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High Speed VCSEL Transmission at 1310 nm and 1550 nm Transmission Wavelengths

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Abstract: Vertical cavity surface emitting lasers (VCSELs) operating at 1310 nm and 1550 nm are very promising sources for access and interconnections in telecommunication systems due to their technologically attractive properties such as low threshold currents and narrow spectral linewidth due to single mode operation. VCSELs are also being rapidly commercialized for single-mode fibre metropolitan area and wide area network applications. All these advantages leads to cost-effective wavelength-tunable lasers, which are essential for the future intelligent, all-optical networks. Direct modulation (DM) of VCSEL with separate optical and current apertures enables high modulation bandwidth operating at single mode at low current density. However, dispersion and attenuation is a major hurdle to VCSELs transmission at bit rate of 10 Gb/s and above. In this study, a 1310 and 1550 nm VCSELs were directly modulated with 10 Gb/s NRZ PRBS 2^7-1 and transmitted over 25 km ITU. T G.652 and ITU. T G.655 fibres and optimized for metro-access distances. A low dispersion penalty was realized when a 1550 nm VCSEL was used on a G.655 fibre and when a 1310 nm source was transmitted over a G.652 fibre. The transmission system has been analyzed on the basis of different parameters, which are (Bit error rate) BER, Quality (Q) factor and Output power.

Keywords: Optical Fibre, VCSEL, Dispersion, BER

1. Introduction

Fiber-optic communication systems have revolutionized the telecommunications industry and played a major role in the advent of the Information Age [1]. However, dispersion and other non-linearity's of optical fibres hindered ultra-long distance transmission and high bit rate transmission [2]. Dispersion is defined as the pulse spreading in an optical fibre. When different wavelengths of light pulses are launched into the optical fibre, these pulses travelled with different speeds due to the variation of refractive index with wavelengths. The light pulses tend to spread out in time domain after travelling some distance in fibre and this is continued throughout the fibre length. Dispersion limits the information carrying capacity at high transmission speeds, reduces the effective bandwidth and increases the bit error rate (BER) [3]. In single mode fibre (SMF), the performance is primarily limited by chromatic dispersion (CD) and polarization mode dispersion (PMD), CD occurs because of the wavelength dependency of refractive index of fibre and the fibre has some inherent properties like birefringence that lead to PMD.

With the explosive growth in demand for capacity in national, regional, and even metropolitan optical networks, high bit rate fibre transmission have recently become an essential part of state-of-the-art communications. Modern optical networks are now primarily based on 2.5 Gb/s and 10 Gb/s channels [4]. 40 Gb/s channels have begun to be implemented in new product offerings. In addition to increases in data rate per channel, the number of channels per fibre is also increased through wavelength division multiplexing (WDM) or dense WDM (DWDM) to further improve overall capacity [5]. VCSELs are semiconductor sources that emit a light beam that is perpendicular to the planes of an active region or perpendicular from the top surface of the cavity [6]. VCSELs offer high bandwidth, single mode operation within C-L bands, wavelength tunabilities, the convenience of direct modulation and energy efficiency at low drive currents [7]. VCSELs are promising candidates for light sources at customer premises because of their cost-effective production and capability for chirp integration. However, small optical power coupled into the optical fibre in VCSEL restricts the coverage range for application in passive optical networks (PON) links with a large splitting ratio and long distance. [8].

The power dissipated in the laser cavity induces to VCSEL self-heating [9]. The internal temperature rise as the result of self-heating has an impact on VCSEL modulation performance. Increase in threshold current increases the temperature hence contributing to a reduction in gain. These effects cause the output power and the resonance frequency to saturate at a certain current level called the thermal rollover current [10]. The frequency chirp $\Delta\upsilon$ associated with direct modulation of a VCSEL can be described as [11];

$$\Delta\upsilon(t) = -\frac{\alpha}{4\pi}\left(\frac{d}{dt}\ln P(t) + kP(t)\right) \quad (1)$$

Where α is the linewidth enhancement factor, $P(t)$ is the instantaneous optical power, k is the structure dependent constant which is proportional to the modal confinement factor and inversely proportional to the volume of the active region.

