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Li

(54) LASER PHOSPHOR ILLUMINATION SYSTEM USING STATIONARY PHOSPHOR FIXTURE

(71) Applicant: **Optonomous Technologies, Inc.**, Agoura Hills, CA (US)

(72) Inventor: **Kenneth Li**, Agoura Hills, CA (US)

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(2) Date: **May 4, 2022**

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Publication Classification

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G02B 26/00	(2006.01)
F21V 5/02	(2006.01)

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

CPC ***F21V 9/30*** (2018.02); ***G02B 26/101*** (2013.01); ***F21V 7/0033*** (2013.01); ***G02B 26/008*** (2013.01); ***F21V 5/02*** (2013.01)

(57) **ABSTRACT**

A laser-excited-phosphor light-source system in which a phosphor plate remains stationary while a laser beam is made to scan across the phosphor plate. In some embodiments, the phosphor-plate assembly includes a plurality of areas each having a different phosphor substance that emits wavelength-converted light in response to excitation from the scanned laser beam and/or a diffusive material. In some embodiments, one or more rotating prisms and/or one or more rotating or oscillating or angularly displaced mirrors are used to deflect the input laser light on the way toward the phosphor plate and to deflect the wavelength-converted and/or diffused light in the opposite direction such that the output beam of wavelength-converted and/or diffused light remains stationary with respect to the phosphor plate as the input laser beam is moved across the surface of the phosphor-plate assembly.

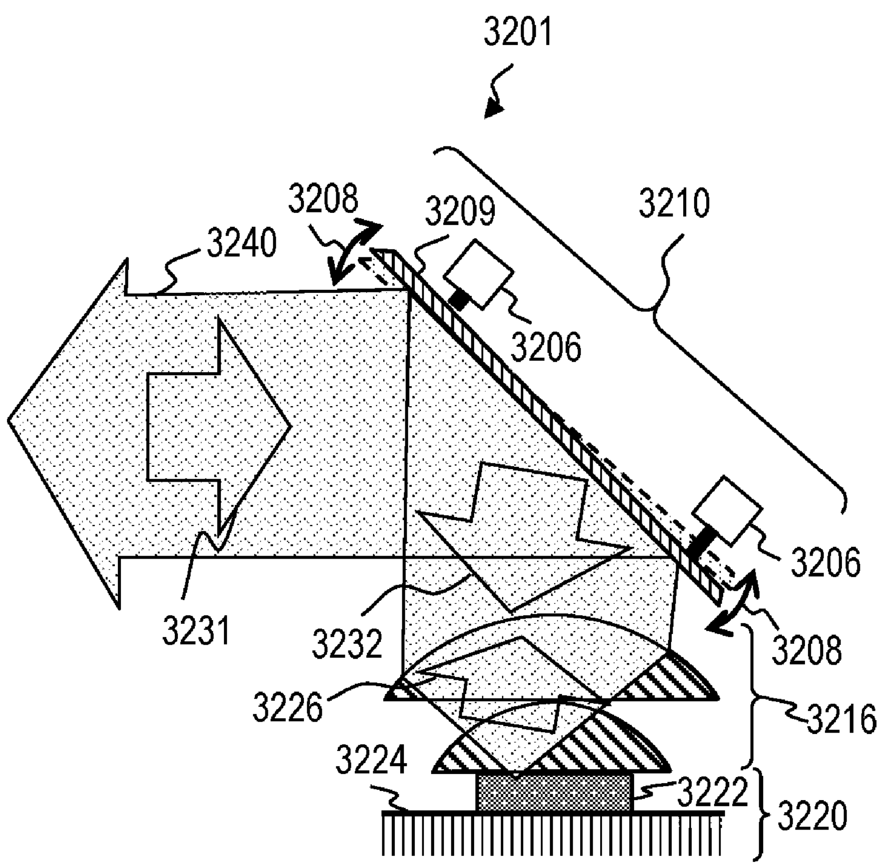

FIG. 1A

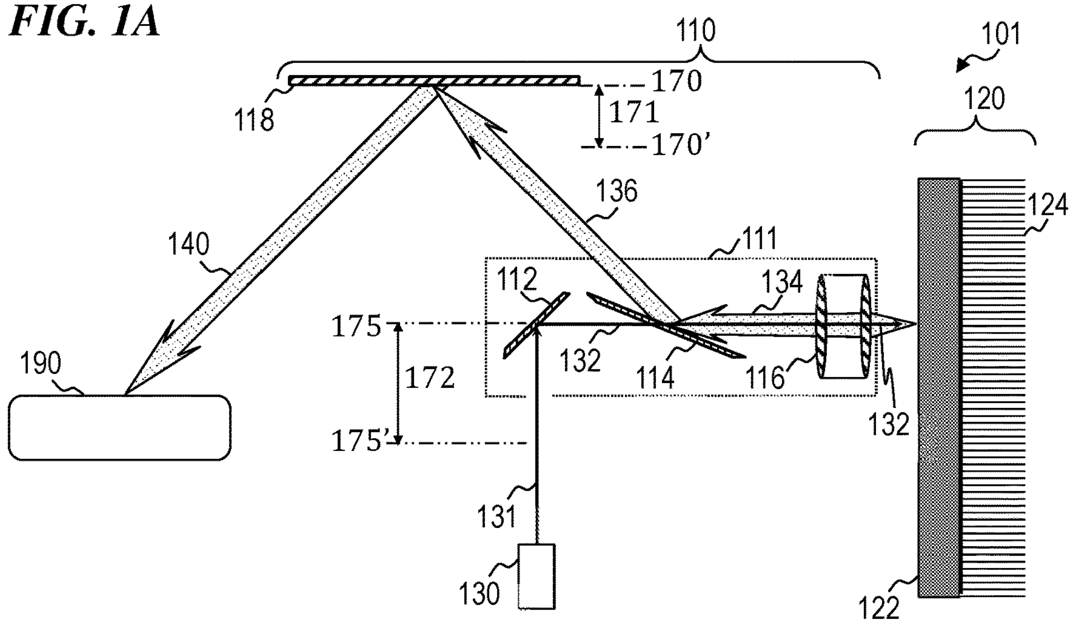

FIG. 1B

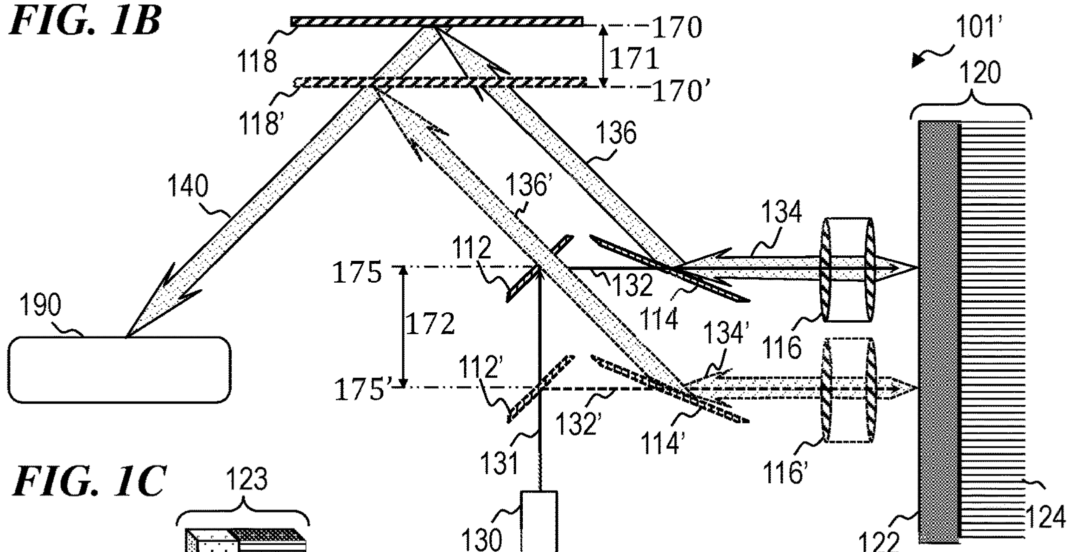

FIG. 1C

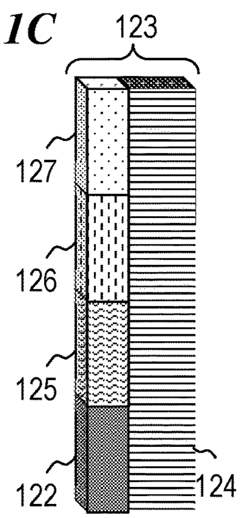

FIG. 2A

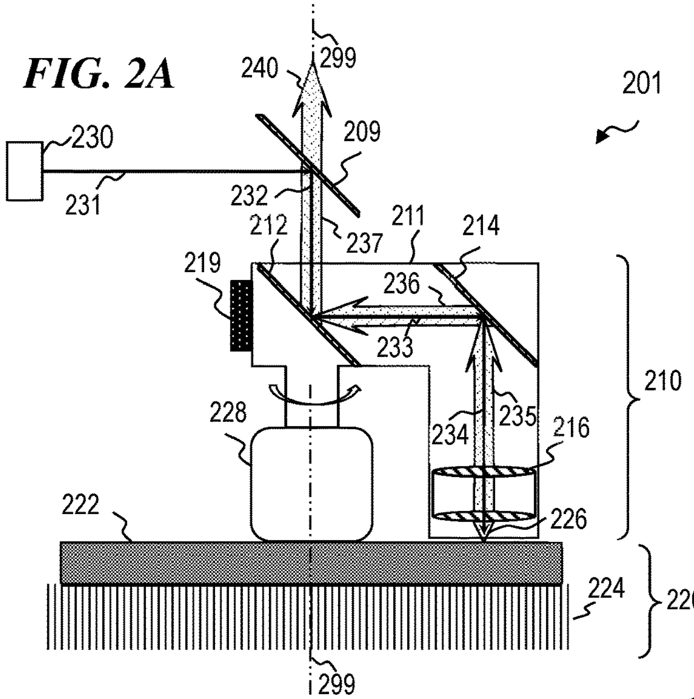

FIG. 3

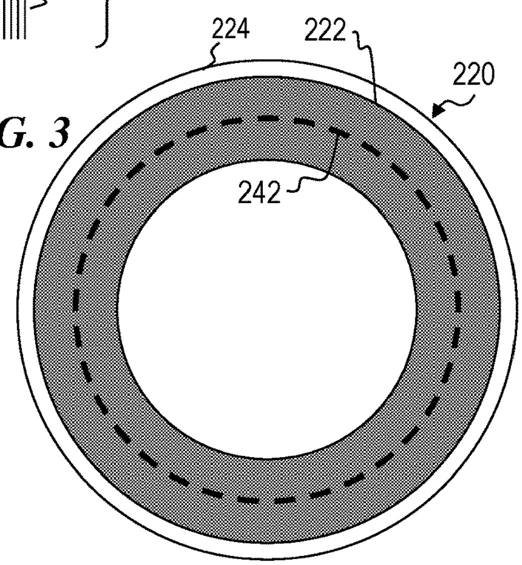

FIG. 2B

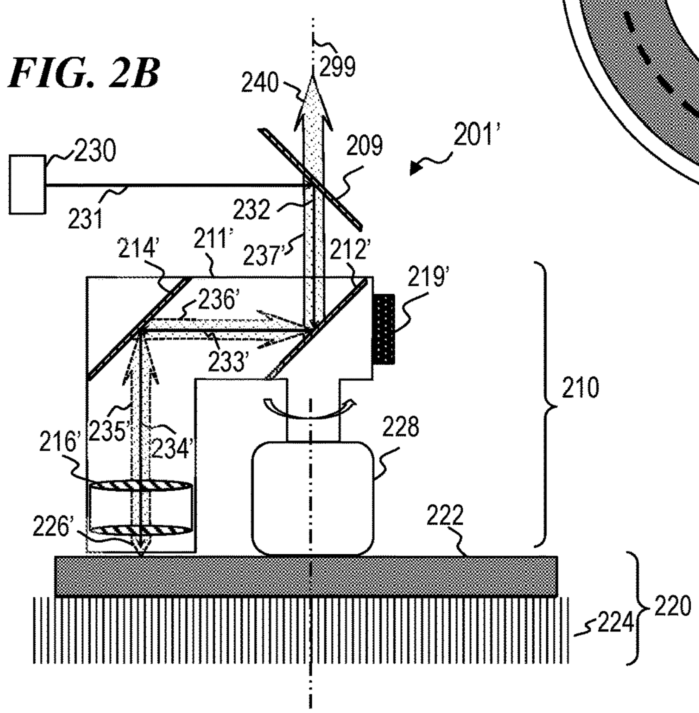

FIG. 4A

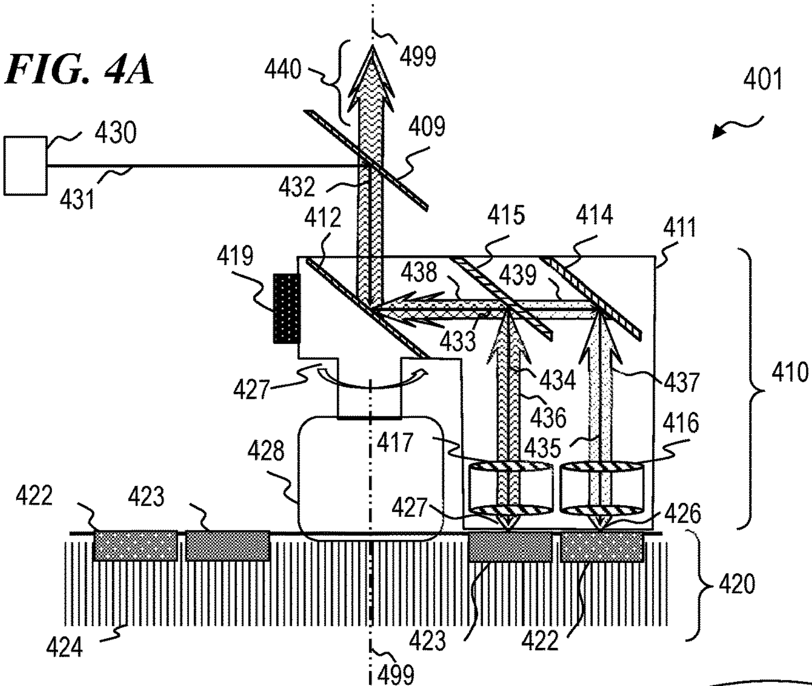

FIG. 5

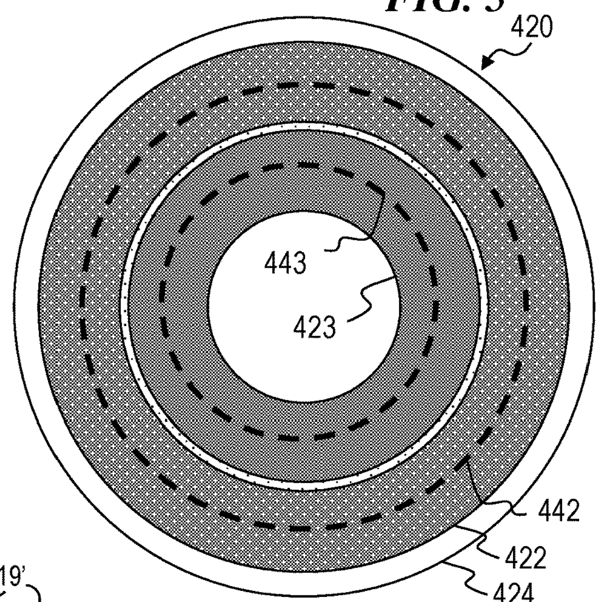

FIG. 4B

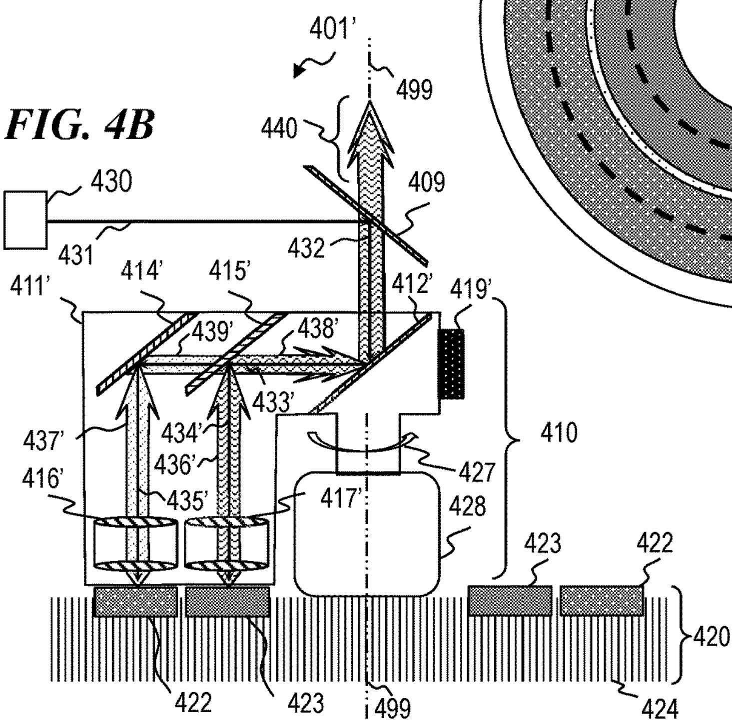

FIG. 6A

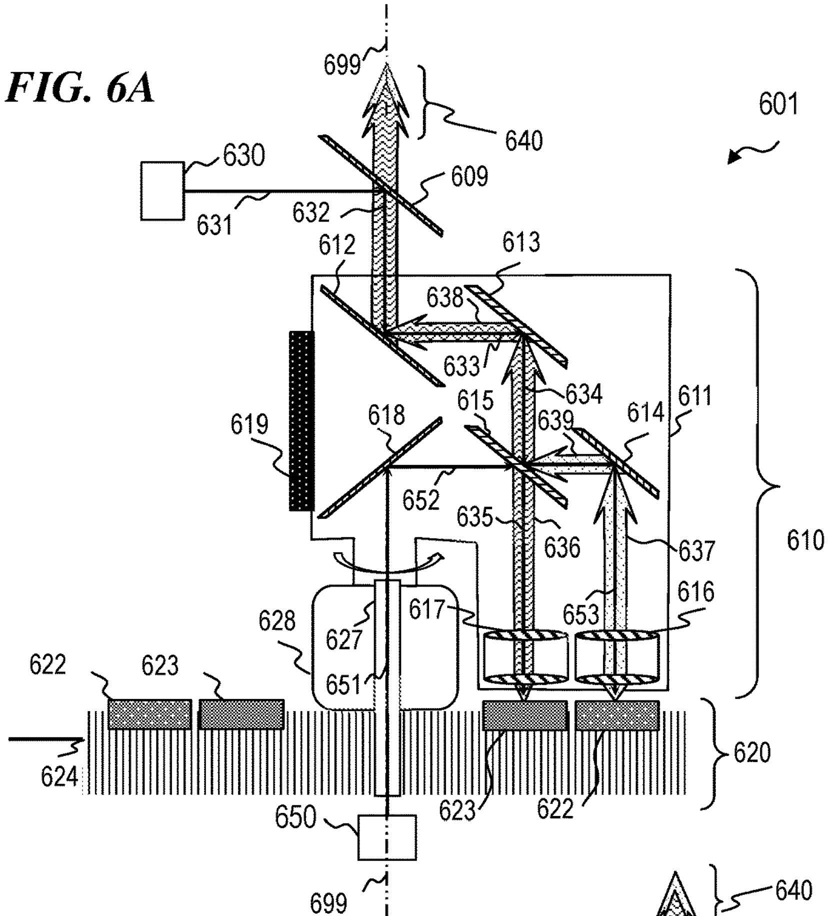
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FIG. 6B

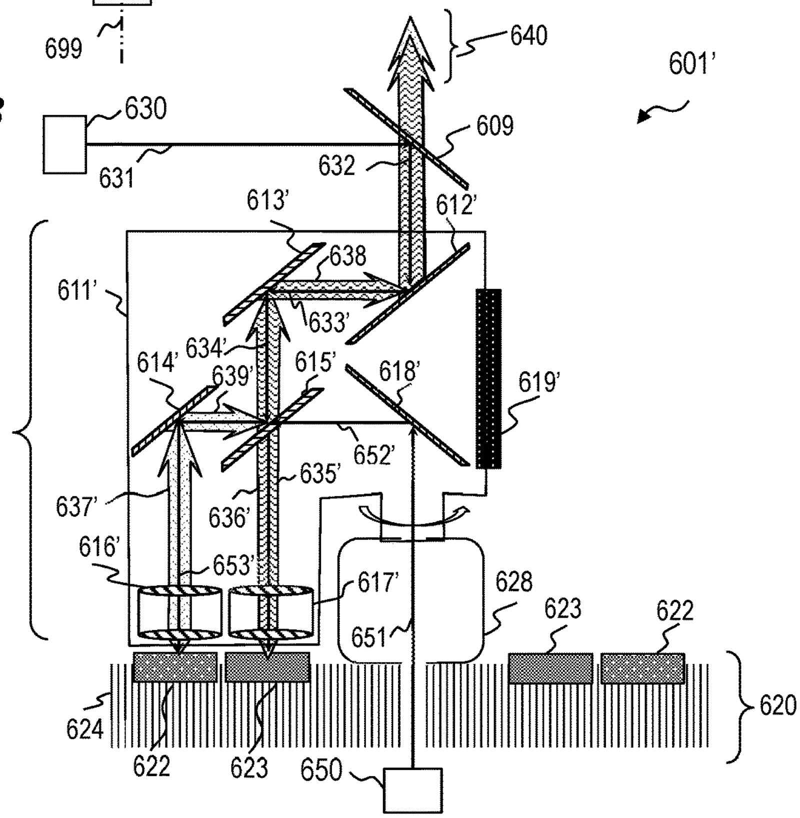
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FIG. 7A

