Experimental study of the optical fiber characteristics by digital hologram*

HUANG Su-juan(黄素娟)**, FU Xing-hu**(付兴虎)**, and WANG Ting-yun**(王廷云)
Key Laboratory of Specialty Fiber Optics and Optical Access Networks, School of Communication and Information Engineering, Shanghai University, Shanghai 200072, China

(Received 28 December 2010)

The characteristics of optical fiber are quite important for improving the performance of optical fiber communication and sensor systems. Based on the Mach-Zehnder interferometer, a new measuring method is proposed and the digital holograms between the single mode fibers (SMFs) and specialty double-cladding (DC) fibers are analyzed. The experimental results show that the fringe density can be changed under the conditions of coaxial and off-axial interferences. Therefore it can be used to analyze the optical fiber characteristics including refractive index distribution, fiber modes, phase difference, etc.
Document code: A **Article ID:** 1673-1905(2011)03-0222-3
DOI 10.1007/s11801-011-0179-8

Optical fiber has many applications in optical communication and sensor systems, including fiber to the home (FTTH)[1], temperature sensor[2], pressure sensor[3], fiber laser[4], etc. The fiber characteristics, light source, and photodetector can affect the performance of optical communication and sensor systems. Especially, the fiber characteristics are quite important and become one of the desired conditions for expanding application of optical fiber. Digital hologram[5-10] is a method for recording and reconstructing three-dimensional complex wave fields, which has been found a lot of applications in optical testing and metrology. Some researchers have studied the refractive index distribution characteristics in different optical fibers. For example, Hamdy H. Wahba et al[11] investigated the distribution of parabolic or nonparabolic refractive index field in graded index (GRIN) optical fibers. K.M. Yassien et al[12] used digital holographic interferometry for researching the optical properties of polyvinylidene fluoride (PVDF) polymer fiber and graded-index (GRIN) optical fiber. However, these analyses are only suitable to describe the conventional optical fiber, but difficult to analyze the specialty fibers. In this paper, we experimentally demonstrate the digital hologram with a Mach-Zehnder interferometer to measure double-cladding (DC) fiber characteristics. The digital holograms between the single mode fibers (SMFs) and two DC fibers are analyzed under the coaxial and off-axial interference conditions, respectively. The experimental results show that the optical fiber characteristics can be obtained by the digital hologram.

The experimental setup for getting the digital hologram is shown in Fig.1. A fiber-based Mach-Zehnder interferometer is demonstrated by a tunable laser (TL) (81600B, Agilent) with the centered wavelength at 1550 nm and output power of 5 mW. The full width at half-maximum (FWHM) of the source is ~0.36 nm, and its coherence length is ~6.67 mm. The light source from tunable laser is split into signal and reference arms respectively by a three-port 3-dB fiber directional coupler. The reference arm is affixed to a piezoelectric translator (PZT). Two polarization controllers (PCs) are included to control the polarization state of light. In the signal arm, the specialty DC fiber is ~4 mm long, which is spliced with SMF. The distance between DC fiber end and CCD is ~70 mm. The holograms are recorded by a CCD camera (SP-

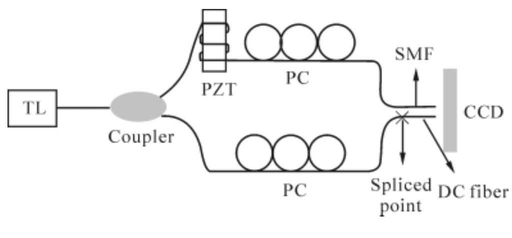
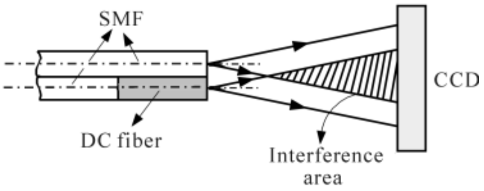


Fig.1 Experimental setup for getting digital holograms

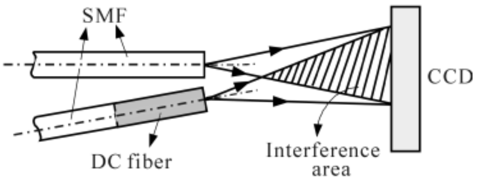
* This work has been supported by the Key Program of the National Natural Science Foundation of China (No.60937003) and the Science and Technology Commission of Shanghai Municipality (STCSM) (No.0952nm06800).
** E-mail: sjhuang@shu.edu.cn

1550M, Spiricon Incorporated) with a pixel pitch of 8.4 μm× 9.8 μm and pixel numbers of 768 × 494 in the horizontal and vertical directions. The interference pattern is displayed on the computer.

