

A TUBULAR LIGHT TRANSMITTING
UNIT AND ASSEMBLY

The present invention relates to a tubular light transmitting unit capable of efficiently transferring optical energy such as solar energy converged by an optical system to any desired location. The present invention also relates to an optical energy transmitting assembly using such a tubular unit.

Various techniques have heretofore been proposed by the applicant in order to converge light from a light source such as sunlight into a light transmitting element by means of an optical system such as a lens, so that the light may be transmitted through the element to a desired place for the purpose of illumination or the like. In effectively introducing sunlight converged by the optical system and transmitting the light effectively with a minimum of loss throughout the transmission path, it is a prerequisite that the light transmitting element be made of a material which causes least attenuation to light and, therefore, features excellent transmissibility. Such materials may be typified by silica glass or fused silica, as well known to the art. Silica glass, however, is quite expensive and so will be a light transmitting element used in, for example, a sunlight supply device which the applicant has proposed and require a large number of such elements. Thus, the use of silica glass for light transmitting elements have so far failed to be readily practiced. Where sunlight is converged by a lens or like optical system, it is impossible to focus all the wave-

length components thereof to one point due to the chromatic aberration with the result that the focussed image of the sun inevitably has certain largeness. Stated another way, it is quite difficult to introduce into an optical fiber all the solar energy converged by the optical system. Though a substantial amount of optical energy may be transferred efficiently if use is made of a light transmitting element having a larger diameter, the consumption of a large amount of expensive silica glass would render the cost prohibitive and make it difficult to achieve the efficient transmission of optical energy. Besides, the resulting optical fiber would be very heavy to make the transportation of installation thereof troublesome.

According to one aspect of the present invention there is provided a tubular light transmitting unit for transmitting optical energy from a light source to a desired location, comprising a tubular member made of silica glass and defining a bore, at least one of a light inlet end portion and a light outlet end portion of the tubular member being plugged by a transparent plug member having a refractive index which is less than or equal to the refractive index of the tubular member.

In a preferred embodiment of the present invention, the bore inside the tubular member is plugged at each of its light inlet and light outlet end portions by a transparent plug member whose refractive index is equal to or smaller than that of the tubular member.

An end face of the plug member positioned inside the bore of the unit may be flat, convex, or concave.

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There may also be provided a plurality of optical fibers which are individually connected with the outer periphery of the tubular member to guide the optical energy into the tubular member through said outer periphery.

The diameter of the tubular member may be smaller at the light outlet end portion than at the light inlet end portion.

There may also be provided an optical system for converging the optical energy from the light source and introducing the converged optical energy onto the inlet end portion of the unit.

According to another aspect of the invention there is provided a tubular light transmitting assembly for transmitting optical energy from a light source to a desired location and having a plurality of tubular light transmitting units, each of the units comprising a tubular member made of silica glass and defining a bore, at least one of a light inlet end portion and a light outlet end portion of each said tubular member being plugged by a transparent plug member having a refractive index which is less than or equal to the refractive index of that tubular member.

At at least one end of the assembly, the plurality of tubular light transmitting units may be bundled up together.

In a described embodiment, a space or spaces between adjacent ones of the tubular members at said one end of the assembly is or are plugged by a transparent material which has a refractive index which is smaller than or equal to the refractive index of the tubular members.

Reference will now be made to the accompanying drawings, in which:

Figures 1-3 are sectional side elevations showing different forms of a tubular light transmitting element;

Figures 4-6 are sectional side elevations showing some examples of modifications of a basic tubular light transmitting element;

Figures 7-9 are views of some examples of an optical system which neighbors a light inlet end of a tubular light transmitting element;

Figure 10 is a view of an example of an optical system which neighbors a light outlet end;

Figure 11a is a view of a light inlet end portion of a tubular light transmitting unit according to the present invention;

Figure 11b is a section along line X-X of Figure 11a;

Figure 12 is a section of a modification to the embodiment shown in Figures 11a and 11b;

Figures 13a and 13b are views of an exemplary assembly constituted by tubular light transmitting elements of the present invention;

Figure 14 is a view of another form of the assembly of the tubular light transmitting elements;

Figure 15 is a view of a modification to the construction shown in Figure 14;

Figure 16 is a view of another embodiment of the present invention;

Figures 17a and 17b are views of a modified form of the outlet end of the tubular member shown in Figure 16; and

Figure 18 is a view of the tubular element shown in Figure 16 which is in an exemplary state of use.

