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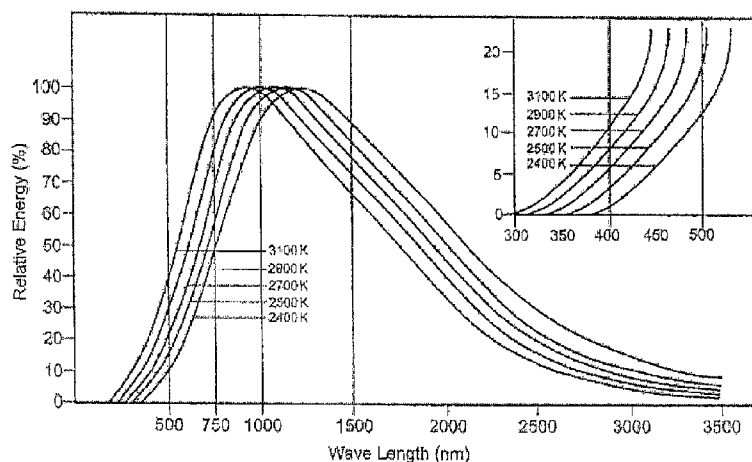
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(54) Title: HIGH-LIFETIME BROADBAND LIGHT SOURCE FOR LOW-POWER APPLICATIONS



(57) Abstract: Embodiments described herein include broadband light source system comprising an optic coupler including a plurality of input branches coupled to an output. The system includes a plurality of light sources coupled to the plurality of input branches. Each light source outputs light having a different wavelength distribution than any other light source of the plurality of light sources. The output emits a broadband light source comprising a combined spectral output of the plurality of light sources.

From International Light Technologies, ILT Sources Catalog
(http://files.intl-lighttech.com/pdf/Halogen_Lamps-ILT_Sources_Catalog_2010.pdf)

Figure 1



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- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

HIGH-LIFETIME BROADBAND LIGHT SOURCE
FOR LOW-POWER APPLICATIONS

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RELATED APPLICATION

This application claims the benefit of United States (US) Patent Application Number 61/586,934, filed January 16, 2012.

TECHNICAL FIELD

This invention relates generally to the field of light sources used with portable equipment, particularly with miniature spectrometers.

BACKGROUND

Compact fiber-optic detector-array-based spectrometers (“miniature spectrometers”) pioneered by H. -E. Korth of IBM Germany and popularized most notably by Ocean Optics, Inc. have found widespread use in a multitude of applications due to their low cost, small size, and low power consumption compared to conventional spectrometers. The purpose of these spectrometers is to measure the intensity of light as a function of wavelength. For example, see “A Computer Integrated Spectrophotometer for Film Thickness Monitoring,” H.-E. Korth, IBM Germany, JOURNAL DE PHYSIQUE, Colloque C10, Supplement Number 12, Tome M, December 1983, pg. C10-101.

Oftentimes such a spectrometer is used in a system that characterizes a material by analyzing how the material interacts with light over a range of wavelengths. Common examples are reflectance and transmittance measurement systems. Such systems require a light source to generate the light that is eventually analyzed by the spectrometer.

The type of light source that is used with a miniature spectrometer depends primarily on the wavelength range of the spectrometer. For ultraviolet wavelengths (below ~380nm) a deuterium light source (e.g., Hamamatsu L10290) is generally used. In some limited cases (e.g., color measurements) when only visible
5 wavelengths (450-700nm) are of interest a white-light LED can be used. However, the majority of miniature spectrometer applications fall within the 380-2200nm wavelength range, where an incandescent source is nearly always used. By far the most common incandescent source used with miniature spectrometers is a tungsten-halogen lamp, e.g., the LS-1 from Ocean Optics, Inc.

10 Incandescent light sources are widely used for broadband applications because they are relatively stable, bright, and inexpensive. However, they do require a considerable amount of power to operate; the lamp in the aforementioned Ocean Optics LS-1 uses 6.5W, for example. This is on the order of fifty times more power than is required to operate a typical miniature spectrometer. This not only greatly
15 restricts the length of time that battery-powered incandescent-based miniature spectrometer systems can operate on a single charge, but it also prevents such systems from being powered through a Universal Serial Bus (USB) cable (which is limited to 2.25W power draw).

20 INCORPORATION BY REFERENCE

Each publication, patent, and/or patent application mentioned in this specification is herein incorporated by reference in its entirety to the same extent as if each individual publication, patent and/or patent application was specifically and individually indicated to be incorporated by reference.

25 BRIEF DESCRIPTION OF THE DRAWINGS

The components in the figures are not necessarily to scale, emphasis instead being placed upon illustrating the principles of the embodiments. In the figures, like reference numerals designate corresponding parts throughout the different views.

Figure 1 shows light output from incandescent lamps of different color temperature.

Figure 2 shows the light output from a typical white-light LED.

Figure 3 shows an apparatus for combining light from a white-light LED and a low-color-temperature incandescent lamp using a fiber-optic coupler, under an embodiment.

Figure 4 shows a light-combining apparatus that combines light from a white-light LED, a low-color-temperature incandescent lamp, and two shorter-wavelength LEDs using a fiber-optic coupler, under an alternative embodiment.

Figure 5 shows a light-combining apparatus that combines light from a white-light LED and a low-color-temperature incandescent lamp using a beamsplitter, under another alternative embodiment.

Figure 6 shows a light-combining apparatus that combines light from a white-light LED and a low-color-temperature incandescent lamp using an integrating sphere, under yet another alternative embodiment.

Figure 7 is a flow diagram for generating a broadband light source, under an embodiment.

DETAILED DESCRIPTION

Embodiments are described herein that provide a low-cost high-lifetime broadband light source for low-power applications, particularly those that use miniature spectrometers.

Incandescent lamps emit light by heating a filament by passing an electric current through the filament. The heated filament emits light as a function of wavelength as described by the well-known blackbody radiation equation. The hotter a filament is the higher will be its equivalent blackbody temperature and the more its light output will be shifted to shorter wavelengths. For example, **Figure 1** shows a plot of light output from incandescent lamps of different color temperature versus relative energy (percent). Also, the hotter the filament the faster that it evaporates or

sublimes and thus the shorter the lamp lifetime (approximately 250 hours for 3100K and 40,000 hours for 2200K are typical for tungsten-halogen lamps). In addition, a hotter filament uses considerably more power than a cooler filament.

