Beyond 50 Gb/s Directly-Modulated Long-Wavelength VCSELs for Next-Gen Access Network

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***Abstract*— The employment of long-wavelength directly-modulated VCSELs for applications in next-generation access networks is proposed. Suitable simulations are shown in case of DMT modulation and SSB filtering, demonstrating the capabilities of LW-VCSEL for future 50-Gb/s access networks.**

Keywords*— *Vertical cavity surface emitting laser, direct modulation, DMT, SSB, optical access networks

I. INTRODUCTION

In recent years, the continuous growth of bandwidth demand in the access and metro optical networks is pushing towards a line rate increase beyond 10 Gb/s. Actually, after the standardization process for 25G Time Division Multiplexing Passive Optical Networks (TDM-PON), the modulation formats and technologies for the next 50-Gbit/s PON (50G-PON) still need to be defined in the next future [1]. A suitable solution could be to follow the 50-Gb/s lane standardization for data center intra-connect (DCI). However, the challenge is to perform the next upgrade of the optoelectronic front-ends in a cost-effective way by maintaining intensity-modulated (IM) transmitters and direct-detection (DD) receivers, while addressing longer reaches (up to 20-40 km) with respect to point-to-point DCI optical links reducing at the same time cost, footprint and power consumption [1].

To achieve high transmission bit rates employing limited bandwidth devices, multicarrier modulation, as discrete multitone (DMT), has been identified as a promising technology. Thanks to bit and power loading techniques, a spectral manipulation tailored on channel conditions can be achieved, leading to an efficient usage of the bandwidth resource, even maintaining the cost-effective IM/DD approach [2]. Moreover, photonic technologies can provide new energy- and cost-efficient solutions, starting from the adoption of direct modulation (DM) of laser sources; among them, vertical cavity surface emitting lasers (VCSELs) could allow a radical reduction of transmitter cost, power consumption and footprint. We recently proposed the exploitation of DMT with a DM tunable VCSEL to achieve a colorless optical network unit (ONU) transmitter, targeting a transported upstream (US) capacity greater than 25 Gb/s up to 40-km standard single-mode fiber (SSMF) [3].

In order to further increase the line rate to 50 Gb/s, a suitable solution could be the adoption of fixed wavelength short-cavity (SC) VCSELs, reliable both in O and C bands and providing modulation bandwidths up to 17 GHz [4, 5]. Since chromatic dispersion (CD) is the main impairment when increasing the serial rate beyond 25 Gb/s in an IM/DD system, we evaluate the resilience of DMT modulation for fiber lengths compliant with access distances in case of single sideband (SSB) filtering using suitable simulations.

II. VCSEL-BASED SOLUTIONS FOR DIRECT-DETECTED ACCESS NETWORKS

A. *Long Wavelength SC-VCSELs*

Long-wavelength (LW) VCSELs are based on a laser design featuring a dielectric bottom mirror, a buried tunnel junction (BTJ) for the current confinement, a gold substrate acting as a heat sink, a multi quantum well (MQW) active region and an optimized waveguide design. The material structure consists of III-V semiconductors, such as In, P, Al, As and Ga, which enables the production of lasers from 1.3 μm to 2.3 μm, thus covering both the C and O bands. Indium Phosphide (InP) LW VCSELs can be designed to allow laser operation from -20°C to +80°C, providing excellent single mode performance with a side mode suppression ratio (SMSR) of 40 dB and more. LW VCSELs features very efficient power consumptions with output optical powers up to 7 dBm at bias currents in the range of 5-10 mA. SC VCSELs are optimized for achieving large modulation bandwidths by reducing their effective cavity length and the photon lifetime. Moreover, high relaxation-resonance frequencies, and reduced parasitic effects guarantee high-speed modulations [6]. Both O and C band devices present a current aperture of about 5 μm and an effective cavity length of 2.5 μm leading to modulation bandwidths up to 20 GHz with relative intensity noise below -140 dB/Hz [4, 5]. In Fig. 1 a schematic of the SC VCSEL is reported.

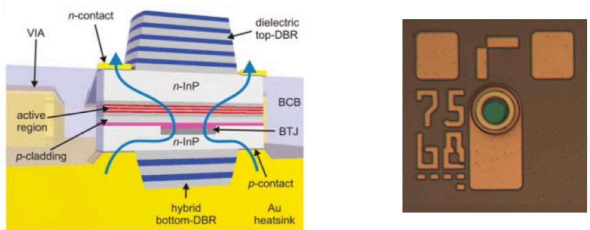

Fig. 1. (left) Short-cavity VCSEL structure optimized for high modulation bandwidth and (right) picture of the Vertilas long-wavelength VCSEL.

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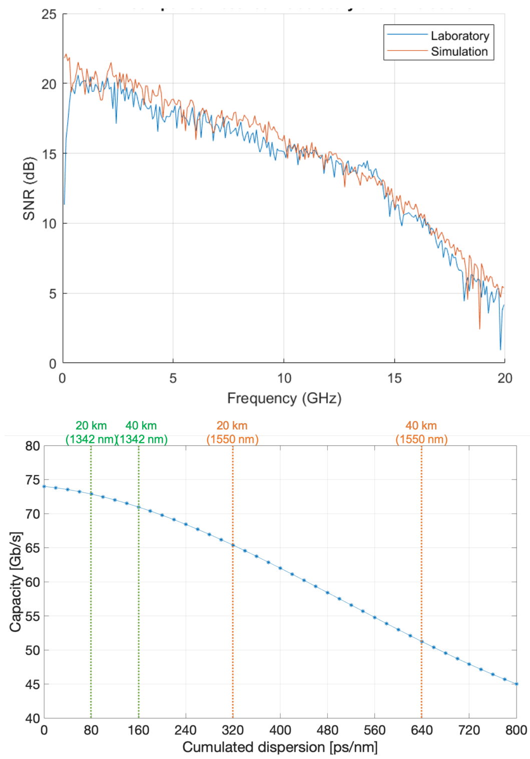
B. *DMT modulation for high-capacity VCSEL-based next-generation optical access networks*

