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Recent Advances in Fabrication and Application of Multi-Core Fibres

Yang Chen, Li Borui, Tong Weijun

Abstract: More and more attention has been paid to the design, fabrication and application of multi-core fibre because of the special structure of the fibre. In this paper, the latest development of YOFC's multi-core fibre fabrication technology is introduced, including the development of coupler. At the same time, the progress of the study on the application of multi-core fibre in communication and sensing fields depending on its characteristic of space division multiplexing is also introduced.

Key words: Multi-core, fan-in and fan-out, space division multiplexing, communication, sensing

1 Introduction

In recent years, the Specialty Products Business Unit of YOFC has cooperated with the optical communications and network engineering research team of Huazhong University of Science and Technology to take the lead in producing homogeneous weakly coupled 7-core single-mode optical fibre in China, which fills the technical gap in the field of this specialty optical fibre in China.

2 Multi-Core Fibre and the Rise of Space Division Multiplexing Technology

According to the results of statistics made by Bell Labs, Cisco and other industry giants on the existing optical network traffic growth trend in different applications, the current optical fibre communication network traffic is growing at a high speed of 20% ~ 60%. As shown in Figure 1, considering that the port rate of 100Gb/s has been realized in the commercial optical communication system in 2010 with the system capacity of 10Tb/s, the capacity of the optical fibre communication system will reach about 100Tb/s in the next ten years. However, there are some limitations in current optical fibre communication systems. Firstly, considering low loss transmission window and amplifier bandwidth, the useful spectrum is about 10THz. Secondly, the optical signal-to-noise ratio (OSNR) of the signal will be deteriorated due to Amplified Spontaneous Emission Noise (ASE) in the optical fibre transmission, and the nonlinear damage will be caused by the nonlinear Kerr effect of the optical fibre. In this case, the system capacity will have nonlinear Shannon limit, that is, the improvement of the transmission quality of the signal with high spectral efficiency through increasing the signal-to-noise ratio will cause very serious nonlinear distortion.

From the essence of optical signal, its physical multiplexing dimension includes five aspects (as shown in Figure 2): time, polarization, frequency, quadrature, and space. Many multiplexing technologies are being used for high-speed signals in optical fibre communication systems, such as time-division multiplexing, wavelength-division multiplexing, polarization multiplexing, and amplitude-phase quadrature multiplexing using coherent detection technology. The only unstudied spatial dimension (space) - space division multiplexing (SDM) technology - in optical fibre physical layer has become the inevitable choice for breaking through the capacity limit of optical fibre communication system.