FIG. 7B

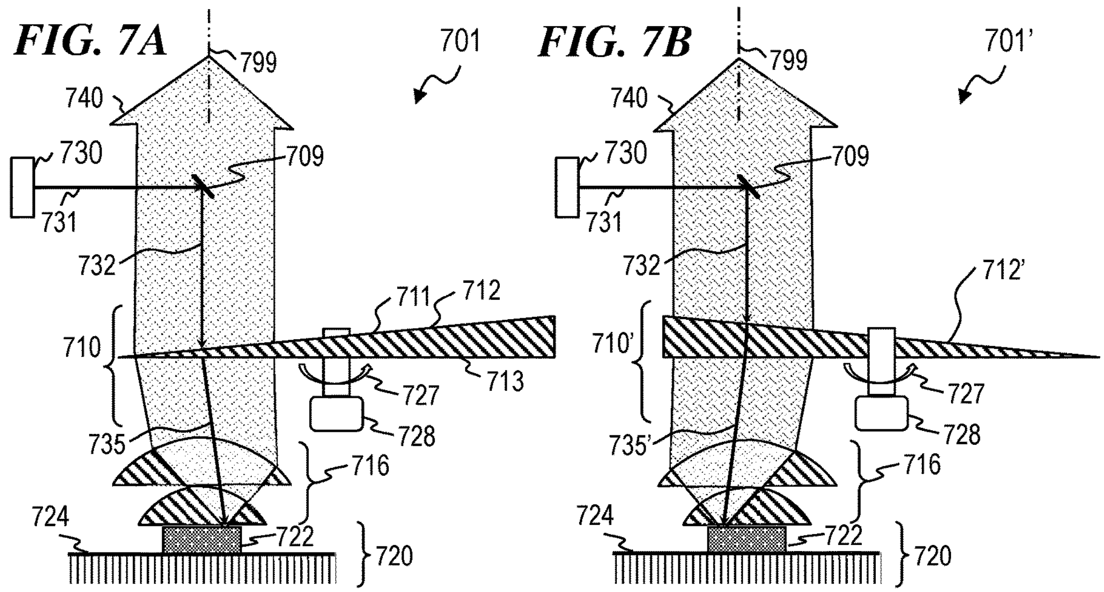


FIG. 8A

FIG. 8B

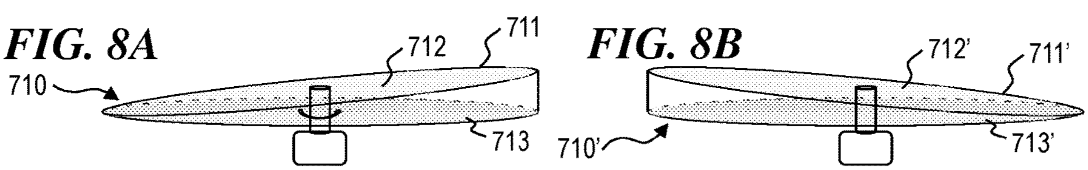


FIG. 9A

FIG. 9B

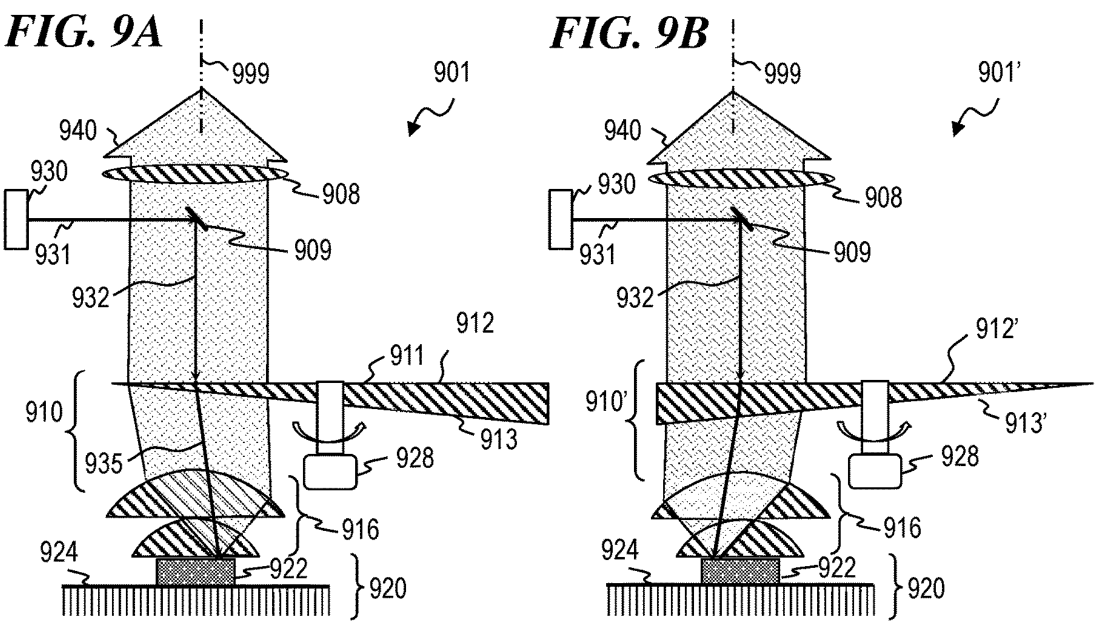


FIG. 10A

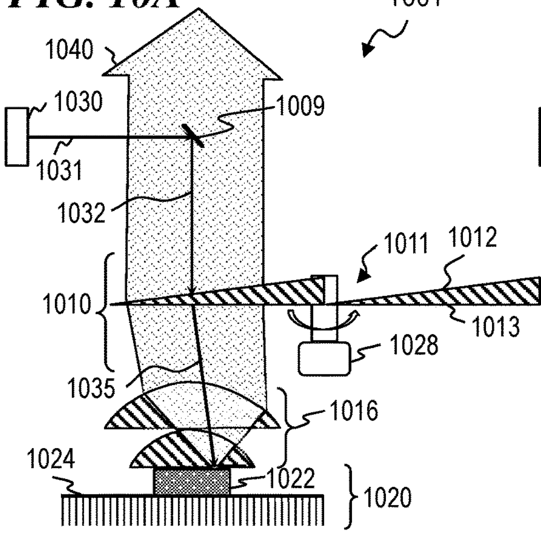


FIG. 10B

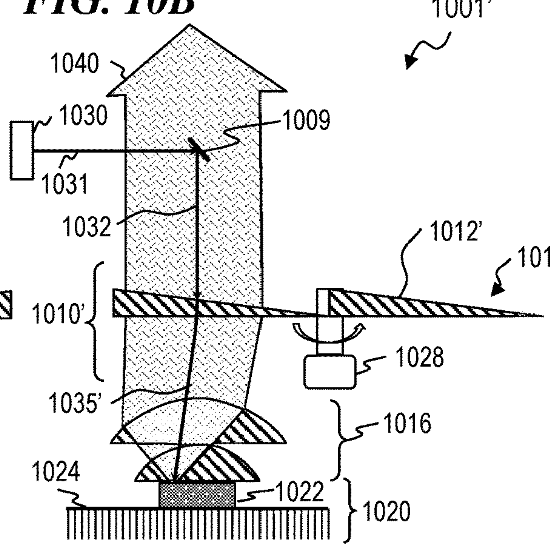


FIG. 10C

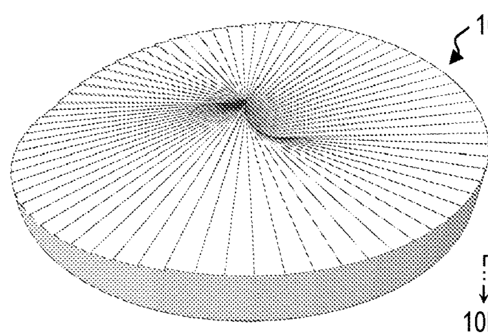


FIG. 10D

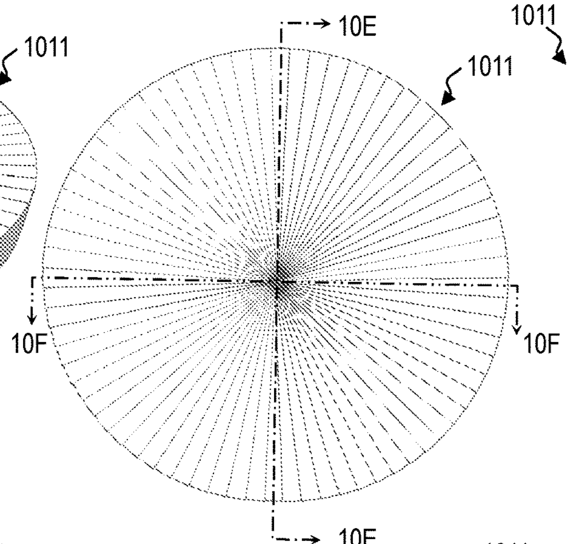


FIG. 10E

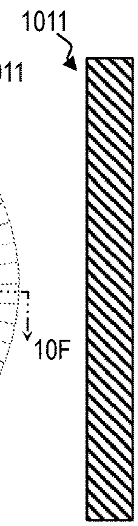


FIG. 10F

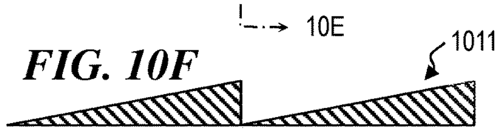


FIG. 11

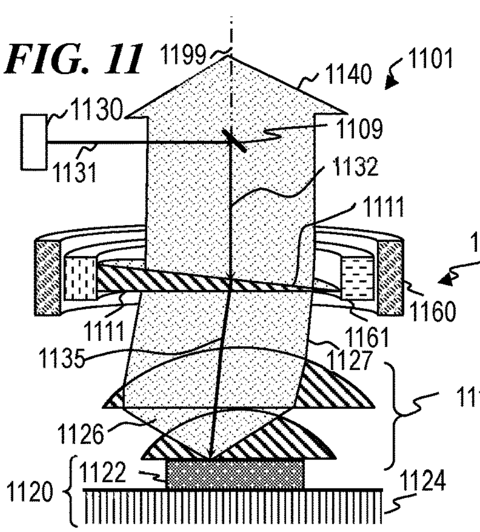


FIG. 12A

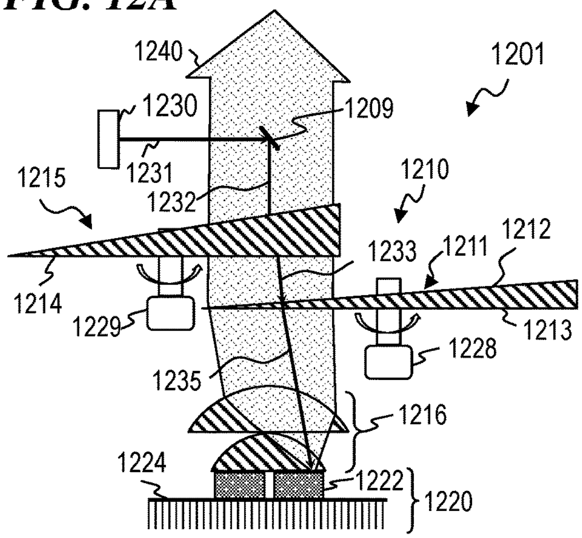
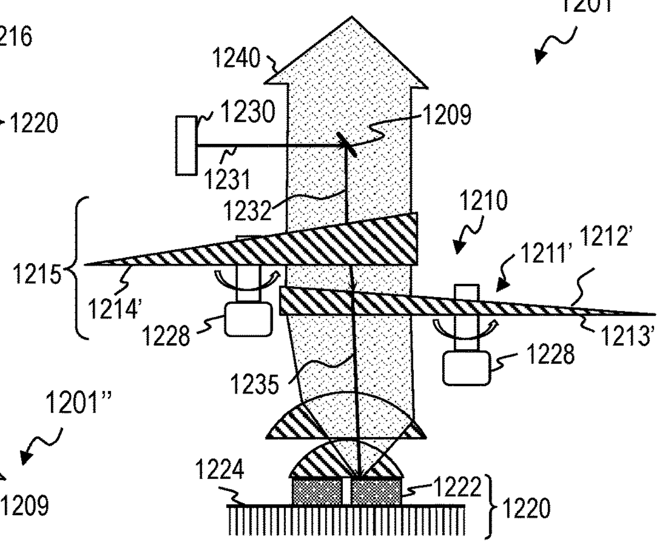


FIG. 12B



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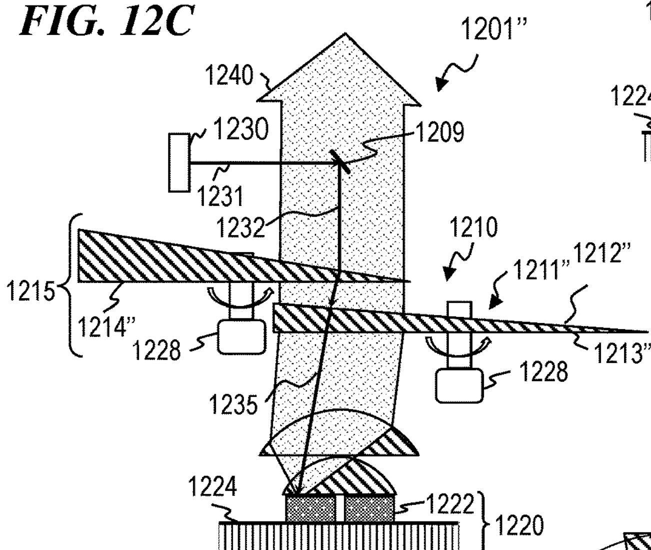


FIG. 12D

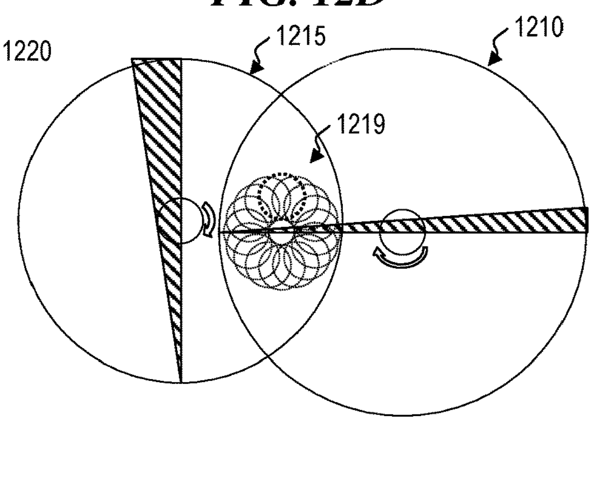


FIG. 13A

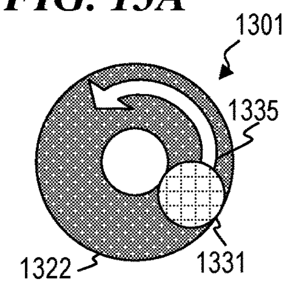
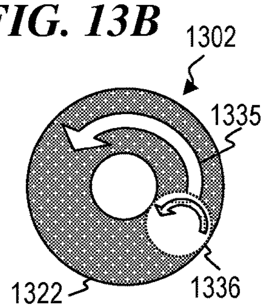


FIG. 13B



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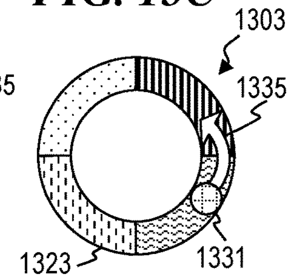


FIG. 13D

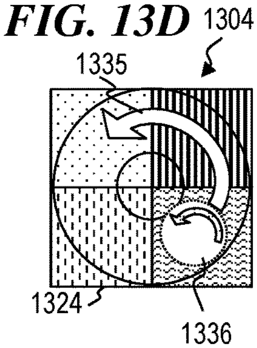


FIG. 14A

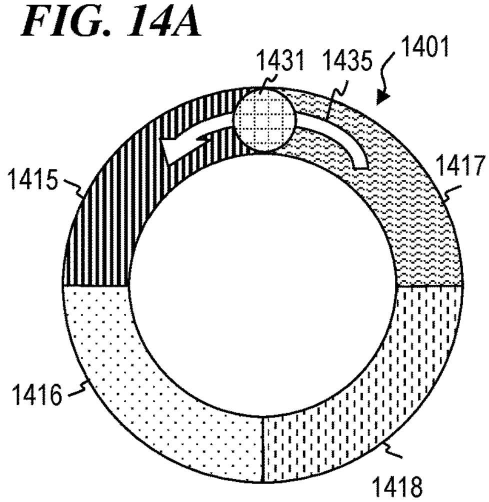
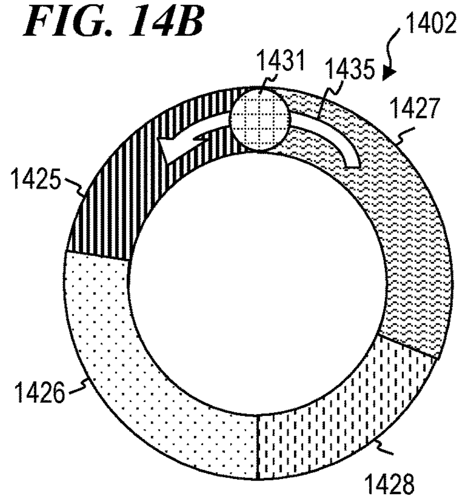


FIG. 14B



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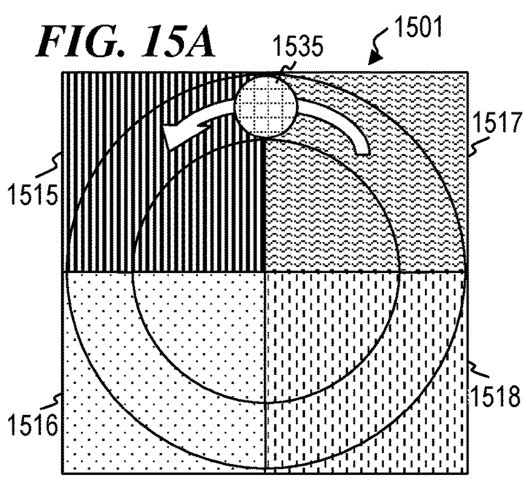

