P.C.T. Patent Application No. PCT/US2020/034447, filed May 24, 2020 by Y. P. Chang et al., titled "LiDAR INTEGRATED WITH SMART HEADLIGHT AND METHOD,"

[0013] U.S. Provisional Patent Application No. 62/853,538, filed May 28, 2019 by Y. P. Chang et al., titled "LIDAR Integrated With Smart Headlight Using a Single DMD,"

[0014] U.S. Provisional Patent Application No. 62/857,662, filed Jun. 5, 2019 by Chun-Nien Liu et al., titled "Scheme of LIDAR-Embedded Smart Laser Headlight for Autonomous Driving," and

[0015] U.S. Provisional Patent Application No. 62/950,080, filed Dec. 18, 2019 by Kenneth Li, titled "Integrated LIDAR and Smart Headlight using a Single MEMS Mirror,"

[0016] PCT Patent Application PCT/US2019/037231 titled "ILLUMINATION SYSTEM WITH HIGH INTENSITY OUTPUT MECHANISM AND METHOD OF OPERATION THEREOF," filed Jun. 14, 2019, by Y. P. Chang et al. (published Jan. 16, 2020 as WO 2020/013952);

[0017] U.S. patent application Ser. No. 16/509,085 titled "ILLUMINATION SYSTEM WITH CRYSTAL PHOSPHOR MECHANISM AND METHOD OF OPERATION THEREOF," filed Jul. 11, 2019, by Y. P. Chang et al. (published Jan. 23, 2020 as US 2020/0026169);

[0018] U.S. patent application Ser. No. 16/509,196 titled "ILLUMINATION SYSTEM WITH HIGH INTENSITY PROJECTION MECHANISM AND METHOD OF OPERATION THEREOF," filed Jul. 11, 2019, by Y. P. Chang et al. (published Jan. 23, 2020 as US 2020/0026170);

[0019] U.S. Provisional Patent Application 62/837,077 titled "LASER EXCITED CRYSTAL PHOSPHOR SPHERE LIGHT SOURCE," filed Apr. 22, 2019, by Kenneth Li et al.;

[0020] U.S. Provisional Patent Application 62/853,538 titled "LIDAR INTEGRATED WITH SMART HEADLIGHT USING A SINGLE DMD," filed May 28, 2019, by Y. P. Chang et al.;

[0021] U.S. Provisional Patent Application 62/856,518 titled "VERTICAL CAVITY SURFACE EMITTING LASER USING DICHROIC REFLECTORS," filed Jul. 8, 2019, by Kenneth Li et al.;

[0022] U.S. Provisional Patent Application 62/871,498 titled "LASER-EXCITED PHOSPHOR LIGHT SOURCE AND METHOD WITH LIGHT RECYCLING," filed Jul. 8, 2019, by Kenneth Li;

[0023] U.S. Provisional Patent Application 62/857,662 titled "SCHEME OF LIDAR-EMBEDDED SMART LASER HEADLIGHT FOR AUTONOMOUS DRIVING," filed Jun. 5, 2019, by Chun-Nien Liu et al.;

[0024] U.S. Provisional Patent Application 62/873,171 titled "SPECKLE REDUCTION USING MOVING MIRRORS AND RETRO-REFLECTORS," filed Jul. 11, 2019, by Kenneth Li;

[0025] U.S. Provisional Patent Application 62/881,927 titled "SYSTEM AND METHOD TO INCREASE BRIGHTNESS OF DIFFUSED LIGHT WITH FOCUSED RECYCLING," filed Aug. 1, 2019, by Kenneth Li;

[0026] U.S. Provisional Patent Application 62/895,367 titled "INCREASED BRIGHTNESS OF DIFFUSED LIGHT WITH FOCUSED RECYCLING," filed Sep. 3, 2019, by Kenneth Li;

[0027] U.S. Provisional Patent Application 62/903,620 titled "RGB LASER LIGHT SOURCE FOR PROJECTION DISPLAYS," filed Sep. 20, 2019, by Lion Wang et al.; and

[0028] PCT Patent Application No. PCT/US2020/035492, filed Jun. 1, 2020 by Kenneth Li et al., titled "VERTICAL-CAVITY SURFACE-EMITTING LASER USING DICHROIC REFLECTORS";

each of which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0029] This invention relates to the field of light sources, and more specifically to a method and light source that includes lasers, laser-pumped phosphor light sources, LED-pumped phosphor light sources, and/or diffusers, along with optics to recycle light combined together to provide improved light-beam quality, higher beam intensity, and reduced speckle, and a method and apparatus to increase brightness of diffused light with focused recycling (some embodiments of which include light recycling with an offset-focus reflector that is particularly useful for high-power light applications).

BACKGROUND OF THE INVENTION

[0030] Laser-pumped phosphor light sources provide higher luminance compared to light-emitting-diode (LED) light sources, and are important for applications such as projectors or spotlights. The fact that phosphor emissions are Lambertian in nature makes efficient collection and coupling very challenging.

[0031] Light diffusers are sometimes used with laser light sources, and also can output diffused light that is Lambertian in nature, similarly making efficient collection and coupling very challenging.

[0032] U.S. Pat. No. 5,907,436 entitled "Multilayer dielectric diffraction gratings" issued May 25, 1999 to Perry et al., and is incorporated herein by reference. U.S. Pat. No. 5,907,436 describes the design and fabrication of dielectric grating structures with high diffraction efficiency. The gratings have a multilayer structure of alternating index dielectric materials, with a grating structure formed on top of the multilayer, and obtain a diffraction grating of adjustable efficiency, and variable optical bandwidth.

[0033] U.S. Pat. No. 5,454,004 issued to Leger on Sep. 26, 1995 with the title "Phase grating and mode-selecting mirror for a laser", and is incorporated herein by reference. U.S. Pat. No. 5,454,004 describes a method for making a custom phase-conjugating diffractive mirror for a laser resonator comprising the steps of: (a) choosing a specified beam mode profile ai (x,y) that will suit need of said designer, (b) calculating the mode profile b(x',y') which is a value of the specified ai (x,y) that is propagated to the reflection surface of the diffractive mirror and (c) calculating mirror reflectance t(x',y') which reflects phase conjugate of b(x',y'). A method for fabricating such a mirror is shown. Another aspect of U.S. Pat. No. 5,454,004 is the addition of a phase-adjusting element having a random Cartesian pattern for the phase-adjustment element into a laser resonator, and compensating for the addition of a phase-adjusting element in the design of other phase-adjusting elements such as the mirrors.

[0034] U.S. Pat. No. 6,709,119 issued to Gillich et al. on Mar. 23, 2004 with the title "Resistant surface reflector", and is incorporated herein by reference. U.S. Pat. No. 6,709,119 describes a reflector with high total reflection which is resistant to mechanical stresses. The reflector includes a reflector body and superimposed thereon (a) a functional coating such as a varnish, (b) a reflecting layer structure composed of a reflecting metallic layer and optionally arranged thereon one or several transparent ceramic layers, for example, layers having an optical depth of $\lambda/2$. The reflecting layer structure contains, as its surface layer, a protective layer. The protective layer is a silicon oxide of general formula SiO_x, wherein x is a number from 1.1 to 2.0, or it is aluminum oxide of formula Al_2O_3, in a thickness of 3 nm or more. The protective layer protects the underlying layers from mechanical damages. In the DIN 58196 abrasion test the protected surface does not show any damages after 50 test cycles with 100 abrasion strokes.

[0035] U.S. Pat. No. 8,979,308 issued to Li on Mar. 17, 2015 with the title "LED illumination system with recycled light", and is incorporated herein by reference. U.S. Pat. No. 8,979,308 describes an LED illumination system includes at least one LED element and a recycling reflector having a transmissive aperture through which emitted light passes. The recycling reflector has a curved surface adapted to reflect the impinging light back to the LED element for improved light output through the transmissive aperture.

[0036] U.S. Pat. No. 8,858,037 issued to Li on Oct. 14, 2014 with the title "Light emitting diode array illumination system with recycling", and is incorporated herein by reference. U.S. Pat. No. 8,858,037 describes an LED illumination system includes a plurality of LED modules and a plurality of corresponding collimating lenses to provide increased brightness. Each LED module has at least one LED chip having a light emitting area that emits light and a recycling reflector. The reflector is positioned to reflect the light from the light emitting area back to the LED chip and has a transmissive aperture through which the emitted light exits. The collimating lenses are arranged to receive and collimate the light exiting from the LED modules.

[0037] U.S. Pat. No. 8,602,567 issued to Ouyang et al. on Dec. 10, 2013 with the title "Multiplexing light pipe having enhanced brightness", and is incorporated herein by reference. U.S. Pat. No. 8,602,567 describes multi-color light sources mixed in a recycling housing to achieve high light output. Light from each color light source is multiplexed and a portion of the mixed light passes through an output aperture in the light pipe and a portion light is recycled back, for example, by a shaped reflective surface and/or a reflective coating adjacent the aperture. In one embodiment, the light is directed back from the output side of the housing to an input light source having the same color. In another embodiment, the light is directed back from the output side of the housing to a coating designed to reflect that color. The reflected light is then reflected back toward the output aperture and a portion of that reflected light is again reflected toward the input and impacts the original source for that color light. In this way, light theoretically recycles infinitely.

[0038] U.S. Pat. No. 8,388,190 issued to Li, et al. on Mar. 5, 2013 with the title "Illumination system and method for recycling light to increase the brightness of the light source", and is incorporated herein by reference. U.S. Pat. No. 8,388,190 describes an illumination system for increasing the brightness of a light source that includes an optical recycling device coupled to the light source, preferably light emitting diode (LED), for spatially and/or angularly recycling light. The optical recycling device spatially recycles a portion of rays of light emitted by the LED back to the light source using a reflector or mirror and/or angularly recycles high angle rays of light and transmits small angle rays of light, thereby increasing the brightness of the light source's output.

[0039] U.S. Pat. No. 8,317,331 issued to Li on Nov. 27, 2012 with the title "Recycling system and method for increasing brightness using light pipes with one or more light sources, and a projector incorporating the same", and is incorporated herein by reference. U.S. Pat. No. 8,317,331 describes a recycling system and method for increasing the brightness of light output using at least one recycling light pipe with at least one light source the output end of the recycling light pipe reflects a first portion of the light back to the light source, a second portion the light to the input end of the recycling light pipe, and transmits the remaining portion of the light as output. The recycling system is incorporated into a projector to provide color projected image with increased brightness. The light source can be white LEDs, color LEDs, and dual paraboloid reflector (DPR) lamp.

[0040] U.S. Pat. No. 7,976,204 issued to Li et al. Jul. 12, 2011 with the title "Illumination system and method for recycling light to increase the brightness of the light source", and is incorporated herein by reference. U.S. Pat. No. 7,976,204 describes an illumination system for increasing the brightness of a light source comprises an optical recycling device coupled to the light source, preferably light emitting diode (LED), for spatially and/or angularly recycling light. The optical recycling device spatially recycles a portion of rays of light emitted by the LED back to the light source using a reflector or mirror and/or angularly recycles high angle rays of light and transmits small angle rays of light, thereby increasing the brightness of the light source's output.

[0041] U.S. Pat. No. 7,710,669 issued to Li on May 4, 2010 with the title "Etendue efficient combination of multiple light sources", and is incorporated herein by reference. U.S. Pat. No. 7,710,669 describes a multi-colored illumination system including a beam combiner. The beam combiner includes two triangular prisms and a filter for transmitting a first light and reflecting a second light, each light having a different wavelength. The beam combiner combines the transmitted first light and the reflected light to provide a combined beam. The six surfaces of each of the triangular prism of the beam combiner are polished, thereby combining the lights without increasing etendue of the multi-colored illumination system.

[0042] U.S. Pat. No. 7,232,228 issued to Li on Jun. 19, 2007 with the title "Light recovery for projection displays", and is incorporated herein by reference. U.S. Pat. No. 7,232,228 describes a light-recovery system for a projection display with a reflector having a first and a second focal points. A source of electro-magnetic radiation is disposed proximate to the first focal point of the reflector to emit rays of radiation that reflect from the reflector and converge substantially at the second focal point. A retro-reflector reflects at least a portion of the electromagnetic radiation that does not impinge directly on the reflector toward the reflector through the first focal point of the reflector to increase the flux intensity of the converging rays. A light pipe with an input surface and an output surface is disposed with the input surface proximate to the second focal point to collect and transmit substantially all of the radiation. A PBS is disposed proximate to the output surface to collect and polarize substantially all of the radiation into a radiation of a first polarization and a second polarization. Radiation of the first polarization is transmitted, while radiation of the second polarization is reflected toward the output surface. A wave plate is disposed in a path of the radiation of the second polarization.

[0043] U.S. Pat. No. 4,520,116 issued to Gentilman et al. on May 28, 1985 with the title "Transparent aluminum oxynitride and method of manufacture", and is incorporated herein by reference. U.S. Pat. No. 4,520,116 describes a polycrystalline cubic aluminum oxynitride having a density of at least 98% of theoretical density, and being transparent to electromagnetic radiation in the wavelength range from 0.3 to 5 micrometers with an in-line transmission of at least 20% in this range. A method of preparing the optically transparent aluminum oxynitride is also provided including the steps of forming a green body of substantially homogeneous aluminum oxynitride powder and pressureless sintering said green body in a nitrogen atmosphere and in the presence of predetermined additives which enhance the sintering process. Preferred additives are boron and yttrium in elemental or compound form.

[0044] U.S. Pat. No. 4,686,070 issued to Maguire, et al. on Aug. 11, 1987 with the title "Method of producing aluminum oxynitride having improved optical characteristics", and is incorporated herein by reference. U.S. Pat. No. 4,686,070 describes a method of preparing substantially homogeneous aluminum oxynitride powder that includes the steps of reacting gamma aluminum oxide with carbon in the presence of nitrogen, and breaking down the resulting powder into particles in a predetermined size range. A method of preparing a durable optically transparent body from this powder is also provided that includes the steps of forming a green body of substantially homogeneous cubic aluminum oxynitride powder and sintering said green body in a nitrogen atmosphere and in the presence of predetermined additives which enhance the sintering process. Preferred additives are boron, in elemental or compound form, and at least one additional element selected from the group of yttrium and lanthanum or compounds thereof. The sintered polycrystalline cubic aluminum oxynitride has a density greater than 99% of theoretical density, an in-line transmission of at least 50% in the 0.3- to 5-micron range, and a resolving angle of 1 mrad or less.

[0045] The Wikipedia internet website's entry for "speckle pattern" includes the following: "A speckle pattern is produced by the mutual interference of a set of coherent wavefronts. . . . Speckle patterns typically occur in diffuse reflections of monochromatic light such as laser light. Such reflections may occur on materials such as paper, white paint, rough surfaces, or in media with a large number of scattering particles in space, such as airborne dust or in cloudy liquids." There remains a need in the art for methods and apparatus using lasers and laser-pumped phosphor light sources with recycled light combined together to provide improved intensity and reduced speckle.

SUMMARY OF THE INVENTION

[0046] The present invention provides a method and apparatus for increasing brightness of diffused light along with reduction of speckling from laser light for high-power lighting applications. In some embodiments, the apparatus includes a diffuser system for use with laser light source and method. Some embodiments include a diffuser arranged to receive and diffuse laser light at a first location on the diffuser; and a first curved reflector located and configured to redirect at least some of the diffused laser light back toward the first location in order to preserve a brightness of the diffused laser light. Some embodiments further include a heatsink connected to the diffuser(s), laser(s), phosphor(s) and/or LED(s), and configured to spread and dissipate heat from the laser light at the first location. In some embodiments, the diffuser is a transmissive diffuser. In some embodiments, the diffuser is a reflective diffuser. In some embodiments, the diffuser includes a reflective diffuser. In some embodiments, the diffuser includes a phosphor that absorbs pump light from a laser and/or LED and emits emissive light having longer wavelengths than the wavelength(s) of the pump light. In some embodiments, the first curved reflector is a parabolic reflector.

[0047] In some embodiments, the present invention provides lasers and laser-pumped phosphor light sources with recycled light combined together to provide improved intensity and/or brightness and reduced speckle for high-power lighting applications.

[0048] Apparatus and method using a recycling light source. The recycling light source includes: one or more lasers that generate one or more laser beams, a phosphor plate and/or a diffuser plate that receive the one or more laser beams and emit wavelength-converted light and/or diffused light, one or more curved reflective surfaces that collect the wavelength-converted light and/or diffused light and reflect the collected light back to the phosphor plate and/or diffuser plate to increase brightness of output light. Some embodiments mount the phosphor plate and/or diffuser plate on a heatsink and optionally vibrate one or more of these structures. Some embodiments include a plurality of parabolic reflectors to image the phosphor plate and/or diffuser plate to an output aperture in one of the parabolic reflectors.

[0049] A diffuser system for use with laser light source and method. Some embodiments include a diffuser arranged to receive and diffuse laser light at a first location on the diffuser; and a first curved reflector located and configured to reflect at least some of the diffused laser back toward the first location in order to increase a brightness of the diffused laser light. Some embodiments further include a heatsink connected to the diffuser and configured to spread and dissipate heat from the laser light at the first location. In some embodiments, the diffuser is a transmissive diffuser. In some embodiments, the diffuser is a reflective diffuser. In some embodiments, the first curved reflector is a parabolic reflector. In some embodiments, the diffuser is a reflective diffuser. Some embodiments include a laser-excited phosphor light source and method with light recycling.

BRIEF DESCRIPTION OF THE DRAWINGS

[0050] FIG. **1**A is a side-view cross-sectional block diagram of a light-recycling light source **101** that uses a plurality of lasers **121** (e.g., in some embodiments, eight) and outputs it light through an aperture in a parabolic reflector, according to some embodiments of the present invention.

[0051] FIG. **1**B is a bottom-view block diagram of light source **101**, according to some embodiments of the present invention.

[0052] FIG. **1**C is a top-view block diagram of heatsinked laser and phosphor assembly **110**, according to some embodiments of the present invention.

[0053] FIG. **1**D is a top-view block diagram of light source **101**, according to some embodiments of the present invention.

[0054] FIG. **1**E is a bottom-view block diagram of an alternative light-recycling light source **105** that uses sixteen lasers **121**, according to some embodiments of the present invention.

[0055] FIG. **1**F is a side-view cross-sectional block diagram of a light-recycling light source **106** that uses a plurality of lasers **121** (e.g., eight) and a blue-wavelength-transmissive and other-wavelengths-reflective planar reflector **167**, according to some embodiments of the present invention.

[0056] FIG. **1**G is a side-view cross-sectional block diagram of a light-recycling light source **107** that uses a plurality of lasers **121** (e.g., eight) and outputs its light into an optical waveguide **138**, according to some embodiments of the present invention.

[0057] FIG. **2**A is a side-view cross-sectional block diagram of a light source **201** that uses four lasers **121** according to some embodiments of the present invention.

[0058] FIG. **2**B is a bottom-view block diagram of light source **201** according to some embodiments of the present invention.

[0059] FIG. **2**C is a top-view block diagram of heatsinked laser and phosphor assembly **210**, according to some embodiments of the present invention.

[0060] FIG. **2**D is a top-view block diagram of light source **201**, according to some embodiments of the present invention.

[0061] FIG. **3**A is a side-view cross-sectional block diagram of a transmissive-reflective diffuser system **301** with a diffuser plate **312** that receives a laser beam **141**, according to some embodiments of the present invention.

[0062] FIG. **3**B is a side-view cross-sectional block diagram of a transmissive-reflective diffuser system **302** with a plurality of diffuser plates **312.1** . . . **312.2** that receive a laser beam **141**, according to some embodiments of the present invention.

[0063] FIG. **4**A is a side-view cross-sectional block diagram of a recycling transmissive-reflective diffuser assembly **401** with a diffuser plate **412**, and a back-side dome-shaped (spherical) light-recycling reflector **416**, according to some embodiments of the present invention.

[0064] FIG. **4**B is a side-view cross-sectional block diagram of a recycling transmissive-reflective diffuser assembly **402** with a diffuser plate **412**, and a back-side orthogonal-parabolic light-recycling reflector **426**, according to some embodiments of the present invention.

[0065] FIG. **4**C is a side-view cross-sectional block diagram of a recycling transmissive-reflective diffuser assembly **403** with a diffuser plate **412**, a back-side dome-shaped (spherical) light-recycling reflector **416**, and a front-side dome-shaped (spherical) light-recycling reflector **436**, according to some embodiments of the present invention.

[0066] FIG. **4**D is a side-view cross-sectional block diagram of a recycling transmissive-reflective diffuser assembly **404** with a diffuser plate **412** and a back-side orthogonal-parabolic light-recycling reflector **426**, and a front-side orthogonal-parabolic light-recycling reflector **436**, according to some embodiments of the present invention.

[0067] FIG. **5**A is a side-view cross-sectional block diagram of a reflective diffuser system **501** having a reflective diffuser **514**, according to some embodiments of the present invention.

[0068] FIG. **5**B is a side-view cross-sectional block diagram of a reflective diffuser system **502** having a reflective diffuser **514** on a substrate **541**, according to some embodiments of the present invention.

[0069] FIG. **5**C**1** is a side-view cross-sectional block diagram of a reflective diffuser system **503** having a reflective diffuser **514** on a heatsink substrate **511** and a spherical dome reflector **516**, according to some embodiments of the present invention.

[0070] FIG. **5**C**2** is a side-view cross-sectional block diagram of a reflective diffuser system **503'** having a reflective diffuser **514** on a heatsink substrate **511** and a spherical dome reflector **516** with laser beam **141** impinging off center, according to some embodiments of the present invention.

[0071] FIG. **5**D**1** is a side-view cross-sectional block diagram of a reflective diffuser system **504** having a reflective diffuser **514** on a heatsink substrate **511** and an orthogonal-parabolic reflector **517**, according to some embodiments of the present invention.

[0072] FIG. **5**D**2** is a side-view cross-sectional block diagram of a reflective diffuser system **504'** having a reflective diffuser **514** on a heatsink **511**, one or more lasers **121** mounted to heatsink **511** to emit laser beams **141** through holes **525** in the heatsink **511**, and an orthogonal parabolic recycling reflector **517** that reflects high-angle light **546** horizontally across as light **547** to the opposite side and reflects that as light **546** back to the focus location **549** on the diffuser **514** to complete light recycling, according to some embodiments of the present invention.