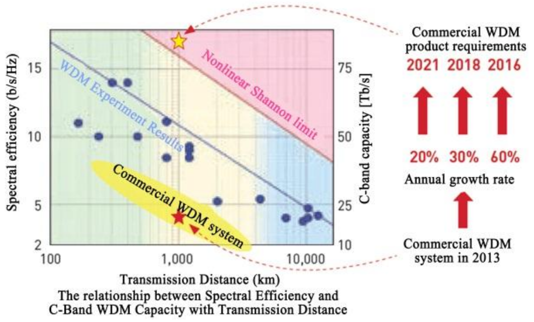


Figure 1 Capacity Growth Trend of Optical Fibre Communication System

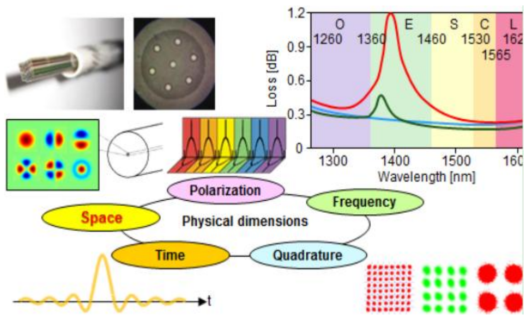


Figure 2 Optical Signal Physical Multiplexing Dimensions

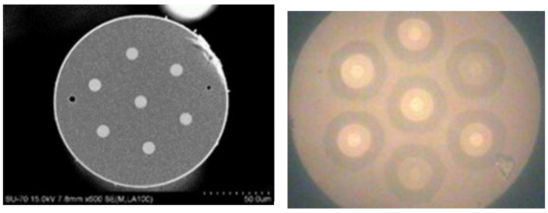
At the European Conference on Optical Communications in 2010, the space division multiplexing (SDM) technology based on multi-core fibre and few-mode fibre was recognized as the key technology to improve the optical fibre communication system by many scientific research scholars from various organizations, and was regarded as the second technological revolution of the optical fibre transmission technology after wavelength division multiplexing technology. Mr. Li Dingyi, the father of WDM, spoke highly of SDM.

Since SDM technology was proposed, over the past six years, it has been highly valued by scientific research institutes in Europe, America and Japan. Among them, the EXAT project led by Japan's National Institute of Information and Communications Technology (NICT) and Nippon Telegraph and Telephone Public Corporation (NTT), with the participation of Tohoku University, Hokkaido University, Osaka University, Sumitomo Company, and Fujikura Company, has put forward the goal of achieving a thousand fold jump in optical fibre communication system capacity by 2020. In just a few years, many batches of multi-core optical fibres with low loss and low crosstalk have been designed, drawn and tested. Many kinds of multiplexers/demultiplexers with low loss and low crosstalk have been fabricated, and hero transmission experiments have been reported in OFC, ECOC and other international conferences for many times. In Europe, the European Union has established the MODE-GAP project for the research on the space division multiplexing technology, and invited many universities and companies, including Southampton University, Aston University and Eindhoven University of Technology, to focus on the research of space division multiplexing technology based on few-mode fibre, especially the fabrication and development of multiplexing/demultiplexing devices based on few-mode fibre, and quickly industrialized them. In the United States, Bell Labs and other scientific research institutions have reported a large number of transmission experimental results by using multi-core fibres and few-mode fibres developed by Corning Company and OFS Company, and realized space division multiplexing real-time transmission experiment, which indicates the transformation of space division multiplexing transmission in ideal laboratory environment to more complex real-time field transmission.

3 Recent Advances in Fabrication Technology of Multi-Core Fibre and its Multiplexer

Since the extremely complex DSP algorithm needs to be adopted in the coherent receiver for the space division multiplexing technology based on few-mode fibre, and the mode-dependent loss will significantly reduce the transmission performance and other essential characteristics (and these characteristics will deteriorate dramatically with the increase of transmission distance and the number of mode multiplexing), we choose the space division multiplexing technology based on multi-core fibre which has a clearer application prospect and is more conducive to solve the capacity bottleneck of the existing optical fibre communication system in the medium and short term.

Yangtze Optical Fibre and Cable Joint Stock Limited Company is the first company in China to produce homogeneous weakly coupled 7-core single-mode optical fibre through the cooperation with the optical communications and network engineering research team of Huazhong University of Science and Technology. Two kinds of homogeneous multi-core fibres, namely non-low-crosstalk and low-crosstalk 7-core fibres, are fabricated through the simulation and calculation of 7-core waveguide structure. The scanning electron microscopy test results are shown in Figure 3. Through testing the performance parameters such as fibre loss spectrum, cutoff wavelength, bending loss, crosstalk, dispersion, and PMD, as well as the continuous optimization of the process, 7-core fibre with low crosstalk and loss has been achieved. The attenuation of optical fibre at 1550nm is about 0.20 dB/km, and the crosstalk is less than -40dB/100km, which fills in the technical gap in the field of this special optical fibre in China and is close to the performance of the products manufactured by many leading international optical fibre manufacturers such as OFS, Corning, and Fujikura.

