Data Transmission with 1.55 μm Wavelength InGaAlAs VCSELs

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We investigate high bit rate data transmission behavior of buried tunnel junction single-mode, linearly-polarized InGaAlAs VCSELs for 1.55 μm wavelength. The devices show output powers of 0.73 mW and maximum modulation bandwidths of 5.9 GHz. We demonstrate 5 Gbit/s data rate over 20.5 km standard single-mode fiber as well as 10 Gbit/s for back-to-back transmission.

1. Introduction

Vertical-cavity surface-emitting lasers emitting at 850 nm wavelength are currently used as transmitters for serial and parallel optical links over multimode fibers [1]. The advantages of VCSELs are their high beam quality, longitudinal and transverse single-mode operation, low power consumption and the possibility of array arrangements. Additionally easy on-wafer testing leads to low production and packaging costs. At 1.55 μm wavelength standard single-mode fibers (SSMF) with high bandwidth length products and low optical dispersion and attenuation can be used. Taking into account that the eye safety restrictions at an emission wavelength of 1.55 μm are relaxed by a factor of about 100 compared to 850 nm wavelength [2], the maximum interconnect length can be up 80 km of SSMF [3, 4]. The technological challenges of monolithically grown 1.55 μm wavelength VCSELs are the poor thermal conductivity and low reflectivities of InP-based Bragg mirrors. Additionally a natural oxidation process for current confinement is not yet known. As an alternative to Bragg mirrors active regions on GaAs, metamorphic growth or wafer bonding techniques are conceivable. Using a substrate removal technique and bottom dielectric mirrors in combination with a buried tunnel junction (BTJ) for current confinement, a significant improvement with respect to single-mode power and operation temperature has been demonstrated [5]. In this paper we present the static and significantly improved dynamic characteristics of InGaAlAs-based BTJ-VCSELs emitting at 1.55 μm wavelength. For the first time we demonstrate 5 Gbit/s data transmission over 20.5 km SSMF as well as 10 Gbit/s for back-to-back (BTB) operation. This shows the excellent performance of 1.55 μm VCSELs for Metropolitan Area Network applications.

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2. 1.55 μm Wavelength InGaAlAs VCSEL Layout

Figure 1 shows a schematic cross-sectional view of the BTJ-VCSEL.

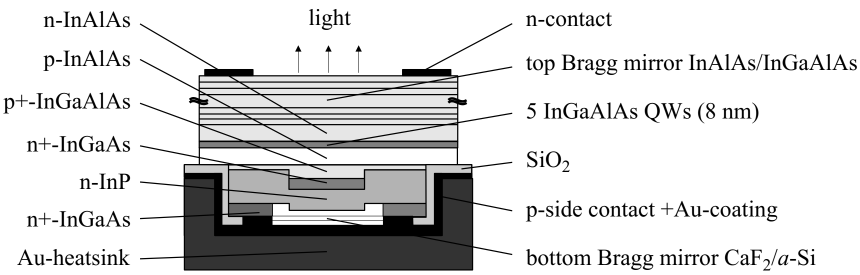

Fig. 1: Schematic layout of 1.55 μm InGaAlAs VCSELs.

The use of the BTJ leads to self-adjusted current confinement as well as optical confinement. Applying highly conductive n-doped spreading layers rather than highly resistive p-doped material, a low series resistances with associated small internal heating is obtained. The front and back mirrors consist of 34.5 pairs of epitaxial InGaAlAs and 2.5 pairs of dielectric CaF_2/a-Si stacks, respectively. The InP substrate on top of the upside-down mounted structure is completely removed. Despite of substrate removal, an electroplated layer at the bottom ensures mechanical stability and additionally acts as an excellent heatsink.

3. Static Characteristics

Figure 2 shows typical room temperature, continuous wave (CW) output characteristics of 1.55 μm BTJ-VCSELs with an elliptic aperture of $3{\times}4\,\mu m^2$.

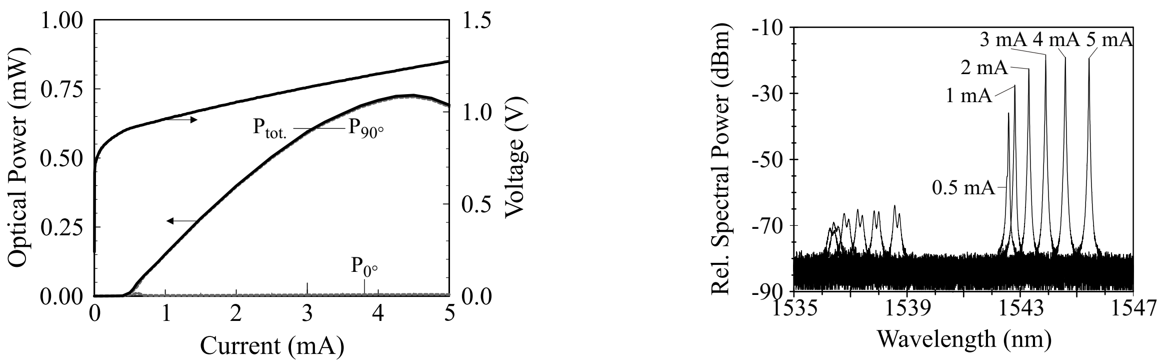

Fig. 2: Operation characteristics of 1.55 μm InGaAlAs-VCSELs with an aperture size of $3{\times}4\,\mu m^2$ (left) and spectra for different driving currents (right).