[0073] FIG. **5**E is a side-view cross-sectional block diagram of a reflective diffuser system **505** having a reflective diffuser **514** on a heatsink substrate **511**, a spherical dome reflector **516**, and a small mirror **551** to direct the input beam **141** to the focus location **539** on the diffuser **514**, according to some embodiments of the present invention.

[0074] FIG. **5**F is a side-view cross-sectional block diagram of a reflective diffuser system **506** having a reflective diffuser **514** on a heatsink substrate **511**, an orthogonal-parabolic reflector **517**, and a small mirror **551** to direct the input beam **141** to the focus location **549** on the diffuser **514**, according to some embodiments of the present invention.

[0075] FIG. **6**A is a side-view cross-sectional block diagram of a reflective diffuser system **601** having a reflective diffuser **614** on a heatsink substrate **611**, a parabolic reflector **616**, a planar reflector **617** on the heatsink substrate **611** to reflect the initially diffused input light **652** back to the parabolic reflector **616**, which the reflects that light **652** back to the focus location **609** on the diffuser **614**, according to some embodiments of the present invention.

[0076] FIG. **6**B is a side-view cross-sectional block diagram of a reflective diffuser system **602** having a reflective diffuser **614** on a heatsink substrate **611**, a parabolic reflector **616**, a planar reflector **617** on the heatsink substrate **611** to reflect the initially diffused input light **652** back to the parabolic reflector **616**, which the reflects that light back to the focus location **609** on the diffuser, and one or more lasers **121** mounted to the heatsink substrate **611** to emit laser beams **141** through holes **625** in the substrate **611**, according to some embodiments of the present invention.

[0077] FIG. **6**C is a side-view cross-sectional block diagram of a reflective diffuser system **603** having a reflective diffuser **614** on a heatsink substrate **611**, diffuser **614** being surrounded by a bottom-side secondary parabolic reflector **634**, a top-side primary parabolic reflector **631**, a planar reflector **617** on the heatsink substrate **611** to reflect the initially diffused input light **653** back to the top parabolic reflector **631**, which the reflects that light **653** back to the focus location **609** on the diffuser, one or more lasers mounted to the heatsink substrate to emit light through holes **625** in the substrate **611**, and an optional light guide **658** at the output aperture **632** through the parabolic reflector **631**, according to some embodiments of the present invention.

[0078] FIG. **6**D is a bottom-view block diagram of reflective diffuser system **603** having a heatsink substrate **611**, one or more lasers **121** mounted to the heatsink substrate **611** to emit their respective laser beams **141** through holes **625** (see FIG. **6**C) in the substrate **611**, according to some embodiments of the present invention.

[0079] FIG. **7**A is a block diagram of a system **701** having one or more lasers **121**, one or more light-recycling diffuser systems **740** (each including one or more light-recycling diffuser system such as systems **301**, **401**, **402**, **403**, **404**, **501**, **502**, **503**, **503'**, **504**, **505**, **506**, **601**, **602**, or **603** of FIG. **3**, **4**A, **4**B, **4**C, **4**D, **5**A, **5**B, **5**C**1**, **5**C**2**, **5**D, **5**E, **5**F, **6**A, **6**B, or **6**C respectively), one or more modulator and/or projection optics systems **750**, one or more controllers **791**, and/or a vehicle- or land-based system **798** onto which the other components are mounted, according to some embodiments of the present invention.

[0080] FIG. **7**B is a block diagram of a system **702** having one or more lasers **121**, one or more light-recycling phosphor and/or diffuser systems **760** (each including one or more light-recycling phosphor systems such as systems **101**, **106**, **107**, or **201** of FIG. **1**A, **1**F, **1**G, or **2**A, respectively, and/or one or more light-recycling laser-phosphor, LED and/or diffuser systems such as systems **901**, **902**, **903**, **904**, **905**, **906**, **907**, **908**, **1001**, **1002**, **1101**, **1102**, or **1103** of FIG. **9**A, **9**B, **9**C, **9**D, **9**E, **9**F, **9**G, **10**A, **10**B, **11**A, **11**B or **11**C, respectively), one or more modulator and/or projection optics systems **770**, one or more controllers **792**, and/or a vehicle- or land-based system **799** onto which the other components are mounted, according to some embodiments of the present invention.

[0081] FIG. **8**A is a block diagram of a reflective multilayer dielectric diffuser system **801** having a lithographically-defined dielectric diffuser layer **810** formed on a dielectric-layer stack **820** operatively coupled to a heatsink **830**, according to some embodiments of the present invention.

[0082] FIG. **8**B is a block diagram of a reflective multilayer dielectric diffuser system **802** having a ceramic diffuser layer **811** formed on a dielectric-layer stack **820** operatively coupled to a heatsink **830**, according to some embodiments of the present invention.

[0083] FIG. **9**A is a side-view cross-sectional block diagram of a system **901** having a compound recycling reflector **910** that includes a parabolic reflector **916** and a conical reflector **915** sharing the same optical axis **944** such that light is focused toward a central phosphor and/or diffuser plate **914**, according to some embodiments of the present invention.

[0084] FIG. **9**B is a side-view cross-sectional block diagram of a system **902** having a compound recycling reflector **910** that includes a parabolic reflector **916** and a conical reflector **915** along the same optical axis **944**, also including a heatsink **911** with one or more laser diodes **121** that each emit a respective laser beam **141** through openings **925** in the heatsink **911** and through openings **919** in the conical reflector **915** to impinge on the parabolic reflector **916**, reflecting toward a central phosphor plate, LED, and/or diffuser plate **914**, according to some embodiments of the present invention.

[0085] FIG. **9**C is a side-view cross-sectional block diagram of a system **903** having a compound recycling reflector **910** that includes a parabolic reflector **916** and a conical reflector **915** along the same optical axis **944**, also including a heatsink **911** with one or more laser diodes **121** that emit a respective laser beam **141** through openings **925** in the heatsink **911** and through openings **919** in the conical reflector **915** to impinge on the parabolic reflector **916**, reflecting toward a central phosphor plate, LED, and/or diffuser plate **914**, and having an intermediate output **953** from projection lens **933** directed toward a scanning mirror **954** that scans in a one-dimensional (1D) or two-dimensional (2D) pattern **955** that forms a scanning output beam **956**, according to some embodiments of the present invention.

[0086] FIG. **9**D is a side-view cross-sectional block diagram of a system **904** having a scanning laser source **921** (such as system **903** shown in FIG. **9**C or the like) that scans the scanning laser light **951** toward a phosphor plate, LED, and/or diffuser plate **914**, and then the diffused light **949** from phosphor plate, LED, and/or diffuser plate **914** is shaped through a projection lens **933** to form projected light **948**, according to some embodiments of the present invention.

[0087] FIG. **9**E is a side-view cross-sectional block diagram of a system **905** having a scanning laser source **921** (such as system **903** shown in FIG. **9**C or the like) that scans the scanning laser light **951** toward a central phosphor plate, LED, and/or diffuser plate **914** through an opening in a compound recycling reflector **910** (including a parabolic reflector **916** and a conical reflector **915** along the same optical axis) such that light **951** is scanned toward central phosphor plate, LED, and/or diffuser plate **914**, and then the diffused light from plate **914** is shaped through projection lens **933**, according to some embodiments of the present invention.

[0088] FIG. **9**F is a side-view cross-sectional block diagram of a system **906** having an orthogonal parabolic recycling reflector **967** and a light source **921** with one or more laser beams **951** of one or more colors propagating through one or more openings **935** in the orthogonal parabolic recycling reflector **967**, wherein the recycling light **966** goes through two reflections, which is an even number of reflections, producing an upright image, so as to allow the recycled spot(s) to coincide with the respective original stationary or scanned spot(s), producing a scanning beam **968**, according to some embodiments of the present invention.

[0089] FIG. **9**G is a side-view cross-sectional block diagram of a system **907** having an orthogonal parabolic recycling reflector **967** and one or more laser beams **141** of one or more colors propagating through one or more openings **935** in the orthogonal parabolic recycling reflector **967**, wherein the recycling light goes through two reflections, wherein the system **907** also includes a projection lens **933** and a scanning mirror **954** to produce a scanning output beam **956**, according to some embodiments of the present invention.

[0090] FIG. **9**H is a side-view cross-sectional block diagram of a system **908** having a parabolic reflector **916** and a heatsink **911** with one or more laser diodes **121** that emit laser beams **141** through openings **925** in heatsink **911** to impinge on the parabolic reflector **916**, reflecting toward a phosphor, LED and/or diffuser plate **914**, the heatsink **911** having a planar reflector **917** that directs recycled light **952** from the central phosphor, LED and/or diffuser plate **914** back toward plate **914**, the system **908** having an intermediate output beam **953** that has been formed by a projection lens **933** and directed toward a scanning mirror **954** that forms a scanning output beam **956**, according to some embodiments of the present invention.

[0091] FIG. **10**A is a side-view cross-sectional block diagram of a system **1001** having a dome (spherical) recycling reflector **1016** (optionally having a vibration mechanism), a heatsink **911** with a phosphor, LED and/or diffuser plate **914** mounted to heatsink **911** (optionally having a vibration mechanism **1021**), and source(s) of one or more laser beams **141** coming through one or more openings **1015** in dome recycling reflector **1016** to impinge on the phosphor, LED and/or diffuser plate **914**, the light from phosphor, LED and/or diffuser plate **914** reflecting off the dome recycling reflector **1016** toward phosphor, LED and/or diffuser plate **914**, wherein system **1001** has an intermediate output **1053** from projection lens **1033** directed toward a scanning mirror **1054** that scans in a one-dimensional (1D) or two-dimensional (2D) pattern **1055** that forms a scanning output beam **1056**, according to some embodiments of the present invention.

[0092] FIG. **10**B is a side-view cross-sectional block diagram of a system **1002** having a compound recycling reflector **1010** that includes a first parabolic reflector **1035** and a conical reflector **1036** and a further second parabolic reflector **1034** on a heatsink **911**, all centered along the same optical axis **1044**, also including one or more laser diodes **121** that emit collimated laser light **141** through openings in the heatsink **1011** and through openings in the conical reflector **1036** to impinge on first parabolic reflector **1035**, reflecting toward a central phosphor, LED and/or diffuser plate **914** surrounded by the second parabolic reflector **1034**, that receives low-angle light collimated from first parabolic reflector **1035** and focuses an intermediate focused output light **1053** directed through the first parabolic reflector **1035** toward a light guide **1038**, according to some embodiments of the present invention.

[0093] FIG. **11**A is a side-view cross-sectional block diagram of a system **1101** having a compound recycling reflector **1110** (having a parabolic reflector **1116** and a planar reflector **1117**), a phosphor, LED and/or diffuser plate **914** on a heatsink **1111** with optional vibration **1121** (not shown), according to some embodiments of the present invention.

[0094] FIG. **11**B is a side-view cross-sectional block diagram of a system **1102** having a compound recycling reflector **1110** (having a parabolic reflector **1116** and a planar reflector **1117**), a phosphor, LED and/or diffuser plate **914** on a heatsink **1111** with optional vibration **1121**, and one or more lasers **121** that emit laser beams **141** through openings **1118** in planar reflector **1117**, according to some embodiments of the present invention.

[0095] FIG. **11**C is a side-view cross-sectional block diagram of a system **1103** having a compound recycling reflector **1130** (having a spherical (dome) reflector **1136** and a planar reflector **1137**), a phosphor, LED and/or diffuser plate **914** on a heatsink **1111** with optional vibration **1121**, and one or more lasers **121** that emit laser beams **141** through openings **1118** in planar reflector **1137** or dome reflector **1136**, according to some embodiments of the present invention.

[0096] FIG. **12**A is a cross-sectional elevation-view block diagram of a light source **1201**, according to some embodiments of the present invention. In some embodiments, light source **1201** includes a spherical, toroidal, or elliptical concave reflector **1210**, an LED **1214**, and a planar specular reflector **1212** (such as a flat mirror coated with metal or multi-layer dielectric coating of the proper wavelengths under consideration or to be emphasized).

[0097] FIG. **12**B is a cross-sectional top-view block diagram of light source **1201** (which is shown in a cross-section side view in FIG. **12**A), according to some embodiments of the present invention. In some embodiments, the high-angle portion of the light output of LED **1214** is reflected by the spherical concave reflector **1210** and imaged onto specular reflector **1212**. LED **1214** and specular reflector **1212** are placed symmetrically on opposite sides of the center of curvature of spherical concave reflector **1210**.

[0098] FIG. **12**C is a cross-sectional elevation-view block diagram of a light source **1203**, according to some embodiments of the present invention, where the LED **1214** of light source **1201** is replaced by a laser-excited phosphor plate **1216**, such that when the phosphor in phosphor plate **1216** is excited by laser beam **114** from laser **121**, light of one or more longer wavelengths will be emitted from the phosphor in phosphor plate **1216**. In some embodiments, emitted and diffused light from phosphor plate **1216** appears to the human eye to be very similar to the output of the LED **1214**, although the laser pump light **114** diffused from phosphor plate **1216** has a much narrower linewidth that pump light from a blue LED such as in system **1201**.

[0099] FIG. **12**D is a cross-sectional elevation-view block diagram of a light source **1204**, according to some embodiments of the present invention, wherein one or more excitation lasers **121** is/are placed on, in, and/or under heatsink **1211** with an opening for each laser **121** in heatsink **1211** through which the laser beam(s) from the laser(s) propagates such that the laser beams reflect from the dome **1210** or other laser reflector on or under the dome towards one or more phosphor structures and/or diffusive structures **1216**.

[0100] FIG. **12**E is a cross-sectional elevation-view block diagram of a light source **1205**, according to some embodiments of the present invention.

[0101] FIG. **12**F is a cross-sectional elevation-view block diagram of a light source **1206** having a plurality of phosphor structures **1213** . . . **1214**, each emitting light of a different selected color when pumped by a suitable laser beam **114**, according to some embodiments of the present invention.

[0102] FIG. **13**A is a cross-sectional top-view block diagram of a light source **1301**, according to some embodiments of the present invention, with the specular reflector **1313** made larger than the image **1312** of the LED.

[0103] FIG. **13**B is a top-view diagram of a four-color LED assembly **1324** that includes a red-light-emitting LED **1325**, a green-light-emitting LED **1326**, a blue-light-emitting LED **1327** and a white-light-emitting LED **1328**, according to some embodiments of the present invention.

[0104] FIG. **14**A is a cross-sectional top-view block diagram of a light source **1401**, according to some embodiments of the present invention, where a set of red, green, and blue (RGB) LEDs **1412**, **1413**, and **1414**, respectively, each individually packaged, are used.

[0105] FIG. **14**B is a cross-sectional side-view block diagram of light source **1401**, according to some embodiments of the present invention, where the outputs **1431**, **1432**, and **1433**, of the RGB LEDs **1412**, **1413**, and **1414**, respectively, exiting the apertures **1428** above the LEDs are collimated using three individual collimating lenses **1438** outside the spherical concave reflector **1410**, providing three colored beams of light with increased brightness due to light recycling by internal reflections in spherical concave reflector **1410**.

[0106] FIG. **14**C is a cross-sectional top-view block diagram of a light source **1403**, according to some embodiments of the present invention, in which the three RGB LEDs **1442**, **1443**, and **1444**, respectively are placed triangularly (in some embodiments, each LED at the same distance from the center of curvature **1441** of the spherical dome reflector **1410**), with the specular reflectors **1440** placed symmetrically opposite to the respective LEDs (in some embodiments, each specular reflector **1440** is located at the same distance from the center of curvature **1441** of the spherical dome reflector **1410**).

[0107] FIG. **15**A is a cross-sectional top-view block diagram of a light source **1501**, according to some embodiments of the present invention, where the colored beams are combined into a single beam **1556** (going toward the right in FIG. **15**A) using an X-Cube **1521**.

[0108] FIG. **15**B is a cross-sectional side-view block diagram of light source **1501**, according to some embodiments of the present invention, in which the three beams exiting the spherical concave reflector **1510** through the apertures are collimated, reflected by their respective 45-degree mirrors **1544**, **1545**, and **1546**, enter the X-Cube, and exit as a combined single beam **1556** (coming toward the viewer in FIG. **15**B).

[0109] FIG. **16**A is a cross-sectional side-view block diagram of a light source **1601**, according to some embodiments of the present invention, where the spherical concave reflector (e.g., reflector **1210** of FIG. **12**A) is replaced by a parabolic reflector **1616** and large specular reflector **1617**.

[0110] FIG. **16**B is a cross-sectional side-view block diagram of a light source **1602**, according to some embodiments of the present invention, where the spherical concave reflector (e.g., reflector **1210** of FIG. **12**A) is replaced by a parabolic reflector **1616** and large specular reflector **1617**, and where the LED (e.g., LED **1214** of FIG. **12**A) is replaced by a laser-excited phosphor plate **1624**, with the excitation laser **121** placed under the specular reflector **1617** and heatsink **1611**.

[0111] FIG. **17** is a block diagram of a vehicle **1701** that includes a LED/laser-pumped-phosphor light source **1711**, according to some embodiments of the present invention.

[0112] FIG. **18**A is a side-cross-sectional-view block diagram of an LED/laser-pumped-phosphor light source assembly **1801**. In some embodiments, LED/laser-pumped-phosphor light source assembly **1801** is substituted in place of any of the LEDs, diffusers, phosphor plates, or diffuser (PLD) structures described herein.

[0113] FIG. **18**B is a plan-view block diagram of LED/laser-pumped-phosphor light source assembly **1801**, according to some embodiments.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0114] Although the following detailed description contains many specifics for the purpose of illustration, a person of ordinary skill in the art will appreciate that many variations and alterations to the following details are within the scope of the invention. Specific examples are used to illustrate particular embodiments; however, the invention described in the claims is not intended to be limited to only these examples, but rather includes the full scope of the attached claims. Accordingly, the following preferred embodiments of the invention are set forth without any loss of generality to, and without imposing limitations upon the claimed invention. Further, in the following detailed description of the preferred embodiments, reference is made to the accompanying drawings that form a part hereof, and in which are shown by way of illustration specific embodiments in which the invention may be practiced. It is understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention. The embodiments shown in the Figures and described here may include features that are not included in all specific embodiments. A particular embodiment may include only a subset of all of the features described, or a particular embodiment may include all of the features described.

[0115] The leading digit(s) of reference numbers appearing in the Figures generally corresponds to the Figure number in which that component is first introduced, such that the same reference number is used throughout to refer to an identical component which appears in multiple Figures. Signals and connections may be referred to by the same reference number or label, and the actual meaning will be clear from its use in the context of the description.

[0116] Certain marks referenced herein may be common-law or registered trademarks of third parties affiliated or unaffiliated with the applicant or the assignee. Use of these marks is for providing an enabling disclosure by way of example and shall not be construed to limit the scope of the claimed subject matter to material associated with such marks.

[0117] Laser-pumped phosphor light sources provide higher luminance compared to LED light sources and are important for applications such as projectors or spotlights. The fact that laser-pumped phosphor emissions are Lambertian in nature, makes efficient collection and coupling of the emitted light very challenging. At the same time, the easiest way to use a laser-phosphor system is to use the transmissive mode, in which the laser beam enters from one side of a phosphor plate and emission exits the opposite side. The optical configuration for such transmissive mode is simple. One major disadvantage of this mode is the difficulty in providing efficient heatsinking of the phosphor plate, which cannot be mounted on an opaque heatsink.

[0118] On the other hand, a reflective-mode laser-phosphor system allows more efficient heatsinking of the phosphor plate, as the phosphor plate can be mounted directly on a reflective face of an opaque heatsink. One major disadvantage of a reflective-mode laser-phosphor system is that a more complicated optical system has to be used because light from the pump laser source enters, and the emission light leaves, through the same face of the phosphor plate. In some embodiments, the present invention provides a laser-pumped phosphor system in which the phosphor plate is mounted on a heatsink and used in a reflective mode. In some embodiments, low-angle laser-pumped phosphor-emission light (light at small angles to the central-axis normal (right-angle) vector of the face of the phosphor plate) is output directly. In addition, high-angle light (light at large angles to the central-axis normal vector of the phosphor plate's face) emitted from the phosphor plate is recycled back to the phosphor plate for added brightness. The total light, including the light initially emitted at low angles, plus the recycled light that, once it is recycled, leaves at low angles, can be coupled efficiently using standard optics such as lenses and reflectors.

[0119] FIG. **1**A is a side-view cross-sectional block diagram of a light source **101** that uses a plurality of lasers **121** (e.g., in some embodiments, eight), according to some embodiments of the present invention. In some embodiments, light source **101** includes a heatsinked laser and phosphor assembly **110** having a heatsink **111**, phosphor plate **112**, flat planar reflector **117**, and a plurality of lasers **121** each having a collimating lens **126** such that the emitted beams **141** are collimated and parallel to the center axis **144** of the parabolic reflector **116**. In some embodiments, phosphor plate **112** includes, or is, a thin layer of silicone phosphor, glass phosphor, ceramic phosphor, and/or crystal phosphor, mounted on a surface of heatsink **111** (the top surface in FIG. **1**A). In some embodiments, phosphor plate **112** is placed proximal to the focus **109** of the parabolic reflector **116**. One or more lasers **121** (two of which are shown in FIG. **1**A), each with collimated laser beam outputs **141**, are mounted on the heatsink **111** such that the output beams pass through the openings **125** through the heatsink **111**. In some embodiments, holes **115** through the reflective layer **117** are aligned with openings **125** to allow laser beams **141** to pass therethrough. Dashed lines with single arrows with reference number **145** represent the initially emitted high-angle light from phosphor plate **112** to parabolic reflector **116**, and dashed lines with double arrows with reference number **146** represent recycling light. Diffused light **145** from different locations on phosphor plate **112** will impinge on different locations of parabolic reflector **116** and be reflected to different locations on planar reflector **117**, and the same in the reverse direction with recycled light **146**. In other embodiments (see FIG. **1**F), reflective layer **117** is replaced by wavelength-selective reflector **167** that is configured to transmit the wavelengths of the laser beams **141** but to reflect the emitted light of phosphor plate **112**. The laser beams **141** are reflected by parabolic reflector **116** and directed towards the phosphor plate **112** at the focus **109** of parabolic reflector **116**. In some embodiments, the laser-pumped excited phosphor in laser-pumped phosphor plate **112** emits longer-wavelength light (the emissive light) in substantially all directions, generally in a Lambertian angular distribution.