Incandescent lamps used in miniature spectrometer applications generally have a color temperature of at least 2900K, primarily for sufficient output at wavelengths near 400nm and below. Lifetimes of around 1000 hours and power consumption of more than 5W are typical (e.g., Welch-Allyn part number 01175-U). A lamp with comparable output at longer wavelengths (e.g., International Light Technologies part number 4115-12A) running at 2200K has a lifetime of 40,000 hours and only uses 0.58W, but its output below 500nm is too low to be useful for most spectrometer applications.

Light-emitting diodes (LEDs) are replacing incandescent lamps in many applications due to their greater efficiency and 50,000-hour (typical) lifetime. LEDs are now available throughout the 240-1000nm wavelength range with power requirement in the 20mW range (for output levels suitable for miniature spectrometer applications). For low-power applications a consideration when using LEDs is the narrow wavelength range of their output. Most LEDs in the UV and visible wavelength ranges have an output that is only 20-30nm wide. White-light LEDs use a phosphor that emits approximately 460-650nm, which augments the output of the blue LED that drives the phosphor to produce a total output of approximately 430-650nm. For example, **Figure 2** shows the light output from a typical white-light LED.

Embodiments described herein include an apparatus that efficiently combines the light from one or more LEDs with a low-color-temperature incandescent lamp, thereby realizing a high-lifetime broadband light source suitable for low-power applications. As an example, **Figure 3** shows a light-combining apparatus 300 that combines light from a white-light LED with light from a low-color-temperature incandescent lamp using a fiber-optic coupler, under an embodiment. The apparatus 300 includes a two-input fiber optic coupler 3 coupled to a white-light LED 1 and a

low-color-temperature incandescent lamp 2. The fiber-optic coupler 3 of an embodiment is a dual-branch fiber-optic light guide available from Edmund Optics (part number NT54-199), or a fused coupler such as those available from OZ Optics (www.ozoptics.com), for example, but is not so limited. White-light LED 1 and the low-color-temperature incandescent lamp 2 can be of the types described herein, but are not so limited.

In this embodiment, the output of white-light LED 1 and the output of low-color-temperature incandescent lamp 2 are directed into the two input legs of the two-input fiber optic coupler 3. The resultant spectrum 4 emitting from the fiber-optic coupler 3 is the combined spectral output of the white-light LED 1 source and the low-color-temperature incandescent lamp 2 source.

Fiber-optic couplers generally have light-throughput efficiency as high as approximately 70%. The numerical aperture (NA) and diameter of the ends of the fiber-optic coupler 3 of an embodiment provide from the light-combining apparatus 300 most of the light available from white-light LED 1 and low-color-temperature incandescent lamp 2 for a specific miniature spectrometer application.

Figure 4 shows a light-combining apparatus 400 that combines light from a white-light LED, a low-color-temperature incandescent lamp, and two shorter-wavelength LEDs using a fiber-optic coupler, under an alternative embodiment. The apparatus 400 includes a four-input fiber optic coupler 7 coupled to a white-light LED 1, a low-color-temperature incandescent lamp 2, and two LEDs 5 and 6. The four-input fiber optic coupler 7 operates under the same principles as the two-input fiber optic coupler 3. The white-light LED 1 and the low-color-temperature incandescent lamp 2 can be of the types described herein, but are not so limited.

In this embodiment, the output of white-light LED 1 and the output of low-color-temperature incandescent lamp 2 are directed into two input legs of a four-input fiber optic coupler 7. Further, at least two additional LEDs 5 and 6 are directed into the two remaining input legs of the four-input fiber optic coupler 7. The two additional LEDs 5 and 6 of an embodiment fill in the short wavelength end of the

resultant spectrum 8, but are not so limited. The resultant spectrum 8 emitting from fiber-optic coupler 7 is the combined spectral output of the white-light LED 1 source, the low-color-temperature incandescent lamp 2 source, and the two additional LED sources 5 and 6. The light contributions from LED 5 and LED 6 can be seen as additional peaks 9 and 10 in the resultant spectrum 8.

Figure 5 shows a light-combining apparatus 500 that combines light from a white-light LED and a low-color-temperature incandescent lamp using a beamsplitter, under another alternative embodiment. The apparatus 500 includes two collimating lenses 12 and 13, and a focusing lens 15. The apparatus 500 also includes a beamsplitter. The beamsplitter 14 of an embodiment comprises a broadband beamsplitter or a “hot mirror” or “cold mirror” beamsplitter that reflects and transmits the higher and lower wavelengths selectively for a more efficient combining process, but is not so limited. In this embodiment the collimating lenses 12 and 13 collimate light from the white-light LED 1 and the low-color-temperature incandescent lamp 2, respectively. The beamsplitter 14 combines the resulting collimated beams into a single collimated beam, and the focusing lens 15 focuses the combined collimated beam to a point 16.

Figure 6 shows a light-combining apparatus 600 that combines light from a white-light LED and a low-color-temperature incandescent lamp using an integrating sphere, under yet another alternative embodiment. The apparatus 600 includes an integrating sphere 17 coupled to a white-light LED 1 and a low-color-temperature incandescent lamp 2. In this embodiment, light from the white-light LED 1 and the low-color-temperature incandescent lamp 2 are combined inside of the integrating sphere 17. The integrating sphere 17 is used to measure the reflectance of a sample 18, but is not so limited.

Figure 7 is a flow diagram for generating a broadband light source 700, under an embodiment. Generally, the generating of a broadband light source of an embodiment comprises coupling 702 a plurality of light sources to an optical device. The generating comprises operating 704 each light source of the plurality of light

sources to emit light having a different wavelength than other light sources of the plurality of light sources. The generating comprises forming 706 a broadband light source by combining at the optical device light of the plurality of light sources.

5 Embodiments described herein include a system comprising an optic coupler including a plurality of input branches coupled to an output. The system includes a plurality of light sources coupled to the plurality of input branches. A first light source of the plurality of light sources outputs light has a different wavelength distribution than at least one other light source of the plurality of light sources. The first light source comprises an incandescent light. The output emits a broadband light
10 source comprising a combined spectral output of the plurality of light sources.