The current-voltage (IV) relationship can be modeled in great detail based on the diode-like character of the VCSEL [12]. The voltage across the device is an arbitrary empirical function of current and temperature using;

$$V = f(I,T) \quad (2)$$

The relationship which accounts for a resistance in series with a diode is given by;

$$V = IR_s + V_T L_n\left[1 + \frac{I}{I_s}\right] \quad (3)$$

Where; R_s is the series resistance, V_T Is the diodes thermal voltage. In DM, the light is emitted from a semiconductor laser when a 'mark' is transmitted. In this modulation format, Radio Frequency (RF) signal is directly applied to the laser. The output power of the device depends directly on the input current. VCSELs are utilized in direct modulation [13]. Where; R_s is the series resistance, V_T is the diodes thermal voltage and I_s is diodes saturation currents.

2. Experimental Set up

The set up in figure 1 was used with 1310 nm and 1550 nm VCSELs modulated at 10 Gb/s. The G. 655 and G. 652 single mode fibres were used to investigate the transmission capabilities of the VCSELs. A programmable pattern generator (PPG) directly modulated a VCSEL by a 10 Gb/s with non-return-to-zero (NRZ) pseudo-random binary sequence (PRBS) of length 2^7-1 via a bias-T. The bias –T combined the laser diode controller (LDC) bias current with pattern generator output to directly modulate the VCSEL. The bias current of the VCSEL was restricted to 10 mA so as to avoid damaging the VCSEL device. The output power of the VCSEL was measured as the bias current was increased from 0 mA to 10 mA. Biasing was done above the threshold current preferably the mid region in P-I curve so as to enable optimum performance.

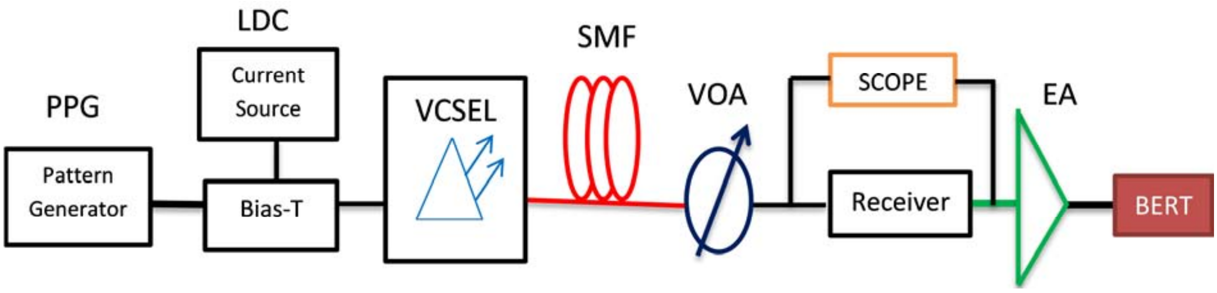


Figure 1. *Experimental set up of the directly-modulated VCSEL.*

3. Results

Figure 2 shows the biasing results of 10 Gb/s VCSEL transmitting at 1310 nm and 1550 nm respectively. The output power of the VCSEL was measured as the bias current was increased. The experimental and simulated VCSEL behaviors at constant temperature agree. At a bit rate of 10 Gb/s, the 1310 nm and 1550 nm VCSELs showed similar characteristics in terms of power output. Both 1310 nm and 1550 nm VCSELs operate in the mA range showing the energy efficiency of the device. From the experimental results, the threshold currents of the device range between 0 and 1 mA. However, from the simulation results, the VCSELs threshold currents were found to be 1 mA and 2 mA for 1310 nm and 1550 nm VCSELs respectively.