FIG. 15B

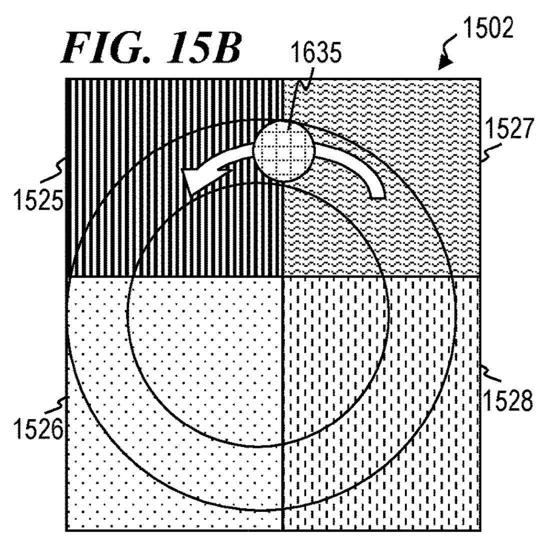

FIG. 16A

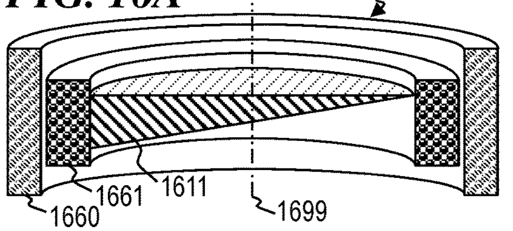

FIG. 16B

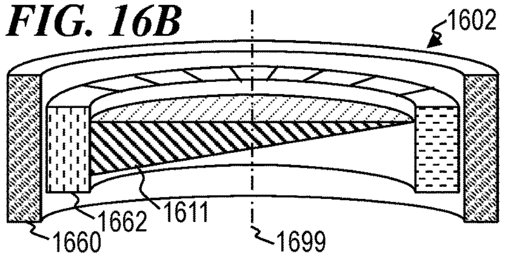

FIG. 17A

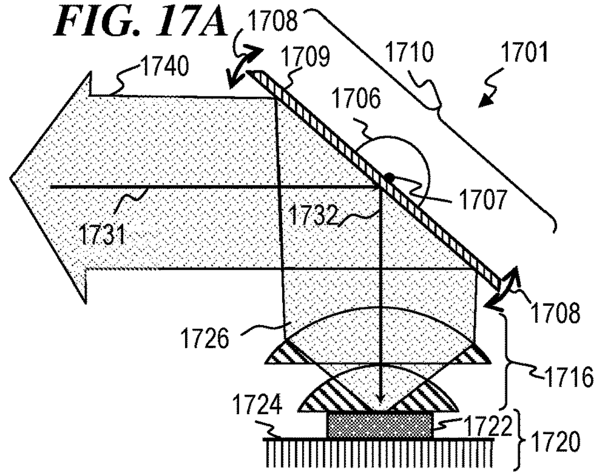

FIG. 17B

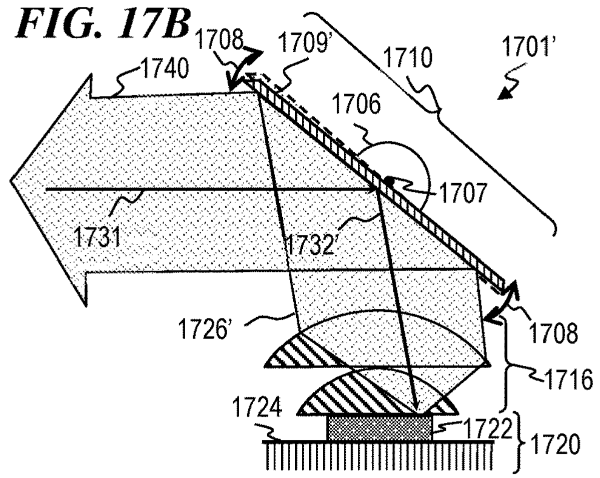

FIG. 17C

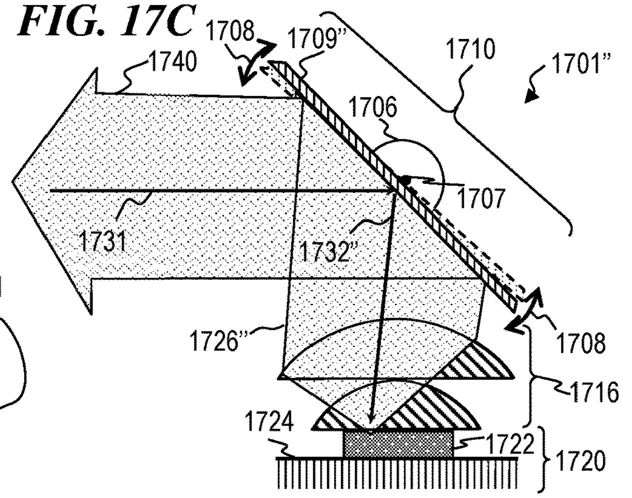

FIG. 18A

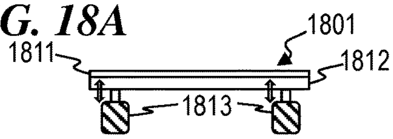

FIG. 18B

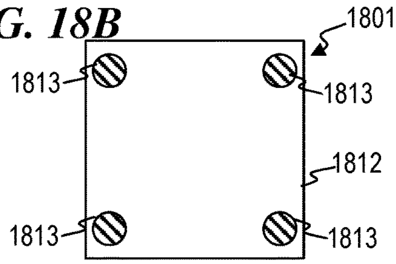

FIG. 19

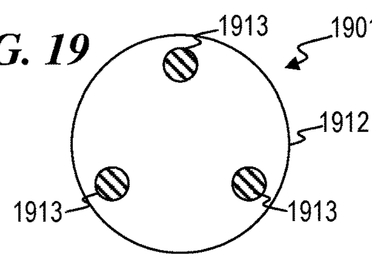

FIG. 20

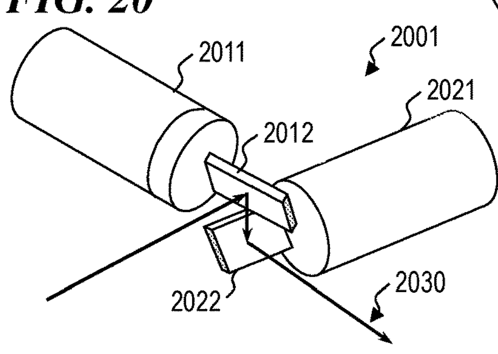

FIG. 21

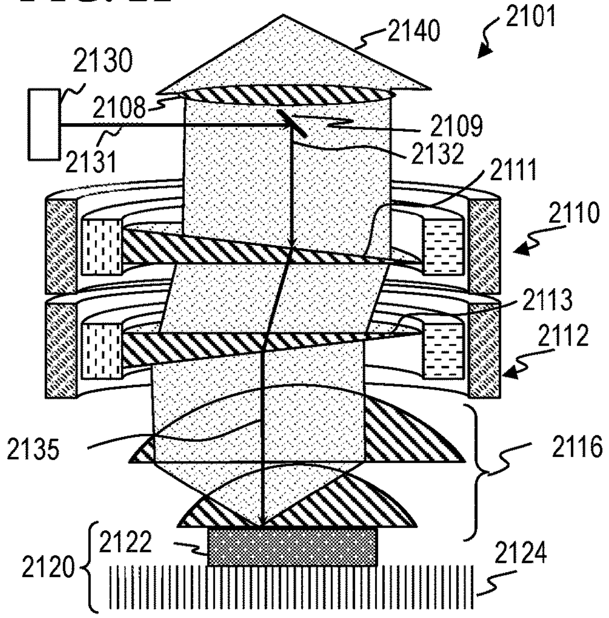

FIG. 22

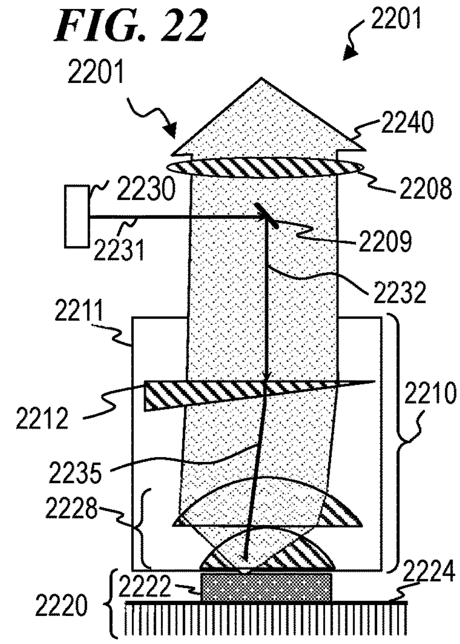

FIG. 23

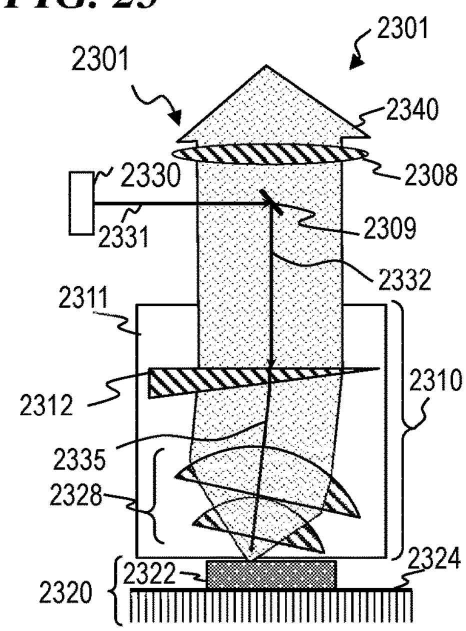

FIG. 24

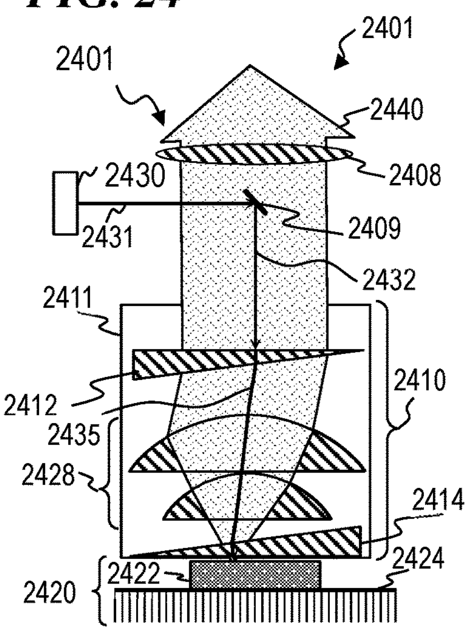

FIG. 25

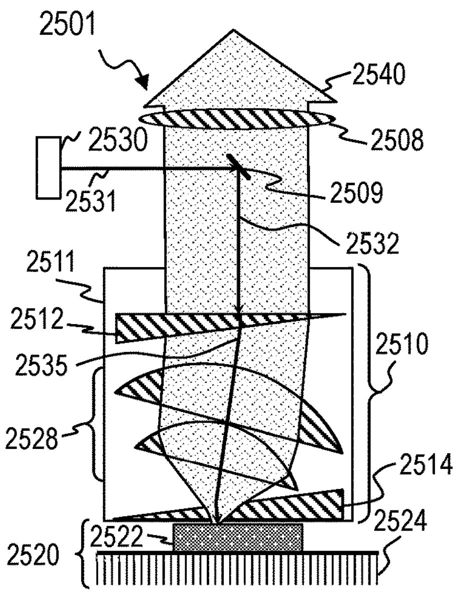

FIG. 26

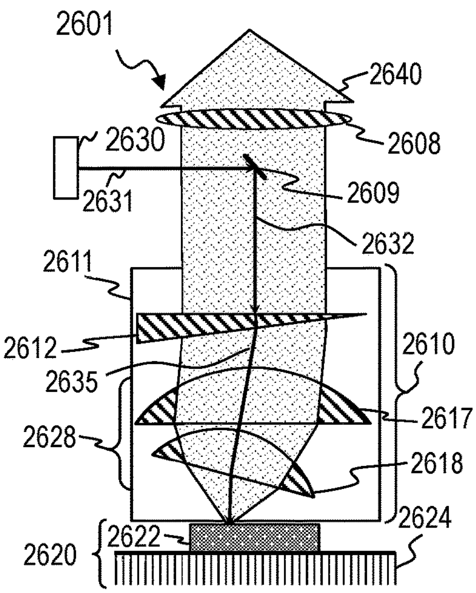

FIG. 27

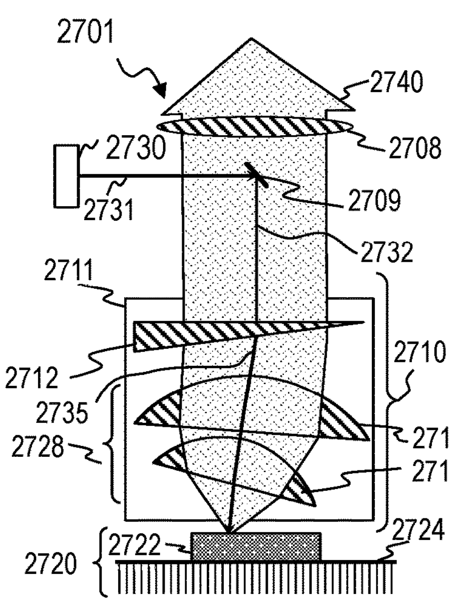

FIG. 28A

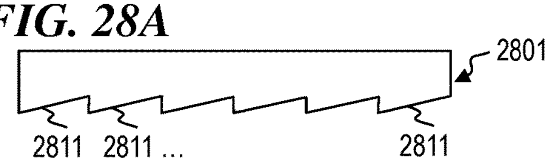

FIG. 28B

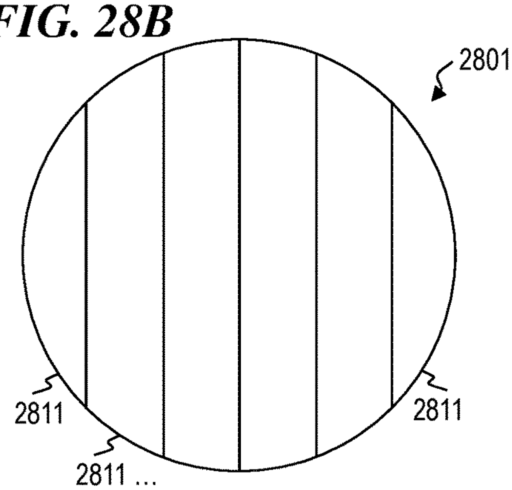

FIG. 29A

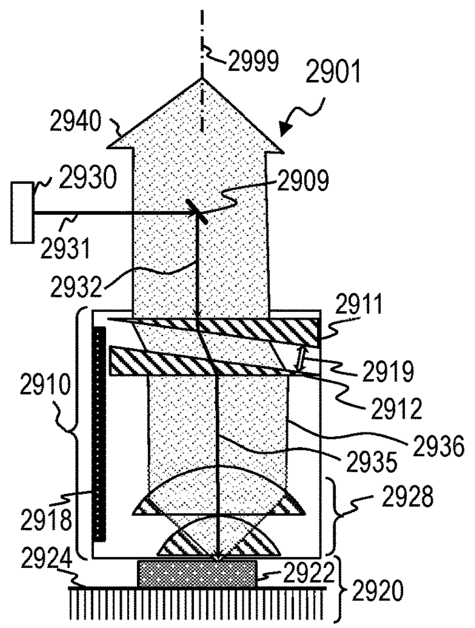

FIG. 29B

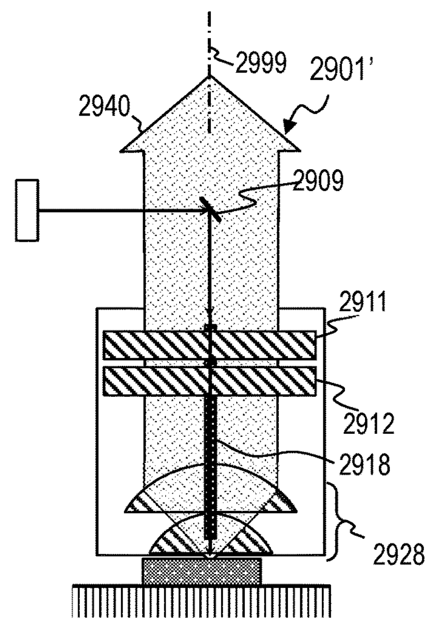

FIG. 29C

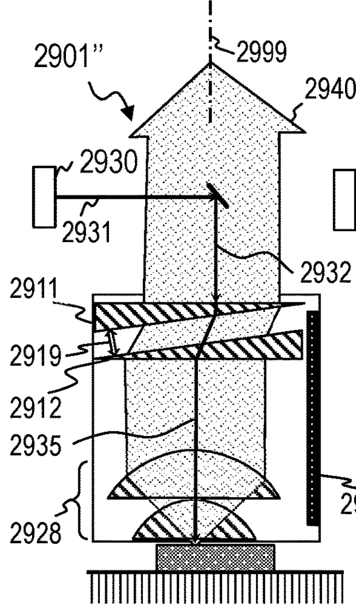

FIG. 29D

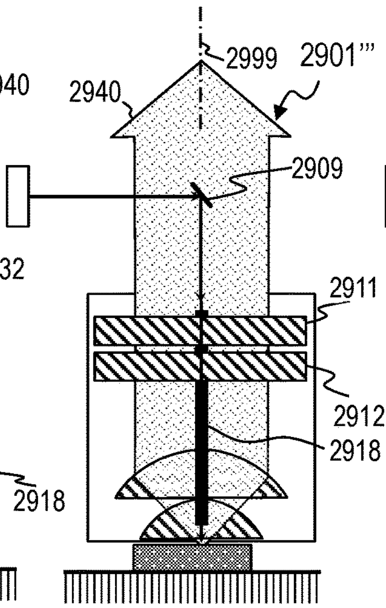

FIG. 29E

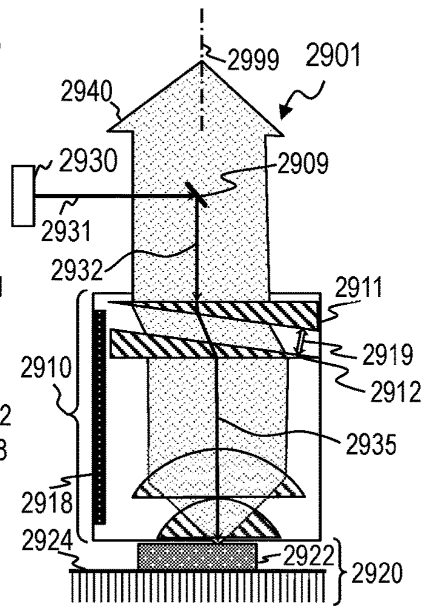

FIG. 30

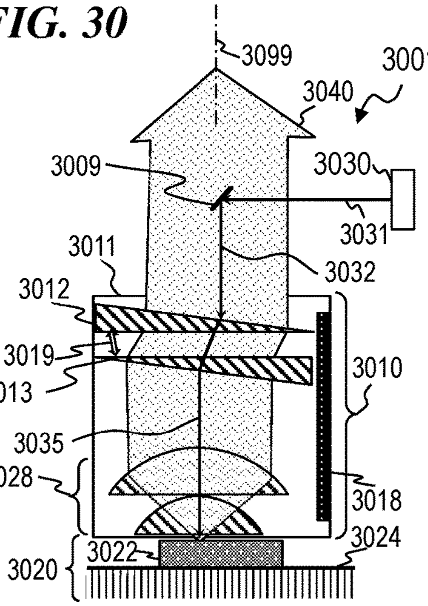

FIG. 31

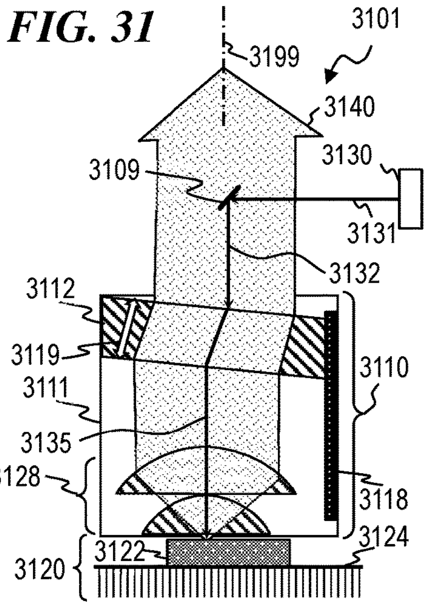

FIG. 32B

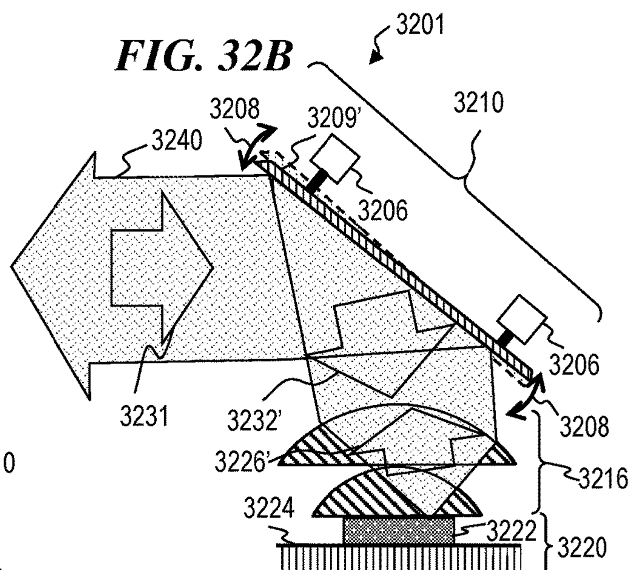

FIG. 32A

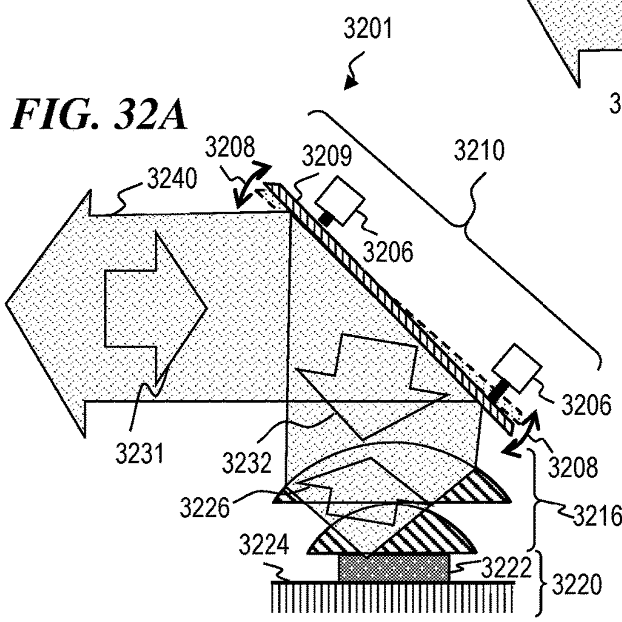

FIG. 33A

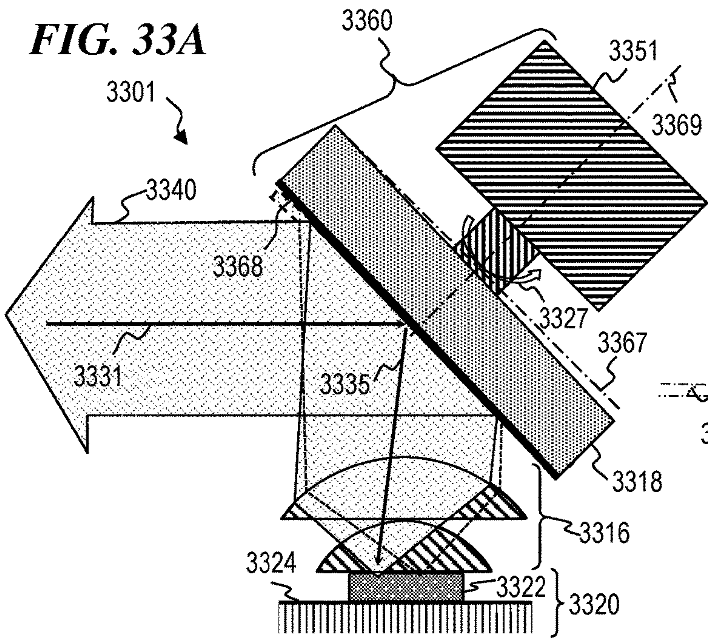

FIG. 33B

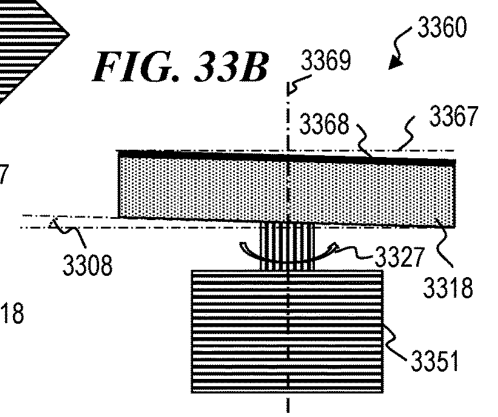

FIG. 34A

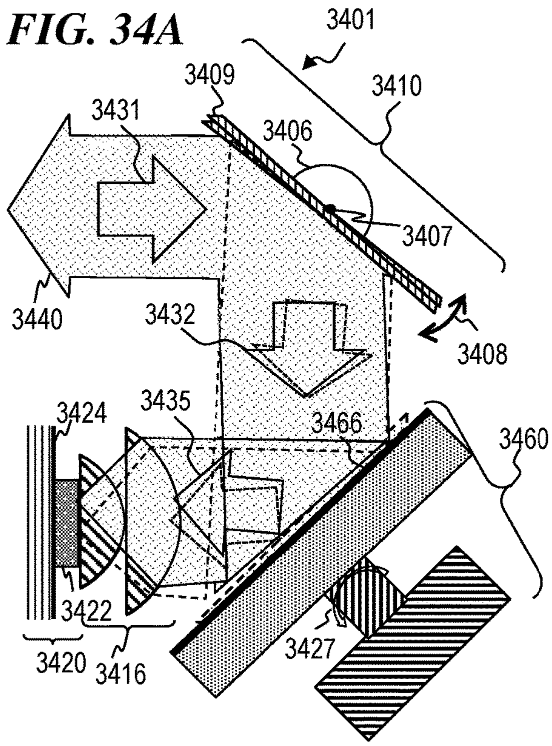

FIG. 34B

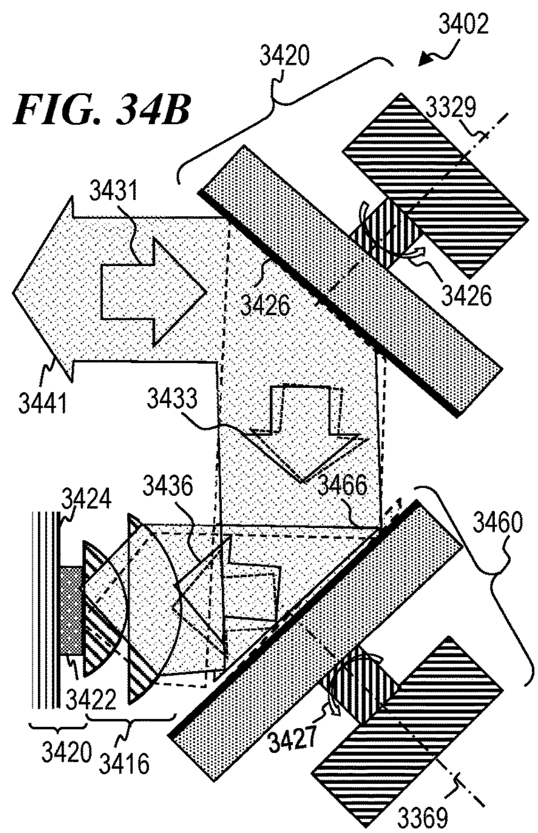

FIG. 35

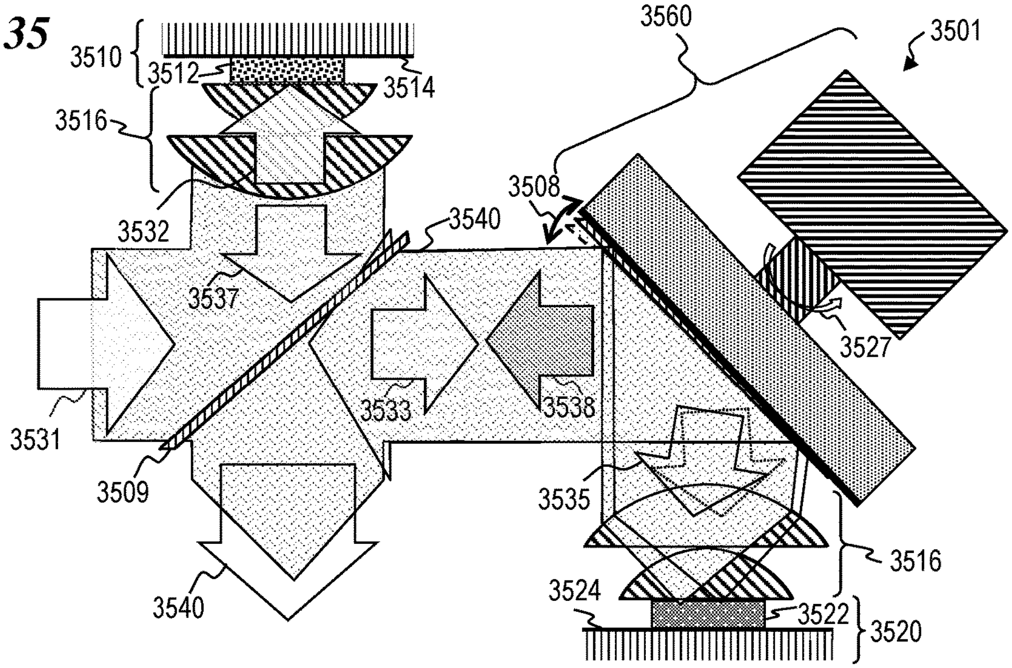
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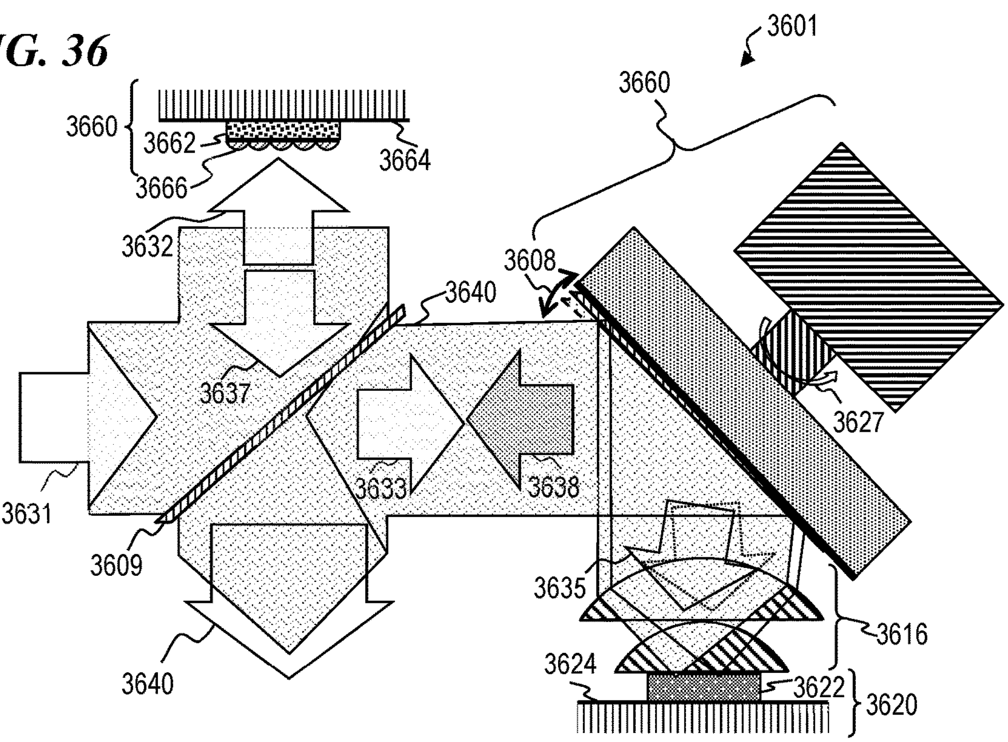
FIG. 36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3635
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FIG. 37

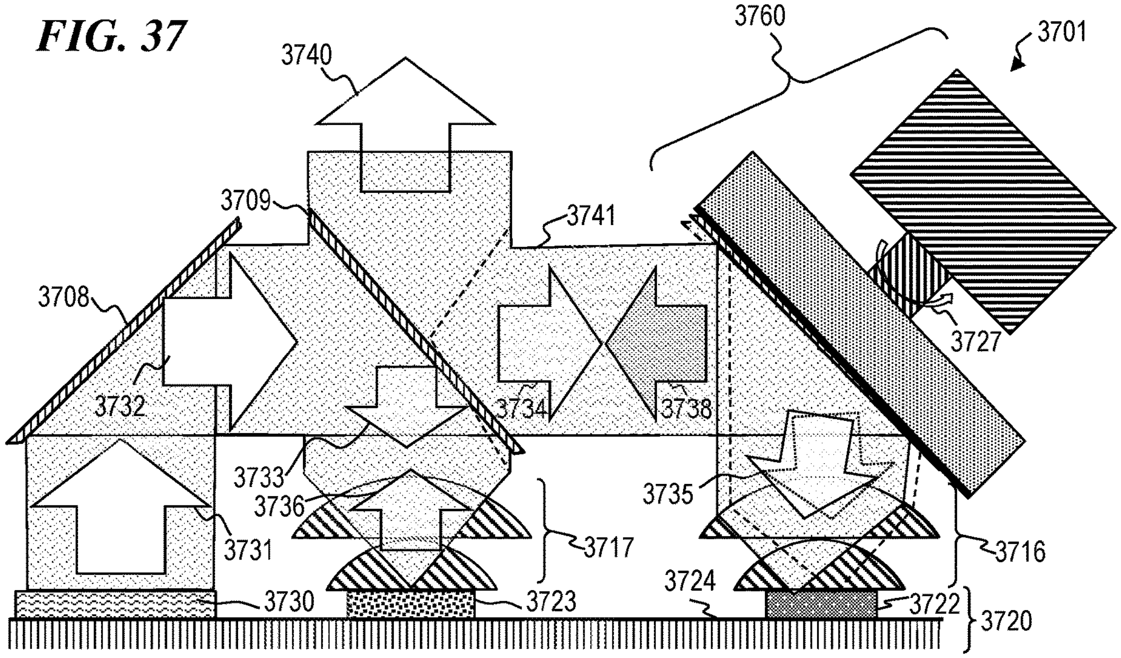
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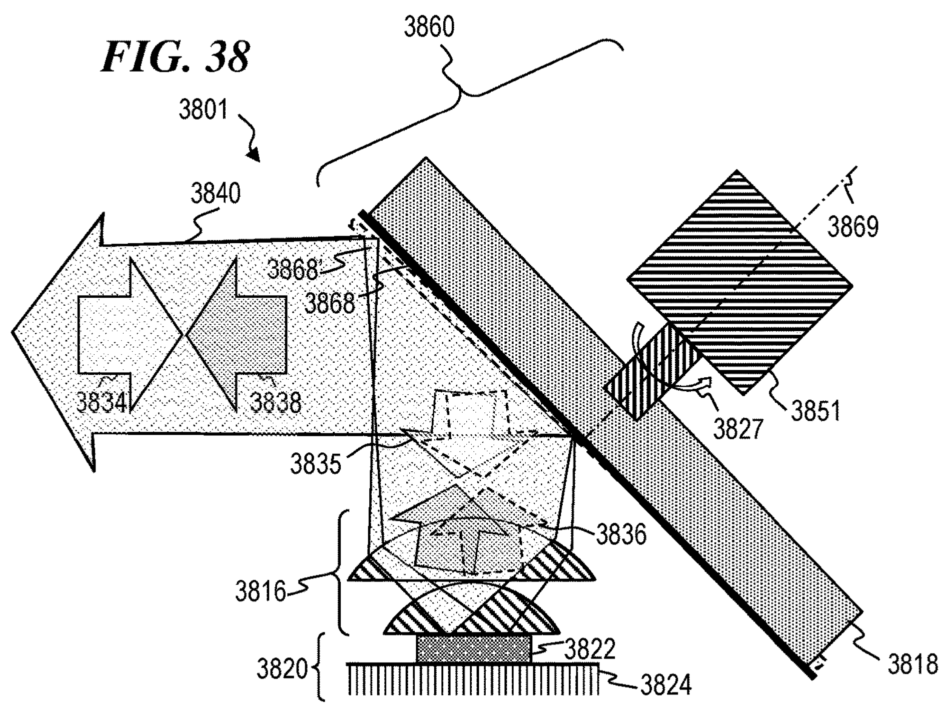
FIG. 38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LASER PHOSPHOR ILLUMINATION SYSTEM USING STATIONARY PHOSPHOR FIXTURE

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 63/079,984 titled "LASER PHOSPHOR ILLUMINATION SYSTEM USING STATIONARY PHOSPHOR FIXTURE," filed Sep. 17, 2020 by Kenneth Li et al.;

[0003] U.S. Provisional Patent Application 62/967,321 titled "LASER PHOSPHOR ILLUMINATION SYSTEM USING STATIONARY PHOSPHOR FIXTURE," filed Jan. 29, 2020 by Kenneth Li;

[0004] U.S. Provisional Patent Application 62/957,036 titled "LASER PHOSPHOR ILLUMINATION SYSTEM USING STATIONARY PHOSPHOR FIXTURE," filed Jan. 3, 2020 by Kenneth Li;

[0005] U.S. Provisional Patent Application 62/931,163 titled "LASER PHOSPHOR ILLUMINATION SYSTEM USING STATIONARY PHOSPHOR FIXTURE," filed Nov. 5, 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";

[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";

[0029] each of which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0030] This invention relates to the field of light sources, and more specifically to a method and light source that includes lasers, laser-pumped stationary phosphor light sources and/or diffusive reflectors, combined together to provide stationary light output with improved light-beam quality, higher beam intensity, and/or reduced speckle.