Embodiments described herein include a system comprising: an optic coupler including a plurality of input branches coupled to an output; a plurality of light sources coupled to the plurality of input branches, wherein a first light source of the plurality of light sources outputs light having a different wavelength distribution than
15 at least one other light source of the plurality of light sources, wherein the first light source comprises an incandescent light; wherein the output emits a broadband light source comprising a combined spectral output of the plurality of light sources.

The optic coupler of an embodiment comprises a fused coupler.

The optic coupler of an embodiment comprises a fiber optic coupler.

20 The optic coupler of an embodiment comprises a dual-branch fiber optic light guide.

The incandescent light of an embodiment is coupled to a first input branch of the fiber optic coupler.

25 The incandescent light of an embodiment comprises a low-color-temperature incandescent light.

The plurality of light sources of an embodiment includes a light emitting diode (LED).

The LED of an embodiment is coupled to a second input branch of the fiber optic coupler.

The LED of an embodiment comprises a white-light LED.

The optic coupler of an embodiment comprises a quad-branch fiber optic light guide.

5 The incandescent light of an embodiment is coupled to a first input branch of the fiber optic coupler.

The incandescent light of an embodiment comprises a low-color-temperature incandescent light.

The plurality of light sources of an embodiment includes a first LED.

10 The first LED of an embodiment is coupled to a second input branch of the fiber optic coupler.

The first LED of an embodiment comprises a white-light LED.

The plurality of light sources of an embodiment includes a second LED.

The second LED of an embodiment is coupled to a third input branch of the fiber optic coupler.

15 The second LED of an embodiment comprises a short-wavelength LED.

The plurality of light sources of an embodiment include a third LED.

The third LED of an embodiment is coupled to a fourth input branch of the fiber optic coupler.

The third LED of an embodiment comprises a short-wavelength LED.

20 The optic coupler of an embodiment comprises a beam splitter.

The plurality of input branches of an embodiment includes a first face of the beam splitter and a second face of the beam splitter.

25 The beam splitter of an embodiment is positioned to receive at the first face first illumination from the first light source, wherein the beam splitter directs the first illumination from the first face to the output.

The beam splitter of an embodiment is positioned to receive at the second face second illumination from a second light source, wherein the beam splitter directs the second illumination from the second face to the output.

The system of an embodiment comprises a first lens positioned between the first light source and the first face of the beam splitter, wherein the first lens is a collimating lens.

5 The system of an embodiment comprises a second lens positioned between the second light source and the second face of the beam splitter, wherein the second lens is a collimating lens.

The output of an embodiment comprises a third face of the beam splitter.

The system of an embodiment comprises a third lens positioned adjacent to the third face of the beam splitter, wherein the third lens is a focusing lens.

10 The incandescent light of an embodiment comprises a low-color-temperature incandescent light.

The second light source of an embodiment includes a light emitting diode (LED).

The LED of an embodiment comprises a white-light LED.

15 The beam splitter of an embodiment comprises a broadband beam splitter.

The beam splitter of an embodiment comprises a hot mirror beam splitter.

The beam splitter of an embodiment comprises a cold mirror beam splitter.

The optic coupler of an embodiment comprises an integrating sphere.

20 The plurality of input branches of an embodiment comprises a plurality of ports.

The output of an embodiment comprises an output port.

The incandescent light of an embodiment is coupled to a first port of the integrating sphere.

25 The incandescent light of an embodiment comprises a low-color-temperature incandescent light.

The plurality of light sources of an embodiment includes a light emitting diode (LED).

The LED of an embodiment is coupled to a second port of the integrating sphere.

The LED of an embodiment comprises a white-light LED.

The plurality of light sources of an embodiment includes a second LED.

The second LED of an embodiment is coupled to a third port of the integrating sphere.

5 The second LED of an embodiment comprises a short-wavelength LED.

The plurality of light sources of an embodiment include a third LED.

The third LED of an embodiment is coupled to a fourth port of the integrating sphere.

The third LED of an embodiment comprises a short-wavelength LED.

10 Embodiments described herein include a system comprising an optic coupler including a plurality of inputs and an output. The system includes a first light source coupled to a first input of the plurality of inputs. The first light source comprises an incandescent light. The system includes a second light source coupled to a second input of the plurality of inputs. The second light source outputs light having a
15 different wavelength distribution than at least the first light source of the plurality of light sources. The output emits a broadband light source comprising a combined spectral output of the first light source and the second light source.

Embodiments described herein include a system comprising: an optic coupler including a plurality of inputs and an output; a first light source coupled to a first
20 input of the plurality of inputs, wherein the first light source comprises an incandescent light; and a second light source coupled to a second input of the plurality of inputs, wherein the second light source outputs light having a different wavelength distribution than at least the first light source of the plurality of light
25 sources; wherein the output emits a broadband light source comprising a combined spectral output of the first light source and the second light source.

The optic coupler of an embodiment comprises a fiber optic light guide including a plurality of input branches.

The plurality of inputs of an embodiment includes the plurality of input branches.

The optic coupler of an embodiment comprises a beam splitter.

The plurality of inputs of an embodiment includes a plurality of faces of the beam splitter.

The optic coupler of an embodiment comprises an integrating sphere.

5 The plurality of inputs of an embodiment comprises a plurality of ports of the integrating sphere.

Embodiments described herein include a system comprising an optic coupler including a plurality of inputs and an output. The system includes a first light source coupled to a first input of the plurality of inputs. The first light source comprises an incandescent light. The system includes a second light source coupled to a second input of the plurality of inputs. The second light source outputs light having a different wavelength distribution than at least the first light source. The system includes a third light source coupled to a third input of the plurality of inputs. The third light source outputs light having a different wavelength than at least the first light source and the second light source. The system includes a fourth light source coupled to a fourth input of the plurality of inputs. The fourth light source outputs light having a different wavelength than at least the first light source and the second light source. The output emits a broadband light source comprising a combined spectral output of the first light source, the second light source, the third light source, and the fourth light source.

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Embodiments described herein include a system comprising: an optic coupler including a plurality of inputs and an output; a first light source coupled to a first input of the plurality of inputs, wherein the first light source comprises an incandescent light; a second light source coupled to a second input of the plurality of inputs, wherein the second light source outputs light having a different wavelength distribution than at least the first light source; a third light source coupled to a third input of the plurality of inputs, wherein the third light source outputs light having a different wavelength than at least the first light source and the second light source; a fourth light source coupled to a fourth input of the plurality of inputs, wherein the

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fourth light source outputs light having a different wavelength than at least the first light source and the second light source; wherein the output emits a broadband light source comprising a combined spectral output of the first light source, the second light source, the third light source, and the fourth light source.

