Experimental Demonstration of Single Channel 800Gb/s On-chip MDM Self-Homodyne Coherent Detection with Ultrafast Laser Inscribed Photonic Chips

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Abstract *We experimentally demonstrate the single channel 800Gb/s mode-division multiplexing (MDM) self-homodyne coherent detection (SHCD) transmission over ultrafast laser inscribed photonic chips. 100Gbaud Dual-polarization (DP) 32-ary quadrature-amplitude modulation (QAM) is realized using a low-cost distributed feedback (DFB) laser with a linewidth of 1 MHz.*

Introduction

The explosive growth of communication demand has significantly promoted the capacity growth of communication systems and driven the rapid development of modern communication technology. Short-reach optical communication accounts for an indispensable portion of nowadays global communication networks. Low power consumption and low cost are the factors that must be considered in short distance optical communication system[1]. Traditional coherent detection can realize high capacity, but it comes with high cost and large power consumption[2]. The self-homodyne coherent detection (SHCD), with the property of laser phase noise cancelling, has been considered as one of the most promising schemes to balance the system capacity and transceiver cost[3, 4]. It is beneficial to discard the employment of narrow linewidth lasers and complex carrier phase recovery algorithms in SHCD systems. Furthermore, mode division multiplexing (MDM) is a promising technology to break through data capacity limitation of a single-mode fiber[5]. The pilot-tone (PT) light that acts as the local oscillator (LO) can be transmitted through one mode channel for SHCD. MDM-SHCD systems can achieve higher system capacity while offering the advantages of low cost and low power consumption.

Integrated optics realizes more efficient, faster, and higher dimensional multi-functional information processing with the advantages of small size, low loss, high integration, and high scalability[6]. To our knowledge, there are no reports on the further penetration of high-capacity MDM-SHCD transmission to centimeter-scale ultra-short-reach transmission. It is a very important trend in the future to carry out high-capacity SHCD optical interconnects over centimeter-scale photonic chips. Femtosecond laser fabrication technology possesses the unique advantages of three-dimensional processing, arbitrary structure design, high processing resolution and wide range of applicable materials[7, 8]. Thanks to these advantages, the femtosecond laser fabrication is an ideal technology for achieving a low-cost MDM system in centimeter-scale glass chips.

In this paper, we propose an on-chip MDM architecture and demonstrate the implementation of single channel 800Gb/s MDM SHCD transmission over centimeter-scale ultrafast laser inscribed photonic chips. 100Gbaud Dual-polarization (DP) 32-ary quadrature-amplitude modulation (QAM) is realized using a low-cost distributed feedback (DFB) laser with a linewidth of 1 MHz. LP_{01} and LP_{11} modes are used, where LP_{01} mode is used to transmit PT. In addition, an assistant waveguide is adopted to transmit PT and each mode carries 800Gb/s 32QAM signals is also demonstrated.

On-chip MDM-SHCD architecture

We fabricate the femtosecond laser inscribed on-chip MDM system in a glass chip, which can operate with advantages of broad bandwidth, low insertion loss, low crosstalk, and high mode selectivity. Figure 1(a) illustrates the architecture of a novel on-chip MDM system, consisting of a photonic lantern mode multiplexer, a few-mode waveguide (FMW), a photonic lantern mode demultiplexer, and an assistant waveguide. The femtosecond laser inscribing is performed by a high repetition rate Ytterbium-based laser (second harmonic generation at 515 nm wavelength, 100 kHz repetition rate, 234 fs pulse duration). The fabrication process was monitored in real time by the light emitting diode (LED) lighting system and a charged coupled device (CCD). The linear polarization femtosecond laser is vertically focused ~50 μm below the top surface of a glass sample through a 50X0.42 objective. The high peak power of femtosecond laser causes local nonlinear absorption, which leads to changes in the refractive index. The waveguide is formed when the glass sample moves along a set trajectory. The size of glass chip is 40mm*20mm*1mm. The input or output of fabricated on-chip MDM system contain three single-mode ports with a pitch of 127 μm, as shown in Figure 1(b). The fabricated single-mode waveguides have a cross-section of 8.5μmx8.5μm diameter. Figure 1(c) shows the cross section of FMW with a diameter of 15 μm and a length of 1 mm.

