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(54) **LIGHT MIXING AND HOMOGENIZING APPARATUS AND METHOD**

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See application file for complete search history.

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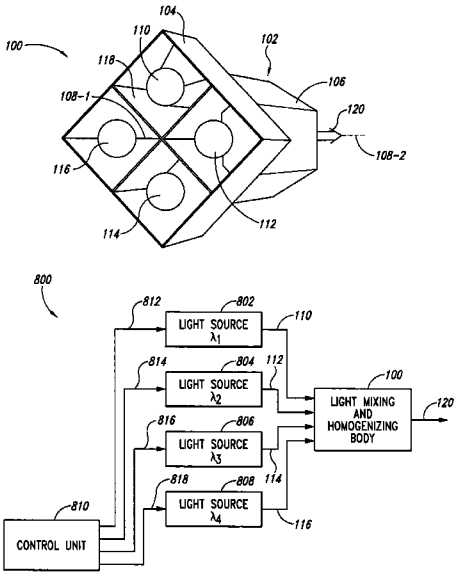
(57) **ABSTRACT**

In accordance with one embodiment, a light mixing and homogenizing apparatus includes a first tubular member and a second tubular member. The first tubular member has a reflective interior surface, a polygonal cross section with a first maximum diameter, and a first number of sides. The first tubular member has a first end and a second end with the first end configured to receive a plurality of incoming light beams. The second tubular member has a reflective interior surface, a polygonal cross section with a second maximum diameter smaller than the first maximum diameter, and a second number of sides that is different from the first number of sides. The second tubular member has a first end disposed adjacent to a first tubular member second end. The second tubular member second end is configured to output a homogeneous light beam comprising a mixture of the plurality of incoming light beams.

21 Claims, 8 Drawing Sheets



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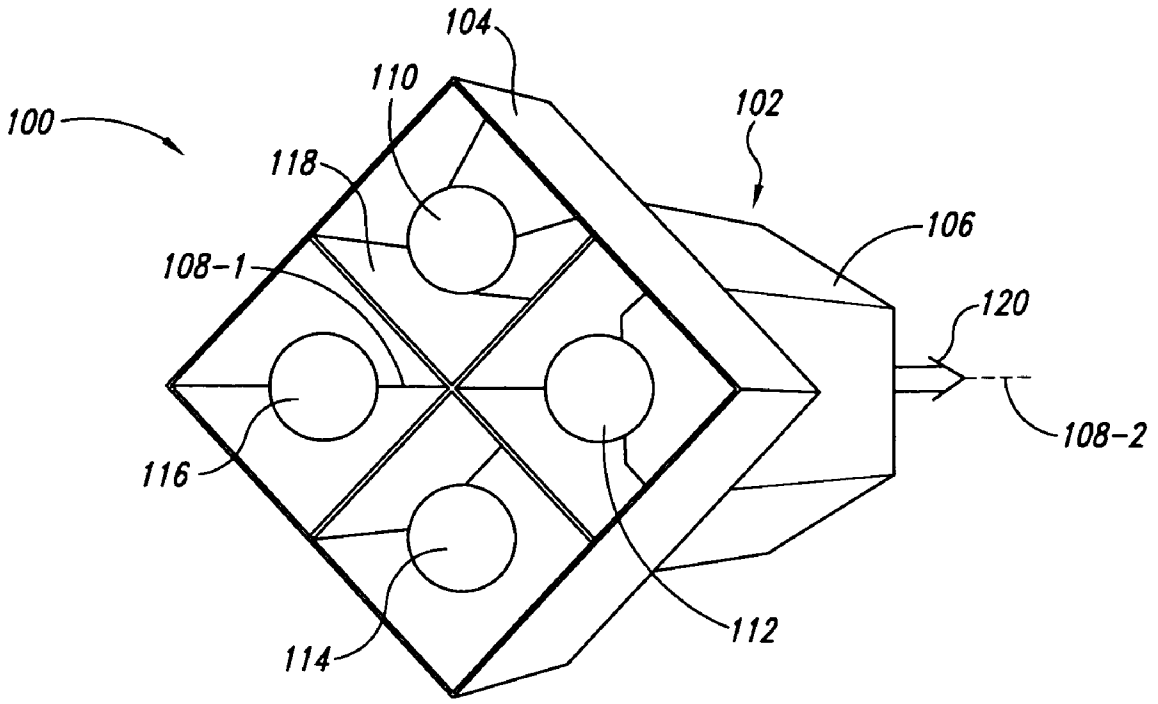

104
110
100
102
118
106
108-1
120
108-2
116
112
114

Fig. 1

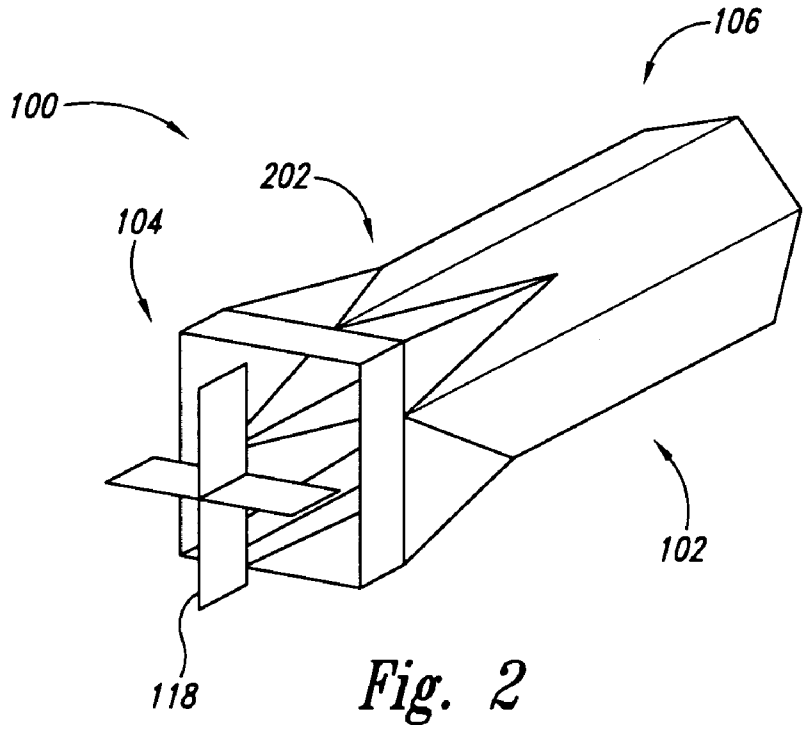
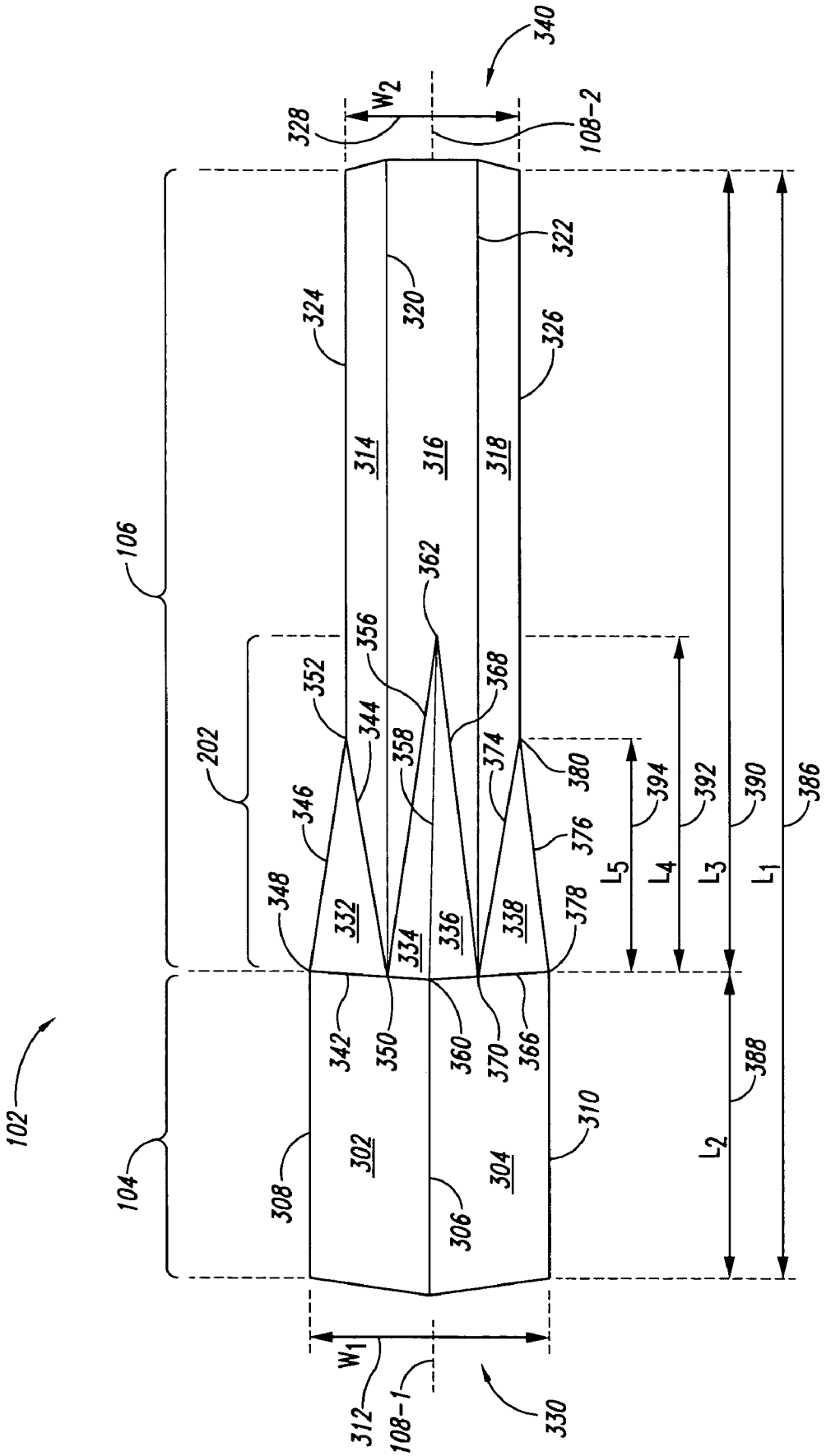