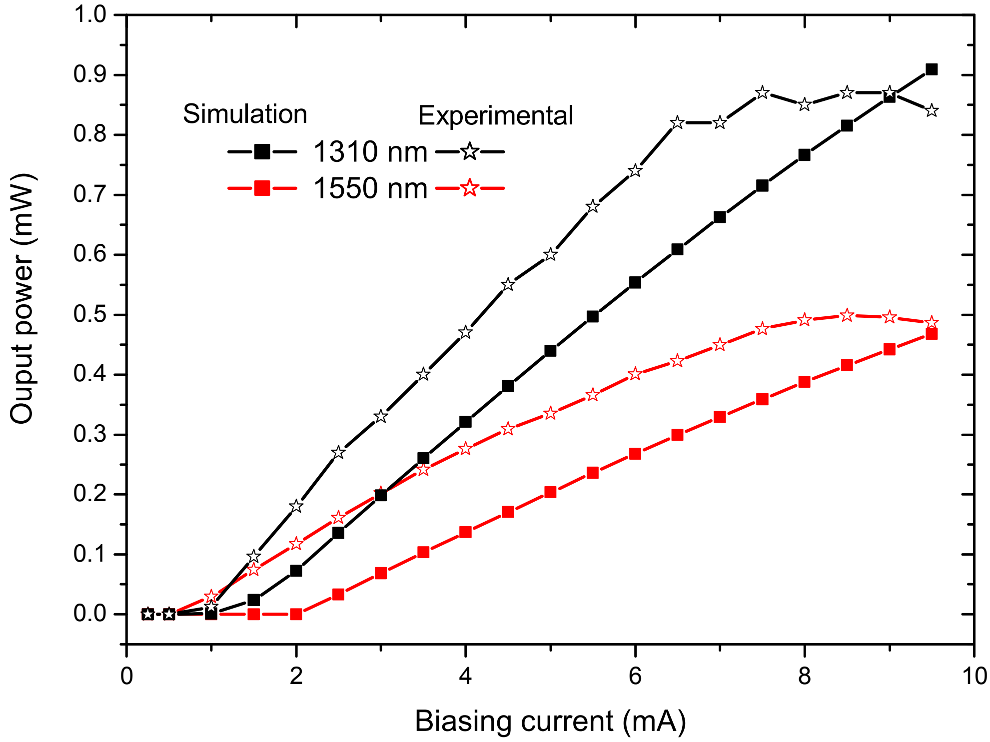
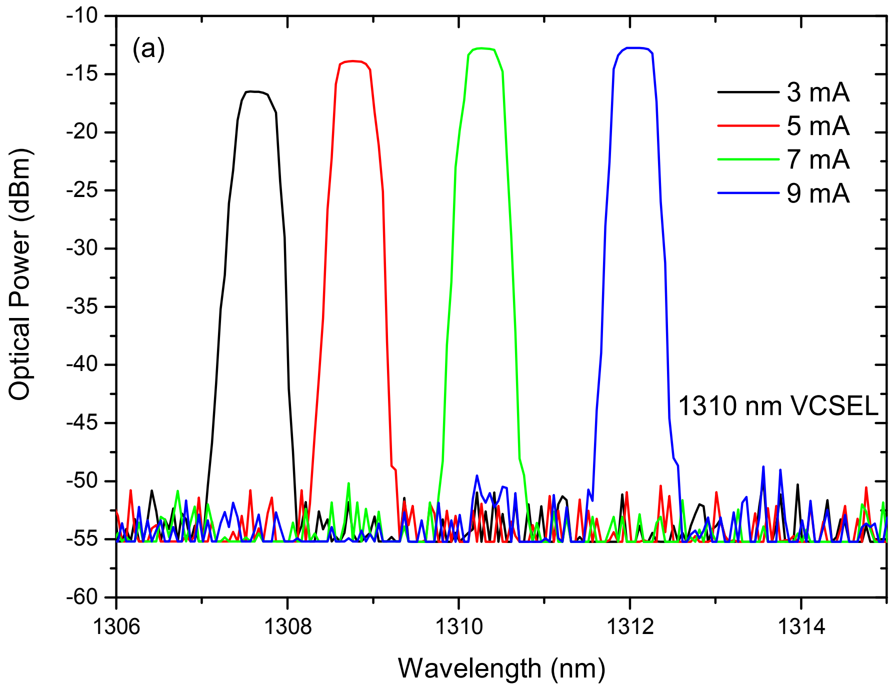


Figure 2. *Biasing of VCSEL at 1310 nm and 1550 nm.*

Above the threshold, the output power from a VCSEL varied linearly with current and we can determine slope efficiency (mW/mA) over some operating region. Experimentally, the saturation current of the device were found to be 4 mA and 8 mA for 1310 nm and 1550 nm VCSEL respectively. Above the saturation level, the output power of the VCSEL reduced as the current was further increased.

