2-µm-band Coherent Transmission of Nyquist-WDM 16-QAM Signal by On-chip Spectral Translation

**Deming Kong(1), Yong Liu(1), Zhengqi Ren(2), Yongmin Jung(2), Chanju Kim(1),
Yong Chen(2), Natalie Wheeler(2), Minhao Pu(1), Kresten Yvind(1), Michael Galili(1),
Leif K Oxenløwe(1), David J Richardson(2), and Hao Hu(1)**
(1) DTU Fotonik, Technical University of Denmark, DK-2800, Kgs. Lyngby, Denmark,
(2) Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK
dmkon@fotonik.dtu.dk, huhao@fotonik.dtu.dk

Abstract: We propose and demonstrate the first low-latency 2-µm-band coherent N-WDM transmission by on-chip spectral translation of 4×32-Gbaud 16-QAM signals with 33-GHz spacing. 318.25 Gbit/s net-rate is achieved with error-free performance after 1.15-km hollow-core fiber transmission.

Attempts to open-up new frequency bands for a sustainable capacity increase are attracting significant interest. The 2-µm spectral window is currently a leading contender due to the emerging of high-gain, low-noise thulium-doped fibre amplifier (TDFA) [1], and low-loss, low-latency, low-nonlinearity hollow-core fibre (HCF) [2]. This band is also attractive for silicon photonics for reduced two-photon absorption [3]. Recent demonstrations of 2-µm-band transmission have focused on intensity-modulated direct-detection (IM/DD) [4, 5] due to current lack of I/Q modulators and coherent receivers in this band. These IM/DD systems suffer from low capacity and low spectral efficiency, and are vulnerable from transmission impairments such as chromatic dispersion.

In this paper, we propose and demonstrate 2-µm-band coherent transmission of a Nyquist-WDM (N-WDM) signal by on-chip spectral translation using AlGaAsOI nanowaveguides and a specialized 1.74-µm TDFA. We spectrally translate the 1.55-µm signal to and back from the 2-µm band at the transmitter-side and receiver side, bridging these two bands together. Using a 1.15-km HCF, we are able to transmit the 2-µm-band 4×32 Gbaud 16-QAM signals spaced at 33 GHz with a latency of 3.82 µs. With low-density parity-check (LDPC) code, error-free performance is achieved for all four channels. We achieve a net rate of 318.25 Gbit/s and a spectral efficiency of 2.42 bit/s/Hz. To the best of our knowledge, this is the first demonstration of a 2-µm-band coherent N-WDM transmission system with a record-high rate and spectral efficiency.

The principle is to bridge the 1.55-µm band and the 2-µm band by spectrally translating the N-WDM signal using degenerate four-wave mixing, avoiding the need for bespoke a 2-µm-band N-WDM transmitter and coherent receiver [6]. This, however, requires a strong pump in the 1.74-µm region, and a nonlinear platform for 450-nm translation bandwidth with high conversion efficiency (CE). We developed an all-fibre short-wavelength TDFA with a gain profile centred around 1739 nm, achieving an output power higher than 500 mW [7]. We designed and fabricated the AlGaAsOI nanowaveguides (350 nm in height, 920 nm in width, 5-mm long) with a zero-dispersion wavelength around 1739 nm and a flat conversion band $>$1000 nm [8].

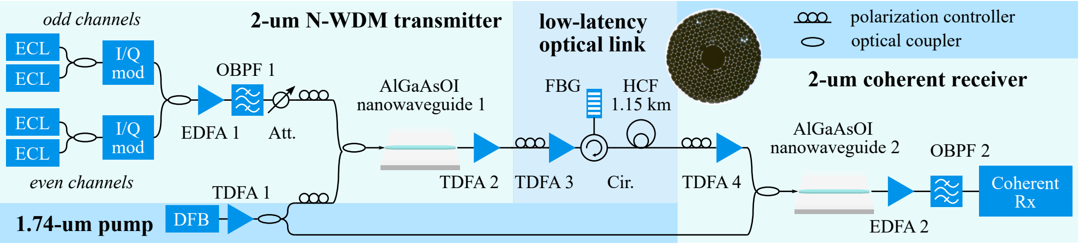

Fig. 1: Experiment setup. (ECL: external cavity laser; EDFA: erbium-doped fibre amplifier; Att.: attenuator, Cir.: circulator; DFB: distributed feedback laser.)

Figure 1 shows the experimental setup. A 1.55-µm 4×32 Gbaud 16-QAM N-WDM signal is generated by four ECLs grouped to odd and even channels and two I/Q modulators with independent data encoded with LDPC block codes from the DVB-S2 standard with 33% overhead. The N-WDM signal is launched into the first AlGaAsOI nanowaveguide with the 1.74-µm pump, being translated to a central wavelength of 1980.58 nm. TDFA 2 passes and amplifies the generated 2-µm signal. A DFB laser at 1739.74 nm with 2-MHz linewidth together with our in-house made TDFA [7] (TDFA 1) gives the 1.74-µm CW pump, which splits into two with 20.5-dBm and 19.3-dBm optical power for the 2-µm-band N-WDM signal and 2-µm-band coherent detection, respectively.

