Design and Construction of High Efficiency Fiber Optic Solar Concentrator for Solar Lighting

Sang Chun Lee[1,2*], Hyunkook Park[1,2], Jungsoo Woo[2], Kookhyun Choi[2] and Yunyoung Choi[2]

[1]Department of Nanoengineering, Kyungnam University, South Korea
[2]Creative Energy and Technology Inc., South Korea
*Sanglee@kyungnam.ac.kr

Abstract

In this study, we have designed three types of fiber optic solar concentrators for solar lighting, and compared their solar concentrating efficiency. The efficiency was measured by comparing the luminance of the direct solar radiation with the luminance of the concentrated solar radiation.

We constructed a fiber optic solar lighting system which composed of solar concentrators, optical fibers, sun light emitters and a sun tracker. The homemade fiber optic solar lighting system had shown a good luminance when we apply to indoor lighting.

1. Introduction

In recent years solar energy has been made widely available for several specific use in thermal applications, direct production of electricity and direct solar lighting. Certain solar applications uniquely require very high photon densities such as solar surgery [1], solar-pumped lasers [2], solar-driven synthesis of carbon nanomaterials [3,4] and electricity generation with advanced semiconductor materials [5]. We need a high performance solar concentrator to obtain a high photon density from the sun. Studies on the concentrating of solar energy have been performed by many researchers. The solar energy concentrating system, coupled with an optical fiber, enables us to use highly concentrated daylight at the desired location regardless of the position of a solar concentrator [6]. Some kinds of fiber optic solar concentrators have been developed for solar lighting and have also been improved to increase their solar concentrating performance [7-10].

In this study, we have designed three types of fiber optic solar concentrators for solar lighting, and compared their solar concentrating efficiency. The efficiency was measured by comparing the luminance of the direct solar radiation with the luminance of the concentrated solar radiation. We have constructed a fiber optic solar lighting system with the most efficient solar concentrator, and have measured the luminance at the floor in indoor when the sunlight transferred 25 meters by using silica optical fiber from the fiber optic solar lighting system.

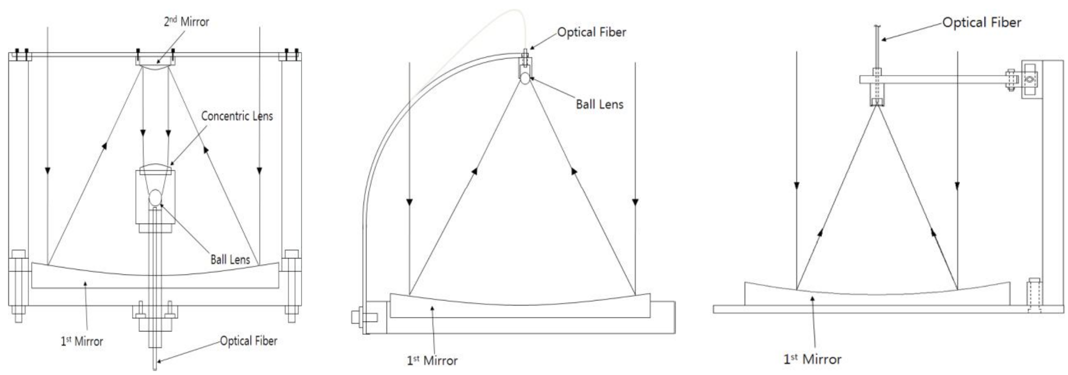
2. Design of solar concentrators for solar lighting

The designs of three types of the solar concentrators are shown in Figure 1. Type A was composed of the first mirror (concave spherical mirror), the second mirror (convex spherical mirror), a concentric lens, a ball lens and an optical fiber [4]. In the design of Type A, the first mirror reflects the sunlight towards to the second mirror, the second mirror reflects again the light toward to concentric lens, a concave mirror concentrates the light, and finally a ball lens focuses the light to a surface of a single optical fiber. Type B was composed of the first mirror, a ball lens and an optical fiber [5]. In the design of Type B, the first mirror has the same role as Type A. However, a ball lens locates in the same position instead of the second mirror. Then, the reflected sunlight by the first mirror towards to the ball lens, and the ball lens focuses the light to a surface of a single optical fiber. Last, Type C has the simplest design and was composed of only the first mirror and an optical fiber [6]. Sunlight is reflected by the first mirror, and focused directly to a surface of a single optical fiber in this design.

