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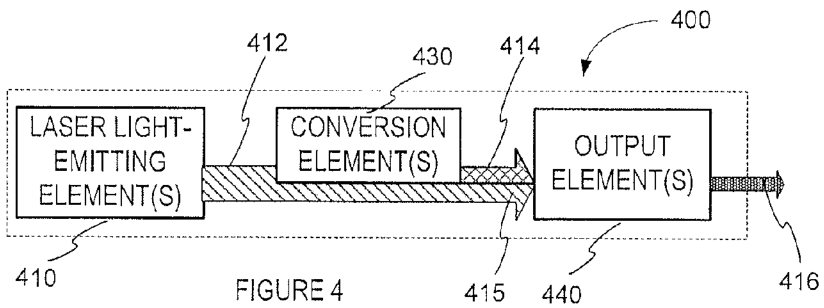

FIGURE 4

(57) Abstract: A laser light source (400) is configured to emit a light with a desirable luminous intensity suitable for general illumination. The laser light source (400) includes at least one laser light-emitting element (410) configured to generate a laser light; at least one light source output element (440) configured to direct the laser light into predetermined locations; and at least one conversion element (430). Furthermore, the at least one conversion element (430) includes a set of wavelength-conversion regions, e.g., phosphor regions, disposed on at least part of the predetermined locations. Each wavelength-conversion region is adapted to convert the laser light into a converted light (414), such that a combination of each of the converted lights (414) and the laser light (415) forms the light (416) with the desirable luminous intensity.

WO 2009/112961 A1

LASER LIGHT SOURCE AND LUMINAIRE

TECHNICAL FIELD

[0001] The present invention pertains to illumination systems. More particularly, various inventive methods and apparatus disclosed herein relate to a laser light source and luminaire.

BACKGROUND

[0002] Production of electricity requires considerable infrastructure, a significant amount of energy and has associated environmental costs of smog and carbon dioxide pollution. In the US, about 20% of electricity produced is used for lighting. Therefore, efficient means for lighting can result in significant energy savings and hence, cost savings.

[0003] The most widely used light sources for general illumination are incandescent and fluorescent lamps. Recently, solid-state lighting (SSL) devices have been touted to replace the above-mentioned conventional light sources with economic and environmental savings. These SSL devices are often associated, for example, with reduced heat generation, reduced parasitic energy dissipation, high switching speeds, vibration, wear and shock resistance, and long life times. They can be adapted for a wide variety of lighting applications including the provision of artificial lighting similar to natural daylight. Moreover, with appropriate circuitry and/or control systems, both the color and intensity of the light can be controlled.

[0004] The light output from SSL devices can be monochromatic or of narrow bandwidth in comparison to the light output from conventional light sources such as incandescent lamps and fluorescent lamps. For a number of general illumination applications, however, white light or broad spectrum light is preferred. One method for generating white light is to efficiently mix the respective spectral outputs of red, green, and blue light sources, for example red, green and blue LEDs, or other such colour combinations. Another method involves the use of LEDs with phosphorescent materials (phosphors), the output of which combining with the LED output to produce a substantially white light.

[0005] Currently, the most common SSL devices are light emitting diodes (LED) and organic LEDs (OLED). However, both of these are limited in their efficiencies, which typically range from about 5% to about 12%. In contrast, semiconductor lasers, also SSL devices, typically have much higher external quantum efficiencies of about 45% to 50%. Semiconductor lasers also offer many of the above mentioned advantages of SSL devices. Unlike LEDs, however, the light produced by lasers is coherent, and therefore, can result in undesirable optical effects when manipulated using conventional illumination technology.

[0006] To date, known laser light sources have not been adequately configured for lighting applications, such as general illumination applications. Therefore, there is a need for a laser light source and luminaire that addresses at least some of the drawbacks of known light sources.

SUMMARY

[0007] An object of the invention is to provide a laser light source and luminaire. Generally, in one aspect, the invention focuses on the laser light source, the laser light source configured to emit a light with a desirable luminous intensity suitable for general illumination. The laser light source further includes at least one laser light-emitting element configured to generate a laser light; at least one light source output element configured to direct the laser light into predetermined locations; and at least one conversion element. Furthermore, the at least one conversion element includes a set of wavelength-conversion regions, e.g., phosphor regions, disposed on at least part of the predetermined locations. Each wavelength-conversion region is adapted to convert the laser light into a converted light, such that a combination of each of the converted lights and the laser light forms the light with the desirable luminous intensity.

[0008] Phosphors are subject to saturation effects, wherein increase in a density of the laser light does not increase a phosphor luminous emittance. Hence, in some embodiments, the laser light source includes an optical element, e.g., a diffuser, positioned on a path of the laser light, the diffuser adapted to increase a divergence of the laser light, such that a saturation effect of at least one wavelength-conversion region in the set of phosphor regions is reduced.

[0009] In one embodiment, the set of wavelength-conversion regions includes a first wavelength-conversion region and a wavelength-conversion phosphor region. A wavelength-conversion material of the first wavelength-conversion region is selected based on a wavelength-conversion material of the second wavelength-conversion region, the luminous intensity of the laser light, and the desirable luminous intensity.

[0010] In accordance with one aspect of the invention, there is provided a laser light source comprising: one or more laser light-emitting elements operable to generate laser light; one or more light source output elements for providing illumination; and one or more conversion elements disposed to convert at least a portion of said laser light and optically couple at least a portion of said converted light to said one or more output elements for providing the illumination.

[0011] In accordance with another aspect of the invention, there is provided a laser luminaire comprising: one or more laser light-emitting elements operable to generate laser light; one or more luminaire output elements for providing illumination; one or more conversion elements disposed to convert at least a portion of said laser light and optically couple at least a portion of said converted light to said one or more output elements for providing the illumination; and a driving means for driving said one or more laser light-emitting elements.

[0012] As used herein for purposes of the present disclosure, the term "LED" should be understood to include any electroluminescent diode or other type of carrier injection/junction-based system that is capable of generating radiation in response to an electric signal. Thus, the term LED includes, but is not limited to, various semiconductor-based structures that emit light in response to current, light emitting polymers, organic light emitting diodes (OLEDs), electroluminescent strips, and the like. In particular, the term LED refers to light emitting diodes of all types (including semi-conductor and organic light emitting diodes) that may be configured to generate radiation in one or more of the infrared spectrum, ultraviolet spectrum, and various portions of the visible spectrum (generally including radiation wavelengths from approximately 400 nanometers to approximately 700 nanometers). Some examples of LEDs include, but are not limited to, various types of infrared LEDs, ultraviolet LEDs, red LEDs, blue

LEDs, green LEDs, yellow LEDs, amber LEDs, orange LEDs, and white LEDs (discussed further below).

[0013] For example, one implementation of an LED configured to generate essentially white light (e.g., a white LED) may include a number of dies which respectively emit different spectra of electroluminescence that, in combination, mix to form essentially white light. In another implementation, a white light LED may be associated with a phosphor material that converts electroluminescence having a first spectrum to a different second spectrum. In one example of this implementation, electroluminescence having a relatively short wavelength and narrow bandwidth spectrum "pumps" the phosphor material, which in turn radiates longer wavelength radiation having a somewhat broader spectrum.

[0014] The term "light source" should be understood to refer to any one or more of a variety of radiation sources, including, but not limited to, LED-based sources (including one or more LEDs as defined above), incandescent sources (e.g., filament lamps, halogen lamps), fluorescent sources, phosphorescent sources, high-intensity discharge sources (e.g., sodium vapor, mercury vapor, and metal halide lamps), lasers, other types of electroluminescent sources, pyro-luminescent sources (e.g., flames), candle-luminescent sources (e.g., gas mantles, carbon arc radiation sources), photo-luminescent sources (e.g., gaseous discharge sources), cathode luminescent sources using electronic satiation, galvano-luminescent sources, crystallo-luminescent sources, kine-luminescent sources, thermo-luminescent sources, triboluminescent sources, sonoluminescent sources, radioluminescent sources, and luminescent polymers.

[0015] A given light source may be configured to generate electromagnetic radiation within the visible spectrum, outside the visible spectrum, or a combination of both. Hence, the terms "light" and "radiation" are used interchangeably herein. Additionally, a light source may include as an integral component one or more filters (e.g., color filters), lenses, or other optical components. Also, it should be understood that light sources may be configured for a variety of applications, including, but not limited to, indication, display, and/or illumination. An "illumination source" is a light source that is particularly configured to generate radiation having a sufficient intensity to effectively illuminate an interior or exterior space. In this context, "sufficient intensity" refers to sufficient radiant power in the visible spectrum generated in the space or environment (the unit "lumens" often is employed to represent the total light output from a light source in all directions, in terms of radiant power or "luminous flux") to provide ambient illumination (i.e., light that may be perceived indirectly and that may be, for example, reflected off of one or more of a variety of intervening surfaces before being perceived in whole or in part).