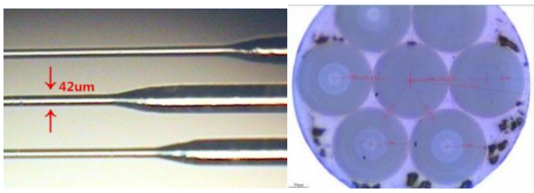


(a) (b)

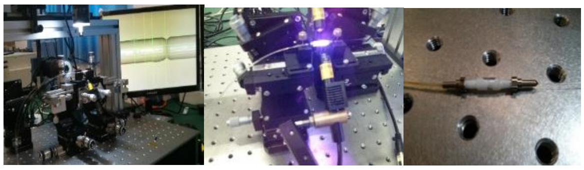
Figure 3 SEM of 7-core Optical Fibre End Face

On the other hand, the spatial multiplexer/demultiplexer for multi-core fibre is very important, because the devices at both receiving and transmitting ends as well as the network nodes are still based on single-mode optical fibre; therefore, it is necessary to multiplex the signals from multi-path single-mode fibre into multi-core fibre and demultiplex the multi-path parallel signals from multi-core fibre into multi-path single-mode fibre. As for the multi-core fibre multiplexer/demultiplexer, after comprehensively comparing the advantages and disadvantages of the mainstream technologies in the world and considering our own conditions, we select the cold connection process of optical fibre bundle to realize the multiplexer/demultiplexer.

The fabrication of multiplexer/demultiplexer is mainly implemented through the process steps including fibre pretreatment → fibre bundle pre-assembly → online space alignment → packaging. The specific process flow is shown in Figure 4. After continuous process optimization, the insertion loss < 1.5 dB, crosstalk < -45dB, echo reflection < -50dB are finally realized, and the comprehensive performance index has reached the international advanced level.



(a) Micrograph of corroded fibre bundle (b) End-face micrograph of fibre bundle



(c) Six-dimensional alignment platform (d) UV curing process (e) Picture of multi-core fibre multiplexer/demultiplexer

Figure 4 Fabrication Flow of Multi-Core Fibre Multiplexer/Demultiplexer

On the one hand, high-quality multi-core optical fibre multiplexer/demultiplexer has quickly opened up the domestic and international markets, and won the favor of customers, and has been praised by Tsinghua University, Ji'nan University, University of Science & Technology Beijing, Hong Kong Polytechnic University, Chalmers University of Technology (Sweden), and the Chiral Photonics Company (the US).

4 Application Test of Multi-core Fibre

Based on the above multi-core fibre and multiplexing devices, we have done some experimental work for applications in communication transmission.

Firstly, based on the current research situation of short distance, low speed, and low-level modulation format of the current SDM high-capacity access network, as well as the general use of time division multiplexing (TDM), a multi-core optical fibre transmission platform is built, in which the optical frequency comb is used as downlink light source to modulate high-order format signals and transmit them to ONU through six cores around the center core; at the ONU end, the tunable laser is used as the uplink light source to modulate the OOK signal which is also transmitted through six cores around the center core. In order to reduce the cost, direct modulation and direct detection technology is adopted for the uplink and downlink signals. In order to be compatible with mobile backhaul services, mobile backhaul signals are transmitted in the middle cores and coherently received at the OLT, thereby realizing a new high-capacity wavelength division/space division access network architecture compatible with mobile services (as shown in Figure 5). The system has initially realized a downlink transmission capacity of 300Gb/s in 58km multi-core fibre, supporting 60 users with 5Gb/s per user. The experimental results are shown in Figure 6 and Figure 7.