3. Experimental set-up

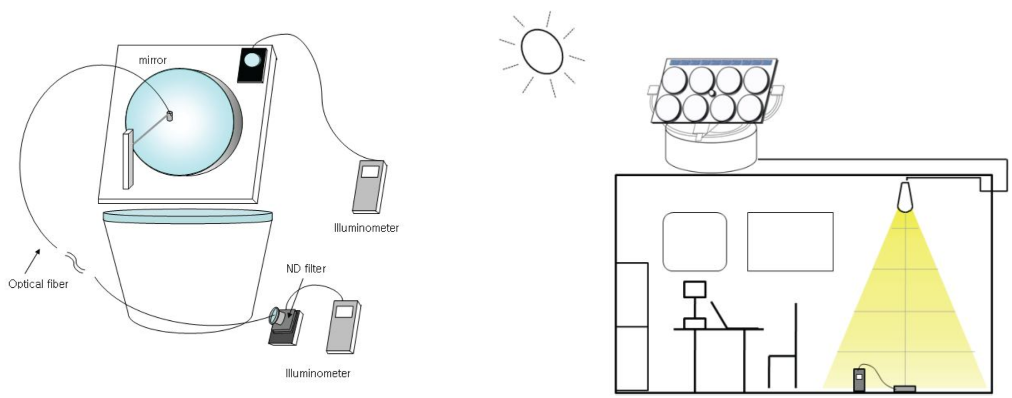
Figure 2(a) shows an experimental set-up to compare the efficiencies of the solar concentrator deigns. All the optical components of the fiber optic solar lighting system were aligned towards the sun. To compare the efficiency of the concentrators, we prepared two illuminometers and an optical fiber (2 meter long). The luminance of the direct solar radiation was measured with one illuminometer, which has positioned at the same flat plate as the first mirror. The luminance of the concentrated solar radiation was measured with the other illuminometer. Because the concentrated solar radiation has high photon flux, it had to reduce the radiation, then some pair of neutral density filters (ND filter) were inserted between the optical fiber end and the illuminometer. The system tracks the sun automatically by using a photo sensor which is placed on the flat plate.

Figure 2(b) is a schema of indoor solar lighting with the fiber optic solar lighting system. This system would well to be installed on the rooftop of the building which is located at place without buildings or obstacles are higher than, so it must have no problem to receiving the sunlight. The concentrated sunlight is focused on to a single silica optical fiber (SOF), and the light is delivered to the indoor by 25 meter long of SOF. Finally, the delivered light was measured by illuminometer with the height. The optical components and sun tracking parts for the system are presented in Table 1.



a) Type A b) Type B c) Type C

Figure 1. Design configurations of solar concentrators for solar lighting.



a) Fiber optics solar lighting system b) Indoor solar lighting

Figure 2. Schematics of experimental set-up for fiber optic solar lighting system and indoor solar lighting.

Table 1. The optical components and instrument parts for fiber optic solar lighting system.