106
100
202
104
102
118

Fig. 2


102
104
106
108-1
108-2
202
302
304
306
308
310
312
314
316
318
320
322
324
326
328
330
332
334
336
338
340
342
344
346
348
350
352
356
358
360
362
366
368
370
374
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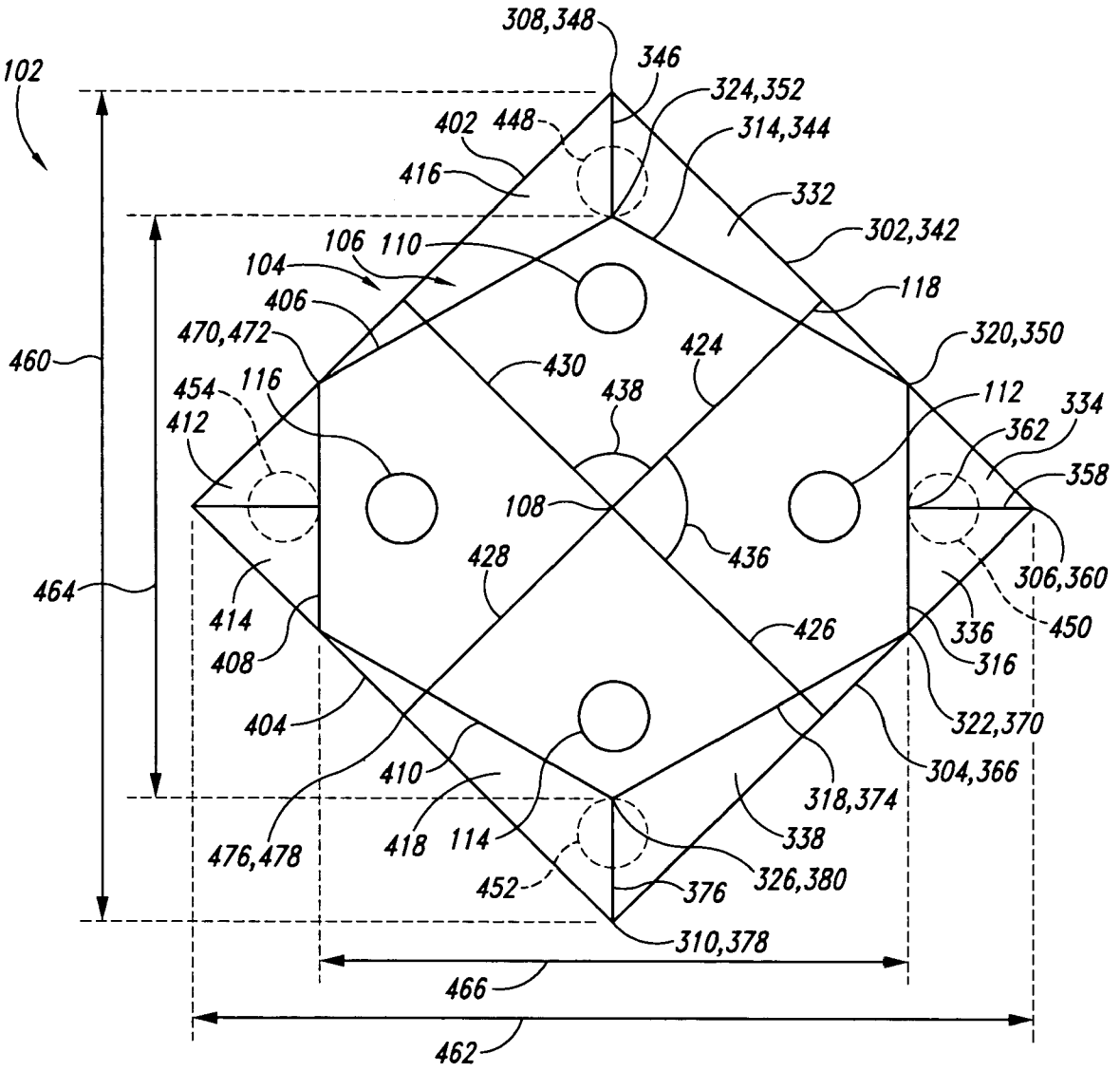
380
386
388
390
392
394
L1
L2
L3
L4
L5
W1
W2

Fig. 3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346
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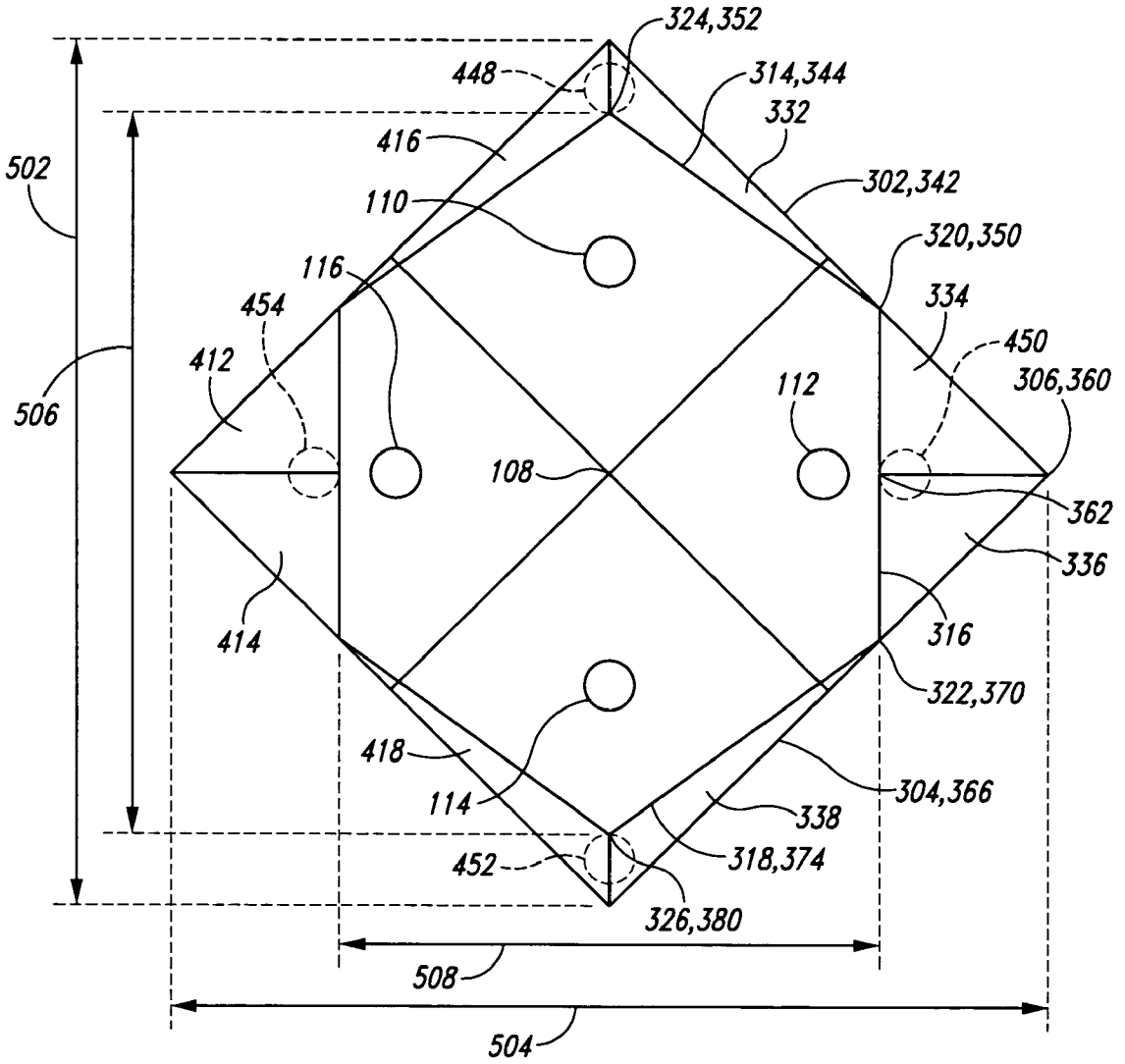
324,352
402
448
314,344
416
332
302,342
106
110
104
118
406
320,350
470,472
424
460
430
438
454
116
112
334
412
362
358
108
436
464
428
306,360
414
426
450
336
408
316
404
322,370
410
304,366
318,374
476,478
418
114
338
452
326,380
376
310,378
466
462

