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(54) **UTILIZING FIBER BUNDLES AND HOMOGENIZERS FOR UNIFORM ILLUMINATION OF OPHTHALMOLOGY SURGICAL MICROSCOPES**

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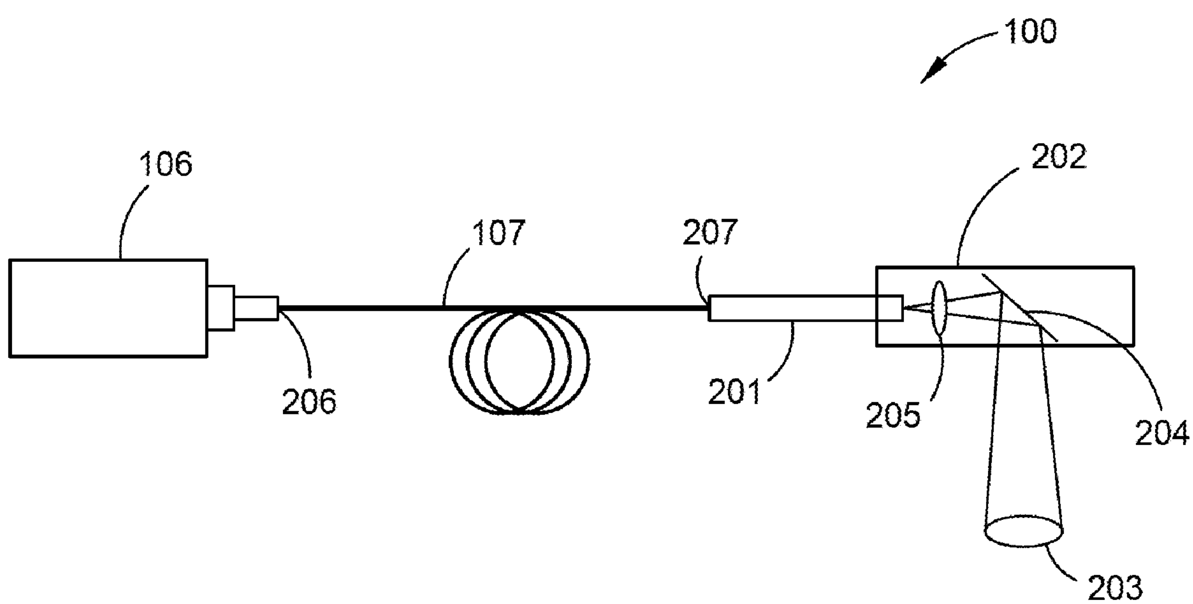
(57) **ABSTRACT**

Optical systems for forming uniform illumination are disclosed. The optical system includes a light source coupled to a plurality of first light carriers providing a plurality of light intensities and a second light carrier coupled to the plurality of first light carriers. The second light carrier spatially homogenizes the plurality of light intensities to form a homogenized light intensity. The optical system further includes an illumination module coupled to the second light carrier and operable to receive the homogenized light intensity.