BACKGROUND OF THE INVENTION

[0031] Some laser-excited phosphor sources direct a laser beam onto a single small spot on a phosphor plate or layer affixed to a heatsink, and then collect and collimate the phosphor-emitted light as an output beam. Because of the small spot size and the fact that some of the absorbed laser light is converted to heat, such systems have limited power-handling capabilities. Some other systems are similar, but move the phosphor and heatsink (such as by coating the phosphor on a spinning disk) to spread the absorbed heat over a larger area, but such systems are limited in their power-handling capability due to the problems of cooling a spinning disk or handling the weight of a larger heatsink and/or the problems of trying to water-cool a moving heatsink.

[0032] Various prior art patents that describe various diffraction gratings usable in some embodiments of the present invention include U.S. Pat. No. 3,728,117 issued Apr. 17, 1973 to Heidenhain et al. titled "Optical Diffraction Grid", which describes a method for making blazed gratings having asymmetric grooves; U.S. Pat. No. 4,895,790 issued Jan. 23, 1990 to Swanson et al. titled "High-efficiency, multilevel, diffractive optical elements", which describes a method for making blazed gratings having asymmetric grooves using binary photolithography to create stepped profiles; U.S. Pat. No. 6,097,863 issued Aug. 1, 2000 to Chowdhury, titled "Diffraction Grating with Reduced Polarization Sensitivity", which describes a reflective diffraction grating with reduced polarization sensitivity; U.S. Pat. No. 4,313,648 issued Feb. 2, 1982 to Yano et al. titled "Patterned Multi-Layer Structure and Manufacturing Method", which describes a manufacturing method for a patterned (striped) multi-layer article; U.S. Pat. No. 6,822,796 issued Nov. 23, 2004 to Takada et al. titled "Diffractive optical element", which describes a method for making blazed gratings having asymmetric grooves with dielectric coatings; U.S. Pat. No. 6,958,859 issued Oct. 25, 2005 to Hoose et al. titled "Grating device with high diffraction efficiency", which describes a method for making blazed gratings having dielectric coatings; and U.S. Pat. No. 5,907,436 issued May 25, 1999 to Perry et al. titled "Multilayer dielectric diffraction gratings", which describes the design and fabrication of a multilayer structure of alternating index dielectric materials and grating with high diffraction efficiency or adjustable efficiency and variable optical bandwidth. Each of the patents described in this entire disclosure is incorporated herein by reference.

[0033] There is a need in the art for an improved laser-excited-phosphor light source and method for projection and lighting applications, particularly for such systems with high-power capabilities.

SUMMARY OF THE INVENTION

[0034] The present invention provides a method and apparatus for laser-excited phosphor on a stationary heat sink as a light source for projection and lighting applications, providing a light source that is "brighter" than light-emitting diodes (LEDs), but without speckles that may be associated with lasers. (The Wikipedia 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.") The output power is mainly limited by the need to dissipate the heat of the phosphor layer that is being excited by the laser. Many existing systems use a rotating disc coated with a phosphor layer, such that the heat is spread from a single point to a moving ring. At very high power, this method is insufficient for heat dissipation. One method to allow better heat sinking is to use extensive heat sinks with optional fans, and/or liquid cooling. These methods will be difficult to implement if the phosphor layer is coated on a rotating disc. The present invention includes a laser-excited phosphor system in which the phosphor layer remains stationary while the beam is made to scan across the phosphor layer. This allows heat to be spread from a single point to a line, a circle, a curvilinear or other scanned path and allows the phosphor layer and/or diffusive reflector to be put on top of an extensive stationary heat sink for air and/or liquid cooling. In addition, all mentions of phosphor in this specification are applicable to diffusing materials with phosphor being a wavelength-conversion material and diffusing materials do not change wavelength.

BRIEF DESCRIPTION OF THE DRAWINGS

[0035] FIG. **1**A is a side-view cross-sectional block diagram, at one point in time, of a laser-excited stationary-phosphor light source **101**, according to some embodiments of the present invention.

[0036] FIG. **1**B is a side-view cross-sectional block diagram, at two points in time (one point in time, such as shown in FIG. **1**A indicated in solid lines, and another point in time indicated in dashed lines), of laser-excited stationary phosphor light source **101'**, according to some embodiments of the present invention.

[0037] FIG. **1**C is a perspective view, partially in cross-section, diagram of a stationary phosphor and/or diffuser heatsink assembly **123**, according to some embodiments of the present invention.

[0038] FIG. **2**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **201**, according to some embodiments of the present invention.

[0039] FIG. **2**B is a side-view cross-sectional block diagram, at a second point in time **201'**, of laser-excited stationary phosphor light source **201**, according to some embodiments of the present invention.

[0040] FIG. **3** is a top-view block diagram of a laser-excited stationary phosphor assembly **220**, according to some embodiments of the present invention.

[0041] FIG. **4**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited two-color stationary-phosphor light source **401**, according to some embodiments of the present invention.

[0042] FIG. **4**B is a side-view cross-sectional block diagram, at a second point in time **401'**, of laser-excited two-color stationary phosphor light source **401**, according to some embodiments of the present invention.

[0043] FIG. **5** is a top-view block diagram of a laser-excited stationary phosphor assembly **420**, according to some embodiments of the present invention.

[0044] FIG. **6**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited two-color stationary-phosphor light source **601**, according to some embodiments of the present invention.

[0045] FIG. **6**B is a side-view cross-sectional block diagram, at a second point in time **601'**, of a laser-excited two-color stationary-phosphor light source **601**, according to some embodiments of the present invention.

[0046] FIG. **7**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **701**, according to some embodiments of the present invention.

[0047] FIG. **7**B is a side-view cross-sectional block diagram, at a second point in time **701'**, of laser-excited stationary phosphor light source **701**, according to some embodiments of the present invention.

[0048] FIG. **8**A is a perspective side-view block diagram, at a first point in time, of a rotating prism assembly **710**, according to some embodiments of the present invention.

[0049] FIG. **8**B is a side-view cross-sectional block diagram, at a second point in time **710'**, of rotating prism assembly **710**, according to some embodiments of the present invention.

[0050] FIG. **9**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **901**, according to some embodiments of the present invention.

[0051] FIG. **9**B is a side-view cross-sectional block diagram, at a second point in time **901'**, of laser-excited stationary phosphor light source **901**, according to some embodiments of the present invention.

[0052] FIG. **10**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **1001**, according to some embodiments of the present invention.

[0053] FIG. **10**B is a side-view cross-sectional block diagram, at a second point in time **1001'**, of laser-excited stationary phosphor light source **1001**, according to some embodiments of the present invention.

[0054] FIG. **10**C is a perspective side-view block diagram, slightly after the first point in time, of rotating prism **1011**, according to some embodiments of the present invention.

[0055] FIG. **10**D is a top-view block diagram, at the first point in time, of rotating prism **1011**, according to some embodiments of the present invention.

[0056] FIG. **10**E is a side-view cross-sectional block diagram, at cross-section line **10**E of FIG. **10**D, of rotating prism **1011**, according to some embodiments of the present invention.

[0057] FIG. **10**F is a side-view cross-sectional block diagram, at cross-section line **10**F of FIG. **10**D, of rotating prism **1011**, according to some embodiments of the present invention.

[0058] FIG. **11** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **1101**, according to some embodiments of the present invention.

[0059] FIG. **12**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **1201**, according to some embodiments of the present invention.

[0060] FIG. **12**B is a side-view cross-sectional block diagram, at a second point in time **1201'**, of laser-excited stationary phosphor light source **1201**, according to some embodiments of the present invention.

[0061] FIG. **12**C is a side-view cross-sectional block diagram, at a third point in time **1201"**, of laser-excited stationary phosphor light source **1201**, according to some embodiments of the present invention.

[0062] FIG. **12**D is a top-view block diagram, at the first point in time, of rotating prism assemblies **1210** and **1215**, and a resulting light path **1219** according to some embodiments of the present invention.

[0063] FIG. **13**A is a top-view block diagram of a system **1301** with a rotated focused spot **1331** moved around circular path **1335** on phosphor plate **1322**, according to some embodiments of the present invention.

[0064] FIG. **13**B is a top-view block diagram of a system **1302** with a rotating pattern **1336** that is moved around a circular path **1335** on phosphor plate **1322**, according to some embodiments of the present invention.

[0065] FIG. **13**C is a top-view block diagram of a system **1304** with a rotated focused spot **1331** moved around circular path **1335** on a phosphor and/or diffuser plate **1323**, according to some embodiments of the present invention.

[0066] FIG. **13**D is a top-view block diagram of a system **1304** with a rotating pattern **1336** that is moved around a circular path **1335** on a phosphor and/or diffuser plate **1324**, according to some embodiments of the present invention.

[0067] FIG. **14**A is a top-view block diagram of a combined diffuser and multi-color phosphor plate **1401** with equal arc lengths of red phosphor **1415**, green phosphor **1416**, yellow phosphor **1417** and a diffuser **1418** for the blue laser light, as used in some embodiments of the system of the present invention.

[0068] FIG. **14**B is a top-view block diagram of a combined diffuser and multi-color phosphor plate **1402** with unequal arc lengths of red phosphor **1425**, green phosphor **1426**, yellow phosphor **1427** and a diffuser **1428** for the blue laser light, as used in some embodiments of the system of the present invention, to adjust the proportions of the various colors.

[0069] FIG. **15**A is a top-view block diagram of a combined diffuser and multi-color phosphor plate **1501** with equal arc lengths of red phosphor **1515**, green phosphor **1516**, yellow phosphor **1517** and a diffuser **1518** for the blue laser light, according to some embodiments of the present invention.

[0070] FIG. **15**B is a top-view block diagram of a combined diffuser and multi-color phosphor plate **1502** with unequal arc lengths of red phosphor **1525**, green phosphor **1526**, yellow phosphor **1527** and a diffuser **1518** for the blue laser light to adjust the proportions of the various colors, according to some embodiments of the present invention.

[0071] FIG. **16**A is a side-view cross-sectional block diagram, at a first point in time, of a rotating prism-motor assembly **1601**, according to some embodiments of the present invention.

[0072] FIG. **16**B is a side-view cross-sectional block diagram, at a first point in time, of a rotating prism-motor assembly **1602**, according to some embodiments of the present invention.

[0073] FIG. **17**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **1701**, according to some embodiments of the present invention.

[0074] FIG. **17**B is a side-view cross-sectional block diagram, at a second point in time **1701'**, of laser-excited stationary phosphor light source **1701**, according to some embodiments of the present invention.

[0075] FIG. **17**C is a side-view cross-sectional block diagram, at a third point in time **1701"**, of laser-excited stationary phosphor light source **1701**, according to some embodiments of the present invention.

[0076] FIG. **18**A is a side-view cross-sectional block diagram of a four-activator mirror-tilt device **1801**, according to some embodiments of the present invention.

[0077] FIG. **18**B is a back-side-view cross-sectional block diagram of a four-activator mirror-tilt device **1801**.

[0078] FIG. **19** is a side-view cross-sectional block diagram of a three-activator mirror-tilt device **1901**, according to some embodiments of the present invention.

[0079] FIG. **20** is an isometric block diagram of an XY scanning-mirror system **2001**, according to some embodiments of the present invention.

[0080] FIG. **21** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2101**, according to some embodiments of the present invention.

[0081] FIG. **22** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2201**, according to some embodiments of the present invention.

[0082] FIG. **23** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2301**, according to some embodiments of the present invention.

[0083] FIG. **24** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2401**, according to some embodiments of the present invention.

[0084] FIG. **25** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2501**, according to some embodiments of the present invention.

[0085] FIG. **26** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2601**, according to some embodiments of the present invention.

[0086] FIG. **27** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2701**, according to some embodiments of the present invention.

[0087] FIG. **28**A is a side-view cross-sectional block diagram of a prism device **2801** made of a plurality of prism wedges **2811**, according to some embodiments of the present invention.

[0088] FIG. **28**B is a top-view block diagram of prism device **2801** made of a plurality of prism wedges **2811**, according to some embodiments of the present invention.

[0089] FIG. **29**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2901**, according to some embodiments of the present invention.

[0090] FIG. **29**B is a side-view cross-sectional block diagram, at a second point in time **2901'** with assembly **2910** rotated 90 degrees relative to FIG. **29**A, of laser-excited stationary-phosphor light source **2901**, according to some embodiments of the present invention.

[0091] FIG. **29**C is a side-view cross-sectional block diagram, at a third point in time **2901"** with assembly **2910** rotated 180 degrees relative to FIG. **29**A, of laser-excited stationary-phosphor light source **2901**, according to some embodiments of the present invention.

[0092] FIG. **29**D is a side-view cross-sectional block diagram, at a fourth point in time **2901'"** with assembly **2910** rotated 270 degrees relative to FIG. **29**A, of laser-excited stationary-phosphor light source **2901**, according to some embodiments of the present invention.

[0093] FIG. **29**E is a side-view cross-sectional block diagram, at a fifth point in time with assembly **2910** rotated 360 degrees relative to FIG. **29**A, of a laser-excited stationary-phosphor light source **2901**, according to some embodiments of the present invention.

[0094] FIG. **30** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **3001**, according to some embodiments of the present invention.

[0095] FIG. **31** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **3101**, according to some embodiments of the present invention.

[0096] FIG. **32**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **3201**, according to some embodiments of the present invention.

[0097] FIG. **32**B is a side-view cross-sectional block diagram, at a second point in time, of a laser-excited stationary-phosphor light source **3201**, according to some embodiments of the present invention.

[0098] FIG. **33**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **3301**, according to some embodiments of the present invention.

[0099] FIG. **33**B is a side-view cross-sectional block diagram, at a first point in time, of a rotating-tilted-mirror assembly **3360** used to move a reflection-deflected laser beam **3335** (see FIG. **33**A) in a circular path, according to some embodiments of the present invention.

[0100] FIG. **34**A is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3401**, according to some embodiments of the present invention.

[0101] FIG. **34**B is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3402**, according to some embodiments of the present invention.

[0102] FIG. **35** is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3501**, according to some embodiments of the present invention.

[0103] FIG. **36** is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3601**, according to some embodiments of the present invention.

[0104] FIG. **37** is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3701**, according to some embodiments of the present invention.

[0105] FIG. **38** is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3801**, according to some embodiments of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0106] 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.

[0107] 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.

[0108] 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.

[0109] Laser-pumped phosphor light sources can provide higher luminance compared to LED light sources and are important for applications such as projectors, vehicle headlights 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 transmissive phosphor plate, which cannot be mounted on an opaque heatsink. In some embodiments, the present invention uses a phosphor plate/layer and/or a diffuser plate/layer mounted on an opaque heatsink and moves the laser beam(s) along a straight-line or curvilinear path across the phosphor plate and/or diffuser plate to spread the heat across a larger area of the phosphor plate and/or diffuser plate and underlying heatsink.

[0110] FIG. **1A** is a side-view cross-sectional block diagram, at one point in time, of a laser-excited stationary-phosphor light source **101** that uses a vertically moving mirror-lens assembly **111** to move a reflected laser beam **132** from laser source **130** (such as a conventional laser) across a phosphor **122** in a straight-line path, and outputs a wavelength-converted stationary output beam **140** having light reflected from a vertically moving mirror **118** that, in some embodiments, moves half the distance and speed as the moving mirror-lens assembly **111**, according to some embodiments of the present invention.

[0111] In some embodiments, light source **101** includes a two-part linear scanning system **110** that includes oscillating mirror **118** that moves (vertically in FIG. **1A**) back and forth at a first speed between positions **170** and **170'**, separated by a first distance **171**, and oscillating mirror-lens assembly **111** that moves (vertically in FIG. **1A**) synchronously to mirror **118** back and forth at a second speed that is twice the first speed between positions **175** and **175'**, separated by a second distance **172** that is twice the distance **171**. In some embodiments, mirror-lens assembly **111** includes a mirror **112** (in some embodiments, a mirror that is highly reflective at least for the wavelength of laser beam **131** and is oriented at a 45-degree angle to laser beam **131**), a wavelength-selective mirror **114** (in some embodiments, oriented at a 22.5-degree angle to reflected laser beam **132** and wavelength-converted collimated beam **134**), which reflects to form wavelength-converted collimated beam **136** at a 45-degree angle toward mirror **118**. Laser beam **131** is reflected by mirror **112** to form laser beam **132** that, in some embodiments, is scanned onto the stationary phosphor layer **122** as a straight line. As shown in the embodiment of FIG. **1A**, the directions of the light beams are at 0-degrees, 90-degrees, or 45-degrees to the horizontal line. It can be seen that when the mirror/lens assembly **111** travels twice the distance and at twice the speed as that of the oscillation mirror **118**, the phosphor-light output beam **140** path will remain stationary without any movement, which is needed to conserve etendue and for coupling to a projection engine **190**. In addition, for system **101**, the path length between the phosphor layer **122** to where the output beam **140** reaches the projection engine **190** remains constant during the oscillation, allowing the output beam **140** to be focused accurately. In some embodiments, mirror **112** is a broadband reflector (while in other embodiments, mirror **112** is a narrow-band reflector) for the laser beam **131**, which, in some embodiments, is typically blue in color (e.g., in some embodiments, having a selected wavelength between 400 nm and 480 nm, for example, about 440 nm, about 445 nm, about 450 nm, about 455 nm, about 460 nm, about 465 nm, about 470 nm, about 475 nm, about 480 nm, or other suitable wavelength). In some embodiments, mirror **114** transmits the wavelength of laser beam **132** (e.g., blue) and reflects the light spectrum of the phosphor output light **134**. In some embodiments, lens **116** is a single lens, or in other embodiments, preferably, a set of lenses better suited to focusing the laser beam onto the phosphor **122** and collecting and collimating the phosphor-emission light. The collimated output beam **134** from the laser-excited phosphor **122** is reflected by wavelength-selective mirror **114** and then reflected by the oscillation mirror **118**, producing the phosphor-light output beam **140**. In some embodiments, stationary phosphor layer **122** is coated on top of heat-sink structure **124**, which, in some embodiments, is air cooled and/or liquid cooled for high-power applications. In various embodiments, projection engine **190** includes a light projector, vehicle headlight, spotlight and/or other system that uses light beam **140** for some purpose (in some embodiments of each of the other light sources described herein, such a projection engine **190** is added to receive each respective output beam).

[0112] FIG. **1**B is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary phosphor light source **101'**, according to some embodiments of the present invention. At the first point in time, oscillating mirror **118** is at position **170** and oscillating mirror-lens assembly **111** is at position **175**. At a second point in time, oscillating mirror **118** has moved to position **170'** (at a distance **171** from position **170**) and oscillating mirror-lens assembly **111** has synchronously moved to position **175'** at a distance **172** (which is two times distance **171**) from position **175**. Reference numbers **118'**, **112'**, **132'**, **114'**, **134'**, and **116'** refer to the parts or beams **118**, **112**, **132**, **114**, **134**, and **116**, respectively, at the second point in time.

[0113] FIG. **1**C is a perspective view, partially in cross-section, diagram of a stationary phosphor and/or diffuser heatsink assembly **123** that is substituted for heatsink assembly **120** in FIG. **1**A and FIG. **1**B, according to some embodiments of the present invention. In some embodiments, a plurality of phosphor stripes **122**, **125**, and/or **126** having a plurality of different color outputs (optionally having different stripe widths to adjust the amount of each phosphor's contribution to the output beam color) and/or reflective diffuser stripes **127** are used in place of a single-color phosphor **122** on heatsink **124** to obtain an output beam **140** having a desired combination of colors or white light of a desired color temperature, wherein the speed of scanning is sufficiently high that the colors blend together, and/or wherein the scanning across the various phosphor light colors is synchronized with a light modulator (such as a digital mirror device) that modulates each of the various colors differently (such as a three- or four-color image projector) to obtain a full-color video projection. In other embodiments, the order, and/or the relative widths, of the phosphor stripes **122**, **125**, and/or **126** and/or diffuser stripe **127** is changed to obtain desired designed amounts and timing of the various colors in output beam **140**.

[0114] FIG. **2**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **201** that uses a rotating mirror-lens assembly **210** to move a reflected laser beam **234** across a phosphor **222** in a circular path, and outputs a wavelength-converted stationary output beam **240** having light reflected from rotating mirror-lens assembly **211**, according to some embodiments of the present invention. In some embodiments, mirror-lens assembly **210** includes a stationary motor **228** (which, in some embodiments, is attached to phosphor-heatsink assembly **220**), wherein stationary motor **228** is configured to rotate rotating mirror-lens assembly **211** around an axis of rotation **299**. In some embodiments, rotating mirror-lens assembly **211** includes a counterweight **219** configured to balance the other components of rotating mirror-lens assembly **211** relative to the axis of rotation **299**.

[0115] FIG. **2**B is a side-view cross-sectional block diagram, at a second point in time **201'**, of a laser-excited stationary phosphor light source **201**, according to some embodiments of the present invention. At the second point in time, mirror-lens assembly **211** has rotated 180 degrees around axis of rotation **299**. Reference numbers **211'**, **212'**, **214'**, **216'**, **219' 233'**, **234'**, **235'**, **236'**, and **237'** refer to the parts or beams **211**, **212**, **214**, **216**, **219**, **233**, **234**, **235**, **236**, and **237**, respectively, at the second point in time. FIG. **2**A and FIG. **2**B show a configuration in which the laser beam **234** scans a circle **242** (see FIG. **3**) onto the phosphor layer **222** using rotating assembly **211** driven by a motor **228**. In some embodiments, laser source **230** generates laser beam **231**, which, in some embodiments, is blue in color. In some embodiments, laser beam **231** is directed to a 45-degree stationary wavelength-selective mirror **209**, which, in some embodiments, reflects the blue laser light **231** as beam **232**, and transmits the output phosphor light **237**, as output beam **240** such that the output beam **240** is stationary on the axis of rotation **299** of system **201**. A 45-degree mirror **212**, which reflects both the input blue laser light **232** radially outward as laser beam **233** and the output phosphor light **236** (as beam **237** propagating upward in FIG. **2**A), is centered on the axis of rotation **299** and is mounted on the rotating assembly **211** such that mirror **212** rotates about the axis of rotation **299**. Mirror **212** reflects the downward laser beam **232** radially away from the axis of rotation **299** as laser beam **233**. Another 45-degree mirror **214**, which reflects both the radially outward laser beam **233** downward as laser beam **234**, and the collimated upward phosphor output beam **235**, is placed intercepting the laser beam **233**, redirecting the laser beam **233** downward as laser beam **234** towards the phosphor layer **222** focused by the lens assembly **216**. In other embodiments, mirrors **212** and **214** are oriented at other angles, for example at Brewster's or other suitable angle(s), in order to obtain better reflectivity on mirrors **212** and **214**, while still receiving vertical beams **232** and **235** but having intermediate beams **233** and **236** at suitable corresponding intermediate angles. As the whole assembly **211** is rotating, the laser beam **234** will be scanning a circle **242** onto the phosphor layer **222**, as shown in FIG. **3**. The emission **226** at the first point in time (and **226'** at the second point in time) from the excited phosphor **222** is collected by the lens assembly **216**, which is designed to accept the large-angle emission of light from the phosphor plate(s) that is/are excited by the laser, and collimate the light **235** that is reflected by mirror **214** to be beam **236** and mirror **212** to be beam **237**, and then transmitted around and/or through mirror **209** as the phosphor-light output beam **240** along the axis of rotation **299**. This beam **240** is stationary relative to the phosphor-heatsink assembly **220**, and, in some embodiments, is coupled to a projection engine (not shown here, but such as, but not limited to, projection engine **190** shown in FIG. **1**A).

