30 Gbps Bottom-Emitting 1060 nm VCSEL

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Abstract *1060 nm VCSEL-based data transmission over 50 m OM3 MMF at 30 Gbit/s is experimentally demonstrated. A highly-strained bottom-emitting QW VCSEL with p-type modulation doping is used with 3.77 mA bias and 0.55 V data amplitude.*

Introduction

Vertical cavity surface emitting lasers (VCSELs) have long been recognized as key components for optical interconnects due to their small size, high speed and low power consumption. The most common operating wavelength for VCSELs used for data transmission, using multimode fibers (MMF), is 850 nm. Other VCSELs wavelengths explored are 980 nm, 1010 nm, 1060 nm, 1090 nm and 1310 nm. Moving to higher wavelengths allows taking advantage of e.g. lower fiber attenuation.

VCSELs operating in the wavelength region around 1060 nm are particularly attractive due to very high energy efficiency[1,2] and good reliability[3]. An interesting feature of the presented 1060 nm VCSEL is the possibility of emitting the light through the bottom of the VCSEL rather than through top as it is usually done[4]. This offers significant benefits in terms of optical coupling, packaging and heat management, since the wirebonding can be placed opposite the optical aperture[5]. As previously mentioned, the 1060 nm wavelength region has the advantage over 850 nm region in terms of lower fiber attenuation (1.5 dB/km@1060 nm compared to 3.5 dB/km @850 nm), lower power consumption (threshold currents below 1 mA) and of existence of high sensitivity indium-gallium-arsenide (InGaAs) photodiodes. Unfortunately, the most common multi-mode fibers OM3 and OM4 have higher modal dispersion at 1060 nm than at 850 nm; a factor that makes high-speed transmission challenging. Even so, in this paper we present the FEC-conformed performance over 50 m of OM3 multimode fiber.

A transmission over 200 m OM3 MMF has been recently reported using a top emitting 1060 nm VCSEL operating at 25 Gbaud[4]. In this contribution we present a 30 Gbps transmission over 50 m of OM3 MMF. This result is realized with a bottom-emitting 1060 nm VCSEL using only 3.77 mA bias and 0.55 V peak-to-peak data amplitude.

1060 nm VCSEL design

The employed light source is a bottom emitting, highly-strained 1060 nm QW VCSEL with p-type modulation doping. It has previously been presented and described in the referenced work[1]. Fig. 1 shows the schematic diagram of the device.

The VCSEL is grown on a semi-insulating GaAs substrate using molecular beam epitaxy (MBE). The bottom mirror consists of GaAs/AlAs and Si doped GaAs. The top mirror consists of GaAs/AlGaAs. The active region is surrounded by an asymmetric $Al_{0.3}Ga_{0.7}As$ separate

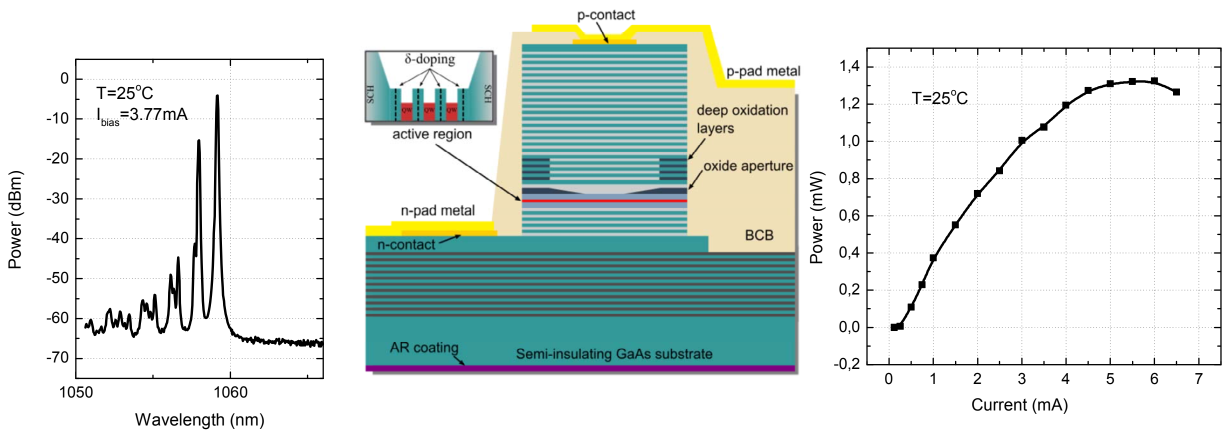


Fig. 1: Optical spectrum; VCSEL structure[1]; Power versus current curve.