[0120] In some embodiments, phosphor plate **112** absorbs much of the laser light **141** and re-emits light (sometimes herein called "emissive light") of a longer wavelength (e.g., in some embodiments, absorbing blue laser light in the range of about 420 nm to about 490 nm and re-emitting many wavelengths (i.e., a broad spectral bandwidth) centered at generally yellow wavelengths, such as having a peak center wavelength in a range of about 520 nm to about 660 nm). In some embodiments, some of the light from laser beam(s) **141** that is not absorbed is reflected, diffused and/or scattered by phosphor plate **112** and is recycled and/or output in light **143**, which results in output light **143** having a combination of shorter and longer wavelengths (e.g., in some embodiments, "white" light).

[0121] The lower-angle emissive light **143** (light emitted at small angles to the central-axis surface normal vector **144** of the phosphor plate **112**) exits through aperture **118** in parabolic reflector **116**, contributing to the output of the light source **101**. The high-angle portion **145** of the emissive light is collected for recycling by parabolic reflector **116** and collimated (in a downward vertical direction in FIG. **1**A) towards planar reflector **117**. The recycling light **146** is then retro-reflected back (in an upward vertical direction in FIG. **1**A) to parabolic reflector **116** which reflects and focuses recycling light **146** back to focus location **109** on phosphor plate **112**, completing the recycling process. A portion of this recycling light **146** is then emitted (in a generally upward direction in FIG. **1**A) at small angles relative to the central-axis surface normal vector **144** of phosphor plate **112** (called small-angle light), exiting through aperture **118** and contributing to an increase in brightness of output light **143**. The high-angle portion **145** of this recycling light (the portion at a large angle to the central-axis surface normal vector **144**) is again recycled (reflecting from parabolic reflector **116**, planar reflector **117** and again by parabolic reflector **116** back toward the focus **109**), and the process repeats, contributing further to the output light **143** of light source **101**. (Note that reference number **145** refers to one part of the high-angle portion of light initially emitted from phosphor plate **112** due to laser pump light, while reference number **146** refers to recycling light that is repeatedly reflected by parabolic reflector **116** and planar reflector **117** to go back to phosphor plate **112** so that some eventually is added to the output light **143**. The light initially emitted, diffused and/or reflected from phosphor plate **112** will come out at all angles, typically in a Lambertian pattern, and examples of the high-angle portion (the light that does not initially exit through aperture **119**) are indicated by reference number **145**, and all of this light, regardless of emission angle, will be reflected as collimated light indicated by reference number **146** by parabolic reflector **116** toward planar reflector **117**, and then retroreflected, again as collimated light by planar reflector **117** toward parabolic reflector **116** and all will then be reflected and focused toward phosphor plate **112**—indicated by reference number **146** to show exemplary recycling paths.) In one embodiment, planar reflector **117** reflects all wavelengths of light.

[0122] In some embodiments, the inner and outer diameters of the parabolic reflector **116** and the inner and outer diameters of the planar reflector **117** (both of which, in some embodiments, are circular in overall shape, as may be appreciated in the bottom view of FIG. **1**B) are designed to optimize (i.e., a designer-chosen compromise for a given application) between maximizing the total recycling efficiency and minimizing the physical dimensions of light source **101**. In some such embodiments, the outer diameter of the parabolic reflector **116** is the same size as the outer diameter of planar reflector **117** and the inner diameter (the size of aperture **118**) of the parabolic reflector **116** is the same size as the inner diameter (the size of aperture **119**) of planar reflector **117**. With the phosphor-emission outputs of phosphor plate **112** being Lambertian (e.g., see FIG. **5**B), most of the output will be within a half angle of about 70 degrees. In this case, the diameters of parabolic reflector **116** and planar reflector **117** can be made smaller to reduce the overall dimensions of the system of light source **101**. In another embodiment (not explicitly shown, but substantially similar to FIG. **1**A), the upper-face surface of the phosphor plate **112** is coated with a photonic-crystal layer and/or a diffraction grating such that the output angular distribution is narrower than Lambertian, and in this case, the diameter of the parabolic reflector(s) can be even smaller. In some embodiments, since both the phosphor plate **112** and the lasers **121** are mounted on the same heatsink **111**, a single heat-dissipating structure (i.e., heatsink **111**) is used, simplifying the design and reducing the cost of the system using light source **101**.

[0123] FIG. **1**B is a bottom-view block diagram of light source **101**, according to some embodiments of the present invention. In FIG. **1**B, the large-circle dash-dot-dot line outlines the outer circumference of parabolic reflector **116** on the top of FIG. **1**A (which is not directly visible from this bottom view), and the smaller-circle dash-dot-dot line outlines the circumference of aperture **118** in parabolic reflector **116**. The small-dash-dot cross-section indicator **1**A indicates the location of the cross-section plane for the diagram of FIG. **1**A.

[0124] FIG. **1**C is a top-view block diagram of heatsinked laser and phosphor assembly **110**, according to some embodiments of the present invention. In this view, the diameter of holes **115** in planar reflector **117**, and the diameter of openings **125** through the heatsink **111** are the same, so openings **125** are not separately labeled. In some embodiments (not shown here in order to clarify the drawing), the outer diameter of phosphor plate **112** and the size of aperture **119** in planar reflector **117** are the same in order to maximize light recycling and also maximize the thermal contact between phosphor plate **112** and heatsink **111**.

[0125] FIG. **1**D is a top-view block diagram of light source **101**, according to some embodiments of the present invention. In some embodiments (not shown here in order to clarify the drawing), the outer diameter of parabolic reflector **116** and the outer diameter of planar reflector **117** are the same size, and the size of aperture **118** in parabolic reflector **116**, the outer diameter of phosphor plate **112**, and the size of aperture **119** in planar reflector **117** are all the same in order to maximize light recycling.

[0126] FIG. **1**E is a bottom-view block diagram of an alternative light-recycling light source **105** that uses more lasers **121** (e.g., in some embodiments, sixteen), according to some embodiments of the present invention. In some embodiments, recycling light source **105** arranges the plurality of lasers **121** in two or more circumferential rings around the center of phosphor plate **112** (or other patterns, such as patterns of approximately even spacing across the surface of heatsink **111**).

[0127] FIG. **1**F is a side-view cross-sectional block diagram of a light-recycling light source **106** that uses a plurality of lasers **121** (e.g., in some embodiments, eight) and a blue-wavelength-transmissive and other-wavelengths-reflective planar reflector **167**, according to some embodiments of the present invention. In some embodiments, the wavelength-selective planar reflector **167** is coated (e.g., in some embodiments, with a plurality of dielectric layers) such that only blue light from the lasers **121** passes through (is transmitted) and other wavelengths (particularly the wavelengths emitted by the phosphor plate **112** when excited by blue pump light from lasers **121**) are reflected. In contrast to FIG. **1**A, in some such embodiments, the wavelength-selective reflector planar reflector **167** covers the whole, or at least most of heatsink **111**, outside the diameter of the phosphor plate **112**, without the need for making matching holes **115** corresponding to the openings **125** in heatsink **111**, as were shown in FIG. **1**A. Other aspects of FIG. **1**F are as described above for FIG. **1**A.

[0128] FIG. **1**G is a side-view cross-sectional block diagram of a light-recycling light source **107** that uses a plurality of lasers **121** (e.g., in some embodiments, eight) and that outputs its light into an optical waveguide **138** (or a light pipe, as described below), according to some embodiments of the present invention. In some embodiments, optical waveguide **138** includes a glass optical fiber or rod, optionally coated with a material having a lower index of refraction than the glass optical fiber or rod, such that light propagating in the waveguide is contained by total internal reflection (TIR). When light is confined by an internally reflective pipe or coatings such as metal on a transparent rod, rather than by TIR, structure **138** may be referred to as a light pipe rather than a waveguide. In some embodiments, light source **107** includes two parabolic reflectors—parabolic reflector **131** at the top of FIG. **1**G and parabolic reflector **134** at the surface of heatsink **111**, such that the output is not merely a divergent beam from the phosphor plate **112**. Instead, an image of the laser-excited light-emission spot at the phosphor plate **112** is transferred from the physical location of phosphor plate **112** to the aperture **132** of the parabolic reflector **131** through reflection from the first and second parabolic reflectors, **131** and **134**, respectively. The phosphor plate **112** is placed at the focus of the first parabolic reflector **131** and the aperture **132** in parabolic reflector **131** (which, in some embodiments, is smaller than the aperture **118** of parabolic reflector **116** of FIG. **1**A) is placed at the focus of the second parabolic reflector **134**. In some embodiments, the image of the spot on the phosphor plate **112** at the aperture **132** is used for direct coupling into fiber optics, light pipes of projection systems (such as light pipe **138** shown here), and the like. The use of two parabolic reflectors—parabolic reflector **131** and parabolic reflector **134**—eliminates the need for high-numerical-aperture (high-NA) coupling lenses, which are expensive, inefficient, and do not focus well. The light-recycling portion (that portion outside of parabolic reflector **134**) of light source **107** is similar to that of FIG. **1**A, as described above. In some embodiments, the output light **137** from light pipe **138** is coupled to further output optics (not shown).

[0129] FIG. **2**A is a side-view cross-sectional block diagram of a light source **201** that uses a plurality of lasers **121** (e.g., in some embodiments, four), according to some embodiments of the present invention. In some embodiments, light source **201** includes a heatsinked laser and phosphor assembly **210** having a heatsink **211**, phosphor plate **212**, flat planar reflector **217**, and a plurality of lasers **121** each having a collimating lens **126** such that the emitted beams **141** are collimated and parallel to the center axis **144** of the parabolic reflector **116**. In some embodiments, phosphor plate **212** includes, or is, a thin layer of silicone phosphor, glass phosphor, and/or crystal phosphor, mounted on a surface of heatsink **211** (the top surface in FIG. **2**A). In some embodiments, phosphor plate **212** is placed proximal to the focus **109** of the parabolic reflector **116**. One or more lasers **121** (two of which are shown in FIG. **2**A), each with collimated laser beam outputs **141**, are mounted on the heatsink **211** such that the output beams pass through the openings **125** through the heatsink **211**. In some embodiments, holes **115** through the reflective layer **217** are aligned with openings **125** to allow laser beams **141** to pass therethrough. In other embodiments (see FIG. **1**E), reflective layer **217** is replaced by a wavelength-selective reflector **167** that is configured to transmit the wavelengths of the laser beams **141** but to reflect the emitted light of phosphor plate **212**. The laser beams **141** are reflected by parabolic reflector **116** and directed towards the phosphor plate **212** at the focus **109** of parabolic reflector **116**. In some embodiments, the laser-pumped excited phosphor in laser-pumped phosphor plate **212** emits longer-wavelength light (the emissive light) in substantially all directions, typically in a Lambertian angular distribution.

[0130] FIG. **2**B is a bottom-view block diagram of light source **201** according to some embodiments of the present invention. The descriptions for many of the reference numbers in FIG. **2**B are set forth above in the descriptions of FIG. **1**A and FIG. **2**A. In some embodiments, heatsink **211** is smaller than heatsink **111** of FIG. **1**A (e.g., in some embodiments, heatsink **211** has a 25-mm diameter) and phosphor plate **212** is smaller than phosphor plate **112** of FIG. **1**A (e.g., in some embodiments, phosphor plate **212** has a 2-mm diameter).

[0131] FIG. **2**C is a top-view block diagram of heatsinked laser and phosphor assembly **210**, according to some embodiments of the present invention. The descriptions for many of the reference numbers in FIG. **2**C are set forth above in the descriptions of FIG. **1**A and FIG. **2**A. In some embodiments, openings **115** each have a 2-mm diameter.

[0132] FIG. **2**D is a top-view block diagram of light source **201**, according to some embodiments of the present invention. The descriptions for the reference numbers in FIG. **2**D are set forth above in the descriptions of FIG. **1**A and FIG. **2**A.

[0133] In some embodiments, the present invention provides a light source that includes a heatsink; a plurality of lasers, each mounted to a respective opening in the heatsink, wherein each of the plurality of lasers emits laser light of one or more first wavelengths through its respective opening in the heatsink; a phosphor mounted to a reflective surface on the heatsink; a parabolic reflector arranged to reflect the light from the plurality of lasers toward the phosphor mounted to the reflective surface on the heatsink and arranged such that the laser light from the plurality of lasers passes through the phosphor die twice to the reflective surface on the heatsink and then back through the phosphor toward the parabolic reflector.

[0134] In some embodiments, the phosphor converts the laser light of one or more first wavelengths to a set of one or more second wavelengths. In some embodiments, the parabolic reflector includes an aperture opposite the phosphor. In some embodiments, the heatsink includes a planar reflector facing the parabolic reflector. In some embodiments, the excited phosphor emits light in many directions toward the parabolic reflector. In some embodiments, lower-angle light exits through the aperture, contributing to output of the light source, a high-angle portion of the light from the phosphor and any unconverted laser light is collected by the parabolic reflector and collimated back towards the planar reflector, and the light from the parabolic reflector is then reflected by the planar reflector back to the parabolic reflector and focused back to the phosphor plate by the parabolic reflector, completing a light-recycling process.

[0135] FIG. **3**A is a side-view cross-sectional block diagram of a transmissive-reflective diffuser system **301** with a diffuser plate **312** that receives a laser beam **141**, according to some embodiments of the present invention. In some embodiments, the transmissive diffuser **312** is attached to a heatsink **311** having a very small hole therethrough (shown larger here for clarity) to permit substantially all of the laser beam **141**, which is incident from the bottom side (i.e., from the bottom in this FIG. **3**A), to pass through heatsink **311** to the diffuser **312**. In some embodiments, not shown, the bottom of the transmissive diffuser plate **312** is coated with a wavelength-selective optical filter, e.g., in some embodiments, a multi-layer dielectric reflective coating, such that the wavelength-selective optical filter transmits the laser light for excitation of the phosphor, but reflects any downward phosphor emission back to the top side, adding to the output light of the system, thus increasing the efficiency. In some embodiments, the transmissive diffuser **312** (optionally including the heatsink **311**) is attached to a vibrational actuator **321** that vibrates the diffuser in one or more transverse directions (e.g., in the X and/or Y direction shown schematically here in FIG. **3**A, which is/are orthogonal to the Z direction of the incident incoming laser beam **141**). In some other embodiments, the vibration **321** is applied to the diffuser **312** (such as shown in FIG. **3**B, applied of diffuser **312.1**), alternatively or additionally, in the Z-direction. In some embodiments, the direction of incident laser beam **141** is orthogonal to the plane of the exit face (the top face in FIG. **3**A) of the diffuser **312**, while in other embodiments, the incident laser direction is not orthogonal to the face of diffuser plate **312** (as shown in FIG. **3**A), but instead is incident at an acute angle, which is useful, for example, when using multiple incoming laser beams (e.g., in some embodiments, using a plurality of different wavelengths or colors—e.g., red, green, blue (RGB), cyan, yellow, violet, orange, infrared (IR), ultraviolet (UV) and/or the like). The laser beam **141** is incident to the diffuser **312** from one side (from the bottom in this FIG. **3**A) and the diffused output light **343** is collected from the other side of the diffuser **312** (out the top in this FIG. **3**A). In some such embodiments, some of the diffused light **344** also exits the same face through which the incident laser beam **141** entered, which reduces the efficiency of system **301**. In some embodiments, laser beam **141** is focused onto diffuser plate **312** using an appropriate optical system (not shown), with the smallest or the desired spot size.

[0136] FIG. **3**B is a side-view cross-sectional block diagram of a transmissive-reflective diffuser system **302** with a plurality of diffuser plates **312.1** . . . **312.2** that receive a laser beam **141**, according to some embodiments of the present invention. In some embodiments, the diffuser **312** includes a plurality of diffusive layers **312.1** . . . **312.2**. In both FIG. **3**A and FIG. **3**B, the angle and spread of diffusion depend on the properties of the diffusive layer(s), such as the bulk features (e.g., bubbles or particulates), the surface features of the top and/or bottom faces, such as roughness, etc., and/or spacing between layers (**312.1** . . . **312.2**) if a plurality of spaced layers are used. The basic properties of most of these features diffuses the light both in the forward direction (upward in the FIG. **3**A) as diffused output **343**, and backward direction (downward in the FIG. **3**A) as diffused output **344** as shown. If the backward diffused light **344** is not collected, it contributes to the losses of the system, thus reducing the efficiency. In some embodiments, an optional vibration actuator **321** applies a vibration to the diffuser **312**, reducing the amount of speckles in the output light.

[0137] FIG. **4**A is a side-view cross-sectional block diagram of a recycling transmissive-reflective diffuser assembly **401**, according to some embodiments of the present invention. In some embodiments, assembly **401** includes a transmissive diffuser **412** and a dome-shaped (spherical) light-recycling reflector **416**, added to the back side (the side through which laser beam **141** enters) of the diffuser **412**, with an aperture **418** through reflector **416** such that the incident laser beam **141** passes through the aperture **418**. In some embodiments, the dome-recycling reflector **416** is preferably spherical with the center of curvature **415** located at, or proximal to, the laser entry spot (the location where the incoming laser beam is incident onto diffuser bottom face), such that all the back-diffusion light is reflected back from reflector **416** to the laser entry spot, increasing the output of diffused light from the top face of the diffuser. In some embodiments, an optional vibration is applied (e.g., by vibration actuator **421**) to diffuser **412** and/or to reflector **416**. In some embodiments, the vibration is applied to reduce the amount of speckles. In some embodiments, the recycling reflector **416** is an orthogonal parabolic reflector as shown in FIG. **4**B.

[0138] In some embodiments (not shown) of assembly **401** of FIG. **4**A, the input aperture **418** of the dome reflector **416** is off-center, such that the input laser beam **141** is not incident on the diffuser **412** at an orthogonal angle, so as to reduce retroreflection back toward the input aperture **418** in order to reduce light loss out the input aperture **418**. In some embodiments, a plurality of such off-center input apertures are provided to receive, at one or more acute angles and/or directions toward the input face of diffuser **412**, a plurality of laser beams of the same wavelength, or to increase the number of colors by receiving a plurality of laser beams of different wavelengths.

[0139] FIG. **4**B is a side-view cross-sectional block diagram of a recycling transmissive-reflective diffuser assembly **402** with a diffuser plate **412** and a back-side orthogonal-parabolic light-recycling reflector **426**, according to some embodiments of the present invention. In some embodiments, assembly **402** includes diffuser plate **412**, an optional heatsink **411**, and an orthogonal parabolic reflector **426** that serves as the recycling reflector. The laser beam **141** enters the system **402** through input aperture **428** in the orthogonal-parabolic light-recycling reflector **426**, arriving at the laser entry spot at the focus location **425** on the back face of the diffuser **412** (which includes one or more layers of diffusion material, for example, as shown in FIG. **3**B), and the light **442** diffused backward (downward in FIG. **4**B) from the laser spot at the focus **425** of the reflector **426** is reflected from one side of the reflector, and horizontally directed as light **432** towards the opposite side of the reflector **426** in a direction orthogonal to the center axis of the orthogonal parabolic reflector **426**, and is there reflected back to the focus location **425**, completing the light-recycling process and increasing the output of the assembly **402**. Again, in some embodiments, an optional vibration is applied to diffuser **412** (e.g., by a vibration actuator **421** as shown in FIG. **4**A) and/or to the reflector **426**, reducing the amount of speckles.

[0140] In some embodiments of system **402** of FIG. **4**B, the input aperture **428** of the orthogonal parabolic reflector **426** is off-center such that the input laser beam **141** is angled so as to not be incident on the diffuser **412** at an orthogonal angle, in order to reduce retroreflection back toward the input aperture **428**, thus reducing backscattered light loss out the input aperture **428**. In some embodiments, a plurality of such off-center input apertures are provided receive, at one or more acute angles and/or directions toward the input face of diffuser **412**, to accommodate a plurality of laser beams of the same wavelength to increase power, or to increase the number of colors by receiving a plurality of laser beams of different wavelengths.

[0141] FIG. **4**C is a side-view cross-sectional block diagram of a recycling transmissive-reflective diffuser assembly **403** with a diffuser plate **412**, a back-side dome-shaped (spherical) light-recycling reflector **416**, and a front-side dome-shaped (spherical) light-recycling reflector **436**, according to some embodiments of the present invention. In some embodiments, system **403** is substantially similar to system **401**, but with the addition of front-side dome reflector **436** that recycles high-angle light **431** back to a center location on diffuser plate **412**.

[0142] FIG. **4**D is a side-view cross-sectional block diagram of a recycling transmissive-reflective diffuser assembly **404** with a diffuser plate **412** and a back-side orthogonal-parabolic light-recycling reflector **426**, and a front-side orthogonal-parabolic light-recycling reflector **446**, according to some embodiments of the present invention. In some embodiments, system **404** is substantially similar to system **403**, but with the addition of orthogonal-parabolic light-recycling reflector **446** that recycles high-angle light **444** back to a center location on diffuser plate **412**.