[0116] FIG. **3** is a top-view block diagram of laser-excited stationary phosphor assembly **220** (shown in FIG. **2**A and FIG. **2**B), according to some embodiments of the present invention. In some embodiments, phosphor assembly **220** includes a heatsink **224** and a phosphor layer **222**, and laser beam **234** (see FIG. **2**A) is moved along a circular path **242** across phosphor layer **222**.

[0117] FIG. **4**A and FIG. **4**B show another embodiment, where two types of phosphors **422** and **423** are excited by individual portions **435** and **434**, respectively, of the initial laser beam **431**, with outputs **437** and **436** combined to a single stationary output beam **440**. In this case, the laser-beam output **433** from the mirror **412** is separated into two beams with the desired proportion by wavelength-selective mirror **415** (partially transmissive and partially reflective to the wavelength(s) of laser beam **433**, highly transmissive to the wavelengths of phosphor emission beam **439** (the reflection of beam **437** by mirror **414** that becomes beam **439**), and highly reflective to the wavelengths of phosphor emission beam **436**) and **414** (highly reflective to the wavelength(s) of laser beam **433** and phosphor emission beam **437**), for excitation of the phosphor layers of different colors, e.g., red **422** and green **423**, as shown. FIG. **5** shows the red-phosphor circle **442** and green-phosphor circle **443**, where the laser beams **435** and **434** will be scanning, and from which the corresponding output red-colored light **437** and green-colored light **436** wavelengths are collected. In the embodiment shown in FIG. **4**A and FIG. **4**B, wavelength-selective mirror **415** reflects green wavelengths, reflects blue wavelengths partially, and transmits red wavelengths. The mirror **414** reflects both blue and red wavelengths. In this case, separating the phosphors for different colors allows more-efficient colored phosphors to be used, and also allows color balancing, by changing the proportion of laser light exciting each of the two colors by adjusting parameters of wavelength-selective mirror **415** for the amounts of laser light reflected and transmitted.

[0118] More particularly, FIG. **4**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited two-color stationary-phosphor light source **401** that uses a rotating mirror-lens assembly **410** to move a reflected laser beam **435** (from that portion of beam **433** partially transmitted by wavelength-selective mirror **415**) across phosphor **422** (having a first color output) and a reflected laser beam **434** (from that portion of beam **433** partially reflected by wavelength-selective mirror **415**) across phosphor **423** (having a second color output), each in a circular path, and outputs a wavelength-converted stationary output beam **440** having two colors of light reflected from rotating mirror-lens assembly **410**, according to some embodiments of the present invention. In some embodiments, laser source **430** generates laser beam **431**, which, in some embodiments, is blue in color. In some embodiments, laser beam **431** is directed to a 45-degree wavelength-selective stationary mirror **409**, which, in some embodiments, reflects the blue laser light **431** and transmits the combined two (or more) colors of output phosphor light **439** (the combination of phosphor light **436** and phosphor light **437**) such that the output beam **440** is stationary on the axis of rotation **499** of system **401**. In some embodiments, rotating assembly **411** includes 45-degree mirror **412**, which reflects both the input blue laser light **432** and the output phosphor light **438** (which contains both colors of phosphor-emitted light from collimated beams **436** and **437**), is centered on the axis of rotation **499** and is mounted on the rotating assembly **411** such that mirror **412** rotates about the axis of rotation **499**. Mirror **412** reflects the laser beam **432** radially away from the axis of rotation **499** as beam **433**. Wavelength-selective mirror **415** reflects a first portion of laser beam **433** as laser beam **434**, and transmits the remainder to another 45-degree mirror **414**, which reflects the laser beam **435** downward to be focused by lens assembly **416** to phosphor layer **422**. Mirror **414** reflects the red-phosphor collimated output beam **437** toward the axis of rotation **499**. Wavelength-selective mirror **415** transmits the red-phosphor collimated output beam **439** and reflects green-phosphor beam **436** as combined beam **438** toward mirror **412** on the axis of rotation **499**. As the whole assembly **411** is rotating, laser beam **434** will be scanning a circle **443** onto green-phosphor layer **423**, and laser beam **435** will be scanning a circle **442** onto red-phosphor layer **422**, as shown in FIG. **5**. The red-phosphor emission **426** from the excited phosphor **422** is collected by the lens assembly **416**, and green-phosphor emission **427** from the excited phosphor **423** is collected by the lens assembly **417**. Lens assembly **416** and lens assembly **417** are each designed to accept the large-angle emission of light from the phosphor plate(s) that is/are excited by light from laser source **430**, and collimate the light **436** and **437** that is then reflected by mirrors **414** and **415**, and then transmitted around and/or through mirror **409** (in some embodiments, mirror **409** is made much smaller, to be just large enough to reflect laser beam **431**, but small so as to allow much of beam **440** to pass around the outside perimeter of mirror **409**) as the phosphor-light output beam **440** along the axis of rotation **499**. This beam **440** is stationary relative to the phosphor-heatsink assembly **420**, and, in some embodiments, is coupled to a projection engine (not shown here, but such as projection engine **190** shown in FIG. **1**A)

[0119] FIG. **4**B is a side-view cross-sectional block diagram, at a second point in time **401'**, of a laser-excited two-color stationary phosphor light source **401**, according to some embodiments of the present invention. Reference numbers **411'**, **412'**, **414'**, **415'**, **416'**, **417'**, **419'**, **433'**, **434'**, **435'**, **436'**, and **437'** refer to the parts or beams **411**, **412**, **414**, **415**, **416**, **417**, **419**, **433**, **434**, **435**, **436**, and **437**, respectively, at the second point in time.

[0120] Again, FIG. **5** is a top-view block diagram of a laser-excited stationary phosphor assembly **420**, according to some embodiments of the present invention. In some embodiments, phosphor assembly **420** includes heatsink **424**, two concentric rings of phosphor **422** and **423** deposited on heatsink **424**, wherein laser beam **435** (see FIGS. **4**A and **4**B) scans around phosphor ring **422** along circular path **442**, and laser beam **434** (see FIGS. **4**A and **4**B) scans around phosphor ring **423** along circular path **443**.

[0121] Although the system of FIG. **4**A and FIG. **4**B is described for two colors, more than two colors can be implemented by having additional mirrors and lenses in rotating assembly **411**, together with more rings of colored phosphors and/or diffusive reflector on heatsink **424** of phosphor assembly **420**. In some such embodiments, a ring of diffusive reflector is provided to add speckle-reduced laser light to the overall light output.

[0122] To increase the power further, two lasers can be used, one for each color, as shown in FIG. **6**A and FIG. **6**B. In some embodiments, fixed mirror **609** reflects the first laser beam **631** from laser source **630** totally downward as beam **632**, then rotating mirror **612** reflects it radially outward as beam **633**, mirror **613** reflects the first laser beam **633** totally downward as beam **634** without partial transmission, and wavelength-selective mirror/filter **615** is highly transmissive to the wavelength of beam **634** (e.g., in some embodiments, a blue laser beam), and transmits it as scanning beam **635**. In some embodiments, a special motor **628** with hollow center shaft **627** is used such that the second laser beam **651** from laser source **650** passes through the hole in the shaft **627** and is reflected radially outward by rotating mirror **618** as beam **652**. In some embodiments, wavelength-selective mirror **615** transmits beam **652** (e.g., in some embodiments, also a blue laser beam) to outer mirror **614** to become the outer downward beam **653** that is focused by lens assembly **616** onto outer phosphor ring **622**, and transmits beam **634** to become the inner downward beam **635** that is focused by lens assembly **617** onto inner green phosphor ring **623** of the system **601**. In some embodiments, wavelength-selective mirror **615** reflects collimated phosphor-emission beam **639**

and transmits collimated phosphor-emission beam **636** to mirror **613** (described further, below).

[0123] In other embodiments, wavelength-selective mirror/filter **615** is highly reflective to the wavelength of beam **634** and reflects beam **634** outward to mirror **614** to become scanned beam **653**, and also reflects light **652** from the second laser beam **651**, to be the second scanned laser beam **635** towards the outer red-phosphor ring **622** for the red excitation.

[0124] In both cases, wavelength-selective mirror/filter **615** is highly transmissive to the green emitted light beam **636** from the inner phosphor ring **623**, and highly reflective to the red emitted light beam **639** from the outer phosphor ring **622**, and these combined red and green emitted light beams are directed upward towards mirror **613**, then inward toward mirror **612** which reflects the combined red and green beams through and/or around mirror **609** (depending on the designed size of mirror **609** and whether this mirror is wavelength selective to reflect laser beam **631** and pass the combined ren and green phosphor-emitted wavelengths). Finally, system **601** outputs beam **640** as the combined phosphor-light output along the axis of rotation **699**. Again, in other embodiments (not shown), more than two colors (from phosphors and/or diffusers) can be used by combining the configurations of both FIG. **4**A and FIG. **6**A.

[0125] In further detail, FIG. **6**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited two-color stationary-phosphor light source **601** that uses a rotating mirror-lens assembly **610** to move a reflected laser beam **635** across phosphor **623** (having a first color output) and to move a reflected laser beam **653** across phosphor **622** (having a second color output), each in a circular path, and outputs a wavelength-converted stationary output beam **640** having two colors of light reflected from rotating mirror-lens assembly **610**, according to some embodiments of the present invention. In some embodiments, laser source **630** generates laser beam **631**, which, in some embodiments, is blue in color. In some embodiments, laser beam **631** is directed to a 45-degree wavelength-selective stationary mirror **609**, which, in some embodiments, reflects the blue laser light **631** downward as beam **632** and transmits the combined two (or more) colors of output phosphor light **638**, such that the output beam **640** is stationary on the axis of rotation **699** of system **601**. In some embodiments, rotating assembly enclosure **611** includes 45-degree mirror **612**, which reflects both the input blue laser light **632** and the output phosphor light **638** (which contains both colors of phosphor-emitted light from collimated beams **636** and **637**), is centered on the axis of rotation **699** and is mounted on the rotating assembly enclosure **611** such that mirror **612** and mirror **618** each rotate about the axis of rotation **699** (as do mirrors **613**, **614** and **615**). Mirror **612** reflects the laser beam **632** radially away from the axis of rotation **699** as beam **633**. In some embodiments, mirror **615** transmits laser beam **634** as downward laser beam **635** focused by lens assembly **617** toward green phosphor **623**, and mirror **615** transmits laser beam **652** to 45-degree mirror **614**, which reflects laser beam **653** downward to be focused by lens assembly **616** to red-phosphor layer **622**. Mirror **614** reflects the red-phosphor collimated output beam **637** as beam **639** toward mirror **615**, then from mirror **613** toward the axis of rotation **699**. Mirror **615** transmits the green-phosphor collimated output beam **636** and reflects red-phosphor beam **639** to mirror **613**, from where it is reflected as combined beam **638** toward mirror **612** on the axis of rotation **699**. As the whole assembly **611** is rotating, laser beam **635** will be scanning a circle onto green-phosphor layer **623**, and laser beam **653** will be scanning a circle onto the outer red-phosphor layer **622**, similar to what is shown in FIG. **5**. The red-phosphor emission from the excited phosphor **622** is collected by the lens assembly **616**, and green-phosphor emission from the excited phosphor **623** is collected by the lens assembly **617**. Lens assembly **616** and lens assembly **617** are each designed to accept the large-angle emission of light from the phosphor plate(s) that is/are excited by light from laser source **630** and laser source **650**, and collimate the light **637** and **636** that is then reflected by mirror **614** and transmitted by mirror **615**, respectively, and then transmitted around and/or through mirror wavelength-selective **609** (in some embodiments, mirror **609** is made much smaller, to be just large enough to reflect laser beam **631**, but small so as to allow much of beam **640** to pass around the outside perimeter of mirror **609**) as the phosphor-light output beam **640** along the axis of rotation **699**. This beam **640** is stationary relative to the phosphor-heatsink assembly **620**, and, in some embodiments, is coupled to a projection engine (not shown here, but such as projection engine **190** shown in FIG. **1**A). In some embodiments, rotating mirror-lens assembly **610** includes a counterweight **619** configured to balance the other components of rotating mirror-lens assembly **610** relative to the axis of rotation **699**.

[0126] FIG. **6**B is a side-view cross-sectional block diagram, at a second point in time, of a laser-excited two-color stationary-phosphor light source **601** (labeled here as **601'**), according to some embodiments of the present invention. Reference numbers **611'**, **612'**, **613'**, **614'**, **615'**, **618'**, **619'**, **633'**, **634'**, **635'**, **636'**, and **637'** refer to the parts or beams **611**, **612**, **613**, **614**, **615**, **618**, **619**, **633**, **634**, **635**, **636**, and **637**, respectively, at the second point in time.

[0127] Since laser outputs have very narrow spectra, in some embodiments more than two lasers are used if the laser outputs are combined with proper narrow-band filter/reflectors such that each phosphor ring is excited separately by a separate laser, which will increase the output power even further.

[0128] In the various embodiments described herein, such as FIGS. **4**A, **4**B, **6**A, and **6**B, by having a plurality of continuous rings each of the same phosphor composition, the output beam of each phosphor can be continuous in time (i.e., not flickering or pulsed). In some other embodiments, one or more of the plurality of phosphor and/or diffuser rings is segmented with a plurality of stripes or scannable areas of different-colored phosphors and/or diffusers (such as shown and described in FIGS. **13**C, **13**D, **14**A, **14**B, **15**A and **15**B) and the laser beam is scanned across the stripes of different-colored phosphors fast enough to blend the resulting emitted colors, as observed by the human eye.

[0129] FIG. **7**A and FIG. **7**B show another embodiment of this invention, in which the collimating lenses **716** are also stationary. The laser beam **735** is scanned onto the phosphor plate **722** using a rotating prism plate **711**. The laser beam **735** is deflected from the axis **799** of the collimating lens assembly **716** by a certain angle, depending on the design (e.g., angle between surface **712** and surface **713** and/or index of refraction) of the prism plate **711**. In this case as shown in FIG. **7**A, the laser beam **735** will be deflected to the right and the focused spot will be away from the center axis **799** to the right. The output from the phosphor **722** will also be collimated at the same angle towards the prism plate, and will be deflected back to the axial direction **799** by the same prism plate **711**. As motor **728** rotates the prism plate **711** around axis **727** by 180 degrees, to the position as shown in FIG. **7**B, the prism **711** is of the opposite (left-right) shape. The input beam is deflected to the left as shown in FIG. **7**B and the focused spot will be away from the center axis **799** to the left. The output from the phosphor **722** will also be collimated at the same angle towards the prism plate **711**, and will be deflected back to the axial direction **799** by the same prism plate **711**.

[0130] Continuing, FIG. **7**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **701** that uses a rotating prism assembly **710** (which includes prism **711**, with top surface **712** and bottom surface **713**, rotated in a circular direction **727** by motor **728**) to move a deflected laser beam **735** (from laser beam **732** reflected by small mirror **709** from laser beam **731** from laser source **730**) across phosphor **722** (having a first color output) in a circular path, and outputs a wavelength-converted stationary output beam **740** of light deflected from rotating prism **711**, according to some embodiments of the present invention.

[0131] FIG. **7**B is a side-view cross-sectional block diagram, at a second point in time **701'**, of a laser-excited stationary phosphor light source **701**, according to some embodiments of the present invention. Reference numbers **710'**, **711'**, **712'**, **713'**, and **735'** refer to the parts or beams **710**, **711**, **712**, **713**, and **735**, respectively, at the second point in time.

[0132] FIG. **8**A is a perspective side-view block diagram, at a first point in time, of a rotating prism assembly **710** that includes prism **711**, with top surface **712** and bottom surface **713**, according to some embodiments of the present invention.

[0133] FIG. **8**B is a side-view cross-sectional block diagram, at a second point in time **710'**, of rotating prism assembly **710**, according to some embodiments of the present invention. Reference numbers **710'**, **711'**, **712'**, and **713'** refer to the parts or beams **710**, **711**, **712**, **713**, respectively, at the second point in time.

[0134] FIG. **9**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **901** that uses a rotating prism assembly **910** (which includes prism **911**, with top surface **912** and bottom surface **913**, rotated in a circular direction by motor **928**) to move a deflected laser beam **935** across phosphor **922** (having a first color output) in a circular path, and outputs a wavelength-converted stationary output beam **940** of light deflected from rotating prism assembly **910**, according to some embodiments of the present invention. In some embodiments, output beam **940** is further collimated and/or focused by lens **908**. In some embodiments, laser beam **931** from laser source **930** is reflected downward as beam **932** by small mirror **909**. Rotating prism **911** receives beam **932** and deflects it in a rotating conical path as beam **935** at an acute angle to optical axis **999**. In some embodiments, mirror **909** is reflective for the wavelength(s) of laser beam **931** and transmissive for phosphor-emitted beam **940**.

[0135] FIG. **9**B is a side-view cross-sectional block diagram, at a second point in time **901'**, of a laser-excited stationary phosphor light source **901**, according to some embodiments of the present invention. Reference numbers **910'**, **911'**, **912'**, and **913'** refer to the parts or beams **910**, **911**, **912**, **913**, respectively, at the second point in time.

[0136] FIG. **10**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **1001** that uses a rotating prism assembly **1010** to move a deflected laser beam **1035** across phosphor **1022** (having a first color output) in a circular path, and outputs a wavelength-converted stationary output beam **1040** of light deflected from rotating prism assembly **1010**, according to some embodiments of the present invention. In some embodiments, laser beam **1031** from laser source **1030** is reflected by small mirror **1009** to become laser beam **1032** (in some embodiments, mirror **1009** is reflective for the wavelength(s) of laser beam **1031** and transmissive for phosphor-emitted beam **1040**). In some embodiments, rotating prism assembly **1010** includes a prism **1011** (with a top surface **1012**) that transitions in thickness as shown in FIG. **10**C from sloping from its center downward in the outward direction as shown at the left side in FIG. **10**F, to a constant thickness as shown in FIG. **10**E and then transitions in thickness from sloping from its center upward in the outward direction as shown at the right side in FIG. **10**F.

[0137] FIG. **10**B is a side-view cross-sectional block diagram, at a second point in time **1001'**, of a laser-excited stationary phosphor light source **1001**, according to some embodiments of the present invention. In FIG. **10**B, motor **1028** has rotated prism **1011** by 180 degrees so that top surface **1012'** (the same top surface of prism **1011** of FIG. **10**A, but now rotated 180 degrees) deflects beam **1032** as beam **1035'** in the opposite angular direction as was shown in FIG. **10**A).

[0138] FIG. **10**C is a perspective side-view block diagram, at the first point in time, of rotating prism **1011**, according to some embodiments of the present invention. In some embodiments, as shown here, rotating prism **1011** is formed as a series of wedge prisms each having a slightly different angle than each of its neighbors, such that each wedge prism deflects the laser beam **1032** only radially outward or radially inward by a different amount (or not deflected, in the case of the profile show in FIG. **10**E), and thus the scanned pattern on phosphor **1022** will be spots along a straight line. In other embodiments, rotating prism **1011** is formed having a continuously sloped surface in the circumferential direction that deflects the laser beam **1032** not only radially inward and outward, but also sideways relative to the radius of rotating prism **1011**, such that the scanned pattern is an oval or circle or other curvilinear shape.

[0139] FIG. **10**D is a top-view block diagram, at the first point in time, of rotating prism **1011**, according to some embodiments of the present invention. FIG. **10**D shows prism plate **1011** with the shape at cross-section line **10**E shown by the thickness of plate **1011** in FIG. **10**E, and the shape at cross-section line **10**F shown by the thickness of plate **1011** in FIG. **10**F. When the top and bottom positions of the plate **1011** of FIG. **10**D are under the laser beam (where the thickness of prism **1011** is uniform (not tilted in a radial direction), as shown in FIG. **10**E), the focused spot will be at the axis position of the system. In some embodiments, the rest of the area of the prism plate **1011** has a step-wise transition from the four positions (top and bottom, left and right), such that the focused spot will be moving along the phosphor plate back and forth in along a line, increasing the effective area of excitation of the phosphor plate **1122**, which is cooled by a larger area of heatsink **1124**.

In other embodiments (not shown), the rest of the area of the prism plate **1011** has a continuous transition, such that the focused spot will be moving along the phosphor plate in a curvilinear path (such as a circle), increasing the effective area of excitation.

[0140] FIG. **10**E is a side-view cross-sectional block diagram, at cross-section line **10**E of FIG. **10**D, of rotating prism **1011**, according to some embodiments of the present invention.

[0141] FIG. **10**F is a side-view cross-sectional block diagram, at cross-section line **10**F of FIG. **10**D, of rotating prism **1011**, according to some embodiments of the present invention.

[0142] FIG. **11** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **1101**, according to some embodiments of the present invention. In FIG. **11**, the scanning of the focused input laser spot on phosphor plate **1122** is performed by an on-axis rotating prism **1111** that is part of brushless-motor-prism assembly **1110**, which, in some embodiments, also includes a circumferential set of permanent magnets **1161** attached to prism plate **1111**, and which is rotated around the axis of rotation **1199** by electrical signals in coil **1160**. The laser input beam **1131** from laser source **1130** used for excitation is directed downwards by reflector **1109** as beam **1132** along the optical axis **1199** of system **1101**, and then deflected by prism **1111** as beam **1135** and focused by stationary collimating lens assembly **1116** towards the stationary phosphor plate **1122**. In some embodiments, a mirror or wavelength-selective blue-reflective filter is used as reflector **1109**, which is made as small as possible so as to cover the laser beam **1131**, while minimally blocking the output beam **1140**. In some embodiments, when the input laser beam **1132** passes through the prism plate **1111**, the output **1135** is shifted at an angle with respect to the optical axis **1199** and as a result, as prism plate **1111** rotates will be focused through the collimating lens **1116** in a circle at a radial distance from the optical axis **1199** onto the phosphor plate **1122**, which in some embodiments, is deposited on heatsink **1124** to form phosphor-heatsink assembly **1120**. The emission **1126** from the phosphor **1122** excited by the focused laser beam **1135** at a radial distance from the optical axis **1199** is collimated by collimating lens assembly **1116**, with the output beam **1127** tilted at an angle from the optical axis **1199**. This tilted output beam **1127** then passes through the rotating prism **1111** and is thereby tilted back again centered along the optical axis **1199**. As the rotating prism **1111** continues to rotate, the path of the focused laser beam **1135** traces a circle on the phosphor plate **1122**, such as circle **242** as shown in FIG. **3**. The circular path **242** of the focused spot around the optical axis spreads the heat from laser-excited phosphor plate **1122** over a much larger area of heatsink **1124** than a single spot. At any position of the spot around the axis of rotation due to the rotating prism plate **1111**, the output beam **1140** remains stationary for coupling to the output apparatus (in various embodiments, a projection engine **190** (such as shown in FIG. **1**A) that includes a light projector, vehicle headlight, spotlight or other system that uses light beam **1140** for some purpose). In some embodiments, the output-power capacity based on the increased effective area of the focused spot on phosphor plate **1122** is increased eight times, which is very beneficial to high-power applications. If higher power is desired, the angle of the prism plate **1111** can be increased, providing a larger-diameter circle and circumference length of the excitation region, increasing the area of the excitation area that is cooled by heatsink **1124**. This further increases the power capacity of the system **1101**.

[0143] In other embodiments, one or both of the surface(s) of the prism plate of any of the embodiments described herein can be designed using a free-form (e.g., computer-designed) surface such that the focused spot can be scanned to a desired pattern across a larger area.

[0144] In another embodiment, two rotating prism plates as shown in FIG. **12**A, FIG. **12**B, FIG. **12**C are used, placing them in a serial path to each other as shown in the top view of FIG. **12**D. If the two prism plates are rotating at the same speed, the focused spot from beam **1235** will form a circle on the phosphor plate **1222**. If the two prism plates are of different deflection angles and/or are rotated at different speeds relative to one another, the focused spot will form a two-dimensional pattern such as **1219** of FIG. **12**D (such as generated by a spirograph toy) on the phosphor plate **1222**, further increasing the area of the focused spot. If the two prism plates have different-angle prisms (i.e., wherein the angle between the two faces of one prism is different than the angle between the two faces of the other prism), and/or have different indices of refraction, the amount of offset at the focused spot will be different in two directions, forming an elliptical path on the phosphor plate. As a result, the combination of two prism plates provides a wide range of focused spot patterns and dimensions, further increasing the power-handling capacities of the system.

[0145] In further detail, FIG. **12**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **1201** that uses two rotating prism assemblies **1210** (which includes motor **1228** and prism **1211**) and **1215** (which includes motor **1229** and prism **1214**) mounted to serially deflect a laser beam to be a deflected laser beam **1235** that scans across phosphor **1222** (having a first color output) in a spiral-circular path, and outputs a wavelength-converted stationary output beam **1240** of light deflected in reverse trajectories by the two rotating prism assemblies **1210** and **1215**, according to some embodiments of the present invention. In some embodiments, laser beam **1231** from laser source **1230** is reflected by small mirror **1209** to be laser beam **1232** (in some embodiments, mirror **1209** is highly reflective for the wavelength(s) of laser beam **1231** and highly transmissive for phosphor-emitted beam **1240**, while in other embodiments, mirror **1209** is highly reflective at many wavelengths (in order to reduce cost) and simply made small enough to block only a negligible amount of wavelength-converted output beam **1240**). In some embodiments, motor **1229**, located to a side of the light beams **1232** and **1240**, rotates a thicker prism **1214** that deflects laser beam **1232** at a relatively larger angle to be beam **1233**, and motor **1228**, located to another side of the light beams **1232** and **1240**, rotates a thinner prism **1211** that deflects laser beam **1233** at a relatively smaller additional angle to be beam **1235**.