5 The optic coupler of an embodiment comprises a fiber optic light guide including a plurality of input branches.

 The plurality of inputs of an embodiment includes the plurality of input branches.

 The optic coupler of an embodiment comprises at least one beam splitter.

10 The plurality of inputs of an embodiment includes a plurality of faces of the at least one beam splitter.

 The optic coupler of an embodiment comprises an integrating sphere.

 The plurality of inputs of an embodiment comprises a plurality of ports of the integrating sphere.

15 Embodiments described herein include a system comprising a plurality of light sources. A first light source of the plurality of light sources comprises an incandescent light. A second light source of the plurality of light sources outputs light has a different wavelength distribution than the first light source. The system includes a plurality of lenses. Each lens of the plurality of lenses is optically coupled
20 to each light source of the plurality of light sources. The system includes an optical device optically coupled to the plurality of lenses. The optical device combines light received from the plurality of lenses. An output from the optical device comprises broadband light having a combined spectral output of the plurality of light sources.

 Embodiments described herein include a system comprising: a plurality of
25 light sources, wherein a first light source of the plurality of light sources comprises an incandescent light, wherein a second light source of the plurality of light sources outputs light having a different wavelength distribution than the first light source; a plurality of lenses, wherein each lens of the plurality of lenses is optically coupled to each light source of the plurality of light sources; and an optical device optically

coupled to the plurality of lenses, wherein the optical device combines light received from the plurality of lenses, wherein an output from the optical device comprises broadband light having a combined spectral output of the plurality of light sources.

Embodiments described herein include a system comprising a plurality of
5 light sources. A first light source of the plurality of light sources comprises an incandescent light. A second light source of the plurality of light sources outputs light has a different wavelength distribution than the first light source. The system includes an optical integrating sphere comprising a plurality of input ports and an output port. The plurality of light sources is optically coupled to the plurality of input
10 ports. The optical integrating sphere combines light of the plurality of light sources. The output port outputs broadband light comprising a combined spectral output of the plurality of light sources.

Embodiments described herein include a system comprising: a plurality of
light sources, wherein a first light source of the plurality of light sources comprises an
15 incandescent light, wherein a second light source of the plurality of light sources outputs light having a different wavelength distribution than the first light source; and an optical integrating sphere comprising a plurality of input ports and an output port, wherein the plurality of light sources are optically coupled to the plurality of input
ports, wherein the optical integrating sphere combines light of the plurality of light
20 sources, wherein the output port outputs broadband light comprising a combined spectral output of the plurality of light sources.

Embodiments described herein include a method comprising coupling a
plurality of light sources to an optical device. The method includes operating a first
light source of the plurality of light sources to emit incandescent light. The method
25 includes operating a second light source of the plurality of light sources to emit light having a different wavelength distribution than the at least the first light source. The method includes forming a broadband light source by combining at the optical device
light of the plurality of light sources.

Embodiments described herein include a method comprising: coupling a plurality of light sources to an optical device; operating a first light source of the plurality of light sources to emit incandescent light; operating a second light source of the plurality of light sources to emit light having a different wavelength distribution than the at least the first light source; and forming a broadband light source by combining at the optical device light of the plurality of light sources.

Coupling the plurality of light sources to an optical device of an embodiment comprises coupling each light source to each input branch of a plurality of input branches of a fiber optic light guide.

Coupling the plurality of light sources to an optical device of an embodiment comprises coupling each light source to each face of at least one beam splitter.

The beam splitter of an embodiment comprises a broadband beam splitter.

The beam splitter of an embodiment comprises a hot mirror beam splitter.

The beam splitter of an embodiment comprises a cold mirror beam splitter.

Coupling the plurality of light sources to an optical device of an embodiment comprises coupling each light source to each input port of a plurality of input ports of an integrating sphere.

The incandescent light of an embodiment comprises a low-color-temperature incandescent light.

The second light source of an embodiment includes a light emitting diode (LED).

The LED of an embodiment comprises a white-light LED.

The plurality of light sources of an embodiment includes a second LED.

The second LED of an embodiment comprises a short-wavelength LED.

The plurality of light sources of an embodiment include a third LED.

The third LED of an embodiment comprises a short-wavelength LED.

Unless the context clearly requires otherwise, throughout the description, the words “comprise,” “comprising,” and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in a sense of

“including, but not limited to.” Words using the singular or plural number also include the plural or singular number respectively. Additionally, the words “herein,” “hereunder,” “above,” “below,” and words of similar import refer to this application as a whole and not to any particular portions of this application. When the word “or”
5 is used in reference to a list of two or more items, that word covers all of the following interpretations of the word: any of the items in the list, all of the items in the list and any combination of the items in the list.

The above description of embodiments of the light source systems and methods is not intended to be exhaustive or to limit the systems and methods
10 described to the precise form disclosed. While specific embodiments of, and examples for, the light source systems and methods are described herein for illustrative purposes, various equivalent modifications are possible within the scope of other light source systems and methods, as those skilled in the relevant art will recognize. The teachings of the light source systems and methods provided herein
15 can be applied to other processing and measurement systems and methods, not only for the systems and methods described above.

The elements and acts of the various embodiments described above can be combined to provide further embodiments. These and other changes can be made to the light source systems and methods in light of the above detailed description.

20 In general, in the following claims, the terms used should not be construed to limit the light source systems and methods to the specific embodiments disclosed in the specification and the claims, but should be construed to include all systems and methods that operate under the claims. Accordingly, the light source systems and methods are not limited by the disclosure, but instead the scope of the light source
25 systems and methods is to be determined entirely by the claims.

While certain aspects of the light source systems and methods are presented below in certain claim forms, the inventors contemplate the various aspects of the light source systems and methods in any number of claim forms. Accordingly, the inventors reserve the right to add additional claims after filing the application to

pursue such additional claim forms for other aspects of the light source systems and methods.