While the tubular light transmitting element and optical energy collecting and transferring device of

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the present invention is susceptible of numerous physical embodiments, depending upon the environment and requirements of use, substantial numbers of the herein shown and described embodiments of the invention have been made, tested and used, and all have performed in an eminently satisfactory manner. It should be mentioned at this point that Figures 1 to 10 and the associated description are submitted as providing matter useful as background to the invention, and do not disclose structures which are in themselves embodiments of the present invention.

Referring to Figure 1 of the drawings, a tubular light transmitting element is shown and generally designated by the reference numeral 10. The tubular element is made of silica glass. As previously described, silica glass is well known as a material which exhibits good transmissibility to light and has heretofore been used to constitute the cores of optical fibers and the like. Optical fibers, however, find application mainly to optical data transmission or the like and are very small in diameter. Therefore, optical fibers are unsuitable for use as an optical energy transferring medium which has to allow a large amount of optical energy to be efficiently introduced therein and transmitted therethrough. In light of this, the tubular element 10 is designed such that convergent or parallel rays of light L provided by a lens or like optical system (not shown) becomes incident on a light input end of 10' of the tube 10 and propagates through the tube 10. Such a hollow configuration of the light transmitting element minimizes the consumption of silica glass, production cost and overall weight.

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When light converged by a lens or the like is incident on the inlet end 10' of the tube 10, light rays L' around the convergent or parallel rays L become incident on an end face 14' of a side wall 14 of the tube 10 and then propagate through the side wall 14.

Referring to Figure 2, another structure is shown in which the tubular element 10 is surrounded by a clad layer 16. Besides the optical energy introduced in the side wall 14 of the tube 10, even the optical energy propagating through the bore 12

of the tube 10 may enter the side wall 14 in a location where the tube 10 is bent, for example. Thus, the clad layer 16 allows the tube 10 to successfully transmit such optical energy to a desired place without any wasteful emission to the outside. An additional function of the clad layer 16 is protecting the tube 10 which is made of silica glass. Also, retaining the silica glass tube 10 through the clad layer 16 will eliminate the release of the optical energy at the retaining section.

Referring to Figure 3, the optical energy transmitted through the tube 10 may be picked out at a desired portion of the tube 10 by the illustrated arrangement. The tube 10 made of silica glass is provided on its side wall 14 with a light diffusing member 18 whose refractive index is larger than that of silica glass. With this arrangement, light passing through the side wall 14 of the tube 10 will be discharged to the outside through the light diffusing member 18. When it is desired to discharge a larger amount of optical energy to the outside, a mirror 20 may be located in the bore 12 or the side wall 14 of the tube 10 as illustrated so that the light I" reflected by the mirror 20 becomes incident on the light diffusing member 18. While in Figure 3 the member 18 and mirror 20 are shown as being applied to the tube 10 shown in Figure 2, it will be readily understood that such a light receiving member and/or a mirror is applicable to the tube 10 shown in Figure 1 as well.

Referring to Figures 4-6, some exemplary arrangements of the tubular light transmitting element are illustrated. In Figure 4, the tube 10 is bent in generally L-shape and a mirror 20' is located at the L-shaped bend. In Figure 5, the tube 10 is branched in generally T-shape while a prism 22 is positioned at the branching section. In Figure 6, the tube 10 is also branched but provided with a half-mirror

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In each of the foregoing arrangements, the optical means for feeding convergent or parallel light rays L to the inlet end of the tube 10 may comprise a convex lens 26 as shown in Figure 7 or the combination of a convex lens 26 and a concave lens 28 as shown in Figure 8. The convex lens 26 in Figure 7 causes rays of sun or the like to converge so that the convergent rays Lc become incident on the inlet end 10' of the tube 10. The convex lens 26 in Figure 8 functions in the same manner as in Figure 7 while the concave lens 28 transforms the convergent rays from the convex lens 26 into parallel rays Lp and feeds them to the tube 10. The combined lens system shown in Figure 8 provides substantially parallel light rays which will be substantially totally reflected by the inner surface of the tube 10 and, therefore, its loss inside the tube 10 will be significantly reduced. Preferably, the light receiving surface 28' of the concave lens 28 is provided with a meniscus or flat configuration in order to minimize a loss due to reflection thereat.

The lens system shown in Figure 7 or 8 may be replaced by an annular mirror 30 as illustrated in Figure 9. The annular mirror 30 is mounted on the inlet end 10' of the tube 10 so that the light rays L' reflected by, for example, the end face 14' of the side wall 14 at the tube inlet 10' may be reflected by the mirror 30 into the tube 10.