[0143] FIG. **5**A is a side-view cross-sectional block diagram of a reflective diffuser system **501** having a reflective diffuser **514**, according to some embodiments of the present invention. Incoming laser beam **141** is incident to laser spot **539** on a surface of diffuser **514**. The central-axis surface normal vector **544** from laser spot **539** is orthogonal to the surface of diffuser **514**, and the diffused reflected light **543** comes off at a plurality of directions. In contrast to transmissive diffusers (as shown in FIGS. **3**A, **4**B, **4**A, and **4**B), system **501** uses a reflective diffuser **514**. In some embodiments, reflective diffuser **514** is mounted on top of a substrate (e.g., such as shown in FIG. **5**B) having a high heat conduction, which provides a heatsinking function, allowing a higher power operation of system **501**. In the systems **301**, **302**, **401**, and **402** of FIGS. **3**A, **4**B, **4**A, and **4**B, respectively, with the need for passing the laser beam through the transmissive diffuser **312** or **412**, heatsinking becomes difficult (though not impossible since, as described above, some embodiments include a heatsink substrate **311** or **411** having a small through-hole), which limits the ultimate power-handling capacity of the transmissive systems **301**, **302**, **401**, and **402**. Another limit is caused by the light passing through the diffuser material, which inherently absorbs some of the laser light. In contrast, in some embodiments, reflective diffuser **514** is made so that very little of the laser light passes through the diffusive material. In some embodiments, reflective diffuser materials used for reflective diffuser **514** that handle high power include a ceramic such as aluminum nitride, aluminate silicate, etc. An example of these materials is Accuratus's Accuflect® Light-Reflecting Ceramic (available from www.accuratus.com), which reflects 95% to 99% of incident light from 450 nm to 2500 nm, and the reflectivity is essentially non-specular with nearly perfect Lambertian behavior across the entire spectrum. Accuratus's Accuflect® Light-Reflecting Ceramic (see, e.g., www.accuratus.com/accuflprods.html) is a porous ceramic usable to 1100° C. that is used in some embodiments of the present invention. When a laser beam **141** is focused into a small spot on such a ceramic, the laser light will be scattered into the output directions with a Lambertian distribution emitted from a very small area, which provides a very-small-etendue light source, as shown in FIG. **5**B. In addition, to reduce the speckles, in some embodiments, the reflective diffuser is mounted on a vibrating substrate (such as substrate **541** of FIG. **5**B or heatsink substrate **511** of FIGS. **5C1** and **5**D). In some embodiments, with proper amplitude and frequency of the vibration from vibration actuator **521**, illumination without visible speckles is obtained. In some embodiments, with the high reflectivity of these diffusing ceramics used for reflective diffuser **514**, together with the high reflectivity of the recycling reflector (e.g., reflector **516** of FIG. **5C1** or reflector **517** of FIG. **5**D), the brightness-increase factor is very high. For one particular case that includes reflectors such as shown in FIG. **5C1**, **5**D or **5**E, where the output angle is +/−20 degrees, diffuser reflectivity is 98%, and recycling-reflector reflectivity is 99%, the brightness of the system increases by a factor of up to 6.4 times.

[0144] FIG. **5**B is a side-view cross-sectional block diagram showing the Lambertian reflection-intensity pattern **522** of a reflective diffuser system **502** having a reflective diffuser **514** on a substrate **541**, according to some embodiments of the present invention. The dotted-line circle of reflection-intensity pattern **522** illustrates the Lambertian distribution, wherein the lengths of the arrows **542** from the laser spot **539** on the front face of diffuser **514** to the circle **522** represent the relative intensities in the various output directions in the plane of the paper. In some embodiments, the Lambertian distribution is substantially spherical. In some embodiments, a single input laser beam **141** is used. In some other embodiments, a plurality of input laser beams **141** (in some embodiments, all of the same wavelength for greater intensity, while in other embodiments, of a plurality of different wavelengths for more colors) are incident from a plurality of three-dimensional (3D) directions surrounding the location of the laser spot **539** on the surface of diffuser **514**. In some embodiments, the plurality of 3D directions for the incoming laser beams **141** also vary in the angle of incidence toward the surface of diffuser **514**. Depending on the type of diffusers used, in some embodiments, the output distribution has a smaller divergence angle. For example, instead of +/−90 degrees, in some embodiments, the divergence angle is made smaller by diffuser design, such as +/−30 degrees or other range of angles, or other non-circularly symmetric shape of the intensity. In addition, in various other embodiments, the intensity profile is flat top, concave in shape (i.e., less intensity in the center and more intensity at some distance from the center optical axis), or other desired shapes, instead of the convex shape (i.e., more intensity in the center) exhibited in the Lambertian distribution.

[0145] FIG. **5C1** is a side-view cross-sectional block diagram of a reflective diffuser system **503** having a reflective diffuser **514** on a heatsink substrate **511** and a spherical dome reflector **516**, according to some embodiments of the present invention. In some embodiments, system **503** includes a dome-shaped light-recycling reflector **516** (in some embodiments, spherical reflector **516** having a center of curvature at the location of the laser spot **539**) with one or more input apertures **515** to pass one or more input laser beams **141** toward the focus spot location **539** on diffuser **514** at the center of curvature of the reflector **516**. In some embodiments, the light-output angle is determined by the size of output aperture **518** and the distance from the laser spot **539** on the diffuser **514** to output aperture **518**. In some embodiments, a laser-beam-input aperture **515** of the recycling reflector **516** is made for each one of a plurality of input laser beams **141** such that each laser beam passes through and is incident onto the diffuser **514** at the desired laser spot location **539**. In some embodiments, the input laser emits a single-color laser beam **141**, while in other embodiments, a combination of several colors from one or more lasers is combined into a single input laser beam **141**. In yet another embodiment, a plurality of laser-input apertures **515** are made (such as spaced circumferentially around reflector **516**) such that a plurality of laser beams **141** with the same color (or, in other embodiments, having a plurality of different colors) pass through the respective apertures **515** and are incident onto the diffuser **514** at the same spot **539** (or, in other embodiments, at different spots on diffuser **514** (see FIG. **5C2**), depending on the designer's desired application). When using the spherical dome-shaped recycling reflector **516**, the light **534** diffused toward the dome reflector **516** from the incident spot **539** at the center of curvature will be reflected back to the same spot **539** at the center of curvature of recycling reflector **516**. In some such embodiments, it is important that at the assembly process, the dome-shaped light-recycling reflector **516** is aligned accurately such that the input laser beam is incident to the location **539** at the center of curvature. In other embodiments (see FIG. **5C2**, described below), the incoming laser beam **141** is directed to a laser spot **538** located off to one side of the center of curvature **537** and will have its diffused light **534** reflected back to the diffuser **514** to a location **538'** at the opposite side of the center of curvature **537** from laser spot **538**. In some embodiments, an optional vibration is applied to the heatsink **511** and/or to the dome-shaped light-recycling reflector **516** in order to reduce the amount of speckles.

[0146] FIG. **5C2** is a side-view cross-sectional block diagram of a reflective diffuser system **503'** having a reflective diffuser **514** on a heatsink substrate **511** and a spherical dome reflector **516**, according to some embodiments of the present invention. In this embodiment, the incoming laser beam **141** is directed to a laser spot **538** located off to one side of the center of curvature **537** and has its diffused light **534** reflected back to the diffuser **514** to a location **538'** at the opposite side of the center of curvature **537** from laser spot **538**. Light from the secondary location **538'** will then reflect from dome reflector **516** to get recycled back to the original laser spot **538**.

[0147] FIG. **5D1** is a side-view cross-sectional block diagram of a reflective diffuser system **504** having a reflective diffuser **514** on a heatsink substrate **511** and an orthogonal-parabolic reflector **517**, according to some embodiments of the present invention. In order to overcome the alignment requirements needed by some embodiments of FIG. **5C1**, an orthogonal parabolic recycling reflector **517** is used in some embodiments, as shown in FIG. **5D1**. This orthogonal parabolic recycling reflector **517** has the property that when the location of the laser spot **549** is off to one side of the center of the parabola, the light **546** emitted (i.e., the light diffused from the incident laser spot) will be reflected from one side of the reflector **517**, then the reflected light **547** propagates to the opposite side of the reflector **517**, and then back to the same location of the original laser spot **549**. As a result, the stringent requirements in alignment (such as for FIG. **5C1**) are reduced, since the mis-aligned laser spot **549** will be reflected back to the same spot for light recycling. Again, in some embodiments, the laser beam **141** is single-color (e.g., single wavelength), while in other embodiments, a combination of several colors from one or more lasers is combined into a single beam **141**. In some embodiments, a plurality of laser-input apertures **515** are made such that a plurality of laser beams **141**, each with the same color, or the plurality of laser beams **141** having a plurality of different colors, pass through the respective apertures **515** and are incident onto the diffuser **514** at the same spot **549** or at different spots, depending on applications. Again, in some embodiments, an optional vibration is applied to the heatsink **511**, diffuser **514** and/or the orthogonal parabolic recycling reflector **517**, reducing the amount of speckles.

[0148] FIG. **5D2** is a side-view cross-sectional block diagram of a reflective diffuser system **504'** having a reflective diffuser **514** on a heatsink **511**, one or more lasers **121** mounted to heatsink **511** to emit laser beams **141** through holes **525** in the heatsink **511**, and an orthogonal parabolic recycling reflector **517** that reflects high-angle light **546** horizontally across as light **547** to the opposite side and reflects that as light **546** back to the focus location **549** on the diffuser **514** to complete light recycling, according to some embodiments of the present invention. In order to overcome the alignment requirements needed by some embodiments of FIG. **6**B or FIG. **6**C described below, system **504'** uses includes one or more parabolic reflector portions **519** of a parabolic reflector (such as portions of parabolic reflector **616** of FIG. **6**B) on the top but only directly above the lasers **121** to direct the laser beams **141**, and uses orthogonal parabolic recycling reflector **517** for the remainder of the top-side light-recycling, to reduce some of the need for precise alignment of all laser beams **141** to point to the same location. In some embodiments of system **504'**, laser beams **141** come from one or more lasers **121** (with collimating lenses **126**) mounted on heatsink **511** and propagate through the openings **525** through the heatsink **511** toward parabolic reflector portions **519**, which focuses the laser light to location **549** on reflective diffuser **514**. The low-angle initially diffused light exits into output light **543** directly through output aperture **518**, and the high-angle initially diffused light **546** is recycled by two reflections at orthogonal parabolic recycling reflector **517** back to diffuser **514**, increasing the amount of output light **543** of system **504'**. In some embodiments, to remove speckles, vibrations with the appropriate frequencies and amplitudes are applied to orthogonal parabolic recycling reflector **517**, heatsink **511**, and/or diffuser **514**. In some embodiments, the diffuser **514** and lasers **121** are mounted on different heatsinks (not shown) in order that vibrations can be applied to one or the other or, independently, to both, using separate vibration actuators.

[0149] FIG. **5E** is a side-view cross-sectional block diagram of a reflective diffuser system **505** having a reflective diffuser **514** on a heatsink substrate **511**, a spherical dome reflector **516**, and a small mirror **551** to direct the input beam **141** to the focus location **539** on the diffuser **514**, according to some embodiments of the present invention. The mirror

551 is made small and the mounting bracket (not shown) of mirror **551** is made thin, such that obstruction of the output light **534** is minimal. Other aspects and reference numbers are as described above for FIG. **5C1**. In some embodiments, an optional vibration is applied to diffuser **514**, heatsink **511** and/or dome **516**, reducing the amount of speckles.

[0150] FIG. **5F** is a side-view cross-sectional block diagram of a reflective diffuser system **506** having a reflective diffuser **514** on a heatsink substrate **511**, an orthogonal-parabolic reflector **517**, and a small mirror **551** to direct the input beam **141** to the focus location **549** on the diffuser **514**, according to some embodiments of the present invention. Other aspects and reference numbers are as described above for FIG. **5D**. In some embodiments, an optional vibration is applied to diffuser **514**, heatsink **511** and/or orthogonal parabolic recycling reflector **517**, reducing the amount of speckles.

[0151] In some embodiments, each of the reflectors set forth in the description of the present invention includes a plurality of layers of material (such as transparent dielectric material) of different refraction indices, with appropriate thicknesses for one or more of the wavelengths used by the various embodiments, and optionally diffraction gratings (see, e.g., U.S. Pat. No. 5,907,436 entitled "Multilayer dielectric diffraction gratings," which describes the design and fabrication of dielectric grating structures with high diffraction and/or reflection efficiency).

[0152] FIG. **6A** is a side-view cross-sectional block diagram of a reflective diffuser system **601** having a reflective diffuser **614** on a heatsink substrate **611**, a parabolic reflector **616**, a planar reflector **617** on the heatsink substrate **611** to reflect the initially diffused input light **652** back to the parabolic reflector **616**, which the reflects that light **652** back to the focus location **609** on the diffuser **614**, according to some embodiments of the present invention. In some embodiments, the recycling of reflective diffuser system **601** is achieved using a parabolic reflector **616** and a planar reflector **617**. In some embodiments, each laser beam **141** passing through opening **615** in parabolic reflector **616** is incident onto reflective diffuser **614** at a location proximal to the focus location **609** of parabolic reflector **616**. In some embodiments, heatsinked diffuser assembly **660** includes heatsink **611**, reflective diffuser **614**, planar reflector **617**, and optionally vibration actuator **621**. The portion of the diffused light with smaller diffusion-reflection angles (called small-angle diffused light) exits as a portion of output light **643** through the output aperture **618**. The portion of the diffused light **652** with larger angles (called high-angle diffused light) is reflected by parabolic reflector **616** as collimated light **653** incident on the planar reflector **617**, as shown, wherein it is retroreflected back to the parabolic reflector **616**, and reflectively focused back onto the initial laser spot location **609** on the diffuser **614**, completing the cycle of recycling. This recycled light **652** will be combined with the laser light **141** at location **609** and diffused all over again by the diffuser **614**. In some embodiments, to remove speckles, vibrations with the appropriate frequencies and amplitudes are applied by an optional vibration actuator **621** indirectly through heatsink **611**, and/or directly to diffuser **614** and/or planar reflector **617**. In some embodiments, to remove speckles, vibrations with the appropriate frequencies and amplitudes are also or alternatively applied by an optional vibration actuator (not shown) to the parabolic reflector **616**. In some embodiments, the diffuser **614** and the planar reflector **617** are mounted on different heatsinks (not shown) in order that vibrations can be applied to one or the other or, independently, to both, using separate vibration actuators. In some embodiments, diffuser **614** includes a reflective phosphor plate and laser **121** is a blue laser. In some embodiments, the output appears white in color including longer-wavelength emission from the phosphor.

[0153] FIG. **6B** is a side-view cross-sectional block diagram of a reflective diffuser system **602** having a reflective diffuser **614** on a heatsink substrate **611**, a parabolic reflector **616**, a planar reflector **617** on the heatsink substrate **611** to reflect the initially diffused input light **652** back to the parabolic reflector **616**, which the reflects that light back to the focus location **609** on the diffuser, and one or more lasers **121** mounted to the heatsink substrate **611** to emit laser beams **141** through openings **625** in the substrate **611**, according to some embodiments of the present invention. In some embodiments, heatsinked diffuser and laser assembly **610** includes heatsink **611**, reflective diffuser **614**, planar reflector **617**, one or more lasers **121**, and optionally a vibration actuator (such as vibration actuator **621** shown in FIG. **6A**). In some embodiments of system **602**, laser beams **141** come from one or more lasers **121** (with collimating lenses **126**) mounted on heatsink **611**. In some embodiments, laser beams **141** from the one or more lasers **121** propagate through the openings **625** through the heatsink **611** from the back (bottom in FIG. **6B**) to the front (top in FIG. **6B**) of heatsink **611**. The laser beams **141** are directed at parabolic reflector **616** and focused onto location **609** on reflective diffuser **614**. Other aspects and reference numbers of FIG. **6B** are as described above for FIG. **6A**. Similar to that of FIG. **6A**, the diffused light partly exits directly through output aperture **618** and partly is recycled by reflection at parabolic reflector **616** and planar reflector **617** on heatsink **611**, increasing the amount of output **643** of system **602**. In some embodiments, to remove speckles, vibrations with the appropriate frequencies and amplitudes are applied to parabolic reflector **616**. In some embodiments, to remove speckles, vibrations with the appropriate frequencies and amplitudes are applied to heatsink **611**, diffuser **614** and/or planar reflector **617**. In some embodiments, the diffuser **614** and the planar reflector **617** are mounted on different heatsinks (not shown) in order that vibrations can be applied to one or the other or, independently, to both, using separate vibration actuators.

[0154] FIG. **6C** is a side-view cross-sectional block diagram of a reflective diffuser system **603** having a reflective diffuser **614** on a heatsink substrate **611**, diffuser **614** being surrounded by a bottom-side secondary parabolic reflector **634**, a top-side primary parabolic reflector **631**, a planar reflector **617** on the heatsink substrate **611** to reflect the initially diffused input light **652** back to the top parabolic reflector **631**, which the reflects that light **652** back to the focus location **609** on the diffuser, one or more lasers mounted to the heatsink substrate to emit light through holes in the substrate, and an optional light guide at the output aperture through the parabolic reflector, according to some embodiments of the present invention. In some embodiments, heatsinked diffuser and laser assembly **670** includes heatsink **611**, reflective diffuser **614**, planar reflector **617**, parabolic reflector **634**, one or more lasers **121**, and optionally a vibration actuator (such as vibration actuator **621** shown in FIG. **6A**). Other aspects and reference numbers of FIG. **6C** are as described above for FIG. **6A**. In some embodiments of system **603**, the diffused light from the reflective diffuser is partly recycled in a similar manner as in FIG. **6**A. In some embodiments, the smaller-angle diffused light is reflected and collimated by the first (primary) parabolic reflector **631** on the top of FIG. **6**C. The light is collimated and directed toward the second (secondary) parabolic reflector **634** on the bottom of FIG. **6**C. That light **635** is then reflected by the second parabolic reflector and focused to the center aperture **632** of the first parabolic reflector **631**, as shown, where aperture **632** is provided for the light **635** to exit—in some embodiments, entering into light guide **658** and later exit as output light **657**, or, in other embodiments, simply exiting through aperture **632** as a divergent beam diverging from a spot size the same as the laser spot at location **609** on the diffuser **614**. In this arrangement, the laser spot at location **609** on the diffuser **614** is at the focus of the first parabolic reflector **631** and aperture **632** of the first parabolic reflector **631** is at the focus of the second parabolic reflector **634**. Similar to the other embodiments of the other figures, in some embodiments, an optional vibration is applied to the first parabolic reflector **631**, reducing the amount of speckles.

[0155] FIG. **6**D is a bottom-view block diagram of reflective diffuser system **603** having a heatsink substrate **611**, one or more lasers **121** mounted to the heatsink substrate **611** to emit their respective laser beams **141** through holes **625** (see FIG. **6**C) in the substrate **611**, according to some embodiments of the present invention. In some embodiments, the plurality of lasers **121** is arranged as one or more rings of lasers **121** spaced around a center of the substrate **611**.

[0156] FIG. **7**A is a block diagram of a system **701** having one or more lasers **121** that output a plurality of laser beams **141**, respectively, into one or more diffuser systems **740** (each including a diffuser system such as systems **301**, **401**, **402**, **501**, **502**, **503**, **503'**, **504**, **505**, **506**, **601**, **602**, or **603** of FIGs. **3**, **4**A, **4**B, **5**A, **5**B, **5**C**1**, **5**C**2**, **5**D, **5**E, **5**F, **6**A, **6**B, or **6**C respectively), wherein the one or more diffuser systems **740** form intermediate light output **741** into one or more modulator and/or projection optics systems **750**. In other embodiments, LED-based or other light sources are used in addition to, or in place of, lasers **121**. In some embodiments, one or more controllers **791** control operation of the one or more lasers **121**, the one or more diffuser systems **740** and/or the one or more modulator and/or projection optics systems **750**. In some embodiments, system **701** includes a vehicle- or land-based system **798** onto which the other components are mounted.

[0157] FIG. **7**B is a block diagram of a system **702** having one or more lasers **121**, one or more phosphor and/or diffuser systems **760** (each including a diffuser system such as systems **101**, **106**, **107**, or **201** of FIG. **1**A, **1**F, **1**G, or **2**A respectively), wherein the one or more phosphor and/or diffuser systems **760** form intermediate light output **761** into one or more modulator and/or projection optics systems **770**. In some embodiments, one or more controllers **792** control operation of the one or more lasers **121**, the one or more phosphor and/or diffuser systems **760** and/or the one or more modulator and/or projection optics systems **770**. In some embodiments, system **702** includes a vehicle (such as an automobile, battleship, aircraft or boat) or land-based system (such as a movie theater or advertisement billboard) **799** onto which the other components are mounted. In some embodiments, the present invention includes some or all of the systems of FIG. **7**A or FIG. **7**B. In some embodiments, some or all features of the various embodiments herein are combined with features of other embodiments.

[0158] To summarize some main points, some embodiments of the invention provide the following features: In some laser-illumination systems, it is desirable to lower the coherent properties of the laser beam so that speckles, which are viewed as optical noise, and focusing properties, which may cause eye damage, are diminished. While trying to achieve these, in some embodiments, it is desirable to preserve the brightness of the laser beam as much as possible. One practical method for reducing speckles is to use a moving diffuser. The major parameters of the diffusers include diffusion angles, power-density limitations, absorption coefficients, heat-dissipation capacities, and other properties. One of the important parameters is the diffusion angle. Larger angles imply a larger amount of diffusion. Larger diffusion amounts allow slower diffuser movement to achieve the same amount of speckle reduction. On the other hand, a larger amount of diffusion increases the diffusion angle, thus increasing the etendue, and lowering the brightness of the system. Therefore, in some embodiments, it is desirable to provide a system with large diffusion angles, but with reduced etendue.

[0159] In some embodiments, the present invention includes a laser illumination system in which a diffuser with optional movement and/or vibration is used to reduce speckles associated with the coherent properties of the laser, and a focusing optical recycling system is used to reduce the etendue.

[0160] In some embodiments, the present invention provides an apparatus that includes: a first light-diffuser structure; a first laser that generates a first laser beam having a first wavelength, wherein the first laser beam is directed toward the first light-diffuser structure; and a light-recycling reflector assembly, wherein the light-recycling reflector assembly includes an exit aperture through which output light from the light-diffuser structure is emitted, and wherein light-recycling reflector assembly reflects, back toward the first light-diffuser structure, at least some light from the first light-diffuser structure that does not exit through the exit aperture.

[0161] Some embodiments further include a vibration actuator operatively coupled to impart a vibration to at least one of the first light-diffuser structure, the first laser and the light-recycling reflector assembly. Some embodiments further include a heatsink thermally coupled to at least one of the first light-diffuser structure, the first laser and the light-recycling reflector assembly. Some embodiments further include a second light-diffuser structure; and a second laser that generates a second laser beam having a second wavelength that is different than the first wavelength, wherein the second laser beam is directed toward the second light-diffuser structure. Some embodiments further include a second laser that generates a second laser beam having a second wavelength that is different than the first wavelength, wherein the second laser beam is directed toward the first light-diffuser structure. Some embodiments further include a second laser that generates a second laser beam having the first wavelength, wherein the second laser beam is directed toward the first light-diffuser structure.

