1.3 µm all-VCSEL low complexity coherent detection scheme for high bit rate and high splitting ratio PONs

Roberto Rodes, Jesper Bevensee Jensen, Antonio Caballero and Idelfonso Tafur Monroy
DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Ørsteds Plads, B. 343, DK 2800 Kgs. Lyngby
email:rrlo@fotonik.dtu.dk

Abstract: Full 1.3 µm VCSEL-based simplified coherent detection receiver is demonstrated at 5 Gbps. Receiver sensitivity of -34 dBm is achieved providing link reach and splitting ratio extension for future passive optical access networks.

OCIS codes: 060.2330 Fiber optics communications, 140.7260 Vertical cavity surface emitting lasers, 060.1660 Coherent communications

1. Introduction

Passive optical networks (PONs) have become a dominant approach for fiber-to-the-customer (FTTC) network deployments. However, the demand for increasing bandwidth has raised the question of extending the reach, bit-rate and splitting ratio of conventional PON solutions designed for 20 km, 1.25-2.5 Gbps and splitting ratios up to 64 [1]. An interesting approach for extending the reach of PON networks is to consider optical coherent detection. This is motivated by the fact that coherent detection offers advantages on supporting closely spectrally spaced channels with electrical narrow bandwidth selection [2], increased receiver sensitivity [3] and support for advanced modulation formats [4]. However, it will still be important to reduce the cost of coherent networks and put them at the same level with traditional direct detection approaches in order to make them attractive for a real implementation in future wavelength division multiplexing (WDM) PONs.

Vertical cavity surface emitting lasers (VCSELs) are gaining attention for application in access networks due to lower manufacturing cost and lower power consumption than edge-emitter laser [5].

In this paper we propose an all-VCSEL low complexity transmitter and coherent receiver operating close to the zero dispersion wavelength of standards single mode fiber (SSMF) of 1.3 µm, chosen for its compatibility with the up-stream wavelength of PONs architectures. The optical transmitter is a directly modulated photonic bandgap GaInNAs VCSEL TOSA from Alight Technologies ApS. The coherent receiver is realized in a simple configuration using only a 3-dB coupler, local oscillator VCSEL of same type as the transmitter, and a single ended photodiode with the aim of maintaining the overall systems complexity reduced. We experimentally demonstrate the feasibility of our proposed approach in a 5 Gbps amplitude shift-keying (ASK) coherent link with transmission over 40 km of SSMF with no optical dispersion compensation, employing free running and un-cooled VCSEL operation for transmitter as well as local oscillator.

2. Experimental setup

Fig. 1 shows our experimental setup. A pulse pattern generator directly modulates a 1.3 µm VCSEL ($VCSEL_1$) at 5 Gbps. A balanced drive configuration is used for $VCSEL_1$ with a driving peak-peak voltage of 0.9 V. The bias current of $VCSEL_1$ is set to 11.7 mA for optimum performance maximizing the extinction ratio while minimizing pulse amplitude overshoot. The data pattern used for the experiment is a pseudo random binary sequence (PRBS) of length of 2^9-1. The average output power of the $VCSEL_1$ launched into the fiber is -0.7 dBm. The transmission experiment is over 40 km of SSMF with a total attenuation of 13.5 dB at 1.3 µm, and a total dispersion of -45 ps/nm. In order to measure the optical power going into the coherent receiver, a variable optical attenuator (VOA), a 20 dB coupler and an optical power meter are placed after the transmission fiber. Due to the low chromatic dispersion in the spectral region of 1.3 µm, dispersion compensation can be omitted, and the in-phase and quadrature components of the signal are not required in the coherent demodulator. Therefore, the coherent scheme can be simplified from a conventional 90^o hybrid scheme to a simpler one composed of a light source as local oscillator (LO), a 3 dB coupler to do the beating between the received signal and the LO, a photodiode and a subsequent envelope detector. The LO signal is generated by another free running, continuous wave, 1.3 µm VCSEL ($VCSEL_2$). The LO $VCSEL_2$ has been wavelength tuned to match the wavelength of the transmitting $VCSEL_1$ at 1274 nm by adjusting the bias level to 13 mA for intradyne detection. The insertion in Fig. 1 shows the measured optical power spectrum of the signal and the LO. Due to the intradyne detection scheme, the signal spectrum is partially masked by the spectrum of the LO.