[0146] FIG. **12**B is a side-view cross-sectional block diagram, at a second point in time **1201'**, of a laser-excited stationary phosphor light source **1201**, according to some embodiments of the present invention.

[0147] FIG. **12**C is a side-view cross-sectional block diagram, at a third point in time **1201"**, of a laser-excited stationary phosphor light source **1201**, according to some embodiments of the present invention.

[0148] FIG. **12**D is a top-view block diagram, at the first point in time, of rotating prism assemblies **1210** and **1215**, according to some embodiments of the present invention.

[0149] FIG. **13**A is a top-view block diagram of a system **1301** with a rotated focused spot **1331** moved around circular path **1335** (resulting from a single rotating prism (such as shown in FIG. **11**)) on a phosphor plate **1322**, according to some embodiments of the present invention.

[0150] FIG. **13**B is a top-view block diagram of a system **1302** with a rotating pattern **1336** (e.g., formed by a thin rotating prism **1211** of FIG. **12**A) that is moved around a circular path **1335** (e.g., formed by a thicker rotating prism **1214** of FIG. **12**A) on a phosphor plate **1322** resulting from two rotating prism assemblies **1210** and **1215**, according to some embodiments of the present invention.

[0151] FIG. **13**C is a top-view block diagram of a system **1303** with a rotated focused spot **1331** moved around circular path **1335** (resulting from a single rotating prism (such as shown in FIG. **11**)) on a phosphor and/or diffuser plate **1323** having a plurality of different phosphor stripes and/or diffusor stripes (such as assembly **1401** shown in FIG. **14**A), according to some embodiments of the present invention.

[0152] FIG. **13**D is a top-view block diagram of a system **1304** with a rotating pattern **1336** (e.g., formed by a thin rotating prism **1211** of FIG. **12**A) that is moved around a circular path **1335** (e.g., formed by a thicker rotating prism **1214** of FIG. **12**A) on a phosphor and/or diffuser plate **1324** having a plurality of different phosphor areas and/or diffusor areas (such as assembly **1501** shown in FIG. **15**A), according to some embodiments of the present invention.

[0153] FIG. **14**A shows another embodiment, where the phosphor plate is made up of a plurality of segments of different-colored phosphor. As shown in FIG. **14**A, red phosphor **1415**, green phosphor **1416** and yellow phosphor **1417** are used to produce those three colors. The diffuser section **1418** is used for blue-light output where the input laser light is reflectively diffused with the desired output diffusion angle, matching intensity and direction with the other colors. In some embodiments, the lengths of the arcs (or segments) are designed according to the efficiencies of wavelength conversion and desired ratios of the color output intensities. In some embodiments, the rotating prism deflection angle may be increased such that the scanning path is longer, allowing better separation of colors. Instead of making the color phosphor arcs as in FIG. **14**A, other embodiments use simple square (as shown in FIG. **15**A) or triangular or other suitably shaped phosphor plates, according to the chosen ratios of the different color outputs. In some such embodiments, the length of the scan path for each of the segments **1415**, **1416**, **1417**, and **1418** is made of equal length, as shown in FIG. **14**A. In other embodiments, the length of the scan path for each of the segments **1415**, **1416**, **1417**, and **1418** is made of different lengths, as shown in FIG. **14**B.

[0154] Continuing, FIG. **14**A is a top-view block diagram of a combined diffuser and multi-color phosphor plate **1401** with equal arc lengths of red phosphor **1415**, green phosphor **1416**, yellow phosphor **1417**, and diffuser **1418** for the blue laser light, according to some embodiments of the present invention.

[0155] FIG. **14**B is a top-view block diagram of a combined diffuser and multi-color phosphor plate **1402** with unequal arc lengths of red phosphor **1425**, green phosphor **1426**, yellow phosphor **1427**, and a diffuser **1428** for the blue laser light, as used in some embodiments of the systems to adjust the proportions of the various colors.

[0156] FIG. **15**A is a top-view block diagram of a combined diffuser and multi-color phosphor plate **1501** with equal arc lengths of red phosphor **1515**, green phosphor **1516**, yellow phosphor **1517**, and a diffuser **1518** for the blue laser light, each being a square, rectangle or other suitable geometric shape, according to some embodiments of the present invention.

[0157] FIG. **15**B is a top-view block diagram of a combined diffuser and multi-color phosphor plate **1502** with unequal arc lengths of red phosphor **1525**, green phosphor **1526**, yellow phosphor **1527**, and a diffuser **1528** for the blue laser light to adjust the proportions of the various colors, according to some embodiments of the present invention.

[0158] FIG. **16**A is a side-view cross-sectional block diagram of a rotating prism-motor assembly **1601**, at a first point in time, according to some embodiments of the present invention. In some embodiments, prism-motor assembly **1601** includes rotating motor coil **1661** holding rotating prism **1611**, that rotates around axis **1699** inside stationary coil **1660**, wherein the coils **1660** and **1661** are driven by electrical signals to cause the rotation of prism **1611**.

[0159] FIG. **16**B is a side-view cross-sectional block diagram of a rotating prism-motor assembly **1602**, at a first point in time, according to some embodiments of the present invention. In some embodiments, prism-motor assembly **1602** includes rotating permanent-magnet assembly **1662** holding rotating prism **1611**, that rotates around axis **1699** inside stationary coil **1660**, wherein the coil **1660** is driven by electrical signals to cause the rotation of prism **1611**.

[0160] FIG. **16**A and FIG. **16**B show embodiments of the rotating prism assembly in which the prism **1611** is mounted onto the hollow rotating coil **1661** or permanent-magnet assembly **1662**, which in turn is placed inside the static coil **1660**, forming a rotating motor with the rotating prism **1611** inside, without blocking the optical path. In other embodiments, other hollow rotating systems are used where the rotating prism is mounted therein. In some embodiments, one or more rotating prism assemblies are placed in a serial configuration along the optical axis **1699** such that the input laser beam (see FIG. **11** and FIG. **12**A) is scanned with two or more degrees of freedom, increasing the complexity of the scanned pattern on the phosphor and/or diffuser plate (see FIG. **13**A, FIG. **13**B, FIG. **13**C, and FIG. **13**D), as the two or more rotating prisms can have different rotation speeds, deflection angles, and phases. Even with multiple rotating prisms, the output beam will follow the input laser beam, in the opposite direction, and will have the same optical axis **1699** of the system. This increases the area of the scanned phosphor and/or diffuser regions, thus increasing the heat-dissipation capacity and power capacity of the system.

[0161] In another embodiment, the scanning can be performed using an oscillating mirror **1709** that oscillates in directions **1708**, as shown in FIG. **17**A, FIG. **17**B and FIG. **17**C representing system **1701** at three different points in time. The laser input **1731** is reflected by mirror **1709**, focused by lens assembly **1716** and incident onto the phosphor plate **1722** along the optical axis in FIG. **17**A. The wavelength-converted light output **1726** from phosphor plate **1722** is collected and collimated by the collimating lens assembly **1716** and reflected by mirror **1709** towards the output **1740** after being reflected by the oscillating mirror **1709**. When the oscillating mirror **1709** rotates to another position—such as mirror position **1709'** as shown in FIG. **17**B—the reflected laser input **1732'** is tilted at an angle towards the phosphor plate **1722**. Through the collimating lens **1716**, the focused spot from beam **1732'** will be at a distance to the right from the optical axis on phosphor plate **1722**. The output from the phosphor plate **1722** is collimated by the collimating lens **1716** with a beam also at an angle to the optical axis, but parallel to the laser input beam **1732'**. As the output beam is reflected by the oscillating mirror **1709'**, the output beam **1740** will have the same axis as, but opposite direction to, the input beam **1731**.

[0162] Further, FIG. **17**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **1701** that uses an oscillating mirror assembly **1710** (in some embodiments, including a mirror **1709** that rotates on axis **1707** when vibrated or oscillated by a motor **1706** that oscillates mirror **1709** in directions **1708**) to move reflected laser beam **1732** (the reflection of laser beam **1731**) across phosphor **1722** (having a first color output) in a straight-line path, and wavelength-converted light output **1726** from phosphor plate **1722** is collected and collimated by the collimating lens assembly **1716**, reflected by mirror **1709** and outputted as a stationary output beam **1740** of wavelength-converted and/or diffused light deflected from the oscillating mirror assembly **1710**, according to some embodiments of the present invention.

[0163] FIG. **17**B is a side-view cross-sectional block diagram, at a second point in time, of a laser-excited stationary phosphor light source **1701**, according to some embodiments of the present invention. FIG. **17**B shows the configuration where the oscillating mirror **1709'** is at a second position, in which the laser input beam **1732'** is focused at one side of the optical axis and wavelength-converted light output **1726'** from phosphor plate **1722** is collected and collimated by the collimating lens assembly **1716**, reflected by mirror **1709'** and outputted as a stationary output beam **1740** of wavelength-converted and/or diffused light deflected from the oscillating mirror assembly **1710**.

[0164] FIG. **17**C is a side-view cross-sectional block diagram, at a third point in time, of a laser-excited stationary phosphor light source **1701**, according to some embodiments of the present invention. FIG. **17**C shows the configuration where the oscillating mirror **1709"** is at a third position, in which the laser input beam **1732"** is focused on phosphor plate **1722** at the opposite side of the optical axis. The output beam **1726"** collimated by the collimating lens **1716** is also parallel to the laser input beam **1732"** and after reflection by the oscillating mirror **1709"**, the output beam **1740** will be parallel but have opposite direction to, and have the same optical axis as, the laser input beam **1731**.

[0165] FIG. **18**A is a side-view cross-sectional block diagram of a four-activator mirror-tilt device **1801**. In some embodiments, mirror-tilt device **1801** includes a reflector surface **1811** on substrate **1812** that is connected to four linear actuators **1813**, which are computer-controlled to provide a two-dimensional tilt to allow reflection of the impinging laser beam and the impinging phosphor-emitted light in a selected scan pattern (e.g., a raster scan, circular scan or any other desired scan pattern).

[0166] FIG. **18**B is a back-side-view cross-sectional block diagram of a four-activator mirror-tilt device **1801**.

[0167] FIG. **19** is a back-side-view cross-sectional block diagram of a three-activator mirror-tilt device **1901**, according to some embodiments of the present invention. In some embodiments, mirror-tilt device **1901** includes a reflector surface on substrate **1912** that is connected to three linear actuators **1913**, which are computer-controlled to provide a two-dimensional tilt to allow reflection of the impinging laser beam and the impinging phosphor-emitted light in a selected scan pattern (e.g., a raster scan, circular scan or any other desired scan pattern). In some embodiments, the rotary-scan mirror **1710** of FIGS. **17**A, **17**B, and **17**C is replaced by mirror-tilt device **1801** of FIGS. **18**A and **18**B, or by mirror-tilt device **1901** of FIG. **19**.

[0168] FIG. **20** is an isometric block diagram of an XY scanning-mirror system **2001**, according to some embodiments of the present invention. As the first oscillating mirror **2012** is operated by oscillating motor **2011**, the focused beam **2030** will be scanning the phosphor plate (not shown here) along a line for any given orientation of the second mirror **2022**, increasing the effective area of the focused spot on the phosphor plate, increasing the power-handling capacity of the system **2001**. The oscillating motion of additional oscillating mirror **2022** is added in some embodiments of the system **2001**, placed to be centered on the first reflected beam orthogonal to the first oscillating mirror **2012** such that the twice-reflected focused spot can be scanned in two dimensions, further increasing the effective area of the scanned focused spot on the phosphor plate. In some embodiments, the effective area is controlled by the amplitudes, the frequencies, and the phases of the movements of two oscillating mirrors **2012** and **2022**.

[0169] Since the phosphor plate onto which the two-dimensional scanned beam of each of the embodiments described herein is directed is stationary, in some embodiments the phosphor plate is heat sunk effectively with a large heat sink, a water-cooled heat sink, and the like, without having to move the phosphor plate together with its heavy heat sink, as in the case of a rotating or translated (e.g., translated in one or two linear directions) phosphor plate.

[0170] In other embodiments, with any of the configurations described previously, the phosphor plate is replaced by a diffuser plate, not shown, such that instead of emitting light at a different wavelength, the emitted light will be the diffused light with the same wavelength and frequency as the laser. Through the scanning of the laser beam on the diffuser surface, the output speckles will be averaged out, with reduced speckle contrast in the output beam. In some embodiments, such a system is used as a laser-light source with two or more different colors of laser beams and/or in combination with two or more different phosphors with different emission colors or spectrums, and/or diffuser plates, to produce different diffusion characteristics for various applications, such as projectors, vehicle headlights, entertainment lighting, etc.

[0171] FIG. **21** shows another embodiment, where two rotating prisms **2111** and **2113** are used so that the laser beam **2135** is steered in any direction as determined by the orientations, thicknesses, speeds of rotation and the like of the individual prisms **2111** and **2113**. In various embodiments, the two prisms **2111** and **2113** are rotated at different speeds, different phases, and/or different directions. Instead of scanning the phosphor plate in a circle, various patterns can be achieved, allowing an increase in total scanned area, thus increasing the power-handling capacity of the system **2101** through greater heat-dissipation capacity.

[0172] In further detail, FIG. **21** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2101** that uses two rotating prism assemblies **2110** and **2112** to successively deflect a laser beam, and thus move a deflected laser beam **2135** across phosphor assembly **2122** (having one or more phosphor-color and/or diffuser outputs, such as shown in FIGS. **13**A-**13**D, **14**A-**14**B, and **15**A-**15**B) in a spiral-circular (or other shaped) path, and light source **2101** outputs a stationary output beam **2140** of wavelength-converted and/or diffused light deflected from the two rotating prism assemblies **2110** and **2112** and output lens **2108**, according to some embodiments of the present invention. In some embodiments, laser source **2130** generates a laser beam **2131** that is reflected by stationary mirror **2109** to form downward stationary beam **2132**. In some embodiments, two rotating prisms are used so that the laser beam **2132** can be steered in any direction determined by the orientations of the individual prisms **2111** and **2113**. In some embodiments, the two prisms **2111** and **2113** are rotated at different speeds, different phases, and/or oriented to deflect in arbitrary different directions and/or are of different thicknesses or indices of refraction to deflect the beam by the same or different angular amounts. In addition to the option of scanning the phosphor plate **2122** in a circle, various patterns (such as spiral-circular, raster-scan or other shaped patterns obtained by the vector addition of the deflection due to the orientation of prism **2111** (and its thickness) and the deflection due to the orientation of prism **2113** (and its thickness)) can be achieved, allowing an increase in total scanned area of phosphor plate **2122** in contact with heatsink **2124**, thus increasing the power-handling capacity of the system **2101**.

[0173] FIG. **22** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2201** that uses a rotating prism-lens assembly **2210** to move a deflected laser beam **2235** across phosphor assembly **2222** (having one or more phosphor-color and/or diffuser reflectors, such as shown in FIGS. **13**A-**13**D, **14**A-**14**B, and **15**A-**15**B) in a circular path, and light source **2201** outputs a stationary output beam **2240** of wavelength-converted and/or diffused light deflected from the rotating prism-lens assembly **2210** and output lens **2208**, according to some embodiments of the present invention. In some embodiments, laser beam **2231** from laser source **2230** is reflected by fixed mirror **2209** as beam **2232** directed into rotating prism-lens assembly **2210** that includes prism **2212** and lens assembly **2228** mounted in housing **2211**. Some embodiments include an output lens **2208**. FIG. **22** shows an embodiment where the wedge prism **2212** and the collimating lenses **2228** are integrated into a single assembly **2210** for rotation. Although the moving weight is higher, the assembly can be made simply and can be made much more cost effectively than some other embodiments. In some embodiments, a counterweight (not shown) is provided to balance the spinning structure **2210**. This provides more flexibility for the system designer.

[0174] FIG. **23** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2301** that uses a rotating prism-lens assembly **2310** having a tilted collimating lens assembly **2328** to move a deflected laser beam **2335** across phosphor assembly **2322** (having one or more phosphor-color and/or diffuser reflectors, such as shown in FIGS. **13**A-**13**D, **14**A-**14**B, and **15**A-**156**B) in a circular path. In some embodiments, light source **2301** outputs a stationary output beam **2340** of wavelength-converted and/or diffused light deflected from the rotating prism-lens assembly **2310** and output lens **2308**, according to some embodiments of the present invention. In some embodiments, laser beam **2331** from laser source **2330** is reflected by fixed mirror **2309** as beam **2332** directed into rotating prism-lens assembly **2310** that includes prism **2312** and tilted lens assembly **2328** mounted in housing **2311**. Some embodiments include an output lens **2308**. For further improvements on coupling efficiency, instead of having the collimating lenses used with an off-axis focused spot as in FIG. **22**, the collimating lenses **2328** of FIG. **23** are positioned with a tilted axis matching to the tilt of the beam **2335** deviated by the prism **2312**, as shown in FIG. **23**, such that the focusing of the laser beam and the collimation of the collected light are on the same optical axis of the collimating lens **2328**, eliminating off-axis aberrations. For small angular deviations of the light beam (s) by the prism **2312**, this may not be a big factor, but for very-high-power operations with larger angles, such off-axis focusing aberrations could be significant if not corrected, such as by the embodiment of FIG. **23**. In the case shown in FIG. **23**, the total weight of prism-lens assembly **2310** to be rotated will be greater than rotating the prism **2312** alone, but the improved focusing result is worth the effort of rotating the prism-lens assembly **2310**.

[0175] FIG. **24** and FIG. **25** show embodiments where a second prism (**2414** or **2514**) is added to each of the systems **2401** and **2501**, respectively, such that the incident beam and collimation of the collected light are perpendicular to the phosphor plate assembly **2422** or **2522**, respectively (each having one or more phosphor-color and/or diffuser reflectors, such as shown in FIGS. **13**A-**13**D, **14**A-**14**B, and **15**A-**156**B). This allows higher absorption of the excitation laser light and/or collection efficiency of emitted, diffused and/or reflected light, as the emission from the phosphor assembly surface is Lambertian and collection of light in the perpendicular direction can be most efficient.

[0176] In further detail, FIG. **24** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2401** that uses a rotating prism-lens assembly **2410** with two prisms **2412** and **2414** to move a deflected laser beam **2435** across phosphor assembly **2422** (having one or more different-color phosphor and/or diffuser reflectors) in a circular path, and outputs a stationary output beam **2440** of wavelength-converted and/or diffused light deflected from the rotating prism-lens assembly **2410** and output lens **2408**, according to some embodiments of the present invention. In some embodiments, laser beam **2431** from laser source **2430** is reflected by fixed mirror **2409** as beam **2432** directed into rotating prism-lens assembly **2410** that includes prism **2412**, lens assembly **2416**, and prism **2414** mounted in housing **2411**. Some embodiments include an output lens **2408**.

[0177] FIG. **25** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2501** that uses a rotating prism-lens assembly **2510** having a tilted collimating lens assembly **2528** (in some embodiments, having a plurality of lenses each along the same optical axis) and two prisms **2512** and **2514** to move a deflected laser beam **2535** across phosphor plate **2522** (having one or more phosphor-color and/or diffuser reflectors) in a circular path, and outputs a stationary output beam **2540** of wavelength-converted and/or diffused light deflected from the rotating prism-lens assembly **2510** and output lens **2508**, according to some embodiments of the present invention. In some embodiments, laser beam **2531** from laser source **2530** is reflected by fixed mirror **2509** as beam **2532** directed into rotating prism-lens assembly **2510** that includes prism **2512**, tilted lens assembly **2528**, and prism **2514** mounted in housing **2511**. Some embodiments include an output lens **2508**.

[0178] FIG. **26** and FIG. **27** show embodiments in which the collimating lens assembly (**2628** or **2728**) is "wedged" (acts as if the lens assembly includes a wedge prism), such that the bottom surface of the bottom lens is polished or molded at a non-perpendicular angle to the optical axis of the top lens. Such wedging in the collimating lens performs similar functions as the second wedge prism **2414** and **2514**, shown in FIGS. **24** and **25** respectively.

[0179] Continuing, FIG. **26** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2601** that uses a rotating prism-lens assembly **2610** having a tilted collimating lens assembly **2628** (in some embodiments, having a plurality of lenses, with a first lens **2617** oriented along a vertical optical axis (with respect to FIG. **26**) and a second lens **2618** oriented along a tilted axis relative to lens **2617**) and one prism **2612** to move a deflected laser beam **2635** across phosphor plate **2622** (having one or more phosphor-color and/or diffuser reflectors) in a circular path, and outputs a stationary output beam **2640** of wavelength-converted and/or diffused light deflected from the rotating prism-lens assembly **2610** and output lens **2608**, according to some embodiments of the present invention. In some embodiments, laser beam **2631** from laser source **2630** is reflected by stationary mirror **2609** as beam **2632** directed into rotating prism-lens assembly **2610** that includes prism **2612**, partially tilted lens assembly **2628** having a non-tilted lens **2617** and tilted lens **2618**, mounted in housing **2611**. Some embodiments include an output lens **2608**.

[0180] FIG. **27** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2701** that uses a rotating prism-lens assembly **2710** having a tilted collimating lens assembly **2728** (in some embodiments, having a plurality of lenses, with a first lens **2717** oriented along a first tilt optical axis (with respect to vertical in FIG. **27**) and a second lens **2718** oriented along a further-tilted axis relative to lens **2717**) and one prism **2712** to move a deflected laser beam **2735** across phosphor plate **2722** (having one or more phosphor-color and/or diffuser reflectors) in a circular path, and outputs a stationary output beam **2740** of wavelength-converted and/or diffused light deflected from the rotating prism-lens assembly **2710** and output lens **2708**, according to some embodiments of the present invention. In some embodiments, laser beam **2731** from laser source **2730** is reflected by fixed mirror **2709** as beam **2732** directed into rotating prism-lens assembly **2710** that includes prism **2712**, tilted lens assembly **2728** having a less-tilted lens **2717** and more-tilted lens **2718**, mounted in housing **2711**. Some embodiments include an output lens **2708**.

[0181] In other embodiments, the wedge-prism optical element of each of the embodiments herein can be composed of an array of wedges, as shown in FIG. **28**A and FIG. **28**B. In this case, the deviation angle can be made larger without a proportional increase in the overall prism thickness. In other embodiments (not shown), the two wedge-prism optical elements of FIGS. **12**A-**12**D, FIG. **21**, FIG. **24**, FIGS. **29**A-**29**E, and FIG. **30**, and the tilted plate **3112** of FIG. **31** are each replaced by two diffraction gratings (such as described in U.S. Pat. Nos. 3,728,117, 4,895,790, 6,097,863, 4,313,648, 6,822,796, 6,958,859 and/or 5,907,436 and configured to deflect a plurality of wavelengths including the wavelength of the excitation laser beam and the emitted wavelengths of the phosphor(s)), which, in some embodiments, each is a blazed diffraction grating (such as described in U.S. Pat. No. 5,907,436) for increased efficiency.

[0182] FIG. **28**A is a side-view cross-sectional block diagram, at a first point in time, of a multi-wedge prism device **2801** made of a plurality of prism wedges **2811**, according to some embodiments of the present invention. In some embodiments, each of the prism elements of the various embodiments described elsewhere herein that used a single-prism element is replaced by one or more multi-prism device(s) **2801** or diffraction grating(s), in particular, one or more blazed diffraction grating(s) such described in U.S. Pat. Nos. 3,728,117; 4,895,790; 6,097,863; 4,313,648; 6,822,796; 6,958,859; and/or 5,907,436, each of which is incorporated herein.

[0183] FIG. **28**B is a top-view block diagram, at the first point in time, of prism device **2801** made of a plurality of prism wedges **2811**, according to some embodiments of the present invention.

[0184] In some of the embodiments described herein, the motors used are made with static and moving coils, static permanent magnets and moving coils, or static coils with moving fields and/or moving magnets. In some embodiments, a DC motor or an AC motor is used. In some embodiments, the present invention uses brushless motors. In other embodiments, the present invention uses motors with brushes.

[0185] In some embodiments, the single-wedge or multi-wedge prisms described above are made with transparent materials, such as glass, quartz, plastic polymers, etc. In addition, the systems with wedge prisms in some embodiments are made instead using holographic elements or diffraction gratings that achieve the corresponding angle deflections. In some embodiments, such holographic elements or diffraction gratings are printed, molded, or etched onto various suitable transparent materials. In some embodiments, the holographic patterns are made using laser interference, or digitally created, forming a digital hologram of the wedge prism. In some embodiments, one or more holograms are used for the function(s) of the lens(es) and/or for the function(s) of the prism(s). In some embodiments, a single hologram combines the function of both a lens or lens system and one of the prisms.

