Optically switched 56 GBd PAM-4 using a hybrid InP-TriPleX integrated tunable laser based on silicon nitride micro-ring resonators

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Abstract: Tunable lasers are key elements for switching fabrics in future datacenter networks. Experimental results show transmission of 56 GBd PAM-4 data in a switching environment using an integrated silicon nitride micro-ring resonator based tunable laser.

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1. Introduction

Inter and intra-datacenter (DC) networks are experiencing an explosion in demand due to the proliferation of cloud based applications and the continued virtualization of networking functionality [1]. Current Ethernet based DC networking solutions cannot efficiently handle predicted traffic growth due to the inherent optical-electrical-optical (OEO) conversions, and so networking functionality must be shifted to the optical domain in order to efficiently handle extremely high bandwidth static and bursty data flows.

Silicon based micro-ring resonators (MRR) can be used for a multitude of optical functionalities as they can be controlled through thermal tuning, allowing reconfigurable networking, on a µs timescale, in the optical domain [2]. Indeed, they are an important building block in silicon photonics (SiP) which has been highlighted as a promising solution for the development of reconfigurable optical platforms, including DC networking [3]. Four level pulse amplitude modulation (PAM-4) is an attractive modulation scheme for DC networking as it represents a straightforward augmentation from non-return-to-zero (NRZ) standards while doubling spectral capacity and maintaining compatibility with optical direct detection systems. Recent works have demonstrated the use of PAM-4 transmission for short reach high bandwidth applications using external cavity (ECL) [2], distributed feedback (DFB) lasers [4] and vertical cavity surface emitting lasers (VCSEL) [5]. These sources can be bulky, expensive (ECL) and lack fast tuning/switching characteristics (ECL, DFB, VCSEL). Additionally, they are not suitable for integration with other silicon technologies/components, hindering their suitability for use in future reconfigurable DC networks. In this work, a MRR based tunable laser (TL) is used to perform optical switching of a 56 GBd (112 Gb/s) PAM-4 signal for the first time - indicating the TL's suitability for use in future agile DC networks.

2. InP-TriPleX Tunable Laser

The device structure is schematically shown as part of the setup diagram Fig. 1(a). The pigtailed hybrid laser assembly has two optimized optical interfaces: the InP gain section coupled to the TriPleX photonic integrated circuit (PIC), forming the hybrid tunable laser cavity; and the TriPleX PIC coupled to the polarisation maintaining (PM) fiber output. The InP based semiconductor optical amplifier (SOA) has a high reflective (HR) coated back-facet to reduce cavity losses, and a low reflectivity front facet to impose lasing on the external TriPleX cavity. Wavelength tuning is achieved through the Vernier effect which is imposed using the TriPleX waveguide circuit which consists of two cascaded MRRs with slightly different radii. The MRRs' radii and power coupling coefficients are chosen so that the free spectral range (FSR) of the mirror exceeds the 3 dB gain bandwidth of the SOA; thereby suppressing the spectral side peaks of the mirror response, avoiding lasing at undesired side modes [6]. The result is a highly frequency selective feedback mirror enforcing single-frequency operation. The device is capable of an output power of >10 dBm, side mode suppression ratio (SMSR) >50 dB and a 50 nm tuning range [7]. Relative intensity noise (RIN) is measured to be less than -130 dB/Hz [7] which is required for PAM [8].

3. Experimental Setup

The experimental setup is shown in Fig. 1(a). A pulse generator is used to 'clock' (frequency = 4 kHz) one of the MRRs with a square wave voltage. The high and low values of the driving signal correspond to the voltage levels

