Semiconductor Physics, Quantum Electronics & Optoelectronics, 2013. V. 16, N 2. P. 206-209.

PACS 42.15.Eq

Features of the development of LED spotlight for local illumination of extended objects

K.A. Kudrautsau, Y.V. Kernazhytski, V.I. Tsvirka, Yu.V. Trofimov, V.S. Posedko, A.S. Posedko
SE Center of LED and Optoelectronic Technologies of National Academy of Sciences of Belarus,
Lagoiski trakt 22, office 2207, Minsk, 220090, Belarus
Phone: +375-17-281-13-35, fax: +375-17-283-91-51; WEB: www.ledcenter.by
Corresponding author phone: (+37533)-697-19-02; e-mail: kudrautsau@gmail.com

Abstract. The peculiarities of extra narrow-angle LED spotlight development for accent lighting have been described. The optical layout of lighting fixture was developed. The mathematical model that can be used to calculate the optical and geometrical parameters of extra narrow-angle spotlight have been developed. The two actual samples with output lens with the diameters 50 and 100 mm were developed and tested. The results of computer simulation and actual testing the spotlight samples were compared.

Keywords: LED, pencil beam, extra narrow-angle spotlight, LED spotlight.

Manuscript received 18.12.12; revised version received 06.02.13; accepted for publication 19.03.13; published online 25.06.13.

1. Introduction

LED narrow-angle spotlight can be used for accent, architectural, secure and technology lighting as well as for other applications where low divergence light beam is needed.

The task to form low divergence light beam has many solutions. When it comes to the LED light source, one of the solutions is to use total internal reflection (TIR) optics that are mass produced by companies such as Ledil, Carclo, Fraen, etc. However, in this case we are talking about the value of full width at half maximum (FWHM) angle no less than 4°. The lower divergence can be obtained by using additional converging lenses. An optical scheme for this solution is shown in Fig. 1.

The additional lens, further called as the output lens, can form extra narrow beam under certain conditions. The distance (L) from the TIR lens to the output lens should be at least 10 times longer than the TIR lens output surface diameter (S). In that case, it can be considered as a point source [1]. Obviously, greater light output will come from the system using TIR lens with a lower FWHM angle and output lens with a larger diameter (D). However, the secondary lens output diameter also plays a very important role. The beam divergence angle is determined by the diameter of the TIR lens outflow face on a relatively far finite distance, which, in its turn, depends on the output lens linear increase and the secondary lens aperture size. The output lens optical power also affects the beam divergence of the system, and, as a consequence, the distance to the secondary lens outflow face. Output lens diameter affects the overall system performance (output luminous flux).

2. System modeling

Two types of TIR lenses were selected for the simulation. The lenses parameters are shown in Table.

The table shows that the lower divergence lens is larger.

All the parameters of the system can be described by equations that allow to calculate the divergence angle, spot size, and the average illuminance at a given distance, the system overall efficiency [2,3].

The output lens diameter was taken from the range 50 to 110 mm in 10 mm increments. The lens output optical power was taken from 1 to 4 diopters in 0.25 diopters increments. The LED luminous flux was assumed to be of a typical value 100 lm.

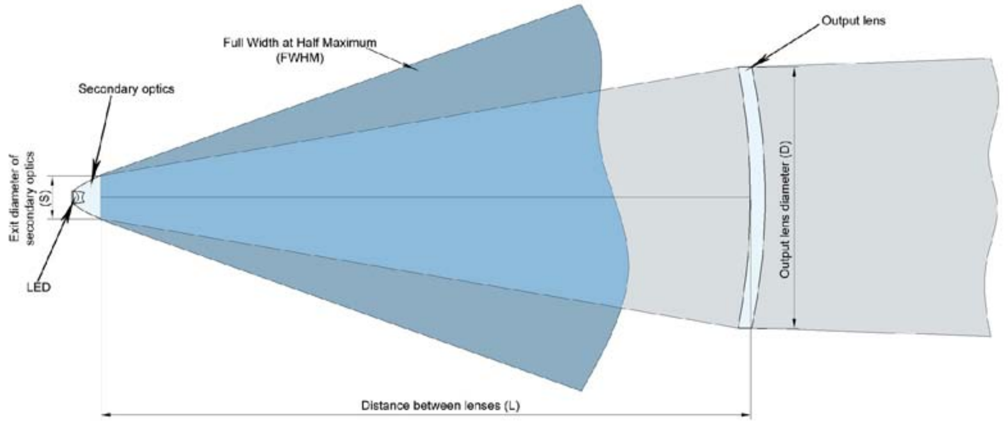


Fig. 1. Optical layout of system.

