

Optical design of a freeform lens based on multi-chip-on- single-board LED light source for 140W street lamp

Shih-Chang Shei^{1,*}, Nan-Ming Lin², Shouu-Jinn Chang³, and Yu-Xian Wu¹

¹ Department of Electrical Engineering, National University of Tainan, Taiwan

² Graduate Institute of Nanotechnology and Microsystems Engineering, National Cheng Kung University, Taiwan

³ Department of Electrical Engineering, National Cheng Kung University, Taiwan

Abstract--In this study, the 140 W LED street lamp with combining a multi-chip-on-single-board (MCOSB) LED light source and a freeform lens was proposed and simulated. In order to prevent two adjacent luminaries from generating strong brightness contrast on the road surface, i.e. the Zebra effect (repeated bright and dark regions). We designed a freeform lens which can provide that the light intensity is good batwing distribution with light intensity about 3000 cd at the middle and 7000 cd at ± 60 deg. This indicates that a uniform and wide illumination area on whole road surface can be achieved. The uniformity values are 0.723, 0.866, and 0.875 for three basic placement of single-sided, zigzag, and opposite, respectively. These results suggest that the lamp installation numbers could be eliminated, and the electrical power consumption could be reduced.

Index Terms—LED, MCOSB, Street lamp

I. INTRODUCTION

LED lighting is regarded as a new energy-saving strategy in 21st century, the LED has many advantages, such as low-power consumption, high reliability, and long life time compared to conventional metal halide (MH) lamps and high pressure sodium lamps. Therefore, LED has begun to play an important role in many applications, for example, backlighting for LCD displays, cell phones, and interior and exterior lighting. It is very important for the LED road lighting to precisely control the light direction through optical lens due to the fact that the most of LED light sources are Lambertian distributed, i.e. the light radiation pattern is round, with a full beam angle around 120° . If the LED road lighting is constructed by bare LEDs without optical lens, two adjacent luminaries can generate strong brightness contrast on the road surface. This will result in 'Zebra effect' (repeated bright and dark regions) on the road surface, which may cause strong psychological and visual disturbance to drivers. Thus, we designed a freeform lens to control the light direction and produce an even luminance on the road surface.*

According to the open literatures, the most of street lamps

are designed with a discrete-LED-lamp-array (DLLA) structure[1-3], which distributes on the slim printed circuit board (PCB) for the power input of LEDs and the mechanical frame for both the heat dissipation [4] and support of the LED lamps. The array of LED lamps has some disadvantages, first, the array of LED lamps is multi-point light source which provides overlapping shadows; second, in order to form a high power street lamp, the array of LED lamps needs much space to occupy and integrate with the mechanical frame [5], [6]; third, the thermal resistance is high due to the fact that the thermal resistance includes three parts, the first part is between the chip and the silver resin, the second part is between the silver resin and substrate, the third part is between the substrate and the PCB; four, each LED lamp in the array needs mounting a designed lens to control the light direction. This discrete-LED-lamp-array (DLLA) structure cause difficulties and high cost. Therefore, in this study, we adopt a multi-chip-on single board (MCOSB) for the LED light source. Compared with the conventional DLLA light source, the MCOSB LED light source is like a single point light source which can clearly produce the clear shadow, and reduce much space to integrate with the mechanical frame. In addition, the thermal resistance is low due to the fact that the thermal resistance only includes two parts; the first part is between the chip and the silver resin, the second part is between the silver resin and Al plate, i.e. the heat need not pass through the PCB. In addition, only one Len is necessary in the MCOSB LED light source. Prof. Lee has reported the second optical design of MCOSB LED street lamp for the first time [7]. But, in this paper, the road illumination and uniformity by using the MCOSB LED as light source are not further investigated.

In this study, we focus on the optical design for the MCOSB LED light source combining with a freeform lens, and investigate the simulation of road lighting. The new second optical design results in high-uniformity road lighting. Detailed performance of the optical design and the road lighting effect will be reported.

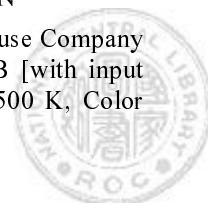
II. RESULTS AND DISCUSSION

In the LED street light lamp, two Lighthouse Company products with model no. LE070WC-D10B0-B [with input electrical power: 70 W, color temperature: 4500 K, Color

* Corresponding author:

Tel: +886 6 2606123x7776

E-mail address: scshei@mail.nutn.edu.tw (S.C.She)



rendering index (CRI): 70, total luminance: 5200 lm, and efficiency: 74.2lm/W) was used as the light sources in our simulation [8]. Fig. 1 (a) and (b) show the MCOSB photography and circuit layout connected with 10 series and 110 parallels, respectively. Fig. 1 (c) shows a cross-sectional view of the multi-chip on single board (MCOSB). The chip size of packaged LED is 10x23 mil².