As shown on the left-hand side of Fig. 2, the maximum output power of this single-mode, single polarization device is 0.73 mW at 4.7 mA. The threshold voltage and threshold current are as low as 0.91 V and 0.4 mA, respectively, while the differential series resistance is 78 Ω. The right-hand side of Fig. 2 shows the high resolution emission spectra of single-mode BTJ-VCSELs under CW operation. It is important to note that single-mode emission with at least 30 dB side-mode suppression-ratio (SMSR) can be observed over the entire current range. Due to internal heating, the peak wavelength shifts from 1542.6 nm at 0.5 mA current to 1545.4 nm at 5 mA.

4. Dynamic Characteristics

The left-hand side of Fig. 3 shows the small-signal frequency responses of single-mode BTJ-VCSELs for various bias currents.

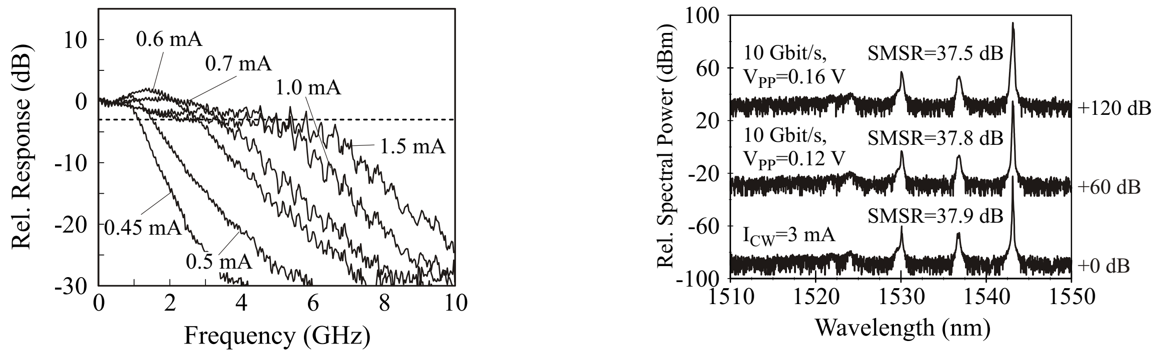

Fig. 3: Modulation response (left) and spectra for CW operation and with 10 Gbit/s modulation (right) of 1.55 μm InGaAlAs VCSELs with an aperture size of 3×4 μm^2.

The maximum measured 3 dB modulation frequency of 5.9 GHz at 1.5 mA is limited by external parasitics, indicating necessary optimizations toward a high-frequency capable electrical VCSEL layout. The right-hand side of Fig. 3 shows the emission spectra for CW operation as well as for 10 Gbit/s modulation with $V_{pp} = 0.12$ V and $V_{pp} = 0.16$ V. The peak wavelengths for all cases are around 1543.1 nm, and SMSRs of more than 37 dB are observed. The spectral width increases from $\delta\lambda_{RMS,CW} = 0.0167$ nm for CW operation to $\delta\lambda_{RMS,V_{pp}=0.16\,V} = 0.0567$ nm.

5. Data Transmission over Standard Single-Mode Fibers

The 10 Gbit/s eye diagram on the left-hand side of Fig. 4 was recorded for BTB transmission with 3 mA bias current and a modulation with $V_{pp} = 0.15$ V. Even for very high bit rates of 10 Gbit/s, wide openings can be observed. As shown on the right-hand side of Fig. 4, error-free data transmission with bit error rates (BER) of better than 10^{-12} is obtained up to data rates of 10 Gbit/s. For BTB operation at 5, 8 and 10 Gbit/s the minimum received optical power is −18.6 dBm, −15.4 dBm and −11.4 dBm, respectively. The measured power penalty for 5 Gbit/s data transmission over 20.5 km SSMF is about 1 dB, while for 8 Gbit/s over 10.5 km SSMF the power penalty is only 0.4 dB.

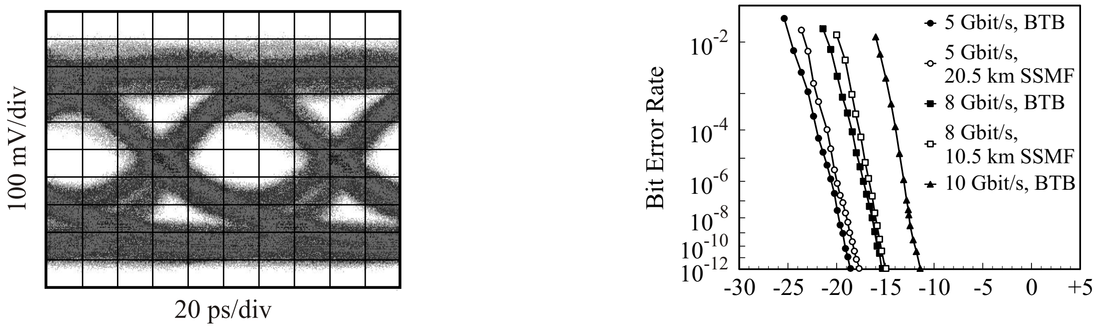

Fig. 4: 10 Gbit/s eye diagram after BTB transmission with 3 mA bias current and a modulation with $V_{pp} = 0.15$ V (left) and bit error rates for 5, 8 and 10 Gbit/s data rates with 3 mA bias current and a modulation voltage of $V_{pp} = 0.15$ V (right).

6. Conclusion

We have demonstrated excellent output performance of single-mode, single polarization BTJ InGaAlAs VCSELs emitting at 1.55 μm wavelength for MAN applications. Measured output power of 0.73 mW as well as a maximum modulation bandwidth of 5.9 GHz makes these VCSELs capable to transmit 5 Gbit/s over 20.5 km SSMF and 8 Gbit/s over 10.5 km SSMF with power penalties of only 1 dB and 0.4 dB, respectively. BTB transmission of 10 Gbit/s was demonstrated for the first time with 1.55 μm VCSELs.

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