Towards Single-Mode VCSEL Arrays for 10 Gb/s Data Links

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Vertical-cavity lasers at 850 nm emission wavelength, designed and fabricated for high-speed operation, are used for 10 Gb/s and 12.5 Gb/s data transmission using pseudo-random-bit-sequence (PRBS) signals of different word length. Solitary single- and multi-mode devices as well as linear 1 × 10 arrays of single-mode devices are tested on wafer for their high-speed performance.

1. Introduction

Since IEEE's P802.3ae 10 Gb/s Ethernet Task Force adopted an 850 nm wavelength option in the physical media dependent layer standard for short range optical data links, the interest in this field has greatly increased. Owing to the surface-normal operation and many other favorable properties, like low power dissipation, high-speed modulation, and Si IC compatible low-cost manufacturing, vertical-cavity surface-emitting lasers (VCSELs) are going to be the preferred choice for the transmitter part. Single channel as well as one-dimensional fiber ribbonized parallel interconnect modules for data rates up to a few Gb/s per channel using VCSELs are already on the market [1, 2, 3]. Here we study single- and multi-mode selectively oxidized VCSELs emitting at 850 nm wavelength for very high speed operation. Solitary devices as well as linear arrays are characterized.

2. Properties of Solitary Devices

Fig. 1 shows the continuous wave (CW) output characteristics of a VCSEL emitting at 846 nm wavelength. Threshold current and threshold voltage are 0.4 mA and 1.7 V, respectively. The differential resistance approaches 207 Ω for higher operating currents. Thermal rollover starts at about 3 mA due to the small active diameter of 2 μm. The maximum optical output power of 3.2 mW is reached at an operating current of 7 mA. The inset shows optical spectra for various operating currents. Up to 2.5 mA the emission remains single-mode with a side mode suppression ratio of more than 30 dB. The modulation efficiency of $7.4\,\mathrm{GHz}/\sqrt{\mathrm{mA}}$ is obtained by fitting theoretical curves to measured small-signal modulation response data. For 1.5 mA bias current a 3 dB modulation bandwidth of 9 GHz is determined.

A multi-mode laser with an active diameter of 5 μm was investigated as well. Emission occurs around 843 nm in 4 to 5 transverse modes. Threshold current and threshold voltage are 0.87 mA and 1.6 V, respectively. The differential resistance is as low as 86 Ω. At 15 mA a maximum output power of 8 mW is reached. Small signal modulation response measurements yield a maximum modulation bandwidth of 8.5 GHz at a corresponding modulation efficiency of 5.2 GHz/$\sqrt{\text{mA}}$.

In Fig. 2 the bit error rate (BER) for 12.5 Gb/s pseudo random bit sequence (PRBS) modulation of word length $2^7 - 1$ is plotted against the received optical power for both lasers described above. Measurements are performed using an InGaAs PIN photodetector (supplied by Optospeed SA) of 0.4 A/W sensitivity in a back-to-back transmission setup. For the single-mode device bit error rates below 10^{-11} are reached for a received optical power of −11.7 dBm when the laser is biased at a current of 1.3 mA. The multi-mode device shows a minor power penalty of 1.5 dB at a bias of 10 mA for the same BER level.

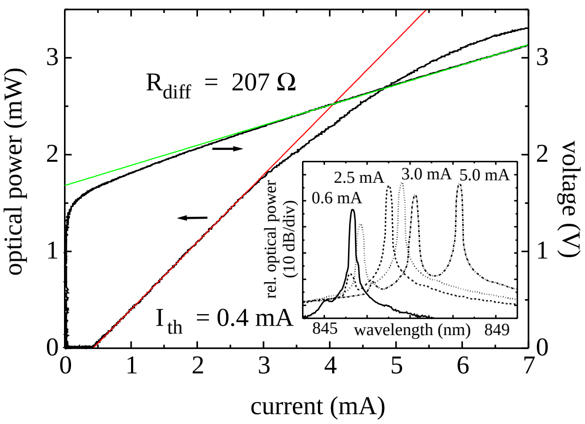

Fig. 1. CW operation characteristics and optical spectra of a single-mode VCSEL of 2 μm active diameter.

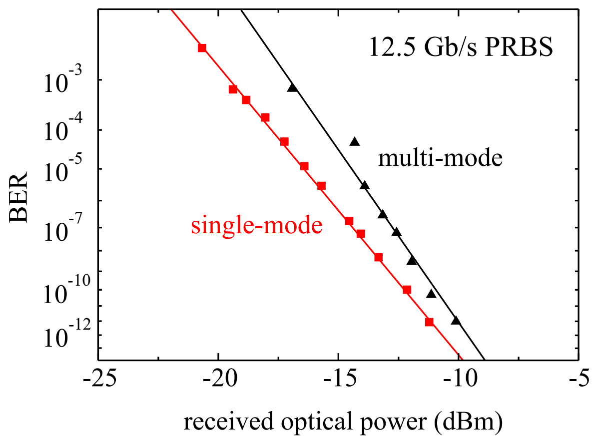

Fig. 2. BER vs. received optical power for a single-mode (squares) and a multi-mode (triangles) VCSEL.