Figure 2 (a) and (b) show the radiation distribution of the two MCOSB LED light sources for the polar distribution and the rectangular distribution, respectively.

As shown in Fig. 3, the 3-D (three dimension) models of a freeform lens [polymethyl methacrylate (PMMA)] combining with two MCOSB LED light sources are generated by the 3-D modeling software. The 3-D models are then imported into the ray-tracing software such as TracePro [9] for the ray tracing.

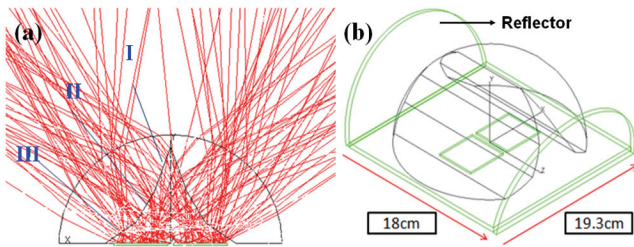
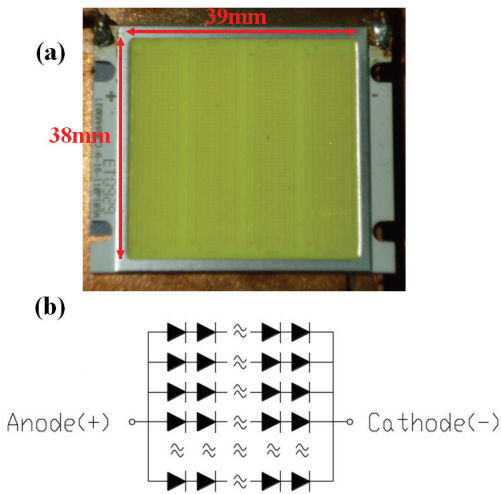


Fig.4 Ray tracing of the MCOSB of LED light source combining with a freeform: (a) without reflector; and (b) with reflector.

In order to evaluate the whole road performance of the uniform illumination, the light intensity far field angle distribution for the freeform lens with reflector is imported into the road lighting simulation such as the Dialux software [10]. Thus, based on the above reason, we can deduce the calculation equation for the uniformity (U_0) of the whole road as the following [1]:

$$U_0 = \frac{E_{min}}{E_{av}} \quad (1)$$

where E_{av} is the averaged illuminance of the whole road, E_{min} is the minimum average illuminance value among all of the divided small areas.

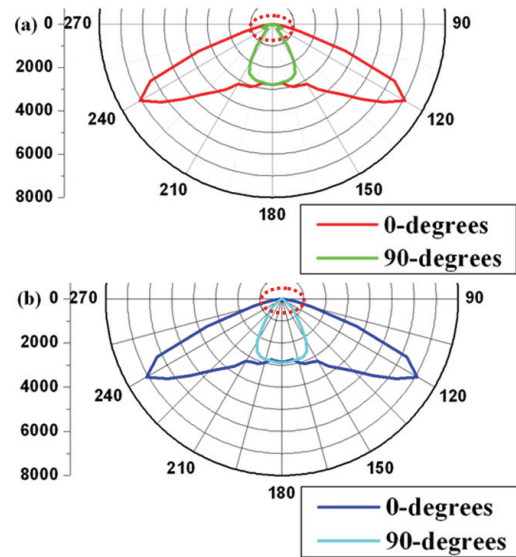


Fig.5 Light intensity angle distribution curves: (a) without reflector; and (b) with reflector.

Figure 6 shows the mostly current three basic placement types [Fig.6 (a-c)] for road lighting. The uniformity of the whole road depends on the mounting height, installation pitch, road width, install angle, and lamp placement type. The simulation results of three basic placement types are summarized in Table I. As shown in Fig.6 (a), the lamps were placed on an 8 m road width (W); the pitch (S) between adjacent lamps on one side is 35 m. The uniformity is 0.723. Fig. 6 (b) shows two lamps were placed on a 12 m road width; the pitch between adjacent lamps on one side is 35 m. The uniformity is 0.866. Fig.6 (c) shows two lamps were placed on a 16 m road width; the pitch between adjacent lamps on one side is 24 m. The uniformity is 0.875. Based on the above simulation results, the proposed freeform lens can provide a high uniformity and wide illumination area, which can eliminate the lamp installation numbers, and can reduce electrical power consumption. Table I summarized the uniformity at three different arrangements, the uniformity values can satisfy the requirements of Taiwan (>0.33), China (>0.35) [11], and Illuminating Engineering Society (IES) uniformity: E_{av}/E_{min} (<3) standard for three basic placement of single-sided, zigzag, and opposite.

