1.25-2.5Gbps Cost-Effective Transceiver Based on Directly Phase Modulated VCSEL for Flexible Access Networks

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Abstract: A 1.25-2.5Gbps cost-effective transceiver based on DPSK directly phase modulated VCSEL and a heterodyne receiver with a VCSEL as LO is proposed. The proposed transmitter sensitivity is -43.5dBm for 1.25Gbps and -40.5dBm for 2.5Gbps.

OCIS codes: (140.7260) Vertical cavity surface emitting lasers; (060.5060) Phase modulation

1. Introduction

The traffic demand over the access networks is growing exponentially due to new streaming media, cloud computing, Internet of Things (IoT) and the convergence between wireless and optical communications in the new 5G paradigm [1]. Cost-effective Optical Network Units (ONU) have to be developed in order to address the necessities of the new access networks requirements. In the recent years, some cost effective devices have been proposed, using directly phase modulated Reflective Semiconductor Optical Amplifiers (RSOA) [2], Distributed Feedback lasers (DFB) [3] and intensity modulated (IM) Vertical Cavity Surface Emitting Lasers (VCSEL) [4].

In this work, we present a 1.25Gbps and 2.5Gbps low cost ONU transceiver based on Differential Binary Phase-Shift Keying (DPSK) over a directly phase modulated VCSEL as the transmitter and a heterodyne single photodiode receiver with VCSEL as Local Oscillator (LO). VCSELs are potentially the cheapest laser that can be fabricated, so they may reduce the cost of the ONU transmitters.

2. Experimental Setup

Fig. 1 shows the experimental setup used in our work. The proposed ONU transceiver is based on a directly phase modulated VCSEL combined with a testbed Optical Line Termination (OLT). Digital Transmitter (DTX), where the pulse shaper will vary depending on the experiment and Receiver (DRX), which will be different depending on the transmitter modulation, are also shown. We will also use a reference On-Off Keying (OOK) intensity modulated VCSEL (IM VCSEL) as a comparison for the directly phase modulated ONU transmitter.

The proposed ONU transceiver consists of a directly phase modulated VCSEL as transmitter and a heterodyne receiver with VCSEL as LO. Both VCSELs are from Raycan, exhibiting thermal stabilization, a relatively wide linewidth, higher than 10MHz, and an electrical bandwidth of 4GHz. The transmitter VCSEL is biased to a current of 8mA and emits -1dBm optical power. The wavelength of this VCSEL can be thermally tuned in a range of 5nm allowing the flexible wavelength allocation of the transceiver. The 1.25Gbps and 2.5Gbps DPSK data-streams are encoded and pulse shaped at the Digital Transmitter (DTX). The pulse shaper for the phase modulated transmitter is based on a sharp transition at the start of the symbol and a fast exponential decay in the rest of the symbol. This modulation shape in the input current produces an instantaneous frequency shift at the VCSEL spectrum because of its chirp, causing a rotation of the optical phase of the signal and achieving a directly phase modulation of the optical
signal. This modulation shape also generates a short residual intensity modulation of the optical signal. The amplitude of the modulation signal has been optimized to obtain a phase rotation of π radians. The DTX for the reference ONU, based on an IM VCSEL, uses a NRZ pulse shaper, and the DTX of the testbed OLT uses a Nyquist pulse shaper combined with DPSK modulation at the MZM. All these signals are digitally generated at 12GSa/s using an Arbitrary Waveform Generator (AWG).

The proposed ONU receiver is based on single photodetector heterodyne detection with a VCSEL as LO, as can be seen in Fig. 1. The receiver VCSEL is biased to 9.5mA and emits -0.14dBm. The LO and the signal are coupled at the photodiode using an optical coupler and a polarization controller. These heterodyne receivers are easily upgradeable to a polarization insensitive heterodyne receiver [5]. The LO used in the testbed receiver is an external cavity laser (ECL) with a linewidth smaller than 100kHz adjusted to the same emitting power of -0.14dBm. The wavelength of the LO is tuned 2.5 GHz away from this of the transmitter in the 1.25Gbps case and 5GHz in the case of the 2.5Gbps.

The received signal is amplified and then digitalized with a 40GSa/s Digital Signal Oscilloscope. The DRX for the digitalized signal is, first, a bandpass FIR filter in order to eliminate the possible adjacent channels and reduce the noise. The filtered signal is then multiplied by itself delayed one symbol in case of the DPSK modulation and squared in case of the IM modulation. Finally the signal is lowpass filtered with FIR filter to obtain the transmitted data, as shown in Fig 1.

