Light diffusing optical fiber for Illumination

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Abstract: We describe the design of thin, ~ 100-180 micron diameter, optical silica fibers for illumination. The fiber has a silica core with specially engineered scattering centers to scatter light through walls of the fiber across a wide wavelength range. **OCIS codes:** (160.6030), (160.2290)

Introduction

Optical fibers are used for a variety of applications where light needs to be delivered from a light source to a remote location. Because optical fibers are typically designed to efficiently deliver light from point to point over long distances, they are not typically considered well-suited for use in forming an extended illumination source. Yet, there are a number of applications such as specialty lighting, signage and display applications where select amounts of light need to be provided in an efficient manner to the specified areas. In this presentation we describe an optical fiber in which scattering centers are placed in the core of the fiber provide very efficient scattering of light through the sides of the optical fiber.

Both the small size and the scattering mechanism employed in the fiber afford a very small, flexible illumination source. The fibers are about the size of normal silica transmission fibers. The glass core diameter can vary from about 100-200 microns, and the polymer clad thickness is ~ 50 micron, making the OD of the fiber less than 150-250 um. For high power or UV applications, the fiber can employ a glass cladding as well to more efficiently emit these wavelengths. The efficiency of coupling light sources may also be adjusted to accommodate a variety of light sources, both lambertian and laser sources. One way that the coupling may be controlled is by the use of a low index polymer cladding to increase the numerical aperture (NA) of the fiber so that it can range from 0.35-0.53. In addition, the light diffusing fibers may be bundled together to effectively increase the core size to more effectively couple light from LED's and similar light sources. The extraction of light from the fiber is very uniform and may be tuned to scatter more or less light through the sides by controlling the number of scattering sights within the core of the fiber. The emitted light may also be converted to different colors by the use of phosphor coatings.

Results

The light diffusing fiber has a silica core in which a section of the core contains a ring of non-periodically distributed (radially and axially) scattering sights. The scattering sights have diameters in the ~ 50-500 nm range and lengths of ~ 10-1000 mm.[i] These Scattering centers range in size from 50-500 nm, consequently they effectively scatter the propagating light almost independently of the wavelength of light used. As mentioned earlier, the magnitude of scattered light may be controlled and depends on the size of the scattering centers and their relative area compared to the fiber core. The absorption losses within the fiber are negligible, and the scattering losses can be as high as 5 -7 dB/m. The bending losses are also small with minimum bending diameters as small as a 5 mm radius.
The large core size and high NA of the fiber allow low loss coupling of light from inexpensive laser sources, such as visible or near infrared (NIR) laser diodes with efficiencies higher than 85%. Coupling from other types of lasers with reasonable beam quality can also be done with very high efficiency. The relatively low cost of blue diode lasers (405 or 445 nm) creates an economically feasible route to scattering visible light with different colors by placing one or more phosphors in the coating of the fiber. In addition, other scattering materials also can be placed in the coating to provide a fiber with a uniform angular scattering distribution. Several of these fibers were bundled together to couple extended light sources, such as LED or high brightness lamps, into the fiber. The bundles with ~ 40 fibers have been demonstrated with coupling efficiency ~ 50% to LED sources.

The use of fiber in illumination applications has been demonstrated in a variety of potential applications and demonstrated the following benefits:

The flexibility of thin glass fibers enables the LDF to be deployed in complex configurations and shapes in special lighting applications. Light from the fiber can also be coupled into glass sheets for illumination purposes.

The use of yellow phosphor such as Ce-YAG used for white LED placed on the surface of the fiber allows making bright white colors flexible light source. The brightness of the fiber as shown can exceed 10000 lux (Figure 1).

This type of fiber, due to its small size, can be coupled to flat glass to make a very low bezel illumination fixture similar to back light unit (BLU) used for LCD displays. Figure 2 shows transparent glass place with LDF coupled to the side of 0.7 mm glass. The glass has a coating on the surface, which scatters light coupled to the wave-guiding plate.

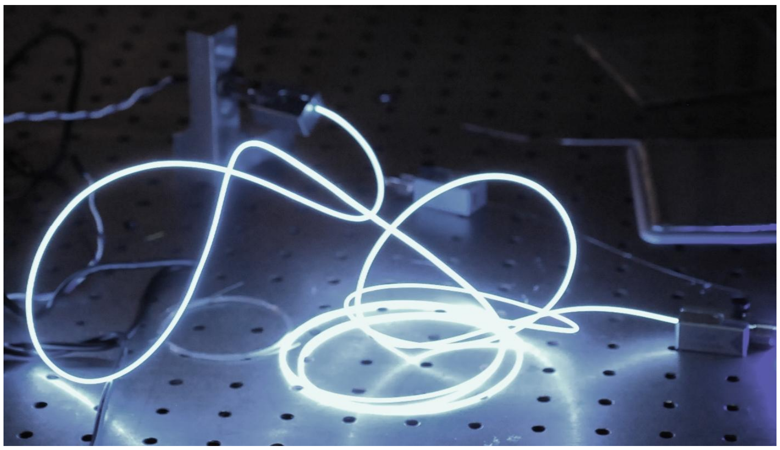

Figure 1: White colors light diffusing fiber with 445 nm laser diode as a source and with “effective length” ~ 1.5 m. The color conversion of blue light to white is done using Ce-Yag phosphor placed in the coating of the fiber. The diameter of the fiber is 500 um.

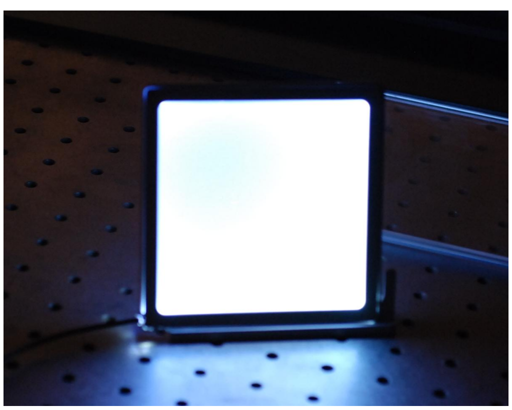

Figure 2: 4”x4” glass plate with scattering top layer with LDF coupled to the side of the plate. The 445 nm diode is 1 W, brightness of the plate ~ 1000 nits.

The light diffusing fibers can be easily connected to low loss delivery fiber, thereby allowing a light source to be remotely placed away from light diffusing portion of the fiber. This helps to deal with heat dissipation and bring additional flexibility to the lighting fixture designs.

Conclusions

We describe a light diffusing fiber with a silica glass core containing scattering centers that effectively scatters light through walls of the fiber. The flat wavelength dependence, high flexibility, scattering uniformity, and low absorption losses make it an interesting illumination product for a variety of light sources and applications. Separation of light source from light dissipating element with help of low loss delivery fiber helps to deal with heat dissipation issues.

References

[i] S. Bickham, E. Fewkes, D. Bookbinder, S. Logunov "Optical Fiber Illumination Systems and Methods" US patent application US20110122646A.