



Square-core single-mode-fiber (SC-SMF) with high bending tolerance for data center networks



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ABSTRACT

Square-core optical fiber has been proposed recently for high optical power delivery in industrial processing tools with core size larger than $400 \times 400 \mu\text{m}^2$. In this work, we first study the possibility of significantly reducing the core side to single-mode condition (i.e. $9 \times 9 \mu\text{m}^2$) at optical communication wavelength. In the proposed square-core single-mode-fiber (SC-SMF), high bandwidth–distance product and low bending loss are achieved. We also discuss the fabrication of the SC-SMF. After this, the bending losses of the SC-SMF and standard single mode fiber (SSMF) are analyzed and compared. Finally, 10 Gb/s signal transmission using conventional on–off keying (OOK) and orthogonal frequency division multiplexing (OFDM) passing through 200 m, 500 m and 1 km SC-SMFs are performed. Negligible power penalty is observed. We believe that this can be another choice of high bending tolerance fiber which is simple to manufacture.

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1. Introduction

Recently, the bandwidth demand of Internet is increasing exponentially owing to the increase in popularity of applications, such as video streaming, online gaming, cloud computing, etc. All these increase the burden of data centers for supporting these video-rich content applications [1]. Hence, the data centers are required to upgrade. Operators are looking for solutions to reduce the port-counts per server rack, power consumption and the space occupied of the data centers to maintain the profit margin. Owing to low cost, low transmission loss and high bandwidth, multimode fibers (MMF) and plastic optical fiber (POF) are traditionally used for these short-reach networks [2,3]. As the data center networks are becoming bigger and bigger, in order to reduce the number of port-counts per rack as well as increase the transmission distance, single-mode-fiber (SMF) is used. Wavelength division multiplexing (WDM) is also considered for the next generation data centers to increase the transmission capacity [4]. Recently, we have proposed, manufactured and demonstrated using an $80 \mu\text{m}$ large core fiber (LCF) to reduce the bending loss and increasing the

coupling efficiency [5]. However, the $80 \mu\text{m}$ LCF could suffers from high modal dispersion and can be disadvantageous for long transmission distances used in the next generation data center networks. Hence, SMF with high bend tolerance and supporting relatively long transmission distance is highly desirable.

Square-core optical fiber has been proposed recently [6] for the high optical power delivery in industrial processing tools with core size larger than $400 \times 400 \mu\text{m}^2$. In this work, we first study the possibility of significantly reducing the core side to single-mode condition (i.e. $9 \times 9 \mu\text{m}^2$) at optical communication wavelength. It is believe that by using the square-core fiber, the coupling loss between square-core fiber and the square-core waveguide device in glass-based planar lightwave circuit (PLC) can be negligible theoretically. In the proposed square-core single-mode-fiber (SC-SMF), high bandwidth–distance product and low bending loss are achieved. The paper is organized as follow: we first study and analyze the single mode condition of the SC-SMF. Then, we discuss the fabrication of the SC-SMF. After this, the bending losses of the SC-SMF and standard single mode fiber (SSMF) are analyzed and compared. Finally, 10 Gb/s signal transmission using conventional on–off keying (OOK) and orthogonal frequency division multiplexing (OFDM) passing through 200 m, 500 m and 1 km SC-SMFs are performed. Negligible power penalty is observed. We believe that this can be another choice of high bending tolerance fiber

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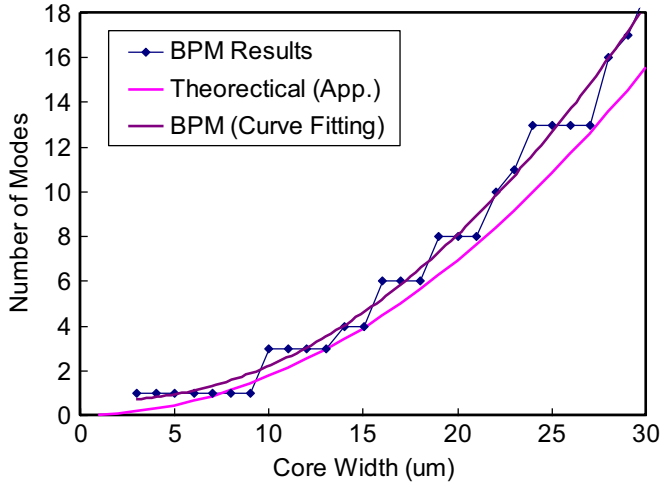


Fig. 1. Relationship between number of modes and the core widths.