The optical spectrum of the 1310 nm and 1550 nm VCSEL at different biasing currents is plotted in figure 3. A wavelength tuneability of 6 nm and 5 nm for 1310 nm and 1550 nm VCSEL respectively was obtained. The shifting of the emission spectra with increasing bias current indicates internal heating of the VCSEL. As the current was increased, a VCSELs gain spectrum broadens and its peak location shifts to longer wavelengths.



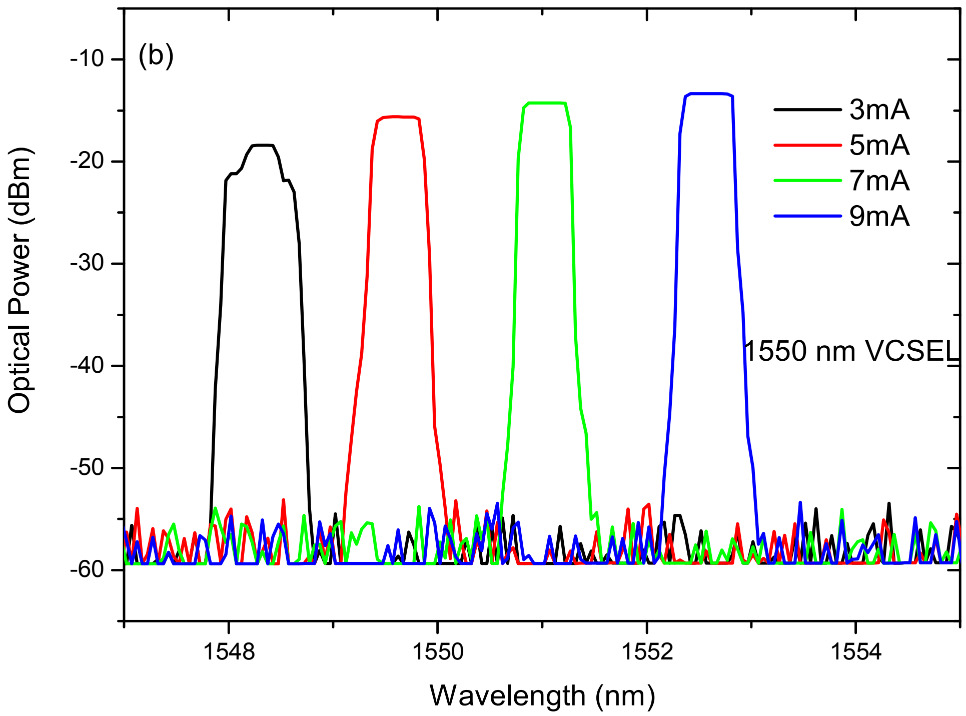
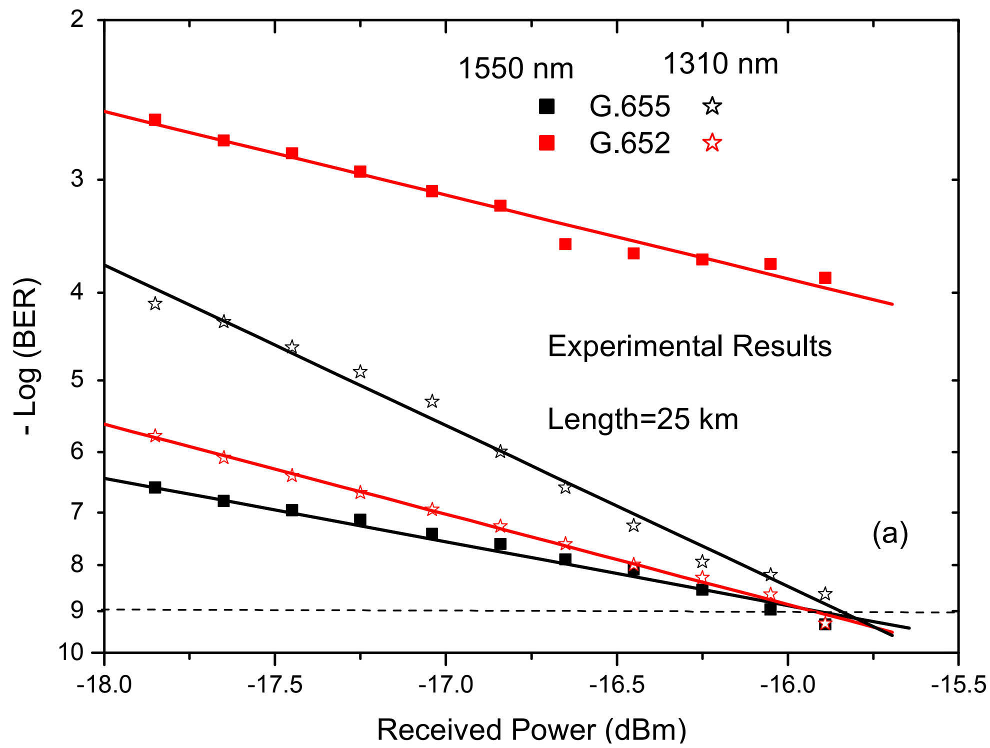