[0186] FIGS. **29**A-**29**E show cross-sectional side views of another embodiment where the optical axis of collimating lens **2928** remains vertical and parallel to the system optical axis, which is also the rotational axis. This arrangement reduces off-axis aberrations and increases efficiency of the system. The deviation between the rotational axis and the collimating lens axis is provided by the two back-to-back wedge prisms in which the slanting surfaces are facing each other and the thin-side edge of one wedge prism is lined up with the thick side of the other wedge prism. In such configuration, the input beam direction will be turned by the top wedge prism from the system optical axis and the direction will be corrected by the bottom wedge prism such that the output of the second wedge prism is parallel to the system optical axis, but deviated by an amount, which is dependent on the separation between the two prisms and the angle between the two faces of the wedge prisms. A larger deviation will produce a larger circle of the scanned laser beam on the phosphor plate, as shown in FIG. **13**A, or two prisms can produce a spiral pattern as shown in FIG. **12**D and FIG. **13**B and FIG. **13**C, providing a larger effective area of the phosphor plate across which the laser beam is scanned, and increasing the system's heat-sink capability, for higher-power operations. As a result, the prism separation can be designed according to the required power level. In some embodiments, the two prisms and the collimating lens are housed assembled inside a column with a housing, which will be rotating during operation. Since the optical components are offset to one side according to the amount of deviation, the center of gravity of the system will not be at the rotational axis unless a balancing mass is added. As a result, in some embodiments, a balancing weight is added to the rotating column such that the center of gravity is shifted back to the rotational axis, providing a stable rotating column.

[0187] In more detail, FIG. **29**A is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **2901** that uses a rotating prism-lens assembly **2910** having a collimating lens assembly **2928** and two prisms **2911** and **2912** that rotate together to move a deflected laser beam **2935** across phosphor plate **2922** (having one or more phosphor-color and/or diffuser reflectors) in a circular path, and outputs a stationary output beam **2940** of wavelength-converted and/or diffused light deflected from the rotating prism-lens assembly **2910**, according to some embodiments of the present invention. In some embodiments, laser beam **2931** from laser source **2930** is reflected (downward in FIG. **29**) by stationary mirror **2909** to become beam **2932**. In some embodiments, rotating prism-lens assembly **2910** includes prisms **2911** and **2912** separated by a gap **2919**, optional counterweight **2918**, and lens assembly **2928** all mounted in housing **2911**. In some embodiments, the chromatic dispersion (spreading of different colors (wavelengths)) introduced into the wavelength-converted output light **2936** by one prism (e.g., prism **2912**) is removed (compensated by spreading in the opposite direction) by the other prism (e.g., prism **2911**). In some embodiments, reference number **2922** represents one or more phosphor and/or diffuser segments (such as shown in FIGS. **13**A, **14**A, **14**B, **15**A and/or **15**B) deposited on heatsink **2924** to form stationary phosphor-heatsink assembly **2920**.

[0188] FIG. **29**B is a side-view cross-sectional block diagram, at a second point in time, of laser-excited stationary-phosphor light source **2901'**, that shows the system **2901** of FIG. **29**A when system is rotated by 90 degrees relative to the side view of FIG. **29**A (i.e., when oriented in the orthogonal direction around the vertical axis **2999**).

[0189] FIG. **29**C is a side-view cross-sectional block diagram, at a third point in time, of laser-excited stationary-phosphor light source **2901"**, shows the system **2901** of FIG. **29**A when the system is rotated by 90 degrees relative to the side view of FIG. **29**A (i.e., when oriented in the opposite left-right direction around the vertical axis **2999**).

[0190] FIG. **29**D is a side-view cross-sectional block diagram, at a fourth point in time, of laser-excited stationary-phosphor light source **2901'"** that shows the system **2901** of FIG. **29**A when the system is rotated by 270 degrees around the vertical axis **2999** relative to the side view of FIG. **29**A.

[0191] FIG. **29**E is a side-view cross-sectional block diagram, at a fourth point in time, of laser-excited stationary-phosphor light source **2901""** that shows the system **2901** of FIG. **29**A when the system is rotated by 360 degrees around the vertical axis **2999**, back to the original view of FIG. **29**A. Rotating the lens-prism system **2910** draws the circular path on the phosphor plate, as shown in FIGS. **13**A and **13**C. FIGS. **29**A-**29**E illustrate various positions of the system (at 0-, 90-, 180-, and 270-degree positions and then back to the 0-degree position) during the continuous rotation of the rotating column. It is also noted that the input and output beams above the top wedge prism remain stationary on the original system optical axis **2999** and rotational axis. This allows the etendue of the rotating system to remain the same as the etendue of a single spot.

[0192] FIG. **30** is a cross-sectional side view of another embodiment, where the two wedge prisms are each flipped over (relative to the system of FIGS. **29**A-**29**E), with the flat surfaces of the two wedge prisms facing each other. In general, two wedge prisms **3012** and **3013** with different surface angles (i.e., where the angle between the two faces of one prism is different than the angle between the two faces of the other prism, with a corresponding selection or adjustment to the relative indices of refraction of the two prisms, if needed) can be used, as long as the deviation angle of the laser beam and phosphor emission light passing through each prism is the same angle as, and opposite in direction to, those of the other prism, such that the output beam after passing through the two prisms is parallel to the input beam, with a determined amount of deviation producing the focused spot circle onto the phosphor plate during rotation.

[0193] Continuing, FIG. **30** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **3001** that uses a rotating prism-lens assembly **3010** having a housing **3011** that holds a collimating lens assembly **3028** and two prisms **3012** and **3013** that rotate together to move a deflected laser beam **3035** across phosphor plate **3022** in a circular path, wherein beam **3035** is perpendicular to the surface of phosphor **3022**, and outputs a stationary output beam **3040** of wavelength-converted and/or diffused light deflected from the rotating prism-lens assembly **3010**, according to some embodiments of the present invention. In some embodiments, laser source **3030** emits a laser beam **3031** that is reflected (downward in FIG. **30**) by stationary mirror **3009** to become beam **3032**. In some embodiments, rotating prism-lens assembly **3010** includes prisms **3012** and **3013** separated by a gap **3019**, optional counterweight **3018**, and lens assembly **3028** all mounted in housing **3011** to rotate together. In some embodiments, reference number **3022** represents one or more phosphor and/or diffuser segments (such as shown in FIGS. **13**A, **14**A, **14**B, **15**A and/or **15**B) deposited on heatsink **3024** to form stationary phosphor-heatsink assembly **3020**.

[0194] FIG. **31** is a cross-sectional side view of another embodiment, where the two prisms **3012** and **3013** of FIG. **30** are replaced by an angled plate **3112** having thickness **3119**, in which the input beam **3132** and output beam **3135** are parallel to each other with the output axis of beam **3135** being displaced to the side of the system optical axis **3199** and the rotational axis (also aligned to optical axis **3199**).

The amount of displacement is determined by the angle of the plate **3112** relative to the rotational axis **3199** and thickness **3119** of plate **3112**. In some embodiments, plate **3112** is shaped as shown or, in other embodiments, is simply a round plate having top and bottom surfaces that are perpendicular to its cylindrical perimeter, assembled at a tilted angle in housing **3111**, which may have a lower cost. In some embodiments, plate **3112** is made from one or more transparent materials such as glass, fused silica, plastic, or other suitable material. In some embodiments, higher-index-of-refraction materials are used to make the plate thinner for the same amount of deviation.

[0195] Continuing, FIG. **31** is a side-view cross-sectional block diagram, at a first point in time, of a laser-excited stationary-phosphor light source **3101** that uses a rotating angled-plate-lens assembly **3110** having a collimating lens assembly **3128** and angled plate **3112** having thickness **3119** that rotate together to move a deflected laser beam **3135** across phosphor plate **3122** in a circular path, and outputs a stationary output beam **3140** of wavelength-converted and/or diffused light deflected from the rotating prism-lens assembly **3110**, according to some embodiments of the present invention. In some embodiments, laser beam **3131** from laser source **3130** is reflected (downward in FIG. **31**) by stationary mirror **3109** to become beam **3132**. In some embodiments, rotating prism-lens assembly **3110** includes angled plate **3112** having thickness **3119**, optional counterweight **3118**, and lens assembly **3128** all mounted in housing **3111**. In some embodiments, reference number **3122** represents one or more phosphor and/or diffuser segments (such as shown in FIGS. **13**A, **14**A, **14**B, **15**A and/or **15**B) deposited on heatsink **3124** to form stationary phosphor-heatsink assembly **3120**.

[0196] FIGS. **32**A and **32**B are side-view cross-sectional block diagrams, at two points in time, of a laser-excited stationary-phosphor light source **3201** that uses a scanning-mirror assembly **3210** (in some embodiments, including a mirror **3209** that is tilted to a pattern of X-Y angles to produce oscillations, rotations or other movements **3208** when tilted by actuators **3206** (similar to those shown in FIGS. **18**A, **18**B and **19**) to move a scan-deflected laser beam **3232**, focused through a stationary collimating-lens assembly **3216** across phosphor plate **3222** (having one or more phosphor-color and/or diffuser reflectors) along a straight-line path, and outputs a stationary output beam **3240** of wavelength-converted and/or diffused light deflected from the scanning-mirror assembly **3210**, according to some embodiments of the present invention.

[0197] FIG. **32**A and FIG. **32**B show an embodiment where the incoming blue laser beam **3231** is wide and collimated and is scanned by the mirror **3409** as shown such that the reflected beam **3232** is directed towards the stationary collimating lens **3216**, which is also a focusing lens. While mirror **3209** is scanning (moving from position **3209** in FIG. **32**A to position **3209'** in FIG. **32**B), the reflected beam (moved from direction labeled **3232** in FIG. **32**A to direction **3209'** in FIG. **32** is also scanning across X-Y deflection angles. When incoming beam **3232** is perpendicular to phosphor plate **3222** after being reflected from mirror **3209**, it will be focused onto a point on phosphor plate **3222** on the optical axis of the lens **3216**. When incoming beam **3232** is at an angle to the optical axis after being reflected from mirror **3209**, it will be focused to a point on phosphor plate **3222** towards the side of the optical axis. As mirror **3209** is scanning, the focused spot is also moving along a line on phosphor plate **3222**, increasing the effective area of excitation, reducing the power density, and allowing better heatsinking of phosphor plate **3222**. In various embodiments, scanning of mirror **3209** is done using a galvo scanner, motorized mirror, etc. In some embodiments, at the focus, laser beam **3232** excites phosphor plate **3222** and yellow light **3226** is emitted from the phosphor, usually with a Lambertian distribution. A portion of the output yellow light **3226**, within the numerical aperture of the stationary collimating lens **3216**, is collected and collimated towards the scanning mirror **3209**. The output beam **3226** will be aligned and in the opposite direction as the incoming laser beam **3232** and will be reflected by mirror **3209** to be output **3240** in the opposite direction and along the same axis of incoming laser beam **3231**; thus, the output beam **3240** remains stationary while mirror **3209** is scanning. This effectively produces an output from the moving focus spot on phosphor plate **3222** to become a fixed beam **3240** with the etendue value of a fixed focus spot.

[0198] In some embodiments, the scanning mirror system **3201**, as shown in FIG. **32**A and FIG. **32**B, is a single-axis system. The resulting focused spot on the phosphor plate **3222** moves along a straight line. In some embodiments, one or more additional scanning mirrors are added, not shown, but in a manner similar to that shown in FIG. **34**A or FIG. **34**B, in an orthogonal direction, with two-dimensional scanning being produced and various patterns, including circles, ellipses, etc. being produced, increasing the effective area of the scanned spot on phosphor plate **3222**, allowing better heat sinking while maintaining the etendue of the system as a single focused spot.

[0199] FIG. **33**A is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3301** that uses a rotating-tilted-mirror assembly **3360** with mirror **3368** mounted at a non-perpendicular angle to axis of rotation **3369** to move a scan-deflected laser beam **3335** through a stationary collimating-lens assembly **3316** across phosphor plate **3322** in a circular path, and outputs a stationary output beam **3340** of wavelength-converted and/or diffused light deflected from the scanning-mirror assembly **3360**, according to some embodiments of the present invention. In some embodiments, a laser (not shown) emits a laser beam **3331** (rightward in FIG. **33**) that is deflected downward around a circular path by rotating tilted mirror **3368** to become beam **3335**. In some embodiments, rotating-tilted-mirror assembly **3360** includes a plate **3318** rotated in a rotational direction **3327** around a rotational axis **3369** by motor **3351**, wherein plate **3318** has a reflective surface **3368** that is tilted at a non-perpendicular angle to the rotational axis **3369**. In some embodiments, reference number **3322** represents one or more phosphor and/or diffuser segments (such as shown in FIGS. **13**A, **14**A, **14**B, **15**A and/or **15**B) deposited on heatsink **3324** to form stationary phosphor-heatsink assembly **3320**.

[0200] FIG. **33**B is a side-view cross-sectional block diagram, at a first point in time, of a rotating-tilted-mirror assembly **3360** used to move a reflection-deflected laser beam **3335** around a circular path on phosphor **3322** in FIG. **33**A, according to some embodiments of the present invention. The top mirror surface **3368** is tilted at an angle relative to a perpendicular plane **3367** of the motor axis **3369** such that when the mirror **3368** is rotating, its surface is "wobbling" and will reflect an incoming laser beam to a scanning output beam on a conical path. As shown in FIG. **33**A, the scanning mirror **3209** in FIG. **32**A is replaced by this motorized rotating-tilting mirror **3368**. In some embodiments, incoming laser beam **3331** will then be scanned as rotating beam **3335** into a circular or other curvilinear pattern, focused by the collimating lens **3316** onto the phosphor plate **3322**. The locus of the focus path is also a circle or other curvilinear pattern, thus increasing the effective area of the focused spot on phosphor plate **3322**. In a similar manner as shown in FIG. **32**A, the emission from the phosphor plate **3322** is collected and collimated by stationary lens assembly **3316**, reflected by the rotating tilted mirror **3368**, and retraces the optical path back to the direction of the incoming laser beam **3331**; thus, output beam **3340** remains stationary such that the output etendue is the same as the output etendue from a stationary focused spot.

[0201] Similar to the scanning-mirror case, in some embodiments a second motorized tilted-rotating mirror is optionally added (as shown in FIG. **34**B) in an orthogonal direction, such that the two rotating mirror assemblies **3410** and **3460**, when combined, produce more complicated patterns, increasing the effective area of the focused spot on phosphor plate **3422** and allowing better heat sinking while maintaining the etendue of the system as a single focused spot.

[0202] FIG. **34**A is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3401** that uses a scanning-mirror assembly **3410** to move a scan-reflected laser beam **3432** along an oscillating straight-line path, and then a rotating-tilted-mirror assembly **3460** to reflect the scan-deflected beam **3432** to be oscillating-rotationally reflected laser beam **3435** that is directed through a stationary collimating-lens assembly **3416** across phosphor plate **3422** (having one or more phosphor-color and/or diffuser reflectors) in an oscillating-scan-plus-circular path, and outputs a stationary output beam **3440** of wavelength-converted and/or diffused light deflected back via rotating-tilted-mirror assembly **3460** and scanning-mirror assembly **3410**, according to some embodiments of the present invention. In some embodiments, scanning-mirror assembly **3410** includes mirror **3409** that rotates on axis **3407** when vibrated or oscillated by motor **3406**, and rotating-tilted-mirror assembly **3460** is substantially similar to rotating-tilted-mirror assembly **3360** of FIG. **33**B. In some embodiments, reference number **3422** represents one or more phosphor and/or diffuser segments (such as shown in FIGS. **13**A, **14**A, **14**B, **15**A and/or **15**B) deposited on heatsink **3424** to form stationary phosphor-heatsink assembly **3420**. Thus, laser-excited stationary-phosphor light source **3401** uses a combination of a scanning-mirror assembly **3410** and a rotating-tilted-mirror assembly **3460** that, together, scan across a larger scan area of phosphor plate **3422**, with added flexibility of patterns that can be generated, increasing the effective area scanned by the focused spot on phosphor plate **3422**.

[0203] FIG. **34**B is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3402** that uses a first rotating-tilted-mirror assembly **3420** to move a rationally-reflected laser beam **3433** along an rotating conical path, and then a second scanning-tilted-mirror assembly **3460** to further rotationally reflect laser beam **3436** to be then focused through a stationary collimating-lens assembly **3416** across phosphor plate **3422** (having one or more phosphor-color and/or diffuser reflectors) in a spirally-circular path, and outputs a stationary output beam **3441** of wavelength-converted and/or diffused light reflected back via rotating-tilted-mirror assembly **3460** and rotating-tilted-mirror assembly **3420**, according to some embodiments of the present invention. In some embodiments, rotating-tilted-mirror assembly **3420** is substantially similar to rotating-tilted-mirror assembly **3460**, but in some such embodiments, the tilted mirror surfaces **3426** and **3466** have different tilt angles relative to their respective rotational axes **3329** and **3369**. Even in embodiments of source **3402** where the tilt angles of tilted mirror surfaces **3426** and **3466** are the same, the distance from mirror **3426** to mirror **3466** being farther than the distance from mirror **3466** to lens **3416**, means that the circle pattern of mirror **3426** will be larger than the additional circle pattern from mirror **3466**. Thus, laser-excited stationary-phosphor light source **3402** uses a combination of two rotating-tilted-mirror assemblies **3420** and **3460** that, together, scan across a larger scan area of phosphor plate **3422**, with added flexibility of patterns that can be generated, increasing the effective area scanned by the focused spot on phosphor plate **3422**, thus allowing greater heat-dissipation capability. Other aspects of source **3402** are substantially similar to those of source **3401**.

[0204] FIG. **35** is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3501** that uses a wavelength-selective partially-reflecting-mirror assembly **3509** to reflect a portion of laser beam **3531** as laser beam **3532** toward a first collimating-lens assembly **3516** which focuses that partially reflected portion laser light **3532** onto reflective diffuser plate **3512** that is mounted on heatsink **3514** to form diffuser-heatsink assembly **3510**, wherein the remaining portion of laser light **3531** is passed by wavelength-selective partially-reflecting-mirror assembly **3509** as laser light **3533** and reflected by a rotating-tilted-mirror assembly **3560** to move a reflection-deflected laser beam **3535** through a stationary collimating-lens assembly **3516** across phosphor plate **3522** (having one or more phosphor-color and/or diffuser reflectors) in a circular path, and light source **3501** outputs a stationary output beam **3540** of wavelength-converted **3538** light reflected from the rotating-tilted-mirror assembly **3560** and from wavelength-selective partially-reflecting-mirror assembly **3509** (which is highly reflective to the wavelengths of wavelength-converted light **3538**), and diffused laser light **3537** from reflective diffuser plate **3512** that is transmitted through wavelength-selective partially-reflecting-mirror assembly **3509**, according to some embodiments of the present invention. In some embodiments, rotating-tilted-mirror assembly **3560** is substantially similar to rotating-tilted-mirror assembly **3360** of FIG. **33**B.

[0205] FIG. **36** shows an embodiment of a white-light system **3601** in which part of the blue laser input **3631** is reflected by wavelength-selective partially-reflecting mirror **3609** as beam **3632** towards a diffuser assembly **3660** having a reflective diffuser **3662** on a heatsink **3664** and a plurality of lenslets **3666**. The rest of blue laser input **3631** is passed through wavelength-selective partially-reflecting mirror **3609** as blue light **3633** directed towards the rotating tilted mirror assembly **3660** from which yellow light **3638** is generated as described above. Then the reflected diffused blue light **3637** transmitted through mirror **3609** and the yellow light **3638** reflected by mirror **3609** are combined using the partially reflecting mirror **3609** as shown, with a white output beam **3640** being produced. The ratio of blue light and yellow light is determined by the amount of partial reflection of blue light by wavelength-selective partially-reflecting-mirror assembly **3609**. The higher the amount of blue light that is reflected, the higher is the color temperature of the output white light **3640**.

[0206] Continuing, FIG. **36** is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3601** that uses a wavelength-selective partially-reflecting-mirror assembly **3609** to reflect a portion of laser beam **3631** as laser bream **3632** toward a two-dimensional micro-lens array **3666** which focuses that laser light **3632** onto reflective diffuser plate **3662**, wherein the remaining portion of laser light **3631** is passed by wavelength-selective partially-reflecting-mirror assembly **3609** as laser light **3633** and reflected by a rotating-tilted-mirror assembly **3660** to move a reflection-deflected laser beam **3635** through a stationary collimating-lens assembly **3616** across phosphor plate **3622** (having one or more phosphor-color and/or diffuser reflectors) in a circular path, and light source **3601** outputs a stationary output beam **3640** of wavelength-converted light **3638** reflected from scanning-mirror assembly **3660** and wavelength-selective partially-reflecting-mirror assembly **3609**, combined with the diffused light **3637** from diffuser assembly **3660** that is transmitted through wavelength-selective partially-reflecting-mirror assembly **3609**, according to some embodiments of the present invention.

[0207] In the embodiment of FIG. **36**, the collimated laser beam target at the diffuser is replaced by a micro lens array **3666** such that each lenslet focuses a portion of the blue laser beam **3632** onto the reflective diffuser plate **3662**. The diffused light is then collected and collimated by the lenslets of micro lens array **3666** and directed towards the output **3637**. As a result, each focused spot on diffuser plate **3662** will have a fraction of the total power and reduce the possibility of damaging the diffuser plate **3662**. The combined diffused output **3637** will form a portion of the combined single output beam **3640** of diffused blue light from diffuser **3662** and emitted phosphor light **3638**.

[0208] FIG. **37** is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3701** that uses a wavelength-selective partially-reflecting-mirror assembly **3709** to reflect a portion **3733** of laser-beams light **3732** (coming from laser beams **3731** from laser array **3730** reflected by highly reflective mirror **3708**) toward a first collimating-lens assembly **3717** which focuses that laser light **3733** onto reflective diffuser plate **3723**, wherein the remaining portion of laser light **3734** passed by wavelength-selective partially-reflecting-mirror assembly **3709** is reflected by a rotating-tilted-mirror assembly **3760** to move a reflection-deflected laser beam **3735** through a stationary collimating-lens assembly **3716** across phosphor plate **3722** (having one or more phosphor-color and/or diffuser reflectors) in a circular path, and light source **3701** outputs a stationary output beam **3740** of wavelength-converted light **3738** reflected from the scanning-mirror assembly **3760** and wavelength-selective partially-reflecting-mirror assembly **3709**, combined with the diffused light **3736** from diffuser assembly **3723** mounted on heatsink **3724** that is transmitted through wavelength-selective partially-reflecting-mirror assembly **3709**, according to some embodiments of the present invention. In some embodiments, laser array **3730**, reflective diffuser **3723** and phosphor plate **3722** are mounted to a common heatsink **3724**.

[0209] In some embodiments of FIG. **37** (not shown), lens assembly **3717** that focuses collimated laser beam **3733** onto diffuser plate **3723** is replaced by a micro lens array (such as micro lens array **3662** shown in FIG. **36**), such that each lenslet focuses a portion of the blue laser beam onto spaced-apart locations on the diffuser plate **3723**. The diffused light is then collected and collimated by the lenslet array and directed towards the output **3740**. As a result, each focused spot will have a fraction of the total power and reduce the possibility of damaging diffuser plate **3723**. The combined diffused output will form a single output beam of diffused blue light **3736** that is transmitted through partially-reflecting-mirror assembly **3709** to combine with the reflected phosphor-emitted light **3738** into output beam **3740**.

[0210] In the embodiment of FIG. **37** the phosphor plate **3722**, the diffuser plate **3723**, and the laser array **3730** are all placed on the same heat sink **3724** to form assembly **3720**, such that a single cooling system can be used, simplifying the configuration of the system. Similarly, in some embodiments, the diffuser section **3717**-**3723** as shown can also be replaced by the diffuser-lenslet section **3660** as shown in FIG. **36**.

[0211] FIG. **38** is a side-view cross-sectional block diagram, at two points in time, of a laser-excited stationary-phosphor light source **3801** that uses a rotating-tilted-mirror assembly **3860** with mirror **3868** mounted at a non-perpendicular angle to axis of rotation **3869** to reflect incoming laser beam **3834** from only a portion of mirror **3868** to one side of rotational axis **3869** to form a scan-deflected laser beam **3835** that is directed through a stationary collimating-lens assembly **3816** across phosphor plate **3822** in a circular or other curvilinear path, and outputs a stationary output beam **3840** of wavelength-converted and/or diffused light deflected from the scanning-mirror assembly **3860**, according to some embodiments of the present invention. In some embodiments, rotating-tilted-mirror assembly **3860** includes a plate **3818** rotated in a rotational direction **3827** around a rotational axis **3869** by motor **3851**, wherein plate **3818** has a reflective surface **3868** that is tilted at a non-perpendicular angle to the rotational axis **3869**. In some embodiments, reference number **3822** represents one or more phosphor and/or diffuser segments (such as shown in FIGS. **13**A, **14**A, **14**B, **15**A and/or **15**B) deposited on heatsink **3824** to form stationary phosphor-heatsink assembly **3820**. In some embodiments, incoming laser beam **3834** (propagating rightward in FIG. **38**) is deflected downward around a circular or other curvilinear path by rotating tilted mirror **3868** to become moving beam **3835** (shown in solid line at a first point in time and in dashed line at a second point in time) that is scanned across phosphor plate **3822**, and the phosphor-emitted or diffused return light **3836** (shown in solid line at the first point in time and in dashed line at the second point in time) is reflected by mirror **3868** to become beam **3838** that is co-linear with, but propagating in the opposite direction as input laser beam **3834**. In embodiments where input beam **3834** is stationary, output beam **3838** is stationary and is output as stationary beam **3840**. Dashed line **3868'** represents mirror **3868** at a second point in time when it has rotated around axis of rotation **3869**. In some embodiments, light source **3801** further includes an additional rotating mirror assembly (such as additional rotating-tilted-mirror assembly **3420** shown in FIG. **34**B) such that the input beam

3834 is rotating, and thus the output light **3838** will also be rotating and when reflected by the additional rotating-tilted-mirror assembly becomes a stationary output beam.

