Ring-core Fiber Supporting OAM-based Optical Communications

Yang Yue
School of Information and Communications Engineering
Xi'an Jiaotong University
Tianjin, China
yueyang@xjtu.edu.cn

Yuanpeng Liu
Institute of Modern Optics
Nankai University
Tianjin, China
2120210235@mail.nankai.edu.cn

Wenqian Zhao
Institute of Modern Optics
Nankai University
Tianjin, China
2120200263@mail.nankai.edu.cn

Jian Yang
Institute of Modern Optics
Nankai University
Tianjin, China
2120210250@mail.nankai.edu.cn

Wenpu Geng
Institute of Modern Optics
Nankai University
Tianjin, China
2120190214@mail.nankai.edu.cn

Yingning Wang
Institute of Modern Optics
Nankai University
Tianjin, China
yingning.wang@usc.edu

***Abstract*—Several types of ring-core optical fibers are presented for OAM modes, including multi ring-core fiber supporting thousands of modes, coupled ring-core fiber with large dispersion, and non-zero dispersion-shifted ring-core fiber to balance dispersion and nonlinearity.**

Keywords—optical fiber communication system, OAM multiplexing, ring-core fiber, dispersion compensation

I. Introduction

To satisfy the ever growing demand for communication system's capacity and spectral efficiency, the beams carrying orbital annular momentum (OAM) have aroused extensive attention in the optical communication society [1, 2]. The OAM modes could be used as an additional dimension in optical transmission systems to provide further capacity growth [3]. Many fiber structure designs have been proposed for better OAM transmission performance. This talk presents some latest progress on OAM ring-core fiber design.

II. Ring-core Fiber Design

A. Concept of Ring-core Fiber

The OAM beams featuring spiral phase front have infinite topological charges, which offer a promising direction for multiplexing technology. Since OAM beams have the donut intensity profile, the ring-core fiber has been proposed to better support the OAM mode transmission. Fig. 1(a) demonstrates the multiplexing of different-order OAM modes in fiber. The cross section and the refractive index profile are illustrated in Fig. 1(b), where the fiber parameters are displayed. By selecting proper parameters to adjust, one can acquire a flexible tuning range of fiber properties, such as mode order, mode number and effective mode area, etc. [4].

Moreover, one can also combine the space division multiplexing with OAM mode division multiplexing in multi-core fibers (MCFs) to obtain numerous OAM modes as communication channels, which is considered as one of the most enticing approaches to overcome the capacity crunch of the current optical communication systems [5-7]. Fig. 2 depicts the fiber structure parameters, the supported OAM mode number and the schematic diagrams of multi-ring-air-core fiber (MRACF) under several different optimized circumstances. Owing to its high refractive index contrast, the MRACF with 37 rings can support a record-high 4440 radially fundamental OAM modes at 1550 nm, featuring <−53 dB inter-ring crosstalk and $>5.67\times10^{-4}$ intra-ring modal effective refractive index difference.

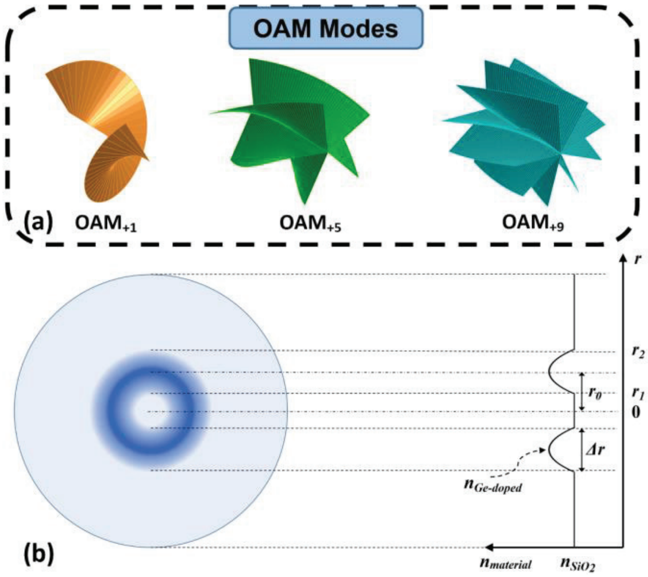

Fig. 1. (a) Concept of OAM mode-division-multiplexing; (b) Cross-section view and refractive index profile of the ring-core fiber [4].