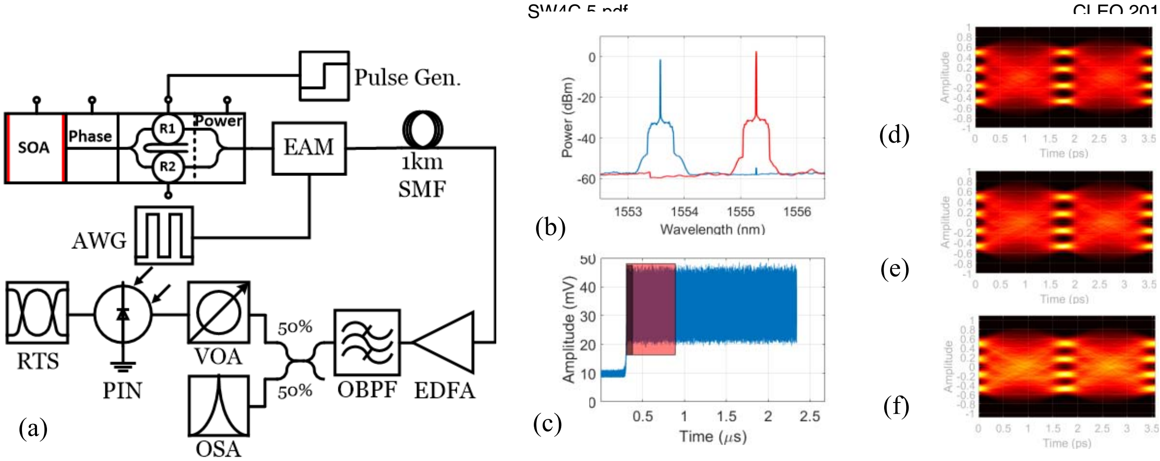

Fig. 1: (a) experimental setup, (b) optical spectrum showing switching wavelengths, (c) captured time domain modulated switching event, (d) PAM-4 eye diagram with 12.5% TS, (e) PAM-4 eye diagram with 1.5% TS and (f) PAM-4 eye diagram with 0.75% TS.

required to switch the laser, through thermal tuning of the MRR, between two adjacent wavelengths: 1553.6 nm and 1555.28 nm (Fig. 1 (b)). The +7 dBm output light signal was modulated with a 56 GBd PAM-4 signal -generated from an arbitrary waveform generator (AWG) sampling at 84 GSa/s - using an electro absorption modulator (EAM) and transmitted through 1 km of single mode fiber (SMF). The received signal was amplified using an Erbium doped fiber amplifier (EDFA) and the 1555.28 nm signal was isolated using an optical bandpass filter (OBPF). A variable optical attenuator (VOA) was used to set the power falling on the 70 GHz PIN to an average of 0 dBm and the electrical signal was captured using a 200 GS/s real time oscilloscope (RTS). A PAM sequence length of 2^{15} symbols was transmitted continuously and contained a training sequence (TS) used for synchronization and to aid convergence on the finite impulse response (FIR) equalizer (EQ) tap weights, using a decision directed least mean square (DD-LMS) algorithm. Bit error rate (BER) testing was completed offline.

4. Results

Fig. 1 (c) shows the captured time domain PAM-4 switching signal, where switching between the two wavelengths occurs on a µs timescale [7]. The overlaid red window corresponds to a complete data sequence which starts at the beginning of the data burst; which we define as the time at which the incoming burst reaches 90% of its steady state average amplitude. BER calculations are performed over this sequence as it is closest to the switching event. The TS is used to attain the optimum EQ taps weights and is situated at the beginning of each PAM sequence, so it follows that its length will have an impact on the overall performance of the sequence. Figs. 1 (d), (e) and (f) show received equalized 56 GBd PAM-4 eye diagrams using TS lengths of 12.5%, 1.5% and 0.75% of the overall sequence, respectively. A BER of 3.3×10^{-4} was achieved using a 12.5% TS. Reducing this length to 1.5% resulted in a small degradation in performance with BER measured to be 7.6×10^{-4}. A TS length of 0.75% raises the BER above the 7% forward error correction (FEC) limit (3.8×10^{-3}) to 4.6×10^{-3} as the switching transients have a greater impact on the TS, and hence the remainder of 112 Gb/s signal – the payload.

5. Conclusion

In future data center networks tunable lasers may be the key to enabling the critical requirement of network re-configurability in the optical domain. The hybrid InP-TriPleX TL based on silicon nitride MRRs used is not only suitable for integration with other silicon networking elements/sub-systems but, as the work described has shown, is capable of switching extremely high speed data, in µs timescales – a highly attractive feature for bursty DC environments. Results also show the robustness of PAM-4 to laser switching transients, as sufficient performance can be achieved using just a 1.5% TS, extracted immediately after a switching event.

6. References

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