In combination with the tube 10 shown in Figure 8, a convex lens 32 may be located adjacent to a light outlet end 10" of the tube 10 as indicated in Figure 10. The convex lens 32 is adapted to focus parallel rays transmitted through the bore 12 of the tube 10 and causes the convergent rays L to enter a tubular light transmitting element or optical fiber 34 smaller in diameter than the tube 10. With this arrangement, optical energy can be

transmitted using the tube or optical fiber 34 which is light weight and incostly. It will be clear that the convergent rays L from the convex lens 32 may be transformed into parallel rays by a concave lens (not shown) before introduced into the tube or optical fiber 34.

Referring to Figures 11a and 11b, an embodiment of the present invention is shown. Figure 11a shows the inlet end 10' of the tube 10 while Figure 11b is a section along line X-X of Figure 11a. The tube 10 in this embodiment has its inlet end 10' stopped up by a transparent plug member 36 made of silica glass having a refractive index which is equal to or smaller than that of the tube 10. Light rays L converged by a lens or like optical system is conducted by the transparent plug 36 into the silica glass which forms the side wall 14 of the tube 10. The silica glass side wall 14, which is excellent in light transmission efficiency, transfers the input light rays L to any desired location. At the current stage of development, it is easy to produce a tube 10 which is 500 μ m in outside diameter D and has a bore 12 dimensioned 400 μ m in diameter d. The so dimensioned tube 10 requires silica glass consumption which is not more than about 36% of a solid tube for the same diameter D.

Referring to Figure 12, a modification to the embodiment shown in Figures 11a and 11b is indicated. As shown, the tube 10 is provided with a modified plug member 36' which not only stops the inlet end of the tube 10 but covers the end face 14' of the side wall 14. This arrangement, like that of Figures 11a and 11b, successfully guides the converged optical energy into the side wall 14 of the tube 10 which is made of silica glass.

In a preferred construction, the output end 36a of the plug 36 or 36' shown in Figures 11a and 11b or 12 is shaped flat as indicated by a solid line, concave as indicated by a dash-and-dot line or convex as indicated

by a dash-and-dots line so that output rays from the surface 36a may be effectively directed into the side wall 14 of the tube 10, which is made of silica glass. This will reduce the amount of light propagating through the bore 12 and minimize the transmission loss, thereby promoting efficient transfer of the optical energy.

Referring to Figures 13a and 13b, there is shown an example of an assembly made up of tubular light transmitting elements of the present invention. As shown, a number of tubes 10 shown in Figures 11a and 11b or 12 are bundled up together at their inlet ends 10'. Gaps 38 left between adjacent tubes 10 are individually filled with a material exhibiting the same optical characteristics as the plugs 36 or 36', ^{in this case} ~~the~~ transparent silica glass whose refractive index is equal to or smaller than that of the tubes 10. Each of the fillers extends over a length substantially common to the length l of the plug 36 or 36' from the inlet end of the tube 10. It will be seen that the fillers of silica glass give the assembly a wider light receiving area at the inlet end and, thereby, allows the high density optical energy converged by the lens system to be more effectively introduced into the tubes 10. The fillers in the gaps 38 also serve to prevent the tubes 10 from being chipped off while the inlet end 10' of the tube bundle 10 is machined to a flat surface. Additionally, the fillers check small particles of dust which would otherwise enter the gaps 38.

Referring to Figure 14, another possible form of the tube assembly is illustrated. A tubular light transmitting element 40 has an outside diameter D of about 10 mm and is formed with a bore which is about 8 mm in diameter d , thus being far larger in diameter than the tube 10 in any of the foregoing embodiments. In this assembly, the light guided by the narrow tubes or conventional optical fibers 10 can be introduced into the large diameter tube

40 through the side wall of the latter. Hence, a large amount of optical energy can be effectively transferred through the side wall of the tube 40 which is made of silica glass. The tubes or optical fibers 10 are mounted to the outer periphery of the tube 40 through a connector member 42 which is formed of a transparent material having a refractive index equal to or smaller than that of the tube 40. If necessary, the outer periphery of the connector 42 may be covered with a thin reflector layer in order to prevent the light introduced through the connector 42 from leaking to the outside.

A modified form of the assembly shown in Figure 14 is indicated in Figure 15. As shown, the smaller tubes or optical fibers 10 are directly connected to the outer periphery of the larger tube 40 by means of an optical adhesive or the like. This assembly is comparable with that of Figure 14 in the ability of conducting a large amount of optical energy into the side wall of the larger tube 40 made of silica glass and, thereby, efficiently transferring the optical energy therethrough.