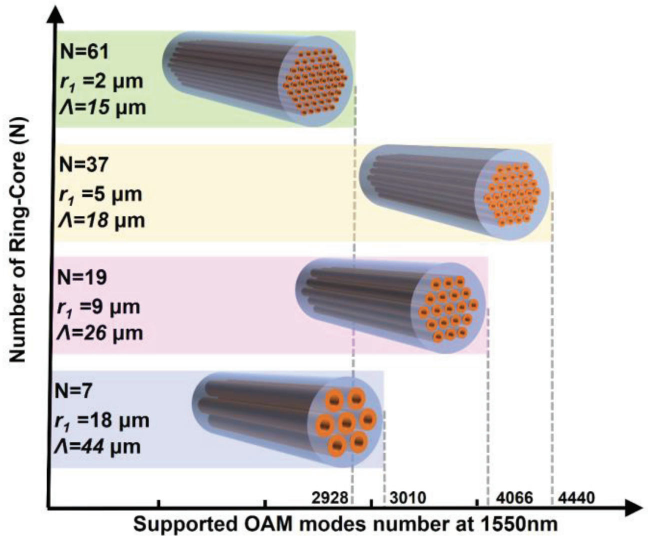

Fig. 2. Total supported OAM mode numbers of 7, 19, 37, 61-ring-core fibers under optimized structure parameters [5].

B. Dispersion Compensating Ring-core Fiber

In the practical optical fiber communication systems, chromatic dispersion (CD) is a non-negligible effect. With the extension of the transmission distance, CD will accumulate in the optical fiber, which induces the temporal broadening of optical pulse, and seriously degrades the optical signal quality and system capacity. People propose the dispersion compensating fiber (DCF) to depress the CD-induced penalty by compensating for the positive dispersion. Considering the minimization of the CD effect in OAM-based communication systems, we propose a novel highly dispersive coupled ring-core fiber (HD-CRF) using germanium-doped (Ge-doped) silica for OAM modes [8, 9]. In the proposed HD-CRF, the most dispersive wavelength of the $OAM_{1,1}$ mode can be flexibly controlled over a 449.8-nm wide spectral range around −37,126 ps/(nm·km) with <2.8% CD variation. Furthermore, by changing the material of the ring core into Schott glass and adjusting the structure parameters, the HD-CRF can support higher-order OAM modes with large negative dispersion over a broad spectral range [10].

The schematic diagram of triple ring-core dispersion compensation fiber (TRDCF) supporting OAM mode is depicted in Fig. 3 [11]. The relatively linear negative dispersion over wide bandwidth can be achieved from the proposed TRDCF, which has broad application prospects in the transmission of OAM beams.

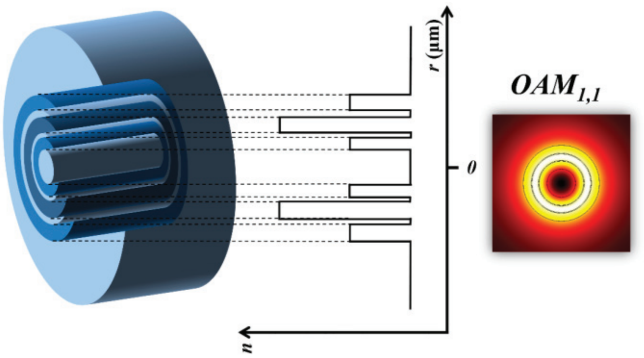

Fig. 3. Schematic diagram of TRDCF supporting OAM mode [11].

C. Non-Zero Dispersion-Shifted Ring-core Fiber

In the traditional optical fiber communication systems, the DCF are placed after the SMF to balance the CD and nonlinearity, which will significantly complicate the fiber link management [12]. To simplify it, we propose and design a non-zero dispersion-shifted ring-core fiber (NZDSRF) supporting OAM modes as shown in Fig. 4 [13]. The designed NZDSRF can provide a low dispersion (3.296 ps/(nm·km)) at 1550 nm and small dispersion variation (<2.831 ps/(nm·km) in total) for the $OAM_{1,1}$ mode across C-band from 1530 to 1565 nm in theory. This new type NZDSRF could be a prospective candidate for balancing the trade-off between CD and nonlinear effects in OAM-based wavelength division multiplexing communication system.