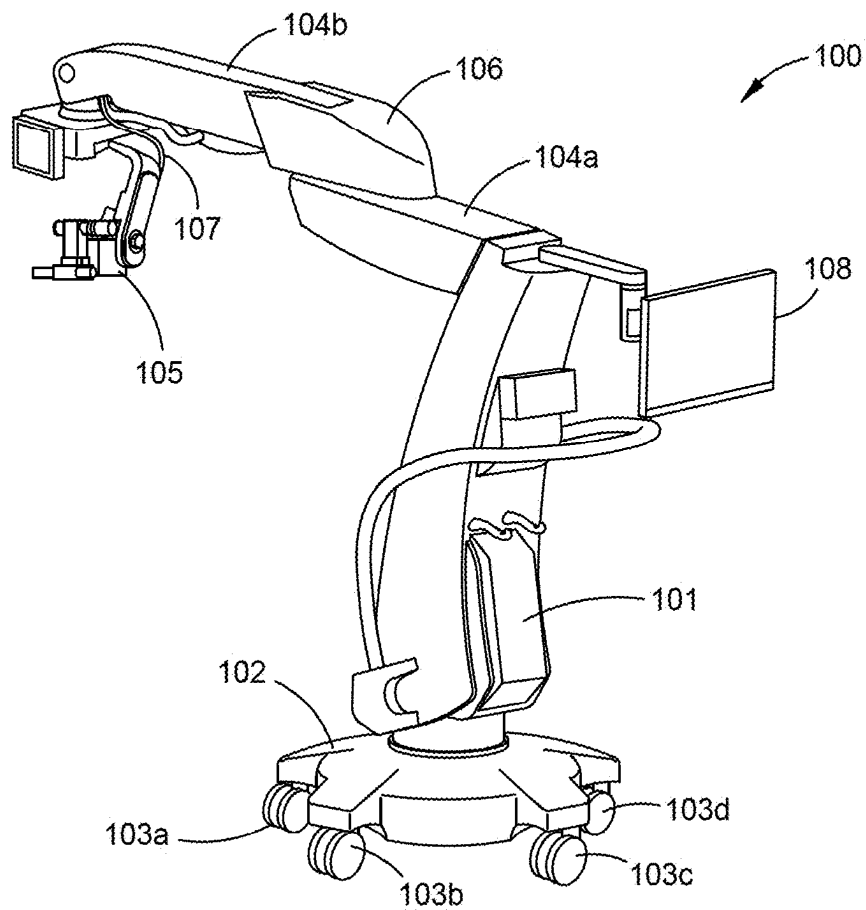

104b
106
100
104a
107
108
105
101
102
103d
103a
103c
103b

FIG. 1

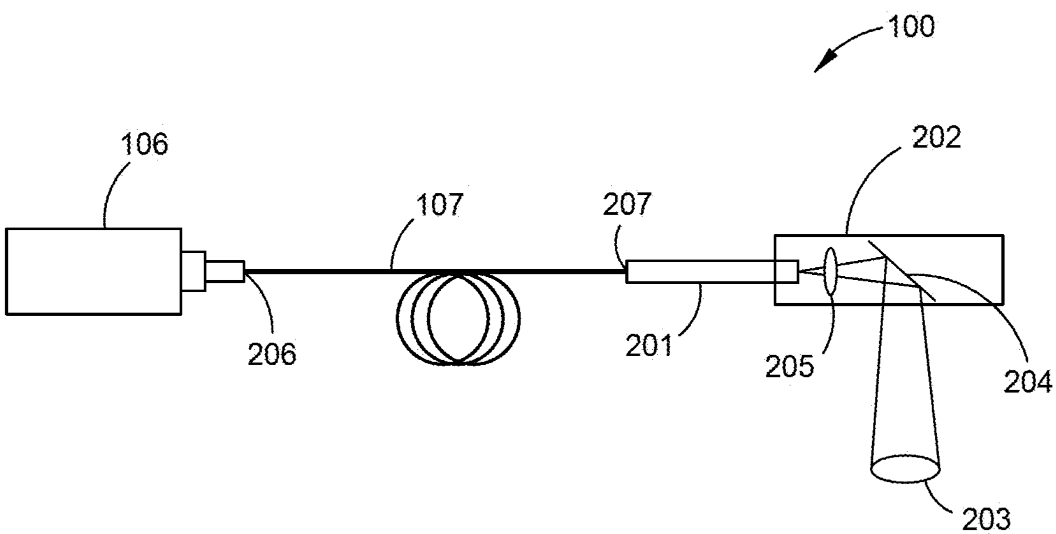

100
106
202
107
207
206
201
205
204
203

FIG. 2

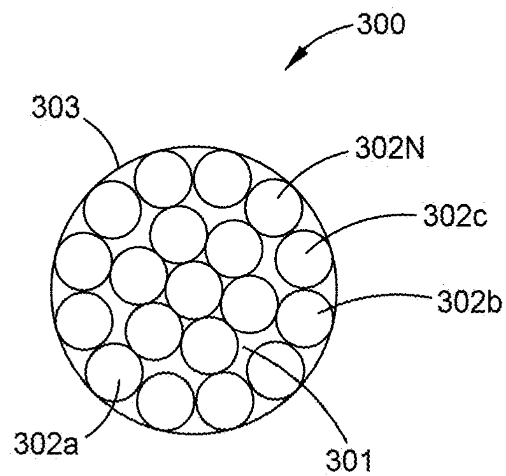

300
303
302N
302c
302b
302a
301

FIG. 3A

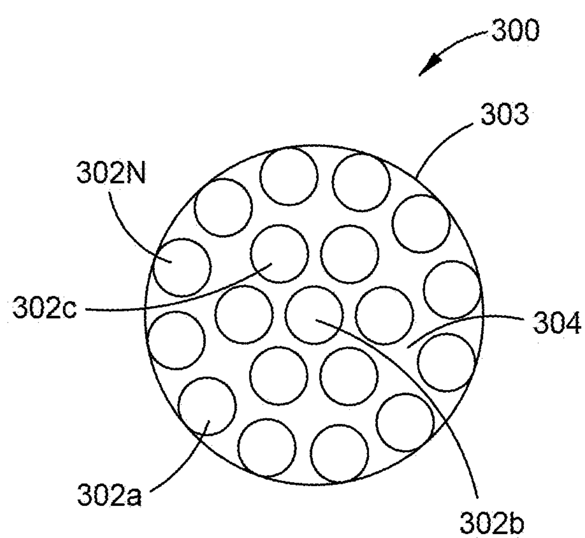

300
303
302N
302c
304
302a
302b

FIG. 3B

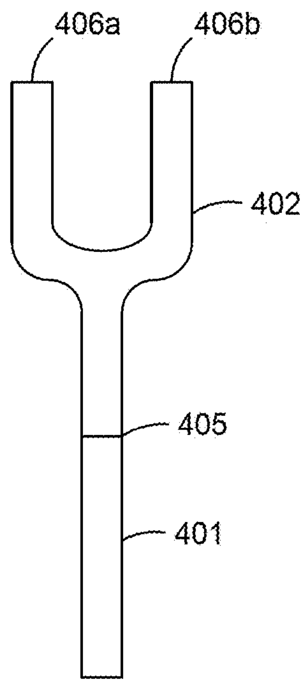


FIG. 4A

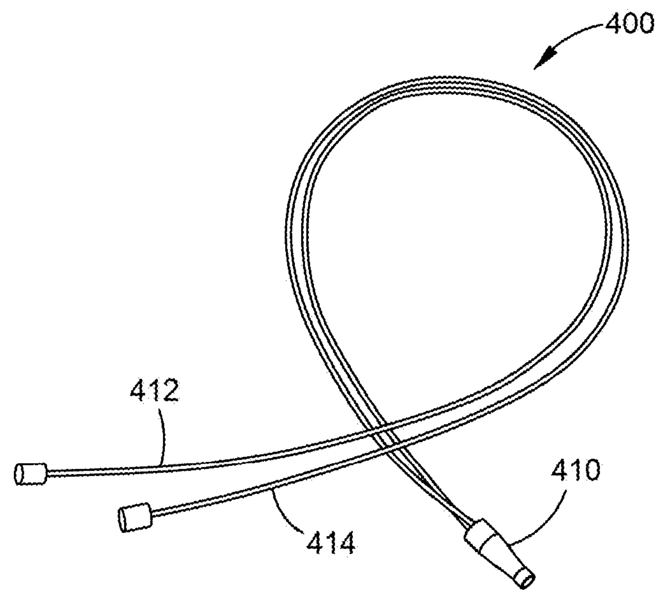


FIG. 4B

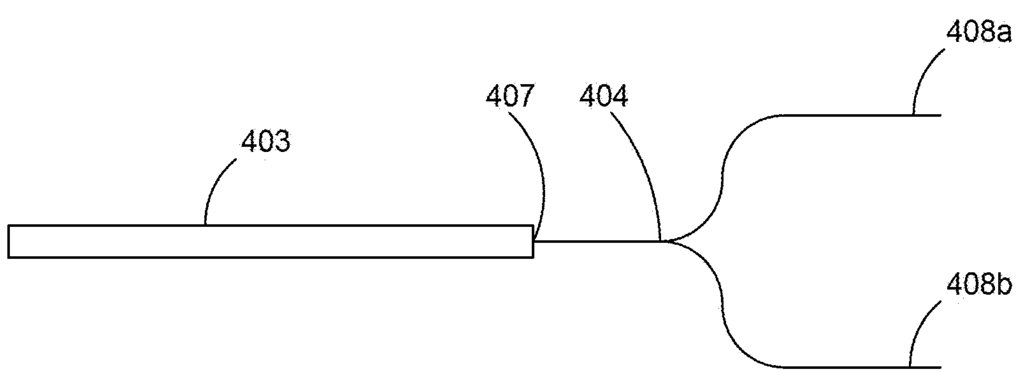


FIG. 4C

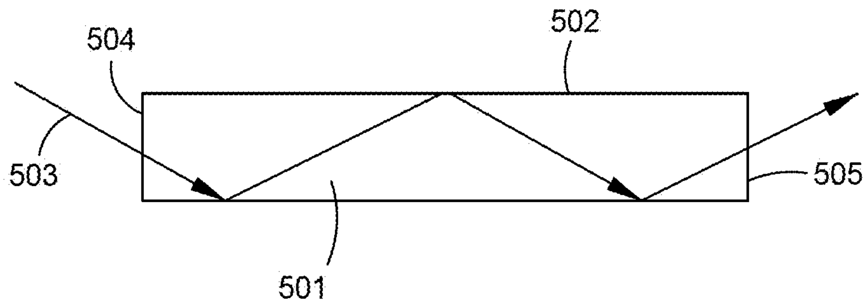


FIG. 5

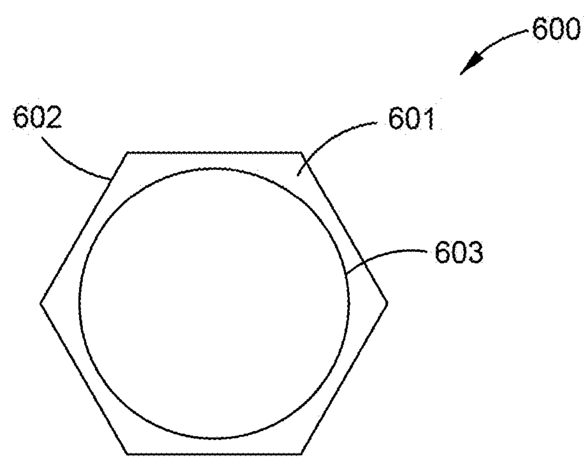


FIG. 6

UTILIZING FIBER BUNDLES AND HOMOGENIZERS FOR UNIFORM ILLUMINATION OF OPHTHALMOLOGY SURGICAL MICROSCOPES

INTRODUCTION

[0001] This section provides information to facilitate a better understanding of the various aspects of the disclosure. It should be understood that the statements in this section of this document are to be read in this light, and not as admissions of prior art.

[0002] Ophthalmic microscopes are generally designed to provide high contrast and detailed imaging of all regions of an eye. Illumination systems of ophthalmic microscopes provide light to illuminate regions of the eye during an eye procedure at a working area (e.g., the corneal plane). While these illumination systems may provide illumination to the eye, they suffer from having a non-uniform distribution of light and provide poor color mixing at the region being viewed (e.g., the corneal plane). In addition, these systems generally experience bending loss in optical waveguides when the ophthalmic microscope arm and/or optical head are moved.

SUMMARY

[0003] This summary is provided to introduce a selection of concepts that are further described below in the Detailed Description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it to be used as an aid in limiting the scope of the claimed subject matter.

[0004] Certain embodiments herein pertain to an optical system including a light source coupled to a plurality of first light carriers providing a plurality of light intensities and a second light carrier coupled to the plurality of first light carriers. The second light carrier spatially homogenizes the plurality of light intensities to form a homogenized light intensity. The optical system further includes an illumination module coupled to the second light carrier and is operable to receive the homogenized light intensity.