CLAIMS

What is claimed is:

1. A system comprising:
an optic coupler including a plurality of input branches coupled to an output;
5 a plurality of light sources coupled to the plurality of input branches, wherein
a first light source of the plurality of light sources outputs light having a different
wavelength distribution than at least one other light source of the plurality of light
sources, wherein the first light source comprises an incandescent light;
wherein the output emits a broadband light source comprising a combined
10 spectral output of the plurality of light sources.
2. The system of claim 1, wherein the optic coupler comprises a fused coupler.
3. The system of claim 1, wherein the optic coupler comprises a fiber optic
15 coupler.
4. The system of claim 3, wherein the fiber optic coupler comprises a dual-
branch fiber optic light guide.
- 20 5. The system of claim 4, wherein the incandescent light is coupled to a first
input branch of the fiber optic coupler.
6. The system of claim 5, wherein the incandescent light comprises a low-color-
temperature incandescent light.
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7. The system of claim 5, wherein the plurality of light sources includes a light
emitting diode (LED).

8. The system of claim 7, wherein the LED is coupled to a second input branch of the fiber optic coupler.

9. The system of claim 7, wherein the LED comprises a white-light LED.

10. The system of claim 3, wherein the fiber optic coupler comprises a quad-branch fiber optic light guide.

11. The system of claim 10, wherein the incandescent light is coupled to a first input branch of the fiber optic coupler.

12. The system of claim 11, wherein the incandescent light comprises a low-color-temperature incandescent light.

13. The system of claim 11, wherein the plurality of light sources include a first LED.

14. The system of claim 13, wherein the first LED is coupled to a second input branch of the fiber optic coupler.

15. The system of claim 13, wherein the first LED comprises a white-light LED.

16. The system of claim 13, wherein the plurality of light sources include a second LED.

17. The system of claim 16, wherein the second LED is coupled to a third input branch of the fiber optic coupler.

18. The system of claim 16, wherein the second LED comprises a short-wavelength LED.

19. The system of claim 16, wherein the plurality of light sources include a third LED.

20. The system of claim 19, wherein the third LED is coupled to a fourth input branch of the fiber optic coupler.

21. The system of claim 19, wherein the third LED comprises a short-wavelength LED.

22. The system of claim 1, wherein the optic coupler comprises a beam splitter.

23. The system of claim 22, wherein the plurality of input branches include a first face of the beam splitter and a second face of the beam splitter.

24. The system of claim 22, wherein the beam splitter is positioned to receive at the first face first illumination from the first light source, wherein the beam splitter directs the first illumination from the first face to the output.

25. The system of claim 24, wherein the beam splitter is positioned to receive at the second face second illumination from a second light source, wherein the beam splitter directs the second illumination from the second face to the output.

26. The system of claim 25, comprising a first lens positioned between the first light source and the first face of the beam splitter, wherein the first lens is a collimating lens.

27. The system of claim 26, comprising a second lens positioned between the second light source and the second face of the beam splitter, wherein the second lens is a collimating lens.

5 28. The system of claim 27, wherein the output comprises a third face of the beam splitter.

29. The system of claim 28, comprising a third lens positioned adjacent to the third face of the beam splitter, wherein the third lens is a focusing lens.

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30. The system of claim 25, wherein the incandescent light comprises a low-color-temperature incandescent light.

15 31. The system of claim 25, wherein the second light source includes a light emitting diode (LED).

32. The system of claim 31, wherein the LED comprises a white-light LED.

20 33. The system of claim 22, wherein the beam splitter comprises a broadband beam splitter.

34. The system of claim 22, wherein the beam splitter comprises a hot mirror beam splitter.

25 35. The system of claim 22, wherein the beam splitter comprises a cold mirror beam splitter.

36. The system of claim 1, wherein the optic coupler comprises an integrating sphere.

37. The system of claim 36, wherein the plurality of input branches comprise a plurality of ports.

38. The system of claim 37, wherein the output comprises an output port.

39. The system of claim 37, wherein the incandescent light is coupled to a first port of the integrating sphere.

40. The system of claim 39, wherein the incandescent light comprises a low-color-temperature incandescent light.

41. The system of claim 39, wherein the plurality of light sources includes a light emitting diode (LED).

42. The system of claim 41, wherein the LED is coupled to a second port of the integrating sphere.

43. The system of claim 42, wherein the LED comprises a white-light LED.

44. The system of claim 42, wherein the plurality of light sources include a second LED.

45. The system of claim 44, wherein the second LED is coupled to a third port of the integrating sphere.

46. The system of claim 44, wherein the second LED comprises a short-wavelength LED.

47. The system of claim 44, wherein the plurality of light sources include a third LED.

48. The system of claim 47, wherein the third LED is coupled to a fourth port of the integrating sphere.

49. The system of claim 47, wherein the third LED comprises a short-wavelength LED.

50. A system comprising:
an optic coupler including a plurality of inputs and an output;
a first light source coupled to a first input of the plurality of inputs, wherein the first light source comprises an incandescent light; and
a second light source coupled to a second input of the plurality of inputs, wherein the second light source outputs light having a different wavelength distribution than at least the first light source of the plurality of light sources;
wherein the output emits a broadband light source comprising a combined spectral output of the first light source and the second light source.

51. The system of claim 50, wherein the optic coupler comprises a fiber optic light guide including a plurality of input branches.

52. The system of claim 51, wherein the plurality of inputs includes the plurality of input branches.

53. The system of claim 50, wherein the optic coupler comprises a beam splitter.

54. The system of claim 53, wherein the plurality of inputs includes a plurality of faces of the beam splitter.

55. The system of claim 50, wherein the optic coupler comprises an integrating sphere.

5 56. The system of claim 55, wherein the plurality of inputs comprises a plurality of ports of the integrating sphere.

57. A system comprising:

an optic coupler including a plurality of inputs and an output;

10 a first light source coupled to a first input of the plurality of inputs, wherein the first light source comprises an incandescent light;

a second light source coupled to a second input of the plurality of inputs, wherein the second light source outputs light having a different wavelength distribution than at least the first light source;

15 a third light source coupled to a third input of the plurality of inputs, wherein the third light source outputs light having a different wavelength than at least the first light source and the second light source;

a fourth light source coupled to a fourth input of the plurality of inputs, wherein the fourth light source outputs light having a different wavelength than at least the first light source and the second light source;

20 wherein the output emits a broadband light source comprising a combined spectral output of the first light source, the second light source, the third light source, and the fourth light source.