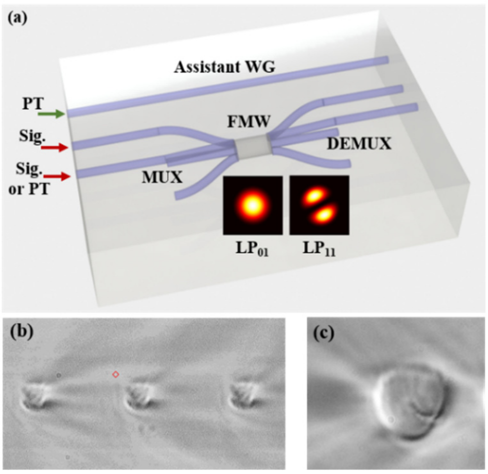


Fig. 1: The architecture diagram of proposed novel on-chip MDM system. FMW: few-mode waveguide. MUX: mode multiplexer. DEMUX: mode demultiplexer. WG: waveguide.

We realize two MDM-SHCD schemes. The first one is to utilize LP_{01} mode to transmit PT, LP_{11} mode to carry 100Gbaud DP-32QAM signals. The light from the laser is split into two separate spatial channels with one channel for PT and the other for signals. The second scheme is to transmit remote LO by an assistant waveguide, and the two modes carry 100Gbaud DP-32QAM signals, realizing a total net rate of 1.6Tb/s. The light from the laser is split into three separate spatial channels with one channel for PT and the remainder carrying the signals. The signals and PT are coupled into/out the on-chip MDM system by an SMF array. Finally, the transmitted signals and PT are injected into a coherent receiver, enabling SHCD. The length difference between the LO path and the signal path on the chip is of the order of millimetres, which is sufficient for high-capacity SHCD system. The remote LO has the same central frequency and reference phase as the transmitted signals. In the on-chip MDM-SHCD system, the impact of laser phase noise and frequency offset can be minimized, thereby relaxing the requirements on lasers and carrier recovery algorithm.

Experimental setup

Figure 2 shows the experimental setup of the on-chip MDM-SHCD system. The DFB laser with a linewidth of 1MHz is pre-amplified by an erbium-doped fiber amplifier (EDFA) and then a tunable filter is used to reduce the amount of amplified spontaneous emission noise. The light beam is split into two branches by a 90:10 coupler. One of the branches is modulated by 100Gbaud 32QAM signals, which are pre-distorted to compensate the nonlinearity of optical in-phase and quadrature modulator (IQM). An arbitrary waveform generator (AWG, Keysight M8199A) at a sampling rate of 125GSa/s and a DP-IQM with 35GHz 3dB bandwidth are employed. The other branch is used as the remote LO and then propagates in the photonic chip. The first SHCD scheme specifically is that the remote LO propagates through LP_{01} mode and LP_{11} mode carries 100Gbaud DP-32QAM signals, while the second is that the remote LO propagates through an assistant waveguide and both the two modes carry 100Gbaud DP-32QAM signals. The EDFAs in signal link and remote LO link are used to compensate for the link loss. At the receiver, the signals and the remote LO are sent to a coherent receiver which consists of a state-of-the-art 2x8 optical 90°-hybrid and four 70-GHz balanced photodiodes (BPDs). A real-time oscilloscope (Keysight UXR0594A) operating at 256 GSa/s digitizes the electrical signal. The remote LO, from the same laser as the signal, has a similar transmission path to the signal transmission path in the proposed MDM-SHCD system. Such a system eliminates the impact of laser phase noise and frequency offset, allowing receiver digital signal processing (DSP) without the use of frequency offset compensation and phase recovery algorithms. As a result, the receiver DSP only consists of resampling and real-value 4x4 MIMO equalization.