In experiment, the superposition between the outputs of two arms causes interference. By adjusting the relative position between SMF and specialty DC fiber, there are coaxial and off-axial interference conditions as shown in Fig.2.



(a) Coaxial interference



(b) Off-axial interference

Fig.2 Different interference conditions

In Fig.2, for the SMF, the core and cladding diameters are approximately 9 μm and 125 μm, respectively. The DC fiber refers to fluorine-doped fiber or boron-doped fiber. For the fluorine-doped DC fiber, the core and the inner cladding diameters are approximately 9.3 μm and 26 μm, respectively. Likewise, for the boron-doped DC fiber, the core and the inner cladding diameters are approximately 6.3 μm and 17.7 μm, respectively. The outer cladding diameter of both DC fibers is pulled to be 125 μm to match and connect with the SMF easily.

For the interference between two SMFs, we can obtain the digital hologram under coaxial interference condition as shown in Fig.3.

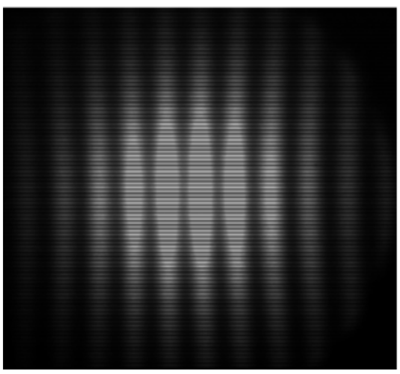
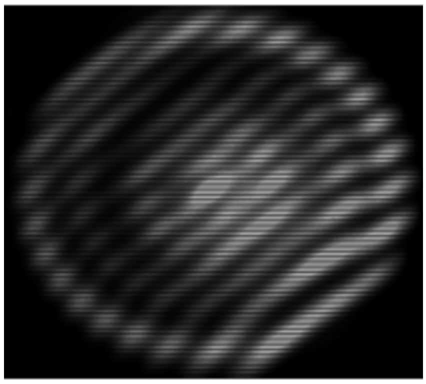
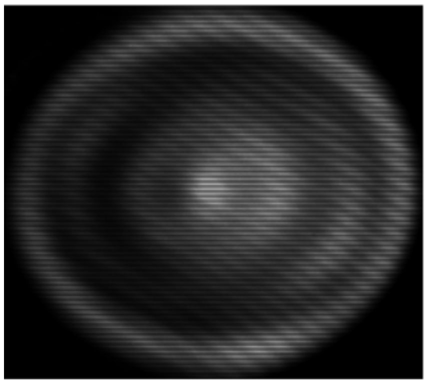


Fig.3 Digital hologram between two SMFs under coaxial interference condition

In Fig.3, the superposition between the outputs of two SMF ends produces an interference pattern with bright and dark lines. The interference pattern is uniform and can be influenced by the phase difference between two arms. By adjusting the PZT voltage, the phase difference can be changed. Likewise, a similar interference pattern under off-axial interference condition is denser than that under coaxial interference condition. Thus, different interference areas can be obtained by adjusting the angle between SMF and DC fiber. The digital holograms between SMF and DC fiber under coaxial and off-axial interference conditions are shown in Figs.4 and 5.