Fig. 4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448
314,344
332
416
302,342
110
320,350
116
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112
506
108
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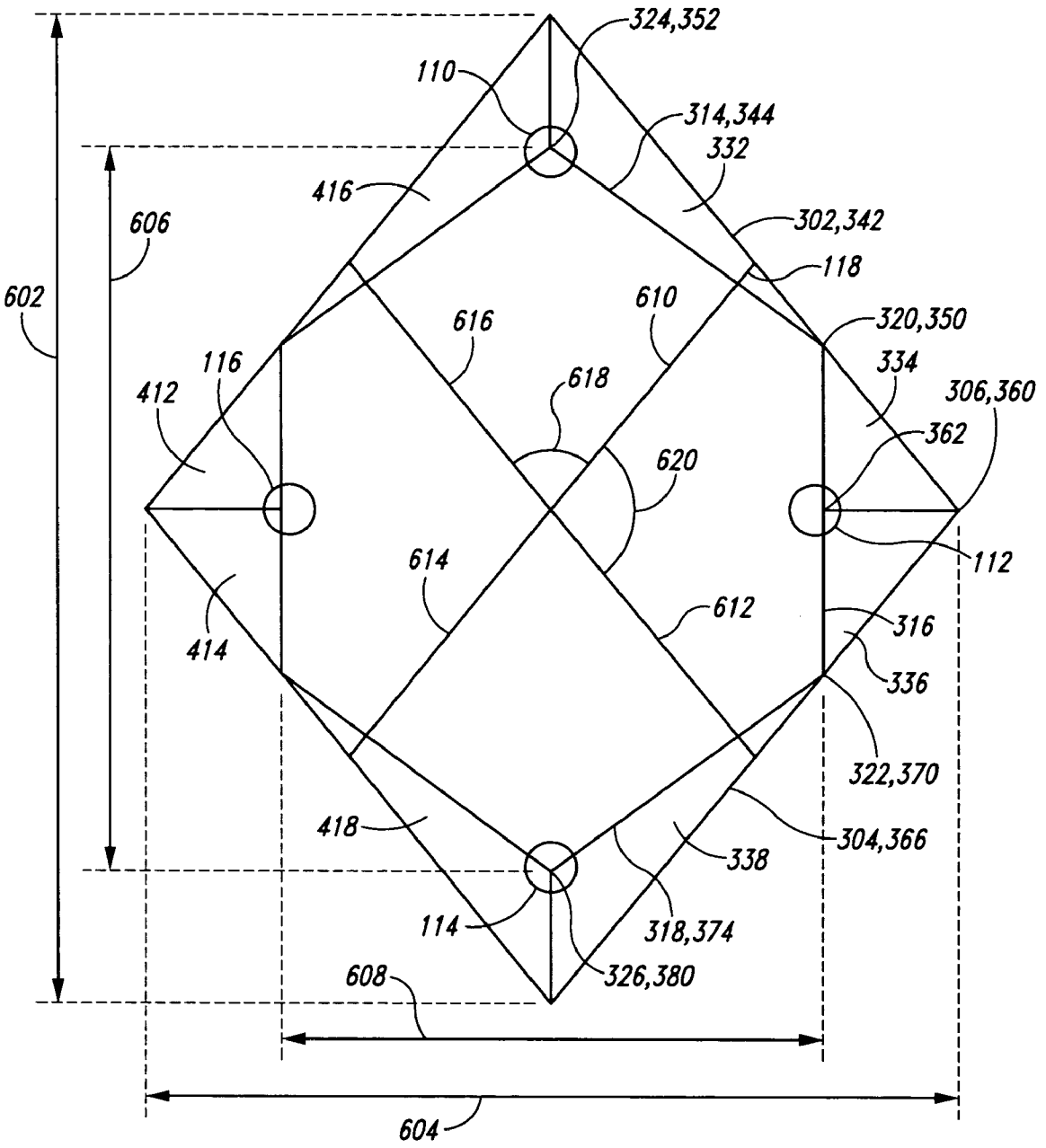
418
304,366
114
338
452
318,374
326,380
508
504
502

Fig. 5


324,352
110
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332
416
606
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118
602
610
616
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116
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362
620
614
112
612
414
316
336
322,370
418
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338
114
318,374
326,380
608
604

Fig. 6

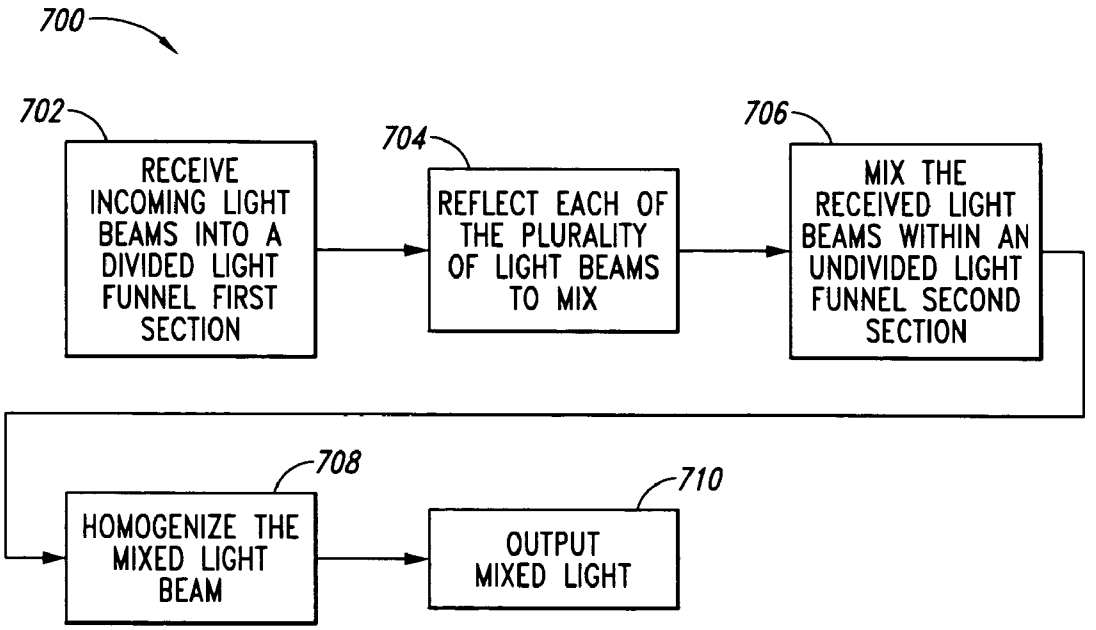
700
702
RECEIVE INCOMING LIGHT BEAMS INTO A DIVIDED LIGHT FUNNEL FIRST SECTION
704
REFLECT EACH OF THE PLURALITY OF LIGHT BEAMS TO MIX
706
MIX THE RECEIVED LIGHT BEAMS WITHIN AN UNDIVIDED LIGHT FUNNEL SECOND SECTION
708
HOMOGENIZE THE MIXED LIGHT BEAM
710
OUTPUT MIXED LIGHT

