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Wideband QAM-OFDM with Hybrid Integrated InP-Si_3N_4 Tunable Laser Source for Short-reach Systems

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Abstract *We demonstrate a record high transmission rate of 160 Gbps with 32 GHz 32QAM and 40 GHz 16QAM OFDM signal (over C-band) using a wavelength-tunable InP-Si_3N_4 laser source for short-reach application. We successfully show the performance is within the standard FEC limits.*

Introduction

The continuous evolution of technology coupled with devices offering cloud-based services have induced a massive traffic flow through the data center (DC) networks. This necessitates a shift towards using higher transmission capacity per lane by utilizing higher bandwidths and higher-order modulation formats in the DCs. Moreover, integrated optical solutions that can reduce the power consumption and cost of the DCs need to be employed[1]. Scaling capacities with single-carrier transmission entails stringent optimization at the transmitter, higher bit resolution samplers and larger signal to noise ratio at the receiver. Use of multi-carrier transmission schemes like orthogonal frequency division multiplexing (OFDM) would be advantageous over pulse amplitude modulation (PAM) options as they exhibit flexible data assignment to subcarriers with software controllable subcarrier spacing, no change in the receiver side signal processing and allows the use of different flavours of OFDM that can optimise throughput or system complexity.[2] .

The choice of the laser used for the transmission is also a critical factor that decides the performance limits. For intensity-modulation direct detection (IM-DD) systems, relative intensity noise (RIN) is an important parameter that decides the performance limits when scaling the order of modulation[3]. In the past demonstrations, integrable VCSELs with -140dB/Hz RIN were deployed for the transmission of 100 Gbps 16QAM OFDM over a short distance of 100 m[4] and a single mode tunable DFB laser has been used for transmission of 178 Gbps OFDM over 2 km[5]. Authors in[6] have reported a 200 Gbps transmission over 1.6 km for a high receiver power of 7 dBm.

In this work, for the first time, we have demonstrated the transmission of wideband 40 GHz 16QAM and 32 GHz 32QAM OFDM signals with a (record high) data rate of 160 Gbps using a InP-Si_3N_4 hybrid integrated dual laser module over a 1 km short-reach link and show the performance within the standard FEC limits at lower received power levels than previously observed. Being a silicon photonic (SiP) integrated circuit, this device has a compact size, high yield, a potential for mass production and photonic integration with other SiP components.

Laser Description and Experimental Setup

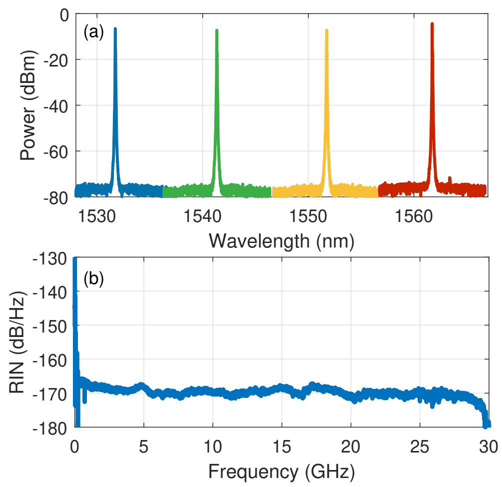

Fig. 1: (a) Superimposed spectra of the optical carrier used in this demonstration using the DLM and (b) the typical RIN of the DLM optical carrier at 1551.12 nm.

The dual laser module (DLM) comprises two on-chip external cavity lasers, each laser having an independent InP semiconductor optical amplifier (SOA) hybridly coupled to a Si_3N_4 feedback circuit. A detailed description of this widely tunable and low noise device is given in our previous work[3]. In this work, we have tuned one of the

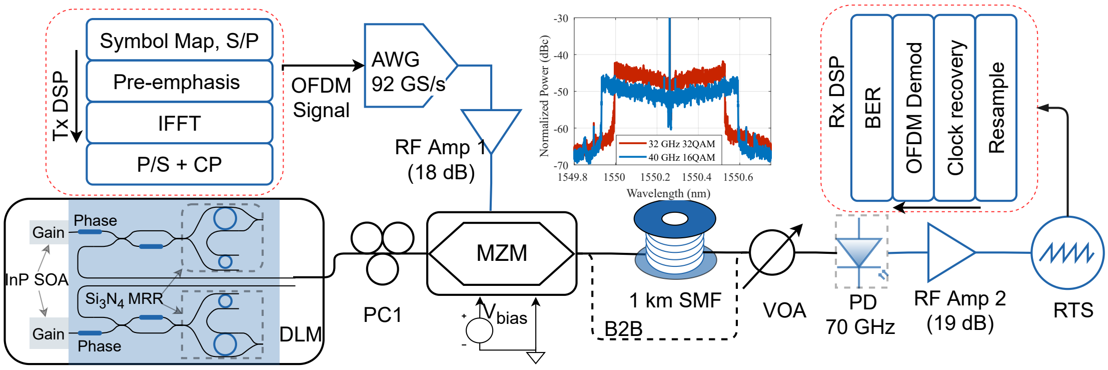

Fig. 2: Schematic of the experimental setup for the demonstration of wideband OFDM transmission using InP-Si_3N_4 laser.