Figure 3. *Experimental characterization of the VCSEL wavelength tuneabililty for (a) 1310 nm (b) 1550 nm.*

This implies that VCSEL can be tuned to different wavelengths using the different bias currents. The wavelength stability and tuneability allows for wavelength multiplexing which is used to increase the data rate.



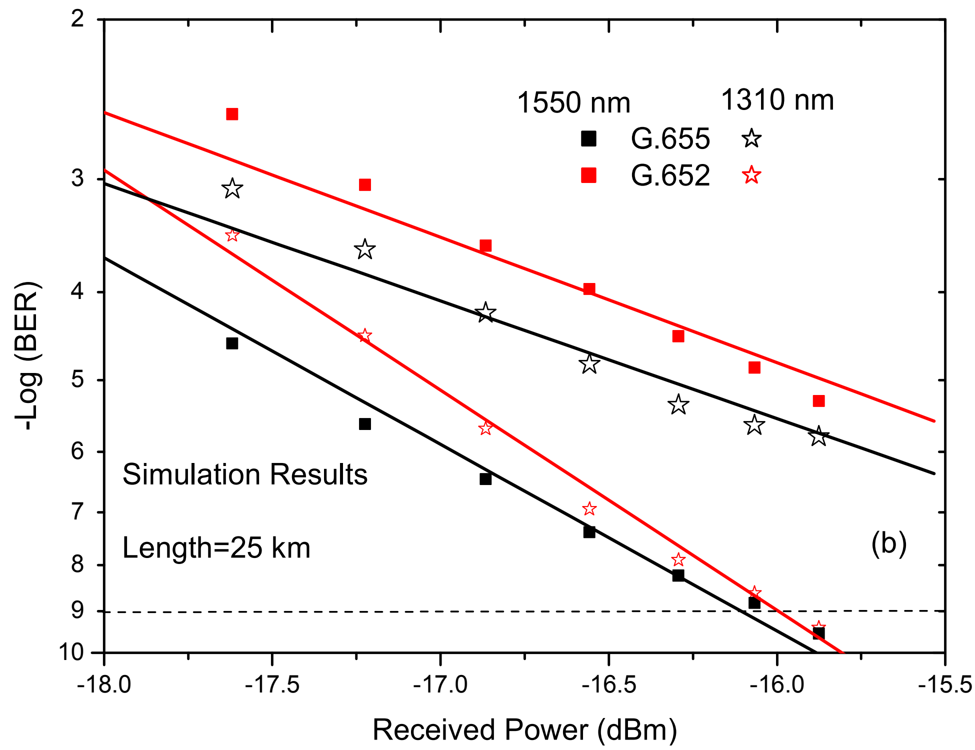


Figure 4. *Experimental results of VCSELs transmission using G. 655 and G. 652 fibres (a) Experimentaly (b) Theoretically.*

Figure 4 (a) shows experimental BER measurements of G. 652 and G. 655 fibres of lengths 25 km with the 1310 nm and 1550 nm VCSELs transmitting at 10 Gb/s. A receiver sensitivity of -15.8 dBm and -15.9 dBm were obtained when G. 652 fibre was transmitted on 1310 nm and G. 655 fibre on 1550 nm VCSEL respectively.

