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High-Speed 1.55 µm VCSELs

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Abstract:

Vertical-cavity surface-emitting lasers with buried tunnel junction at 1.55 µm wavelength with novel high-speed design are presented. The devices show superior modulation bandwidths above 10 GHz. Wide open eye diagrams enable error-free data-transmission at 10-Gb/s.

1 Introduction

Recently, VCSELs for 1.3 µm and longer wavelengths (LW-VCSELs) have become commercially available, cover the wavelength-range from 1.3 to 2.3 µm, show cw-operation beyond 100 °C, provide high output powers and modulation bandwidths above 10 GHz [1, 2]. This enables several important applications, particularly in the fields of optical data transmission. One of the most powerful approaches for the InP-based devices is the BTJ-VCSEL, introduced in 2000.

In this paper, we present our latest results on long-wavelength BTJ-VCSELs in the AlGaInAs-InP material system optimized for high-speed applications.

2 Structure

The VCSELs are based on the InP-material system using a buried tunnel-junction (BTJ). This technique enables the replacement of p-conducting by n-conducting semiconductor material with lower optical losses, resistance and ohmic heating. This concept has yielded high-performance long-wavelength VCSELs for the entire 1.3 to 2.3 µm wavelength range [3].

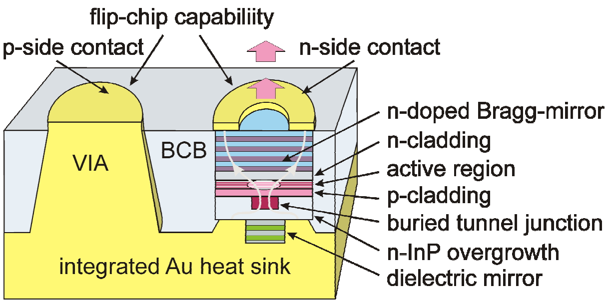

Figure 1: Schematic cross-section of a high-speed VCSEL

Keeping the BTJ-design, we recently reworked our device structure according to Fig. 1 with several benefits. With chip sizes around 30 µm this design shows reduced RC-products for higher modulation bandwidths exceeding 10 GHz [1]. In addition, these devices are flip-chip bondable and feature coplanar connectivity. This features are essential for datacom VCSELs at 1.3 or 1.55 µm.

3 Results

Especially VCSELs at the telecommunications-wavelengths between 1.3 and 1.6 µm require broadband modulation performance to achieve high data rates. The large electro-thermal tunability can be used to stabilize the wavelength in uncooled operation. The threshold current is typically below 1 mA and the single-mode output-power is above 2 mW at high quantum efficiencies around 36 %. Depending on current aperture and bias current, the differential series resistance is between 25 Ω and 75 Ω. Therefore, no matchbox is needed to drive the VCSEL with a standard 50 Ω RF-system.

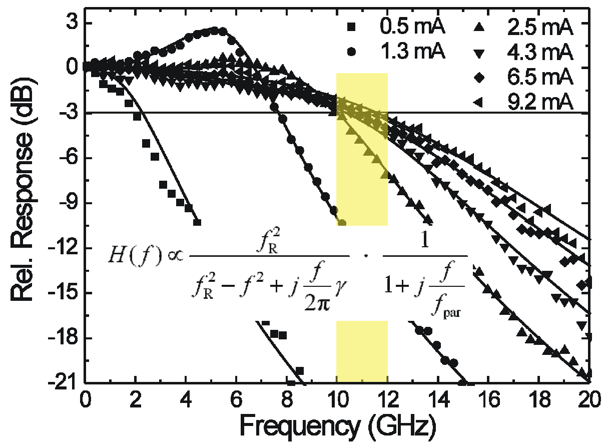

Figure 2: Small signal frequency response of a high-speed VCSEL. The solid lines are fits to the inset equation.

Fig. 2 shows the small-signal modulation performance of such a device. A 3 dB-bandwidth of 10 to 12 GHz is demonstrated in a wide bias range. This assures open eyes at 10 Gb/s. The measurement was done using a HP 8720D – 20 GHz – VNA (Vector Network Analyzer) and a calibrated HP 11982A photo-detector. The response of the detector was subtracted from the presented data. The chip with its coplanar connectivity was directly connected by a calibrated cascade microprobe. In order to judge intrinsic and parasitic response, we fitted the measured S_{12}-data to the inset equation, a three-pole filter function.
The first part of this equation can be directly derived by small-signal analysis of the rate-equations above threshold yielding a two-parameter modulation transfer function characterized by the relaxation oscillation frequency f_R and the damping-factor γ. This damping-factor is proportional to the resonance-frequency with

offset γ_0 and the *K*-factor *K*, yielding a maximum intrinsic bandwidth

$$f_{\max} = \sqrt{2}\,\frac{2\pi}{K} \tag{1}$$

due to over-damping [4]. The second part of the inset equation in Fig. 1 models the electrical chip-parasitics by a parasitic pole. The advantage of this approach compared to other techniques is that it can account for parasitics that vary over the biasing conditions. For edge-emitting lasers, the oscillation frequency, and the 3 dB-bandwidth is expected to rise with the square-root of the bias-current above threshold, proportional to the modulation current efficiency.

