Generation and heterodyne detection of a 2-µm-band 16-QAM signal based on inter-band wavelength conversion

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Abstract: We demonstrate the generation and self-heterodyne detection of a 2-µm-band 32-Gbit/s line-rate 16-QAM signal based on inter-band wavelength conversion in an AlGaAsOI nanowaveguide. Error-free performance is achieved using LDPC codes with 33% overhead.

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1. Introduction

Bandwidth-hungry Internet applications such as virtual reality and cloud computing have spurred research into advanced optical communication technologies [1]. Exploring new frequency bands to achieve higher capacity is gaining renewed research interest. The 2-µm band is especially appealing due to the availability of key enabling devices such as thulium-doped fibre amplifiers (TDFA) [2] and hollow-core fibres [3]. However, essential devices for transceivers in the 2-µm-band such as I/Q modulators and coherent receivers are still in their infancy. As a result, high-speed 2-µm-band transmission demonstrations are based on intensity-modulated direct-detection systems [4, 5]. However, advanced modulation formats and coherent detection are essential for a sustainable capacity increase.

In this paper, we propose and demonstrate the generation and self-heterodyne detection of a 2-µm-band 16-QAM signal. The 32-Gbit 16-QAM signals are generated in the 1.55-µm band, and then converted to the 2-µm band using four-wave mixing (FWM) in an AlGaAs on insulator (AlGaAsOI) nanowaveguide. The signal is then heterodyne-detected through one photodiode with an offset local oscillator converted together with the signal to the 2-µm band. Error-free performance is achieved with low-density parity-check (LDPC) codes with a 33% overhead.

2. The AlGaAsOI nanowaveguide

We use an AlGaAsOI nanowaveguide to perform the wavelength conversion due to its large nonlinearity [6], large conversion bandwidth [7], and high conversion efficiency (CE) [8]. The AlGaAsOI (21% aluminium concentration) nanowaveguide is designed to be 350 nm high and 920 nm wide so that the zero-dispersion wavelength (ZDW) is engineered to be close to 1739 nm. The waveguide is inversely tapered at the input facet to ensure fundamental-mode excitation. The AlGaAsOI wafer was fabricated using wafer-bonding and substrate removal [9]. The waveguide is patterned by optimized electron-beam lithography using HSQ resist followed by dry-etching [10].

3. Experimental setups and results

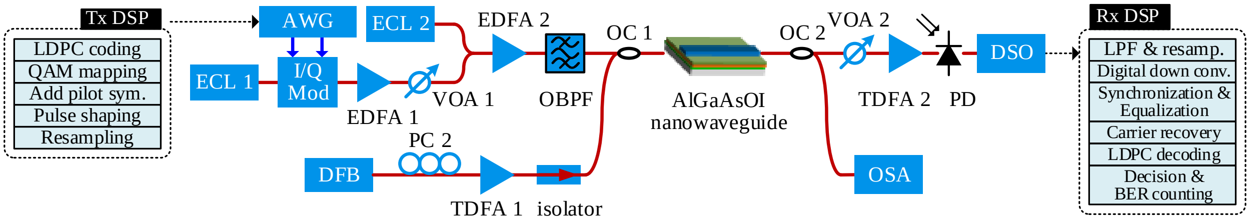

Fig. 1 Experimental setup

Figure 1 shows the experimental setup. The 16-QAM signal is generated at 1550.12 nm using an external cavity laser (ECL 1) and an I/Q modulator. The 8 Gbaud I/Q signals are generated from an arbitrary waveform generator (AWG) with a sampling rate of 64 GSa/s and a symbol length of 131072. The digital signal processing (DSP) at the transmitter side includes LDPC coding with 33% overhead, QAM mapping, addition of pilot symbols (20%), pulse shaping with a roll-off factor of 0.01, and resampling. The pilot symbols are used for eliminating cycle slips originating from the phase noise of the pump laser. The 16-QAM signal is then combined with another continuous wave (CW) beam from ECL 2 with 12-GHz offset which acts as a local oscillator later for heterodyne detection. The CW beam is adjusted to be 6dB higher than signal by a variable optical attenuator (VOA 1). Then the signal and the CW are combined with the 1739nm pump beam, which is generated from a DFB laser followed by an in-house made TDFA (TDFA1). The launched power into the AlGaAsOI chip is 15 dBm and 23 dBm for the signal (including the CW) and the pump, with fibre-to-fibre coupling losses of 10 dB and 11.2 dB, respectively. The generated 2-µm-band idler (16-QAM signal with an offset CW) is launched into the optically preamplified self-heterodyne receiver, consisting of VOA 2, TDFA 2 and a 2-µm-band photodiode (PD) with a 20-GHz bandwidth. TDFA 2 also acts as a filter to suppress the signal and the pump. A digital storage oscilloscope with 160-GSa/s sampling rate and 63-GHz bandwidth is used to record the data. Four 4-million-sample records per each evaluated power are used for offline DSP, mainly including digital down-conversion, adaptive linear equalization based on the multi-modulus algorithm, carrier recovery based on decision-directed phase-locked loop, as well as LDPC decoding.