From simulation results in figure 4 (b), the sensitivity for G. 652 and G. 655 fibres were found to be -15.9 dB and -16.1 dB when transmitted on 1310 nm and 1550 nm window respectively. It is therefore evident that 1310 nm signal transmission are best suited for long distance G. 652 fibre while 1550 nm signal transmission are best suited for long distance G. 655 fibre. The dispersion effects are lower for G. 652 fibre on 1310 nm and G. 655 on 1550 nm window.

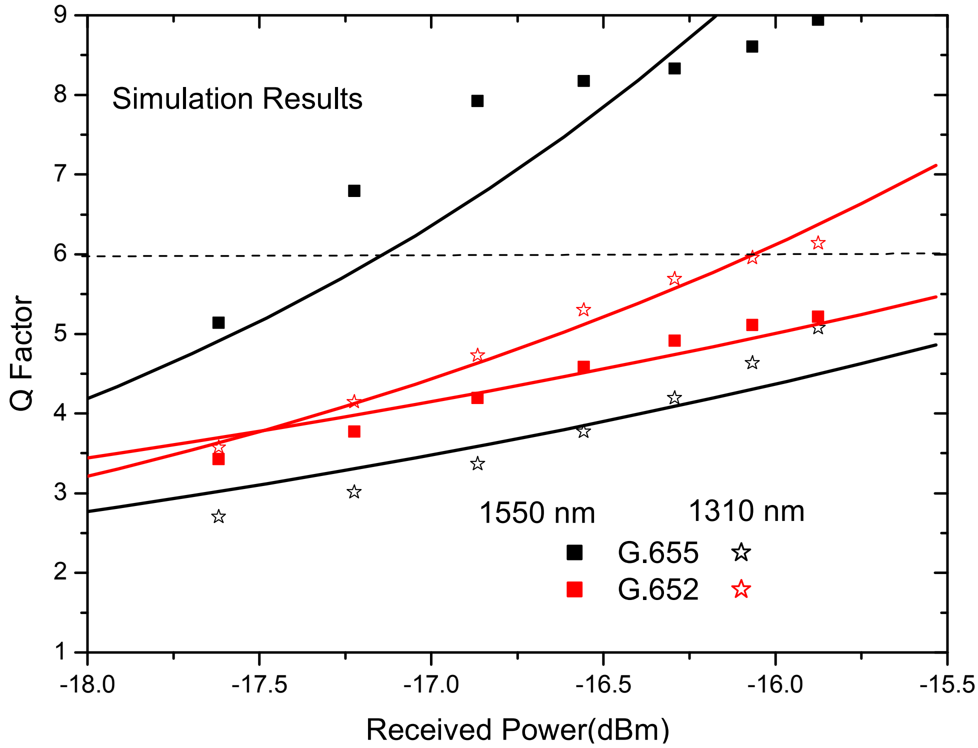


Figure 5. *Variation of received power with the Q Factor at 1310 nm and 1550 nm VCSELs.*