[0005] Certain embodiments herein pertain to an optical system including a light source coupled to a light carrier. The light carrier spatially homogenizes a plurality of light intensities to form a homogenized light intensity. The optical system further includes an optical head having an illumination module coupled to the light carrier and operable to receive the homogenized light intensity. The optical head is spaced apart from the light source.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] A more complete understanding of the subject matter of the present disclosure may be obtained by reference to the following Detailed Description when taken in conjunction with the accompanying Drawings wherein:

[0007] FIG. **1** illustrates an example microscope, according to aspects of the disclosure.

[0008] FIG. **2** illustrates an example optical system operable to be coupled to, or integrated with, a microscope (e.g., the microscope of FIG. **1**), according to aspects of the disclosure.

[0009] FIG. **3**A illustrates a first end of a randomized fiber optic bundle, according to aspects of the disclosure.

[0010] FIG. **3**B illustrates a second end of the randomized fiber optic bundle, according to aspects of the disclosure.

[0011] FIG. **4**A illustrates a fiber optic bundle having a split-rod, according to aspects of the disclosure.

[0012] FIG. **4**B illustrates a bifurcated fiber optic bundle, according to aspects of the disclosure.

[0013] FIG. **4**C illustrates a fiber optic bundle having a fiber optic splitter, according to aspects of the disclosure.

[0014] FIG. **5** illustrates an example embodiment of a second light carrier, according to aspects of the disclosure.

[0015] FIG. **6** illustrates an example embodiments of a second light carrier having a hexagonal shape, according to aspects of the disclosure.

DETAILED DESCRIPTION

[0016] It is to be understood that the following disclosure provides many different embodiments, or examples, for implementing different features of various embodiments. Specific examples of components and arrangements are described below to simplify the disclosure. These are, of course, merely examples and are not intended to be limiting. The section headings used herein are for organizational purposes and are not to be construed as limiting the subject matter described.

[0017] Various ophthalmic microscopes may utilize either a single core optical fiber or liquid light guides (LLGs) as a waveguide medium in the microscope. Although the light transmission from LLGs are decent, there are several drawbacks with them. For example, LLGs have poor mechanical reliability, especially at the shipping temperature, which is generally less than −40° C. and sometimes more than 70° C. Additionally, the seals that protect the liquid inside the LLGs tend to break, which can result in the formation of bubbles within the LLGs. Once the seal of an LLG is broken, the damage is irreversible. Furthermore, the lifetime of an LLG is generally only around 2 to 4 years, and therefore, LLGs are not suitable for long-life equipment. Another problem with LLGs is that the allowable bend radius is large, preventing opto-mechanical engineers from designing a flexible cable routing path for ophthalmic microscopes.

[0018] In certain ophthalmic microscopes, there may be a fiber optic bundle that propagates light from a remotely positioned source, for example, a xenon source, to its illumination optics. However, these fiber optic bundles are not randomized, and there is no beam homogenizing component, or homogenizer, after the fiber optic bundle. As such, the light intensity is not evenly distributed and "hot spots" of higher light intensity are noticeable in the middle of the projected beam at the corneal plane.

[0019] As used herein, the term "randomized", when referring to fiber optic bundles or other light carriers, refers to the placement of light carriers within a ferrule, sheathing, or other holder/containment device (e.g., purposeful placement of one or more fibers of the fiber optic bundle). For example, with respect to randomized fiber optic bundles, relative end positions of one or more fibers within the randomized fiber optic bundle may change from its input end position to another position at the output end of the fiber optic bundle. As such, light waves may enter at one position of the randomized fiber optic bundle and exit at a different position.

[0020] Stated differently, light entering into the input end of the randomized fiber optic bundle (or other light carrier) may or may not have the same corresponding position at the output end of the randomized fiber optic bundle, relative to each fiber optic within the randomized fiber optic bundle. As an example, if light enters into the randomized fiber optic bundle at a top portion of the input end, the light will propagate through a fiber optic of the randomized fiber optic bundle and may exit at a bottom portion of the output end of the randomized fiber optic bundle. In this example, the fiber optic had a top position in the randomized fiber optic bundle at the input end and a bottom position in the randomized fiber optic bundle at the output end. It should be noted that, as used herein, randomized fiber optic bundles and/or light carriers may or may not have a one-to-one mapping from an input end to an output end. However, in certain embodiments, a randomized fiber optic bundle and/or light carrier may have substantially no one-to-one mappings.

[0021] Accordingly, certain embodiments herein pertain to utilizing a light carrier that may include, for example, a fiber optic bundle in conjunction with a light beam homogenizer to produce a spatially homogenized beam for ophthalmic illumination applications. In various embodiments disclosed herein, various light-emitting diodes (LEDs), for example red, green, and blue LEDs, are mixed to obtain a white light, and may be remotely located in the microscope system. In certain embodiments, a module that contains a randomized fiber optic bundle, in combination with a clad-rod homogenizer, may be used to route the light beam to the corneal plane. The clad-rod homogenizer may spatially homogenize the light intensity and mix the color of the LEDs.

[0022] In certain embodiments, the systems described herein may have various advantages over optical systems currently available. For example, one advantage of using a randomized fiber optic bundle as a light carrier is that the routing may be more flexible when compared to a single core optical fiber. The remote light source (e.g., red, blue, and green LEDs), the randomized fiber optic bundle, and the clad-rod homogenizer may be integrated via simple, and standard, SubMiniature version A (SMA) connectors.