Fig. 7

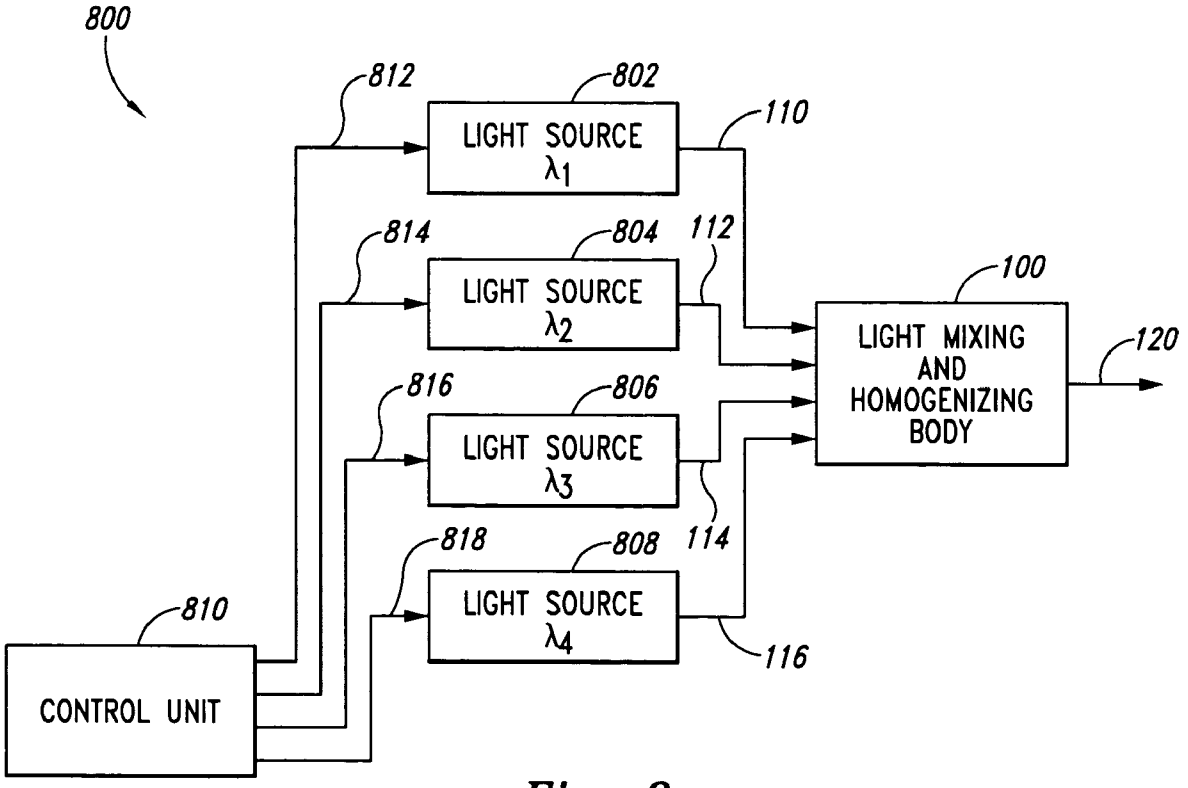
800
812
802
LIGHT SOURCE λ1
110
814
804
112
LIGHT SOURCE λ2
100
LIGHT MIXING AND HOMOGENIZING BODY
120
816
806
LIGHT SOURCE λ3
114
818
808
LIGHT SOURCE λ4
116
810
CONTROL UNIT