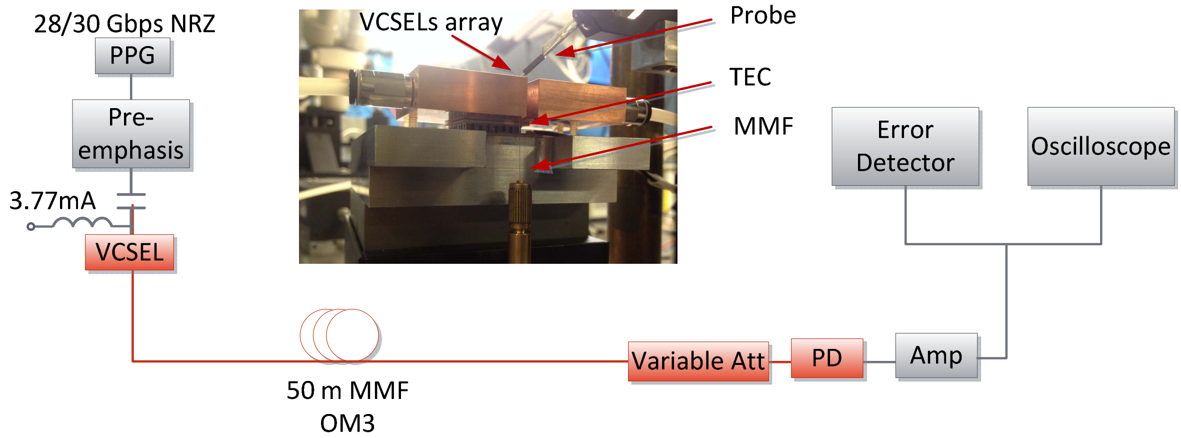


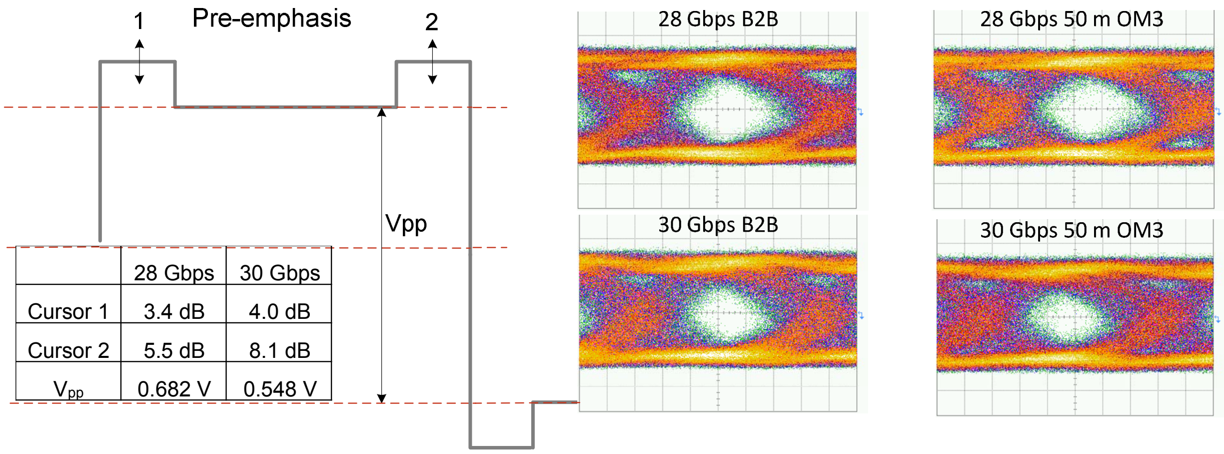
Fig. 2: Experimental setup for high speed transmission with 1060 nm VCSEL.

confinement heterostructure (SCH) that is parabolically graded down to GaAs spacers. Three 8 nm thick highly-strained $In_{0.3}Ga_{0.7}As$ quantum wells (QWs) are separated by 8 nm GaAs barriers. Growth is stopped halfway into the barrier and the surface is δ-doped with carbon using a carbon tetrabromide (CBr_4) precursor. The high differential gain of the 1060 nm laser comes at the price of increasing the nonlinear gain compression. Modulation p-type doping was used to suppress nonlinear gain compression which resulted in increasing the K-factor compared to stained QWs alone.

Fig. 1 shows the power versus current curve measured at T=25°C for the VCSEL used in the transmission experiment. A very low threshold current of 0.15 mA is observed. The corresponding optical spectrum measured at a bias current of 3.77 mA is presented in an inset of Fig.1. Further information on the presented 1060 nm VCSEL design are described in referenced work[1] and the details on analogous device design at 980 nm is presented in the Chapter 7 of 'VCSELs'[6].