DMT is a very effective multicarrier modulation technique to increase the transported capacity, matching the non-uniform and bandwidth-limited response of the whole communication system. The spectral efficiency of the optical channel can be drastically increased even using directly-modulated sources as VCSELs thanks to the exploitation of bit and power loading [7]. However, increasing the serial rate beyond 25 Gb/s, frequency chirp can strongly limit system performance, owing to the frequency fading generated by the interaction between VCSEL frequency chirp and the cumulated chromatic dispersion (CD) [8]. Even if its impact can be mitigated by adaptive subcarrier loading, a drastic reduction of the transported capacity is expected. A promising solution for 50-Gb/s limited reach access networks (e. g. few tens of km) could be the exploitation of DMT transmission together with single sideband filtering. As a proof of principle, we demonstrate the feasibility of a directly-modulated LW VCSEL characterized by an electro-optical bandwidth of 17 GHz without any CD compensation. In particular, suitable simulations have been performed to assess the resilience of SSB VCSEL-based optical transmission on standard access SSMF reaches.

Fig. 2 reports the simulative results. The model of a 17-GHz VCSEL has been implemented in the simulation tool by matching its BTB performance in presence of SSB filtering. Moreover, the measured chirp parameters have been exploited in order to obtain the same behavior after SSMF propagation. The DMT signal is composed by 256 sub-carriers in 20 GHz range, i.e. the sub-carrier spacing is 78.125 MHz. A cyclic prefix of about 2.1% of the symbol length is added. The bias current is set at 9 mA, with an optimized 10-mA modulation amplitude to limit the frequency chirp. SSB modulation is performed by exploiting a super-gaussian transfer function [9], which is detuned by 8 GHz with respect to the signal carrier, removing the low-frequency signal sideband. In Fig. 2(a) the matching of the BTB transmitter performance is shown in terms of signal-to-noise ratio (SNR) for the different sub-carriers, while Fig. 2(b) reports the capacities achievable for different cumulated chromatic dispersions. Thanks to the wide modulation bandwidth, about 75 Gb/s can be obtained in back-to-back (BTB) condition. Thanks to SSB filtering, more than 50 Gb/s could be achieved even after 40-km SMF propagation in the C-band, showing a 33% reduction with respect to the BTB case. However, the exploitation of O-band devices will lead to capacities higher than 70 Gb/s even after 40-km propagation, i.e. just few Gb/s lower than the BTB condition, thanks to the limited impact of chromatic dispersion. The LW-SC VCSEL technology can thus provide promising devices for 50G-PON low-cost, energy-efficient compact transmitters

III. Conclusions

We reported suitable simulations that demonstrate that directly modulated LW VCSELs can support 50G-PON transmission over more than 20-km SSMF thanks to SSB filtering. SC VCSELs are confirmed as promising transmitter building-blocks of sustainable low cost, reduced footprint, and power consumption next-generation access networks, compliant with existing standards.



a)

b)

Fig. 2. (a) Measured (blue) and simulated (red) SNRs for a 17-GHz directly-modulated VCSEL with SSB filtering in BTB condition. (b) Transported capacities in function of the cumulated chromatic dispersion (blue curve, diamonds); cumulated CD corresponding to 20 km and 40 km SSMF propagation in case of O-band (green dotted curves) and C-band (orange dotted curves) devices.

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References

[1] V. E. Houtsma, D. T. van Veen, “Optical Strategies for Economical Next Generation 50 and 100G PON” in Optical Fiber Communication Conference (OFC) 2019, San Diego, CA, paper M2B.1 (2019).

[2] T. Takahara, T. Tanaka, M. Nishihara et al., "Discrete Multi-Tone for 100 Gb/s optical access networks," in Optical Fiber Communication Conference (OFC) 2014, San Francisco, CA, paper M2I.1, (2014).

[3] A. Gatto, P. Parolari, C. Neumeyr, and P. Boffi, "Beyond 25 Gb/s Directly-Modulated Widely Tunable VCSEL for Next Generation Access Network," in OFC Conference, 2018, paper Th1E.2.

[4] Malacarne, C. Neumeyr, W. Soenen et.al., “Optical transmitter based on 1.3µm VCSEL and SiGe Driver Circuit for Short Reach Applications and beyond”, J. Lightwave Technol., 2018, **36**, pp.1527-1536.

[5] R. Rodes, M. Mueller, B. Li et al., "High-Speed 1550 nm VCSEL Data Transmission Link Employing 25 GBd 4-PAM Modulation and Hard Decision Forward Error Correction," J. Lightwave Technol., 2013, **31**, pp. 689-695.

[6] S. Spiga et al.., "Single-Mode High-Speed 1.5-µm VCSELs," J. Lightwav. Technol., vol. 35, no. 4, pp. 727-733, Feb.15, 15 2017.

[7] M. Svaluto Moreolo, et al., "Modular SDN-enabled S-BVT Adopting Widely Tunable MEMS VCSEL for Flexible/Elastic Optical Metro Networks," in OFC Conference, 2018, paper M1A.7.

[8] M. Rapisarda, et al. “Impact of Chirp in High-Capacity Optical Metro Networks Employing Directly-Modulated VCSELs,” Photonics, 5, 51 (2018).

[9] C. Pulikkaseril, L. A. Stewart, M. A. F. Roelens, et al., “Spectral modeling of channel band shapes in wavelength selective switches” Opt. Express, 2011, **19**, pp. 8458-8470.