In Figs 2a and 2b, the average illuminance dependences on the lens optical power for the different output lens diameters with TIR lenses “Lens 1” and “Lens 2” are shown, respectively. In Figs 3a and 3b, the system efficiency dependence on different output lens diameters with TIR lenses “Lens 1” and “Lens 2” are shown, respectively.

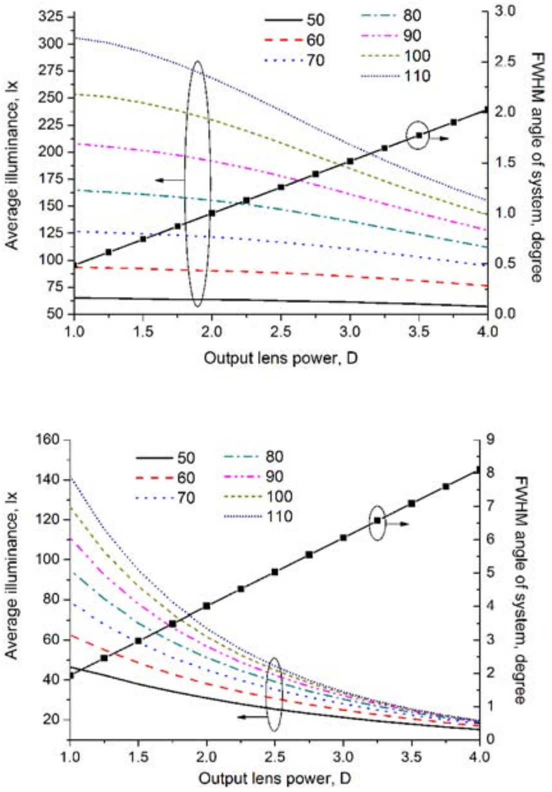


Fig. 2. System provided the average illuminance at 17-m distance vs the output lens power for secondary optics “Lens 1” (a), “Lens 2” (b) and different output lens diameters.

The graphs show that using the TIR lens with a smaller exit surface diameter is much more efficient. It allows to get the divergence angles between 0.5° and 2°.

3. Experiment and discussion

On the basis of the calculations, two types of light fixtures were designed and produced. Each fixture consist of one LED (Cree), TIR lens (Ledil) with 9-mm output surface diameter and different output lenses. The first fixture has the lens with the output diameter 50 mm and optical power 2.25 diopters, the second one has the 100-mm lens and optical power 2.5 diopters. Power consumption in each fixture was no higher than 2.5 W.

The spot diameter of the system with 50-mm lens is near 350 mm at a distance of 17 m. In Fig. 4, the image of this light spot is shown.

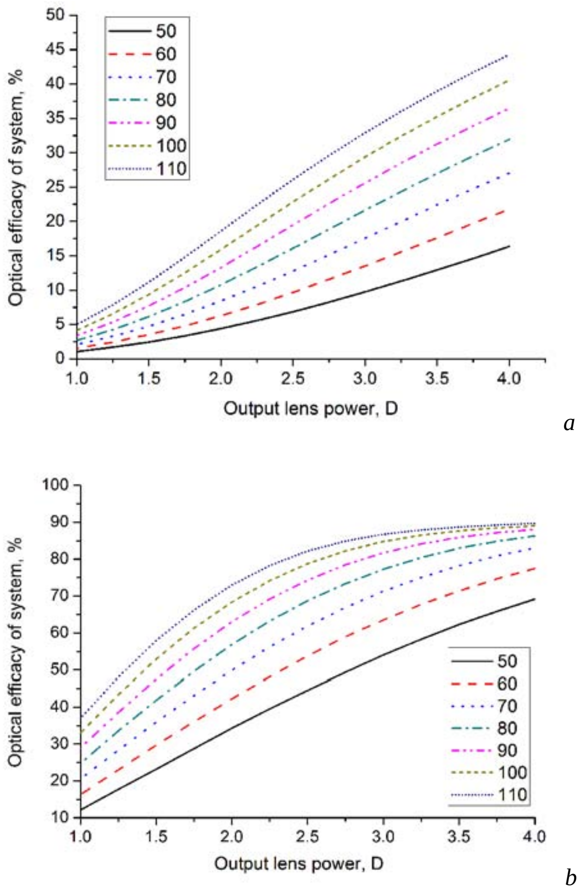
Goniophotometer SMS 10C (Optronik Berlin GmbH) was used for measurements of luminous intensity angle dependences. In Fig. 5, the results of these measurements are shown.