25 58. The system of claim 57, wherein the optic coupler comprises a fiber optic light guide including a plurality of input branches.

59. The system of claim 58, wherein the plurality of inputs includes the plurality of input branches.

60. The system of claim 57, wherein the optic coupler comprises at least one beam splitter.

5 61. The system of claim 60, wherein the plurality of inputs includes a plurality of faces of the at least one beam splitter.

62. The system of claim 57, wherein the optic coupler comprises an integrating sphere.

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63. The system of claim 62, wherein the plurality of inputs comprises a plurality of ports of the integrating sphere.

64. A system comprising:

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a plurality of light sources, wherein a first light source of the plurality of light sources comprises an incandescent light, wherein a second light source of the plurality of light sources outputs light having a different wavelength distribution than the first light source;

20

a plurality of lenses, wherein each lens of the plurality of lenses is optically coupled to each light source of the plurality of light sources; and

an optical device optically coupled to the plurality of lenses, wherein the optical device combines light received from the plurality of lenses, wherein an output from the optical device comprises broadband light having a combined spectral output of the plurality of light sources.

25

65. A system comprising:

a plurality of light sources, wherein a first light source of the plurality of light sources comprises an incandescent light, wherein a second light source of the

plurality of light sources outputs light having a different wavelength distribution than the first light source; and

an optical integrating sphere comprising a plurality of input ports and an output port, wherein the plurality of light sources are optically coupled to the plurality of input ports, wherein the optical integrating sphere combines light of the plurality of light sources, wherein the output port outputs broadband light comprising a combined spectral output of the plurality of light sources.

66. A method comprising:

coupling a plurality of light sources to an optical device;
operating a first light source of the plurality of light sources to emit incandescent light;

operating a second light source of the plurality of light sources to emit light having a different wavelength distribution than the at least the first light source; and

forming a broadband light source by combining at the optical device light of the plurality of light sources.

67. The method of claim 66, wherein coupling the plurality of light sources to an optical device comprises coupling each light source to each input branch of a plurality of input branches of a fiber optic light guide.

68. The method of claim 66, wherein coupling the plurality of light sources to an optical device comprises coupling each light source to each face of at least one beam splitter.

69. The method of claim 68, wherein the beam splitter comprises a broadband beam splitter.

70. The method of claim 68, wherein the beam splitter comprises a hot mirror beam splitter.

71. The method of claim 68, wherein the beam splitter comprises a cold mirror beam splitter.

72. The method of claim 66, wherein coupling the plurality of light sources to an optical device comprises coupling each light source to each input port of a plurality of input ports of an integrating sphere.

73. The method of claim 66, wherein the incandescent light comprises a low-color-temperature incandescent light.

74. The method of claim 66, wherein the second light source includes a light emitting diode (LED).

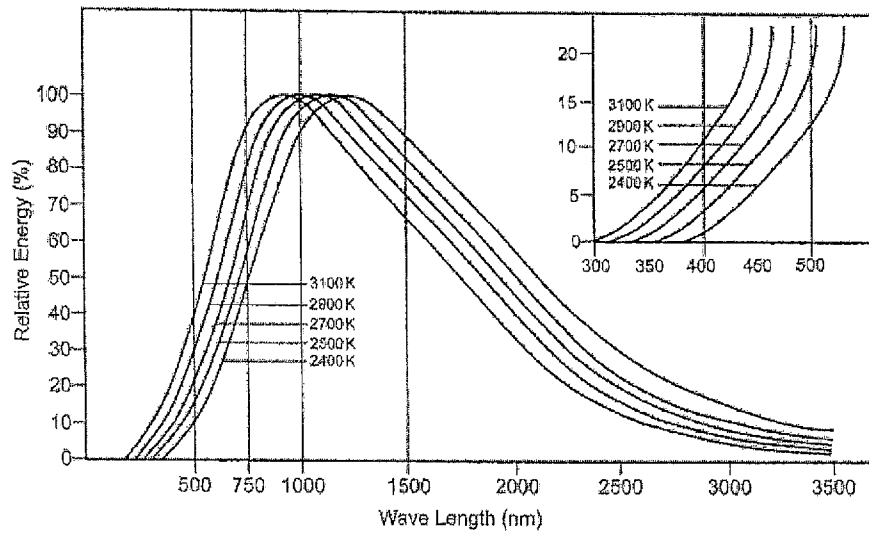
75. The method of claim 74, wherein the LED comprises a white-light LED.

76. The method of claim 74, wherein the plurality of light sources include a second LED.

77. The method of claim 76, wherein the second LED comprises a short-wavelength LED.

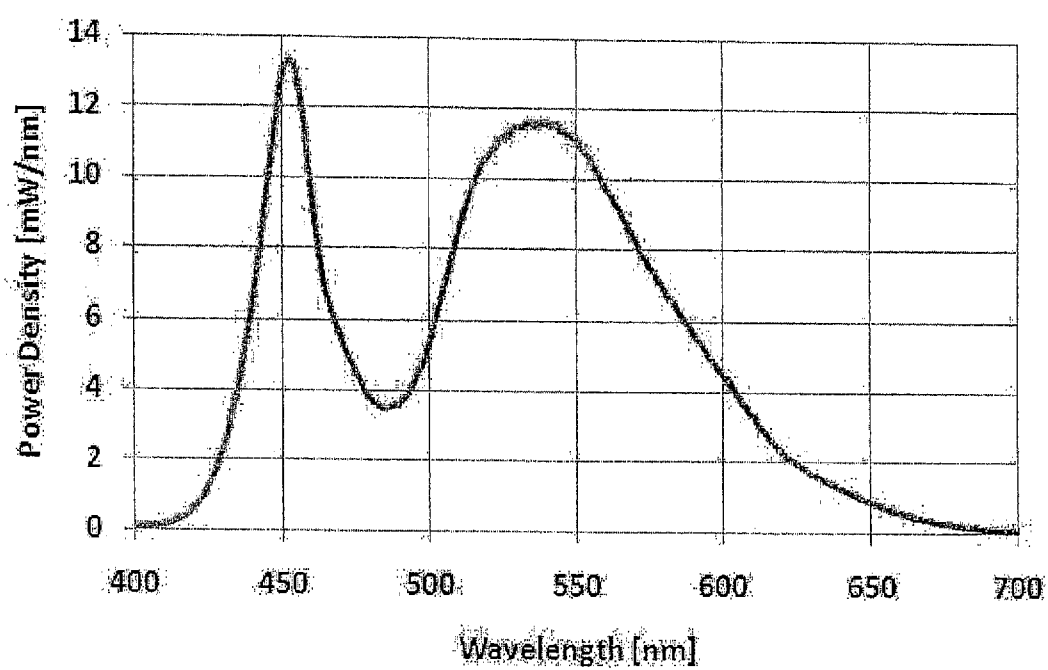
78. The method of claim 76, wherein the plurality of light sources include a third LED.