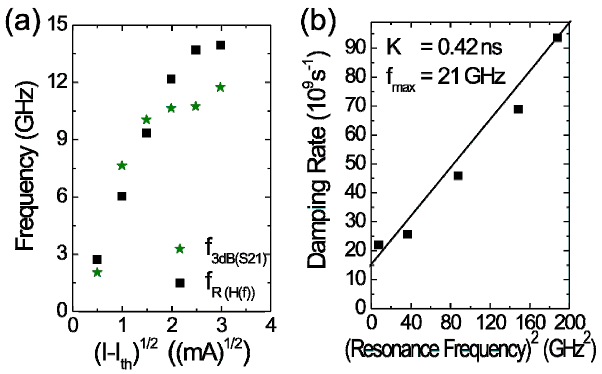

Figure 3: (a) Resonance frequency and bandwidth versus square-root of driving current avove threshold and (b) derived K-factor and maximum bandwidth acc. to eq. (1).

As can be seen in Fig. 3 (a), the resonance frequency of a VCSEL shows a thermal roll-over according to the output-power. This behaviour can explained by rate-equation analysis. The commonly used equation

$$f_R \propto \sqrt{I - I_{th}} \tag{3}$$

is derived from

$$f_R^2 \propto P_0 \tag{4}$$

with P_0 as laser output-power under the assumption that P_0 rises linearly with bias-current above threshold which, however, is not the case for the VCSEL with its thermal roll-over in the L-I-characteristics.

Fitting all curves in Fig. 2, a *K*-factor of 0.42 ns can be derived as presented in Fig. 3 (b). According to equation (1) this yields an intrinsic limitation by over-damping of 21 GHz.

The transmission performance of the VCSELs was evaluated regarding their feasibility as directly-modulated transmitters in optical communication systems. The laser was biased at 5.2 mA and modulated with non return to zero (NRZ) data of 2^{23}-1 pseudo-random bit sequence (PRBS) pattern length at 10 Gbit/s. Bit-error-rate (BER) measurements in Fig. 4 (a), obtained in back-to-back (BTB) and in transmission experiments using 22 km dispersion shifted fibre (DSF) and 10 km non-zero DSF, demonstrate error-free performance. The corresponding widely open eye diagrams at BER = 10^{-9} are shown in Fig. 3(b).

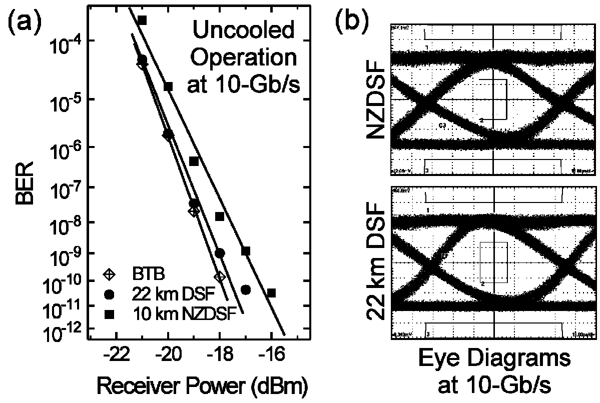

Figure 4: (a) BER performance of 10 Gb/s modulated VCSELs; (b) corresponding eye diagrams at BER = 10^{-9}.

As compared to the BTB case, the transmission penalty for 22 km DSF fibre is negligible at 0.4 dB due to zero-dispersion around the 1550 nm wavelength with minimum attenuation. Both the bandwidth limitation of the used bias-T and the photodetector cause degradation of the eye diagrams which have to be taken into account. Consequently, the eye-diagram of the electrical driver without laser and PD already showed considerable rise- and fall-times. Our transmission results highlight the potential of the VCSELs as uncooled transmitters in passive optical networks that eliminate the need for optical amplification or costly high-bandwidth DFB laser transmitters.

4 Conclusions

With their high modulation bandwidth above 11 GHz, LW-VCSELs enable a variety of novel applications in the fields of optical data communications.

5 Acknowledgements

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6 References

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