lasers of DLM over the C-band, as shown in Fig. 1 (a), by setting the gain current to 170 mA and fine-tuning the voltages to the micro-heaters associated with the phase section, feedback circuit and on-chip tunable couplers. The RIN measured for the optical output from the DLM shown as in Fig. 1 (b) was extremely low ≈-169 dB/Hz. The lower values of RIN compared to that in[3] are due to the increase in the current to the gain section of the laser.

The schematic of the experimental setup for the transmission of 160 Gbps using the integrated hybrid InP-Si_3N_4 tunable laser module is shown in Fig. 2. To generate the OFDM signal, a PRBS-17 bit sequence was first mapped to 16QAM/32QAM symbols. The serial data is then parallelized, and a digital pre-distortion is applied to boost the power of higher frequency components, as shown in Fig. 3. The signal in the frequency domain

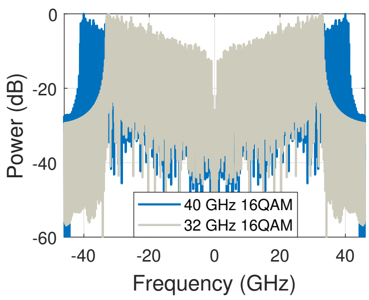

Fig. 3: Spectrum of the 32 GHz and 40 GHz signal at the transmitter with digital pre-distortion.

consists of 256 subcarriers with ≈360 MHz spacing, loaded with symbols on 180 (32 GHz) or 224 (40 GHz) subcarriers (considering Hermitian-symmetry), along with a guard band of 5 zero subcarriers around DC and 71 (32 GHz case) or 29 (40 GHz case) outer subcarriers. This signal is transferred to the time-domain by performing an inverse fast Fourier transform (IFFT) operation. This parallel data is then converted to serial data and a 16 samples cyclic prefix (CP) guard interval was added. Amplitude clipping with a clipping ratio of 4 was performed to reduce the peak to average power ratio (PAPR). Each frame of the data consists of 100 OFDM symbols, and for the 40 GHz and 32 GHz signals the net data rate of transmission was 160 Gbps.

An external cavity laser (ECL with -170 dBc/Hz RIN at 1550.12 nm as a reference) and/or the DLM at specific wavelength was fed to the MZM (40 GHz). The MZM was driven by the electrical OFDM signal generated by 92 GS/s arbitrary waveform generator (AWG) and amplified by an RF amplifier (18 dB gain). The modulated signal (optical spectrum shown as an inset in Fig. 3) was then transmitted in back-to-back (B2B) and 1 km single mode fiber (SMF) (launch power of 3 dBm) configurations, and passed through a variable optical attenuator (VOA) before it was detected by a 70 GHz photodetector. The detected signal was then amplified by an RF amplifier (19 dB gain), fed to the real-time scope (RTS) (200 GS/s), and was further processed for performance evaluation.

In the offline processing, the captured data were first normalized and then re-sampled to have exactly 1 sample per subcarrier. Frame synchronization based on the standard correlation technique with the transmitted frame was performed to locate the start of the frame in the received data. The CP in each symbol was first removed and the signal was converted from time-domain to frequency-domain by performing FFT operation. Channel estimation with spectral averaging was performed using the first five transmitted and received frame symbols. Next, channel equalization was performed over the frequency domain information symbols. Symbols are then de-mapped to bit sequences, and the BER performance was evaluated for each received power values.