79. The method of claim 78, wherein the third LED comprises a short-wavelength LED.



From International Light Technologies, ILT Sources Catalog
(http://files.intl-lighttech.com/pdf/Halogen_Lamps-ILT_Sources_Catalog_2010.pdf)

Figure 1



From <http://www.prizmatix.com/docs/UHP-Mic-LED-White.cfm>

Figure 2

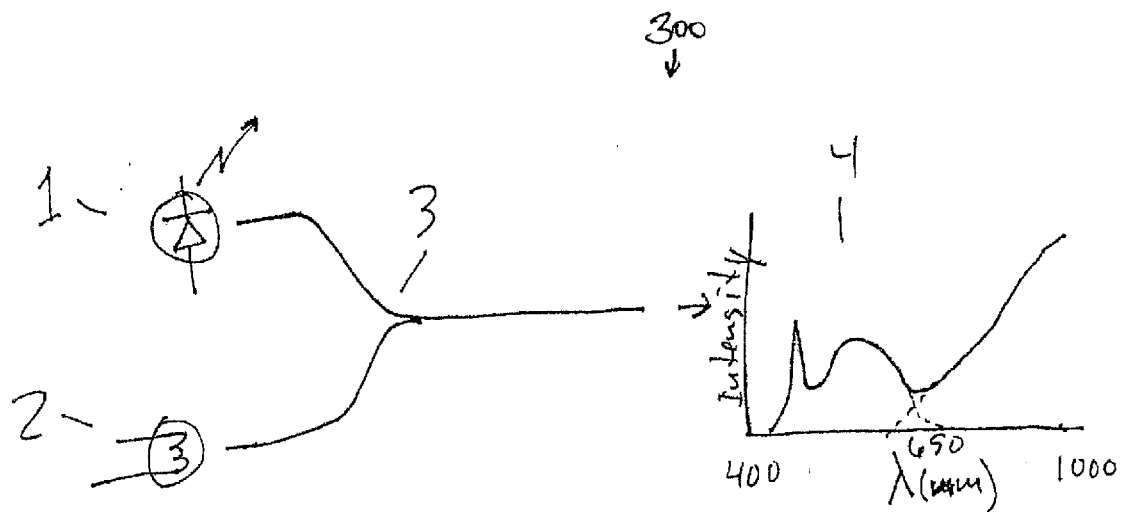


Figure 3

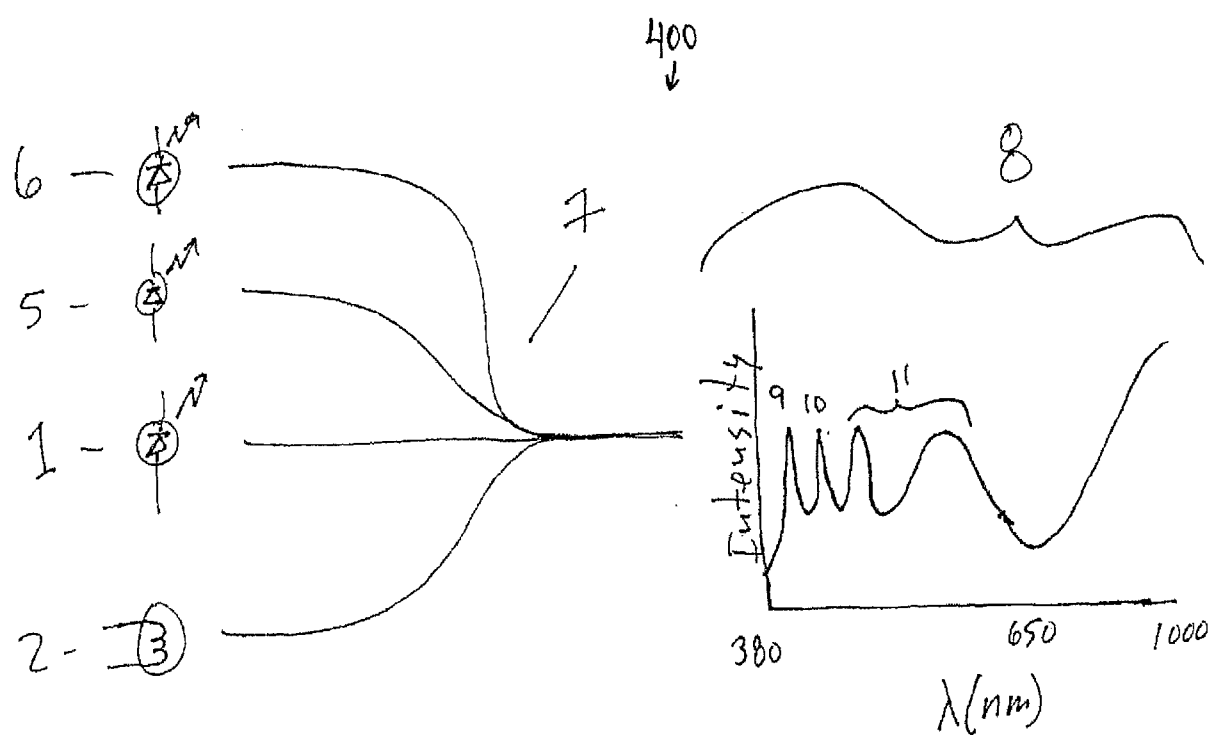


Figure 4

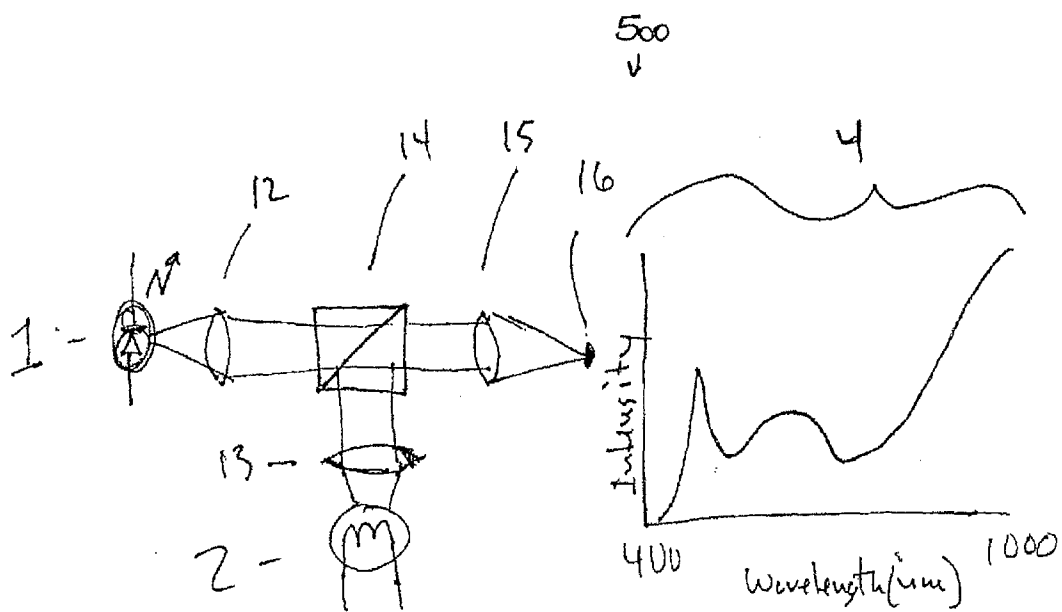


Figure 5

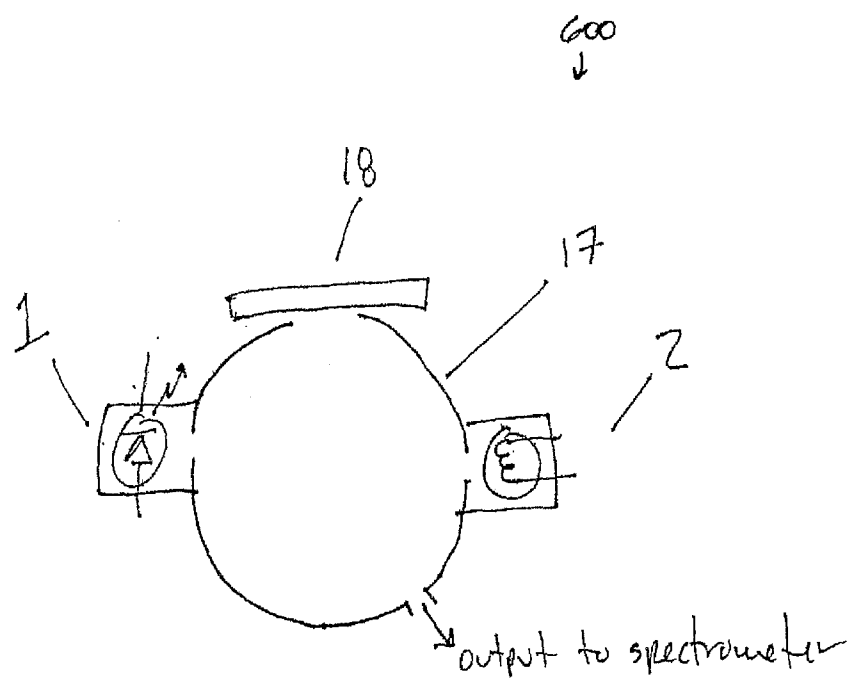
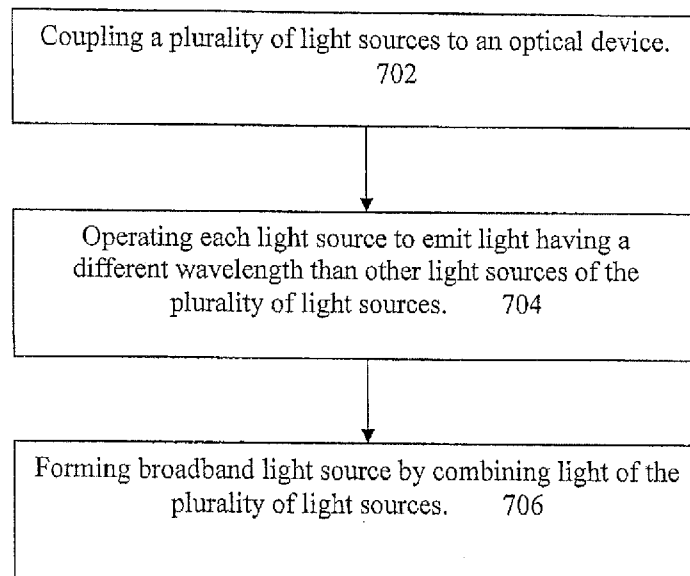


Figure 6

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**Figure 7**

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 13/21716

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - G01N 33/48 (2013.01)

USPC - 385/39

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)

IPC(8): G01N 33/48 (2013.01)

USPC: 385/39

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

IPC(8): G01N 33/48 (2013.01) (keyword limited - see terms below)

USPC: 356/497; 385/24, 39, 45, 51 (keyword limited - see terms below)

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

PatBase(All), Google Patent, Google Scholar, Search Terms: optic, coupler, input, branches, broadband, light, wavelength, fiber optic

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,475,221 A (Wang) 12 December 1995 (12.12.1995), entire document, especially Fig 1, claim 1 and col 3, ln 15-25	1-79
Y	US 2008/0304712 A1 (Rowe et al) 11 December 2008 (11.12.2008) see para [0014], [0060]	1-79
Y	US 2003/0234751 A1 (Hwang) 25 December 2003 (25.12.2003) see para [0035], [0036], [0048], [0050], [0052], [0076]	22-49, 51-56, 58-65, 67-79
Y	US 6,055,099 A (Webb) 25 April 2000 (25.04.2000) see abstract, col 2, ln 13-15, 49-52	37-49, 56, 63 and 65

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:

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"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

26 April 2013 (26.04.2013)

Date of mailing of the international search report

05 JUN-2013

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