Uniform line source using a holed cavity and a laser

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***Abstract*— A line source consisting of a laser, a fiber-like waveguide, phosphor and a holed cavity is suggested. The simulation demonstrated that this type of line source provided small emission thickness and good uniformity with reasonable energy efficiency.**

***Keywords*— laser, illumination, phosphor, cavity**

I. Introduction

In the design of illumination system, a point source is an ideal light source for making a collimated light. In fact, there is no point source in real world since all artificial light sources such as filament, arc lamp and light-emitting diode (LED) have finite physical size. The source size and the divergence angle compose a finite étendue of the light source, which is conserved throughout the optical system regardless of the optics used [1]. If the étendue is large, it means that it is very difficult to obtain the collimated light for a small beam diameter. Along this line, a laser beam with a small divergence angle or a small mode size has quite an advantage from the viewpoint of etendue. Usually, the divergence angle of a laser beam relates to the beam diameter by means of diffraction phenomenon. Since the diffraction is inevitable, the diffraction limited beam of a laser can be a light source closest to a point source in the real world.

Recently, there have been many attempts to take advantages of lasers and phosphor in illumination industry [2]. The development of a line source based on a laser can be a good choice of direction. Like a point source, a line source can be used to make a thin and uniform plane light source such as a backlight of liquid crystal display television (LCD TV) and other general lighting devices. The use of laser as an excitation source of phosphor can increase the emission energy and decrease the emission volume dramatically due to its small étendue. In this study, we provide a design concept for a line source based on laser and phosphor and prove its feasibility through simulation. The main targets of the line source include how to achieve the good uniformity in the axial direction and the small emission width in the transverse direction.

II. Simulation

Currently, the backlight of LCD TV comprises LEDs and light guide plate in case of the edge type. The LEDs attached on the side of a light guide plate emit the light into the plate and the light spreads throughout the plate by total internal reflection. Therefore, the thickness of a LED and a plate determine the thickness of the backlight unit. In general, the size of LED puts a limit on the reduction of the thickness of a backlight. In addition, the need of multiple LEDs in the module demands the use of printed circuit board, which also increases the cost.

Therefore, we design a line source which utilizes a laser and a fiber-like light guide. The laser can enter the small cross-section of a fiber without much power loss and excite the phosphors inside to generate the broad spectrum of light along the fiber. This scheme can take advantage of the small étendue of a laser and impart the small transverse dimension to the final line source.

However, there is a problem to this type of line source. If the phosphor inside the fiber has a uniform density as shown in Fig. 1-(a) and (b), the emitted light decreases exponentially as the excitation laser beam travels along the fiber. It gives non-uniformity to the line source and can cause many troubles in the design of secondary optics for a backlight

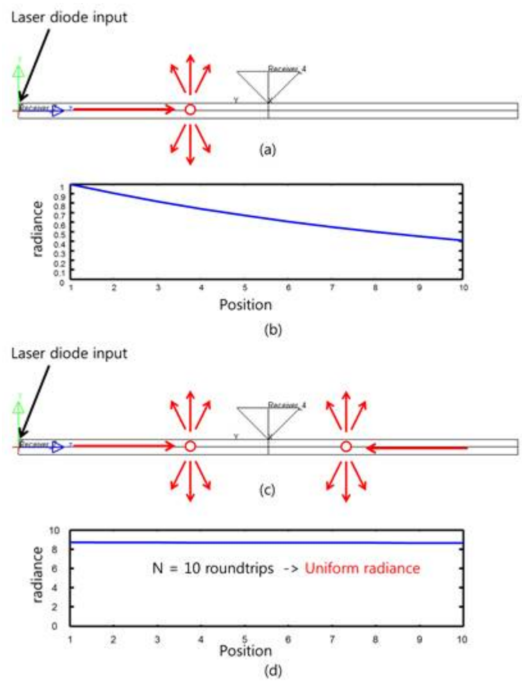

Fig. 1. The effect of multiple reflection inside a cavity on the uniformity of a line source: (a) a laser line source without a cavity, (b) the radiance of the line source as shown in (a), (c) a laser line source with a cavity, (d) the radiance of the line source as shown in (c)