[0016] The term "spectrum" should be understood to refer to any one or more frequencies (or wavelengths) of radiation produced by one or more light sources. Accordingly, the term "spectrum" refers to frequencies (or wavelengths) not only in the visible range, but also frequencies (or wavelengths) in the infrared, ultraviolet, and other areas of the overall electromagnetic spectrum. Also, a given spectrum may have a relatively narrow bandwidth (e.g., a FWHM having essentially few frequency or wavelength components) or a relatively wide bandwidth (several frequency or wavelength components having various relative strengths). It should also be appreciated that a given spectrum may be the result of a mixing of two or more other spectra (e.g., mixing radiation respectively emitted from multiple light sources).

[0017] The term "lighting fixture" or "luminaire" is used herein to refer to an implementation or arrangement of one or more lighting units in a particular form factor, assembly, or package. The term "lighting unit" is used herein to refer to an apparatus including one or more light sources of same or different types. A given lighting unit may have any one of a variety of mounting arrangements for the light source(s), enclosure/housing arrangements and shapes, and/or electrical and mechanical connection configurations. Additionally, a given lighting unit optionally may be associated with (e.g., include, be coupled to and/or packaged together with) various other components (e.g., control circuitry) relating to the operation of the light source(s). An "LED-based lighting unit" refers to a lighting unit that includes one or more LED-based light sources as discussed above, alone or in combination with other non LED-based light sources. A "multi-channel" lighting unit refers to an LED-based or non LED-based lighting unit that includes at least two light sources configured to respectively generate different spectrums of radiation, wherein each different source spectrum may be referred to as a "channel" of the multi-channel lighting unit.

[0018] The term “controller” is used herein generally to describe various apparatus relating to the operation of one or more light sources. A controller can be implemented in numerous ways (e.g., such as with dedicated hardware) to perform various functions discussed herein. A “processor” is one example of a controller which employs one or more microprocessors that may be programmed using software (e.g., microcode) to perform various functions discussed herein. A controller may be implemented with or without employing a processor, and also may be implemented as a combination of dedicated hardware to perform some functions and a processor (e.g., one or more programmed microprocessors and associated circuitry) to perform other functions. Examples of controller components that may be employed in various embodiments of the present disclosure include, but are not limited to, conventional microprocessors, application specific integrated circuits (ASICs), and field-programmable gate arrays (FPGAs).

[0019] In various implementations, a processor or controller may be associated with one or more storage media (generically referred to herein as “memory,” e.g., volatile and non-volatile computer memory such as RAM, PROM, EPROM, and EEPROM, floppy disks, compact disks, optical disks, magnetic tape, etc.). In some implementations, the storage media may be encoded with one or more programs that, when executed on one or more processors and/or controllers, perform at least some of the functions discussed herein. Various storage media may be fixed within a processor or controller or may be transportable, such that the one or more programs stored thereon can be loaded into a processor or controller so as to implement various aspects of the present invention discussed herein. The terms “program” or “computer program” are used herein in a generic sense to refer to any type of computer code (e.g., software or microcode) that can be employed to program one or more processors or controllers.

[0020] The term “laser light-emitting element” is used to define a device that emits laser radiation in a region of the electromagnetic spectrum for example, the visible region, infrared and/or ultraviolet region, when activated by applying a potential difference across it or passing a current through it, for example. Examples of laser light-emitting elements include, but are not limited to, semiconductor, diode, organic, and polymer/polymeric lasers, and other similar devices as would be readily understood by a worker skilled in the art. Furthermore, the term laser light-emitting element is used to define the specific device that emits the radiation, for example a laser diode, and can equally be used to define a combination of the specific device that emits the radiation together with a housing or package within which the specific device or devices are placed.

[0021] The term "laser luminaire" is generally used to define a light source, lighting unit and/or light fixture, primarily used in general illumination applications, comprising one or more laser light-emitting elements, and optionally one or more additional or complementary light sources such as conventional light sources and/or non-laser light-emitting elements (e.g. semiconductor, organic, or polymer/polymeric light-emitting diodes, optically pumped phosphor coated light-emitting diodes, optically pumped nano-crystal light-emitting diodes, etc.), together with a combination of parts designed to support, position and/or provide power to the one or more light-emitting elements. Other such parts, which may include but are not limited to various optical elements for collecting, mixing, collimating, diffusing, focusing and/or orienting light output from the one or more light-emitting elements, optionally in conjunction with various electrical and/or mechanical adjustment mechanisms, may also be comprised in a given luminaire, as should be readily apparent to a worker skilled in the art.

[0022] It should be appreciated that all combinations of the foregoing concepts and additional concepts discussed in greater detail below (provided such concepts are not mutually inconsistent) are contemplated as being part of the inventive subject matter disclosed herein. In particular, all combinations of claimed subject matter appearing at the end of this disclosure are contemplated as being part of the inventive subject matter disclosed herein. It should also be appreciated that terminology explicitly employed herein that also may appear in any disclosure incorporated by reference should be accorded a meaning most consistent with the particular concepts disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] In the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention.

[0024] Figure 1 is a block diagram of a laser light source in accordance with an embodiment of the invention;

[0025] Figure 2 is a block diagram of a laser light source in accordance with an embodiment of the invention;

[0026] Figure 3 is a block diagram of a laser light source in accordance with an embodiment of the invention;

[0027] Figure 4 is a block diagram of a laser light source in accordance with an embodiment of the invention;

[0028] Figure 5 is a block diagram of a laser light source in accordance with an embodiment of the invention;

[0029] Figure 6 is a block diagram of a laser light source in accordance with an embodiment of the invention;

[0030] Figure 7 is a block diagram of a laser light source in accordance with an embodiment of the invention;

[0031] Figure 8 is a block diagram of a laser light source in accordance with an embodiment of the invention;

[0032] Figure 9 is a cross-sectional schematic diagram of a laser light source in accordance with an embodiment of the invention; and

[0033] Figure 10 is a cross-sectional schematic diagram of a laser light source in accordance with another embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0034] The invention provides a laser light source for use primarily in general illumination applications. The laser light source, in one embodiment configured as a laser luminaire, generally comprises at least one laser light-emitting element configured to emit a laser light, at least one light source output element for providing illumination and one or more conversion elements. The light source output element, in one aspect, includes a reflective surface configured to reflect the laser light into predetermined locations. The conversion elements include wavelength-conversion regions disposed on at least part of the predetermined locations, wherein each wavelength-conversion region is adapted to convert the laser light into a converted light, such that a combination of each of the converted light and the laser light forms the light with the desirable luminous intensity.

[0035] The conversion elements are generally disposed to convert at least a portion of the laser light generated by the laser light-emitting element(s), and optically couple at least a portion of this converted light to the one or more output elements.

[0036] In general, the laser light source enables generation of output light suitable for general illumination applications, and other such applications. For example, in various embodiments, conversion elements of the laser light source provide for converted light spectral characteristics differing from those of the laser light such that by combining the converted light with the laser light, combined spectral characteristics amenable for general illumination are achieved. In addition, or alternatively, different or compound conversion elements are used to provide converted light having different spectral characteristics, such that, by combining the converted light generated by these different or compound conversion elements, optionally in combination with an unconverted portion of the laser light, combined spectral characteristics amenable for general illumination again are achieved. Examples of such combined spectral characteristics include, but are not limited to, a desired colour temperature, colour rendering index, colour quality, perceived colour, spectral power distribution, and the like, as will be described in greater detail below.

[0037] In addition, or alternatively, conversion elements of the laser light source provide for a reduction in the coherence of the converted light generated thereby relative to that of the laser light. Accordingly, by combining the converted light with the laser light, or by combining converted light provided by different or compounded conversion elements, an overall coherence of the laser light source output is reduced, thereby reducing undesirable effects such as speckle, optical interference and other related effects.

[0038] The laser light source further includes, in some embodiments, one or more diffusing elements for diffusing the laser light, or a portion thereof, prior to incidence upon the one or more conversion elements. This may achieve, for example, a better distribution of laser light upon the conversion element(s) leading to an increase in conversion efficiency, an improved converted light spatial distribution, or to mitigate possible conversion element saturation effects.

[0039] Referring to the block diagram of **Figure 1** and in accordance with one embodiment of the invention, a laser light source **100** generally includes one or more laser light-emitting elements **110** configured to generate laser light, and one or more conversion elements **130** disposed to convert at least a portion of the laser light **112**, and couple at least a portion of the converted light **114** thereby generated to one or more light source output elements **140** configured to provide illumination (*e.g.* output light **116**). In general, the output light **116** of the light source **100** has a desirable luminous intensity suitable for general illumination, and is formed by a combination of unconverted laser light (not shown) and converted light, and/or a combination of converted light of different spectral characteristics provided by a same or distinct conversion elements. In general, these light combinations provide a light output defined by combined illumination characteristics suitable for general illumination and/or one or more specific lighting applications.