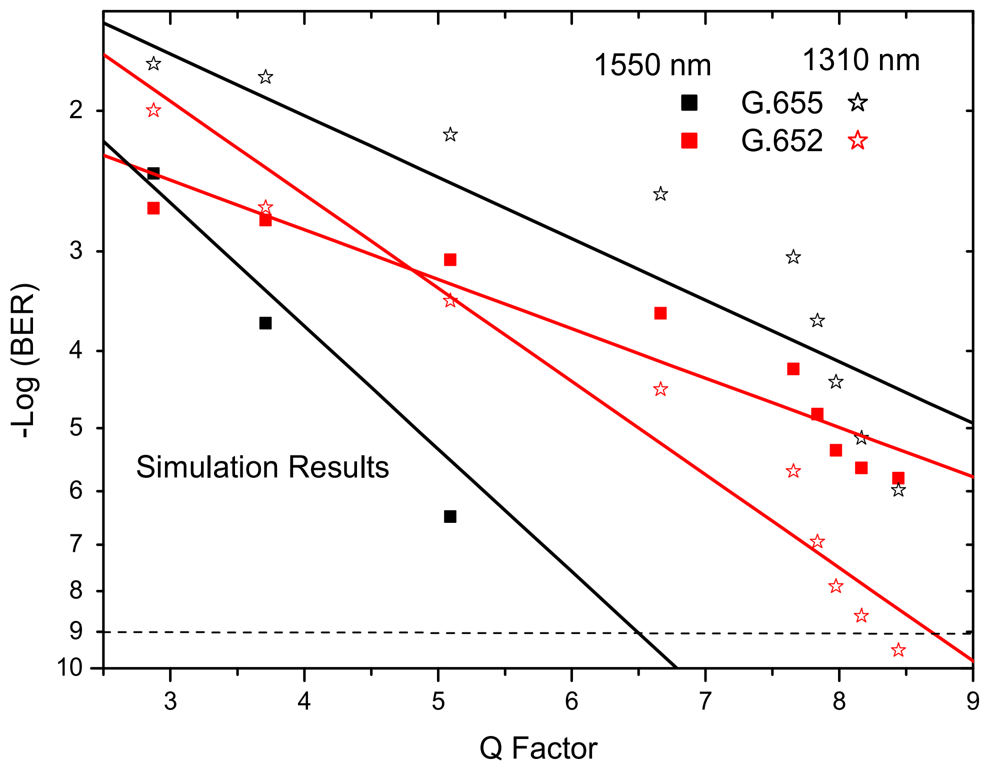


Figure 6. *BER as a function of Q factor.*

A 1550 nm transmission experinces a 17 ps/(nm. km) dispersion in a G. 652 fibre. The low dispersion penalties of G. 655 fibre on this transmission window extended the VCSEL reach. The 1310 nm VCSEL has high dispersion of about 17 ps/(nm. km) on a G. 655 fibre, thus resulting to transmission errors. Therefore, 1310 nm transmission window is best suited for long distance G. 652 fibre since dispersion and attenuation are lower at the 1310 nm transmission window.

The Q factor is used to specify the receiver performance since it is proportional to SNR required to achieve a specific BER. The system performance is quantified through the Q factor and it is related directly to the BER. The higher the value of Q factor means the better the OSNR and therefore a lower BER values.

From figure 5, it should be noted that the Q factor increased with the increase in the output power at the receiver. It can also be seen that low Q value corresponded to lower output power and this is because at lower power, the system error increases due to attenuation in the fibre which decreases the Q factor of the system. At a bit rate of 10 Gb/s, the 1550 nm VCSEL transmission over G. 655 fibre and 1310 nm VCSEL on G. 652 fibre recorded high quality (Q) factor values. A minimum power of -17.4 dBm and -16 dBm was required at the output for 1550 nm VCSEL on G. 655 and 1310 nm VCSEL on G. 652 fibres respectively to achieve the Q factor of 6. However, when 1310 nm and 1550 nm wavelengths were transmitted over G. 655 and G. 652 fibres respectively, Q factor below 6 was recorded.

From figure 6, it can be seen that the BER is inversely proportional to the Q factor. If the system error decreases, the BER will thus decrease. The simulation results shows that G. 655 fibre recorded Q factor value of 6.0 on 1550 nm VCSEL when the BER measurements were performed at 10^{-9} threshold level. When G. 652 fibre was transmitted over 1310 nm VCSEL, high Q factor value of 8.4 was attained. The minimum value of Q Factor that will enable a system to operate in region below BER of 10^{-9} is 6 and this is the most used value in telecommunication systems. However, the G. 652 and G. 655 fibres exhibited the worst performance with high BER values when transmitted over 1550 nm and 1310 nm windows respectively. Therefore, to reduce the BER we must increase the Q factor. Higher values of Q factor mean better performance.