[0023] In another example, randomized fiber optic bundles discussed herein may contain tiny borosilicate fibers with a core diameter in a range of ~15 to 100 μm, ~20 to 70 μm, and/or ~30 to 70 μm. In certain embodiments, the core diameter may be ~50 μm. Approximately 1,000 to 2,000 of these fibers may be packed to form an active area in a range of ~0.5 to 4 mm (millimeters). In certain embodiments, 1,400 of these fibers are packed to form an active area of ~2 mm and are randomly arranged. The randomization of the individual fibers can help in spatial intensity homogenization, especially when an input light is spatially quasi-Gaussian (e.g., LED sources are spatially quasi-Gaussian in nature, with a central hot spot that monotonically decreases in a radial fashion towards the edge of the beam). Additionally, fiber bending macro-level loss is directly proportional to the fiber core diameter, and for a given bend radius, larger core diameter fibers have higher bending loss than the smaller core diameter fibers. Therefore, in certain embodiments, the use of micron-sized fibers (e.g., ~15 to 100 μm core diameters) allows the fiber optic bundle to be bent as small as ~2.5 to 10 mm in short term and ~15 to 35 mm in long term bend radii, thereby providing flexibility in routing the fiber optic bundle.

[0024] In various embodiments, as further advantages, various optical systems described herein enable light sources, light engines, and/or illumination sources to be mounted anywhere in the optical system, as the light can be propagated through the flexible optical fibers. The fibers may be fused at the input end to achieve a higher packing fraction and epoxied at the output end. A higher packing fraction can provide higher transmittance. In certain applications, fusing only the input end may be necessary. However, both ends may be fused or epoxied in some embodiments. In certain embodiments, fused fiber optic bundles may provide more than ~20% higher transmission compared to unfused, or epoxied fiber optic bundles. Moreover, in various embodiments, superior spatial homogenization and color mixing can be achieved by adding a homogenizer at the output end.

[0025] In certain embodiments, a second light channel (e.g., a homogenizer) may contain a thin cladding layer which protects the core material from touching other material. Taking advantage of the cladding layer, the homogenizer can be assembled in a unique male-female SMA adapter, making it much easier to couple with the fiber optic bundle and integrate with the light source, that is remotely placed, and into the existing illumination system.

[0026] FIGS. **1-2** illustrates an example microscope system **100** according to aspects of the disclosure. FIG. **1** is a perspective view of the microscope system **100**, while FIG. **2** illustrates certain operational aspects of the microscope system **100**. In certain embodiments, microscope system **100** may be an ophthalmic microscope system. For clarity, FIGS. **1-2** will be described collectively.

[0027] As shown in FIG. **1**, microscope system **100** can include a base **101** coupled to a floor stand **102** having wheels **103***a-d* (collectively referred to as wheels **103**). While FIG. **1** illustrates microscope system **100** having a floor stand **102**, in certain embodiments, the microscope system **100** may be mounted on a table, cabinet, wall, or the floor. In some embodiments, microscope system **100** may be a tabletop microscope system. Base **101** is movably coupled to a first arm **104***a* that is coupled to a joint assembly **110**. Joint assembly **110** is coupled to a second arm **104***b* operable to movably couple to an optical head **105** (e.g., a microscope). In some embodiments, the first arm **104***a* and the second arm **104***b* may include a plurality of arms connected together via arm joints such that the optical head **105** may be moved to various locations around the base **101** (e.g., positioned over an eye to view a corneal plane).

[0028] Microscope system **100** includes a light source **106** (shown in FIG. **2**) connected to an illumination module **202** (shown in FIG. **2**) via a plurality of first light carriers **107** (e.g., through second arm **104***b*), as will be described in further detail below. In some embodiments, the light source **106** is spaced apart from the optical head **105**. In some embodiments, the light source **106** may be near and/or connected to the first arm **104***a* and/or the second arm **104***b*. For example, in some embodiments, the light source **106** is housed within the joint assembly **110**. In various embodiments, the light source is coupled to the base **101**. Microscope system **100** includes a display screen **108** operable to output images of a viewing area of the microscope system **100**. Display screen **108** may include, for example, a liquid crystal display (LCD), a plasma display, an LED display, organic LED displays, and the like. While FIG. **1** illustrates the microscope system **100** having one display screen **108**, in certain embodiments, the display screen **108** may include a plurality of display screens **108**.

[0029] With particular reference to FIG. **2**, light source **106** is coupled to the plurality of first light carriers **107** via, for example, a SMA connector. In some embodiments, the light source **106** may include, for example, an ultraviolet light source, a laser, an infrared (IR) light source, a near-IR light source, or one or more LEDs. In certain embodiments, the one or more LEDs may be a red LED, a green LED, a blue LED, and combinations of the same and like.

[0030] In certain embodiments, the plurality of first light carriers **107** includes a randomized fiber optic bundle. In some embodiments, the plurality of first light carriers **107** may be any light carrier operable to propagate light. In some embodiments, the plurality of first light carriers **107** includes a first end **206** and a second end **207**. In some embodiments, the first end **206** may include fused optical fibers (e.g., of a randomized fiber optic bundle). In some embodiments, the second end **207** may include epoxied optical fibers (e.g., of a randomized fiber optic bundle). In some embodiments, the plurality of first light carriers may include, for example, a fiber optic bundle having a split rod, a bifurcated fiber optic bundle, or a fiber optic bundle having one or more fiber splitters. In the illustrated embodiment, the first end **206** is a light input end and the second end **207** is a light output end. Examples of the plurality of first light carriers **107** will be described in greater detail relative to FIGS. **3A-3B** and **4A-4C**.