[0040] For example, in one embodiment, the light source output element **140** is configured to direct the laser light **112** into predetermined locations (not shown). The conversion element **130** includes a set of wavelength-conversion regions disposed on at least part of the predetermined locations, such that during an operation of the laser light source, the wavelength-conversion regions are irradiated by the laser light **112**. Each wavelength-conversion region is adapted to convert the laser light into a converted light in response to the irradiation. The set of wavelength-conversion regions comprises at least one region, as defined herein.

[0041] In one embodiment, the laser light is a blue laser light, and upon irradiation, each wavelength-conversion regions down-converts the received blue light and diffusely re-emits yellow and/or red light, such that a combination of each of the converted light and the laser light forms the light with the desirable luminous intensity.

[0042] The desirable luminous intensity is achieved by selecting the predetermined location for disposing the set of wavelength-conversion regions, and by selecting adaptively a wavelength-conversion material for the wavelength-conversion regions, e.g., a phosphor or the like. In one embodiment, the set of wavelength-conversion regions includes at least two regions, i.e., a first and a second region. Wavelength-conversion material of the first wavelength-conversion region is selected based on a wavelength-conversion material of the second wavelength-conversion region, the luminous intensity of the laser light, and the desirable luminous intensity.

[0043] Referring to the block diagram of **Figure 2** and in accordance with another embodiment of the invention, a laser light source **200** generally comprises one or more laser light-emitting elements **210** operable to generate laser light, and one or more conversion elements **230** disposed to convert at least a portion of the laser light **212**, and couple at least a portion of the converted light **214** thereby generated to one or more output elements **240** configured to provide illumination (*e.g.* output light **216**). In this embodiment, the output light **216** of the light source **200** comprises a combination of an unconverted laser light **215** coupled directly to the output element **240** and converted light **214,** such that a combination of each of the converted light **214** and the laser light **215** forms the light **216** with the desirable luminous intensity.

[0044] Referring to the block diagram of **Figure 3** and in accordance with yet another embodiment of the invention, a laser light source **300** generally includes one or more laser light-emitting elements **310** operable to generate laser light, and one or more conversion elements **330** disposed to convert at least a portion of the laser light **312**, and couple at least a portion of the converted light **314** thereby generated to one or more output elements **340** configured to provide illumination (*e.g.* output light **316**). In this embodiment, the output light **316** of the light source **300** is formed by a combination of a portion **315** of laser light unconverted by the conversion element but coupled thereby to the output element **340** and converted light **314**, such that a combination the converted light **314** and the laser light **315** forms the light **316** with the desirable luminous intensity.

[0045] Referring to the block diagram of **Figure 4** and in accordance with yet another embodiment of the invention, a laser light source **400** generally includes one or more laser light-emitting elements **410** operable to generate laser light, and one or more conversion elements **430** disposed to convert at least a portion of the laser light **412**, and couple at least a portion of the converted light **414** thereby generated to one or more output elements **440** configured to provide illumination (*e.g.* output light **416**). In this embodiment, the output light **416** of the light source **400** is formed by a combination of a portion **415** of laser light unconverted by the conversion element **430** and coupled directly to the output element **440** and converted light **414**.

[0046] Referring to the block diagram of **Figure 5** and in accordance with still another embodiment of the invention, a laser light source **500** generally includes one or more laser light-emitting elements **510** operable to generate a laser light **515**, and one or more conversion elements **530** disposed to convert at least a portion of the laser light **512**, and couple at least a portion of distinctly characterised converted light **514** thereby generated to one or more output elements **540** configured to provide illumination (*e.g.* output light **516**). In this embodiment, the output light **516** of the light source **500** is formed by a combination of the distinctly characterised converted light **514,** such that a combination of each of the converted light **514** and the laser light **515** forms the light **516** with the desirable luminous intensity.

[0047] Referring to the block diagram of **Figure 6** and in accordance with one embodiment of the invention, a laser light source **600** generally includes one or more laser light-emitting elements **610** operable to generate distinct laser light beams, and one or more conversion elements **630** disposed to convert at least a portion of the laser light **612**, and couple at least a portion of distinctly characterised converted light beams **614** thereby generated to one or more output elements **640** configured to provide illumination (*e.g.* output light **616**). In this embodiment, the output light **616** of the light source **600** is formed by a combination of the distinctly characterised converted light beams **614**.

[0048] Referring to the block diagram of **Figure 7** and in accordance with one more embodiment of the invention, a laser light source **700** generally includes one or more laser light-emitting elements **710** operable to generate distinct laser light beams, and one or more conversion elements **730** disposed to convert at least a portion of the laser light **712**, and couple at least a portion of the converted light **714** thereby generated to one or more output elements **740** configured to provide illumination (*e.g.* output light **716**). In this embodiment, the output light **716** of the light source **700** is formed by a combination of unconverted laser light (not shown) and converted light, and/or a combination of converted light of different spectral characteristics provided by a same or distinct conversion elements.

[0049] Referring to the block diagram of **Figure 8** and in accordance with another embodiment of the invention, a laser light source **800** generally comprises one or more laser light-emitting elements **810** operable to generate laser light, and one or more conversion elements **830** disposed to convert at least a portion of the laser light **812**, and couple at least a portion of the converted light **814** thereby generated to one or more output elements **840** configured to provide illumination (*e.g.* output light **816**). In this embodiment, the output light **816** of the light source **800** is formed by a combination of unconverted laser light (not shown) and converted light, and/or a combination of converted light of different spectral characteristics provided by a same or distinct conversion elements. In addition, the light source **800** further includes an optical element **820** interposed between the laser light-emitting element(s) **810** and the conversion element(s) **830** to reduce the likelihood of undesirable saturation effects in the conversion element(s) **830**, for example. The optical element **820** can be a diffusing element, beam expander element or other optical element capable of reducing the likelihood of saturation effects as would be readily understood by a worker skilled in the art.

[0050] It will be appreciated by the person skilled in the art that other combinations and configurations of laser light-emitting elements, conversion elements and output elements may be considered herein, as well as various light output combinations provided thereby, without departing from the general scope and nature of the present disclosure. It will be further appreciated that various additional or alternative optical elements, as described below, can be used interchangeably in the present context to provide different light source outputs and/or internal optical manipulations.

Laser Light-Emitting Element(s)

[0051] The laser light source generally includes one or more laser light-emitting elements, as defined above, which vary in output power levels, efficiency, size, and spectral output depending on the application at hand.

[0052] For example, in various embodiments of the invention, one or more semiconductor lasers are employed. Such lasers include, but are not limited to, edge-emitting diode lasers, surface emitting diode lasers, and other such lasers readily known in the art. For example, edge-emitting lasers can include double heterostructure lasers, quantum well lasers, quantum wire lasers, quantum dot lasers, quantum cascade lasers, separate confinement heterostructure lasers, external cavity lasers, distributed feedback lasers, or other similar devices as would be readily understood by a worker skilled in the art. Surface emitting diode lasers can include, but are not limited to, vertical cavity surface emitting lasers (VCSEL), vertical external-cavity surface-emitting lasers (VECSEL), and the like. A worker skilled in the art will readily appreciate that the above, and other such laser light-emitting elements can be considered within the present context without departing from the general scope and nature of the present disclosure.

[0053] In many embodiments, the laser light source includes a thermal management system which is thermally coupled to the one or more laser light-emitting elements and configured to transfer and/or dissipate heat generated by these elements. A thermal management system may employ one or more heatsinks, heat pipes, thermosyphons, or other such active or passive cooling systems, as would be readily understood by the person of skill in the art.

[0054] In some embodiments, the laser light-emitting elements are spatially separated from the other elements of the laser light source, for instance, to facilitate provision of a laser light-emitting element thermal management system, as discussed above, without unduly obstructing the optical path of the laser-light-emitting elements, or other optical paths within the light source.

[0055] In some embodiments, the laser light generated by the laser light-emitting elements is coupled to downstream optical elements of the light source via one or more waveguides such as optical fibres and the like. In these or other embodiments, the laser light generated by the laser light-emitting elements also coupled to downstream optical elements using free-space optics.

[0056] In one embodiment, an optional optical element is used to spread, scatter, disperse, expand, or the like, the laser light, or a portion thereof, for example, prior to incidence upon the one or more conversion elements. This may achieve, for example, a better distribution of laser light upon the conversion element(s) leading to an increase in conversion efficiency, an improved converted light spatial distribution, or to mitigate possible conversion element saturation effects, for example. Examples of diffusing elements include, but are not limited to, ground glass diffusers, teflon diffusers, holographic diffusers, opal diffusers, greyed glass diffusers or other diffusion elements as would be readily understood by a worker skilled in the art. These and other such diffusing elments may be considered herein, as will be appreciated by the person skilled in the art, without departing from the general scope and nature of the present disclosure.