Experimental setup

Fig. 2 shows the setup used in the transmission experiment. Electrical pseudo-random binary (PRBS 2^{15}-1) data signals at 28 Gbps (0.682 V peak-peak) or 30 Gbps (0.548 V peak-to-peak) generated by a pulse pattern generator (PPG) is combined with a 3.77 mA bias current in a bias-Tee and applied to the VCSEL using a 40 GHz electrical probe. The temperature is stabilized at 25°C using a temperature controller. The modulation format used is non-return-to-zero (NRZ). In the transmitter the 1 post/1 pre-cursor pre-emphasis configuration is used, as shown in Fig. 3. The pre-emphasis parameters (Cursor 1, 2 and Vpp in inset Table in Fig. 3) are optimized for the transmission scenario and the same settings are used for measuring the B2B case. The light from the VCSEL is coupled into a 50 m OM3 compliant multimode 50 µm core diameter fiber. Fiber launch power is 0.7 dBm and the attenuation of the used 50 m fiber link is 0.9 dB. The optical signal is received by a VI Systems photodiode with a wavelength range of 900-1350 nm and a 30 GHz 3-dB bandwidth. The



	28 Gbps	30 Gbps
Cursor 1	3.4 dB	4.0 dB
Cursor 2	5.5 dB	8.1 dB
V_{pp}	0.682 V	0.548 V

Fig. 3: Pre-emphasis module settings; Eye diagrams for B2B and transmission over 50 m OM3 MMF at 28 Gbps and 30 Gbps.

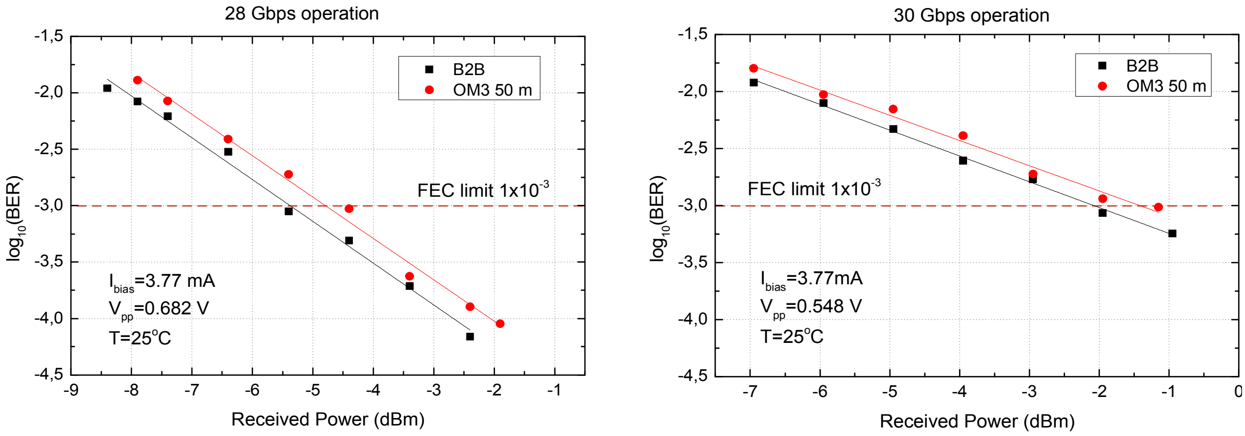


Fig. 4: Bit error rate curves for B2B and Transmission at 28 Gbps and 30 Gbps with 1060 nm VCSEL.

received signal is then amplified to 1 V peak-to-peak and analyzed in real time by an error detector.

Results and Discussions

Fig. 3 shows the measured eye diagrams and Fig. 4 bit error ratio (BER) as a function of the received optical power back-to-back (B2B) and after 50 m MMF transmission for the two considered bit rates. Receiver sensitivity at the 7%-overhead forward error correction (FEC) limit of $1x10^{-3}$ for B2B is -5.4 dBm at 28 Gbps and -2.05 dBm at 30 Gbps. In both cases a penalty of 0.8 dB is observed after fiber transmission.

The optimal setting of pre-emphasis (Fig. 3) improves the transmission BER by 1 order of magnitude allowing BER to be below the FEC limit.

Further work on pre-emphasis is required to maximize the achievable distance. Moreover, the transmission reach can be imcreased by employing OM4 MMF or fibers designed and optimized for 1060 nm range. The 1060 nm VCSEL is proven to be a potential candidate for the optical interconnects which use the benefits of direct intensity modulation and direct detection. The advantage of 1060 nm VCSELs for interconnect links include the ability to balance energy efficiency and reliability.

Conclusions

A high speed 28 Gbps and 30 Gbps transmission employing 1060 nm bottom-emitting VCSEL has been demonstrated with transmission over 50 m of OM3 MMF resulting in a bit rate-distance product of 1.5 Tbpsxm. In the reported experiment, the bias of only 3.77 mA and 0.55 V peak-to-peak data amplitude confirms energy efficiency of the VCSEL based system. The optimized pre-emphasis module at the transmitter allows a FEC-conformed BER values to be achieved.

Our reported results have encouraging prospects in relation to bottom emitting devices for packaging and heat management when incorporating these light sources into modules for interconnects and short range links.

Acknowledgements

We would like to acknowledge VI Systems Germany for supporting this work with the VIS Photoreceiver.

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