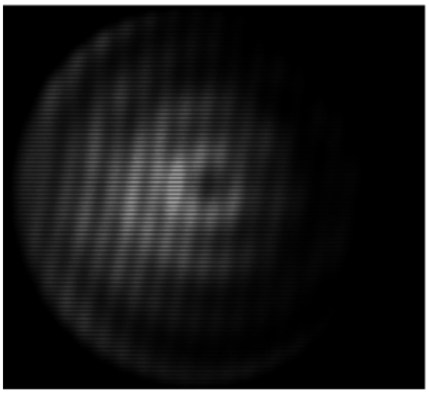
(a) Coaxial interference



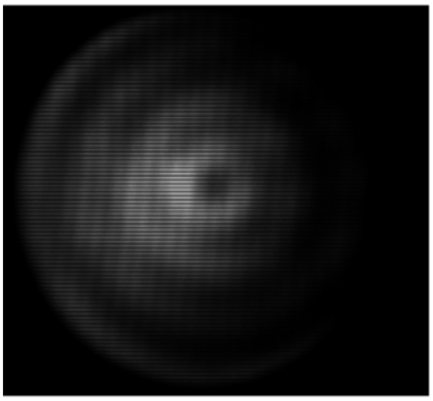
(b) Off-axial interference

Fig.4 Digital holograms between SMF and fluorine-doped fiber

Compared with Fig.3, the obvious differences are that the interference pattern is corrugated distribution and some rings are embedded in Fig.4 and Fig.5. This is due to the added DC fibers. When the coaxial condition happens, the fringe distribution is sparse and uniform. Similarly, when the off-axial condition happens, the fringe distribution is dense and uniform. The fringe density increases with the angle between SMF and DC fiber increasing. By adjusting the PZT voltage, the phase difference between the two arms can be changed and the fringe will shift. By adjusting the PC, the intensity of interference pattern will be changed with the variation of polarization state of light in two arms.



(a) Coaxial interference



(b) Off-axial interference

Fig.5 Digital holograms between SMF and boron-doped fiber

The bright and dark rings in interference pattern are different for two DC fibers. It is mainly because of the different structures of DC fibers, which consist of a core, inner cladding and outer cladding. The core diameter of fluorine-doped DC fiber is larger than that of boron-doped DC fiber. So the coupling loss between SMF and fluorine-doped DC fiber in signal arm is low and the central intensity of the interference pattern is high. Specially, the interference pattern can be influenced by the refractive index distribution. The refractive index differences for the fluorine-doped DC fiber and boron-doped DC fiber are 0.2% and 0.7%, respectively. The refractive index of the core is equal to that of the outer cladding, but higher than that of the inner cladding. The DC fiber is a typical leaky waveguide, so the light wave in the leaky fiber core can tunnel out through the low refractive index inner cladding layer although it satisfies the total reflective condition. So different fiber modes can be induced and the modular interference may happen in DC fibers. In a word, the experimental results show clearly the different characteristics about SMF, fluorine-doped DC fiber and boron-doped DC fiber. Moreover, we can analyze the fiber modes, phase difference and polarization state of light by the digital holograms.

We have demonstrated the digital holograms between SMF and DC fiber based on Mach-Zehnder interferometer. The interference patterns for fluorine-doped DC fiber and boron-doped DC fiber are analyzed, respectively. The experimental results can be used to analyze the optical fiber characteristics effectively.

References

[1] Li M. J., Tandon P., Bookbinder D. C., Bickham S. R., McDermott M. A., Desorcie R. B., Nolan D. A., Johnson J. J., Lewis K. A. and Englebert J. J., Journal of Lightwave Technology **27,** 376 (2009).

[2] Jiang Qi and Kang Yanshen, Optoelectronics Letters **6**, 306 (2010).

[3] Hou Shanglin, Han Jiawei, Zhang Ruirui, Huang Yongqing, Zhang Xia and Ren Xiaomin, Journal of Optoelectronics • Laser **21**, 5 (2010). (in Chinese)

[4] Hu Xudong, Ning Tigang, Chen Qingyan, Pei Li and Li Jing, Optoelectronics Letters **6**, 261(2010).

[5] Yu Lingfeng and Chen Zhongping, Optics Letters **32**, 3005 (2007).

[6] Ping Zhou and James H. Burge, Applied Optics **46**, 657 (2007).

[7] Paurisse M., Hanna M., Druon F., Georges P., Bellanger C., Brignon A. and Huignard J. P., Optics Express **17**, 13000 (2009).

[8] Mathieu Paurisse, Marc Hanna, Frederic Druon and Patrick Georges, Optics Letters **35**,1428 (2010).

[9] Wang Bo and Li Chongguang, Acta Optica Sinica **29**, 2104 (2009). (in Chinese)

[10] Su Ping, Kang Guoguo, Tian Qiaofeng and Jin Guofan, Chinese Optics Letters **7**, 1097 (2009).

[11] Hamdy H. Wahba and Thomas Kreis, Applied Optics **48**, 1573 (2009).

[12] Yassien K. M., Agour M., Kopylow C.von and El-Dessouky H. M., Optics and Lasers in Engineering **48**, 555 (2010).