3. Results

The sensitivity has been defined as the minimum received power with a maximum BER of 2.2·10⁻¹². This is the BER limit recommended by ITU-T G.975.1[6] to ensure 10⁻¹² BER using a 7% overhead FEC. The sensitivity of the proposed directly phase modulated VCSEL transmitter with the testbed heterodyne receiver has been measured and compared with the case of IM VCSEL transmitter as reference, as can be seen in Fig. 2. In addition, the power penalty of using a cost-effective VCSEL as LO instead of using ECL in the heterodyne receiver is shown in Fig. 3.

Fig. 2. BER versus received power for the proposed transmitter (DPSK directly phase modulated VCSEL) and the reference transmitter (IM VCSEL), for 1.25Gbps (solid) and 2.5Gbps (dashed).

Fig. 3. BER versus received power for the receiver using the proposed VCSEL as LO and the reference ECL as LO, for 1.25Gbps (solid line) and 2.5Gbps (dashed line).

Fig.2 shows that the sensitivity of the proposed directly phase modulate VCSEL transmitter is -43.5dBm with a rate of 1.25Gbps and -40.5dBm with a rate of 2.5Gbps. The sensitivity reference IM VCSEL transmitter is -38dBm for the rate of 1.25Gbps and -35.5dBm for the rate of 2.5Gbps. Thus, the penalty of using a common IM VCSEL with heterodyne reception instead of the using the proposed directly phase modulated VCSEL with heterodyne reception is 5.5dB in the case of a rate of 1.25Gbps and 5dB in the case of a rate of 2.5Gbps. Therefore, the proposed transmitter allows increasing the power budget of the link.

The sensitivity of the testbed generated Nyquist-DPSK using the VCSEL as LO in the heterodyne receiver of the ONU transceiver is -48dBm for 1.25Gbps and -43.5dBm for 2.5Gbps, as can be seen in Fig. 3. If the LO is an ECL, the sensitivity for 1.25Gbps is -45.5dBm, and -41.5dBm for 2.5Gbps. Thus, the power penalty of using a VCSEL instead of an ECL is 2.5dB for 1.25Gbps and 2dB for 2.5Gbps. This power penalty is small and admissible due to the cost reduction of using a VCSEL instead of an ECL.

Fig.4 shows the optical spectra of the NRZ-DPSK implemented with our directly phase modulated VCSEL, the NRZ-IM over a VCSEL and the Nyquist-DPSK over a MZM. Fig. 5 shows obtain the optical phase eye diagram and
the IQ diagram of the NRZ-DPSK over our directly phase modulated VCSEL. These results have been obtained using a High Resolution Complex Optical Spectrum Analyzer (HRCOSA).

![Optical Spectra for NRZ-DPSK directly phase modulated VCSEL (top), for NRZ-IM VCSEL (middle) and Nyquist-DPSK MZM (bottom); for 1.25Gbps (left) and for 2.5Gbps (right). The central frequency corresponds to 1539.84 nm](image1)

![Directly phase modulated VCSEL optical phase eye diagram (top) and optical IQ diagram (bottom); for 1.25Gbps (left) and for 2.5Gbps (right).](image2)

The directly phase modulated VCSEL spectra shows a clear NRZ shape for both 1.25Gbps and 2.5Gbps rates where the secondary lobes are attenuated due to the electrical bandwidth of the VCSEL. The IM VCSEL spectra at both rates have been broaden and distorted because of the laser chirp. Therefore, the IM VCSEL transceiver requires more optical spectrum than the directly phase modulated VCSEL in order to establish a communication without crosstalk. The Nyquist-DPSK over a MZM, employed as the input signal at the ONU heterodyne receiver, shows the typical rectangular spectra of this kind of modulation.

The optical phase eye diagram confirms the \( \pi \) radians rotation between the symbols. The optical IQ diagram shows the VCSEL continuous phase modulation because the symbols transitions do not cross the IQ diagram origin and some residual amplitude modulation because these transitions do not lay on the amplitude constant circle.

4. Conclusion
This paper presents a 1.25Gbps-2.5Gbps flexible and cost effective ONU transceiver based on DPSK directly phase modulated VCSEL transmitter and heterodyne receiver with a VCSEL as LO. The VCSEL transmitter presents a sensitivity of -43.5dBm for 1.25Gbps and -40.5dBm for 2.5Gbps using a single photodiode heterodyne receiver. The DPSK directly phase modulated VCSEL transmitter sensitivity has an improvement of 5-5.5dB compared with an IM VCSEL with the same type of receiver. The receiver uses a VCSEL as LO instead of ECL with just a 2-2.5dB of power penalty. In addition, the optical spectrum, the optical phase eye diagram and the optical IQ diagram of the transmitted signal show that a DPSK directly phase modulated VCSEL link can be obtained and presents a more compact spectrum than an IM modulated VCSEL one.

5. References