[0162] In some embodiments, the first light-diffuser structure includes a ceramic light diffuser. In some embodiments, the first light-diffuser structure includes a plurality of spaced-apart light-diffusing layers. In some embodiments, the first light-diffuser structure includes an LED assembly that includes a phosphor wavelength-conversion layer. In some embodiments, the first light-diffuser structure includes a transmissive phosphor plate. In some embodiments, the first light-diffuser structure includes a reflective phosphor plate. In some embodiments, the first light-diffuser structure includes a ceramic diffuser. In some embodiments, the first light-diffuser structure includes a metal diffuser. In some embodiments, the first light-diffuser structure includes a glass diffuser. In some embodiments, the first light-diffuser structure includes a polymer diffuser. In some embodiments, the first light-diffuser structure includes a multi-layer dielectric reflector. In some embodiments, the light-recycling reflector assembly is made with metal. In some embodiments, the light-recycling reflector assembly is made with a polymer. In some embodiments, the light-recycling reflector assembly is made with a glass. In some embodiments, the light-recycling reflector assembly is made with fused silica. In some embodiments, the light-recycling reflector assembly includes a flat reflector, and a first parabolic reflector facing the flat reflector. In some embodiments, the light-recycling reflector assembly includes a flat reflector, a first parabolic reflector facing the flat reflector, and a second parabolic reflector facing the first parabolic reflector. In some embodiments, the light-recycling reflector assembly includes a conical reflector, and a first parabolic reflector facing the conical reflector. In some embodiments, the light-recycling reflector assembly includes a conical reflector, a first parabolic reflector facing the conical reflector, and a second parabolic reflector facing the first parabolic reflector. In some embodiments, the first laser includes a semiconductor diode laser. In some embodiments, the first laser includes an optical fiber laser. In some embodiments, the first laser includes a crystal-rod laser.

[0163] In some embodiments the present invention is used in applications such as projectors, automotive headlights, spot lights, entertainment spot lights, GOBO projectors (a "gobo" (which stands for 'goes before optics') "is a stencil or template placed inside or in front of a light source to control the shape of the emitted light. Lighting designers typically use them with stage lighting instruments to manipulate the shape of the light cast over a space or object—for example to produce a pattern of leaves on a stage floor." [Wikipedia]), general lighting, and architectural lighting.

[0164] In various embodiments, the present invention includes one or more reflector optics and/or diffusers from FIGS. **1**A-**1**G and/or **2**A-**2**D, combined with one or more reflector optics and/or phosphor plates from FIGS. **5**A-**5**F and/or **6**A-**6**D. For example, in some embodiments, a phosphor plate such as described in FIGS. **5**A-**5**F and/or **6**A-**6**D is substituted for or added to a diffuser in one of the embodiments such as described in FIGS. **1**A-**1**G and/or **2**A-**2**D. In some embodiments, the phosphor plate is used for, or added to, the transmissive diffuser of the embodiments of FIGS. **3**A-**3**B and/or **4**A-**4**B. In some other embodiments, the phosphor plate is used for, or added to, the reflective diffuser of the embodiments of FIG. **4**A, **4**B, **5**A-**5**F or **6**A-**6**C **8**A, **8**B, **9**A-**9**H, **10**A, **10**B, or **11**A-**11**C.

[0165] FIG. **8**A is a block diagram of a reflective multi-layer dielectric diffuser system **801** having a lithographically-defined dielectric diffuser layer **810** formed on a dielectric-layer stack **820** operatively coupled to a heatsink **830**, according to some embodiments of the present invention. In some embodiments, the dielectric multi-layer stack **820** is formed using one or more of the methods for creating highly reflective optics such as described in U.S. Pat. No. 5,907,436 to Perry et al. titled "Multilayer dielectric diffraction gratings", and/or U.S. Pat. No. 6,709,119 to Gillich et al. titled "Resistant surface reflector". Rather than forming a diffraction-grating structure as the top layer as described in U.S. Pat. No. 5,907,436 to Perry et al. and/or U.S. Pat. No. 6,709,119 to Gillich et al., some of the embodiments for the reflective diffuser **514** or **614** such as shown in FIG. **5**A-**5**F or **6**A-**6**C, respectively, used in the present invention instead form a random or pseudo-random two-dimensional pattern of phase-shifting (e.g., in some embodiments, a Cartesian array or other pattern of varying heights/thicknesses of the dielectric top layer **810**) in the top lithographically-defined dielectric diffuser layer **810** (such as pseudo-random phase-shift grating element **129** of FIG. 4 of U.S. Pat. No. 5,454,004 to Leger, titled "Phase grating and mode-selecting mirror for a laser") in order to define a designed non-Lambertian pattern for the diffused-reflected light.

[0166] FIG. **8**B is a block diagram of a reflective multi-layer dielectric diffuser system **802** having a ceramic diffuser layer **811** formed on a dielectric-layer stack **820** operatively coupled to a heatsink **830**, according to some embodiments of the present invention. Again, in some embodiments, the dielectric multi-layer stack **820** is formed using one or more of the methods for creating highly reflective optics such as described in U.S. Pat. No. 5,907,436 to Perry et al. titled "Multilayer dielectric diffraction gratings", and/or U.S. Pat. No. 6,709,119 to Gillich et al. titled "Resistant surface reflector" which are both incorporated herein by reference. Rather than forming a diffraction-grating structure as the top layer as described in U.S. Pat. Nos. 5,907,436 and/or 6,709,119, some of the embodiments for the reflective diffuser **514** or **614** such as shown in FIG. **5**A-**5**F or **6**A-**6**C, respectively, used in the present invention instead use a thin layer of ceramic for diffuser layer **811**, such as Accuflect® Light-Reflecting Ceramic described above.

[0167] In some embodiments, reflective multi-layer dielectric diffuser system **801** or **802** is used for any of the diffuser elements described herein. In some embodiments, the diffuser plate or structure of reflective diffuser **514** or **614** or **914** such as shown in FIG. **5**A-**5**F or **6**A-**6**C or **9**A-**11**C, respectively, includes either reflective multi-layer dielectric diffuser system **801** of FIG. **8**A or reflective-ceramic multi-layer dielectric diffuser system **802** of FIG. **8**B. Still other embodiments further include a phosphor layer (not shown) on top of layer **810**, or between layer **810** and layer stack **820** of system **901** of FIG. **8**A, or on top of layer **811**, or between layer **810** and layer stack **820** of system **802** of FIG. **8**B.

[0168] In some embodiments, the reflective surfaces of the dome reflectors, the orthogonal-parabolic reflectors, the parabolic reflectors and/or the planar reflectors described herein include multi-layer dielectric stacks such as described in U.S. Pat. No. 5,907,436 to Perry et al.

[0169] FIG. **9**A is a side-view cross-sectional block diagram of a system **901** having a compound recycling reflector **910** that includes a parabolic reflector **916** and a conical reflector **915** along the same optical axis **944** such that light is focused toward a central phosphor and/or diffuser plate **914**, according to some embodiments of the present invention. Recycling light increases the brightness of a light source. When laser light is diffused, recycling of the diffused light also increases the brightness of the diffused light output. To understand the operation of system **901**, consider recycling ray **931** from the focus **909** of the parabolic reflector **916** and reflected by parabolic reflector **916** (vertically downward in FIG. **9**A) towards conical reflector **915**. The 45-degree conical reflector **915** changes the path of the light from vertical to horizontal as shown. The light is then reflected (vertically upward in FIG. **9**A) by the opposite side of conical reflector **915** and reflected by parabolic reflector **916** again towards focus **909**, completing the recycling process. Since there are a total of four reflections (an even number of reflections), if one considers this as an imaging system, the image will be "upright" in the same orientation of the object. This can be demonstrated by considering recycling ray **932** starting from the off-focus point **909'** next to the focus **909**. Following the path and reflections of recycling ray **932**, it can be shown that recycling ray **932** ends up at the same off-focus point **909'**. From a given point within a certain distance from the focus **909**, any light emitted from that point is recycled back to the same point. This shows that efficient recycling can be obtained even if the incoming laser spot is not at the focus **909** of parabolic reflector **916**, allowing much larger tolerance in the assembly process. The small-angle light (i.e., light within a small angle to center axis **944**) will exit the aperture **918** contributing to the output light **943** of system **901**.

[0170] In some embodiments, the phosphor, LED, and/or diffuser (PLD) plate **914** (of FIGS. **9**A-**9**H), includes a phosphor plate that is excited (pumped) by a laser beam **141** and the phosphor in the phosphor plate emits light of one or more wavelengths that are longer than the wavelength of the pump laser beam **141**. In some embodiments, the PLD plate **914** includes a light-emitting-diode (LED) assembly that includes a short-wavelength LED covered with a phosphor layer that is excited (pumped) by light from the short-wavelength LED from underneath and by a short-wavelength laser beam **141** from above, and the excited phosphor in the phosphor layer emits light of one or more longer wavelengths. In some embodiments, the PLD plate **914** includes one or more diffuser layers that diffuses light from a laser beam **141** and/or an LED assembly. In some embodiments, the PLD plate **914** includes one or more diffuser layers and an LED assembly. In some embodiments, the PLD plate **914** includes one or more diffuser layers and a phosphor plate. In some embodiments of the systems of FIG. **5**A-**5**F or **6**A-**6**D, any of the PLD plates described in this paragraph are substituted for reflective diffuser plates **514** or **614** in the systems of FIG. **5**A-**5**F or **6**A-**6**D, respectively. In some embodiments of the systems of FIG. **1**A, **1**F, **1**G, or **2**A, any of the PLD plates described in this paragraph are substituted for reflective phosphor plates **112**.

[0171] FIG. **9**B is a side-view cross-sectional block diagram of a system **902** having a compound recycling reflector **910** that includes a parabolic reflector **916** and a conical reflector **915**, both along the same optical axis **944**. System **902** also includes a heatsink **911** with one or more laser diodes **121** that each emit a respective laser beam **141** through openings **925** in the heatsink **911** and through openings **919** in the conical reflector **915** to impinge on the parabolic reflector **916**, reflecting toward phosphor plate, LED, and/or diffuser plate **914** located at focus **909** of parabolic reflector **916**, according to some embodiments of the present invention. Although two lasers **121** are shown here, in various embodiments, the number of lasers is one or more, such as the arrangements shown in FIG. **1**B, FIG. **1**E or FIG. **2**B.

[0172] FIG. **9**C is a side-view cross-sectional block diagram of a system **903** having a compound recycling reflector **910** that includes a parabolic reflector **916** and a conical reflector **915** along the same optical axis **944**, also including a heatsink **911** with one or more laser diodes **121** that emit a respective laser beam **141** through openings **925** in the heatsink **911** and through openings **919** in the conical reflector **915** to impinge on the parabolic reflector **916**, reflecting toward a central phosphor plate, LED, and/or diffuser plate **914**, and having an intermediate output **953** from collimating optics **933** such as a projection lens (in other embodiments (not shown), a collimating reflector is used) directed toward a scanning mirror **954** that scans in a one-dimensional (1D) pattern or a two-dimensional (2D) pattern **955** that forms a scanning output beam **956**, according to some embodiments of the present invention. In embodiments that use a mirror **954** that scans a 1D pattern, the output light **956** is scanned along a line, while in other embodiments that use a mirror **954** that scans a 2D pattern, the output light **956** is scanned across an area (such as a raster-scanned area).

[0173] In various embodiments, collimating optics **933** and scanning mirror **954** are used as additional output optics for any of the other embodiments describe herein.

[0174] FIG. **9**D is a side-view cross-sectional block diagram of a system **904** having a scanning laser source **921** (such as, for example, system **903** shown in FIG. **9**C or the like) that scans the scanning laser light **951** (in various embodiments, having one or more laser beams of one or more colors/wavelengths) across a phosphor plate, LED, and/or diffuser plate **914**, and then the low-angle diffused light **949** from phosphor plate, LED, and/or diffuser plate **914** is collected and shaped through a projection lens **933** to form projected a scanning light beam **948**, according to some embodiments of the present invention. In some embodiments, projection lens **933** projects light collected from the scanned focused spot as a beam **948**. As shown in FIG. **9**D, without light recycling, all the high-angle light **959** not collected by the projection lens **933** is lost, lowering the efficiency of the system **904**.

[0175] FIG. **9**E is a side-view cross-sectional block diagram of a system **905** having a scanning laser source **921** (such as system **903** shown in FIG. **9**C or the like) that scans the scanning laser light **951** from laser source **921** toward a central phosphor plate, LED, and/or diffuser plate **914** through an opening in a compound recycling reflector **910** (including a parabolic reflector **916** and a conical reflector **915** along the same optical axis) such that light **951** is scanned toward central phosphor plate, LED, and/or diffuser plate **914**, and then the diffused light from plate **914** is shaped through projection lens **933**, forming the output scanning beam **947**, according to some embodiments of the present invention. In some embodiments, the use of compound recycling reflector **910** recycles the high-angle light (e.g., light **959** of FIG. **9**D that leaks out of that system **904**) back to be added to the moving laser spot of scanned light **951**, increasing the efficiency of system **905**. In some embodiments, one of the useful features of such a system (such as system **905**) is that the recycling reflectors produce upright images so that the recycled spot coincides with the original spot.

[0176] FIG. **9**F is a side-view cross-sectional block diagram of a system **906** having an orthogonal parabolic recycling reflector **967** and a light source **921** with one or more stationary or scanning laser beams **951** of one or more colors propagating through one or more openings **935** in the orthogonal parabolic recycling reflector **967** (although one opening **935** is shown here, other embodiments include a plurality of such openings **935** spaced around the reflector **967** to allow a plurality of scanning laser beams **951** to enter), wherein the recycling light **966** goes through two reflections, which is an even number of reflections, producing an upright image, so as to allow the recycled spot(s) to coincide with the respective original stationary or scanned spot(s), producing an output scanning beam **968**, according to some embodiments of the present invention. This means the recycled spot coincides with the original spot, producing the enhanced-brightness scanning beam **968**.

[0177] FIG. **9**G is a side-view cross-sectional block diagram of a system **907** having an orthogonal parabolic recycling reflector **967** and one or more laser beams **141** of one or more colors propagating through one or more openings **935** in the orthogonal parabolic recycling reflector **967**, wherein the recycling light goes through two reflections, wherein the system **907** also includes a projection lens **933** and a scanning mirror **954**, (which, in some embodiments, is a 1D or 2D scanning mirror that rotates around line or point **955**) to produce a scanning output beam **956**, according to some embodiments of the present invention. In some embodiments, system **907** is a similar system to system **906**, except that in system **907** the recycling is performed using orthogonal parabolic reflector **967**, which is also an upright image recycling reflector.

[0178] FIG. **9**H is a side-view cross-sectional block diagram of a system **908** having a parabolic reflector **916** and a heatsink **911** with one or more laser diodes **121** that emit laser beams **141** through openings **925** in heatsink **911** to impinge on the parabolic reflector **916**, reflecting toward a phosphor, LED and/or diffuser plate **914**, the heatsink **911** having a planar reflector **917** that directs recycled light **952** from the central phosphor, LED and/or diffuser plate **914** (light diffused from this source that has not exited the recycling system, but rather has been reflected by parabolic reflector **916** to planar reflector **917**, from whence back to parabolic reflector **916**) back toward plate **914**. In some embodiments, system **908** has an intermediate output beam **953** formed by projection lens **933** and directed toward scanning mirror **954** that forms a scanning output beam **956**, according to some embodiments of the present invention. In system **908**, the light recycling is performed by the combination of parabolic reflector **916** and planar reflector **917**.

[0179] FIG. **10**A is a side-view cross-sectional block diagram of a system **1001** having a dome (spherical) recycling reflector **1016** (optionally having a vibration mechanism), a heatsink **911** with a phosphor, LED and/or diffuser plate **914** mounted to heatsink **911** (optionally having a vibration mechanism **1021**), and source(s) of one or more laser beams **141** coming through one or more openings **1015** in dome recycling reflector **1016** to impinge on the phosphor, LED and/or diffuser plate **914**, with the light from laser-excited phosphor, LED and/or diffuser plate **914** reflecting off the dome recycling reflector **1016** toward phosphor, LED and/or diffuser plate **914**, wherein system **1001** has an intermediate output **1053** from projection lens **1033** directed toward a scanning mirror **1054** that scans in a one-dimensional (1D) or two-dimensional (2D) pattern **1055** that forms a scanning output beam **1056**, according to some embodiments of the present invention.

[0180] FIG. **10**B is a side-view cross-sectional block diagram of a system **1002** having a compound recycling reflector **1010** that includes a first parabolic reflector **1035** and a conical reflector **1036** and a further second parabolic reflector **1034** on a heatsink **911**, all along the same optical axis **1044**, also including one or more laser diodes **121** that emit collimated laser light **141** through openings in the heatsink **911** and through openings **1019** in the conical reflector **1036** to impinge on first parabolic reflector **1035**, reflecting toward a central phosphor, LED and/or diffuser (PLD) plate **914** surrounded by the second parabolic reflector **1034**. The second parabolic reflector **1034** receives low-angle light **1052** collimated from first parabolic reflector **1035** and reflects and focuses intermediate focused output light **1053** directed through aperture **1032** in the first parabolic reflector **1035** toward a light guide **1038**, according to some embodiments of the present invention. The high-angle light **1061** is reflected by first parabolic reflector **1035** and collimated as light **1062** (in a downward vertical direction in FIG. **10**B) to conical reflector **1036**, which reflects the light horizontally as light **1063** to the opposite side of conical reflector **1036**, where it reflects (in an upward vertical direction in FIG. **10**B) and reflects from first parabolic reflector **1035** as light **1064** back to PLD plate **914**. The low-angle light reflected by first parabolic reflector **1035** is collimated as light **1052** (in a downward vertical direction in FIG. **10**B) back to second parabolic reflector **1034** that, in some embodiments, has the same focal length as first parabolic reflector **1035** and that is used to reflect such collimated light **1052** back in an upward focused direction such that the light **1053** is focused at the aperture **1032** in first parabolic reflector **1035** for outputting the light. In some embodiments, as shown, the focused output light **1053** upon reaching the focus of the second parabolic reflector **1034** is coupled into a light guide **1038**, which then outputs light **1043**. Such arrangement provides an efficient way of collecting, recycling, and coupling light from a large-angle source (e.g., PLD plate **914**) into a light guide **1038** with a small numerical aperture without the use of any lenses. In some embodiments, system **1002** is more efficient and cost-effective as compared to an equivalent lens-based system, since highly accurate and efficient lenses are expensive.

[0181] FIG. **11**A is a side-view cross-sectional block diagram of a system **1101** having a compound recycling reflector **1110** (having a parabolic reflector **1116** and a planar reflector **1117**), a phosphor, LED and/or diffuser plate **914** on a heatsink **1111** with optional vibration **1121**, according to some embodiments of the present invention. In system **1101**, the recycling of light is done by using two reflectors—parabolic reflector **1116** and planar reflector **1117**. In some embodiments, the light source (PLD plate **914**) is an LED, a diffuser and/or a phosphor plate excited by a laser beam, that is placed at the apex of parabolic reflector **1116**. In some embodiments, planar reflector **1117** is placed in the middle (i.e., half way at distance **1171**) between the apex and the focus location **1142** of parabolic reflector **1116** (which has a focal length **1172**). The planar reflector **1117** has an aperture **1118** where the output **1133** from the light source exits system **1101** within the cone angle determined by the diameter of aperture **1118** and the focal length **1172**. When the high-angle output from PLD plate **914** (the diffused-light source) is reflected by planar reflector **1117**, the reflected light is at the same angle as if it were coming from the focus **1142**, and as a result it will be reflected by parabolic reflector **1116** into the direction of the optical axis, which is also perpendicular to planar reflector **1117**. Upon reflection by planar reflector **1117**, the beam retraces itself back to the parabolic reflector **1116**, the planar reflector **1117**, and then back to PLD plate **914**, completing the recycling process. The recycled light will be scattered by PLD plate **914** with a percentage of light directed toward the aperture **1118**, increasing the output intensity. The rest of the scattered light will be recycled again, together with the light from PLD plate **914**. In some embodiments, laser light **141** from one or more lasers **121** is directed through openings in parabolic reflector **1116** (as shown here) and/or through openings in planar reflector **1117** (as shown in FIG. **11**B) and directed either directly onto PLD plate **914**, or indirectly via one or more reflections from parabolic reflector **1116** and/or planar reflector **1117** onto PLD plate **914**. In some embodiments, laser beam **141** is focused to as small a spot as desired at location **1109** using the appropriate optical system—for example, one or more lenses adjacent to laser **121**. In some embodiments, heatsink **1111** is in thermal contact with some or all of the outer surface of parabolic reflector **1116** and/or bottom-side lasers **121**. In some embodiments, a further heatsink (not shown) is in thermal contact with some or all of the outer surface of planar reflector **1117** and/or top-side lasers **121** that are shown in FIG. **11**B without showing heatsinks.

[0182] FIG. **11**B is a side-view cross-sectional block diagram of a system **1102** having a compound recycling reflector **1110** (having a parabolic reflector **1116** and a planar reflector **1117**), a phosphor, LED and/or diffuser (PLD) plate **914** on a heatsink **1111** with optional vibration **1121**, and one or more lasers **121** that emit laser beams **141** through openings **1118** in planar reflector **1117**, according to some embodiments of the present invention. The laser beam **141** in this case is collimated and is focused onto the diffuser plate **914** by the parabolic reflector **1116**. In system **1102**, the light source is excited using laser diodes. One or more laser diodes **121** each generate a respective collimated output beam **141** parallel to the optical axis that is directed through small apertures in the planar reflector **1117** such that beam **141** is reflected by parabolic reflector **1116** and focused onto the focus **1142** of reflector **1116**. Since planar reflector **1117** is placed between the apex and the focus **1142** of the parabolic reflector **1116** ("blocking" the beam reflected from reflector **1116** from reaching the focus **1142**), planar reflector **1117** redirects the beam to PLD plate **914** at the apex, which is the "reflector image" of the focus. The rest of the operation is the same as that of FIG. **11**A.