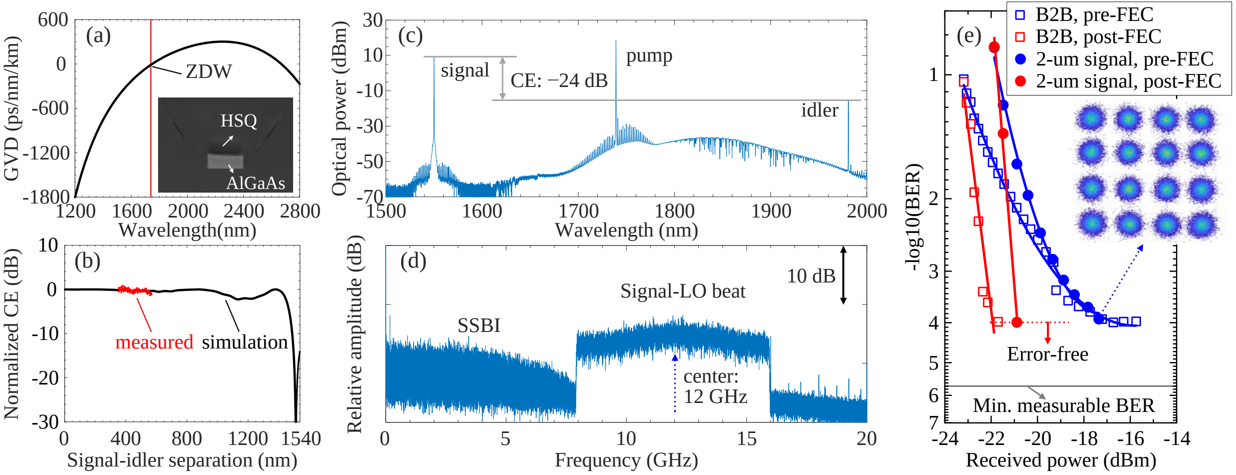

Fig. 2 (a) Simulated dispersion profile of the AlGaAsOI nanowaveguide (inset: the SEM image of the cross-section of the fabricated waveguide, HSQ: hydrogen silsesquioxane); (b) Simulated and measured normalized conversion efficiency; (c) Spectra of the wavelength conversion; (d) Detected electrical spectrum of the 16-QAM signal; (e) BER results of the B2B and converted 16-QAM signals.

The simulated dispersion profile of the waveguide in Fig. 2(a) confirms that the ZDW is close to 1739 nm. In Fig. 2 (b), the simulation indicates that this 5mm-long AlGaAsOI nanowaveguide is capable of supporting an ultra-broad continuous conversion bandwidth over 1000 nm by high-order phase matching [7,11]. The measured normalized CE further verifies the flatness of the CE within the C band. The conversion efficiency of −24 dB in the experiment is achieved with an on-chip pump power of 60 mW and the generated idler at 1981nm is shown in Fig. 2(c). Fig. 2(d) shows the electrical spectrum of the photo-detected signal. The 16-QAM signal and the offset local oscillator are simultaneously wavelength converted and result in a 12-GHz offset in the received electrical spectrum. The signal-signal beat interference (SSBI) occupies the low-frequency region and is digitally filtered out [12]. Then digital down-conversion and signal processing are performed. The BER results in Fig. 2(e) show negligible penalty for a receiver sensitivity at a BER of 10^{-3} between back-to-back (B2B) and wavelength converted signals before LDPC decoding. A 1 dB receiver sensitivity penalty at a BER level of 10^{-4} was observed after the LDPC decoding. The inset of Fig. 2(e) shows the signal constellation after wavelength conversion at a received power of −18 dBm. Error-free performance is achieved for both scenarios with LDPC decoding at a received power > −19 dBm.

4. Conclusion

We have successfully demonstrated the generation and self-heterodyne detection of a 2-µm-band 16-QAM signal using broadband wavelength conversion in an AlGaAsOI nanowaveguide. The 32-Gbit/s line-rate 16-QAM signal was generated in the 1.55-µm band, and then converted to the 2-µm band with an offset local oscillation. Error-free performance is achieved using LDPC codes with 33% overhead.

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5. References

[1] T. Morioka, in OECC 2009, p. FT4.
[2] Z. Li et al., Opt. Express 21, 26450–26455 (2013).
[3] P. J. Roberts et al., Opt. Express 13, 236–244 (2005).
[4] H. Zhang et al., Opt. Express 23, 4946–4951 (2015).
[5] Z. Liu et al., J. Light. Technol. 33, 1373–1379 (2015).
[6] M. Pu et al., Optica 3, 823 (2016).
[7] Y. Liu et al., in CLEO 2019, p. JTu2A.83.
[8] D. Kong et al., in OFC 2019, p. W4F.3.
[9] L. Ottaviano et al., Opt. Lett. 41, 3996 (2016).
[10] Y. Zheng et al., J. Light. Technol. **37**, 868–874 (2019).
[11] M. Pu et al., Laser Photon. Rev. 12, 1800111 (2018).
[12] A. J. Lowery et al., Opt. Express 14, 2079–2084 (2006)