[0057] It will also be appreciated by the person skilled in the art that various alternative or additional optical elements and configurations may be considered herein to manipulate and relay laser light in the laser light source. For example, semiconductor lasers typically generate an elliptical laser beam spreading about 30 degrees by about 10 degrees. In one embodiment using such laser light-emitting elements, the laser beam generated is collimated, for example, into a beam having less divergence. In one embodiment, this is implemented, for example, using a spherical or cylindrical lens, or other such collimating elements known in the art.

[0058] Furthermore, optional beam splitters and/or beam combiners, such as are readily known to a worker skilled in the art, can be used to enable various beam configurations. For example, a common laser light-emitting element is used via a beam splitter to illuminate multiple conversion elements. Similarly, in one embodiment, two beams from distinct laser-light-emitting elements are combined via a beam combiner (reverse beam splitter) to interact with a common conversion element or other optical element of the light source.

[0059] In general, the peak output wavelength of the laser light-emitting element(s) is selected primarily as a function of the conversion element used in a given context and a colour combination required for the application at hand, such that a combination of each of the converted light and the laser light forms the light with the desirable luminous intensity. For example, in one embodiment, a blue or ultraviolet laser light-emitting element is used in combination with a red, orange, yellow and/or green light generating down wavelength-conversion regions, a combination of the laser light and/or of the one or more spectrally distinct converted light sources yielding a combined spectral effect, such as a selected perceived colour or white light, a given chromaticity or colour temperature, *etc.* Similarly, in another embodiment, a longer wavelength laser light-emitting element is used in combination with one or more up wavelength-conversion regions to provide a similar effect. As will be understood by those skilled in the art, other colors of laser light-emitting elements may advantageously be employed to optically pump phosphors that down-convert or up-convert the radiation into visible light with various spectral power distributions, which may then be combined to generate visible light with desirable spectral characteristics.

Conversion Element(s)

[0060] The light source generally comprises one or more conversion elements disposed to convert at least a portion of the laser light generated by the laser light-emitting element(s), and optically couple at least a portion of this converted light to the one or more output elements of the light source.

[0061] For example, in one embodiment, a conversion element is disposed to intercept at least a portion of the laser light, convert same, and direct the converted light toward the light source's one or more output elements. This is achieved, in some embodiments, via one or more at least partially reflective conversion elements, namely one or more at least partially reflective elements covered, layered, embedded or otherwise provided with a conversion medium, layer or material providing for the at least partial conversion of laser light incident thereupon. This element at least partially further reflects an unconverted portion of the laser light incident thereupon, such that converted and unconverted light is co-directed by such converting elements toward an output of the light source. Various examples of such configurations are described in greater detail below with reference to Figures 9 and 10.

[0062] As described above, in one embodiment, the one or more conversion elements of the laser light source provide for converted light spectral characteristics differing from those of the laser light such that by combining the converted light with the laser light, combined spectral characteristics amenable for general illumination is achieved. In addition, or alternatively, different or compound conversion elements are used to provide converted light having different spectral characteristics, such that, by combining the converted light generated by these different or compound conversion elements, optionally in combination with an unconverted portion of the laser light, combined spectral characteristics amenable for general illumination again are achieved. Examples of such combined spectral characteristics include, but are not limited to, a desired colour temperature, colour rendering index, colour quality, perceived colour, spectral power distribution, and the like.

[0063] For instance, in one embodiment, a conversion element is selected to down-convert or up-convert the laser light to a different peak wavelength or emission band such that the combination of the laser light spectral characteristics with converted light spectral characteristics provides for a combined spectral power distribution amenable to general illumination applications, or other such applications. In one embodiment, the conversion element includes a set of wavelength-conversion regions disposed on at the predetermined locations, such that the regions are irradiated by the laser light during the operation of the laser light source. Each wavelength-conversion region is adapted to convert the laser light into a converted light, such that a combination of each of the converted light and the laser light forms the light with the desirable luminous intensity.

[0064] In one example, a blue laser light-emitting element is used in combination with one or more conversion elements adapted to down-convert the blue laser light to one or more of red, orange, yellow or green light, thereby enabling a colour combination leading to improved spectral characteristics for the application at hand. For instance, in one embodiment, a blue laser light-emitting element used in combination with a red-emitting down conversion element, or with both a red and green or yellow-emitting down conversion elements is operated so to provide substantially white light. It will be apparent to the person skilled in the art that other colour combinations may be considered to provide similar or other desired effects.

[0065] Similarly, in one embodiment, an ultra-violet laser light-emitting element is used with different down-conversion elements such that converted light produced by these conversion elements is combined to provide selected spectral characteristics, possibly without contribution of the ultra-violet laser light, which could be filtered out depending on the application at hand.

[0066] In similar or alternative embodiments, up-conversion elements also or alternatively are used to up-convert longer wavelength laser light to shorter wavelength converted light. The person of skill in the art will appreciate that various types, combinations and numbers of laser light-emitting elements, emitting in a same or distinct wavelength regions of the visible or invisible spectrum, can be used with different types, combinations and numbers of up-conversion and/or down-conversion elements providing narrowband or broadband converted light in various regions of the optical spectrum. These combinations can thus provide a light source output having desired combined spectral characteristics. It will also be appreciated that by adjusting the relative power of the one or more laser light-emitting elements, and/or of the one or more portions thereof interacting with the one or more conversion elements, combined output spectral characteristics may be adjusted or fine tuned, either statically or dynamically, to provide adequate illumination for an application for which the light source is to be used.

[0067] In addition, or alternatively, the one or more conversion elements of the laser light source provides for a reduction in the coherence of the converted light generated thereby relative to that of the laser light. Accordingly, in one embodiment, by combining the converted light with the laser light, or by combining converted light provided by different or compounded conversion elements, an overall coherence of the laser light source output is reduced, thereby reducing undesirable effects such as speckle, optical interference and other related effects. For example, in one embodiment, one or more luminescent materials, such as phosphors or the like are used not only as a wavelength conversion medium, but also to partake in the coherence degradation of the laser light.

[0068] In general, light generated by laser light-emitting elements maintains a certain level of coherence that may not be ideal for certain illumination applications, for example, for general illumination applications, coherence may lead to speckle and/or other interference issues not particularly desirable in a selected context. Accordingly, in one embodiment, the combination of laser light-emitting elements with conversion elements comprising, for example, luminescent materials such as phosphors or the like, produces converted light of reduced or limited coherence. Thus, the light source’s conversion element(s) serves a dual purpose: convert the laser light to provide converted light exhibiting differing spectral characteristics, and provides at least an incoherent component, or a component of reduced coherence, of the light source’s overall output. For example, in one embodiment, laser light and converted light are combined to provide both combined output spectral characteristics and an overall reduced coherency of this output, thereby providing an output further amenable for general illumination applications, for example. Alternatively, in another embodiment, residual laser light is filtered out of the output such that only converted light of reduced coherency is output from the light source.

[0069] It will be appreciated that additional or alternative techniques may be considered herein to provide for a reduction in output coherence, for example, using different combinations of optical elements and techniques known in the art. Using such techniques, the worker skilled in the art will understand that wavelength conversion may be achieved independent of coherence degradation. In one embodiment, an optical element is positioned on a path of the laser light, the optical element adapted to increase a divergence of the laser light, such that a saturation effect of at least one wavelength-conversion region in the set of wavelength-conversion regions is reduced. In another embodiment, the coherence of the laser light is reduced prior to wavelength conversion, or again, the coherence of residual laser light is reduced post facto through one or more appropriate optical processes known in the art.

[0070] Depending on the material used, wavelength-conversion materials such as phosphors or the like used in the fabrication of the one or more conversion elements are prone to saturation effects, wherein an increase in intensity of the incident light does not result in a further increase in converted light emittance. For example, in the light sources **800**, **900** and **1000** of Figures 8, 9 and 10 respectively, saturation effects in conversion element(s) **830**, **930** and **1030** are reduced by reducing the peak intensity of the incident light using diffusing element(s) **820**, **920** and **1020** interposed between the laser light-emitting element(s) **810**, **910** and **1010** and the conversion element(s) **830**, **930** and **1030** to increase the beam divergence. A worker skilled in the art will readily understand that the positioning of the diffusing element(s) may be determined based on the saturation characteristics of the wavelength-conversion materials used in the conversion element(s), and other such criteria.

[0071] The geometry of the conversion element(s), or again the materials used therefor in combination with one or more wavelength conversion materials, are selected and/or adapted to achieve a desired output, and/or promote greater material longevity. For example, in one embodiment, the conversion element shape, size and/or configuration within the light source are selected to provide or partake in providing a selected light output from the light source. Namely, the conversion element(s) is adapted to promote effective coupling of the converted light, and optionally an unconverted portion of the laser light incident thereupon, with one or more output elements of the light source.

