

# 1.5 Tbpsxm MMF transmission link with 1060nm VCSEL

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

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## 1. 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 wavelength explored are 980 nm, 1010 nm, 1060 nm, 1090 nm and 1310 nm.

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 1060 nm VCSELs is the possibility of emitting the light through the bottom of the VCSEL rather than through top as it is usually done. This offers significant benefits in terms of optical coupling, packaging and heat management, since the wirebonding can be placed opposite the optical aperture [4]. Compared to 850 nm interconnects, the 1060 nm wavelength region has the advantages lower fiber attenuation (1.5 dB/km compared to 3.5 dB/km @850 nm), and of high sensitivity indium-gallium-arsenide (InGaAs) photodiodes. Unfortunately, the most common multi-mode fibers OM3 and OM4 has 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 highest bit rate distance product ever achieved for 1060 nm MMF interconnects, namely 1.5 Tbpsxm achieved as 30 Gbps transmission over 50 m of OM3 multimode fiber. 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.

## 2. 1060 nm VCSEL design

The employed light source is a bottom emitting, highly-strained 1060 nm QW VCSEL with p-type modulation doping. Fig. 1 shows its schematic diagram. 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  $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$  separate confinement heterostructure (SCH) that is parabolically graded down to GaAs spacers. Three 8 nm thick highly-strained  $\text{In}_{0.3}\text{Ga}_{0.7}\text{As}$  quantum wells (QWs) are separated by 8 nm GaAs barriers. Growth is stopped halfway into the barrier

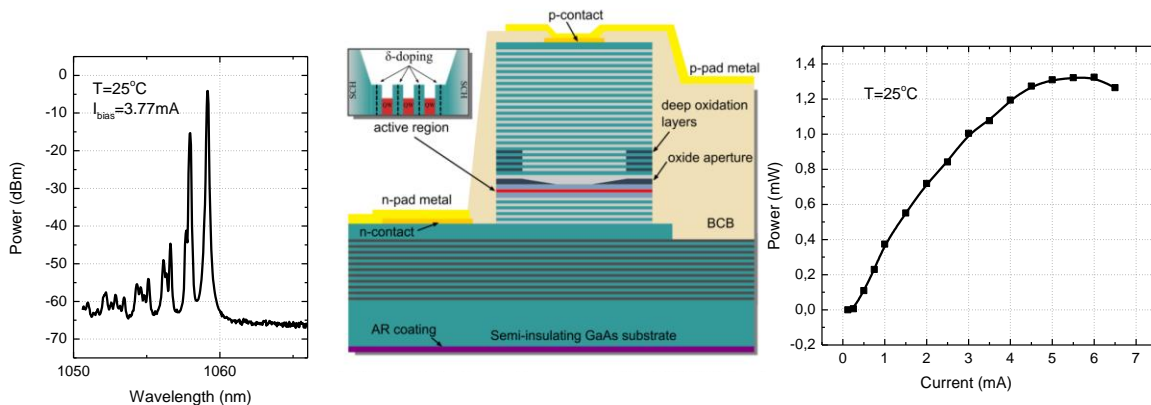


Fig. 1 Optical spectrum; VCSEL structure [1]; Power versus current curve.

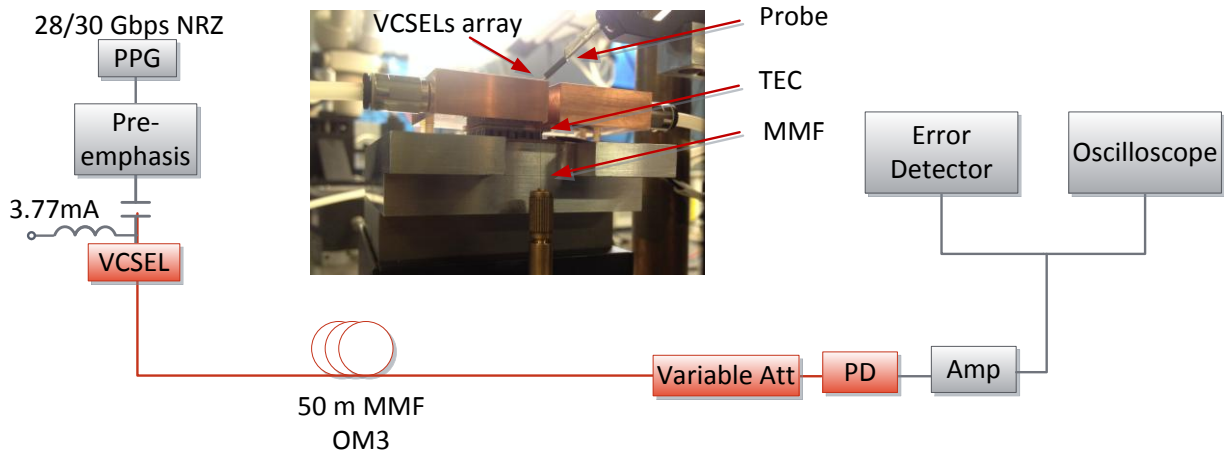


Fig. 2 Experimental setup for high speed transmission with 1060 nm VCSEL.

and the surface is  $\delta$ -doped with carbon using a carbon tetrabromide (CBr<sub>4</sub>) 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 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 0.15mA is observed. The corresponding optical spectrum measured at a bias current of 3.77mA is presented in Fig.1 as an inset. Further details of the VCSEL design can be found in [1].