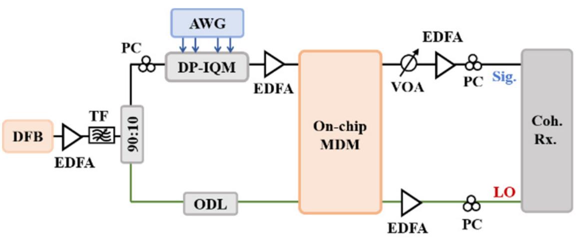
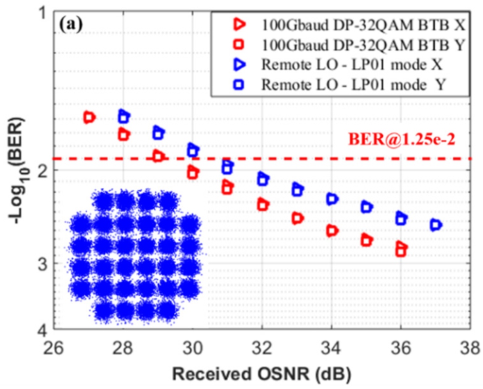


Fig. 2: The experimental setup of the on-chip MDM-SHCD system.

Experimental results and discussion

The performance of the proposed on-chip MDM-SHCD system is experimentally characterized. At first, in the case that the LP_{01} mode acts as the transmission channel of remote LO, the bit-error rate (BER) performance versus the received optical signal-to-noise ratio (OSNR) is measured, as shown in Figure 3(a). The corresponding OSNR at a BER of 1.25×10^{-2} (take the concatenated forward error correction (CFEC) threshold of 400 Ze Best Range (ZR) as a reference) for back-to-back (BTB) case is about 29.6dB. When LP_{11} mode carry 100Gbaud DP-32QAM signals, the corresponding OSNR at a BER of 1.25×10^{-2} is about 30.3dB. Compared to BTB case, the OSNR penalty is about 0.6dB. The insert of Figure 3(a) shows the constellations of 100Gbaud DP-32QAM at an OSNR of 37dB.



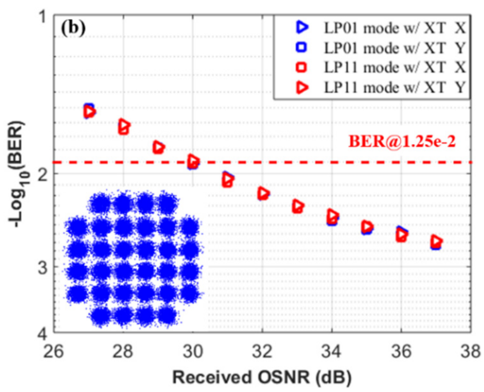


Fig. 3: The performance of on-chip MDM-SHCD system. The BER performance versus OSNR for (a) SHCD scheme using LP_{01} mode as transmission channel of remote LO; (b) SHCD scheme using an assistant waveguide as transmission channel of remote LO

For the case that an assistant waveguide acts as the transmission channel of remote LO and both LP_{01} and LP_{11} mode act as transmission channel of signals, we characterize the BER performance versus OSNR, as shown in figure 3(b). The BER performance of LP_{01} and LP_{11} modes is almost the same. Compared with the performance of BTB, the measured OSNR is about 0.4dB. The insert shows the constellations of 100Gbaud DP-32QAM at an OSNR of 37dB. The experimental results indicate that the femtosecond laser inscribed 3D on-chip MDM system possesses favourable characteristics for high-capacity SHCD transmission.

Conclusions

We propose and experimentally demonstrate a novel on-chip MDM-SHCD system using ultrafast laser inscribed photonic chips. A low-cost DFB laser with a linewidth of 1MHz is successfully employed to realize 100Gbaud DP-32QAM system. The OSNR penalty between on-chip MDM-SHCD system and BTB case is less than 0.6dB. And LP_{01} and LP_{11} mode channels show similar BER performance. As a proof of concept, the experiment successfully demonstrates single channel 800Gb/s MDM SHCD transmission over centimeter-scale photonic chips.

Acknowledgements

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