Fig. 8

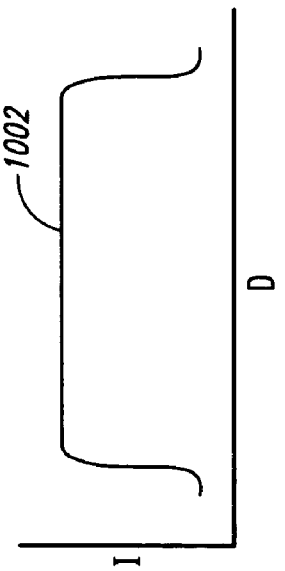

Fig. 10

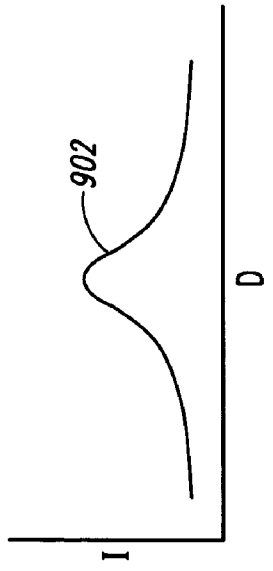

Fig. 9

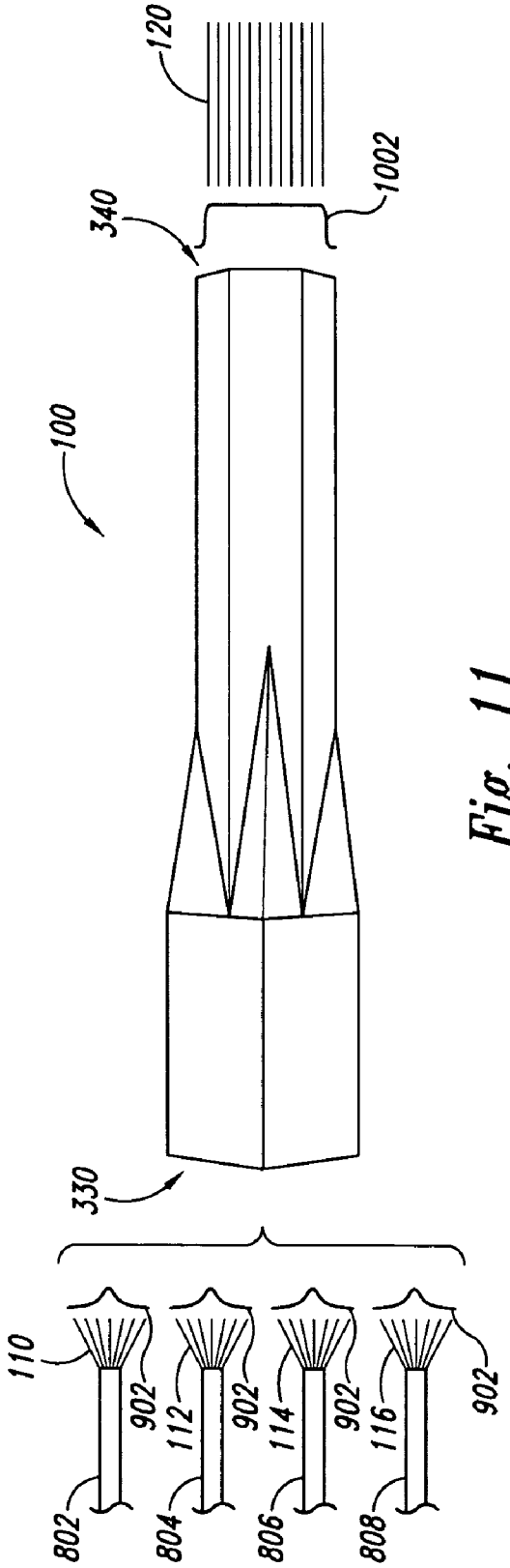

Fig. 11

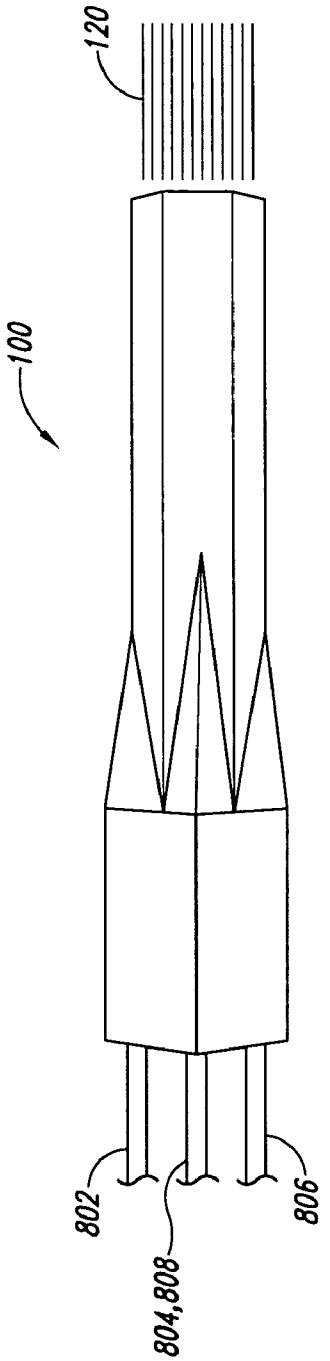
120
100
802
804,808
806

Fig. 12

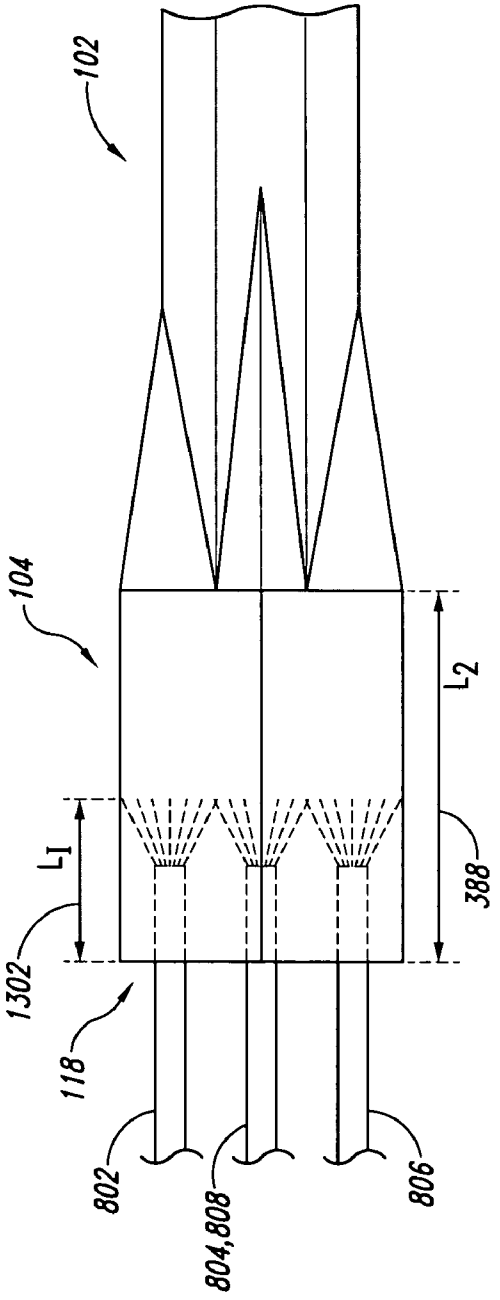
102
104
L_2
L_1
388
1302
118
802
804,808
806

Fig. 13

LIGHT MIXING AND HOMOGENIZING APPARATUS AND METHOD

TECHNICAL FIELD

The present invention relates generally to optical guides, and more particularly to an optical apparatus for mixing and homogenizing a plurality of input light beams and producing a uniform intensity output.

RELATED ART

Optical devices to mix two or more incoming light beams are known, yet such devices typically include heavy, expensive, and delicate components which limit the application of this useful technique. Further, since the incoming light beams typically have a Gaussian, non-uniform intensity distribution, additional components are typically required to produce a uniform intensity distribution. Such additional components contribute to the increased cost and weight of the optical system. Thus, there remains a need for an apparatus and method to produce a mixed and homogenized output light beam from a plurality of non-homogenous incoming light beams in a rugged, compact, and low cost manner.

SUMMARY

Apparatuses, systems, and methods are disclosed herein to provide light mixing and homogenization of a plurality of incoming light beams. For example, in accordance with an embodiment of the present invention, a light mixing and homogenizing apparatus includes a first tubular member and a second tubular member. The first tubular member has a reflective interior surface and a polygonal cross section with a first maximum diameter and a first number of sides. The first tubular member has a first end and a second end with the first tubular member first end configured to receive a plurality of incoming light beams. The second tubular member has a reflective interior surface and a polygonal cross section with a second maximum diameter smaller than the first maximum diameter, and a second number of sides different from the first number of sides. The second tubular member has a first end disposed adjacent to the first tubular member second end. The second tubular member has a second end configured to output a homogeneous light beam comprising a mixture of the plurality of incoming light beams.

According to another embodiment, a light mixing and homogenizing system includes a plurality of light sources, a tubular body, and a divider located within a first portion of the tubular body. Each light source provides a light beam having a unique wavelength. The tubular body has a first end portion with a square cross section and a second end portion with a hexagonal cross section. The first end portion is configured to receive the plurality of light beams. The tubular body second end portion is configured to output a homogeneous light beam including a mixture of the incoming light beams. An interior portion of the tubular body has a highly reflective surface configured to reflect light from the plurality of incoming light beams causing a mixing and homogenizing of the plurality of light beams. The divider is located within the tubular body first end portion and is configured to separate the incoming light beams prior to mixing.

According to yet another embodiment of the present invention, a method of mixing and homogenizing a plurality of light beams includes the operations of receiving the light beams into a divided first portion of an optical funnel, mixing the received light beams within an undivided second portion of the optical funnel to produce a mixed light beam, homogenizing the mixed light beam to produce a homogenized light beam having a substantially equal intensity distribution in a direction perpendicular to the path of the homogenized beam, and outputting the homogenized beam.

The present disclosure teaches structures and methods that fulfill long felt needs in the industry by producing a mixed and homogenized light beam from a plurality of incoming light beams, where each of the incoming light beams has a non-uniform, gaussian intensity distribution. In particular, the structures and methods disclosed have particular application to diverse technology areas including optical components, entertainment, automotive, and mass communications. The disclosed structure is beneficial because it does not include a traditional, filled optical cavity or optical components such as beam splitters, and thus may be manufactured more economically. Additionally, the disclosed structure is rugged and may be used in applications that may receive physical shock. Since no additional optical components are needed, alignment issues are eliminated.

The scope of the present invention is defined by the claims, which are incorporated into this section by reference. A more complete understanding of embodiments of the present invention will be afforded to those skilled in the art, as well as a realization of additional advantages thereof, by a consideration of the following detailed description. Reference will be made to the appended sheets of drawings that will first be described briefly.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a first perspective view of the light mixing and homogenizing apparatus with the divider member inserted along the longitudinal axis in accordance with an embodiment.

FIG. **2** shows a second perspective view of the light mixing and homogenizing apparatus with the divider removed in accordance with an embodiment.

FIG. **3** shows a side view of the light mixing and homogenizing apparatus in accordance with an embodiment.

FIG. **4** shows an end view of tubular body as viewed from the first end of first tubular member where first tubular member is a regular, square polygon having equal length sides while second tubular member is not a regular, hexagonal polygon, in accordance with an embodiment.

FIG. **5** shows and end view of tubular body as viewed from the first end of first tubular member where first tubular member is a regular, square polygon having equal length sides while second tubular member is a regular, hexagonal polygon, also having equal length sides, in accordance with an embodiment.

FIG. **6** shows and end view of tubular body as viewed from the first end of first tubular member where first tubular member is not a regular, square polygon yet still has equal length sides, while second tubular member is a regular, hexagonal polygon having equal length sides.

FIG. **7** shows a flow diagram indicating operations for a method of using a light mixing and homogenizing apparatus, in accordance with an embodiment.

FIG. **8** shows a block diagram of a light mixing and homogenizing system that includes a plurality of light sources, a control unit, and a light mixing and homogenizing apparatus, in accordance with an embodiment.

FIG. **9** shows an example of light intensity from a single optical fiber output where the light intensity profile varies

across the diameter, in a direction perpendicular to the cross section of the fiber, with a typical Gaussian intensity distribution.

FIG. **10** shows an example of light output from the light mixing and homogenizing apparatus producing a uniform intensity across the span of the tubular body output, with a typical top-hat intensity distribution.

FIG. **11** shows a plurality of incoming light sources producing a plurality of incoming light beams that are applied to a wider input as a receiving end of the light mixing and homogenizing apparatus.

FIG. **12** shows the plurality of incoming light sources located within a receiving portion of the tubular body.

FIG. **13** shows the ends of each light source as inserted within the tubular body first end portion.

Embodiments of the present invention and their advantages are best understood by referring to the detailed description that follows. It should be appreciated that like reference numerals are used to identify like elements illustrated in one or more of the figures.

DETAILED DESCRIPTION

In reference to FIG. **1**, an embodiment of a light mixing and homogenizing apparatus **100** includes a tubular body **102** having a first end portion or tubular member **104** with a square cross-section and a second end portion or tubular member **106** with a hexagonal cross-section. Both first end portion **104** and second end portion **106** are arranged about a central, longitudinal axis **108** so that the geometric cross-section for each end portion (**104**, **106**) extends symmetrically in the direction of longitudinal axis **108** forming sides of the end portions.