[0072] For example, in one embodiment, at least one of the one or more conversion elements is rotationally symmetric or faceted, comprising a section described in cross-section by a polynomial equation, such as a parabola, hyperbola, an ellipse or other shape as would be readily understood by a worker skilled in the art, such that light incident thereon, and converted light generated thereby, is effectively and efficiently directed toward one or more equally rotationally symmetric output elements of the light source.

[0073] In one embodiment, the material finish of the conversion element(s) is adapted to achieve a desired light distribution for the light source. For example, these elements comprise a diffuse reflector, a semi-specular reflector, or a specular reflector, including for example, spun metal, peened metal, anodized metal, electroplated metal, electroplated plastic, electroplated glass, sputtered metal, sputtered plastic, sputtered glass, or other reflector finishes as known to those skilled in the art.

[0074] The material finish of the conversion element may further include a transparent passivating layer to protect the wavelength-converting material thereof from degradation due to oxidation or other chemical interactions. In one embodiment, the material finish of the conversion element comprises a brightness enhancement that enhances the luminance of the material in a direction perpendicular to the material surface. In one embodiment, the brightness enhancement used is 3M Vikuiti™ DBEF. In another embodiment, the material finish of the conversion element comprises an embossed surface that enhances the luminous exitance of the material in substantially all directions above the material surface.

[0075] In general, the conversion element(s) is fabricated using one or more of a variety of wavelength conversion materials placed at the conversion element(s) forming the wavelength-conversion regions, such as for example, but not limited to, one or more phosphors, quantum dot materials, luminescent dopant materials and the like. The conversion element, in one embodiment, further comprises a transparent host material into which the wavelength-conversion material is dispersed.

[0076] For example, in one embodiment, the transparent host material may include, but is not limited to polymer materials and inorganic materials. The polymer materials may include, but are not limited to, acrylates, polystyrene, polycarbonate, fluoroacrylates, perfluoroacrylates, fluorophosphinate polymers, fluorinated polyimides, polytetrafluoroethylene, fluorosilicones, sol-gels, epoxies, thermoplastics, thermosetting plastics, silicones, and the like. Exemplary inorganic materials may include, but are not limited to, silicon dioxide, optical glasses, chalcogenide glasses, and the like.

[0077] Luminescent dopant materials may include, but are not limited to, organic laser dyes such as coumarin, fluorescein, rhodamine and perylene-based dyes. Other types of luminescent dopant materials may include lanthanide dopants, which can be incorporated into polymer materials, for example. The lanthanide elements may include for example lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium.

[0078] Powdered phosphor materials may include, but are not limited to inorganic materials doped with ions of lanthanide (rare earth) elements or ions such as chromium, titanium, vanadium, cobalt and neodymium. The lanthanide elements may include lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium. Inorganic materials may include, but are not limited to, sapphire (Al_2O_3), gallium arsenide (GaAs), beryllium aluminum oxide ($BeAl_2O_4$), magnesium fluoride (MgF_2), indium phosphide (InP), gallium phosphide (GaP), yttrium aluminum garnet (YAG or $Y_3Al_5O_{12}$), terbium-containing garnet, yttrium-aluminum-lanthanide oxide compounds, yttrium-aluminum-lanthanide-gallium oxide compounds, yttrium oxide (Y_2O_3), calcium or strontium or barium halophosphates $(Ca,Sr,Ba)_5(PO_4)_3(Cl,F)$, the compound $CeMgAl_{11}O_{19}$, lanthanum phosphate ($LaPO_4$), lanthanide pentaborate materials ((lanthanide)$(Mg,Zn)B_5O_{10}$), the compound $BaMgAl_{10}O_{17}$, the compound $SrGa_2S_4$, the compounds $(Sr,Mg,Ca,Ba)(Ga,Al,In)_2S_4$, the compound SrS, the compound ZnS and nitridosilicate. There are several exemplary phosphors that can be excited at 250 nm or thereabouts. An exemplary red emitting phosphor is $Y_2O_3:Eu^{3+}$. An exemplary yellow emitting phosphor is $YAG:Ce^{3+}$. Exemplary green emitting phosphors include $CeMgAl_{11}O_{19}:Tb^{3+}$, ((lanthanide)$PO_4:Ce^{3+},Tb^{3+}$) and $GdMgB_5O_{10}:Ce^{3+},Tb^{3+}$. Exemplary blue emitting phosphors may include $BaMgAl_{10}O_{17}:Eu^{2+}$ and $(Sr,Ba,Ca)_5(PO_4)_3Cl:Eu^{2+}$.

[0079] In general, quantum dot materials include small particles of inorganic semiconductors having particle sizes less than about 40 nm. Exemplary quantum dot materials may include, but are not limited to, small particles of CdS, CdSe, ZnSe, InAs, GaAs and GaN.

[0080] It will be appreciated by the person skilled in the art that other materials and wavelength-conversion technologies may be considered herein depending on the selected laser light-emitting elements and emission wavelengths thereof, and desired converted light output wavelength(s), and that, without departing from the general scope and nature of the present disclosure.

Output Element(s)

[0081] The laser light source generally employs one or more output elements for providing illumination, namely forming a light by combining the laser light and/or the converted light in a manner or proportion suitable for the illumination application for which the light source is to be used. In one embodiment, wherein the light source output element is configured to optically process the light. For example, in one embodiment, the one or more output elements provide for a direct output of the combined laser and/or converted light, or again provide for a pre-processing of the light before it is output. Pre-processing includes, for example but not limited to, optical filtering, mixing, spatial manipulation and control of polarization and/or intensity, and the like. Additional optical elements are included in some embodiments to manipulate the laser and/or converted light within the light source, for example to direct a portion of the laser light toward the predetermined locations on the conversion element(s). Such additional elements may include, but are not limited to, one or more reflectors, collimators, lenses, filters, diffusers and the like.

[0082] In one embodiment, the one or more output elements perform pre-processing of the light before it is output from the light source, and ensure that this light output meets, at least within a prescribed range, the application-specific design criteria. These criteria may include, but are not limited to, the spatial, intensity and/or spectral distributions of the light source's light output. For example, spatial distribution of the light output is typically depicted graphically in a luminous intensity distribution curve, a polar plot representing the light intensity as a function of angle about the light source, and is generally impacted by the constructional features and design of the light source output elements. Spectral characteristics are generally represented by a spectral power distribution of the light source output and can be effected and/or manipulated via one or more filters, light mixers (*e.g.* diffusers, collimators, reflectors, beam splitters and/or combiners, *etc.*) and the like. It will be appreciated that the output characteristics of the light source can also be manipulated by the configurational arrangement of the light emitters (*e.g.* laser light-emitting element(s), conversion element(s), *etc.*) dictating respective and relative distributions through the light source, as well as the relative output intensities of these components. Such characteristics, in one embodiment, are further adapted or modified statically or dynamically via the operative control of the laser light-emitting elements and/or the output elements.

[0083] In some embodiments, the geometric shape and arrangement of the output elements are selected to ensure that a desired luminous intensity distribution is achieved. A worker skilled in the art will readily understand that the luminous intensity distribution is affected by the geometric shape and spatial arrangement of the various elements of the light source. In one embodiment, the output elements comprise an annular concave reflector that is used for specular or semi-specular reflection of light.

[0084] In one embodiment, the output element(s) comprises one or more optical filters to block light of a specific undesired wavelength range from being present at the output of the light source. For example, when using one or more ultraviolet laser light-emitting element, in one embodiment a filter is used to block any output of this ultraviolet light and let all other emitted wavelengths through.

[0085] In some embodiments, the one or more output elements provide mixing means to allow for mixing at least a portion of the light generated at different wavelengths, or within different wavelength bands. For example, in one embodiment, the one or more output elements provide for mixing of an unconverted portion of the laser light with a portion of converted light. In a same or other example, the one or more output elements are used to mix converted light generated by two or more conversion elements.

[0086] It will be appreciated by the person skilled in the art that various output optical elements may be considered herein to provide similar effects, and that such elements should not be considered to depart from the general scope and nature of the present disclosure.

[0087] The invention will now be described with reference to specific examples. It will be understood that the following examples are intended to describe embodiments of the invention and are not intended to limit the invention in any way.