[0183] FIG. **11**C is a side-view cross-sectional block diagram of a system **1103** having a compound recycling reflector **1130** (having a spherical (dome) reflector **1136** and a planar reflector **1137**), a phosphor, LED and/or diffuser plate **914** on a heatsink **1111** with optional vibration **1121**, and one or more lasers **121** that emit laser beams **141** through openings **1118** in planar reflector **1135** and/or dome reflector **1137**, according to some embodiments of the present invention. In some embodiments, laser beam **141** is focused to as small a spot as desired at location **1109** using the appropriate optical system, for example one or more lenses adjacent to laser **121**. System **1103** includes a spherical reflector **1136** and planar reflector **1137** that is placed at a distance **1181** equal to half the radius of curvature of the spherical reflector **1136** from the focus **1144** and the bottom. The planar reflector **1137** has an aperture **1118** where the output from the diffuse-light source **914** exits the system within the cone angle determined by the diameter of the aperture **1118** and the focal length **1182**. When the output from diffuse-light source **914** is reflected by the planar reflector **1137**, the angle of the reflected light will be the same as if it were coming from the focus **1144** and as a result, it will be reflected by the spherical reflector **1136** back to the direction of the focus **1144**, retracing itself back to the light source, completing the recycling process. The recycled light will be scattered by diffuse-light source **914** with a percentage of light directed toward aperture **1118**, increasing the output intensity. The rest of the scattered light will be recycled again together with the light from light source **914**. Similar to the arrangement shown in FIG. **11**B but not shown here, one or more lasers **121** can be used to excite diffused-light source **914** with the same arrangement of lasers **121** and apertures **1118** in the planar reflector **1137** shown in FIG. **11**B.

[0184] FIG. **12**A is a cross-sectional elevation-view block diagram of a light source **1201**, according to some embodiments of the present invention. In some embodiments, light source **1201** includes a includes a spherical concave reflector **1210** (in other embodiments, a toroidal or elliptical concave reflector is used), an LED **1214**, and a planar specular reflector **1212** (such as a flat mirror coated with metal or multi-layer dielectric coating of the proper wavelengths under consideration or to be emphasized). In some embodiments, the low-emission-angle portion **1233** of the light output of LED **1214** (that portion of the emitted light that is along the emission axis perpendicular to the top face of the LED die or at relatively small angles to that emission axis) is directed out of the aperture **1218** (the opening at the top of the dome reflector shown in FIG. **12**A) as the primary output. The remaining high-angle portion **1235** of the LED light output (that portion of the emitted light that is at larger angles to the emission axis perpendicular to the top face of the LED die) is reflected by spherical concave reflector **1210** and imaged onto the specular reflector **1212**, wherein the LED **1214** and the specular reflector **1212** are placed symmetrically on opposite sides of the center of curvature of the spherical concave reflector **1210**. The reflected light **1236** from specular reflector **1212** is reflected by spherical concave reflector **1210** and imaged back onto the LED **1214**. Since there is no scattering in the reflected light from specular reflector **1212**, the high-angle rays remain at a high angle and will be reflected by specular reflector **1212** back to the spherical concave reflector **1210**, and not through the aperture **1218**, and refocused by spherical dome reflector **1210** back onto LED **1214** itself, completing the first cycle of the light recycling. Part of the recycled light is scattered by LED **1214** and redirected to smaller angles closer to the emission axis that is perpendicular to the top face of LED **1214**, adding to the output through aperture **1218** of system **1201**. The rest of the scattered light will be recycled again and the cycle of light recycling repeats. In some embodiments, LED **1214** includes a phosphor, that is excited by pump light from a blue LED that is part of LED **1214**, and also by pump wavelengths in an unconverted portion of the blue pump light in the recycled light.

[0185] FIG. **12**B is a top-view block diagram of light source **1201** (which is shown in a cross-section side view in FIG. **12**A), according to some embodiments of the present invention. In some embodiments, the high-angle portion of the light output of LED **1214** is reflected by spherical concave reflector **1210** and imaged onto specular reflector **1212**. LED **1214** and specular reflector **1212** are placed symmetrically on opposite sides of the center of curvature of spherical concave reflector **1210**. In the case shown in FIG. **12**A and FIG. **12**B, specular reflector **1212** is shown to have the same dimensions as LED **1214**. In other embodiments, the sizes of LED **1214** and specular reflector **1212** differ.

[0186] FIG. **12**C is a cross-sectional elevation-view block diagram of a light source **1203**, according to some embodiments of the present invention, where the LED **1214** of light source **1201** of FIGS. **12**A and **12**B is replaced by a laser-excited phosphor plate **1216**, such that when the phosphor in phosphor plate **1216** is excited by laser beam **114** from laser **121**, light of one or more longer wavelengths will be emitted from the phosphor in phosphor plate **1216**. In some embodiments, emitted and diffused light from phosphor plate **1216** appears to the human eye to be very similar to the output of the LED **1214** of FIGS. **12**A and **12**B, although the laser pump light **114** diffused from phosphor plate **1216** has a much narrower linewidth that pump light from a blue LED such as in system **1201**. The operation of the system **1203** is similar to that of system **1201** described for FIG. **12**A. As shown in FIG. **12**C, the excitation laser beam **114** enters system **1203** through a small aperture **1228** in concave reflector **1210**. In other embodiments, other optical arrangements for directing the laser beam **114** onto phosphor plate **1216** are used, depending on the desired arrangement of system **1203**. In some embodiments, more than one laser **121** is used (e.g., in some embodiments, laser beams **114** from a plurality of lasers **121** are directed though a plurality of apertures **1218** onto one or more phosphor plates **1216** for higher-power operations). In some embodiments, phosphor plate **1216** is replaced by, or combined with, a diffusive structure. In some embodiments, a plurality of phosphor plates and/or diffusive structures **1216** is provided (along with a corresponding set of specular reflectors **1212** each located on an opposite side of the center axis from the respective phosphor plate **1216**), each phosphor plate or diffusive structure **1216** emitting and/or diffusing one or more different colors of light, and each being pumped by one or more laser beams **114** (see, for example, FIG. **12**F described below).

[0187] FIG. **12**D is a cross-sectional elevation-view block diagram of a light source **1204**, according to some embodiments of the present invention, wherein one or more excitation lasers **121** is/are placed on, in, and/or under heatsink **1211** with a through-opening for each laser **121** in heatsink **1211** through which the laser beams **114** from the one or more lasers **121** propagate such that the laser beams **114** reflect from the dome reflector **1210** or other laser reflector **1222** located on or under dome reflector **1210** towards a corresponding one or more phosphor structures or diffusive structures **1216**. Light source **1204** also includes a specular reflector **1212**, having functions as described above for FIG. **12**A.

[0188] FIG. **12**E is a cross-sectional elevation-view block diagram of a light source **1205**, according to some embodiments of the present invention. In some embodiments, phosphor plate **1215** is a transmissive type and placed over the aperture through which the laser beam **114** propagates, in order to capture the output of the laser beam for the emission of light of longer wavelengths than the wavelength of the laser beam, where the wavelength-converted light is emitted at the top of the transmissive phosphor plate **1215**. Other aspects of the operation of the system **1205** are similar to comparable operations of other embodiments (e.g., as shown in FIG. **12**C and FIG. **12**D).

[0189] FIG. **12**F is a cross-sectional elevation-view block diagram of a light source **1206** having a plurality of phosphor structures **1213** . . . **1214**, each emitting light of a different selected color when pumped by a suitable laser beam **114**, according to some embodiments of the present invention. Other aspects of the operation of the system **1206** are similar to comparable operations of other embodiments (e.g., as shown in FIG. **12**C, FIG. **12**D, and FIG. **12**E).

[0190] FIG. **13**A is a top-view block diagram of light source **1301** according to some embodiments of the present invention. In some embodiments, light source **1301** includes a heatsink **1311**, a spherical dome reflector **1310** having a centrally located top aperture **1318**, an LED or phosphor plate **1314** that emits light reflected by spherical dome reflector **1310** to form an image **1312** on specular reflector **1313**. In actual implementations of some embodiments of light sources **1201**, **1203**, **1204**, **1205** and **1206**, each specular reflector **1212** is replaced by a larger reflector **1313** that is larger than the expected image **1312** of LED **1314** (or reflective phosphor plate **1216** of FIG. **12**C or transparent phosphor plate **1215** of FIG. **12**E) formed by high-angle reflections from the inner surface of spherical dome reflectors **1210** toward the specular reflectors **1212**, as shown in FIG. **14**A, such that light will not be lost due to misalignment of respective specular reflector **1212** with respect to the image of LED **1214** or phosphor plate **1216**, which may be caused by imprecise placement of LED **1214** or phosphor plate **1216** and/or the respective specular reflector **1212** relative to their respective desired locations.

[0191] FIG. **13**B is a top-view diagram of a four-color LED assembly **1324** that includes a red-light-emitting LED **1325**, a green-light-emitting LED **1326**, blue-light-emitting LED **1327** and white-light-emitting LED **1328**, according to some embodiments of the present invention. In some embodiments, the flat chip-type LED **1214** shown in FIGS. **12**A and **12**B described above is replaced by a composite LED package with one or more different-colored LED chips, such as a red-green-blue-white (RGBW) LED assembly **1324** with four colored chips, packaged together as shown in FIG. **13**B (note that the particular arrangement of the four chips, next to each other, may vary). In some embodiments, four-color LED assembly **1324** is substituted for LED or phosphor plate **1314** of FIG. **13**A, and in this case, the output light from each chip LED **1325**, **1326**, **1327** and **1328** is imaged at the specular reflector **1313** and then reflected back to itself after reflections from the specular reflector **1313** and the concave reflector dome **1310**.

[0192] FIG. **14**A is a cross-sectional top-view block diagram of a light source **1401**, according to some embodiments of the present invention, where a set of red, green, and blue (RGB) LEDs **1412**, **1413**, and **1414**, respectively, each individually packaged, are used. In some embodiments, light source **1401** includes dome reflector **1410** mounted on heatsink **1411**, along with red LED **1412**, green LED **1413** and blue LED **1414**, whose respective images **1422**, **1423**, and **1424** are formed on specular reflectors **1415**. For higher-power applications, where heat dissipation is of the utmost importance, in some embodiments, the LEDs that emit red, green, blue, and/or white-colored light (e.g., see

FIG. **13**B) are packaged individually such that they can be heat sunk independently such as shown in FIG. **14**A and FIG. **14**C, with larger heatsinks (and/or spaced further apart from one another on a larger heatsink area on a common heatsink **1411**) for each LED. By the imaging properties of the spherical concave reflector **1410**, the corresponding images of the RGB LEDs on the left are shown on the right with reversed orders (note that top-to-bottom on the left, the LED colors are red-green-blue, while top-to-bottom on the right, the images on the specular reflectors are blue-green-red). In some embodiments, the specular reflector **1415** is made large enough to cover all three images **1422**, **1423**, and **1424** of the RGB LEDs. In some embodiments, the recycling process is similar to descriptions stated above for FIGS. **12**A-**12**F. The end result is that each colored RGB LED is used for recycling its own light output independently, without interacting with the other LEDs or their images.

[0193] FIG. **14**B is a cross-sectional side-view block diagram of light source **1401** shown in FIG. **14**A, according to some embodiments of the present invention, where the outputs **1431**, **1432**, and **1433**, respectively, of the RGB LEDs **1412**, **1413**, and **1414**, respectively, exiting the apertures **1428** above the LEDs are collimated using three individual collimating lenses **1438** outside the spherical concave reflector **1410**, providing three colored beams of light with increased brightness due to light recycling by internal reflections in spherical concave reflector **1410**.

[0194] FIG. **14**C is a cross-sectional top-view block diagram of a light source **1403**, according to some embodiments of the present invention, in which the three RGB LEDs **1442**, **1443**, and **1444**, respectively are placed triangularly (in some embodiments, each LED at the same distance from the center of curvature **1441** of the spherical dome reflector **1410**), with the specular reflectors **1440** placed symmetrically opposite to the respective LEDs (in some embodiments, each specular reflector **1440** is located at the same distance from the center of curvature **1441** of the spherical dome reflector **1410**). As shown by this embodiment, in general, any number of LEDs can be placed at any positions desired, as long as there is a matching location opposite to the locations of the LEDs for the placement of the specular reflectors **1440**. In practice, it is preferred to have the LEDs **1442** . . . **1444** in close proximity to the center of curvature **1441** such that the imaging of the LEDs by the spherical concave reflector **1410** will have minimal distortion, since distortion will lower the efficiency of the system. In some embodiments, when large spacing between the LEDs is needed, a spherical concave reflector with larger diameter is used, such that the distortions of the images remain acceptable. In addition to spherical reflectors such as **1410**, other embodiments use toroidal or elliptical reflectors to minimize distortion and maximize the recycling efficiency of the system. Similar to that shown in FIG. **14**B, in some embodiments, apertures and collimating lenses are added to provide three collimated different-colored beams of light. In general, any suitable number of beams of light can be created using various colored LEDs.

[0195] FIG. **15**A is a cross-sectional top-view block diagram of a light source **1501**, according to some embodiments of the present invention, where the three colored beams from red LED **1536**, green LED **1535** and blue LED **1534** are combined into a single output beam **1556** (propagating toward the right in FIG. **15**A) using a X-Cube **1521**. In some embodiments, the red LED **1536**, green LED **1535** and blue LED **1534** are arranged such that their path lengths are the same for all colors when they exit the X-Cube **1521**.

[0196] FIG. **15**B is a cross-sectional side-view block diagram of light source **1501**, according to some embodiments of the present invention, in which the three beams exiting spherical concave reflector **1510** through apertures **1518** are collimated, reflected by their respective 45-degree mirrors, enter the X-Cube, and exit as a combined single beam **1556** (coming toward the viewer in FIG. **15**B). In some embodiments, light source **1501** includes spherical concave dome reflector **1510** that reflects high-angle light from the red LED **1536**, green LED **1535** and blue LED **1534** and images that light onto specular reflectors as images **1554**, **1555** and **1556**, respectively, and those images are recycled back to the red LED **1536**, green LED **1535** and blue LED **1534**, respectively to add to the combined output light **1556**.

[0197] FIG. **16**A is a cross-sectional side-view block diagram of a light source **1601**, according to some embodiments of the present invention, where the spherical concave reflector (e.g., reflector **1210** of FIG. **12**A) is replaced by a parabolic reflector **1616** and large specular reflector **1617**. In some embodiments, light source **1601** includes a combined recycling reflector assembly **1610** that includes parabolic reflector **1616** and large specular reflector **1617**, and LED **1614** is placed on heatsink **1611** on one side of the optical axis of rotation **1642** and the image **1614'** will be formed on specular reflector **1617** at the opposite side of the axis of rotation. The initial high-angle light for recycling is shown as a light ray represented by the broken-line arrow. By following the path of the light shown by solid-line arrows, the high-angle output light of the LED **1614** whose image **1614'** is formed on specular reflector **1617**, as shown, is being redirected back to the LED **1614** itself, completing the process of light recycling. In some embodiments, LED **1614** includes a phosphor, that is excited by pump light from a blue LED, and also by pump wavelengths in an unconverted portion of the blue pump light in the recycled light.

[0198] FIG. **16**B is a cross-sectional side-view block diagram of a light source **1602**, according to some embodiments of the present invention, where the spherical concave reflector (e.g., reflector **1210** of FIG. **12**A) is replaced by combined recycling reflector assembly **1610** that includes parabolic reflector **1616** and large specular reflector **1617**, and where the LED (e.g., LED **1614** of FIG. **16**A) is replaced by a laser-excited phosphor plate **1624** whose image **1624'** is formed on specular reflector **1617** as shown, with the excitation laser **121** placed under the specular reflector **1617** and heatsink **1611**. In other embodiments, laser **121** is otherwise situated.

[0199] FIG. **17** is a block diagram of a vehicle **1701** that includes a smart headlight system **1710** having an LED/laser-pumped-phosphor light source **1711**, according to some embodiments of the present invention. In some embodiments, light source **1711** outputs a headlight beam **1743**, and signals **1794** are received by sensor **1795** are processed to signals **1796** that are coupled to controller **1790** that controls LED/laser-pumped-phosphor light source **1711**, In some embodiments, LED/laser-pumped-phosphor light source **1711** includes one or more of the light sources described herein in order to take advantage of the light recycling of the present invention to improve headlight beam **1743**.

[0200] In another aspect, FIG. **17** is a block diagram of a vehicle **1701** that includes an LED/laser-pumped-phosphor light source **1711**, according to some embodiments of the present invention. In some embodiments, a scene sensor **1795** is configured to actively (e.g., using LiDAR or the like) and/or passively (using a camera or the like) sense the environment around the vehicle **1701** in which LED/laser-pumped-phosphor light source **1711** is housed, and the received signals or data **1794** received by sensor **1795** are processed into sensed data **1796** and operatively coupled to processor **1790**, which then adjusts the shape, direction and/or intensity of various low-beam, high-beam and/or extreme-high-beam portions of headlight beam **1743**. In some embodiments, this sensing/controlling function is optionally activatable and deactivatable by the human driver (analogous to automobile "cruise control").

[0201] FIG. **18**A is a side-cross-sectional-view block diagram of an LED/laser-pumped-phosphor light source assembly **1801**, according to some embodiments of the present invention. In some embodiments, assembly **1801** includes a blue-light LED **1822** affixed to heatsink **1823**, a phosphor layer **1812** affixed to, or deposited on, blue-light LED **1822**, a transparent heatsink window **1856** affixed to a heat-conductive surrounding wall **1853** that surrounds a perimeter of (but is separated by a gap from) blue-light LED **1822** and phosphor layer **1812**, and a crystal phosphor plate **1855** that is smaller than phosphor layer **1812** and affixed to a portion of transparent heatsink layer **1856**. In some embodiments, a laser beam **114** is directed onto crystal phosphor plate **1855**. Besides phosphor layer **1812** on LED **1822**, assembly **1801** has the additional layer of crystal phosphor **1855** affixed on top of a portion of transparent heatsink layer **1856**, which covers blue-light LED **1822** and phosphor layer **1812**. In some embodiments, assembly **1801** has heat-conductive surrounding wall **1853** that surrounds the entire perimeter of (but is separated by a gap from) blue-light LED **1822** and phosphor layer **1812**, and is covered and sealed by transparent heatsink window **1856**, thus sealing blue-light LED **1822** and phosphor layer **1812**. In some embodiments, the additional crystal phosphor plate **1855** covers only a portion (in some embodiments, less than half) of the outer surface of phosphor layer **1812**, from which it is separated by transparent heatsink window **1856**. In some embodiments, transparent heatsink window **1856** is made of sapphire, quartz, or other suitable material, such that blockage of light emitted from the LED is minimized. In some embodiments, transparent heatsink **1855** is in turn mounted on heatsink wall **1853** around LED assembly **1822-1812**, such that heat from phosphor plate **1856** is conducted away to LED heatsink **1823** through transparent heatsink window **1856**. In some embodiments, transparent heatsink window **1856** is made of a transparent heatsink material such as synthetic diamond or aluminum oxynitride (AlON ceramic, such as ALON-brand by Surmet Corp., or such as described in U.S. Pat. No. 4,520,116 by Gentilman et al. titled "Transparent aluminum oxynitride and method of manufacture" or U.S. Pat. No. 4,686,070 by Maguire, et al. titled "Method of producing aluminum oxynitride having improved optical characteristics," or the like). In other embodiments, where a sealed compartment is not required, transparent heatsink layer **1856** can use a perforated metal such as an aluminum honeycomb plate, or aluminum sheet having etched or punched holes therethrough, or the like. In some embodiments, LED/laser-pumped-phosphor light source assembly **1801** is substituted in place of any of the LEDs, diffusers, phosphor plates, or PLD structures described herein.

[0202] FIG. **18**B is a plan-view block diagram of LED/laser-pumped-phosphor light source assembly **1801**, according to some embodiments. In some embodiments, LED/laser-pumped-phosphor light source assembly **1801** is substituted in place of any of the LEDs, diffusers, phosphor plates, or PLD structures described herein. In some embodiments, laser beam **114** (see FIG. **18**A) impinges on a center area of the phosphor layer **1855** to provide increased light intensity in that one center area of the phosphor layer **1855** such that the output intensity profile is not uniform, but now includes a "hot spot" (an area of higher light output intensity) within the illuminated area. In some embodiments, laser beam **114** is used to additionally pump the center portion of the phosphor **1812** of the LED **1822**, producing an additional or alternative hot spot. In some embodiments, LED **1822** (e.g., in some embodiments, an LED that emits light of a blue color with a center wavelength in the range of about 420 nm to about 490 nm) is mounted to a heatsink **1823** that conducts heat away from LED **1822** and dissipates that heat to the local environment. In some embodiments, LED **1822** is covered by a phosphor layer **1812** that absorbs some of the light of the LED **1822** and re-emits light of a longer wavelength (e.g., in some embodiments, absorbing blue LED light in the range of about 420 nm to about 490 nm and re-emitting yellow light having a peak center wavelength in a range of about 520 nm to about 660 nm). The combination of some unconverted blue light and some light converted to yellow light produces a light that appears to the human eye as white light. Thus, LED assembly **1823** can be considered as a white-light-emitting LED (also called a white LED assembly **123**).

[0203] As used herein, when diffuse light comes from a structure (such as a PLD structure), the structure can be considered as a "source" of the diffuse light, and the process can be considered as one in which the structure "outputs" the diffuse light, or "emanates" the diffuse light or, in the case where a phosphor is excited by a laser or LED source of pump light, the structure "emits" the diffuse light.

[0204] In some embodiments, the present invention provides a first apparatus (such as shown, for example, in FIG. **1**A-**1**F, **2**A-**2**D, **3**A-**3**B, **4**A-**4**D, **5**A-**5**F, **6**A-**6**D, **9**A-**9**H, or **10**A-**10**B) that includes: a light source having a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser; and a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light.

[0205] Some embodiments of the first apparatus further include a heatsink (e.g., heatsink **111** of FIG. **1**A) thermally coupled to the diffuser and configured to spread and dissipate heat from the laser light.

[0206] In some embodiments of the first apparatus (such as shown, for example, in FIGS. **4**A-**4**D), the diffuser is a transmissive diffuser that outputs diffused light from the second face of the transmissive diffuser and wherein the curved concave face of the first reflector faces and is closer to the first face than the second face of the diffuser.

[0207] Some embodiments of the first apparatus further include a second reflector (e.g., reflector **436** of FIG. **4**C) has a curved concave face located facing the second face and configured to reflect at least some of the diffused laser light back toward the first location, wherein the diffuser (e.g., diffuser **412** of FIG. **4**C) is a transmissive diffuser that outputs diffused light from the second face of the transmissive diffuser, and wherein the curved concave face of the first reflector (e.g., reflector **416** of FIG. **4**C) faces and is closer to the first face than the second face of the diffuser.

[0208] In some embodiments of the first apparatus, the diffuser is a transmissive diffuser that outputs diffused light from the second face of the transmissive diffuser and wherein the first reflector includes a spherical dome reflector (e.g., reflector **416** of FIG. **4**A) that faces and is closer to the first face than the second face of the diffuser.