In this disclosure, longitudinal axis **108** can include a central line passing symmetrically through the long or axial direction of tubular body **102** equidistant from each side member in first end portion **104** and second end portion **106**. First end portion **104** can receive a plurality of incoming light beams (**110**, **112**, **114**, **116**), each incoming light beam has a Gaussian distribution where the intensity at the center of the incoming beam is higher than near the edges. A dividing member **118** separates incoming light beams (**110**, **112**, **114**, **116**) prior to mixing and typically extends the entire length of first portion **104**.

The received light beams are mixed by reflection off a highly reflective interior surface of tubular body **102** so that second end portion **106** outputs a mixed, homogenized light beam **120** having a color determined by the intensity and wavelength of each incoming light beam. Any or all of incoming light beams (**110**, **112**, **114**, and **116**) may be either coherent beams comprising a single wavelength of light, or incoherent beams comprising multiple wavelengths. In this disclosure, a plurality of light beams are mixed when a composite light beam is formed having wavelength components from each of the plurality light beams. Similarly, a mixed light beam is homogenized when the mixed light beam has a substantially equal intensity distribution in a direction perpendicular to the output beam path.

FIG. **2** shows dividing member **118** removed from first end **104** of tubular body **102**. A middle portion **202** of tubular body **102** includes a plurality of angled planes joining the different polygonal shapes of first end portion **104** and second end portion **106**, and where each of the incoming light beams is initially reflected. A small portion of light from the incoming light beams may pass through the center portion of tubular body **102** without being reflected from the internal surface and without disturbing the homogenous intensity profile. Even though a square-to-hexagonal shaped transition is shown in this disclosure, other geometrical cross-sections may be used for both first end section **104** and second end section **106** so that middle portion **202** comprises a plurality of planar members that join first end portion **104** to second end portion **106**.

FIG. **3** shows a side view of light mixing and homogenizing apparatus **100** including first end portion **104**, second end portion **106**, and middle portion **202** for joining or mating first end portion **104** and second end portion **106**. In one embodiment, first end portion **104** includes a first square side member **302** and a second square side member **304** where each square side (**302**, **304**) has a planar outer surface extending along longitudinal axis **108** to form the sides of square first end portion **104**. The geometrical cross-section of first end portion **104** determines the number of sides, where a square cross-section has four sides. At the juncture between square side **302** and square side **304** is an edge **306** that runs parallel to longitudinal axis **108**. Similarly, at the juncture between square side **302** and an adjoining square side (not shown) in a direction away from square side **304** is an edge **308** that runs parallel to longitudinal axis **108**.

Finally, at the juncture between square side **304** and an adjoining square side (not shown) in a direction away from square side **302** is an edge **310** that runs parallel to longitudinal axis **108**. In this manner, the polygonal cross-section of first end portion **104** extends in the direction of longitudinal axis **108** in order to form a hollow, square structure with a diagonal opening maximum opening width W_1 **312** corresponding to a maximum diameter of the first end portion **104**. Measured at the corners of first end portion **104**, W_1 represents the largest opening width. The inner surfaces of first portion **104** are highly reflective in order to reflect light within tubular body **102**. In one embodiment, the width of the surface of each square side (**302**, **304**) is 1.931 cm as measured perpendicular to longitudinal axis **108**. The maximum width W_1 **312** is dependent upon the length of tubular body **102**.

Second end portion **106** includes a first hexagonal side member **314**, a second hexagonal side member **316**, and a third hexagonal side member **318** where each hexagonal side (**314**, **316**, **318**) has a planar outer surface extending along longitudinal axis **108** to form the sides of hexagonal second end portion **106**. The geometrical cross-section of second end portion **106** determines the number of sides, where a hexagonal cross-section has six sides. At the juncture between hexagonal side **314** and hexagonal side **316** is an edge **320** that runs parallel to longitudinal axis **108**. Similarly, at the juncture between hexagonal side **316** and hexagonal side **318** is an edge **322** that runs parallel to longitudinal axis **108**. At the juncture between hexagonal side **314** and an adjoining hexagonal side (not shown) in a direction away from hexagonal side **316** is an edge **324** that runs parallel to longitudinal axis **108**. The line of edge **308** and the line of edge **324** define a plane (not shown) that passes through the center of tubular body **102** along longitudinal axis **108**.

Finally, at the juncture between hexagonal side **318** and an adjoining hexagonal side (not shown) in a direction away from hexagonal side **316** is an edge **326** that runs parallel to longitudinal axis **108**. The line of edge **310** and the line of edge **326** define a plane (not shown) that passes through the center of tubular body **102** along longitudinal axis **108**. In this manner, the polygonal cross-section of second end portion **106** extends in the direction of longitudinal axis **108** in order to form a hollow, hexagonal structure with a maximum opening width W_2 **328** corresponding to a maxi-

mum diameter of second end portion **106**. The inner surfaces of second portion **106** are highly reflective in order to reflect light within tubular body **102**. In one embodiment, maximum width W_2 **328** is 2.000 cm, while the minimum width measured perpendicular to opposing sides is 1.732 cm. The width measured between opposite corners of the polygonal cross-section of second end portion **106** is equal to a non-maximum width of the polygonal cross-section of first end portion **104** so that at least one longitudinal edge (**320**, **322**) coincides with a side of first end portion **104**.

Middle portion **202** includes a first triangular side member **332**, a second triangular side member **334**, a third triangular side member **336**, and a fourth triangular side member **338**. Each triangular side (**332**, **334**, **336**, and **338**) has a planar outer surface extending at an angle along longitudinal axis **108** to form a generally conically shaped middle portion **202** that joins the wider first portion **104** with the narrower second portion **106**. The inner surfaces of middle portion **202** are highly reflective in order to reflect light within tubular body **102**. Light received in first portion **104** is conducted through middle portion **202** and exits second portion **106** so that tubular body **102** comprises a light funnel having a wider input **330** and a narrower output **340**.

Triangular side **332** joins a first portion of square side **302** with hexagonal side **314**. At the juncture between triangular side **332** and square side **302** is an edge **342** that runs within a plane (not shown) that is perpendicular to longitudinal axis **108**. At the juncture between triangular side **332** and hexagonal side **314** is an edge **344** that runs on hexagonal side **314** from edge **320** to edge **324**. Finally, at the juncture between triangular side **332** and an adjoining triangular side (not shown) in middle portion **202** is an edge **346** that runs from square side **302** to hexagonal side **314** within the plane defined by the line of edge **308** and the line of edge **324** that passes through the center of tubular body **102** along longitudinal axis **108**. Edge **346** has a slope determined by the difference between W_1 **312** and W_2 **328**. Triangular side **332** is also bounded by a first vertex **348** where edge **342** meets edge **346**, a second vertex **350** where edge **342** meets edge **344**, and a third vertex **352** where edge **344** meets edge **346**. Vertex **348** coincides with a longitudinal edge **308** of square side **302**, vertex **350** coincides with a longitudinal edge **320** of hexagonal side **314**, and vertex **352** coincides with a longitudinal edge **324** of hexagonal side **314**. In this manner, the different geometries of first portion **104** and second portion **106** are joined using an angled planar member having vertices that coincide with longitudinal edges.

Triangular side **334** joins a second portion of square side **302** with hexagonal side **316**. The juncture between triangular side **334** and the second portion of square side **302** is along edge **342**. At the juncture between triangular side **334** and hexagonal side **316** is an edge **356** that runs on hexagonal side **316** from edge **348** to a central portion of hexagonal side **316**. Triangular side **334** is adjacent to triangular side **336**. At the juncture between triangular side **334** and triangular side **336** is an edge **358** that runs within a plane defined by the line of edge **306** and the central longitudinal axis **108**. Triangular side **334** is also bounded by a first vertex **350** where edge **342** meets edges **344** and **356**, a second vertex **360** where edge **342** meets edge **358**, and a third vertex **362** where edge **356** meets edge **358**. Edge **358** has a slope corresponding to the slope of edge **346** so that the sides are symmetrical. Vertices **360** and **362** correspond to a line of longitudinal edge **308**. In this manner, the different geometries of first portion **104** and second portion **106** are joined using an angled planar member having vertices that coincide with the longitudinal edges of the geometries of at least one of first end portion **104** and second end portion **106**.