[0031] In the embodiment shown in FIGS. **1-2**, a second light carrier **201** (e.g., a homogenizer) is coupled to the plurality of first light carriers **107** such that the plurality of first light carriers **107** provide a plurality of light intensities to the second light carrier **201**. In some embodiments, the plurality of first light carriers **107** is coupled to the second light carrier **201** via a SMA connector. In general, the second light carrier **201** spatially homogenizes the plurality of light intensities from the plurality of first light carriers **107** to form a homogenized light intensity. In certain embodiments, second light carrier **201** mixes light color from the plurality of light intensities. In certain embodiments, the plurality of first light carriers **107** integrates with the second light carrier **201**.

[0032] In certain embodiments, the second light carrier **201** may include a cylindrical clad-rod borosilicate. In some embodiments, the second light carrier **201** includes a medium therein, such as, for example, air. In various embodiments, the second light carrier **201** includes a hexagonal rod having a round aperture at the distal end. In some embodiments, the second light carrier **201** may have, for example, a cylindrical shape, a hexagonal shape, a rectangular shape, or a square shape. In certain embodiments, the second light carrier **201** has a cladding surrounding the core of second light carrier **201**. In some embodiments, the second light carrier **201** has a cladding having a mirrored surface surrounding the second light carrier **201**. Examples of the second light carrier **201** will be described in greater detail relative to FIGS. **5** and **6**.

[0033] The illumination module **202** is coupled to the second light carrier **201** and is operable to receive the homogenized light intensity and may project the homogenized light intensity to a viewing area **203**. In some embodiments, the illumination module **202** is coupled to the second light carrier **201** via a SMA connector. In certain embodiments, the viewing area **203** may include, without limitation, a portion of an eye, such as the cornea, the iris, the pupil, the lens, the ciliary muscle, or other regions of the eye. In certain embodiments, the viewing area is the corneal plane of an eye.

[0034] As illustrated in FIG. **2**, the illumination module **202** may also include a beam splitter **204** and/or a lens **205**. In certain embodiments, beam splitter **204** may be integrated into the illumination module **202** to split the homogeneous light intensity (e.g., in the form of light waves) into multiple paths. In such embodiments, the beam splitter **204** may be utilized to coaxially illuminate the viewing area **203** (e.g., a corneal plane).

[0035] In certain embodiments, the beam splitter **204** may be a fold mirror. In such embodiments, the fold mirror may be closer to the second light carrier **201**, outside of the microscope's viewing path relative to beam splitter **204** of FIG. **2**. In certain embodiments, the fold mirror may be angled such that the beam is projected onto the corneal plane at an oblique angle relative to vertical (e.g.,) 6-12°. This may, in some embodiments, provide general illumination of an eye region where strong red reflex is unwanted.

[0036] In certain embodiments, the illumination module **202** may be distinct from other components of the microscope system **100**. In such embodiments, an objective lens of the optical head **105** may be located above the illumination module **202** (such that the illumination module **202** is arranged downstream, or below, the objective lens) to image the corneal plane into a camera or to eyes through a binocular. Alternatively, in certain embodiments, the illumination module may be arranged within, and/or integrated with, microscope system **100**, for example, above the objective lens of the microscope system **100**.

[0037] FIGS. **3A** and **3B** illustrate an example of a randomized fiber optic bundle **300**. In certain embodiments, the randomized fiber optic bundle **300** may serve, for example, as the plurality of first light carriers **107** of FIGS. **1-2**. FIG. **3A** shows a first end **301** of the randomized fiber optic bundle **300**. FIG. **3B** shows a second end **304** of the randomized fiber optic bundle **300**. FIGS. **3A** and **3B** are described together for clarity.

[0038] In certain embodiments, the first end **301** and the second end **304** correspond to the first end **206** and the second end **207**, respectively, of FIG. **2**. In some embodiments, the first end **301** is a light input end and the second end **304** is a light output end. The randomized fiber optic bundle **300** includes optical fibers **302***a*, **302***b*, **302***c* . . . **302**N (collectively referred to as optical fibers **302**) enclosed within sheathing **303**. FIGS. **3A** and **3B** show a randomization of optical fibers **302**. In certain embodiments, one or more fibers of the optical fibers **302** may have a substantially different placement within the sheathing **303** at the first end **301** relative to the second end **304** (e.g., optical fibers **302***b* and **302***c*). In some embodiments, one or more fibers of the optical fibers **302** may have a substantially same placement within the sheathing **303** at the first end **301** relative to the second end **304** (e.g., optical fiber **302***a*). In some embodiments, substantially all the optical fibers **302** may have substantially different placement within the sheathing **303** at the first end **301** relative to the second end **304**.

[0039] In certain embodiments, the randomized arrangement found within the randomized fiber optic bundle **300** may allow for a more uniform distribution and/or mixing of light as it exits the second end **304**. In certain embodiments, the first end **301** may be a fused end such that no adhesive is used to hold together each of the optical fibers **302**. In some embodiments, the second end **304** may be an epoxied end such that an epoxy resin is used to hold together each of the optical fibers **302**. In some embodiments, the first end **301** is a fused end or an epoxied end. In various embodiments, the second end **304** is a fused end or an epoxied end. In some embodiments, the randomized fiber optic bundle **300** is formed by twisting a fiber optic bundle.