### 3. 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) using 1 post/1 pre-cursor pre-emphasis configuration as shown in Fig. 3. Fiber launch power is 0.7 dBm and the attenuation of the 50 m fiber link is 0.9 dB. The light from the VCSEL is coupled into a 50 m OM3 compliant multimode 50  $\mu$ m core diameter fiber. The optical signal is received by a commercially available photodiode with a wavelength range of 900-1350 nm and a 30 GHz 3-dB bandwidth, amplified to 1 V peak-to-peak and analyzed in real time by an error detector.

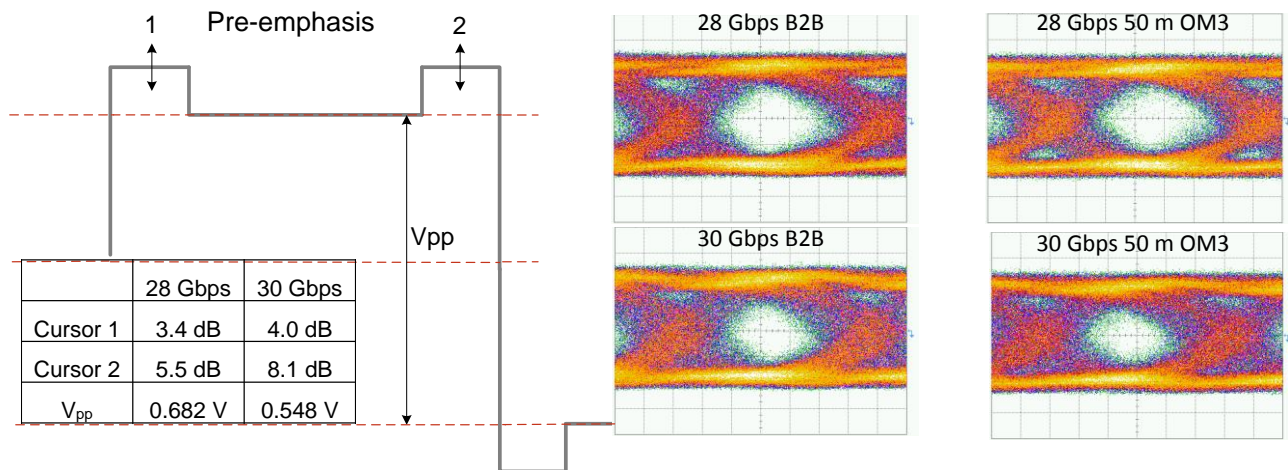


Fig. 3 Pre-emphasis module settings; Eye diagrams for B2B and transmission over 50 m OM3 MMF at 28 Gbps and 30 Gbps.

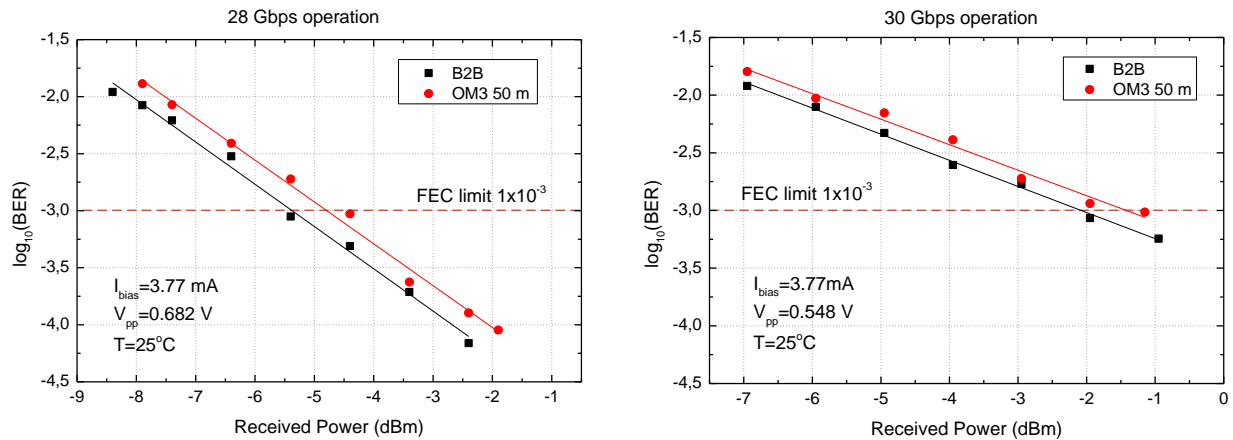


Fig. 4. Bit error rate curves for B2B and Transmission at 28Gbps and 30 Gbps with 1060 nm VCSEL.

#### 4. 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  $1 \times 10^{-3}$  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 improved the transmission BER by 1 order of magnitude allowing all BER curves to be below the FEC threshold.

The advantage of 1060 nm VCSELs for interconnect links include the ability to balance energy efficiency and reliability. Our reported results has encouraging prospects too in relation to bottom emitting devices for packaging and heat management when incorporating these light sources into modules for interconnects and short range links.

#### 5. Conclusions

A high speed 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 this reported experiment, the achieved energy efficiency is high due to the use of only with 3.77 mA bias and 0.55 V peak-to-peak data amplitude.

#### 6. References

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