Triangular side **336** joins a first portion of square side **304** with hexagonal side **316**. The juncture between triangular side **336** and the first portion of square side **304** is along edge **366** within the plane perpendicular to longitudinal axis **108** that includes edge **342**. At the juncture between triangular side **336** and hexagonal side **316** is an edge **368** that runs on hexagonal side **316** from edge **366** to a central portion of hexagonal side **316**. Triangular side **336** is also bounded by a first vertex **360** where edge **366** meets edges **358** and **342**, a second vertex **370** where edge **366** meets edge **368**, and a third vertex **362** where edge **368** meets edges **356** and **358**. Vertex **370** corresponds to a line of longitudinal edge **322**. In this manner, the different geometries of first portion **104** and second portion **106** are joined using an angled planar member having vertices that coincide with the longitudinal edges of the geometries of at least one of first end portion **104** and second end portion **106**.

Triangular side **338** joins a second portion of square side **304** with hexagonal side **318** along edge **366**. At the juncture between triangular side **338** and hexagonal side **318** is an edge **374** that runs on hexagonal side **318** from edge **322** to edge **326**. Finally, at the juncture between triangular side **338** and an adjoining triangular side (not shown) in middle portion **202** in a direction away from triangular side **336** is an edge **376** that runs from square side **304** to hexagonal side **318** within the plane defined by the line of edge **310** and the line of edge **326** that passes through the central longitudinal axis **108**. Edge **376** has a slope determined by the difference between W_1 **312** and W_2 **328** and is a symmetric reflection of the slope of edge **346**. Triangular side **338** is also bounded by a first vertex **370** where edge **366** meets edges **368**, **322**, and **374**, a second vertex **378** where edge **366** meets edge **376**, and a third vertex **380** where edge **376** meets edges **374** and **326**. Vertex **370** coincides with a longitudinal edge **322** of hexagonal side **302**, vertex **366** coincides with a longitudinal edge **310** of square side **304**, and vertex **380** coincides with a longitudinal edge **326** of hexagonal side **318**. In this manner, the different geometries of first portion **104** and second portion **106** are joined using an angled planar member **338** having vertices that coincide with longitudinal edges on first portion **104** or second portion **106**. Due to symmetry, corresponding planar members located oppositely are similar.

The overall length of tubular body **102** along longitudinal axis **108** is shown as L_1 **386**, the length of first end portion **104** is L_2 **388**, giving a remainder length L_3 **390** corresponding to the length of second end portion **106**. L_4 **392** is an outer length of middle portion **202** while L_5 **394** is an inner length of middle portion **202** corresponding to the longitudinal extent of the triangular side members extending to a wider section of second end portion **106**. Similarly, L_4 **392** corresponds to the longitudinal extent of the triangular side members extending to a narrower section of second end portion **106**. In one embodiment, L_1 **386** is 13.600 centimeters (cm) in length, L_2 **388** is 3.800 cm in length, L_3 **390** is 9.800 cm in length, L_4 **392** is 4.034 cm in length, and L_5 **394** is 2.951 cm in length. In this manner, the ratio of the linear distance along central axis **108** of L_2 to L_3 is 3.800 cm/9.800 cm=0.3878, and can range from about 0.3500 to 0.4500. The maximum width W_1 **312** is dependent upon the length of tubular body **102** so that the length L_1 **386** is at least five-times larger than width W_1 **312**.

FIG. **4** shows an end view of tubular body **102** as viewed from the first end of first tubular member **104** where first tubular member **104** is a regular, square polygon having

equal length sides while second tubular member **106** is not a regular, hexagonal polygon. In this case, the four sides (**302**, **304**, **402**, and **404**) of first tubular member **104** meet at 90-degrees at the juncture between adjacent sides. The six sides (**314**, **316**, **318**, **406**, **408**, and **410**) of second tubular member **106** for a hexagonal polygon that is compressed in a vertical direction so as to allow an approximately equal vertical height for edge **346** and horizontal width for edge **358**. In this manner, the planar aspect presented by the horizontal reflective internal surfaces (**334**, **336**, **412**, and **414**) are similar in size to the vertical reflective internal surfaces (**332**, **416**, **338**, and **418**).

Dividing member **118** includes a plurality of radii (**424**, **426**, **428**, **430**) emanating from a central portion of tubular body **102** along central axis **108**. In one embodiment, it is preferable for the distal ends of dividing member **118** radii to meet the internal reflective surface of each side near a midpoint of the side. Since first portion **104** is a regular, square polygon, adjacent radii form right angles with each other where angle **436** between radii (**424**, **426**) is 90-degrees, and angle **438** between adjacent radii (**424**, **430**) is 90-degrees so that the light receiving end of tubular body **102** is divided into square regions. Other configurations are possible (not shown) including where the distal ends of radii (**424**, **426**, **428**, and **430**) are coincident with the corners of square first end portion **104** so that the light receiving end of tubular body **102** is divided into triangular regions by vertical and horizontal divisions. The square or triangular regions form a cavity for separating the incoming beams (**110**, **112**, **114**, **116**) prior to mixing.

In the case where coherent or non-dispersive light is received parallel to the central axis **108**, it is desirable to reflect the incoming beam from a reflective surface in middle section **202** in order to avoid a "hot spot" in the homogeneous output of tubular body **102**. Incoming coherent beams are applied to the reflecting surfaces of middle portion **202** in order to induce mixing and homogenization within second end portion **106**. For example, a first coherent beam **448** is applied to a first pair of reflecting surfaces (**332** and **416**), a second coherent beam **450** is applied to a second pair of reflecting surfaces (**334**, **336**), a third coherent beam **452** is applied to a second pair of reflecting surfaces (**338**, **418**), and a fourth coherent beam **454** is applied to a fourth pair of reflecting surfaces (**412**, **414**).

Each of these incoming coherent beams is applied to a reflecting surface within middle portion **202** in order to initiate mixing. According to this embodiment of tubular body **102**, square first tubular member **104** has a vertical height **460** and a horizontal width **462**. Similarly, hexagonal second tubular member **106** has a vertical height **464** and a horizontal width **466** which are equal to each other. Longitudinal edge **320** meets and end portion of side **302** at vertex **350**. Similarly, longitudinal edge **322** meets an end portion of side **304** at vertex **370**. Due to symmetry, a longitudinal edge **470** between second tubular member **106** sides **406** and **408** meets first tubular member **104** side **402** at a vertex **472**, and a longitudinal edge **476** between second tubular member **106** sides **408** and **410** meets first tubular member **104** side **404** at a vertex **478**.

FIG. **5** shows and end view of tubular body **102** as viewed from the first end of first tubular member **104** where first tubular member **104** is a regular, square polygon having equal length sides while second tubular member **106** is a regular, hexagonal polygon, also having equal length sides. In this manner, the planar aspect presented by the horizontal reflective internal surfaces (**334**, **336**, **412**, and **414**) is different from the planar aspect presented by the vertical reflective internal surfaces (**332**, **416**, **338**, and **418**).

According to this embodiment of tubular body **102**, square first tubular member **104** has a vertical height **502** and a horizontal width **504**. Similarly, hexagonal second tubular member **106** has a vertical height **506** and a horizontal width **508**. Since first tubular member **104** is square, vertical height **502** is equal to horizontal width **504**. However, since second tubular member **106** is a regular hexagon, vertical height **506** is greater than horizontal width **508**. A result of having regular polygonal structures such as the square first tubular member **104** and the hexagonal tubular member **106**, the planar aspect presented by the horizontal reflective internal surfaces (**334**, **336**, **412**, and **414**) is larger than the planar aspect presented by the vertical reflective internal surfaces (**332**, **416**, **338**, and **418**). Thus, when using a coherent incoming beam, the reflecting target is smaller for the vertical reflective internal surfaces (**332**, **416**, **338**, and **418**).

FIG. **6** shows and end view of tubular body **102** as viewed from the first end of first tubular member **104** where first tubular member **104** is not a regular, square polygon yet still has equal length sides, while second tubular member **106** is a regular, hexagonal polygon having equal length sides. In this manner, the planar aspect presented by the horizontal reflective internal surfaces (**334**, **336**, **412**, and **414**) are similar to the vertical reflective internal surfaces (**332**, **416**, **338**, and **418**). According to this embodiment of tubular body **102**, first tubular member **104** has a vertical height **602** and a horizontal width **604**. Similarly, hexagonal second tubular member **106** has a vertical height **606** and a horizontal width **608**. Dividing member **118** includes a plurality of radii (**610**, **612**, **614**, **616**) emanating from a central portion of tubular body **102** along central axis **108**. Since first portion **104** is not a regular, square polygon, adjacent radii do not form right angles with each other where angle **618** between radii (**610**, **616**) is acute, and angle **620** between adjacent radii (**612**, **614**) is obtuse so that the light receiving end of tubular body **102** is divided into rhomboid regions similar to the shape of the first portion **104**.