[0040] In some embodiments, the optical fibers **302** may be randomized borosilicate fibers having a core diameter in a range of ~15 to 100 μm (micrometers), ~20 to 85 μm, and/or ~30 to 70 μm. In certain embodiments, the core diameter may be ~50 μm. In some embodiments, ~1,000 to 2,000 optical fibers **302** may be packed to form an active area of ~0.5 to 4 mm and are randomly arranged. In certain embodiments, ~1,400 optical fibers **302** may be packed to form an active area of ~2 mm. In certain embodiments, the sheathing **303** is a metal mono-coil and polyvinyl chloride sheathing. In various embodiments, the optical fibers **302** of the fiber optic bundle **300** may be borosilicate fibers with the numerical aperture in a range of ~0.22 to 0.85 which are fused on the first end **301** and epoxied on the second end **304**. In some embodiments, the numerical aperture may be ~0.55. In some embodiments, the first end **301** may be fused and have an active area diameter in a range of ~0.5 to 2.5 mm. In certain embodiments, the active area diameter may be ~1.9 mm. In certain embodiments, the second end **304** may be epoxied and have an active diameter in a range of ~1.0 to 3.0 mm. In some embodiments, the second end **304** may be epoxied and have a ~2.05 mm active area diameter.

[0041] FIGS. **4**A-**4**C illustrate example embodiments of fiber optic bundles that may serve, for example, as the first plurality of light carriers **107** of FIGS. **1-2**. FIG. **4**A shows a fiber optic bundle **401** having a split-rod **402**. In some embodiments, the fiber optic bundle **401** may be a randomized fiber optic bundle (e.g., the fiber optic bundle **300**). In some embodiments, the fiber optic bundle **401** may be an ordered fiber optic cable such that a one-to-one mapping exists between a light input end and a light output end. In some embodiments, the split-rod **402** is a split glass rod. In some embodiments, the split-rod **402** receives light at an input end **405** and outputs light via two output ends **406***a* and **406***b*. In certain embodiments, output ends **406***a* and **406***b* are each coupled to a homogenizer (e.g., as illustrated and described in FIG. **2**).

[0042] FIG. **4**B shows a bifurcated fiber optic bundle **400**. In some embodiments, bifurcated fiber optic bundle **400** has an input end **410** where optical fibers are grouped together and subsequently branch out into a first fiber optic segment **412** and a second fiber optic segment **414**. In certain embodiments, each of the first fiber optic segment **412** and the second fiber optic segment **414** may include a randomized fiber optic bundle (e.g., the fiber optic bundle **300**). In certain embodiments, each of the first fiber optic segment **412** and the second fiber optic segment **414** may include an ordered fiber optic bundle. In certain embodiments, the first fiber optic segment **412** and the second fiber optic segment **414** are each coupled to a homogenizer.

[0043] FIG. **4**C illustrates a fiber optic bundle **403** having a fiber optic splitter **404**. In some embodiments, the fiber optic bundle **403** may be a randomized fiber optic bundle (e.g., the fiber optic bundle **300**). In some embodiments, the fiber optic bundle **403** may be an ordered fiber optic cable such that a one-to-one mapping exists between a light input end and a light output end. In certain embodiments, the fiber optic bundle **403** is a fiber optic bundle with a single core. In embodiments illustrated in FIG. **4**C, the fiber optic splitter **404** is a 1×2 fiber optic splitter. However, in other embodiments, the fiber optic splitter **404** may be a 1×n fiber optic splitter, where n is an integer greater than 1 (e.g., 1×2, 1×3, 1×4 . . . 1×n). In some embodiments, the fiber optic splitter **404** receives light at an input end **407** and outputs light from two output ends **408***a* and **408***b*. In certain embodiments, output ends **408***a* and **408***b* are each coupled to a homogenizer.

[0044] While FIG. **4**C is described in relation to the fiber optic bundle **403** being split into two output ends, in some embodiments, multiple input ends may be combined to merge into one output end. In certain embodiments, an n×1 merging (e.g., 4×1) may be utilized to join optical fibers and/or fiber optic bundles into one fiber bundle. For example, a 3×1 merging may occur that merges fiber optics from a green, red, and blue light source into a single fiber optic bundle.

[0045] FIG. **5** illustrates an example embodiment of light carrier **500** that may serve, for example, as the second light carrier **201** of FIG. **2**. Light carrier **500** includes a core **501** having a cladding **502** in contact with an outside surface of the core **501**. Light **503** enters the light carrier **500** through input **504** and travels through the core **501** thus allowing propagation through the light carrier **500**. Light **503** exits through the light carrier **500** via an output **505**. In some embodiments, the light carrier **500** may have a cross-sectional (perpendicular to a main axis of the light carrier **500**) shape that includes, without limitation, a hexagonal shape, a circular shape, a square/rectangular shape, or the like.

[0046] In some embodiments, the core **501** may include, for example, glass, air, silica, fused silica, or other material allowing the light **503** to propagate though the core **501**. In certain embodiments, the cladding **502** may include, for example, a material with a surface in contact with the outside surface of the core **501**. In certain embodiments, the surface may be mirrored or have a metallic coating thereon to provide mirror-like properties. In certain embodiments, the cladding **502** may include air. In various embodiments, the cladding **502** may include a material that has a lower refractive index than the core **501**. In certain embodiments, the second light carrier may form a homogenizer to provide spatial homogenization and color mixing of the light **503**. In certain embodiments, the light carrier **500** may be a clad-rod borosilicate homogenizer.