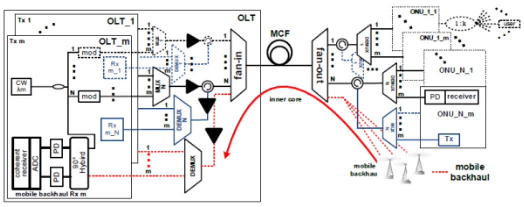


Figure 5 New Wavelength Division/Space Division Access Network Architecture

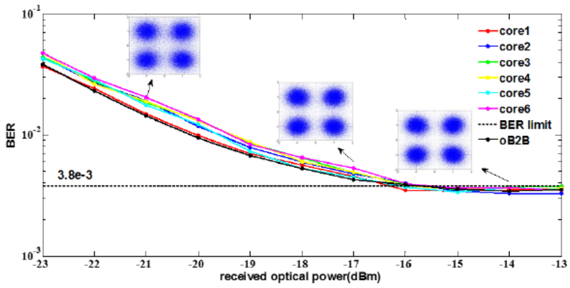
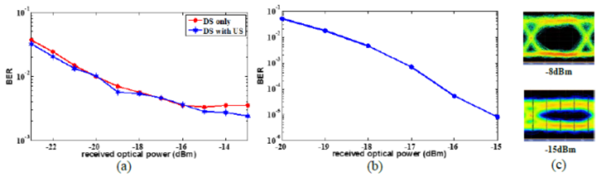


Figure 6 Downlink Transmission Results



(a) Downlink signal transmission results in the presence of uplink transmission (b) Uplink signal transmission results (c) Eye pattern for received power at -8dBm and -15dBm

Figure 7 Uplink Transmission Results

Secondly, we have made optimization and improvement on the basis of this architecture. On the one hand, we use RSOA to achieve low-cost colorless ONU at the receiving end; on the other hand, we use more advanced modulation format and adaptive modulation to increase the system capacity. In the new architecture, the downlink signal is transmitted to the ONU through the five cores around the center core after modulation, and the carrier wave of the uplink signals is transmitted to the ONU through the sixth core of the outer layer, and then transmitted from the center core after demodulation by RSOA. In addition, for mobile backhaul signals, the capacity is increased through polarization multiplexing and the speed reaches 48 Gb/s. The access network architecture is shown in Figure 8. The schematic diagram of the experiment is shown in Figure 9. In the experiment, since the bandwidth of RSOA is limited, water-filling algorithm is used to modulate the OFDM signal adaptively, which makes the transmission rate reach 3.12 Gb/s at 1.25 G bandwidth. Finally, 50 downlink users with the access rate of 5Gb/s for a single user can be realized, and the system capacity reaches 250Gb/s. The uplink rate reaches 3.12 Gb/s and compatible with mobile backhaul service, with the capacity of 48 Gb/s. The experimental results are shown in Figure 10 and Figure 11.

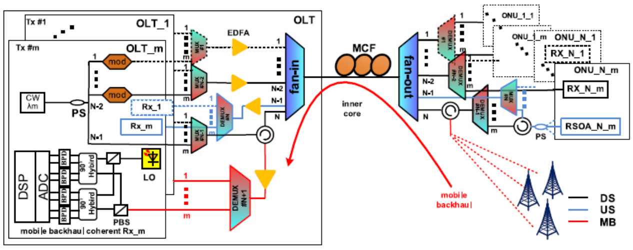


Figure 8 Schematic Diagram of Wavelength Division/Space Division Access Network Architecture