	Company	Name of Model	Specification
1st mirror	CVI	EAV-SMLL-10050-0.5C	Ravg > 92%, 450~650nm, Pyrex
2nd mirror	CVI	SMCX-1037-0.05C	Ravg > 92%, 450~650nm, BK7
Ball lens	Edmund optics, Inc.		Ø10mm, 020487-00, Ø10, LASFN9
Concentric lens	Optron-tec, Inc.		Ø29mm
ND filter	CVI		2"x2", BK7
Silica optical fiber	OFS		Ø2 (Ø1.5 core)
Illuminometer	Lutron	LX-1108	Limit 4,000,000 lux
Tilt controller	Aurora technology Co., Ltd.	VPT-310	
Power controller	Aurora technology Co., Ltd.	VRC-1201	

4. Results and discussion

4.1 Comparison of Efficiencies for Solar Concentrators

This experiment was accomplished to find suitable design of solar concentrator for solar lighting. We designed three types of concentrators. They were compared the relative efficiency as mentioned above. The relative efficiency, defined as luminance of concentrated light of the unit area, was calculated by using the following formula:

$$E_A = \left(\frac{L_{CA}}{L_{SA}}\right) \times 100$$

$$= \left\{ \frac{L_C \times \left(\frac{100}{E_{ND}}\right) \div A_C}{L_S \div A_P} \right\} \times 100$$

where L_{CA} is the luminance of concentrated light per unit area (lux), L_{SA} is the luminance of direct solar radiation per unit area (lux), L_C is the luminance of concentrated light (lux), L_S is the luminance of direct solar radiation (lux), E_{ND} is the transitivity of ND filter (%), A_C is the Area of solar concentrator (cm^2), and A_P is the area of the photodiode (cm^2).

To calculate the efficiency, luminance of direct solar radiation and concentrated light, a transitivity of ND filter, and areas of solar concentrator and photodiode which include in the illuminometer were measured, respectively.

The results of the comparison are shown in Table 2. The efficiency of Type B is higher than that of Type A by about 4.9%. Although the measured direct solar radiation of Type C was lower than those of the other types, it has higher concentrating luminance and the highest efficiency, 64.0%. Type C has the simplest design among the three design types and the number of optics is the lowest. Therefore we consider Type C to be the most appropriate design of solar concentrator for our fiber optic solar lighting system.

Table 2. Comparison of three types of solar concentrators.

Type	Luminance of the sunlight (lux)	Luminance of concentrated light (lux)	Efficiency (%)	Standard deviation	Concentrated Area (mm^2)
Type A	110,700	2,221,200	52.3	0.80	14,557
Type B	101,700	2,428,000	57.2	0.25	15,863
Type C	98,100	2,612,000	64.0	0.80	15,863

4.2 Construction of Fiber Optic Solar Lighting System

We found that Type C is the most suitable design by result of former experiment and we manufactured fiber optic solar lighting system. The system is consisted of three parts. The one is a solar concentrating part which is received the sunlight, and focus on to an optical fiber. Another is a light transportation part which delivers the sunlight from the solar lighting part. The other is light emission part which disperses the delivered sunlight. The solar concentrating part is consisted of 8- Ø17 cm concaved mirror, 2-supporting poles, 8-fiber holders, photo sensor, and tracking system (tracker and its program). A light transportation part is consisted of 8-25 m long silica optical fiber (SOF), which consists of Ø1.5 mm silica core and a few micro meter of clad. The homemade fiber optic solar lighting system is shown in Figure 3.

The light emission part is consisted of ball lens and its holder which holds on SOF and ball lens. The system can be operated by itself without electric consumption because it has generated electricity by using solar cell adopted on the flat plate. This system can track the sun by using a photo sensor and a tracker, automatically, and it was designed to minimize the loss of sunlight by shadow of supporting poles. The optical fibers also were arranged to through the supporting poles to minimize the loss of the sunlight by its shadow.

Figure 3. Photographs of homemade fiber optic solar lighting system.

4.3 Application of the Fiber Optic Solar Lighting System

We applied the fiber optic solar lighting System for indoor solar lighting. Figure 4 shows an example. The fiber optic solar lighting system was installed on the rooftop, and the sunlight delivered our laboratory (the area is 12 m x 7.5 m x 2.4 m) by using 25 meter long of SOF. The luminances of indoor and external direct solar radiation were measured, respectively, and the results are shown in Table 3 and Figure 5. The luminance of the external direct solar radiation was measured ranging from 100,600 ~ 116,600 lux.