[0209] In some embodiments of the first apparatus, the diffuser is a transmissive diffuser that outputs diffused light from a second face of the transmissive diffuser opposite the first face and wherein the first reflector (e.g., reflector **426** of FIG. **4**B) includes an orthogonal-parabolic light-recycling reflector that faces and is closer to the first face than the second face of the diffuser.

[0210] Some embodiments of the first apparatus further include a second reflector (e.g., reflector **436** of FIG. **4**C) that is curved and located facing the second face and configured to reflect at least some of the diffused laser light back toward the first location, wherein the diffuser is a transmissive diffuser that outputs diffused light from the second face of the transmissive diffuser, wherein the first reflector includes a spherical dome reflector that faces and is closer to the first face than the second face of the diffuser, and wherein the second reflector includes a spherical dome reflector that faces and is closer to the second face than the first face of the diffuser.

[0211] Some embodiments of the first apparatus further include a second reflector (e.g., reflector **446** of FIG. **4**D) that is curved and located facing the second face and configured to reflect at least some of the diffused laser light back toward the first location, wherein the diffuser is a transmissive diffuser that outputs diffused light from the second face of the transmissive diffuser, wherein the first reflector includes an orthogonal-parabolic light-recycling reflector that faces and is closer to the first face than the second face of the diffuser, and wherein the second reflector includes an orthogonal-parabolic light-recycling reflector that faces and is closer to the second face than the first face of the diffuser.

[0212] In some embodiments of the first apparatus (such as shown, for example, in FIG. **1**A-**1**G, **2**A-**2**D, **5**C**1**-**5**F, **6**A-**6**D, **9**A-**9**H, or **10**A-**10**B), the diffuser is a reflective diffuser that directs diffused light from the first face of the reflective diffuser and wherein the first curved reflector faces and is closer to the first face than the second face of the diffuser.

[0213] Some embodiments of the first apparatus (such as shown, for example, in FIGS. **5**D**2**, **5**E, **5**F) further include at least a first laser that emits the laser light; a second reflector located and configured to reflect the laser light from the first laser toward the first location, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the transmissive diffuser, and wherein the first reflector faces and is closer to the first face than the second face of the diffuser.

[0214] In some embodiments of the first apparatus (such as shown, for example, in FIGS. **5**C**1**, **5**C**2**, **5**E, **10**A), the diffuser is a reflective diffuser that outputs diffused light from the first face of the reflective diffuser, and the first reflector includes a spherical dome reflector that faces and is closer to the first face than the second face of the diffuser.

[0215] In some embodiments of the first apparatus (such as shown, for example, in FIGS. **5**C**1**, **5**C**2**, **5**E, **9**G), the diffuser is a reflective diffuser that outputs diffused light from the first face of the reflective diffuser, and wherein the first reflector includes an orthogonal-parabolic light-recycling reflector that faces and is closer to the first face than the second face of the diffuser.

[0216] Some embodiments of the first apparatus (such as shown, for example, in FIGS. **6**A, **6**B) further include: at least a first laser that emits the laser light; a second reflector that has a flat face located and configured to reflect light from the first reflector back toward the first reflector, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

[0217] Some embodiments of the first apparatus (such as shown, for example, in FIGS. **6**A, **6**B, **6**C) further include: at least a first laser that emits at least a portion of the laser light; and a second reflector that has a flat face located and configured to reflect light from the first reflector back toward the first reflector, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

[0218] Some embodiments of the first apparatus (such as shown, for example, in FIGS. **6**B, **6**C) further include: a heatsink; a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector; and a second reflector that has a flat face located and configured to reflect light from the first reflector back toward the first reflector, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

[0219] Some embodiments of the first apparatus (such as shown, for example, in FIG. **6**C) further include: a heatsink; a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector; a second reflector that has a flat face located and configured to reflect light from the first reflector back toward the first reflector; and a third reflector that has a concave parabolic reflective face; wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and third reflector, and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser, and wherein the first reflector also faces the third reflector and collimates light from the diffuser toward the third reflector that is located and configured to reflect and focus collimated light from the first reflector back toward an aperture in the first reflector.

[0220] Some embodiments of the first apparatus (such as shown, for example, in FIG. **9**B) further include: a heatsink; a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector; and a second reflector that has an inside conical reflective face located and configured to reflect light from the first reflector back toward the inside conical reflective face and then toward the first reflector, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

[0221] Some embodiments of the first apparatus (such as shown, for example, in FIG. **9**C) further include: a heatsink; a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector; a second reflector that has an inside conical reflective face located and configured to reflect light from the first reflector back toward the inside conical reflective face and then toward the first reflector; a collimating optical element located to receive light from an aperture in the first reflector and configured to collimate that light into a collimated intermediate beam; and a third reflector that rotates about at least one rotational axis and that is configured to reflect the collimated intermediate beam to form a scanned output beam, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

[0222] Some embodiments of the first apparatus (such as shown, for example, in FIG. **9**E) further include: a scanning laser that outputs a scanning laser beam toward the diffuser; a second reflector that has an inside conical reflective face located and configured to reflect light from the first reflector back toward the inside conical reflective face and then toward the first reflector; and collimation optics located to receive light from an aperture in the first reflector and configured to collimate that light into a collimated intermediate output beam, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

[0223] Some embodiments of the first apparatus (such as shown, for example, in FIG. **9**F) further include: a scanning laser that outputs a scanning laser beam toward the diffuser; and collimation optics located to receive light from an aperture in the first reflector, wherein the first reflector has an inside orthogonal-parabolic reflective face located and configured to reflect light from the diffuser across toward an opposite surface of the inside orthogonal-parabolic reflective face and then toward the diffuser, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the collimation optics are configured to collimate light from the aperture in the first reflector into a scanned output beam.

[0224] Some embodiments of the first apparatus (such as shown, for example, in FIG. **9**G) further include: a laser that outputs the laser light toward the diffuser; collimation optics located to receive light from an aperture in the first reflector and configured to form a collimated intermediate beam; and a second reflector that rotates about at least one rotational axis and that is configured to reflect the collimated intermediate beam to form a scanned output beam, wherein the first reflector has an inside orthogonal-parabolic reflective face located and configured to reflect light from the diffuser across toward an opposite surface of the inside orthogonal-parabolic reflective face and then toward the diffuser, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the collimation optics are configured to collimate light from the aperture in the first reflector into a scanned output beam.

[0225] Some embodiments of the first apparatus (such as shown, for example, in FIG. **9**H) further include: a heatsink; a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector; a second reflector that has a flat face located and configured to reflect light from the first reflector back toward the first reflector; collimation optics located to receive light passing through an aperture in the first reflector and configured to form a collimated intermediate beam; a third reflector that rotates about at least one rotational axis and that is configured to reflect the collimated intermediate beam to form a scanned output beam, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

[0226] Some embodiments of the first apparatus (such as shown, for example, in FIG. **10**A) further include: collimation optics located to receive light passing through an aperture in the first reflector and configured to form a collimated intermediate beam; a second reflector that rotates about at least one rotational axis and that is configured to reflect the collimated intermediate beam to form a scanned output beam; and a laser that outputs the laser light, wherein the diffuser is a reflective diffuser that includes a phosphor and outputs emissive light from the phosphor from the first face of the reflective diffuser, and wherein the first reflector includes a spherical dome reflector that faces and is closer to the first face than the second face of the diffuser.

[0227] Some embodiments of the first apparatus (such as shown, for example, in FIG. **10**B) further include: a heatsink; a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector; a second reflector that has an inside conical reflective face located and configured to reflect light from the first reflector back toward the inside conical reflective face and then toward the first reflector; and a third reflector that has a concave parabolic reflective face, wherein the diffuser includes a phosphor plate mounted to the heatsink, wherein the phosphor plate outputs emissive light having wavelengths longer than the laser light, wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and third reflector, and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser, wherein the second reflector reflects collimated light from the first reflector toward an opposite inside surface of the second reflector that then reflects the light toward the first reflector, and wherein the first reflector also faces the third reflector and collimates light from the diffuser toward the third reflector that is located and configured to reflect and focus collimated light from the first reflector back toward an aperture in the first reflector.

[0228] Some embodiments of the first apparatus (such as shown, for example, in FIG. **10**B) further include: a heatsink; a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector; a second reflector that has an inside conical reflective face located and configured to reflect light from the first reflector back toward the inside conical reflective face and then toward the first reflector; a third reflector that has a concave parabolic reflective face; and a light guide operatively coupled to receive output light passed out through an output aperture in the first reflector, wherein the diffuser includes a phosphor plate mounted to the heatsink, wherein the phosphor plate outputs emissive light having wavelengths longer than the laser light, wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and third reflector, and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser, wherein the second reflector reflects collimated light from the first reflector toward an opposite inside surface of the second reflector that then reflects the light toward the first reflector, and wherein the first reflector also faces the third reflector and collimates light from the diffuser toward the third reflector that is located and configured to reflect and focus collimated light from the first reflector back toward the output aperture in the first reflector.

[0229] In some embodiments of the first apparatus (such as shown, for example, in FIGS. **1**A-**1**G, **2**A-**2**D), the diffuser includes a phosphor that outputs emissive light having wavelengths longer than the laser light.

[0230] Some embodiments of the first apparatus (such as shown, for example, in FIGS. **1**A-**1**G, **2**A-**2**D) further include: a heatsink; wherein the diffuser includes a phosphor plate mounted on the heatsink, wherein the phosphor plate outputs emissive light having wavelengths longer than the laser light.

[0231] Some embodiments of the first apparatus (such as shown, for example, in FIGS. **1**A-**1**G, **2**A-**2**D) further include: a heatsink; and a plurality of lasers mounted to the heatsink, wherein each of the plurality of lasers emit laser light of one or more first wavelengths, wherein the diffuser includes a phosphor plate mounted to the heatsink, wherein the phosphor plate outputs emissive light having wavelengths longer than the laser light, and wherein the first reflector is a parabolic reflector that faces the diffuser and that reflects laser light from the plurality of lasers toward the diffuser.

[0232] Some embodiments of the first apparatus (such as shown, for example, in FIGS. **1**A-**1**G, **2**A-**2**D) further include: a heatsink; and a plurality of lasers mounted to the heatsink, wherein each of the plurality of lasers emit laser light of one or more first wavelengths; and a second reflector that has a flat face facing the first reflector, wherein the diffuser includes a phosphor plate mounted to the heatsink, wherein the phosphor plate outputs emissive light having wavelengths longer than the laser light, and wherein the first reflector is a parabolic reflector that faces the diffuser, that reflects laser light from the plurality of lasers toward the diffuser, that collimates light from the phosphor plate toward the second reflector, and that focuses collimated light reflected from the second reflector toward the phosphor plate.

[0233] Some embodiments of the first apparatus (such as shown, for example, in FIG. **1**A) further include: a heatsink; a plurality of lasers mounted to the heatsink, wherein each of the plurality of lasers emit laser light of one or more first wavelengths; and a second reflector that has a flat face facing the first reflector and that is mounted on the heatsink, wherein the diffuser includes a phosphor plate mounted to the heatsink, wherein the phosphor plate outputs emissive light having wavelengths longer than the laser light, and wherein the first reflector is a parabolic reflector that faces the diffuser, that reflects laser light from the plurality of lasers toward the diffuser, that collimates light from the phosphor plate toward the second reflector, and that focuses collimated light reflected from the second reflector toward the phosphor plate.

[0234] Some embodiments of the first apparatus (such as shown, for example, in FIG. **1**A) further include: a heatsink; a plurality of lasers mounted to the heatsink, wherein each of the plurality of lasers emit laser light of one or more first wavelengths; a second reflector that has a flat face facing the first reflector; and a third reflector that has a concave parabolic reflective face, wherein the diffuser includes a phosphor plate mounted to the heatsink, wherein the phosphor plate outputs emissive light having wavelengths longer than the laser light, wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and third reflector, and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser, and wherein the first reflector also faces the third reflector and collimates light from the diffuser toward the third reflector that is located and configured to reflect and focus collimated light from the first reflector back toward an aperture in the first reflector.

[0235] Some embodiments of the first apparatus (such as shown, for example, in FIGS. **7**A, **7**B, **17**) further include: a vehicle, wherein the light source is mounted to the vehicle and provides headlight illumination for the vehicle.

[0236] Some embodiments of the first apparatus (such as shown, for example, in FIGS. **7**A, **7**B) further include: an entertainment system, wherein the light source is mounted to the entertainment system and provides illumination for the entertainment system.

[0237] In some embodiments, the present invention provides a second apparatus (such as shown, for example, in FIG. **11**A, **11**B, or **11**C) that includes: a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser; a first reflector that has a flat face located facing the first face of the diffuser; and a second reflector that has a curved concave face located facing the first reflector, wherein the first and second reflector together are configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light. Some embodiments of the second apparatus further include: a heatsink thermally coupled to the diffuser and configured to spread and dissipate heat from the laser light at the first location. In some embodiments, the second reflector is a parabolic reflector. In some embodiments, wherein the second reflector is a spherical reflector.

[0238] In some embodiments, the present invention provides a third apparatus (such as shown, for example, in FIG. **12**A, **12**C, **12**D, **12**E, or **12**F) that includes: a first laser that emits laser light; a first phosphor plate having a first face and a second face opposite the first face, wherein the first phosphor plate is arranged to receive the laser light from the first laser and to emit wavelength-converted emissive light from the first face of the first phosphor plate; a first reflector that has a specular reflective surface; and a second reflector that has a curved concave face located facing the first face of the phosphor plate and configured to reflect at least some of the emissive light back toward the first reflector, wherein the first reflector is located proximal to the first phosphor plate and on an opposite side of a central axis of the second reflector relative to the first phosphor plate and wherein light reflected from the first reflector is collected by the second reflector and focused back toward the first phosphor plate in order to increase a brightness of the emissive light.

[0239] Some embodiments of the third apparatus further include a heatsink thermally coupled to the phosphor plate and the first reflector and configured to spread and dissipate heat from the phosphor plate. Some embodiments of the third apparatus (such as shown, for example, in FIG. **12**C or **12**D) further include a heatsink thermally coupled to the phosphor plate and the first reflector and configured to spread and dissipate heat from the laser light at the first location, wherein the first phosphor plate is a reflective plate and the laser impinges on the first face of the phosphor plate. Some embodiments of the third apparatus (such as shown, for example, in FIG. **12**E) further include a heatsink thermally coupled to the diffuser and the first reflector and configured to spread and dissipate heat from the laser light at the first location, wherein the first phosphor plate is a transmissive plate and the laser impinges on the second face of the first phosphor plate. Some embodiments of the third apparatus (such as shown, for example, in FIG. **12**F) further include: a second laser that emits laser light; a second phosphor plate having a first face and a second face opposite the first face, wherein the second phosphor plate is arranged to receive the laser light from the second laser and to emit wavelength-converted emissive light from the first face of the second phosphor plate; and a third reflector that has a specular reflective surface, wherein the third reflector is located proximal to the second phosphor plate and on an opposite side of the central axis of the second reflector relative to the second phosphor plate.

[0240] In some embodiments, the present invention provides a fourth apparatus (such as shown, for example, in FIG. **13**A, **13**B, **13**C, **14**A, **14**B, **14**C, **15**A, or **15**B) that includes: a first LED that emits a first color of LED light; a first reflector that has a specular reflective surface; and a second reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the LED light back toward the first reflector, wherein the first reflector is located proximal to the first LED and on an opposite side of a central axis of the second reflector and wherein light reflected from the first reflector is collected by the second reflector and focused back toward the first location on the first LED in order to increase a brightness of the diffused laser light.

[0241] Some embodiments of the fourth apparatus (such as shown, for example, in FIG. **13**A) further include a heatsink thermally coupled to the first LED and the first reflector and configured to spread and dissipate heat from the first LED at the first location.

[0242] Some embodiments of the fourth apparatus (such as shown, for example, in FIG. **14**A) further include: a second LED that emits a second color of LED light; and a third reflector that has a specular reflective surface, wherein the third reflector is located proximal to the second LED and on an opposite side of the central axis of the second reflector relative to the second LED.

[0243] Some embodiments of the fourth apparatus (such as shown, for example, in FIG. **14**A or **14**C) further include: a second LED that emits a second color of LED light; and a third reflector that has a specular reflective surface, wherein the third reflector is located proximal to the second LED and on an opposite side of the central axis of the second reflector relative to the second LED; a third LED that emits a third color of LED light; and a fourth reflector that has a specular reflective surface, wherein the fourth reflector is located proximal to the third LED and on an opposite side of the central axis of the second reflector relative to the third LED.

[0244] Some embodiments of the fourth apparatus (such as shown, for example, in FIG. **14**A) further include: a second LED that emits a second color of LED light; a third LED that emits a third color of LED light, wherein the first reflector is located proximal to the first, second and third LEDs and on an opposite side of the central axis of the second reflector relative to the first, second and third LEDs.

[0245] Some embodiments of the fourth apparatus (such as shown, for example, in FIG. **14**C) further include: a second LED that emits a second color of LED light; a third reflector that has a specular reflective surface, wherein the third reflector is located proximal to the second LED and on an opposite side of the central axis of the second reflector relative to the second LED; a third LED that emits a third color of LED light; and a fourth reflector that has a specular reflective surface, wherein the fourth reflector is located proximal to the third LED and on an opposite side of the central axis of the second reflector relative to the third LED, and wherein the first reflector is located between the second LED and the third LED, and the first LED is located between the third reflector and the fourth reflector.

[0246] Some embodiments of the fourth apparatus (such as shown, for example, in FIG. **15**A or **15**B) further include: a second LED that emits a second color of LED light; a third LED that emits a third color of LED light, wherein the first reflector is located proximal to the first, second and third LEDs and on an opposite side of the central axis of the second reflector relative to the first, second and third LEDs; and an X-cube beam combiner and a plurality of reflective surfaces, wherein light from the first, second and third LEDs is reflected by the plurality of reflective surfaces into the X-cube beam combiner which then outputs a combined beam containing light from the first, second and third LEDs.

[0247] Some embodiments of the fourth apparatus (such as shown, for example, in FIG. **15**A or **15**B) further include: a second LED that emits a second color of LED light; a third LED that emits a third color of LED light, wherein the first reflector is located proximal to the first, second and third LEDs and on an opposite side of the central axis of the second reflector relative to the first, second and third LEDs; and an X-cube beam combiner and a plurality of reflective surfaces, wherein light from the first, second and third LEDs is reflected by the plurality of reflective surfaces into the X-cube beam combiner which then outputs a combined beam containing light from the first, second and third LEDs, and wherein path lengths from each of the first, second and third LEDs to the X-cube beam combiner are equal to one another.

[0248] In some embodiments, the present invention provides a fifth apparatus (such as shown, for example, in FIG. **16**A or **16**B) that includes: a first pump-light emitter that emits pump light; a first phosphor plate having a first face and a second face opposite the first face, wherein the first phosphor plate is arranged to receive the pump light from the first pump-light emitter and to emit wavelength-converted emissive light from the first face of the first phosphor plate; a first reflector that has a specular reflective surface; and a second reflector that has a curved concave face located facing the first face of the phosphor plate and configured to reflect at least some of the emissive light back toward the first reflector, wherein the first reflector is located proximal to the first phosphor plate and on an opposite side of a central axis of the second reflector relative to the first phosphor plate and wherein light reflected from the first reflector is collected by the second reflector and focused back toward the first location on the first phosphor plate in order to increase a brightness of the emissive light. Some embodiments of the fifth apparatus further include: a heatsink thermally coupled to the phosphor plate and the first reflector and configured to spread and dissipate heat from the phosphor plate. In some embodiments of the fifth apparatus (such as shown, for example, in FIG. **16**A), the first pump-light emitter includes an LED. In some embodiments of the fifth apparatus (such as shown, for example, in FIG. **16**B), the first pump-light emitter includes a laser. In some embodiments, the curved concave face of the second reflector is parabolic. In some embodiments, the specular reflective surface of the first reflector is planar.

[0249] In some embodiments, the present invention provides a sixth apparatus (such as shown, for example, in FIGS. **1**A-**1**G, **2**A-**2**D) that includes: a light source having a heatsink; a phosphor plate mounted on the heatsink; a plurality of lasers, wherein each of the plurality of lasers emit laser light of one or more first wavelengths; and a first parabolic reflector arranged to reflect the light from the plurality of lasers toward the phosphor plate to excite a phosphor in the phosphor plate to convert laser light of the one or more first wavelengths into emissive light of one or more second wavelengths that are longer than the one or more first wavelengths. In some embodiments, the phosphor plate is placed proximally to a focus of the first parabolic reflector. In some embodiments, each of the plurality of lasers is mounted to a respective opening in the heatsink, and wherein each of the plurality of lasers emits its laser light through a respective opening in the heatsink toward the first parabolic reflector.

[0250] Some embodiments of the sixth apparatus (such as shown, for example, in FIG. **1**A or **1**G) further include: a planar reflector facing the first parabolic reflector, wherein the first parabolic reflector further includes an aperture opposite the phosphor plate, wherein the excited phosphor emits emissive light in many directions toward the first parabolic reflector, wherein a lower-angle portion of the emissive light from the phosphor plate exits through the aperture, contributing to output light of the light source, wherein a higher-angle portion of the emissive light from the phosphor plate and any unconverted laser light is collected by the first parabolic reflector and collimated back towards the planar reflector, and wherein the planar reflector reflects light from the first parabolic reflector back to the first parabolic reflector to be focused back to the phosphor plate by the first parabolic reflector, completing a light-recycling process.

[0251] Some embodiments of the sixth apparatus (such as shown, for example, in FIG. **1**A or **1**G) further include: a planar reflector facing the first parabolic reflector and mounted to the heatsink, wherein the first parabolic reflector further includes an aperture opposite the phosphor plate, wherein the excited phosphor emits emissive light in many directions toward the first parabolic reflector, wherein a lower-angle portion of the emissive light from the phosphor plate exits through the aperture, contributing to output light of the light source, wherein a higher-angle portion of the emissive light from the phosphor plate and any unconverted laser light is collected by the first parabolic reflector and collimated back towards the planar reflector; and wherein the planar reflector reflects light from the first parabolic reflector back to the first parabolic reflector to be focused back to the phosphor plate by the first parabolic reflector, completing a light-recycling process.

