69 Gb/s DMT direct modulation of a Heterogeneously Integrated InP-on-Si DFB Laser

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Abstract: A heterogeneously integrated InP-on-Si DFB laser, with direct modulation bandwidth of 21GHz has been used for the generation of a 69Gb/s discrete multi-tone signal. Transmission at 56Gb/s over 5 km SSMF is demonstrated as well.

OCIS codes: (130.3120) Integrated optics devices; (140.5960) Semiconductor laser; (230.0230) Optical devices.

1. Introduction

Emerging applications such as high definition video streaming and cloud computing are the main drivers for the user-driven increase in the Internet traffic for the past few years. This has led to an increase in the processing capacity of the data centers demanding high-speed intra-datacenter communication links [1]. To address the expected growth of such short reach high speed links, the use of Wavelength Division Multiplexing (WDM) [2] and advanced modulation formats such as Quadrature Amplitude Modulation (QAM), multiband Carrierless Amplitude Phase Modulation (multi-CAP), Pulse Amplitude Modulation (PAM), and Discrete Multi-Tone (DMT) modulation [3,4] have been reported. Among these approaches, DMT has gained a lot of attention recently due to its ability to deliver 100G transmission using as low as ~20GHz optical devices [5].

Important considerations for such short reach communication links are low cost, small form factor and low power consumption. Silicon photonics is an emerging technology expected to deliver these attributes. Recently, data rates of 400 Gb/s by multiplexing 4 channels [5] and 0.88 Tb/s by multiplexing 10 channels [6] have been reported using silicon photonics. The power consumption of the optical frontend and footprint can be further reduced by implementing Directly Modulated Lasers (DMLs) on a heterogeneously integrated InP-on-Si platform [7]. Further more such lasers have been shown recently to have state-of-the-art modulation bandwidth performance [8]. In this paper we demonstrate single channel 69 Gb/s DMT modulation using a directly modulated heterogeneously integrated InP-on-Si DFB laser.

2. Characteristic of the heterogeneously integrated DFB laser

The heterogeneous integration of the DFB laser is realized using adhesive bonding of unprocessed III-V epi on the Silicon-on-Insulator (SOI) circuit. DFB gratings are patterned on a 400 nm Silicon-on-Insulator (SOI) waveguide wafer by etching 180nm deep. The use of 400nm silicon guiding layer provides an efficient coupling between the III-V mesa and the Si rib waveguide. More details on the III-V processing can be found in [9].

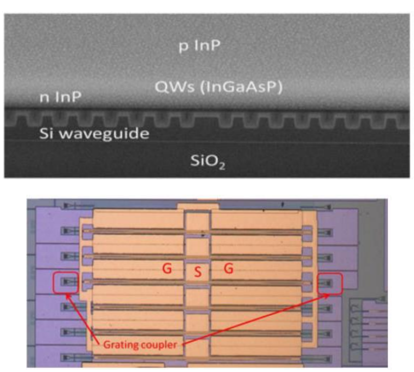

Fig. 1: Lateral view (top) and top view (bottom) for the fabricated device. The grating couplers and G-S-G contacts are marked in red.

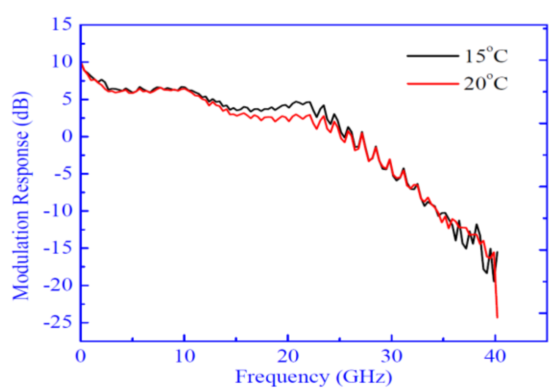

Fig. 2: Modulation response of the DFB laser measured at different temperatures using 100 mA bias current.

In Fig. 1 the lateral view (top) and top view (bottom) of the fabricated device is shown. In Fig. 2 the modulation response for the fabricated laser is shown at 15 ºC and 20 ºC. Contrary to other baseband transmission schemes, DMT requires a highly linear transmission channel [10]. Therefore linearity measurements for the fabricated DFB laser were performed. Two RF tones around 20 GHz are fed to the laser and the third order inter-modulation tones are measured on the spectrum analyzer. Since DMT is a multicarrier modulation scheme, therefore different information is transmitted in different parts of the spectrum. For this reason the 2nd, 3rd and higher order tones can land inside the signal bandwidth and cause interference. This leads to a decrease in the SNR for specific subcarriers. Figure 3 shows good linearity for even very high frequency (beyond 20 GHz) allowing higher bits/symbol for high frequency carriers.

