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Novel hollow optical fibers and their applications as photonic devices for optical communications

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Abstract

Novel photonic devices based on hollow optical fibers are reviewed for bandwidth improvement in multimode Gigabit LAN communications, dispersion compensation in long-haul communications, and broadband channel selection. Fabrication arts of the fibers and operation principles of the devices are discussed.

Various kinds of optical fibers and their applications have been developed for optical communications and sensors since the last few decades. With the early development of conventional singlemode fibers (SMFs), non-zero dispersion shifted fibers (NZDSFs) and dispersion compensating fibers (DCFs) have been massively developed to obtain the optimum chromatic dispersion at the optical transmission bands. Furthermore, specialty fibers such as rare earth doped fibers, photosensitive fibers, attenuation fibers, and polarization maintaining fibers have been developed for optical devices with novel optical functions. Recently, there have been new technical challenges to develop specialty fibers with air holes to provide optical functions that were not available in conventional solid core fibers. Photonic crystal fibers or micro-structured fibers [1], omniguide fibers [2], hollow IR transmitting fibers [3], and hollow optical fibers (HOFs) [4] have been recently introduced with unusual guiding structures and subsequently demonstrated various applications.

In this paper, we focus on HOF applications for optical communications such as a multimode Gigabit Ethernet communication [5], a higher-order-mode dispersion compensation [6], and a tunable bandpass filter [7] among various potentialities. The design and fabrication arts, device integration, and system demonstration are described.

1. Fabrication of a ring core hollow optical fiber and a mode converter

A hollow optical fiber (HOF), composed of a central air hole, GeO_2-SiO_2 ring core, and SiO_2 cladding, was fabricated using MCVD and drawing process through elaborate controls to keep the hole intact along the axial direction. Using the fabricated HOF, a mode converter where an SMF is spliced to a tapered HOF is shown in Fig. 1. One end of the ring core HOF was tapered down to a solid core when it was heated, resulting in the reduction of coupling loss with the input SMF. The other end kept the air hole open at the center for the applications such as Gigabit LAN communication and dispersion compensation. The mode converter has shown an insertion loss less than 0.6 dB from LP_{01} mode of SMF to a ring mode of HOF.

Fig. 1. Photograph of a mode converter that converts the fundamental mode of SMF to a ring shaped mode of HOF.

2. Bandwidth improvement in multimode optical fiber for Gigabit communication

The enormous demand on bandwidth in building and computer backbone links has required the increase of the transmission capacity in a multimode fiber (MMF) based LANs. In order to realize such a high-speed transmission in the already installed MMF links, it is required to reduce differential modal delay (DMD) due to a central refractive index dip and a non-optimum power law profile of the MMFs. In order to overcome DMD, various schemes with special launching conditions to excite a set of modes with similar group velocities into MMFs have been reported. The authors have proposed a launching scheme through flexible control of ring mode in the SMF-HOF mode converter so that the ring mode could effectively excite a set of modes avoiding the central dip when spliced to conventional MMF. Using the HOF mode converter, it was confirmed that the receiver sensitivity was improved about 0.7dB at 10^{-9} BER level for the directly modulated 1.31μm FP laser as shown in Fig.2.

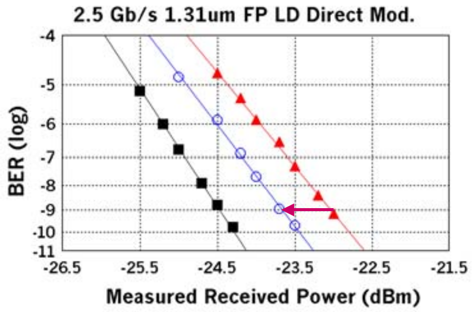

Fig.2 The BER versus the received power. Rectangular: Back-To-Back, Hollow Circle: SMF-HOF-MMF 500m, and Triangular: SMF-MMF 500m.