D. Nonlinearity in Ring-core Fiber

As a promising candidate in future optical communication systems, a laudable goal for the OAM beam would be to have a broad wavelength range. Accordingly, we propose an air-core As_2S_3 ring fiber, in which the supercontinuum (SC) spanning thousands of nanometers can be achieved for high-order OAM modes [14]. By properly adjusting the air-core radius, two-octave SC spanning from 1560 to 6250 nm can be generated for $OAM_{17,1}$ mode in the designed fiber. The proposed fiber is expectable for the transmission and application of OAM beams in the infrared wavelength range.

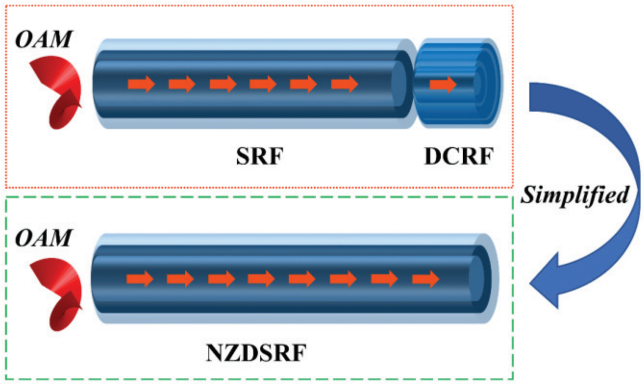

Fig. 4. NZDSRF-based OAM communication system simplifies the traditional OAM-based fiber communication system using the single ring-core fiber (SRF) and dispersion compensating ring-core fiber (DCRF) combination [13].

Acknowledgment

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References

[1] N. Bozinovic *et al.*, "Terabit-scale orbital angular momentum mode division multiplexing in fibers," Science, vol. 340, pp. 1545-1548, 2013.

[2] Y. Yue *et al.*, "Mode properties and propagation effects of optical orbital angular momentum (OAM) modes in a ring fiber," IEEE Photonics Journal, vol. 4, no. 2, pp. 535-543, 2012.

[3] J. Liu *et al.*, "1-Pbps orbital angular momentum fibre-optic transmission," Light: Science & Applications, vol. 11, no. 1, pp. 202, 2022.

[4] Y. Liu *et al.*, "Enhanced OAM Mode Purity in Ring-core Optical Fiber with Graded-index Profile," Advanced Photonics Congress on Specialty Optical Fibers (SOF), paper SoW4F.2, Maastricht, Netherlands, Jul. 2022.

[5] Y. Wang *et al.*, "Multi-Ring-Air-Core Fiber Supporting Numerous Radially Fundamental OAM Modes," Journal of Lightwave Technology, vol. 40, no. 13, pp. 4420-4428, 2022.

[6] Y. Wang *et al.*, "19-ring-air-core fiber supporting thousands of OAM modes for spatial division multiplexing," Optics Letters, vol. 47, no. 9, pp. 2206-2209, 2022.

[7] Y. Wang *et al.*, "Seven air-core fibers with germanium-doped high-index rings supporting hundreds of OAM modes," Optics Express, vol. 29, no. 13, pp. 19540-19550, 2021.

[8] W. Geng *et al.*, "Highly Dispersive Germanium-Doped Coupled Ring-Core Fiber for Vortex Modes," Journal of Lightwave Technology, vol. 40, no. 7, pp. 2144-2150, 2022.

[9] W. Geng *et al.*, "Triple Coupled Ring-Core Fiber with Dual Highly Dispersive Windows for Orbital Angular Momentum Mode," Advanced Photonics Research, vol. 3, no. 10, paper 2100370, 2022.

[10] W. Geng *et al.*, "Highly dispersive coupled ring-core fiber for orbital angular momentum modes," Applied Physics Letters, vol. 117, no. 19, paper 191101, 2020.

[11] W. Zhao *et al.*, "Broadband dispersion compensating ring-core fiber for orbital angular momentum modes," Optics Express, vol. 30, no. 20, pp. 35457-35466, 2022.

[12] W. Zhao *et al.*, "Air-Core Non-Zero Dispersion-Shifted Fiber With High-Index Ring for OAM Mode," IEEE Access, vol. 9, pp. 107804-107811, 2021.

[13] W. Zhao *et al.*, "Non-zero dispersion-shifted ring fiber for the orbital angular momentum mode," Optics Express, vol. 29, no. 16, pp. 25428-25438, 2021.

[14] Y. Wang *et al.*, "Two-Octave Supercontinuum Generation of High-Order OAM Modes in Air-Core As_2S_3 Ring Fiber," IEEE Access, vol. 8, pp. 114135-114142, 2020.