We can see that the system with 50-mm output lens has beam divergence values about 1.05° at the level 0.5 (FWHM angle) and 1.2° at the level 0.1. The maximum value of light intensity was 44 kcd. For a system with 100-mm output lens the beam divergence values were 1.1° at the level 0.5 and 1.35° at the level 0.1. The maximum value of light intensity was 131 kcd.

Table. Characteristics of the TIR lenses used in the calculation.

Lens label	FWHM, degree	Output surface diameter, mm
“Lens 1”	16	9
“Lens 2”	4	36

The calculated values of the system divergence angle with 50- and 100-mm lens are 1.13° and 1.26°, respectively. Comparing these values with the measured ones, we can see that the margin of error is 7% for the system with the 50-mm output lens diameter and 12% for the system with 100-mm output lens diameter.



a

b

Fig. 3. Optical efficiency of the system vs the output lens power for secondary optics "Lens 1" (a), "Lens 2" (b) and different output lens diameters.

Fig. 4. Photo of the light spot at 17-m distance.

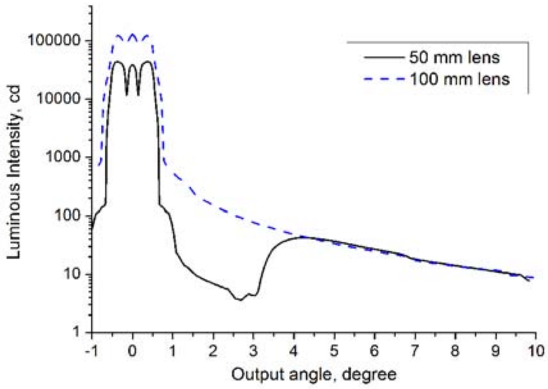
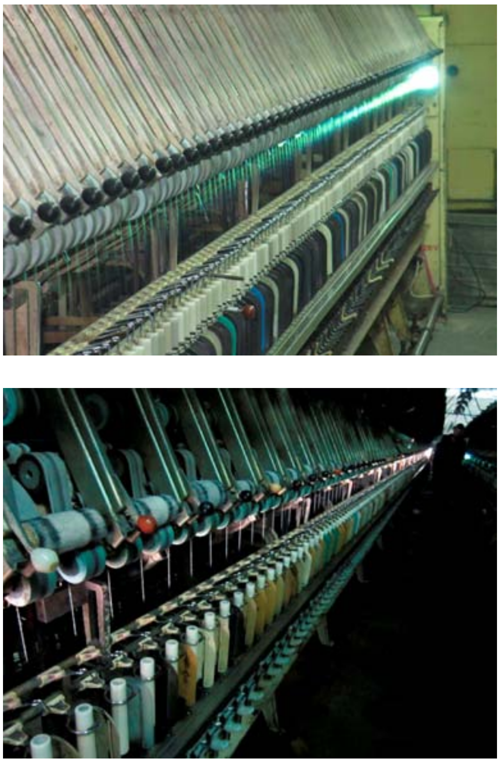


Fig. 5. Angle dependences of luminous intensity for systems with the 50- and 100-mm output lenses.



a

b

Fig. 6. Spinning machines (fibers lighting). (a) – lighting system based on the 250 W mercury gas-discharge lamp, (b) – lighting system based on the 5W LED fixture.

We can note the real-world example of similar system. The twin lighting fixture based on the two LEDs with total consuming power about 5 W was designed for local edge lighting of fibers in spinning machines at JSC "Polesie" (Pinsk). It fully replaces the old lighting system based on 250-W mercury gas-discharge lamp (Fig. 6). In additional, realized in the new lighting fixture was the antiglare effect. As we can see in Fig. 5, a very sharp decline of luminous intensity for angle values larger than 1 degree, which greatly reduces the effect of glare.

4. Conclusion

The optical layout for extra narrow-angle LED spotlight has been presented. The developed mathematical model is valid for LED light source design with beam divergence from 0.5 to 8 degrees and various optical and geometrical parameters. The tight correlation between calculated and measured data confirms the adequacy of our model.

References

1. M.M. Gurevich, *Photometry*. Publ. House Energoatomizdat, Leningrad, 1983 (in Russian).
2. G.G. Slusarev, *Optical Systems Calculation*. Publ. House Mashinostroenie, Leningrad, 1975 (in Russian).
3. S.A. Rodionov, *Principles of Optics*. Publ. House SIPMO, St-Petersburg, 2000 (in Russian).