Results and Discussion

Figures 4 (a) and (b) shows the BER performance of the 32 GHz 32QAM signal performance with ECL and DLM (at different wavelengths) in B2B

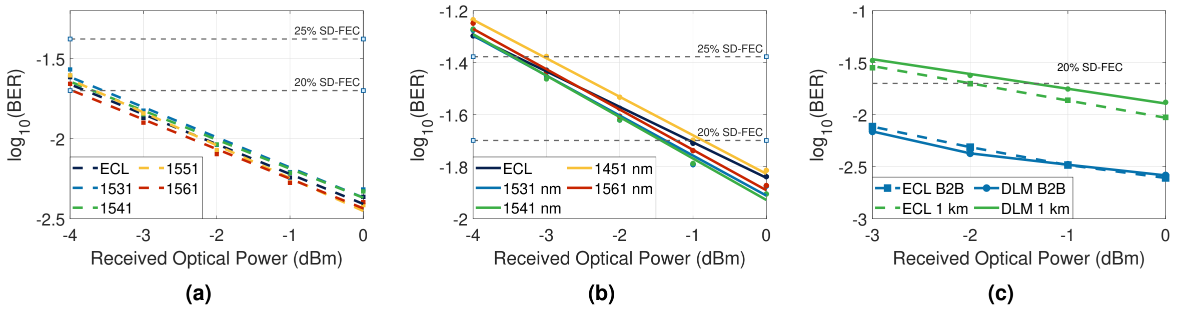

Fig. 4: BER performance of 32 GHz 32QAM-OFDM signal in (b) B2B and (b) after 1 km SMF transmission, evaluated at various wavelength across C-band, and (c) BER performance of 40 GHz 16 QAM-OFDM signal.

and 1 km SMF configurations, respectively. The plot also shows the reference soft-decision FEC (SD-FEC) lines at a BER of 2×10^{-2} and 4.2×10^{-2} at 20% and 25% overhead, respectively. For the B2B configuration, the BER performance of signal from ECL and the four wavelengths from DLM is within the 20% SD-FEC limit for received power $>$ -4 dBm. For the fiber transmission case, the performance is within the 25% SD-FEC limit for received power $>$ -3 dBm.

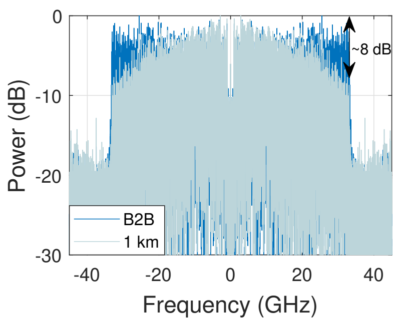

Fig. 5: Effect of dispersive fading on the spectrum of the received 32 GHz signal after 1 km SMF transmission.

We also observe a penalty of about 2.2 dB w.r.t B2B transmission, and this is mainly due to the dispersive fading. The enhanced fading effect of about 8 dB power reduction for the highest frequency subcarrier, as observed from the Fig. 5, is due to the fact that the occupied optical bandwidth spans to 64 GHz due to Hermitian symmetric nature of the signal, despite having 32 GHz information content. Due to the effect of fading, the signal to interference noise ratio is reduced, especially at higher frequencies, and hence the performance is degraded. Figure 4 (c) shows the BER performance of the 40 GHz 16QAM signal with ECL and DLM in B2B and 1 km SMF configuration, respectively, and the performance is within 25% SD-FEC limit for received power $>$ -2.5 dBm.

The scatter plots of the successfully equalized 32QAM and 16QAM signals after 1 km SMF at a received power of -1 dBm are shown in Fig. 6. The performance can be further improved by employing single-sideband modulation, which not

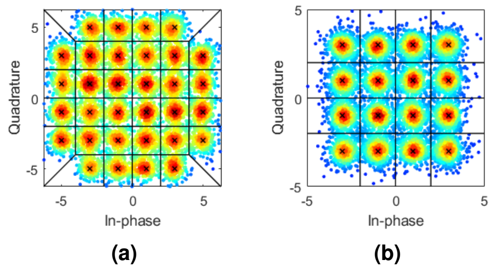

Fig. 6: Scatterplot of (a) 32 GHz 32QAM-OFDM and (b) 40 GHz 16 QAM-OFDM signals after 1 km SMF transmission.

only reduces the effect of fading but also improves the reach and spectral efficiency, especially in multi-channel systems. In addition, use of a non-linear equalizer along with transmitter digital pre-distortion and a simple single-tap equalizer could further enhance the performance.

Conclusions

Increasing capacity per lane in short-reach systems, especially in DC applications, has become a necessity. With the ability of photonic integration and wide wavelength tuning capability, the InP-Si_3N_4 hybrid integrated DLM could potentially be deployed for simple optical-domain reconfigurable wideband multi-channel systems. Integration of Si photonics based modulators and lasers will result in low power-driven and cost-effective pluggable transmitters for high data rate intra/inter the DC links[7]. The results presented here for 160 Gbps per channel (across C-band) with 32 GHz and 40 GHz signals, demonstrate the significant potential of wideband OFDM systems modulated using symbols of higher cardinality (16QAM and 32QAM) and employing tunable and low RIN laser for high capacity, short reach systems.

Acknowledgements

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