While the larger tube 40 may have an even diameter throughout its length from the inlet end 40' to the outlet end 40", it may be provided with an outlet end 40' which is tapered away from the inlet end 40' as illustrated in Figure 16. In Figure 16, light rays converged by a lens system are effectively introduced in the tube 40 through the inlet end 40' and then progressively converged by the side wall of the tube 40 which is made of silica glass. Finally, the converged light is emitted from the tapered outlet end 40" with a high energy density. The tapered outlet end 40" of the tube 40 may be stopped up by a plug member 36" having a refractive index which is equal to or smaller than that of the tube 40. The plug 36" will effectively guide the light propagated through the bore 12' into the side wall of the tube 40. The refractive index

of the plug 36" may be selected to be larger than that of the tube 40 in order to guide the light transmitted through the side wall of the tube 40 to the plug 36" and, thereby, further increase the optical energy density available at the tube outlet end 40". Where the refractive index of the plug 36" is equal to or smaller than that of the tube 40, the plug 36" fit in the tube 40 may be so positioned as to terminate short of the outermost end face of the tube 40 as illustrated in Figure 17a, so that light rays can be converged to the side wall of the tube 40 and effectively discharged from the end face. Where the refractive index of the plug 36" is larger than that of the tube 40, the plug 36" may protrude from the outlet end of the tube 40 as indicated in Figure 17b in order to further effectively release the light which is converged to the plug 36". As shown in Figure 18, a plurality of such tubes 40 having tapered outlet ends 40" may be connected in series fitting the outlet end 40" of one in the inlet end 40' of another, the diameters of the inlet ends 40' and outlet ends 40" being progressively reduced. This multiple tube connection will make the diameter of the final outlet end 40" very small and, thus, realize a far higher optical energy density thereat. When introduced into the smaller tubes in any one of the embodiments described, the light so converged to have a high density and, therefore, its energy can be transferred far more effectively.

Various modifications will become possible for those skilled in the art after receiving teachings of the present disclosure without departing from the scope thereof.



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CLAIMS:

1. A tubular light transmitting unit for transmitting optical energy from a light source to a desired location, comprising a tubular member made of silica glass and defining a bore, at least one of a light inlet end portion and a light outlet end portion of the tubular member being plugged by a transparent plug member having a refractive index which is less than or equal to the refractive index of the tubular member.
2. A tubular light transmitting unit as claimed in claim 1, wherein an end face of the plug member positioned inside the bore of the unit is flat.
3. A tubular light transmitting unit as claimed in claim 1, wherein an end face of the plug member positioned inside the bore of the unit is convex.
4. A tubular light transmitting unit as claimed in claim 1, wherein an end face of the plug member positioned inside the bore of the unit is concave.



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5. A tubular light transmitting unit as claimed in claim 1, further comprising a plurality of optical fibers which are individually connected with the outer periphery of the tubular member to guide the optical energy into the tubular member through said outer periphery.
6. A tubular light transmitting unit as claimed in claim 1, wherein the diameter of the tubular member is smaller at the light outlet end portion than at the light inlet end portion.
7. A tubular light transmitting unit according to claim 6 wherein the light outlet end portion of the tubular member is plugged by a transparent plug member of which an end face furthest from the inlet end portion of the tubular member is spaced from the end face of said tubular member at said light outlet end thereof.
8. A tubular light transmitting unit according to claim 7 wherein said end face of said plug member is disposed within the bore of said tubular member.



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9. A tubular light transmitting unit according to claim 7 wherein the light inlet end portion of the tubular member is plugged by a said transparent plug member having a refractive index which is less than or equal to the refractive index of the tubular member, and wherein said plug member plugging the light outlet end portion of the tubular member protrudes from the end of the tubular member at said light outlet end thereof.

10. A tubular light transmitting unit as claimed in claim 1, wherein the light source is the sun.

11. A tubular light transmitting unit as claimed in claim 1, in assembly with an optical system for converging the optical energy from the light source and introducing the converged optical energy onto the inlet end portion of the unit.

12. A tubular light transmitting assembly for transmitting optical energy from a light source to a desired location and having a plurality of tubular light transmitting units, each of the units comprising a tubular member made of silica glass and defining a bore, at least one of a light inlet end portion and a



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light outlet end portion of each said tubular member being plugged by a transparent plug member having a refractive index which is less than or equal to the refractive index of that tubular member.

13. A tubular light transmitting assembly as claimed in claim 12, wherein at at least one end of the assembly, the plurality of tubular light transmitting units are bundled up together.

14. A tubular light transmitting assembly as claimed in claim 13, wherein a space or spaces between adjacent ones of the tubular members at said one end of the assembly is or are plugged by a transparent material which has a refractive index which is smaller than or equal to the refractive index of the tubular members.

15. A tubular light transmitting device according to claim 1 or claim 12 and substantially as hereinbefore described with reference to any figure of the accompanying drawings.
