Omni-distance uniform LED illuminating system using D-shape photonic crystal fiber

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In order to realize a micro omni-distance uniform illumination, a LED D-shape photonic crystals fibre (PCF) illumination system was designed. White light emitting from white LED was coupled into the D-shape PCF by using the coupling system. As propagating in the D-shape PCF, light exits out from the flat surface of the D-shape PCF for uniform illuminating. The intensity of the illuminating light exiting from the flat surface depends on the number of cladding rings of the D-shape PCF. In our system, the diameter d, and period Λ of the air-hole cladding are 1.78 μm and 7.78 μm, respectively. As keeping 2 rings of the air hole cladding from the center to the flat surface of the D-shape PCF, the omni-distance uniform illuminating in visible light wavelength range was obtained.

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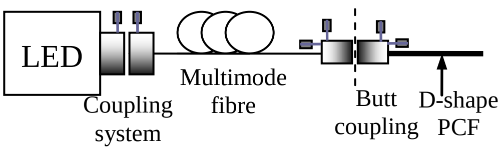
1. Introduction

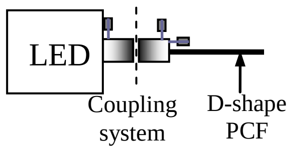
LED has the potential to replace traditional incandescent lamp and fluorescent lamps for their characteristics of long lifetimes, energy saving and environmental protection [1-3]. However, the light distribution of LED is always the Lambert distribution, which is not fit to general uniform illumination. And sometimes, we need some micro illuminating system for specific application, such as human body texture checking, omni-distance throat and stomach checking, and so on. Usually, we used the general fibre (single- or multi-mode) as the propagating and illuminating tool. However, light can only exit from the end face from the general fibre. That is to say, this kind of illuminating system has smaller illuminating area, especially not fit for omni-distance illuminating. Photonic crystals are a class of optical structure, where the propagation of light is controlled by a strong periodic modulation of the refractive index. Large index contrast in a photonic crystal gives rise to a photonic band-gap, within which light cannot propagate, providing a possible mechanism to trap and manipulate light for photonic circuitry. Using the photonic crystal mechanism, different types of optical circuitry components in these structures have been realized, including waveguide and photonic crystal fibre (PCF) [4-8]. In this letter, an omni-distance illuminating system with LED light source using D-shape photonic crystals fibre was designed.

2. Basic system structure

The LED D-shape PCF illumination system was shown schematically in Fig. 1. Two kinds of illumination structure for long- and short-distance illumination applications were designed, respectively. For long-distance illumination, as shown in Fig. 1(a), the light emitting from LED was coupling into multimode fibre firstly, and then the light from multimode fibre was coupled into the D-shape PCF through the butt coupling device. The coupling device is mainly composed of coupling lens. The light will exit from the flat surface of the D-shape PCF uniformly as propagating in the D-shape PCF. The length of the multimode fibre and the D-shape PCF are adjustable for different distance and different illumination application demands. For short-distance illumination, the light emitting from LED was coupled into the D-shape PCF directly for uniform illumination, as shown in Fig. 1 (b). In our system, the D-shape PCF includes the air-hole cladding and the silicon oxide material with the refractive index of 1.446. As shown in Fig. 2, the diameter d, and period Λ of the air-hole cladding are 1.78 μm and 7.78 μm, respectively. The radius R of the PCF is 40.7 μm. The length of perpendiculars D is 26.9 μm with 2 rings of the air-hole cladding from the center to the flat surface.