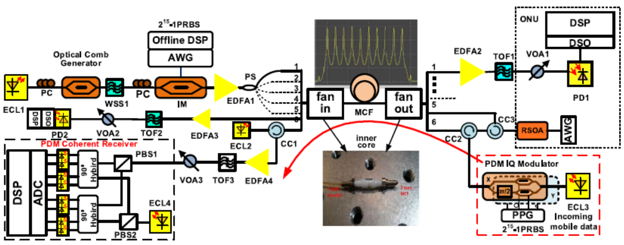


Figure 9 Schematic Diagram of the Experiment

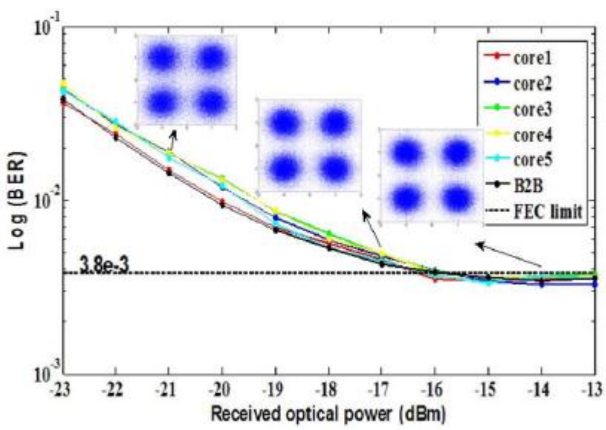


Figure 10 Downlink Transmission Experiment Result

Diagram

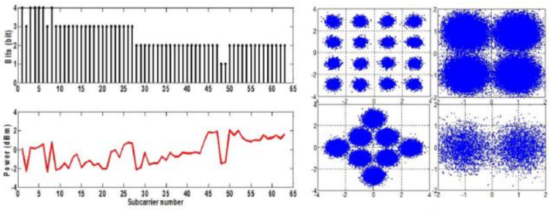


Figure 11 Results of the Uplink Signal after Adaptive Modulation by RSOA

5 Future Development Direction and Prospect

It will be a long process for SDM optical fibre communication technology to become the mainstream of the industry, during which both operators and system providers will continue to tap the potential of the existing single-mode optical fibre communication technology; the game between them and trade-offs will also be included in the process.

From the perspective of the space division multiplexing technology itself, on the one hand, it is necessary to improve the performance of space division multiplexing devices and establish relevant standards as soon as possible. At present, the space division multiplexing system based on multi-core fibre has been continuously improved. Sumitomo (Japan) has manufactured multi-core fibre with ultra-low loss, and Fujikura has also manufactured multi-core fibres such as 22-core and 30-core optical fibres. Multiplexer/demultiplexer is increasingly integrated and miniaturized; multi-core fibre splicing technology, connectors, and amplifiers are all becoming better and approaching perfection. On the other hand, more suitable application scenarios based on the characteristics of the space division multiplexing technology needs to be found out. For example, one of the characteristics of multi-core fibre is high space utilization, which can save more space with the performance being similar to that of multiple single-mode fibres. Therefore, this characteristic is very suitable for the application in space-sensitive data center.

With the popularity of cloud computing, Internet giants plan the construction of more and more large-scale data centers. In this case, multi-core fibre has great potential and will play a significant role. With the development of mobile communication technology, the abundant applications based on mobile communication network have driven the rapid growth of mobile data services. In order to meet the requirements of green and low-cost operation at the same time of substantial capacity expansion, the spectral efficiency and energy efficiency of 5G wireless network need to be improved by an order of magnitude compared with those of 4G wireless network. Massive Multiple Input Multiple Output (Massive MIMO) technology is one of the key technologies in the future 5G communication. Assuming that the array antenna is composed of 128 antennas, the signal bandwidth is 100MHz, and 16bits quantization and 8b/10b encoding are adopted, the digital recombination rate of the array antenna with baseband pooling link will be up to 786Gbps. Therefore, optical fibre-based Radio over Fibre (RoF) transmission technology will be the key technology of future mobile communication transmission. At present, the research and development of the key technology of 5G is in full swing in the world, and the space division multiplexing technology will enrich the choices of its technical schemes, and even has the potential to become one of the key technologies.

长飞光纤光缆股份有限公司
Yangtze Optical Fibre and Cable Joint Stock Limited Company
地址：武汉市光谷大道9号（430073）
ADD：No.9 Optics Valley Avenue, Wuhan, Hubei, China(P.C.: 430073)
电话(Tel)：+86 400-991-6698
邮箱(Email)：marketing@yofc.com
www.yofc.com