The internal luminance was measured with an illuminometer depend on the distance between ground and light emission part (end of SOF) adopted on the ceiling. The distance of the illuminometer increased from 30 cm to 240 cm, and measured with 30 cm interval. The luminance was measured 5 times, repeatedly, and the results were averaged.

The luminance decreased rapidly with increasing distance (see Figure 5), and the average luminance at the ground was measured 180 lux as shown in Table 3. A distance of 180 cm is the same as the position of desk, and the average luminance at the distance was measured as 430 lux. As the recommended levels of illumination, the luminance corresponds to a standard of general working place, such as class room of a school, ward of a hospital, general purpose of office, etc.

Figure 4. Application of the fiber optic solar lighting system to indoor lighting.

Table 3. Average luminance in indoor lighting.

Distance(cm)	30	60	90	120	150	180	210	240
Average luminance(lux)	18,860	4,380	1,951	1,068	622	431	315	180

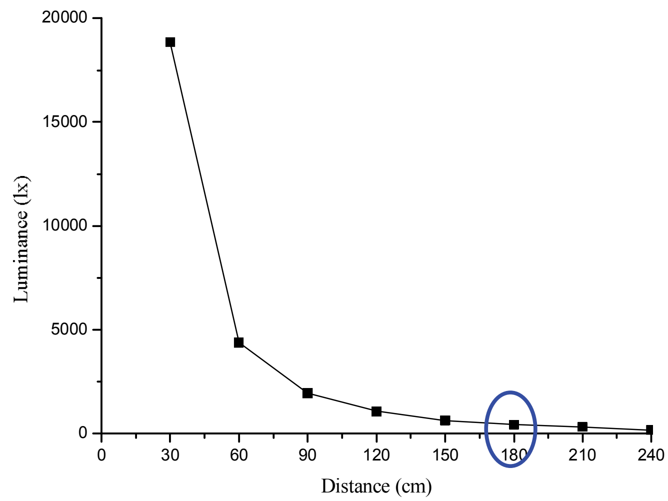


Figure 5. Variation of indoor luminance by fiber optic solar lighting system.

5. Conclusions

In this study we have designed three different types of solar concentrators for fiber optic solar lighting in buildings. The simplest design (type C) was shown to possess the most efficient performance. We have constructed a fiber optic solar lighting system with the design, and found that the system is useful for solar lighting.

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Author Biographies

Dr. Sang Chun Lee is presently Professor, Department of Nanoengineering, Kyungnam University, Masan, Korea (2006-Present), and was previously Professor, Division of Natural Science, Kyungnam University, Masan, Korea (2004-2006), Associate Professor, Division of Natural Science, Kyungnam University, Masan, Korea (1999-2004), Assistant Professor, Department of Chemistry, Kyungnam

University, Masan, Korea (1995-1999), Lecturer, Department of Chemistry, Kyungnam University, Masan, Korea, (1993-1995), Researcher, Ames Laboratory-US-DOE, Ames, USA (1991-1993), and Post-doc, Univ. of Tennessee, USA (1989-1991). His was formerly Director of the Kyungnam Institute of Gifted Education in Science, Kyungnam University Supported by MOST (1998-2004), Vice Chair of Industrial- Academy Cooperation Foundation, Kyungnam University (2005-2006), Chair of The International Symposium on Advanced Technology and Applications, ATA (2005-2006), Executive Officer for Analytical Division Committee, Korean Chemistry Society (2005-2007), Vice President of Korean Society for Mass Spectrometry (2004-2006), and Vice President of International Junior Science Olympiad (2004-2005). He received the Ministry Award (University Education Activity) from the Ministry of Education (2005), the Ministry Award (Science Gifted Education) from the Ministry of Science and Technology (2003), and the Best Research Award (Analytical Chemistry) from Korean Chemistry Society (2000).