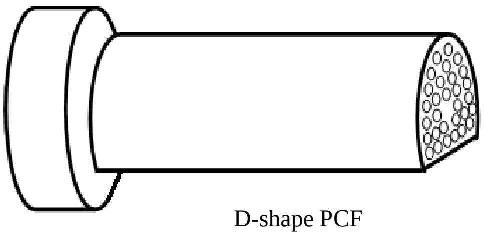


(a) Long-distance LED D-shape PCF illumination system

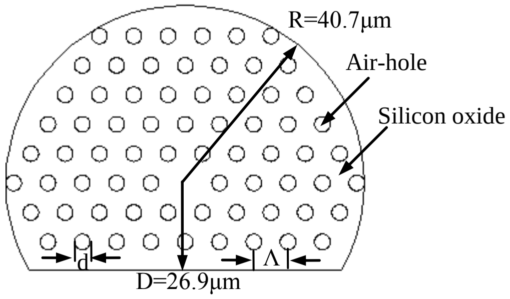


(b)Short-distance LED D-shape PCF illumination system

Fig. 1. Diagram of LED D-shape PCF illumination system.



(a) D-shape PCF diagram



(b) Cross section of D-shape PCF diagram

Fig. 2. D-shape PCF diagram and its cross section.

3. Results and discussion

Photonic crystal has the periodical structure with function of the band gap effect in a certain band. As the light propagates in the fibre with this periodical variety of the refractive index, the propagation of the light was blocked by the band gap effect. As the wavelength of the light belongs to the scope of the band gap, the light was controlled in the fibre and propagated in the axial direction and with little loss in other directions. The light-out was decided by the structure loss and the absorb of the material, given by

$$L_{out} = L_{loss} + L_{absorb}\alpha \qquad (1)$$

Where L_{loss} is the light loss from the clad, L_{absorb} is the absorption of the material, and α is the ratio of the reality absorption in the total absorption.

Assuming $\alpha = 0$, the light out of the PCF has a function with the number of the air hole cladding in the photonic crystal fibre, given by

$$L_{out} = ca^N \qquad (2)$$

Where constant a, c have the value of 0.141 and 4.6093×10^7, and N is the number of the air hole cladding. As shown in Fig. 3, as the number of the air hole cladding is 3, very large amount of the light with the leakage coefficient of 10^5 dB/Km emitted out from the PCF. The light was controlled to propagate in the axial direction of the fibre as the number of the air hole cladding larger enough. On the other hand, if the number of the air hole cladding less than three, most of the light will be lost as it propagates in this kind of PCF. Using this characteristic of the PCF, a LED D-shape PCF uniform illuminating system was designed, as shown in Fig. 1 and Fig. 2.

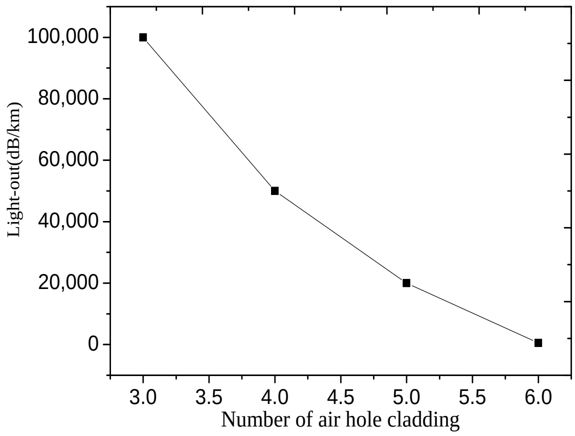


Fig. 3. Light-out of the PCF as the function of the number of the air hole cladding.