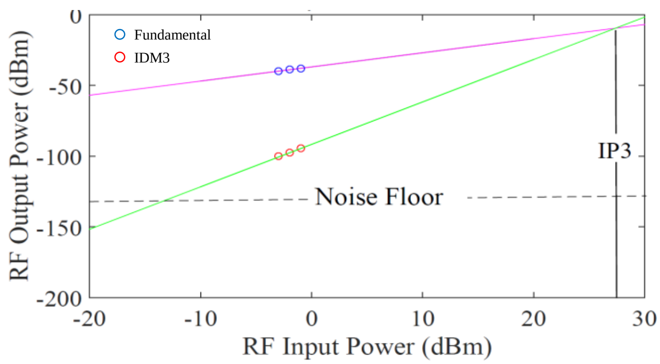

Fig 3. Linearity of the DFB laser performed at 20 GHz

3. DMT using Directly Modulated DFB Laser

DMT is a baseband multicarrier modulation scheme and is derived from Orthogonal Frequency Division Multiplexing (OFDM). In DMT or real valued OFDM the modulation format of each sub-carrier and power is individually optimized by adapting to the signal to noise ratio (SNR) of the transmission channel. The high speed data is divided into a number of low speed sub-channels operating at different frequencies, which is later transmitted simultaneously over the channel.

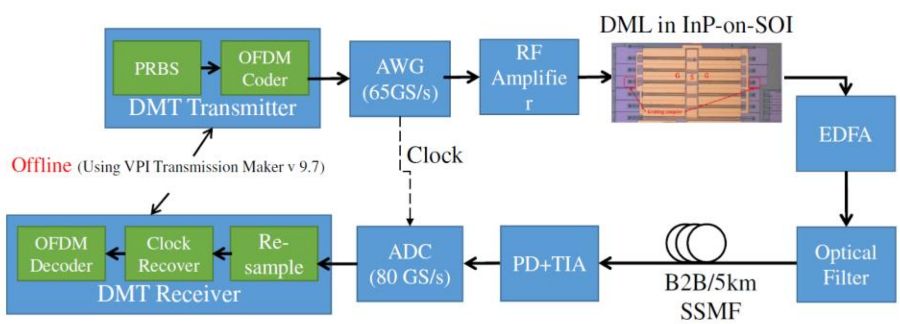

Fig. 4: Schematic representation of DMT transmission and detection.

Fig. 4 shows the schematic for the experimental setup. The DMT signal is generated offline by using VPI labExpert. This offline DMT transmitter consists of a Pseudo Random Bit Sequence (PRBS) generator, an OFDM coder having a cyclic prefix of 12.5% and a Nyquist filter. 1024 subcarriers are used to generate the DMT signal. Each subcarrier has a bandwidth of ~23 MHz. The first subcarrier as well as the last 60 subcarriers are turned off. The signal from the offline transmitter is fed to a 65GS/s Arbitrary Waveform Generator (AWG Keysight M8195A). The signal is amplified by a broadband SHF-S708 high speed RF amplifier. A low noise DC current is combined with the RF data using a bias-tee and the output is used to drive the laser through a GSG RF probe. The laser is biased at 100 mA and a 1.5 Vpp data signal is used. Due to the strong mismatch between the laser impedance and the 50 Ohm transmission line, the actual voltage swing on the laser is estimated to be 0.5 V. The laser is operated at 20 ºC and has a fiber coupled output optical power of ~ -2 dBm (5dBm in silicon waveguide) with a 3dB bandwidth of ~ 21 GHz. An Erbium Doped Fiber Amplifier (EDFA) is used to boost the optical signal, which is fed to an optical filter and a 5 km span of Standard Single Mode Fiber (SSMF) before direct detection by a commercial receiver with a bandwidth

of 32 GHz. The output of the TIA is connected to the real time oscilloscope (Keysight DSA-Z63). Like the DMT transmitter, the DMT receiver is offline. A 100 MHz clock signal is fed to the real time oscilloscope in master slave configuration to provide clock synchronization.
To optimize the transmission capacity, both bit and power loading can be used for DMT modulation. In this experiment no power loading has been applied and all the sub-carriers have the same power. The bit loading is performed by first transmitting an equal number of bits/symbol on all carriers. Later on an optimum number of bits/symbol for each sub-carrier is computed to meet the target BER of $1.5x10^{-2}$ [6]. The B2B DMT system has reached a maximum transmission of 69 Gb/s with a net data rate of ~ 60 Gb/s. For DMT transmission using 5 km of SSMF, 56.8 Gb/s transmission (net data rate of ~ 50 Gb/s) has been achieved. The bit loading for the B2B and the transmission link with 5km of SSMF is shown in Fig. 4 and Fig. 5 respectively. The reduced data rate for the 5 km long span is due to the frequency fading in the channel transmission spectrum resulting from the chirp of the laser and chromatic dispersion of the fiber.