[0047] FIG. **6** illustrates an example embodiment of a light carrier **600** that may serve, for example, as the second light carrier **201** of FIG. **2**. In the illustrated embodiment, the light carrier **600** has a hexagonal shape and includes a core **601** having cladding **602** in contact with an outer surface thereof. Light carrier **600** further includes an aperture **603** on a light output side thereof. In certain embodiments, the optical module **202** focuses light emitted from aperture **603** onto a target area, for example, the corneal plane. In some embodiments, the core **601** may be substantially similar to core **501** of FIG. **5**. In certain embodiments, the cladding **602** may be substantially similar to cladding **502** of FIG. **5**. While FIGS. **5-6** describe light carriers having a physical cladding layer (e.g., a clad rod light carrier), in some embodiments, the light carriers described herein may include light pipes and/or glass rods composed of fused silica, glass, silica, and the like. In such embodiments, the physical cladding layer is replaced by air (i.e., no physical cladding layer) but air effectively acts like a cladding layer in that it results in the confinement of the light within the core via total internal reflection.

[0048] Although various embodiments of the present disclosure have been illustrated in the accompanying Drawings and described in the foregoing Detailed Description, it will be understood that the present disclosure is not limited to the embodiments disclosed herein, but is capable of numerous rearrangements, modifications, and substitutions without departing from the spirit of the disclosure as set forth herein.

[0049] The term "substantially" is defined as largely but not necessarily wholly what is specified, as understood by a person of ordinary skill in the art. In any disclosed embodiment, the terms "substantially", "approximately", "generally", and "about" may be substituted with "within [a percentage] of" what is specified, where the percentage includes 0.1, 1, 5, and 10 percent.

[0050] The foregoing outlines features of several embodiments so that those of ordinary skill in the art may better understand the aspects of the disclosure. Those of ordinary skill in the art should appreciate that they may readily use the disclosure as a basis for designing or modifying other processes and structures for carrying out the same purposes and/or achieving the same advantages of the embodiments introduced herein. Those of ordinary skill in the art should also realize that such equivalent constructions do not depart from the spirit and scope of the disclosure, and that they may make various changes, substitutions, and alterations herein without departing from the spirit and scope of the disclosure. The scope of the invention should be determined only by the language of the claims that follow. The term "comprising" within the claims is intended to mean "including at least" such that the recited listing of elements in a claim are an open group. The terms "a", "an", and other singular terms are intended to include the plural forms thereof unless specifically excluded.

[0051] Conditional language used herein, such as, among others, "can", "might", "may", "e.g.", and the like, unless specifically stated otherwise, or otherwise understood within the context as used, is generally intended to convey that certain embodiments include, while other embodiments do not include, certain features, elements, and/or states. Thus, such conditional language is not generally intended to imply that features, elements, and/or states are in any way required for one or more embodiments.

[0052] While the above detailed description has shown, described, and pointed out novel features as applied to various embodiments, it will be understood that various omissions, substitutions, and changes in the form and details of the embodiments illustrated can be made without departing from the spirit of the disclosure. As will be recognized, the various embodiments described herein can be embodied within a form that does not provide all of the features and benefits set forth herein, as some features can be used or practiced separately from others. The scope of protection is defined by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

What is claimed is:

1. An optical system comprising:

a light source coupled to a plurality of first light carriers providing a plurality of light intensities;

a second light carrier coupled to the plurality of first light carriers, the second light carrier spatially homogenizing the plurality of light intensities to form a homogenized light intensity; and

an illumination module coupled to the second light carrier and operable to receive the homogenized light intensity.

2. The optical system of claim **1**, wherein the plurality of first light carriers comprises a randomized fiber optic bundle.

3. The optical system of claim **2**, wherein the randomized fiber optic bundle comprises a first end and a second end, the first end comprising fused optical fibers of the randomized fiber optic bundle and the second end comprising epoxied fibers of the randomized fiber optic bundle.

4. The optical system of claim **1**, wherein the plurality of first light carriers comprises at least one of a fiber optic bundle comprising a split rod, a bifurcated fiber optic bundle, or a fiber optic bundle comprising one or more fiber splitters.

5. The optical system of claim **1**, wherein the second light carrier comprises a cylindrical clad-rod borosilicate.

6. The optical system of claim **1**, wherein the second light carrier comprises air.

7. The optical system of claim **1**, wherein the second light carrier comprises a hexagonal rod comprising a round aperture.

8. The optical system of claim **1**, wherein the second light carrier comprises at least one of a cylindrical shape, a hexagonal shape, a rectangular shape, or a square shape.

9. The optical system of claim **1**, wherein the second light carrier comprises a cladding.

10. The optical system of claim **1**, wherein the second light carrier comprises a mirrored surface.

11. The optical system of claim **1**, wherein the illumination module comprises at least one of a lens or a beam splitter.

12. The optical system of claim **1**, wherein the light source comprises at least one of a laser, an ultraviolet light source, an infrared (IR) light source, a near-IR light source, or one or more light-emitting diodes (LEDs).

13. The optical system of claim **12**, wherein the second light carrier mixes light color from the plurality of light intensities.

14. An optical system comprising:

a light source coupled to a light carrier, the light carrier spatially homogenizing a plurality of light intensities to form a homogenized light intensity;

an optical head comprising an illumination module coupled to the light carrier and operable to receive the homogenized light intensity; and

wherein the optical head is spaced apart from the light source.

15. The optical system of claim **14**, wherein:

the light source is coupled to a base of a microscope;

the optical head is coupled to a portion of an arm of the microscope; and

the portion of the arm is positioned over a corneal plane.

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