[0252] Some embodiments of the sixth apparatus (such as shown, for example, in FIG. **1**F) further include: a wavelength-selective planar reflector facing the first parabolic reflector, wherein each of the plurality of lasers is mounted to a respective opening in the heatsink, wherein each of the plurality of lasers emits their laser light through a respective opening in the heatsink toward the first parabolic reflector, wherein the wavelength-selective planar reflector covers the respective openings in the heatsink and is configured to transmit the laser light of one or more first wavelengths and to reflect other wavelengths of light, wherein the first parabolic reflector further includes an aperture opposite the phosphor plate, wherein the excited phosphor emits emissive light in many directions toward the first parabolic reflector, wherein a lower-angle portion of the emissive light from the phosphor plate exits through the aperture, contributing to output light of the light source, wherein a higher-angle portion of the emissive light from the phosphor plate and any unconverted laser light is collected by the first parabolic reflector and collimated back towards the planar reflector, and wherein the planar reflector reflects light from the first parabolic reflector back to the first parabolic reflector to be focused back to the phosphor plate by the first parabolic reflector, completing a light-recycling process.

[0253] Some embodiments of the sixth apparatus (such as shown, for example, in FIG. **1**G) further include: a planar reflector facing the first parabolic reflector; a second parabolic reflector having a reflective surface that at least partially surrounds the phosphor plate, wherein the first parabolic reflector further includes an aperture opposite the phosphor plate, wherein the excited phosphor emits emissive light in many directions toward the first parabolic reflector, wherein a lower-angle portion of the emissive light from the phosphor plate exits through the aperture, contributing to output light of the light source, wherein the second parabolic reflector and the first parabolic reflector together form an image of the phosphor plate at the aperture in the first parabolic reflector, wherein a higher-angle portion of the emissive light from the phosphor plate and any unconverted laser light is collected by the first parabolic reflector and collimated back towards the planar reflector, and wherein the light from the first parabolic reflector is then reflected by the planar reflector back to the first parabolic reflector and focused back to the phosphor plate by the first parabolic reflector, completing a light-recycling process.

[0254] Some embodiments of the sixth apparatus (such as shown, for example, in FIG. **1**G) further include: a planar reflector facing the first parabolic reflector; an optical waveguide having an light-entry face proximal to an aperture in the first parabolic reflector that is opposite the phosphor plate; and a second parabolic reflector having a reflective surface that at least partially surrounds the phosphor plate, wherein the excited phosphor emits emissive light in many directions toward the first parabolic reflector, wherein a lower-angle portion of the emissive light from the phosphor plate exits through the aperture, contributing to output light of the light source, wherein the second parabolic reflector and the first parabolic reflector together form an image of the phosphor plate at the aperture in the first parabolic reflector, wherein a higher-angle portion of the emissive light from the phosphor plate and any unconverted laser light is collected by the first parabolic reflector and collimated back towards the planar reflector, and wherein the light from the first parabolic reflector is then reflected by the planar reflector back to the first parabolic reflector and focused back to the phosphor plate by the first parabolic reflector, completing a light-recycling process.

[0255] In some embodiments, the present invention provides a seventh apparatus (such as shown, for example, in FIGS. **1**A-**1**G, **2**A-**2**D) that includes: a heatsink; a plurality of lasers, each mounted to a respective opening in the heatsink, wherein each of the plurality of lasers emit laser light of one or more first wavelengths through their respective opening in the heatsink; a reflective phosphor plate mounted on a surface of the heatsink; a parabolic reflector arranged to reflect the light from the plurality of lasers toward the phosphor plate mounted on the heatsink. In some embodiments, the phosphor plate is placed proximally to a focus of the parabolic reflector. In some embodiments, the phosphor plate converts the laser light of one or more first wavelengths to a set of one or more second wavelengths that are longer than the one or more first wavelengths. In some embodiments, the parabolic reflector further includes an aperture opposite the phosphor, the heatsink further includes a planar reflector facing the parabolic reflector, the excited phosphor emits light in many directions toward the parabolic reflector, lower-angle light exits through the aperture, contributing to output of the light source, a high-angle portion of the light from the phosphor and any unconverted laser light is collected by the parabolic reflector and collimated back towards the planar reflector, and the light from the parabolic reflector is then reflected by the planar reflector back to the parabolic reflector and focused back to the phosphor plate by the parabolic reflector, completing a light-recycling process.

[0256] In some embodiments, the present invention provides an eighth apparatus (such as shown, for example, in FIGS. **4**A-**4**D, **5**A-**5**F, **6**A-**6**C) that includes: a diffuser arranged to receive and diffuse laser light at a first location on the diffuser; and a first curved reflector located and configured to reflect at least some of the diffused laser back toward the first location in order to preserve a brightness of the diffused laser light. Some embodiments further include a heatsink thermally connected to the diffuser and configured to spread and dissipate heat from the laser light. In some embodiments of the eighth apparatus (such as shown, for example, in FIGS. **4**A-**4**D), the diffuser is a transmissive diffuser. In some embodiments of the eighth apparatus (such as shown, for example, in FIGS. **5**A-**5**F, **6**A-**6**C), the diffuser is a reflective diffuser. In some embodiments of the eighth apparatus (such as shown, for example, in FIGS. **6**A-**6**C), the first curved reflector is a parabolic reflector. Some embodiments of the eighth apparatus further include a vibration actuator operatively coupled to vibrate the diffuser. In some such embodiments, the vibration actuator is operatively coupled to vibrate the first curved reflector.

[0257] Some embodiments of the eighth apparatus further include: a vibration actuator operatively coupled to vibrate the diffuser; a plurality of lasers, wherein laser beams from the plurality of lasers are directed toward the first location; a projector system configured to receive light from the diffuser and to project the light in an output pattern toward a desired location; and a controller operatively coupled to control the plurality of lasers. Some embodiments of the eighth apparatus further include: a vibration actuator operatively coupled to vibrate at least one of the diffuser and the first curved reflector; a plurality of lasers, wherein laser beams from the plurality of lasers are directed toward the first location, a projector system configured to receive light from the diffuser and to project the light in an output pattern toward a desired location; a controller operatively coupled to control the plurality of lasers; and a vehicle, wherein the diffuser, the first curved reflector, the plurality of lasers, and the projector system are mounted on the vehicle to provide a functional light output useful for an operation of the vehicle.

[0258] In some embodiments, the present invention provides a ninth apparatus (such as shown, for example, in FIGS. **4**A-**4**D, **5**A-**5**F, **6**A-**6**C) that includes: a first light-diffuser structure; a first laser that generates a first laser beam having a first wavelength, wherein the first laser beam is directed toward the first light-diffuser structure; and a light-recycling reflector assembly, wherein the light-recycling reflector assembly includes an exit aperture through which output light from the light-diffuser structure is emitted, and wherein light-recycling reflector assembly reflects, back toward the first light-diffuser structure, at least some light from the first light-diffuser structure that does not exit through the exit aperture.

[0259] Some embodiments of the ninth apparatus further include: a vibration actuator operatively coupled to impart a vibration to at least one of the first light-diffuser structure, the first laser and the light-recycling reflector assembly. Some embodiments of the ninth apparatus further include: a linear-motion actuator operatively coupled to impart a linear motion to at least one of the first light-diffuser structure, the first laser and the light-recycling reflector assembly. Some embodiments of the ninth apparatus further include: a curvilinear-motion actuator operatively coupled to impart a curvilinear motion to at least one of the first light-diffuser structure, the first laser and the light-recycling reflector assembly. Some embodiments of the ninth apparatus further include: a rotary-motion actuator operatively coupled to impart a rotary motion to at least one of the first light-diffuser structure, the first laser and the light-recycling reflector assembly.

[0260] Some embodiments of the ninth apparatus further include: a heatsink thermally coupled to at least one of the first light-diffuser structure, the first laser and the light-recycling reflector assembly. Some embodiments of the ninth apparatus further include: a second light-diffuser structure; and a second laser that generates a second laser beam having a second wavelength that is different than the first wavelength, wherein the second laser beam is directed toward the second light-diffuser structure. Some embodiments of the ninth apparatus further include: a second laser that generates a second laser beam having a second wavelength that is different than the first wavelength, wherein the second laser beam is directed toward the first light-diffuser structure. Some embodiments of the ninth apparatus further include: a second laser that generates a second laser beam having the first wavelength, wherein the second laser beam is directed toward the first light-diffuser structure.

[0261] In some embodiments of the ninth apparatus, the first light-diffuser structure includes a ceramic light diffuser. In some embodiments of the ninth apparatus, the first light-diffuser structure includes a plurality of spaced-apart light-diffusing layers.

[0262] In some embodiments of the ninth apparatus, the first light-diffuser structure includes an LED assembly that includes a phosphor wavelength-conversion layer. In some embodiments of the ninth apparatus, the first light-diffuser structure includes a transmissive phosphor plate. In some embodiments of the ninth apparatus, the first light-diffuser structure includes a reflective phosphor plate.

[0263] In some embodiments of the ninth apparatus, the light-recycling reflector assembly includes a flat reflector, and a first parabolic reflector facing the flat reflector.

[0264] In some embodiments of the ninth apparatus, the light-recycling reflector assembly includes a flat reflector, a first parabolic reflector facing the flat reflector, and a second parabolic reflector facing the first parabolic reflector.

[0265] In some embodiments of the ninth apparatus, the light-recycling reflector assembly includes a conical reflector, and a first parabolic reflector facing the conical reflector. In some embodiments of the ninth apparatus, the light-recycling reflector assembly includes a conical reflector, a first parabolic reflector facing the conical reflector, and a second parabolic reflector facing the first parabolic reflector.

[0266] It is to be understood that the above description is intended to be illustrative, and not restrictive. Although numerous characteristics and advantages of various embodiments as described herein have been set forth in the foregoing description, together with details of the structure and function of various embodiments, many other embodiments and changes to details will be apparent to those of skill in the art upon reviewing the above description. The scope of the invention should be, therefore, determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled. In the appended claims, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein," respectively. Moreover, the terms "first," " "second," and "third," etc., are used merely as labels, and are not intended to impose numerical requirements on their objects.

1.-**3**. (canceled)

4. An apparatus comprising:
a light source that includes:
a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and
a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light; and
a second reflector has a curved concave face located facing the second face and configured to reflect at least some of the diffused laser light back toward the first location, wherein the diffuser is a transmissive diffuser that outputs diffused light from the second face of the transmissive diffuser, and wherein the curved concave face of the first reflector faces and is closer to the first face than the second face of the diffuser.

5.-**6**. (canceled)

7. An apparatus comprising:
a light source that includes:
a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and
a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light; and
a second reflector that is curved and located facing the second face and configured to reflect at least some of the diffused laser light back toward the first location, wherein the diffuser is a transmissive diffuser that outputs diffused light from the second face of the transmissive diffuser, wherein the first reflector includes a spherical dome reflector that faces and is closer to the first face than the second face of the diffuser, and wherein the second reflector includes a spherical dome reflector that faces and is closer to the second face than the first face of the diffuser.

8. An apparatus comprising:
a light source that includes:
a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and
a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light; and
a second reflector that is curved and located facing the second face and configured to reflect at least some of the diffused laser light back toward the first location, wherein the diffuser is a transmissive diffuser that outputs diffused light from the second face of the transmissive diffuser, wherein the first reflector includes an orthogonal-parabolic light-recycling reflector that faces and is closer to the first face than the second face of the diffuser, and wherein the second reflector includes an orthogonal-parabolic light-recy-

cling reflector that faces and is closer to the second face than the first face of the diffuser.

9. (canceled)

10. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and

a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

at least a first laser that emits the laser light; and

a second reflector located and configured to reflect the laser light from the first laser toward the first location, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the transmissive diffuser, and wherein the first reflector faces and is closer to the first face than the second face of the diffuser.

11.-**12**. (canceled)

13. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and

a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

at least a first laser that emits the laser light; and

a second reflector that has a flat face located and configured to reflect light from the first reflector back toward the first reflector, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

14. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and

a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

at least a first laser that emits at least a portion of the laser light; and

a second reflector that has a flat face located and configured to reflect light from the first reflector hack toward the first reflector, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

15. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and

a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

a heatsink;

a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector; and

a second reflector that has a flat face located and configured to reflect light from the first reflector back toward the first reflector, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

16. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and

a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

a heatsink;

a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector;

a second reflector that has a flat face located and configured to reflect light from the first reflector back toward the first reflector; and

a third reflector that has a concave parabolic reflective face; wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and third reflector, and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser, and wherein the first reflector also faces the third reflector and collimates light from the diffuser toward the third reflector that is located and configured to reflect and focus collimated light from the first reflector back toward an aperture in the first reflector.

17. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

a heatsink;

a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector; and

a second reflector that has an inside conical reflective face located and configured to reflect light from the first reflector hack toward the inside conical reflective face and then toward the first reflector, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

18. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and

a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

a heatsink;

a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector;

a second reflector that has an inside conical reflective face located and configured to reflect light from the first reflector back toward the inside conical reflective face and then toward the first reflector;

a collimating optical element located to receive light from an aperture in the first reflector and configured to collimate that light into a collimated intermediate beam; and

a third reflector that rotates about at least one rotational axis and that is configured to reflect the collimated intermediate beam to form a scanned output beam, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

19. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and

a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

a scanning laser that outputs a scanning laser beam toward the diffuser;

a second reflector that has an inside conical reflective face located and configured to reflect light from the first reflector back toward the inside conical reflective face and then toward the first reflector; and

collimation optics located to receive light from an aperture in the first reflector and configured to collimate that light into a collimated intermediate output beam, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

20. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and

a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

a scanning laser that outputs a scanning laser beam toward the diffuser; and

collimation optics located to receive light from an aperture in the first reflector, wherein the first reflector has an inside orthogonal-parabolic reflective face located and configured to reflect light from the diffuser across toward an opposite surface of the inside orthogonal-parabolic reflective face and then toward the diffuser, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the collimation optics are configured to collimate light from the aperture in the first reflector into a scanned output beam.

21. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and

a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

a laser that outputs the laser light toward the diffuser;

collimation optics located to receive light from an aperture in the first reflector and configured to form a collimated intermediate beam; and

a second reflector that rotates about at least one rotational axis and that is configured to reflect the collimated intermediate beam to form a scanned output beam, wherein the first reflector has an inside orthogonal-parabolic reflective face located and configured to reflect light from the diffuser across toward an opposite surface of the inside orthogonal-parabolic reflective face and then toward the diffuser, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the collimation optics are configured to collimate light from the aperture in the first reflector into a scanned output beam.

22. An apparatus comprising:
a light source that includes:
a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and
a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;
a heatsink;
a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector;
a second reflector that has a flat face located and configured to reflect light from the first reflector back toward the first reflector;
collimation optics located to receive light passing through an aperture in the first reflector and configured to form a collimated intermediate beam; and
a third reflector that rotates about at least one rotational axis and that is configured to reflect the collimated intermediate beam to form a scanned output beam, wherein the diffuser is a reflective diffuser that outputs diffused light from the first face of the diffuser, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser.

23. An apparatus comprising:
a light source that includes:
a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and
a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;
collimation optics located to receive light passing through an aperture in the first reflector and configured to form a collimated intermediate beam;
a second reflector that rotates about at least one rotational axis and that is configured to reflect the collimated intermediate beam to form a scanned output beam; and
a laser that outputs the laser light, wherein the diffuser is a reflective diffuser that includes a phosphor and outputs emissive light from the phosphor from the first face of the reflective diffuser, and wherein the first reflector includes a spherical dome reflector that faces and is closer to the first face than the second face of the diffuser.

24. An apparatus comprising:
a light source that includes:
a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and
a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;
a heatsink;
a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector;
a second reflector that has an inside conical reflective face located and configured to reflect light from the first reflector back toward the inside conical reflective face and then toward the first reflector; and
a third reflector that has a concave parabolic reflective face, wherein the diffuser includes a phosphor plate mounted to the heatsink, wherein the phosphor plate outputs emissive light having wavelengths longer than the laser light, wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and third reflector, and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser, wherein the second reflector reflects collimated light from the first reflector toward an opposite inside surface of the second reflector that then reflects the light toward the first reflector, and wherein the first reflector also faces the third reflector and collimates light from the diffuser toward the third reflector that is located and configured to reflect and focus collimated light from the first reflector back toward an aperture in the first reflector.

25. An apparatus comprising:
a light source that includes:
a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and
a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;
a heatsink;
a plurality of lasers mounted to the heatsink, wherein each one of plurality of lasers emits a portion of the laser light toward the first reflector;
a second reflector that has an inside conical reflective face located and configured to reflect light from the first reflector back toward the inside conical reflective face and then toward the first reflector;
a third reflector that has a concave parabolic reflective face; and
a light guide operatively coupled to receive output light passed out through an output aperture in the first reflector, wherein the diffuser includes a phosphor plate mounted to the heatsink, wherein the phosphor plate outputs emissive light having wavelengths longer than the laser light, and wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and third reflector, and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser, wherein the second reflector reflects collimated light from the first reflector

toward an opposite inside surface of the second reflector that then reflects the light toward the first reflector, and wherein the first reflector also faces the third reflector and collimates light from the diffuser toward the third reflector that is located and configured to reflect and focus collimated light from the first reflector back toward the output aperture in the first reflector.

26.-**28**. (canceled)

29. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and

a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

a heatsink;

a plurality of lasers mounted to the heatsink, wherein each of the plurality of lasers emit laser light of one or more first wavelengths; and

a second reflector that has a flat face facing the first reflector, wherein the diffuser includes a phosphor plate mounted to the heatsink, wherein the phosphor plate outputs emissive light having wavelengths longer than the laser light, and wherein the first reflector is a parabolic reflector that faces the diffuser, that reflects laser light from the plurality of lasers toward the diffuser, that collimates light from the phosphor plate toward the second reflector, and that focuses collimated light reflected from the second reflector toward the phosphor plate.

30. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and

a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

a heatsink;

a plurality of lasers mounted to the heatsink, wherein each of the plurality of lasers emit laser light of one or more first wavelengths; and

a second reflector that has a flat face facing the first reflector and that is mounted on the heatsink, wherein the diffuser includes a phosphor plate mounted to the heatsink, wherein the phosphor plate outputs emissive light having wavelengths longer than the laser light, and wherein the first reflector is a parabolic reflector that faces the diffuser, that reflects laser light from the plurality of lasers toward the diffuser, that collimates light from the phosphor plate toward the second reflector, and that focuses collimated light reflected from the second reflector toward the phosphor plate.

31. An apparatus comprising:

a light source that includes:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser, and

a first reflector that has a curved concave face located facing the first face of the diffuser and configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light;

a heatsink;

a plurality of lasers mounted to the heatsink, wherein each of the plurality of lasers emit laser light of one or more first wavelengths;

a second reflector that has a flat face facing the first reflector; and

a third reflector that has a concave parabolic reflective face, wherein the diffuser includes a phosphor plate mounted to the heatsink, wherein the phosphor plate outputs emissive light having wavelengths longer than the laser light, wherein the first reflector is a parabolic reflector that faces the second reflector and collimates light from the diffuser toward the second reflector and third reflector, and that receives reflected collimated light from the second reflector and focuses that light toward the diffuser, and wherein the first reflector also faces the third reflector and collimates light from the diffuser toward the third reflector that is located and configured to reflect and focus collimated light from the first reflector back toward an aperture in the first reflector.

32. The apparatus of claim **4**, further comprising:

a vehicle, wherein the light source is mounted to the vehicle and provides headlight illumination for the vehicle.

33. The apparatus of claim **4**, further comprising:

an entertainment system, wherein the light source is mounted to the entertainment system and provides illumination for the entertainment system.

34. An apparatus comprising:

a diffuser having a first face and a second face opposite the first face, wherein the diffuser is arranged to receive and diffuse laser light at a first location on the first face of the diffuser;

a first reflector that has a flat face located facing the first face of the diffuser; and

a second reflector that has a curved concave face located facing the first reflector, wherein the first and second reflector together are configured to reflect at least some of the diffused laser light back toward the first location in order to increase a brightness of the diffused laser light.

35. The apparatus of claim **34**, further comprising:

a heatsink thermally coupled to the diffuser and configured to spread and dissipate heat from the laser light at the first location.

36. The apparatus of claim **34**, wherein the second reflector is a parabolic reflector.

37. The apparatus of claim **34**, wherein the second reflector is a spherical reflector.

38.-**86**. (canceled)

87. An apparatus comprising:

a first light-diffuser structure;

a first laser that generates a first laser beam having a first wavelength, wherein the first laser beam is directed toward the first light-diffuser structure;

a light-recycling reflector assembly, wherein the light-recycling reflector assembly includes an exit aperture through which output light from the light-diffuser structure is emitted, and wherein light-recycling reflector assembly reflects, back toward the first light-diffuser structure, at least some light from the first light-diffuser structure that does not exit through the exit aperture;

a second light-diffuser structure; and

a second laser that generates a second laser beam having a second wavelength that is different than the first wavelength, wherein the second laser beam is directed toward the second light-diffuser structure.

88.-**95**. (canceled)

96. An apparatus comprising:

a first light-diffuser structure;

a first laser that generates a first laser beam having a first wavelength, wherein the first laser beam is directed toward the first light-diffuser structure; and

a light-recycling reflector assembly, wherein the light-recycling reflector assembly includes an exit aperture through which output light from the light-diffuser structure is emitted, and wherein light-recycling reflector assembly reflects, back toward the first light-diffuser structure, at least some light from the first light-diffuser structure that does not exit through the exit aperture, wherein the light-recycling reflector assembly includes a flat reflector, a first parabolic reflector facing the flat reflector, and a second parabolic reflector facing the first parabolic reflector.

97. (canceled)

98. An apparatus comprising:

a first light-diffuser structure;

a first laser that generates a first laser beam having a first wavelength, wherein the first laser beam is directed toward the first light-diffuser structure; and

a light-recycling reflector assembly, wherein the light-recycling reflector assembly includes an exit aperture through which output light from the light-diffuser structure is emitted, and wherein light-recycling reflector assembly reflects, back toward the first light-diffuser structure, at least some light from the first light-diffuser structure that does not exit through the exit aperture, wherein the light-recycling reflector assembly includes a conical reflector, a first parabolic reflector facing the conical reflector, and a second parabolic reflector facing the first parabolic reflector.

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