EXAMPLES

EXAMPLE 1

[0088] Referring now to **Figure 9**, and in accordance with one embodiment of the invention, a laser light source, generally referred to using the numeral **900** will now be described. In particular, Figure 9 provides a cross-sectional view of the laser light source **900**, wherein two or more semiconductor laser diodes **910** emit collimated beams of blue laser light through respective linear holographic diffusers **920** disposed in a series of apertures in an annular concave reflector **940**, which acts as an output element of the light source **900**. Each laser beam is preferentially diffused into a fan-shaped beam that illuminates a truncated cone-shaped conversion element **930**, upon an exterior surface of which are disposed one or more regions of a wavelength-conversion material (*e.g.* a phosphor or the like). Upon irradiation, each region down-converts at least a portion of the laser light incident thereupon, and diffusely re-emits yellow and/or red converted light, depending upon the composition and type of wavelength-conversion material used. An unconverted portion of the irradiating laser light is diffusely reflected by the wavelength-conversion material, as can a portion of the laser light incident upon one or more regions of the conversion element devoid of wavelength-conversion material. The blue laser light, and the yellow and/or red converted light is then combined in the annular concave reflector **940** which specularly or semi-specularly forms and reflects the light with the desirable luminous intensity.

[0089] Herein, the annular concave reflector **940** acts as an output element that ensures that a desired luminous intensity distribution is achieved for the light source output. The truncated cone **930** with the phosphor coating, acts simultaneously as a conversion element and as a means for coupling the laser light and converted light to the output element **940**. Furthermore, the coherence of the laser light will be attenuated by the conversion thereof and, depending on the materials used, directly through reflection off the conversion element **930**. Accordingly, speckle or other undesirable interference affects are reduced.

[0090] The positioning of the laser light-emitting element, i.e., laser diodes **910** exteriorly to the elements **940** and **930** offers the advantage that the optical path for the reflected and emitted radiation from truncated cone **930** remains unobstructed by optional heat dissipation means (not shown) for the laser diodes **910**.

[0091] The material finish of truncated cone **930** includes a transparent passivating layer to protect the phosphorescent material from degradation due to oxidation or other chemical interactions. A brightness enhancement material made, for example, of 3M Vikuiti™ DBEF that enhances the luminance of the phosphorescent material in a direction perpendicular to the material surface are also included, in some embodiments. In addition, the material finish of truncated cone **930** comprises an embossed surface that enhances the luminous exitance of the phosphorescent material in all directions above the material surface.

[0092] A worker skilled in the art will readily appreciate that the truncated cone **930** can be removed and replaced in some embodiments, thereby enabling different relative combinations of blue, yellow and/or red light to be generated depending on the composition and concentration of the phosphorescent materials disposed on the surface of the truncated cone **930**.

EXAMPLE 2

[0093] Referring now to **Figure 10**, and in accordance with another embodiment of the invention, a laser light source, generally referred to using the numeral **1000** will now be described. In particular, Figure 10 provides a cross-sectional view of the laser light source **1000**, wherein a semiconductor laser diode **1010** emits a collimated beam of blue light that illuminates a circular holographic diffuser **1020** that is disposed in the center aperture of annular concave reflector **1040**. The beam is preferentially diffused into a cone-shaped beam that illuminates a truncated cone-shaped conversion element **1030**. The shape and positioning of the conversion element **1030** is selected to effectively coupled light generated and/or redirected by this element with the reflector **1040**. Disposed on the exterior surface of the conversion element **1030** are one or more stripes of phosphorescent materials. Upon irradiation, each stripe of phosphorescent material down-converts the received blue light and diffusely re-emits yellow and/or red light, depending upon the phosphor composition. An unconverted portion of the irradiating beam is also diffusely reflected by the phosphorescent material. The blue and yellow/red light is then specularly or semi-specularly reflected by the annular concave reflector **1040** to generate a desired luminous intensity distribution.

[0094] Herein, the annular concave reflector **1040** acts as an output element that ensures that a desired luminous intensity distribution is achieved for the light output from the light source **1000**. The truncated cone **1030** with the phosphor coating, acts simultaneously as a conversion element for wavelength conversion, and to some extent, provides for an overall decrease in the light source's output coherency.

[0095] The positioning of the laser diodes **1010** exterior to the elements **1040** and **1030** offers the advantage that the optical path for the reflected and emitted radiation from truncated cone **1030** remains unobstructed by optional heat dissipation means (not shown) for the laser diodes **1010**.

[0096] The material finish of truncated cone **1030,** in one embodiment, includes a transparent passivating layer to protect the phosphorescent material from degradation due to oxidation or other chemical interactions. A brightness enhancement material made, for example, of 3M Vikuiti™ DBEF that enhances the luminance of the phosphorescent material in a direction perpendicular to the material surface is also included in some embodiments. In addition, in one embodiment, the material finish of truncated cone **1030** comprises an embossed surface that enhances the luminous exitance of the phosphorescent material in all directions above the material surface.

[0097] A worker skilled in the art will readily appreciate that the truncated cone **1030** in some embodiments can be removed and replaced, thereby enabling different relative combinations of blue, yellow and/or red light to be generated depending on the composition and concentration of the phosphorescent materials disposed on the surface of the truncated cone **1030**.

[0098] While several inventive embodiments have been described and illustrated herein, those of ordinary skill in the art will readily envision a variety of other means and/or structures for performing the function and/or obtaining the results and/or one or more of the advantages described herein, and each of such variations and/or modifications is deemed to be within the scope of the inventive embodiments described herein. More generally, those skilled in the art will readily appreciate that all parameters, dimensions, materials, and configurations described herein are meant to be exemplary and that the actual parameters, dimensions, materials, and/or configurations will depend upon the specific application or applications for which the inventive teachings is/are used. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, many equivalents to the specific inventive embodiments described herein. It is, therefore, to be understood that the foregoing embodiments are presented by way of example only and that, within the scope of the appended claims and equivalents thereto, inventive embodiments may be practiced otherwise than as specifically described and claimed.

[0099] All definitions, as defined and used herein, should be understood to control over dictionary definitions, definitions in documents incorporated by reference, and/or ordinary meanings of the defined terms.

[00100] The indefinite articles “a” and “an,” as used herein in the specification and in the claims, unless clearly indicated to the contrary, should be understood to mean “at least one.” The phrase “and/or,” as used herein in the specification and in the claims, should be understood to mean “either or both” of the elements so conjoined, i.e., elements that are conjunctively present in some cases and disjunctively present in other cases.

[00101] As used herein in the specification and in the claims, “or” should be understood to have the same meaning as “and/or” as defined above. For example, when separating items in a list, “or” or “and/or” shall be interpreted as being inclusive, i.e., the inclusion of at least one, but also including more than one, of a number or list of elements, and, optionally, additional unlisted items. Only terms clearly indicated to the contrary, such as “only one of” or “exactly one of,” or, when used in the claims, “consisting of,” will refer to the inclusion of exactly one element of a number or list of elements. In general, the term “or” as used herein shall only be interpreted as indicating exclusive alternatives (i.e. “one or the other but not both”) when preceded by terms of exclusivity, such as “either,” “one of,” “only one of,” or “exactly one of.” “Consisting essentially of,” when used in the claims, shall have its ordinary meaning as used in the field of patent law.

[00102] As used herein in the specification and in the claims, the phrase “at least one,” in reference to a list of one or more elements, should be understood to mean at least one element selected from any one or more of the elements in the list of elements, but not necessarily including at least one of each and every element specifically listed within the list of elements and not excluding any combinations of elements in the list of elements. This definition also allows that elements may optionally be present other than the elements specifically identified within the list of elements to which the phrase “at least one” refers, whether related or unrelated to those elements specifically identified. Thus, as a non-limiting example, “at least one of A and B” (or, equivalently, “at least one of A or B,” or, equivalently “at least one of A and/or B”) can refer, in one embodiment, to at least one, optionally including more than one, A, with no B present (and optionally including elements other than B); in another embodiment, to at least one, optionally including more than one, B, with no A present (and optionally including elements other than A); in yet another embodiment, to at least one, optionally including more than one, A, and at least one, optionally including more than one, B (and optionally including other elements); etc.

[00103] It should also be understood that, unless clearly indicated to the contrary, in any methods claimed herein that include more than one step or act, the order of the steps or acts of the method is not necessarily limited to the order in which the steps or acts of the method are recited.

[00104] In the claims, as well as in the specification above, all transitional phrases such as “comprising,” “including,” “carrying,” “having,” “containing,” “involving,” “holding,” “composed of,” and the like are to be understood to be open-ended, i.e., to mean including but not limited to. Also, the reference numerals in the claims are merely for convenience and are not to be read in any way as limiting.

WE CLAIM:

1. A laser light source configured to emit light (116) with a desirable luminous intensity suitable for general illumination, the laser light source comprising:

at least one laser light-emitting element (110) for generate a laser light (112);

at least one conversion element (130) including a set of wavelength-conversion regions for converting a first portion of the laser light incident thereon into a converted light and transmitting a second portion of the laser light without conversion;

at least one light source output element (140) optically coupled to the at least one conversion element (130) and/or the at least one laser light-emitting element (110) and configured to combine the converted light with the second portion of the laser light, thereby forming the combined light having the desirable luminous intensity, and to direct the combined light into one or more predetermined locations.