[0212] In some embodiments, the present invention provides a method that includes: deflecting a first laser beam in a moving scanned pattern onto a phosphor plate assembly that includes a heatsink, wherein the phosphor plate assembly includes a first phosphor that covers a first area of the heatsink and that emits wavelength-converted light of a first color spectrum in response to excitation from the scanned first laser beam; gathering and at least partially collimating the wavelength-converted light emitted from the first phosphor; and forming an output beam that includes the collimated wavelength-converted light emitted from the first phosphor and that remains stationary relative to the phosphor plate assembly as the first laser beam is moving in the scanned pattern across the phosphor plate assembly. In some embodiments, this method applies to the apparatus embodiments such as shown in FIGS. **1**A-B, **2**A-B, **4**A-B, **6**A-B, **7**A-B, **9**A-B, **10**A-B, **11**, **12**A-D, **17**-**19**, **21**, **22**, **23**, **24**, **25**, **26**, **27** **28**, **29**A-E, **30**, **31**, **32**A-B, **33**A, **34**, **35**, **36**, and/or **37**.

[0213] Some embodiments of the method further include mounting the first phosphor in thermal contact with a heatsink.

[0214] Some embodiments of the method further include depositing the first phosphor to cover the first area of the phosphor plate assembly in thermal contact with the heatsink, and depositing a second phosphor in thermal contact with the heatsink to cover a second area of the heatsink, wherein the second phosphor emits wavelength-converted light of a second color spectrum in response to excitation from the scanned first laser beam, wherein the second color spectrum is different than the first color spectrum; and scanning the first laser beam across both a surface of the first area of the first phosphor and a surface of the second area of the second phosphor of the phosphor plate.

[0215] In some embodiments of the method, the scanning includes reflecting the first laser beam from a moving mirror that is reflective of a wavelength of the first laser beam, wherein the scanning moves the first laser beam back-and-forth along a straight-line scan path across the first phosphor. In some embodiments, this method applies to the apparatus embodiments such as shown in FIGS. **1**A-B, and/or **32**A-B.

[0216] In some embodiments of the method, the scanning includes: reflecting the first laser beam by a first moving mirror that is reflective to a wavelength of the wavelength-converted light emitted from the first phosphor and moving the first moving mirror back and forth along a first direction at a first speed; reflecting the first laser beam reflected from a first moving mirror by a second moving mirror that is reflective to a wavelength of the first laser beam and that moves along the first direction at a second speed that is two times the first speed to scan the first laser beam back-and-forth along a straight-line scan pattern across the first phosphor; and reflecting the wavelength-converted light by a third moving mirror that is transmissive to a wavelength of the first laser beam, that is reflective to a wavelength of the first laser beam and that moves in a fixed distance and orientation in relation to the second moving mirror, wherein the third moving mirror transmits the first laser beam reflected by the second moving mirror, and wherein the gathering and at least partially collimating the wavelength-converted light remains in a fixed position and orientation in relation to the second moving mirror and the third moving mirror, and wherein the gathering and at least partially collimating the wavelength-converted light includes using a collimating assembly of one or more lenses configured to focus, onto the phosphor plate assembly, the first laser beam transmitted through the second moving mirror and to direct the collimated light emitted from the first phosphor toward the second mirror to be reflected by the second moving mirror toward the first moving mirror.

[0217] In some embodiments of the method, the deflecting of the first laser beam in a moving scanned pattern onto the phosphor plate includes reflecting the first laser beam by a first rotating mirror that is reflective of wavelengths of the first laser beam and the wavelength-converted light emitted from the first phosphor and scanning the first laser beam radially outward from a rotational axis of the first rotating mirror; and reflecting the radially scanned laser beam by a second rotating mirror that is reflective of wavelengths of the first laser beam and the wavelength-converted light emitted from the first phosphor, wherein the second rotating mirror and the second optical device are each located in fixed orientations radially outward from the rotational axis of the first rotating mirror, wherein the second rotating mirror and reflects the first laser beam through the second optical device toward the surface of the phosphor plate along a rotating path parallel to a rotational axis of the first rotating mirror such that the first laser beam traces a circular scan pattern across the first phosphor. In some embodiments, this method applies to the apparatus embodiments such as shown in FIGS. **2**A-B, **4**A-B, and/or **6**A-B.

[0218] In some embodiments of the method, the deflecting of the first laser beam in a moving scanned pattern onto the phosphor plate includes reflecting the first laser beam by a first rotating mirror that is reflective of a wavelength of the first laser beam, and wherein the scanning scans the first laser beam along a circular scan pattern across the first phosphor, and wherein the surface of the phosphor plate is planar.

[0219] Some embodiments of the method further include: depositing the first phosphor to cover the first area of the phosphor plate as a first annular ring in thermal contact with the heatsink; depositing a second phosphor that emits wavelength-converted light in response to excitation from the scanned first laser beam and is configured as a second annular ring, and wherein the first annular ring is outside a perimeter of the second annular ring; gathering and collimating wavelength-converted light from the second phosphor; combining the gathered and collimated light from the first phosphor and the gathered and collimated light from the second phosphor into a single combined beam; and reflecting the single combined beam radially inward toward the first mirror and reflecting the radially inward beam by the first mirror to be co-linear with the first rotational axis.

[0220] Some embodiments of the method further include obtaining the first laser beam; obtaining a second laser beam; wherein the phosphor plate assembly further includes a second phosphor that emits wavelength-converted light in response to excitation from the second laser beam and is configured as an annular ring, and wherein first phosphor is configured as an annular ring outside a perimeter of the annular ring of the second phosphor, and holding a plurality of reflectors, and the second optical device and the third optical device a fixed orientation and spacing to one another, wherein the plurality of reflectors includes at least a first wavelength-selective filter-mirror, wherein the plurality of reflectors is configured to scan the first laser beam through the second optical device in a circular path across the annular ring of the first phosphor and to scan the second laser beam through the third optical device in a circular path across the annular ring of the second phosphor, wherein the second optical device gathers and at least partially collimates the wavelength-converted light from the first phosphor, wherein the third optical device gathers and at least partially collimates the wavelength-converted light from the second phosphor, and wherein the first wavelength-selective mirror reflects the wavelength-converted light from the first phosphor and transmits the wavelength-converted light from the second phosphor such that the wavelength-converted light from the first phosphor and the wavelength-converted light from the second phosphor are combined into a single combined beam of wavelength-converted light, and wherein the first optical device is rotated around a rotational axis, and wherein the plurality of reflectors is configured to output light from the single combined beam of wavelength-converted light as a fixed-position beam propagating along the rotational axis.

[0221] Some embodiments of the method further include deflecting the first laser beam using a first prism, rotating the first prism around a rotational axis, wherein the first laser beam is propagated in a first direction along a first optical axis into the first prism, wherein the first rotating prism deflects the first laser beam at a rotated acute angle relative to the first optical axis into the second optical device such that the first laser beam passes through the second optical device to scan a curved path around a surface of first phosphor, wherein the second optical device gathers, collimates and directs the wavelength-converted light emitted from the first phosphor into the first prism, and wherein the first prism deflects the wavelength-converted light emitted from the first phosphor to propagate along the first optical axis in a direction opposite the first direction. In some such embodiments, the first prism has at least one non-planar surface designed to deflect the first laser beam at a plurality of different angular directions and different angular amounts such that the first laser beam traces a non-circular path across the first phosphor. In some other embodiments, the first prism has a plurality of prism wedges formed to have parallel planar surface segments such that the first prism deflect the first laser beam at a plurality of different angular directions such that the first laser beam traces a curved path across the first phosphor. In some embodiments, this method applies to the apparatus embodiments such as shown in FIGS. **7**A-B, **9**A-B, **10**A-B, **11**, **12**A-D, **17-19**, **21**, **22**, **23**, **24**, **25**, **26**, **27 28**, **29**A-E, **30**, **31**, **32**A-B, **33**A, **34**, **35**, **36**, and/or **37**.

[0222] Some embodiments of the method further include deflecting the first laser beam using a first prism that has a first planar major surface and a second planar major surface at an acute angle to the first planar major surface, rotating the first prism around a first rotational axis, wherein the first laser beam is propagated along a first optical axis into the first planar major surface of the first prism, wherein the first rotating prism deflects the first laser beam at a rotated acute angle relative to the first optical axis into the second optical device such that the first laser beam passes through the second optical device to scan a curved path around a surface of first phosphor, directing the wavelength-converted light emitted from the first phosphor into the first prism, and wherein the first prism deflects the wavelength-converted light emitted from the first phosphor to propagate along the first optical axis. In some such embodiments, the first planar major surface is perpendicular to the first optical axis. In other embodiments, the second planar major surface is perpendicular to the first optical axis. In some embodiments, the first rotational axis is colinear with the first optical axis. In some embodiments, the first rotational axis is parallel to and offset from the first optical axis.

[0223] Some embodiments of the method further include rotating a first prism around a first rotational axis, wherein the first prism has a first planar major surface and a second planar major surface at an acute angle to the first planar major surface of the first prism and deflecting the first laser beam using the first prism; rotating a second prism around a second rotational axis, wherein the second prism has a first planar major surface and a second planar major surface at an acute angle to the first planar major surface of the second prism and further deflecting the first laser beam using the second prism, wherein the first laser beam is propagated along a first optical axis into the first planar major surface of the first prism, wherein the first rotated prism deflects the first laser beam at a first rotated acute angle relative to the first optical axis, wherein the second prism is rotated around a second rotational axis, wherein the first laser beam as deflected by the first prism is propagated into the first planar major surface of the second prism, wherein the second rotated prism deflects the first laser beam at a second rotated acute angle relative to the first rotated acute angle such that the first laser beam propagates into the second optical device such that the first laser beam passes through the second optical device to scan a curved path around a surface of first phosphor, wherein the second optical device directs the wavelength-converted light emitted from the first phosphor into the second prism, and wherein the second prism deflects the wavelength-converted light emitted from the first phosphor into the first prism, and wherein the first prism deflects the wavelength-converted light emitted from the first phosphor to propagate along the first optical axis.

[0224] Some embodiments of the method further include rotating a first prism around a first rotational axis, wherein the first prism has a first planar major surface and a second planar major surface at an acute angle to the first planar major surface, maintaining the first prism and the second optical device in a fixed orientation and location relative to one another and rotating the first prism and the second optical device together a first rotational axis, wherein the first laser beam is propagated along a first optical axis into the first planar major surface of the first prism, wherein the first rotating prism deflects the first laser beam at a rotated acute angle relative to the first optical axis into the second optical device, such that the first laser beam passes through the second optical device to scan a curved path around a surface of first phosphor, wherein the second optical device directs the wavelength-converted light emitted from the first phosphor into the first prism, and wherein the first prism deflects the wavelength-converted light emitted from the first phosphor to propagate along the first optical axis. In some such embodiments, the second optical device has an optical axis that is parallel to and laterally offset from the first rotational axis. In some other such embodiments, the second optical device includes a plurality of lenses, at least one of which has an optical axis that is oriented at an acute angle relative to the first rotational axis.

[0225] Some embodiments of the method further include rotating a first prism around a first rotational axis, wherein the first prism has a first planar major surface and a second planar major surface at an acute angle to the first planar major surface, wherein the first prism and the second optical device are maintained in a fixed orientation and location relative to one another and are together rotated around a first rotational axis, wherein the first laser beam is propagated along a first optical axis into the first planar major surface of the first prism, wherein the first rotated prism deflects the first laser beam to propagate at a first rotated acute angle relative to the first optical axis into the second optical device, and wherein the second optical device has an optical axis that is tilted to match the first rotated acute angle relative to the first optical axis, such that the first laser beam passes through the second optical device to scan a curved path around a surface of first phosphor, wherein the second optical device directs the wavelength-converted light emitted from the first phosphor into the first prism, and wherein the first prism deflects the wavelength-converted light emitted from the first phosphor to propagate along the first optical axis.

[0226] Some embodiments of the method further include generating the first laser beam using a first laser.

[0227] Some embodiments of the method further include generating an initial laser beam using a first laser, and passing the initial laser beam through a transmissive diffuser plate to form the first laser beam, and rotating the transmissive diffuser plate around a diffuser-plate axis of rotation, while the transmissive diffuser plate is oriented at a non-perpendicular angle to the diffuser-plate axis of rotation.

[0228] Some embodiments of the method further include providing a heatsink in thermal contact with the first phosphor, and mounting a reflective diffuser to partially cover the heatsink, wherein the first optical device scans the first laser beam across both a surface of the first phosphor and a surface of the reflective diffuser of the phosphor plate.

[0229] Some embodiments of the method further include providing a heatsink in thermal contact with the first phosphor that covers a portion of the heatsink, covering a second area of the heatsink with a second phosphor that emits wavelength-converted light of a second color spectrum in response to excitation from the scanned first laser beam; covering a third area of the heatsink with a third phosphor that emits wavelength-converted light of a third color spectrum in response to excitation from the scanned first laser beam; covering a fourth area of the heatsink with a reflective diffuser, wherein scanning of the first laser beam includes scanning across a surface of the first phosphor, the second phosphor, the third phosphor and the reflective diffuser.

[0230] Some embodiments of the method further include providing a first motor and a first mirror, rotating the first mirror around a first rotational axis by the first motor, wherein the first mirror has a planar surface that is oriented at a non-perpendicular angle to the first rotational axis, wherein the first mirror reflects the first laser beam into the second optical device such that the first laser beam passes through the second optical device to trace a curved path across the first phosphor and the wavelength-converted light emitted from the first phosphor is gathered and at least partially collimated by the second optical device toward the first mirror, which reflects the wavelength-converted light along a path colinear with and in an opposite direction as the first laser beam.

[0231] 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. The apparatus of claim **25**, wherein the first optical device includes a moving mirror that is reflective of a wavelength of the first laser beam and that scans the first laser beam back-and-forth along a straight-line scan path across the first phosphor.

5. A laser-excited-phosphor light-source apparatus comprising:

a first optical device configured to deflect a first laser beam in a scanned pattern;

a phosphor plate assembly, wherein the first optical device scans the first laser beam across a surface of the phosphor plate, and wherein the phosphor plate assembly includes a first phosphor that covers a first area of the phosphor plate assembly and that emits wavelength-converted light of a first color spectrum in response to excitation from the scanned first laser beam; and

a second optical device configured to gather and at least partially collimate the wavelength-converted light emitted from the first phosphor,

wherein the laser-excited-phosphor light-source system forms an output beam that is stationary relative to the phosphor plate assembly,

wherein the first optical device includes:

a first moving mirror that is reflective to a wavelength of the wavelength-converted light emitted from the first phosphor and that moves along a first direction at a first speed;

a second moving mirror that is reflective to a wavelength of the first laser beam and that moves along the first direction at a second speed that is two times the first speed to scan the first laser beam back-and-forth along a straight-line scan pattern across the first phosphor; and

a third moving mirror that is transmissive to a wavelength of the first laser beam, that is reflective to a wavelength of the first laser beam and that moves in a fixed distance and orientation in relation to the second moving mirror, wherein the third moving mirror transmits the first laser beam reflected by the second moving mirror, and wherein the second optical device also moves in a fixed position and orientation in relation to the second moving mirror and the third moving mirror, and wherein the second optical device includes a collimating assembly of one or more lenses configured to focus, onto the phosphor plate assembly, the first laser beam transmitted through the second moving mirror and to direct the collimated light emitted from the first phosphor toward the second mirror to be reflected by the second moving mirror toward the first moving mirror.

6. The apparatus of claim **25**, wherein the first optical device includes:

a first rotating mirror that is reflective of wavelengths of the first laser beam and the wavelength-converted light emitted from the first phosphor and that scans the first laser beam radially outward from a rotational axis of the first rotating mirror; and

a second rotating mirror that is reflective of wavelengths of the first laser beam and the wavelength-converted light emitted from the first phosphor, wherein the second rotating mirror and the second optical device are each located in fixed orientations radially outward from the rotational axis of the first rotating mirror, wherein the second rotating mirror reflects the first laser beam through the second optical device toward the surface of the phosphor plate along a rotating path parallel to a rotational axis of the first rotating mirror such that the first laser beam traces a circular scan pattern across the first phosphor.

7. (canceled)

8. The apparatus of claim **25**, further comprising:

a third optical device that collects and collimates light;

wherein the phosphor plate assembly further includes a second phosphor that emits wavelength-converted light in response to excitation from the scanned first laser beam and is configured as an annular ring, and wherein first phosphor is configured as an annular ring outside a perimeter of the annular ring of the second phosphor, and

wherein the first optical device includes:

a first rotating mirror that is reflective to wavelengths of the first laser beam and the wavelength-converted light emitted from the first phosphor and that scans the first laser beam radially outward from a rotational axis of the first rotating mirror;

a second rotating mirror that is reflective to wavelengths of the first laser beam and the wavelength-converted light emitted from the first phosphor, wherein the second rotating mirror and the second optical device are each located in fixed orientations radially outward from the rotational axis of the first rotating mirror, wherein the second rotating mirror and reflects the first laser beam through the second optical device toward the surface of the phosphor plate along a rotating propagation path parallel to a rotational axis of the first rotating mirror such that the first laser beam traces a circular scan pattern across the annular ring of the first phosphor; and

a third rotating wavelength-selective mirror that is partially transmissive to wavelengths of the first laser beam, mostly transmissive to the wavelength-converted light emitted from the first phosphor, and mostly reflective to the wavelength-converted light emitted from the first phosphor, wherein the third rotating mirror is located in a fixed relationship between the first rotating mirror and the second rotating mirror such that a first portion of the first laser beam is transmitted toward the second rotating mirror and a remaining portion of the first laser beam is reflected toward and through the third optical device toward the surface of the phosphor plate such that the first laser beam traces a circular scan pattern across the annular ring of the second phosphor, and wherein the third optical device is configured to gather and at least partially collimate the wavelength-converted light emitted from the second phosphor as a beam toward the third rotating mirror.

9. (canceled)

10. The apparatus of claim **25**, wherein the first optical device includes a first prism, wherein the first prism is rotated around a rotational axis, wherein the first laser beam is propagated in a first direction along a first optical axis into the first prism, wherein the first rotated prism deflects the first laser beam at a rotated acute angle relative to the first optical axis into the second optical device such that the first laser beam passes through the second optical device to scan a curved path around a surface of first phosphor, wherein the second optical device directs the wavelength-converted light emitted from the first phosphor into the first prism, and wherein the first prism deflects the wavelength-converted light emitted from the first phosphor to propagate along the first optical axis in a direction opposite the first direction.

11. The apparatus of claim **10**, wherein the first prism has at least one non-planar surface designed to deflect the first laser beam at a plurality of different angular directions and different angular amounts such that the first laser beam traces a non-circular path across the first phosphor.

12. The apparatus of claim **10**, wherein the first prism has a plurality of prism wedges formed to have parallel planar surface segments such that the first prism deflect the first laser beam at a plurality of different angular directions such that the first laser beam traces a curved path across the first phosphor.

13. The apparatus of claim **25**, wherein the first optical device includes a first prism that has a first planar major surface and a second planar major surface at an acute angle to the first planar major surface, wherein the first prism is rotated around a first rotational axis, wherein the first laser beam is propagated along a first optical axis into the first planar major surface of the first prism, wherein the first rotated prism deflects the first laser beam at a rotated acute angle relative to the first optical axis into the second optical device such that the first laser beam passes through the second optical device to scan a curved path around a surface of first phosphor, wherein the second optical device directs the wavelength-converted light emitted from the first phosphor into the first prism, and wherein the first prism deflects the wavelength-converted light emitted from the first phosphor to propagate along the first optical axis.

14. The apparatus of claim **13**, wherein the first planar major surface is perpendicular to the first optical axis.

15. (canceled)

16. The apparatus of claim **13**, wherein the first rotational axis is colinear with the first optical axis.

17. (canceled)

18. The apparatus of claim **25**,

wherein the first optical device includes:

a first prism that has a first planar major surface and a second planar major surface at an acute angle to the first planar major surface of the first prism; and a second prism that has a first planar major surface and a second planar major surface at an acute angle to the first planar major surface of the second prism,

wherein the first prism is rotated around a first rotational axis, wherein the first laser beam is propagated along a first optical axis into the first planar major surface of the first prism, wherein the first rotated prism deflects the first laser beam at a first rotated acute angle relative to the first optical axis,

wherein the second prism is rotated around a second rotational axis, wherein the first laser beam as deflected by the first prism is propagated into the first planar major surface of the second prism, wherein the second rotated prism deflects the first laser beam at a second rotated acute angle relative to the first rotated acute angle such that the first laser beam propagates into the second optical device such that the first laser beam passes through the second optical device to scan a curved path around a surface of first phosphor, wherein the second optical device directs the wavelength-converted light emitted from the first phosphor into the second prism, and wherein the second prism deflects the wavelength-converted light emitted from the first phosphor into the first prism, and wherein the first prism deflects the wavelength-converted light emitted from the first phosphor to propagate along the first optical axis.

19. The apparatus of claim **25**, wherein the first optical device includes a first prism that has a first planar major surface and a second planar major surface at an acute angle to the first planar major surface, wherein the first prism and the second optical device are maintained in a fixed orientation and location relative to one another and are together rotated around a first rotational axis, wherein the first laser beam is propagated along a first optical axis into the first planar major surface of the first prism, wherein the first rotated prism deflects the first laser beam at a rotated acute angle relative to the first optical axis into the second optical device, such that the first laser beam passes through the second optical device to scan a curved path around a surface of first phosphor, wherein the second optical device directs the wavelength-converted light emitted from the first phosphor into the first prism, and wherein the first prism deflects the wavelength-converted light emitted from the first phosphor to propagate along the first optical axis.

20. The apparatus of claim **19**, wherein the second optical device has an optical axis that is parallel to and laterally offset from the first rotational axis.

21. The apparatus of claim **19**, wherein the second optical device includes a plurality of lenses, at least one of which has an optical axis that is oriented at an acute angle relative to the first rotational axis.

22. (canceled)

23. The apparatus of claim **25**, further comprising a first laser that generates the first laser beam.

24. The apparatus of claim **5**, further comprising:

a transmissive diffuser plate mounted to rotate around a diffuser-plate axis of rotation, wherein the transmissive diffuser plate is oriented at a non-perpendicular angle to the diffuser-plate axis of rotation; and

a first laser that generates an initial laser beam, wherein the initial laser beam is passed through the transmissive diffuser plate to form the first laser beam.

25. A laser-excited-phosphor light-source apparatus comprising:

a first optical device configured to deflect a first laser beam in a scanned pattern;

a phosphor plate assembly, wherein the first optical device scans the first laser beam across a surface of the phosphor plate, and wherein the phosphor plate assembly includes a first phosphor that covers a first area of the phosphor plate assembly and that emits wavelength-converted light of a first color spectrum in response to excitation from the scanned first laser beam; and

a second optical device configured to gather and at least partially collimate the wavelength-converted light emitted from the first phosphor,

wherein the laser-excited-phosphor light-source system forms an output beam that is stationary relative to the phosphor plate assembly, and

wherein the phosphor plate assembly further includes:

a reflective diffuser that covers an area of the phosphor plate assembly; and

a heatsink in thermal contact with the first phosphor and the reflective diffuser, wherein the first optical device scans the first laser beam across both a surface of the first phosphor and a surface of the reflective diffuser of the phosphor plate.

26. (canceled)

27. The apparatus of claim **25**, wherein the first optical device includes a first motor and a first mirror rotated around a first rotational axis by the first motor, wherein the first mirror has a planar surface that is oriented at a non-perpendicular angle to the first rotational axis, wherein the first mirror reflects the first laser beam into the second optical device such that the first laser beam passes through the second optical device to trace a curved path across the phosphor plate and the wavelength-converted light emitted from the first phosphor is gathered and at least partially collimated by the second optical device toward the first mirror, which reflects the wavelength-converted light along a path colinear with and in an opposite direction as the first laser beam.

28. A method comprising:

deflecting a first laser beam in a moving scanned pattern onto a phosphor plate assembly that includes a heatsink, wherein the phosphor plate assembly includes a first phosphor that covers a first area of the heatsink and that emits wavelength-converted light of a first color spectrum in response to excitation from the scanned first laser beam;

gathering and at least partially collimating the wavelength-converted light emitted from the first phosphor; and

forming an output beam that includes collimating the wavelength-converted light emitted from the first phosphor and that remains stationary relative to the phosphor plate assembly as the first laser beam is moving in the scanned pattern across the phosphor plate assembly.

29. The method of claim **28**, wherein the deflecting of the first laser beam in the moving scanned pattern includes:

providing a first rotating mirror that is reflective of wavelengths of the first laser beam and the wavelength-converted light emitted from the first phosphor;

providing a second rotating mirror that is reflective of wavelengths of the first laser beam and the wavelength-converted light emitted from the first phosphor;

scanning the first laser beam radially outward from a rotational axis of the first rotating mirror; and

reflecting, via the second rotating mirror, the first laser beam toward a surface of the phosphor plate assembly along a rotating path parallel to a rotational axis of the first rotating mirror such that the first laser beam traces a circular scan pattern across the first phosphor.

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