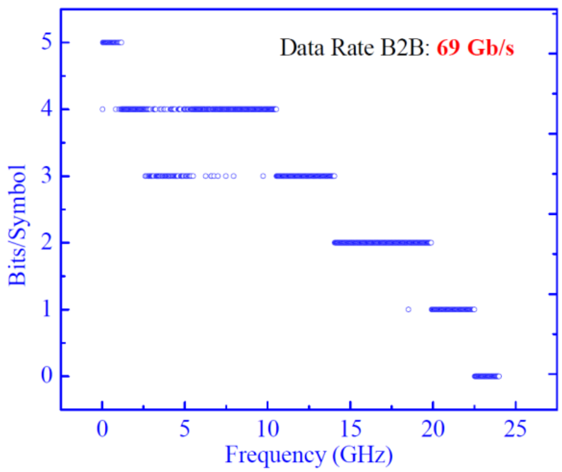

Fig. 4: Allocation of bits/symbol for B2B transmission of DMT modulated data

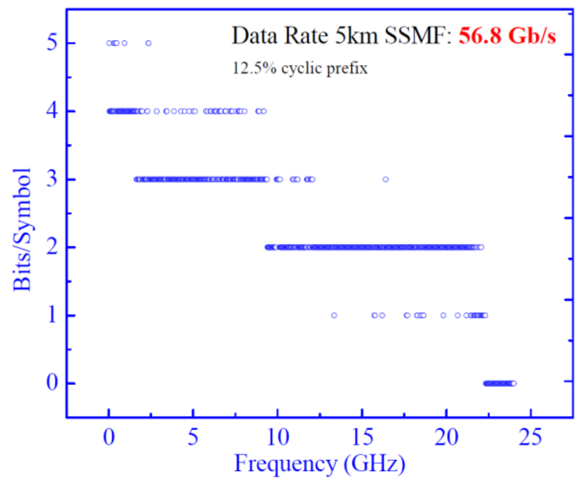

Fig. 5: Allocation of bits/symbol for transmission of DMT modulated data through 5 km of SSMF

4. Conclusion

We have demonstrated DMT transmission of 69 Gb/s in B2B and 56 Gb/s over 5 km SSMF using heterogeneously integrated InP-on-Si DFB laser. These data rates are obtained by optimized bit loading. Further improvement in transmission capacity is possible by using power loading.

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References

[1] C. Kachris, K. Bergman, I. Tomkos, Optical Interconnects for future data center networks (Springer, 2013), Chap. 1.
[2] Y. Matsui et al, "112-Gb/s WDM link using two Directly Modulated Al-MQW BH DFB Lasers at 56 Gb/s," in Optical Fiber Communication Conference Post Deadline Papers, 2015, paper Th5B.6.
[3] T. Tanaka et al., "Experimental demonstration of 448-Gbps+ DMT transmission over 30-km SMF," Optical Fiber Communications Conference and Exhibition (OFC), 2014, San Francisco, CA, 2014, pp. 1-3.
[4] Krzysztof Szczerba et al., "70 Gbps 4-PAM and 56 Gbps 8-PAM Using an 850 nm VCSEL," J. Lightwave Technol. 33, 1395-1401 , 2015.
[5] P. Dong et al., "Four-Channel 100-Gb/s per Channel Discrete Multi-Tone Modulation Using Silicon Photonic Integrated Circuits," in Optical Fiber Communication Conference Post Deadline Papers, 2015, paper Th5B.4.
[6] P. Dong et al., "Ten-Channel Discrete Multi-Tone Modulation Using Silicon Microring Modulator Array," in Optical Fiber Communication Conference, 2016, paper W4J.4.
[7] A. Abbasi et al., "28 Gb/s direct modulation heterogeneously integrated C-band InP/SOI DFB laser," Opt. Express 23, 26479-26485 , 2015.
[8] A. Abbasi et al., Enhanced Modulation Bandwidth of Heterogeneously Integrated III-V-on-silicon DFB Laser for 40 Gb/s NRZ-OOK Direct Modulation, International Semiconductor Laser Conference (ISLC), Japan, 2016.
[9] S. Keyvaninia et al., "Ultra-thin DVS-BCB adhesive bonding of III-V wafers, dies and multiple dies to a patterned silicon-on-insulator substrate," Opt. Mater. Express 3, 35-46 , 2013
[10] N. S. André et al., "Equalization techniques for high-speed OFDM-based access systems using direct modulation and direct detection," 2013 15th International Conference on Transparent Optical Networks (ICTON), Cartagena, 2013, pp. 1-6.