2. The laser light source of claim 1, further comprising:

at least one optical element (820) positioned on a path of the laser light for increasing a divergence of a first portion thereof prior to incidence upon the at least one conversion element (130), such that a saturation effect of at least one wavelength-conversion region is reduced.

3. The laser light source of claim 2, wherein the optical element is a diffuser.

4. The laser light source of claim 1, wherein the laser light has a luminous intensity, and wherein the set of wavelength-conversion regions includes a first wavelength-conversion region and a second wavelength-conversion region, and a wavelength-conversion material of the first wavelength-conversion region is selected based on a wavelength-conversion material of the second wavelength-conversion region, the luminous intensity, and the desirable luminous intensity.

5. The laser light source of claim 4, wherein the wavelength-conversion material is a phosphor.

6. The laser light source of claim 1, wherein the at least one light source output element is configured to optically process the combined light.

7. The laser light source of claim 1, wherein at least one light source output element defines a series of apertures, the at least one light source output element further comprising:

linear holographic diffusers (920) disposed at least partially within the apertures and configured to direct the laser light into the predetermined locations.

8. The laser light source of claim 1, wherein at least one light source output element includes a center aperture, the at least one light source output element further comprising:

a circular holographic diffuser (1020) disposed in the center aperture and configured to direct the laser light into the predetermined locations.

9. A method for converting a laser light into a light with a desirable luminous intensity suitable for general illumination, comprising:

directing the laser light (112) into a set of wavelength-conversion regions, wherein each wavelength-conversion region is adapted to convert a first portion the laser light into a converted light and transmit a second portion of the laser light without conversion;

combining the converted light (114) and the laser light (112) to form the combined light (116) with the desirable luminous intensity.

10. The method of claim 9, wherein the laser light has a luminous intensity, and wherein the set of wavelength-conversion regions includes a first wavelength-conversion region and a second wavelength-conversion region, the method further comprising:

selecting a wavelength-conversion material of the first wavelength-conversion region based on a wavelength-conversion material of the second wavelength-conversion region, the luminous intensity, and the desirable luminous intensity.

11. The method of claim 9, further comprising:

increasing a divergence of the laser light, such that a saturation effect of at least one wavelength-conversion region in the set of wavelength-conversion regions is reduced.

12. A laser light source comprising:

one or more laser light-emitting elements (110) operable to generate laser light (112);

one or more light source output elements (140) for providing illumination; and

one or more conversion elements (130) disposed to convert at least a portion of the laser light and optically couple at least a portion of the converted light to the one or more output elements for providing the illumination.

13. The light source of claim 12, the one or more conversion elements providing for one or more of converted light spectral characteristics and converted light coherence characteristics suitable for general illumination.

14. The laser light source of claim 12, the one or more output elements combining an unconverted portion of said laser light and said portion of said converted light to provide illumination.

15. The laser light source of claim 12, further comprising one or more optical elements for manipulating the portion of the laser light prior to incidence upon the one or more conversion elements.

16. The laser light source of claim 12, the one or more converting elements further coupling an unconverted portion of the laser light to said one or more output elements.

17. The laser light source of claim 12, the one or more conversion elements comprising an at least partially reflective conversion element.