The 2-µm-band N-WDM signal is transmitted through a low-latency optical link, consisting of TDFA 3, a fibre bragg grating (FBG) with 4-nm bandwidth with a circulator, and the 1.15-km HCF. The launch power to the HCF is 15 dBm. The inset of Fig. 1 shows the cross-sectional image of the HCF (i.e. 19-cell hollow core photonic bandgap fibre with 3-dB transmission window from 1959 nm to 2045 nm [2]). The HCF has a loss of 2.8 dB/km but it is spliced with two SSMF patchcords, giving an overall loss of 9 dB. Despite some inaccuracy in the exact length of the HCF and our measurement method, the latency of the HCF is 3.82 µs. Compared with 5.69-µs latency for 1.55-µm-band transmission in the SSMF of the same length, an improvement of 33% is achieved as anticipated.

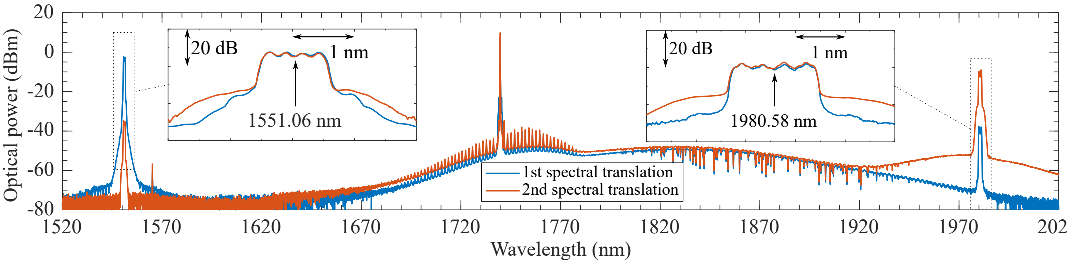

Fig. 2: Optical spectra of (a) the first spectral translation stage, and (b) the second spectral translation stage.

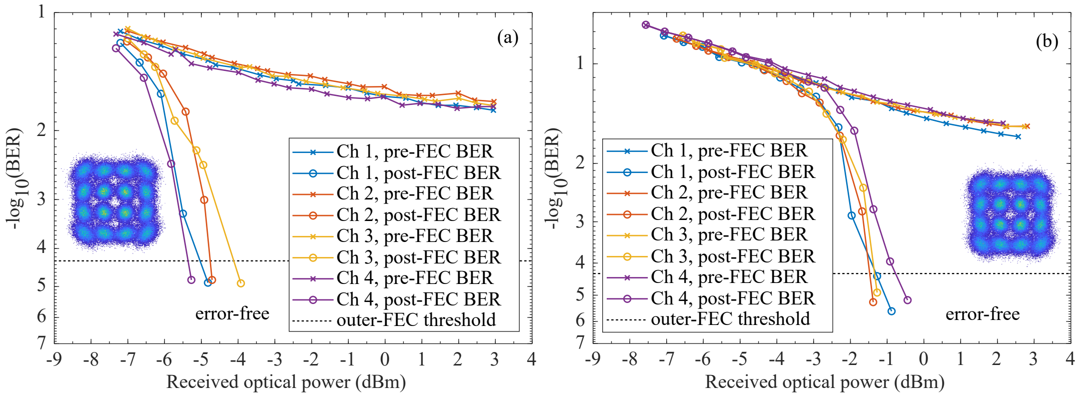

Fig. 3: BER performance of the 2-µm-band N-WDM signal (a) at BtB, and (b) after 1.15-km of HCF transmission.

After transmission, the 2-µm-band N-WDM signal is amplified and launched into a second AlGaAsOI nanowaveguide with the 1.74-µm pump and spectrally translated back to the 1.55-µm band. EDFA 2 amplifies and passes the 1.55-µm signal. The N-WDM signal is then launched into a coherent receiver with 80-GSa/s sampling rate and 32-GHz analogue bandwidth. Five 2-million-sample records for each received power of each N-WDM channel are offline processed with pilot-aided DSP algorithms. A 20% pilot overhead is used to eliminate any cycle slips due to the large linewidth of the pump DFB laser. The recovered signal is LDPC decoded to evaluate performance. Note that the received power is measured before TDFA 4, for the 2-µm-band coherent receiver.

Figure 2 shows the optical spectra from the spectral translations at the 2-µm signal generation and detection side. Insets shows the optical spectra of the signals and idlers. We have achieved an out-of-chip CE of -34.5 dB for the transmitter and a CE of -24.5 dB for the receiver. The difference is due to the fact that the 2-µm signal is larger in coupling loss and waveguide loss.

Figure 3 (a) and (b) show the BER performance of the 2-µm-band 4×32 Gbaud N-WDM signal, at back-to-back (BtB) and after transmission, respectively. Note that the receiver includes the spectral translation from the 2-µm band back to 1.55-µm band, and a 1.55-µm-band coherent receiver, as shown in Fig. 1. All four N-WDM channels exhibit error-free performance after LDPC decoding. A 0.8% outer hard-decision forward error-correction (HD-FEC) code is assumed to eliminate any remaining errors and the well-known BER floor after LDPC decoding. Excluding these FEC overheads and the 20% pilot overhead, a net rate of 318.25 Gbit/s is realized with a spectral efficiency of 2.42 bit/s/Hz. A transmission penalty of 4.5 dB in terms of receiver power is observed.

We have proposed a novel low-latency 2-µm-band coherent N-WDM transmission system enabled by spectral translation. Using AlGaAsOI nanowaveguides and a specialized 1.74-µm-band TDFA, we have effectively built a 2-µm-band N-WDM transmitter and a 2-µm-band coherent receiver. We have demonstrated N-WDM 16-QAM transmission through a 1.15-km length of HCF, achieving a record-high net rate of 318.25 Gbit/s and a spectral efficiency of 2.42 bit/s/Hz.

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