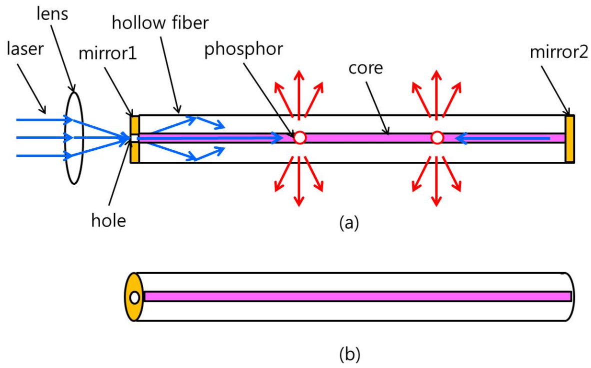

Fig. 2. Schematic diagram of a line source based on a holed cavity and laser

In order to solve this issue, we introduced a cavity structure to the fiber. The mirrors formed on both ends of the fiber make the light travel back and forth multiple times. The radiance along the axis becomes nearly uniform after 10 round trips as seen in Fig. 1-(c) and (d).

Another obstacle to the construction of the line source is how to have the excitation laser beam enter the cavity. The light source is usually placed between two mirrors in case of a laser cavity. But, as for a line source, laser light should come from the outside of the cavity. A solution to this problem is illustrated in Fig. 2. If the cavity has a hole, the laser light can pass through the hole and propagate along the fiber by total internal reflection as long as the numerical aperture of lens conforms to that of the fiber. When the light comes back to the first mirror after reflection from the mirror on the other side, the part of light can escape the cavity. However, if the size of hole is small enough, the loss ratio is ignorable. For example, if the size of a hole is a tenth of the diameter of a fiber, the area of the hole is 1/100 of that of the fiber cross section. Therefore, the loss ratio is only 1/100, which allows the light to make round trips more than 10 times.

Finally, we performed the simulation of a line source to demonstrate the effect of a holed cavity on the uniformity. The simulation setup is illustrated in Fig. 3. The calculation was carried out by LightTools.

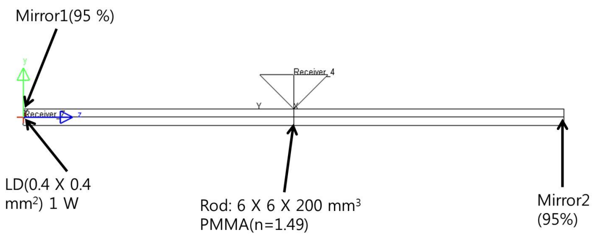

Fig. 3. Simulation of a laer line source with a holed cavity using LightTools

III. Results and Discussion

The simulation showed that the laser line source with a holed cavity had good uniformity along the axis as shown in Fig. 4-(a) and (b). The variation of radiance along the axis was about 3 % and energy efficiency was about 74 %. The energy loss seemed to come mainly from the use of metallic mirror on both sides of the cavity.

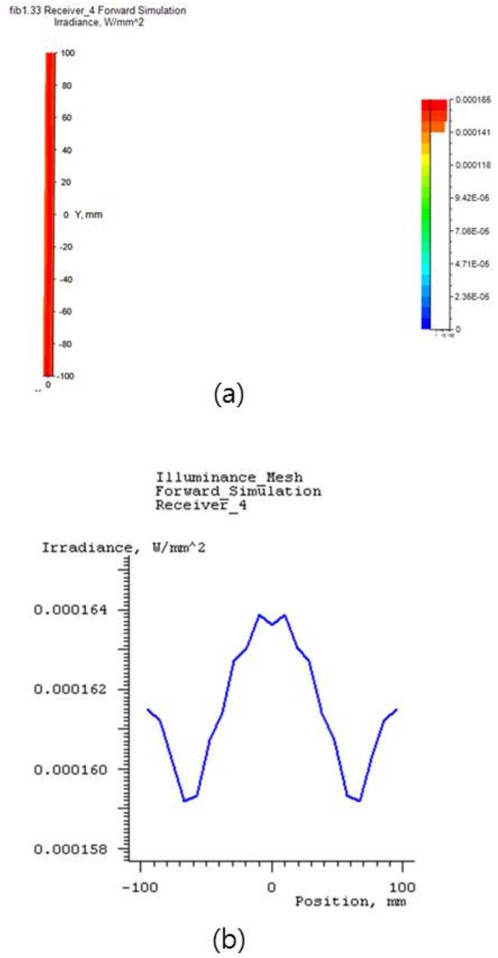

Fig. 4. The irradiance measured at the top surface of the line source: (a) the color map of the irradiance along the rod and (b) the cross-sectional plot along the rod.

IV. Conclusion

We suggested a line source consisting of a laser, a fiber-like waveguide, phosphor and a holed cavity. This type of line source provides small emission thickness and good uniformity with reasonable energy efficiency.

References

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