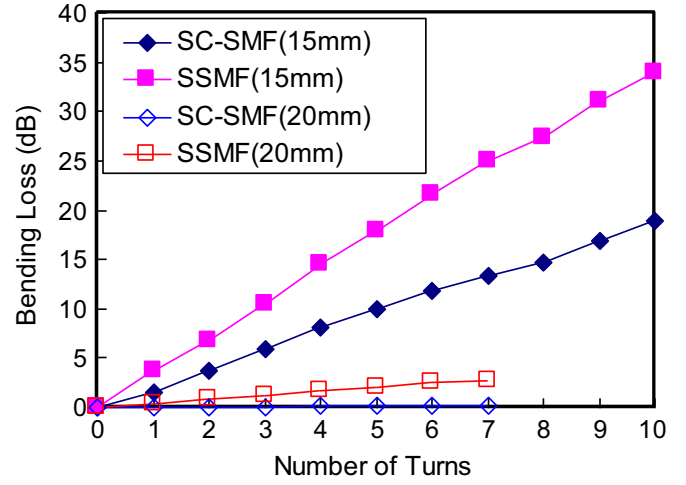


Fig. 3. Measured bending loss characteristics of the proposed SC-SMF and SSMF.

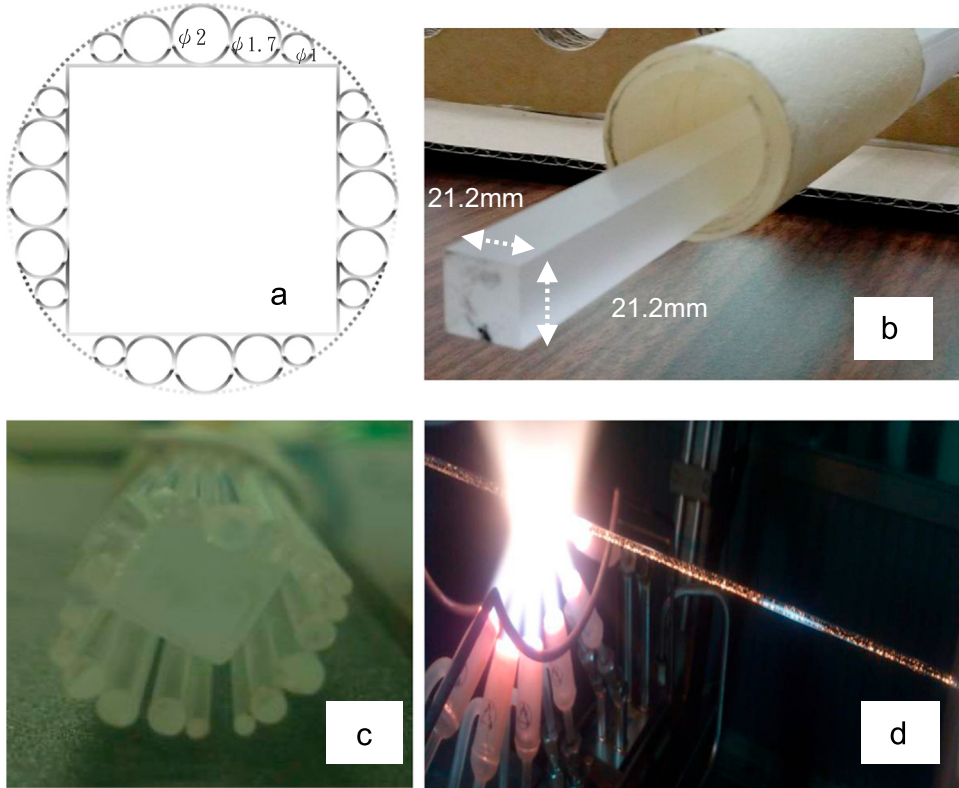


Fig. 2. (a) Schematic of cross-section of the SC-SMF design; photographs of (b) square preform, (c) bundle of glass rods, and (d) producing the final SC-SMF preform.

which is simple to manufacture.

2. Architecture of secure VLC system

We first analyze the requirement for achieving single mode condition in square-core fiber. According to [7], the theoretical number of modes of a square-core optical waveguide is approximately equal to Eq. (1),

$$\#MODE \approx \frac{\pi}{4} \left[\frac{\sin\left(\cos^{-1}\left(\frac{n_{cladding}}{n_{core}}\right)\right)}{\frac{\lambda}{2 \cdot w}} \right]^2 \quad (1)$$

where $n_{cladding}$ is the refractive index of the fiber cladding, n_{core} the

refractive index of the fiber core, λ the wavelength of the incident light, and w is the width of the square-core fiber. Besides, to get a more accurate relation between the number of modes and the core width, beam propagation method (BPM) is used to calculate the number of modes under specific square-core widths. Fig. 1 shows the relationship between the number of modes and the core width obtained theoretically based on Eq. (1), and based on BPM numerical analysis. It is observed that single mode requirement can be achieved while the square-core width is less than $9 \mu m$. Hence, $9 \mu m$ core width is chosen for the fabrication of SC-SMF.

The SC-SMF is fabricated using the same fiber drawing tower as conventional SSMF. The cross-section of the SC-SMF design is shown in Fig. 2(a). The center of the SC-SMF is surrounded by several circular glass rods with different diameters. Then the whole bundle

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