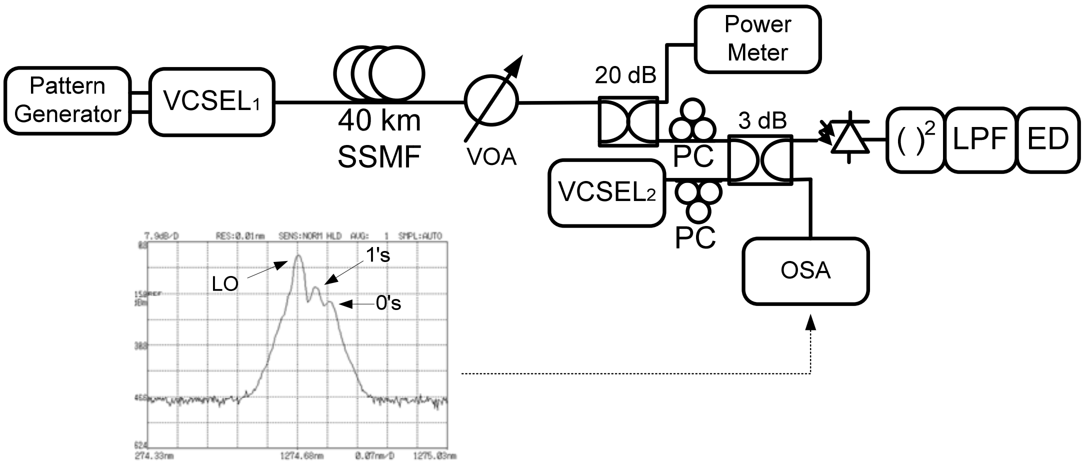


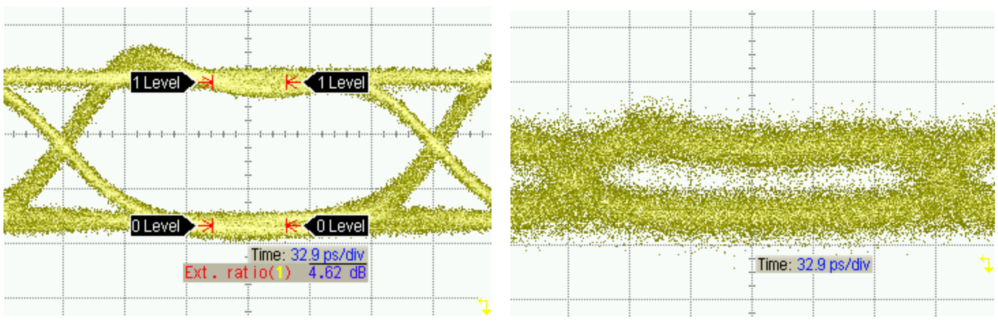
Figure 1: Experimental setup. Local oscillator (LO), optical spectrum analyzer (OSA), polarization controller (PC), variable optical attenuator (VOA), low pass filter (LPF), error detector (ED). The insertion shows the measured combined optical power spectrum of the signal and the LO.

The wavelength tuning range of $VCSEL_2$ was measured to be 5 nm from 1271.1 nm to 1275.8 nm by varying the bias current from 5 mA to 16 mA. This demonstrates the feasibility of bias current wavelength tuning of VCSELs employed as local oscillators in coherent networks. The optical output power of the LO varies from 0.32 mW to 0.85 mW.

The coherent receiver used electronic envelope detection for the ASK signal which removes the frequency offset between the signal and the LO. The envelope detector is emulated digitally in off-line processing by squaring and low pass filtering the signal stored in a digital sampling scope (DSO) with a sample rate of 40 Gsample/s. The signal is compared offline with the PRBS sequence by the error detector (ED) for BER measurements. No extra digital signal processing has been done offline; therefore the digital envelope and ED could be directly substituted by a commercial envelope detector and a 5 Gbps ED for real time measurements.