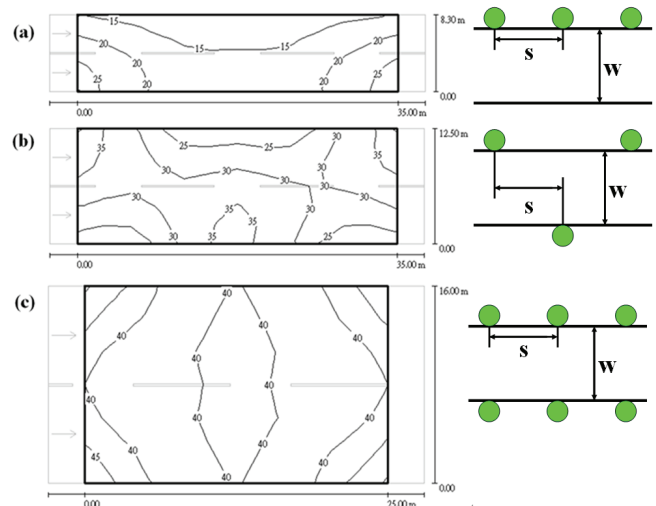


Fig.6 illuminance distribution of three basic placement: (a) single-sided; (b) zigzag; and (c) opposite.

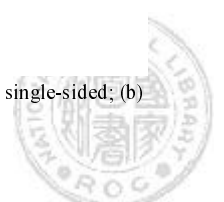


Table I Road illumination simulation results of three basic placement

Lamp arangement		Hight (m)	Road width(m)	Lamp pitch (m)
Single-side		10	8	35
	E_{min} [lx]	13		
	E_{ave} [lx]	18		
	Uniformity	0.723		
Zigzag		10	12	35
	E_{min} [lx]	26		
	E_{ave} [lx]	30		
	Uniformity	0.866		
Opposite		8	16	24
	E_{min} [lx]	35		
	E_{ave} [lx]	40		
	Uniformity	0.875		

III. CONCLUSION

In this study, the freeform lens combining with the MCOB of LED light sources was proposed and simulated. The proposed freeform lens can produce a high efficiency, high uniformity and wide illumination area. The light intensity is a good batwing distribution with light intensity about 3000 cd at the middle and 7000 cd at 60 deg due to the designed freeform lens. The uniformity values are 0.723, 0.866, and 0.875 for three basic placement of single-sided, zigzag, and opposite. This means that the lamp installation numbers can eliminate, and can reduce electrical power consumption.

IV. ACKNOWLEDGMENT

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BIOGRAPHIES



S. C. Shei received his B.S. degree, M.S. degree and Ph.D. degree all from the Department of Electrical Engineering, National Cheng Kung University, Tainan, Taiwan, in 1988, 1990 and 1995, respectively. Currently, he is an assistant professor with the Department of Electrical Engineering, National University of Tainan, Tainan, Taiwan. His major field is focused on III-V optoelectronic semiconductors.

N. M. Lin was born in Taiwan, in 1985. He received the M.S. degree from the Institute of Electro-Optical Engineering, National University of Tainan, Tainan, Taiwan, in 2009. He is currently working toward the Ph.D. degree at the Institute of Nanotechnology and Microsystems Engineering, National Cheng Kung University, Tainan, Taiwan..



S. J. Chang (M'06, SM'10) was born in Taipei, Taiwan on January 17, 1961. He received the B.S. degree from the National Cheng Kung University (NCKU), Tainan, Taiwan in 1983, the M.S. degree from the State University of New York, Stony Brook in 1985 and the Ph.D. degree from the University of California, Los Angeles in 1989, all in electrical engineering.

From 1989 to 1992, he was a Research Scientist with Nippon Telegraph and Telephone (NTT) Basic Research Laboratories, Musashino, Japan. He joined the Department of Electrical Engineering, NCKU in 1992 as an Associate Professor, where he was promoted to Full Professor in 1998.

He is currently the Deputy Director of the Center for Micro/Nano Science and Technology, and the Director of the Institute of Microelectronics, NCKU. He was a Royal Society Visiting Scholar with the University of Wales, Swansea, UK from January 1999 to March 1999, a Visiting Scholar with the Research Center for Advanced Science and Technology, University of Tokyo, Japan from July 1999 to February 2000, a Visiting Scholar with the Institute of Microstructural Science, National Research Council, Canada from August 2001 to September 2001, a Visiting Scholar with the Institute of Physics, Stuttgart University, Germany from August 2002 to September 2002, and a Visiting Scholar with the Faculty of Engineering, Waseda University, Japan from July 2005 to September 2005. He is also a honorary professor with Changchun University of Science and Technology, China. His current research interests include semiconductor physics, optoelectronic devices, and nanotechnology.

Professor Chang is the recipient of the outstanding research award from the National Science Council, Taiwan in 2004.

Y. X. Wu was born in Taiwan, in 1985. He is currently working toward the M.S. degree at the the Department of Electrical Engineering, National University of Tainan, Tainan, Taiwan..