FIG. **7** shows a flow diagram **700** indicating operations for a method of producing mixed and homogenized light from a plurality of incoming light beams each having a different wavelength using a light mixing and homogenizing apparatus. The operations include receiving **702** a plurality of incoming light beams into the divided light funnel first portion as described in reference to FIG. **3**. The method continues with an operation of reflecting **704** light off the interior surface of an undivided light funnel second portion. The method continues with mixing **706** the received light beams within the light funnel second portion. The method continues with homogenizing **708** the mixed light to produce a homogenized light beam having a substantially equal intensity distribution. Finally, the method concludes with outputting **710** the mixed and homogenized light.

FIG. **8** shows a block diagram of a light mixing and homogenizing system **800** that includes a plurality of light sources (**802**, **804**, **806**, and **808**), a control unit **810**, and a light mixing and homogenizing apparatus **100**. Each light source outputs light of a different frequency or wavelength. For example, a first light source **802** outputs a first light beam **110** having a first wavelength λ_1. A second light source **804** outputs a second light beam **112** having a second wavelength $\lambda_2$that is different from first wavelength λ_1. A third light source **806** outputs a third light beam **114** having a third wavelength λ_3 that is different from first wavelength λ_1, and second wavelength λ_1. Finally, a fourth light source **808** outputs a fourth light beam **116** having a fourth wave-

length λ_4 that is different from first wavelength λ_1, second wavelength λ_2, and third wavelength λ_3. Although only four light sources are shown, the number of light sources is not limited to this example.

Control unit **810** outputs a plurality of control signals (**812**, **814**, **816**, and **818**) in order to determine the intensity and wavelength of light emitted from each light source. In this manner, a continuously variable homogenized light beam may be produced having a color determined by the wavelength components of the plurality of incoming light beams. For example, control unit **810** asserts a first control signal **812** to first light source **802** in order to determine the intensity and wavelength of first light beam **110** emitted from light source **802**.

A light beam from a light source may be conducted in an optical conduit such as an optical fiber prior to introduction within light mixing and homogenizing apparatus **100**. The optical fiber may be considered as a part of the light source. Similarly, control unit **810** asserts a second control signal **814** to second light source **804** in order to determine the intensity and wavelength of second light beam **112** emitted from light source **804**. Control unit **810** asserts a third control signal **816** to second light source **806** in order to determine the intensity and wavelength of second light beam **114** emitted from light source **806**. Finally, control unit **810** asserts a second control signal **816** to second light source **808** in order to determine the intensity and wavelength of second light beam **116** emitted from light source **808**.

FIG. **9** shows an example of light intensity from a single optical fiber output where the light intensity profile varies across the diameter, in a direction perpendicular to the cross section of the fiber, in a Gaussian distribution **902**. FIG. **10** shows an example of light output from the light mixing and homogenizing apparatus producing a uniform intensity or top-hat profile **1002** across the span of the tubular body output.

FIG. **11** shows a plurality of incoming light sources (**802**, **804**, **806**, and **808**) producing a plurality of incoming light beams (**110**, **112**, **114**, and **116**) that are applied to a wider input **330** as a receiving end of light mixing and homogenizing apparatus **100**. Each incoming light beam has a gaussian profile **902**. Output beam **120** has a top-hat profile **1002** and is emitted from narrower output **340** as an outputting end of light mixing and homogenizing apparatus **100**.

FIG. **12** shows the plurality of incoming light sources disposed within a receiving portion of the tubular body. A plurality of optical fibers (not shown) may be bundled together to receive the mixed and homogenized light from output **340**. In this manner, the mixed and homogenized light may be applied evenly to each of the optical fibers in the bundle. Alternatively, the light from output **340** may be emitted directly into the air or another medium.

FIG. **13** shows the ends of each light source (**802**, **804**, **806**, and **808**) as inserted within the tubular body first end portion **104**. As shown, the light sources are inserted within first portion **104** a depth **1302** L_I which allows the light beam from each light source to be introduced into the interior portion of tubular body **102** prior to mixing since the incoming light beams are separated from each other by dividing member **118**. Depth **1302** corresponds to the insertion depth of the light beams within first portion **104**, and can vary from near the leading edge of the interior surface of first portion **104** to about half the length **388** L_2 of first portion **104**.

Embodiments described above illustrate but do not limit the invention. It should also be understood that numerous modifications and variations are possible in accordance with the principles of the present invention. Accordingly, the scope of the invention is defined only by the following claims.

We claim:

1. A light mixing and homogenizing apparatus, comprising:

a first tubular member having a reflective interior surface and a polygonal cross section with a first maximum diameter and a first number of sides, the first tubular member having a first end and a second end, the first tubular member first end being configured to receive a plurality of incoming light beams; and

a second tubular member having a reflective interior surface and a polygonal cross section with a second maximum diameter smaller than the first maximum diameter and a second number of sides different from the first number of sides, the second tubular member having a first end disposed adjacent to the first tubular member second end, the second tubular member having a second end configured to output a homogeneous light beam comprising a mixture of the plurality of incoming light beams.

2. The apparatus of claim **1**,

wherein a longitudinal edge is formed at the juncture of each pair of adjacent second tubular member sides, and

wherein at least one of the second tubular member first end longitudinal edges coincides with an end portion of a side of the first tubular member second end.

3. The apparatus of claim **1**, further comprising:

a plurality of planar members configured to mate the first tubular member second end with the second tubular member.

4. The apparatus of claim **3**, wherein the plurality of planar members form a funnel shape having a larger portion and a smaller portion, the larger portion of the funnel shape being disposed adjacent to the first tubular member second end.

5. The apparatus of claim **3**, wherein the plurality of planar members each has a triangular shape having at least one vertex coincident with one of a first tubular member and a second tubular member longitudinal edge.

6. The apparatus of claim **3**, wherein the planar members configured to mate the first tubular member second end with the second tubular member comprise a tubular body middle portion, the inner walls of the tubular body middle portion having a reflective surface, each planar member having a common edge with the first tubular member.

7. The apparatus of claim **1**, wherein the first polygonal cross section has four sides.

8. The apparatus of claim **1**, wherein the second polygonal cross section has six sides.

9. The apparatus of claim **1**, further comprising:

a dividing member disposed within the first tubular member first end configured to separate the plurality of incoming light beams from each other prior to mixing.

10. The apparatus of claim **9**, wherein the dividing member radially separates the first tubular member first end into a plurality of regions about a central longitudinal axis.

11. The apparatus of claim **10**, wherein the dividing member includes a plurality of radial members, each radial member having a first end and a second end, each radial member first end being disposed towards a center portion of the first tubular member, each radial member second end being disposed at about the midpoint of a first tubular member side.

12. The apparatus of claim 10, wherein the dividing member separates the first tubular member first end into four regions for receiving up to four incoming light beams.

13. The apparatus of claim 1, wherein the ratio of a linear distance along the central axis of the first tubular member to a linear distance along the central axis of the second tubular member is between about 0.35 to 0.45.

14. A light mixing and homogenizing system, comprising:

a plurality of light sources, each light source providing a light beam having a unique wavelength;

a tubular body having a first end portion with a square cross section and a second end portion with a hexagonal cross section, the first end portion being configured to receive the plurality of light beams, the tubular body second end portion being configured to output a homogeneous light beam comprising a mixture of the incoming light beams, an interior portion of the tubular body having a highly reflective surface configured to reflect light from the plurality of incoming light beams causing a mixing and homogenizing of the plurality of light beams; and

a divider disposed within the tubular body first end portion configured to separate the incoming light beams prior to mixing.

15. The apparatus of claim 14, further comprising:

a control unit for determining a light intensity level for each of the plurality of light sources.

16. The apparatus of claim 15, wherein the control unit determines a wavelength of output light for each of the plurality of light sources.

17. The apparatus of claim 14, wherein the plurality of light beams each have a gaussian profile.

18. The apparatus of claim 14, wherein the output light beam has a top-hat profile.

19. A method of mixing and homogenizing a plurality of light beams, the method comprising:

receiving the plurality of incoming light beams into a divided first portion of an optical funnel, each incoming light beam having a substantially unequal intensity distribution;

mixing the received plurality of incoming light beams within an undivided second portion of the optical funnel to produce a mixed light beam;

homogenizing the mixed light beam to produce a homogenized light beam having a substantially equal intensity distribution; and

outputting the homogenized light beam.

20. The method of claim 19, wherein mixing the received light beams within an undivided second portion of the optical funnel further comprises:

reflecting each of the incoming light beams from at least one interior surface of the optical funnel second portion.

21. The apparatus of claim 19, wherein the optical funnel first portion has a first diameter and the optical funnel second portion has a second diameter, the first diameter being larger than the second diameter.

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