3. Results

Fig. 2(a) shows the optical eye diagram at the output of the transmitter. At the bias current of 11.7 mA, beginning overshooting of the VCSEL is observed. The extinction ratio (ER) at the transmitter is 4.62 dB measured with an oscilloscope. Fig. 2(b) shows the eye diagram after 40 km SSMF transmission. The fiber attenuation has decreased the signal to noise ratio (SNR), but no pulse broadening is observed due to the negligible chromatic dispersion at 1.3 µm.



a) b)

Figure 2. Direct detected optical eye diagrams. 5 Gbps, Ibias= 11.7 mA, Vpp= 0.9 V. (a) Back-to-back. (b) After 40 km SSMF

The measured bit error ratio (BER) of the 5 Gbps signal back-to-back (B2B) and after 40 km SSMF transmission is plotted in Fig. 3. The plot shows the measured BER with coherent and with direct detection.

For direct detection, a back to back (B2B) receiver sensitivity at the forward error correction limit of BER< $2.23 \cdot 10^{-3}$, was measured to be –26 dBm for B2B configuration and after 40 km of SSMF. SSMF thus negligible power penalty was observed. For the coherent detection case, $2 \cdot 10^5$ bits were stored for further offline analysis. Receiver sensitivity was measured to be -34 dBm for B2B as well as after transmission. Comparing to the direct detection case, the receiver sensitivity has been improved by 8 dB. This corresponds to a passive splitting ratio 6.3 times higher, or an extension of the unamplified transmission reach by 23 km.

In order to estimate the potential maximum transmission that can be reached with this system a simple power budget calculation has been performed considering 0.34 dB/km attenuation and negligible dispersion of the fiber at 1,3 µm. The launch power is -0.7 dBm and the receiver sensitivity of -34 dBm, result in a power margin of 33.3 dB, corresponding to almost 100 km of SSMF. In terms of splitting ratio, after 40 km, the achieved power margin of 19.8 dB correspond to and splitting ratio of 95.

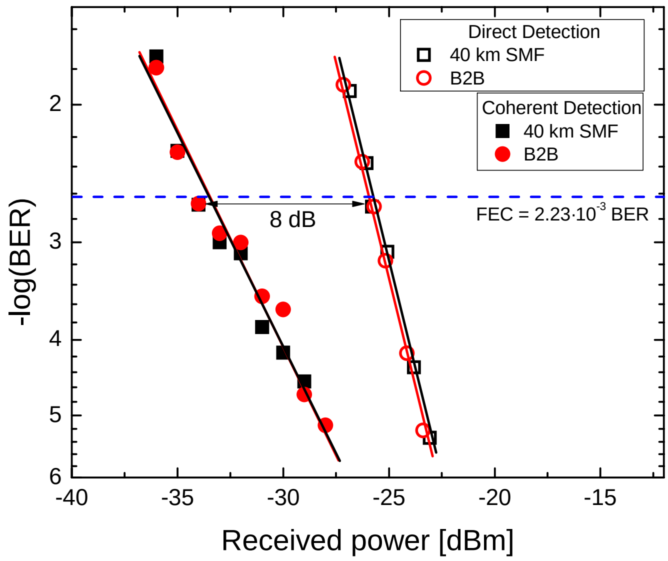


Figure 3: BER curves after 40 km SSMF and for B2B configuration. Bit-rate: 5 Gbps, ER: 4.62 dB, LO power: -0.8 dBm.

4. Conclusion

We have proposed and experimentally demonstrate for the first time, the feasibility of a full VCSELs based coherent detection system with un-cooled and free running operation of the transmitter as well as the local oscillator VCSEL light source. Our experimental demonstration successfully shows 5 Gbps operation at 1.3 µm with increased sensitivity of -34 dBm. Extended link reach over 40 km SSMF and high splitting ratio of 95 have been achieved with a low complexity coherent receiver and with no need of optical amplification or dispersion compensation. The simplicity of our proposed coherent approach is intended to overcome the complexity of conventional coherent systems for access networks. The potential cost reduction and good performance of our proposed approach make VCSEL-based coherent PONs a strong candidate for application in future PONs. We believe that future work on this approach will result in upgrade to 10 Gbps systems.

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