Fig. 3 shows the bit error rate for a solitary laser diode operated at similar bias conditions for two pseudo random bit sequences of different word length at 10 Gb/s data rate. The general decrease in required optical power for a BER of 10^{-9} by about 2 dB in comparison to Fig. 2 is due to the use of an improved photodetector system comprising a PIN photodiode and a transimpedance amplifier (Picometrix AD50xr). The laser under study shows a threshold current of 0.42 mA and emits at 865 nm wavelength. The active diameter of the device is about 3 μm. It reaches a maximum output power of 800 μW at ten times threshold. Compared to the laser presented in Fig. 1 this structure shows reduced optical output power due to the increased number of top mirror pairs.

During modulation the device was biased at about four times threshold. The modulation voltage was adjusted for minimum BER performance. The minimum on/off-ratio was found to be around 5 dB using an optical sampling oscilloscope. In the case of $2^{31} - 1$ PRBS word length the on/off-ratio was strongly dependent on the previously transmitted information. This causes the power penalty of about 2 dB compared to the shorter word length case. Closer analysis shows this to be due to reflections on the electrical line feeding the laser because of the high differential resistance of about 470 Ω in comparison to the 50 Ω output impedance of the signal generator.

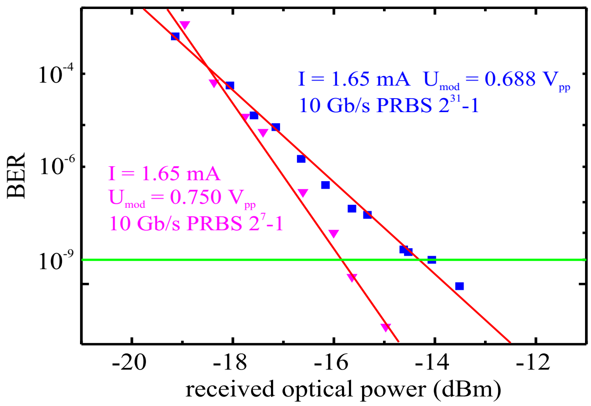

Fig. 3. BER vs. received optical power for a single-mode VCSEL modulated with a $2^7 - 1$ (triangles) and a $2^{31} - 1$ (squares) PRBS signal. Bias current and modulation voltage are only slightly different.

3. Characterization of Arrays

Fig. 4 shows a plot of the threshold current for 10 adjoining lasers. The emission wavelengths vary from 859 nm for laser #1 to about 854 nm for laser #10. All devices have about 2.5 μm active diameter and show a side mode suppression ratio of about 30 dB for the complete operating range.

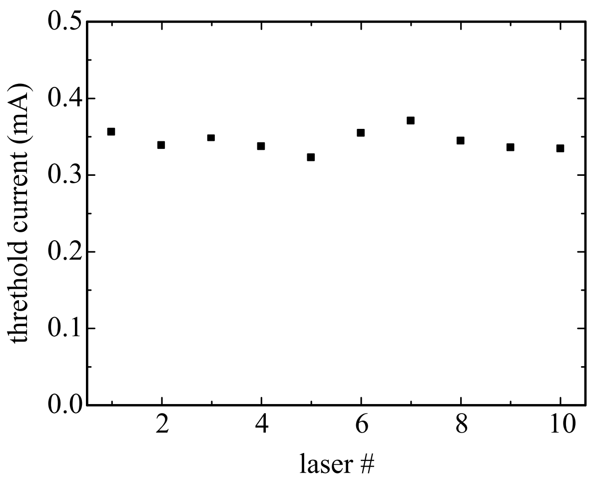

Fig. 4. Threshold current of 10 neighboring single-mode VCSELs of 2.5 μm active diameter.

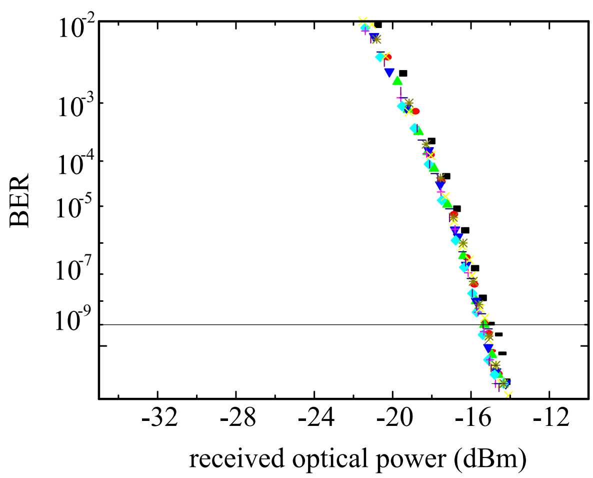

Fig. 5. BER vs. received optical power for a linear array of 10 single-mode VCSELs.

In Fig. 5 the bit error rates for 10 Gb/s pseudo random bit sequence modulation of word length $2^7 - 1$ are plotted against the received optical power for the same 10 lasers presented above. Each laser was biased at around four times threshold for the data transmission experiments. The modulation voltage was adjusted for minimum BER performance between 0.6 and 0.8 V_{pp} from a 50 Ω output impedance signal generator. For detection of the optical signal a photodetector system comprising a PIN photodiode and a transimpedance amplifier was used. An additional electrical 27 dB gain amplifier was used to measure BER and eye diagrams.

The lasers show no variation in modulation behavior with this setup. Small-signal modulation response measurements show 3 dB bandwidths of around 7 GHz for these lasers, preventing an increase in data rate.

4. Conclusion

In conclusion we have fabricated linear 1×10 VCSEL arrays capable of carrying a total data stream of 100 Gb/s. All measurements were taken at room temperature. Different environmental conditions as well as aging effects remain to be investigated.

References

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