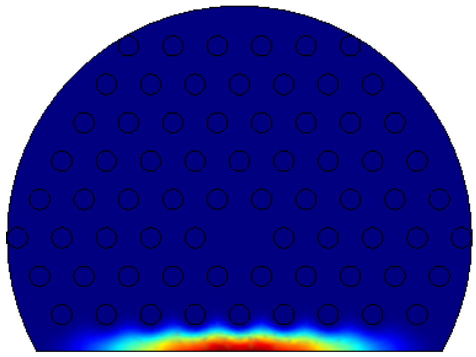
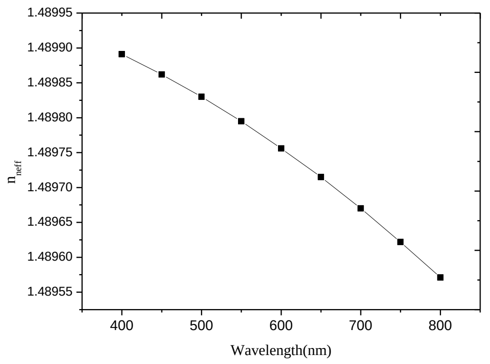
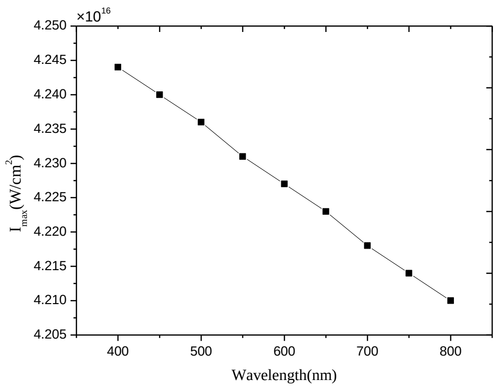


Fig. 4. Light intensity distribution of the D-shape PCF on the cross section.

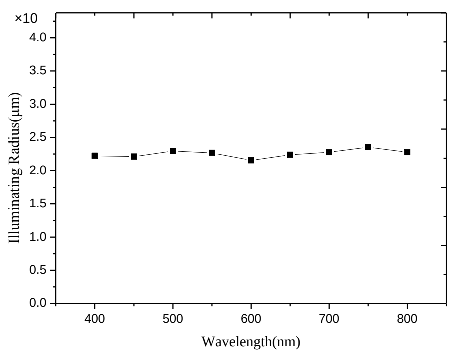
Fig. 4 showed the light intensity distribution of the D-shape PCF on the cross section. The D-shape PCF has the characteristics of two rings of air-cladding on the flat surface, and 5 rings on the other surface. It showed that the light exited from the flat surface of the D-shape PCF with the degree of homogeneity of 90%. The wavelength and the effective refractive index are 550 nm and 1.489795. In actual illumination application, the LED light source is usually the white light, such as omni-distance throat and stomach checking. So the LED D-shape PCF illumination must be suitable for all range of visible light with different modes and wavelength. Fig. 5 showed the effective refractive index, power intensity and illuminating radius varied with different wavelength in visible range. As shown in Fig. 5 (a), for illumination wavelength ranging from 400 nm to 800 nm, the effective refractive index ranged from 1.489571 to 1.489891, which means that this kind of design is suitable for white light illumination application. For relative power intensity and illuminating radius, as shown in Fig. 5 (b) and (c), they varied little (about 0.83% and 0.85%, respectively) for different illumination wavelength in the range of visible light.



(a) Effective refractive index varied with different wavelength of the illumination system



(b) Power intensity varied with different wavelength



(c) Illuminating radius of the flat surface varied with different wavelength

Fig. 5. Effective refractive index, light intensity and illuminating radius varied with different wavelength in visible range.

For different air-hole cladding from the center to the flat surface of the D-shape PCF, there will be different relative illuminating light intensity, as shown in Table 1, where the example illuminating wavelength is 550 nm and assuming the absorb loss is 0, P_0 and P are the input light power from the LED and the illuminating light power from the D-shape PCF, respectively.

Table 1. Relative illuminating light power (P/P_0) for different ring number of D-shape PCF.

Number of air-hole cladding	illuminating light power (P/P_0)
2	99.8%
3	92.5%
4	83.7%

4. Conclusion

In summary, an omni-distance uniform illumination system using LED as light source was designed. Keeping only 2 rings of air-hole cladding from the center to the flat surface of the D-shape PCF, about 99.8% of the light exited out from the D-shape PCF for omni-distance uniform illumination.

Acknowledgments

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