3. Higher-order-mode dispersion compensation scheme for long-haul transmission

Simultaneous compensation of dispersion and dispersion slope in high-speed long-haul wavelength division multiplexing (WDM) transmission systems has been recognized as an important technique to improve performance of transmission links. In order to compensate such an accumulated dispersion, various dispersion compensation techniques have been proposed. Of these, higher-order-mode dispersion compensation (HOMDC) technique has drawn attention due to its high figure of merits and reduction of non-linear effects. An HOMDC module consists of a mode converter that converts LP_{01} mode of SMF into a higher-order-mode and a few-mode DCF. The authors have proposed the use of the SMF-HOF adiabatic mode converter and mating LP_{02} mode DCF. With the compatible design of them, the net chromatic dispersion within –1 to 1 ps/nm/km was theoretically predicted over the whole C-band with a combination of 60km SMF and about 1.31km DCF as shown in Fig. 3.

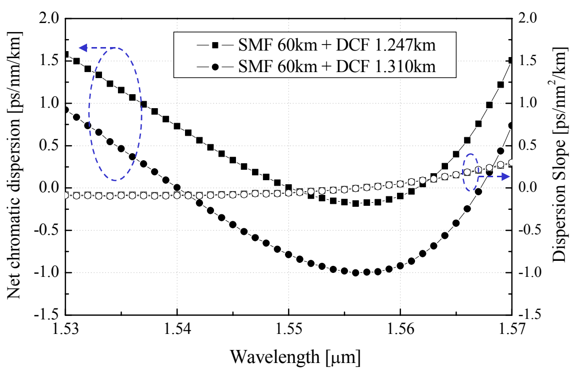

Fig. 3. The total dispersion and dispersion slope compensated for the cascaded SMF-DCF transmission links.

4. All-fiber tunable bandpass filter for optical channel selection in a wide transmission band

With increasing demands on flexible channel selection in WDM system, fixed and tunable wavelength selective components have been developed. All-fiber bandpass filters (BPFs) have been achieved by the use of phase-shifted long-period fiber gratings (LPGs) and core mode blockers in the middle of two LPGs or AOTF. An HOF-BPF consists of a short HOF segment without a ring core between an identical LPG pair. The first LPG couples light from the fundamental core mode to the phase matching cladding modes. A hollow core mode blocker rejects the core mode in the wavelengths that are not resonant with the LPG pair and the cladding modes from the first LPG further propagate along the cladding of a hollow segment. The identical second LPG couples back the cladding modes into the core mode at the resonant wavelength, resulting from BPF. In Fig. 4, the wide tuning range of 84.3nm, from 1465.3 to 1549.6nm covering both S- and C-band, was observed at the pass-band that corresponds to the HE_{14} cladding mode coupling for the temperature range of 25 to 215°C.

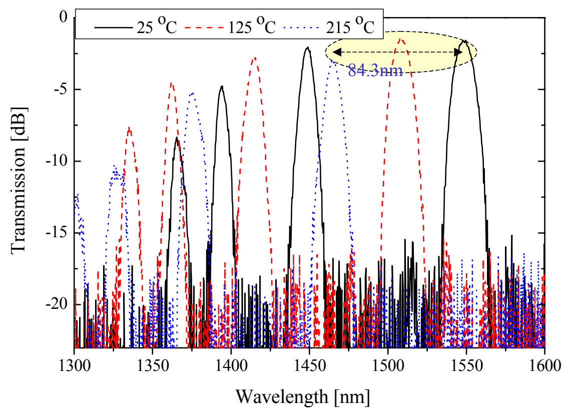

Fig. 4. Transmission spectrum of a tunable HOF-BPF.

5. Conclusions

We have reviewed HOF applications for optical communications. Using guiding properties of HOF, novel fiber devices with versatile functionalities that have not been achieved in the prior arts can be further developed providing a new class of device engineering in fiber amplifiers, lasers, sensors, atomic optics, and medical applications.

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6. References

[1] P. Russell, *Science*, **299**, pp. 358-362, 2003.
[2] B. Temelkuran et al., *Nature*, **420**, pp. 650-653, 2002.
[3] J. A. Harrington et al., *IEEE J. Select. Topics Quantum Electron.*, **5**, pp. 948-953, 1999.
[4] S. Choi et al., *Electron. Lett.*, **37**, pp. 823-825, 2001.
[5] S. Choi et al., *IEEE Photon. Technol. Lett.*, **14**, pp. 248-250, 2002.
[6] S. Choi et al., *Opt. Commun.*, **221**, pp. 307-312, 2003.
[7] S. Choi et al., *Proc. ECOC'03*, Paper Tu1.7.5, 2003.