4. Conclusion

The characterization of 1310 nm and 1550 nm VCSEL were studied. The 1310 nm and 1550 nm VCSELs have low threshold currents between 1- 2 mA. Both VCSELs operate in the mA range. It was found that BER reduces with increase in the received power. When a 1310 nm VCSEL was used, the signal was transmitted over error free region with 25 km G. 652 fibre. Minimum dispersion penalty was realized when a 1550 nm VCSEL was used on a G. 655 fibre. The simulation results showed high quality values when a 1550 nm and 1310 nm VCSELs were transmitted over G. 655 and G. 652 fibres respectively. However, when a 1550 nm and 1310 nm VCSELs was transmitted over G. 652 and G. 655 fibres respectively, Q factor below 6 was recorded.

References

[1] F. Fidler, S. Cerimovic, and C. Dorrer, "High-speed optical characterization of intensity and phase dynamics of a 1.55 µm VCSEL for short-reach applications," in *Optical Fiber Communication Conference*, 2006, p. OWI75.

[2] D. K. Boiyo *et al.*, "Effects of polarization mode dispersion (PMD) on Raman gain and PMD measurement using an optical fibre Raman amplifier," in *2013 Africon*, 2013, pp. 1–5.

[3] M. Y. Aldouri, S. A. Aljunid, R. B. Ahmad, and H. A. Fadhil, "Bit error rate (BER) performance of return-to-zero and non-return-to-zero data signals optical code division multiple access (OCDMA) system based on AND detection scheme in fiber-to-the-home (FTTH) networks," *Opt. Appl.*, vol. 41, no. 1, pp. 207–216, 2011.

[4] R. Hui, S. Zhang, B. Zhu, R. Huang, C. Allen, and D. Demarest, "Advanced Optical Modulation Formats and Their Comparison in Fiber-Optic Systems," *White Pap.*, no. January, 2004.

[5] C. del Río Campos and P. R. Horche, *Effects of Dispersion Fiber on CWDM Directly Modulated System Performance*.

[6] E. Soderberg *et al.*, "Suppression of Higher Order Transverse and Oxide Modes in 1.3-µm InGaAs VCSELs by an Inverted Surface Relief," *IEEE Photonics Technol. Lett.*, vol. 19, no. 5, pp. 327–329.

[7] E. S. Bjorlin *et al.*, "Long wavelength vertical-cavity semiconductor optical amplifiers," *IEEE J. Quantum Electron.*, vol. 37, no. 2, pp. 274–281, 2001.

[8] R. Rodes *et al.*, "Vertical-cavity surface-emitting laser based digital coherent detection for multigigabit long reach passive optical links," *Microw. Opt. Technol. Lett.*, vol. 53, no. 11, pp. 2462–2464, 2011.

[9] T. Quinlan, M. Morant, R. Llorente, and S. Walker, "Ultra-low cost and power VCSEL-based 480Mbit/s UWB radio over a bi-directional CWDM PON," in *Optical Communication (ECOC), 2011 37th European Conference and Exhibition on*, 2011, pp. 1–3.

[10] J.-C. Charlier and S. Krüger, "Long-wavelength VCSELs ready to benefit 40/100-GbE modules.".

[11] J. B. Jensen, R. Rodes, A. Caballero, N. Cheng, D. Zibar, and I. T. Monroy, "VCSEL based coherent PONs," *J. Light. Technol.*, vol. 32, no. 8, pp. 1423–1433, 2014.

[12] P. V Mena, J. J. Morikuni, S.-M. Kang, A. V Harton, and K. W. Wyatt, "A simple rate-equation-based thermal VCSEL model," *J. Light. Technol.*, vol. 17, no. 5, p. 865, 1999.

[13] S. A. Khwandah, J. P. Cosmas, I. A. Glover, P. I. Lazaridis, N. R. Prasad, and Z. D. Zaharis, "Direct and external intensity modulation in OFDM RoF links," *IEEE Photonics J.*, vol. 7, no. 4, pp. 1–10, 2015.