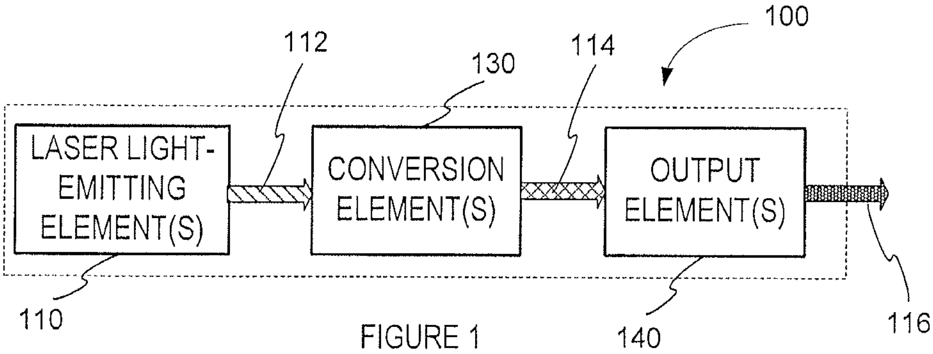

FIGURE 1

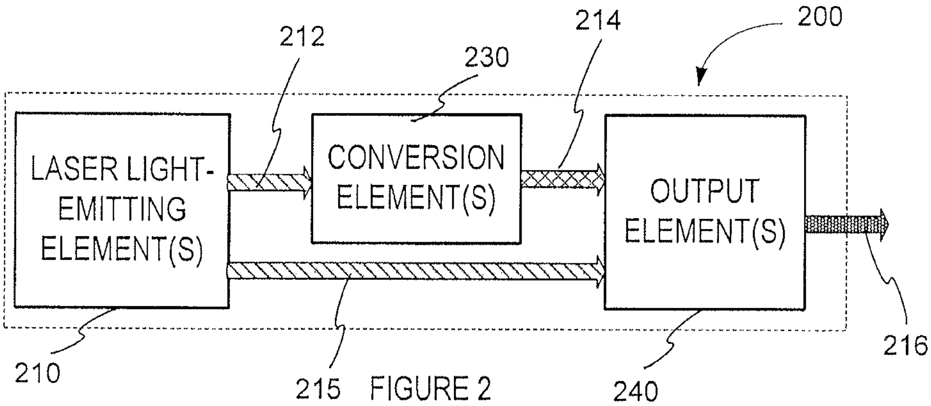

FIGURE 2

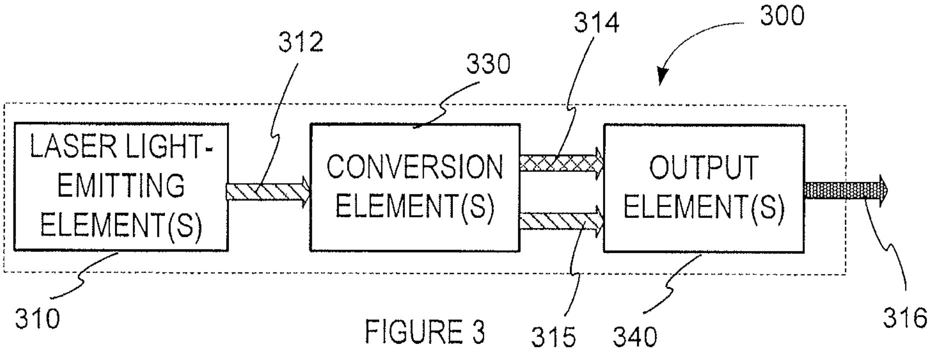

FIGURE 3

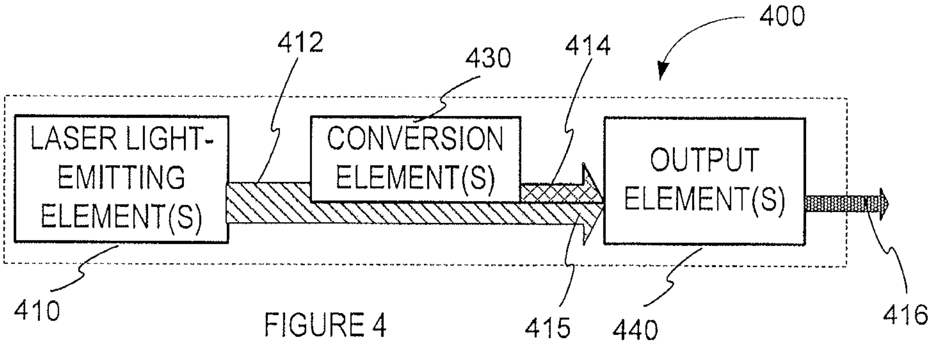

FIGURE 4

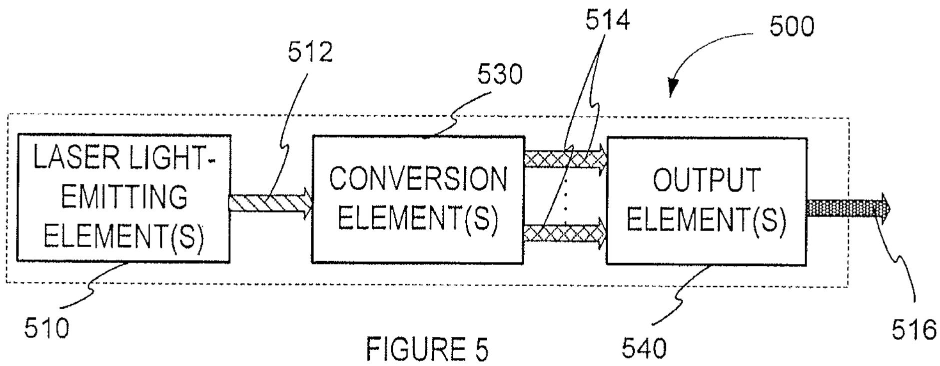

FIGURE 5

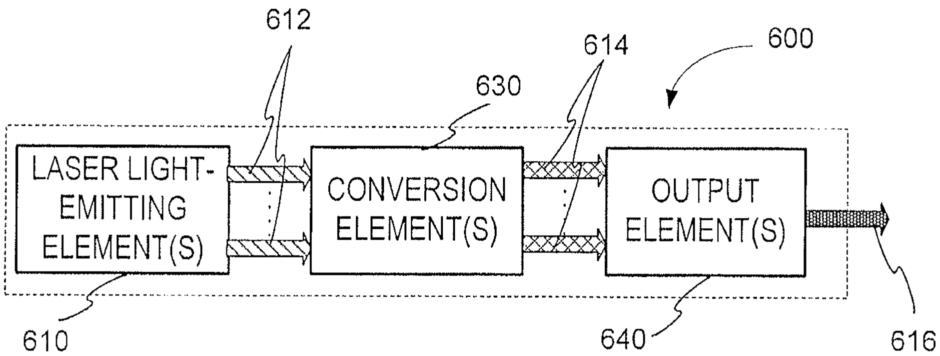

FIGURE 6

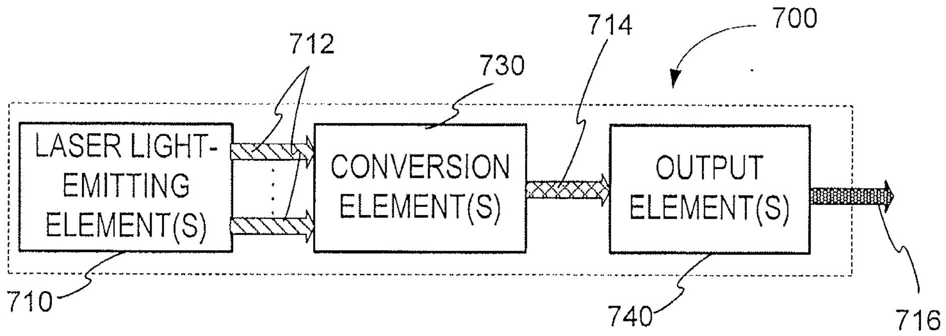

FIGURE 7

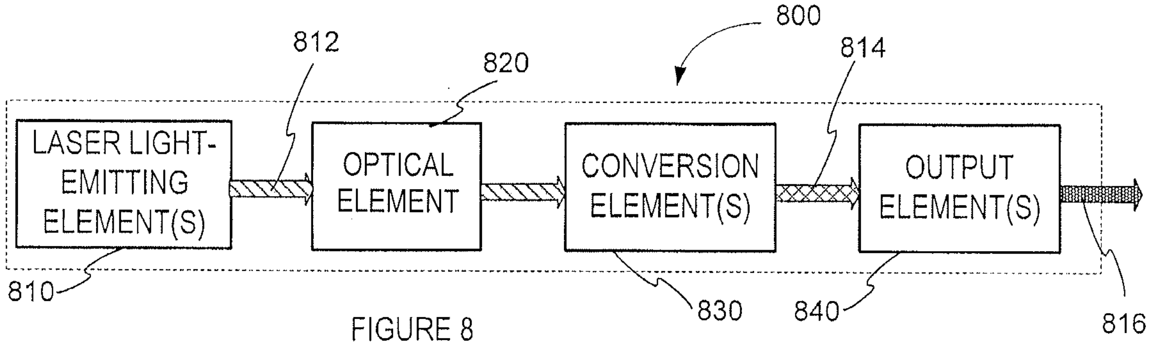

FIGURE 8

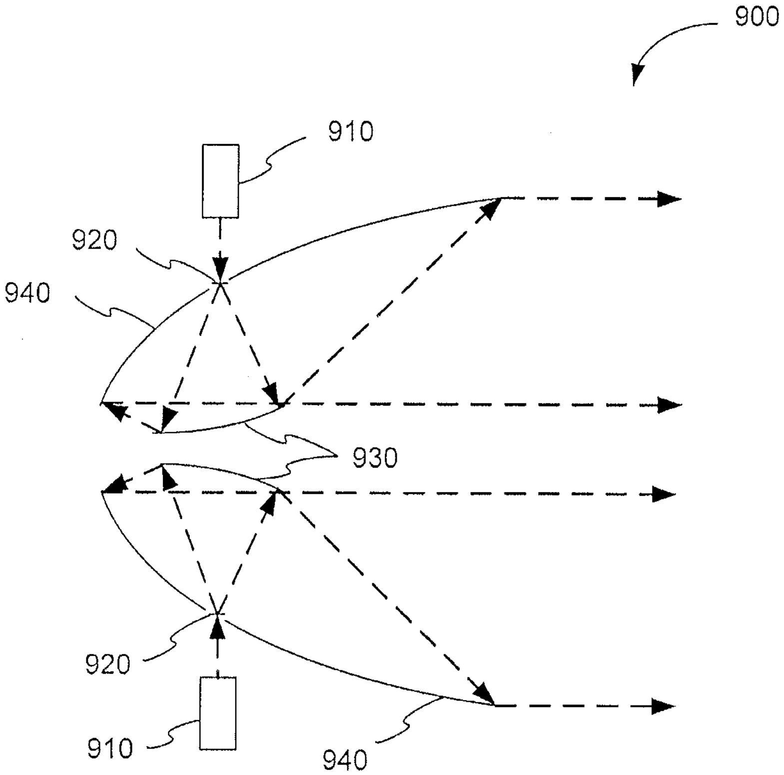

FIGURE 9

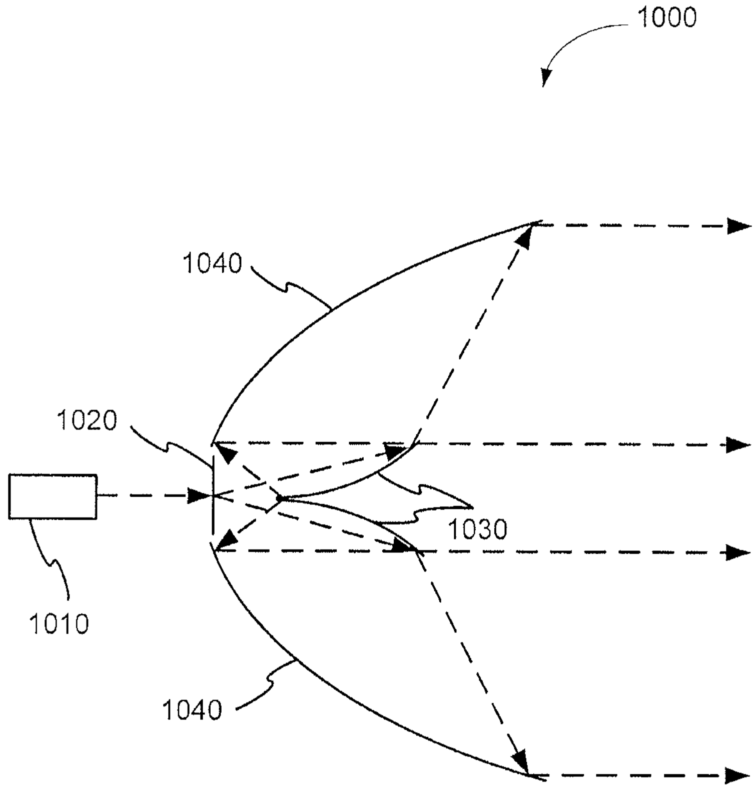

FIGURE 10

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2009/050728

A. CLASSIFICATION OF SUBJECT MATTER
INV. F21K7/00 G02B27/10
ADD. F21Y101/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F21K F21Y G02B H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 653 765 B1 (LEVINSON LIONEL M [US] ET AL) 25 November 2003 (2003-11-25) column 3, line 3 - line 24 column 3, line 60 - column 4, line 5 column 5, line 4 - line 32 column 5, line 62 - column 6, line 9 column 6, line 48 - column 7, line 8 figures 3-5 -----	1-6,9-16
X	US 6 357 889 B1 (DUGGAL ANIL R [US] ET AL) 19 March 2002 (2002-03-19) column 3, line 3 - column 5, line 5 column 6, lines 18-23,55-66 column 7, line 12 - line 16 claim 1 figures 1,6 ----- -/--	1-6,9-16

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 April 2009	14/05/2009

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Fax: (+31–70) 340–3016	Allen, Katie

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2009/050728

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

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