High-Speed High-Power VCSELs based on InP

Tobias Gründl[1], Michael Mueller[1], Robin D. Nagel[1], Kathrin Geiger[1], Gerhard Böhm[1], Christian Grasse[1],
Markus Ortsiefer[2], Markus-Christian Amann[1]

1) Walter Schottky Institut, Technische Universität München, Am Coulombwall 3, 85748 Garching, Germany, gruendl@wsi.tum.de

2) VERTILAS GmbH, Lichtenbergstrasse 8, 85748 Garching, Germany

Abstract: We present 1.55 µm short-cavity BTJ-VCSELs with single mode output powers of 6.6 mW at 20°C and 3 mW at 80°C, respectively, a 3dB-cut-off frequency of 11 GHz and SMSRs beyond 54 dB.

1. Introduction

The increasing data traffic in local and access networks over the past few years and in particular the emerging 100G-Ethernet standard require cost-effective and low power consuming devices offering additionally remarkable properties concerning modulation speed, optical output power and tunability. Big efforts have already been successfully put into the realisation of high-speed vertical-cavity surface-emitting lasers (VCSELs) in the near-infrared range around 850 nm based on GaAs [1, 2]. However, the achieved internal bandwidths beyond 20 GHz on the basis of this wavelength are only applicable for short-range optical interconnects. As a consequence, for making the long-range optical interconnections accessible major developments on the InP based VCSELs containing (Al,Ga)InAs ternary and quaternary alloys had been done. An overview over the present status concerning long-wavelength BTJ-VCSELs emitting at 1.3 – 1.55 µm satisfying long-distance data transfer and optical spectroscopy can be found in [3-5].

In this work we present the first long-wavelength short-cavity BTJ-VCSELs with modulation bandwidths of 11 GHz and optical output powers exceeding 6.6 mW at 20°C and 3 mW at 80°C, respectively. The inherent single-mode behaviour of the VCSELs is guaranteed by SMSRs beyond 54 dB over the whole temperature-range.

2. Device Structure and DC-Characteristics

Fig. 1 shows a sketch of the realized short-cavity VCSELs. In general epitaxial DBRs are used at both sides of the laser cavity for getting high reflectivities whereas the laser contacts are deposited on top of these DBR structures. By contrast our intracavity VCSEL concept enables the implementation of two dielectric DBRs that is one on each side (see Fig. 1). As the refractive index contrast of these dielectric DBRs (for instance based on sulphuric and fluoride materials) is much higher compared with the epitaxial ones the penetration depth of the optical field into the DBRs is tremendously reduced, resulting in a shorter effective cavity length, reduced photon lifetime, reduced intrinsic damping and higher relaxation resonance frequency. Both the reduced cavity length and the use of low-ε dielectric benzocyclobutene (BCB) are crucial for improved high-speed properties of the device.

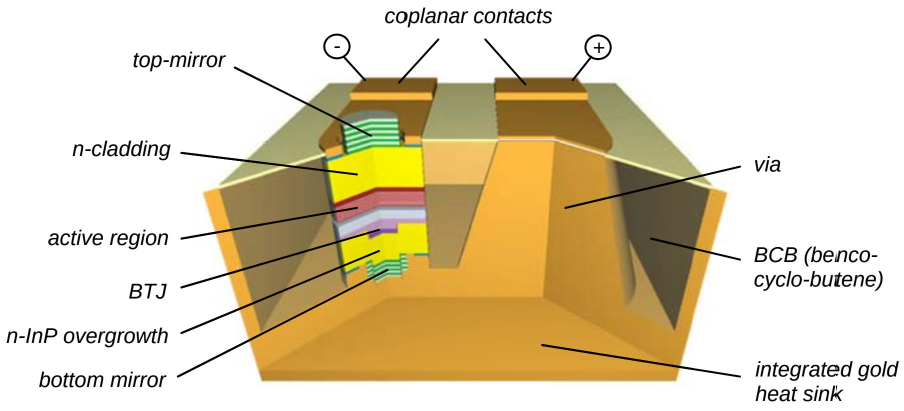

Fig. 1 Schematic view of the realized short-cavity high-power 1.55 µm InP-based BTJ-VCSEL

The active region consists of seven quantum wells, moderately-strained in order to enhance the (differential) gain and to reduce the transparency carrier density which additionally has a beneficial effect on the modulation frequency. By lowering the doping level of the *n*-InP overgrowth (see Fig. 1) the parasitic capacitance of the space charge region is reduced leading to strongly reduced device parasitics [6]. The electrical aspects and the heat management of the whole device has been improved by replacing the formerly used AlGaInAs quarternary *n*-cladding by the modulation doped binary material InP showing much better electrical and thermal properties. Additionally the combination of (a) the above mentioned two dielectric DBRs (b) an adjusted mode-gain offset of the active region of 50 nm, (c) the implemented Au pseudo-substrate and (d) the second intracavity contact (see minus-pole of the VCSEL in Fig. 1) is leading to much better high-temperature device performances beyond 80°C. As a result we observe lasers with BTJ-diameters of 5.5 µm showing maximum output powers exceeding 6.6 mW at 20°C and 3 mW at 80°C (see Fig. 2). The roll-over of these devices take place at currents beyond 17 mA over the whole temperature range. The SMSR in between driving currents of 11 to 14 mA (at these currents the small-signal measurements had been done, see section 3) is still beyond 54 dB both for 20°C and 80°C promising to the best of our knowledge world-record values of single mode behaviour in combination with high-speed and high-power properties (see Fig. 3). First electro-thermal tuning investigations show a tuning range of 5 nm. The slope efficiency of our devices is in the range of 42% whereas the differential series resistance shows values of 40 Ω, being well suited for high-speed operation.

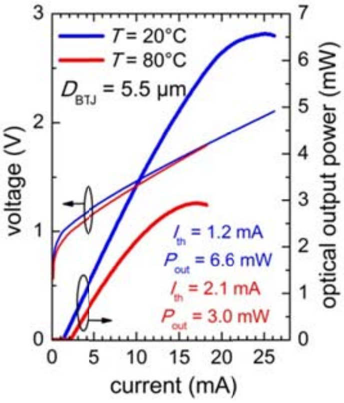

Fig. 2: L-I-V characteristics at different temperatures

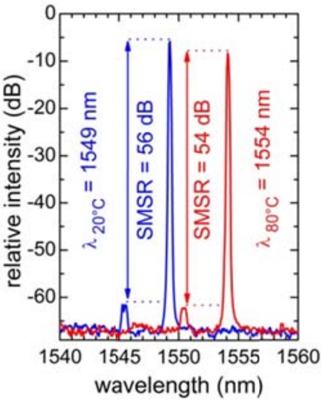

Fig.3: Optical spectra at room-temperature (blue) and 80°C (red)

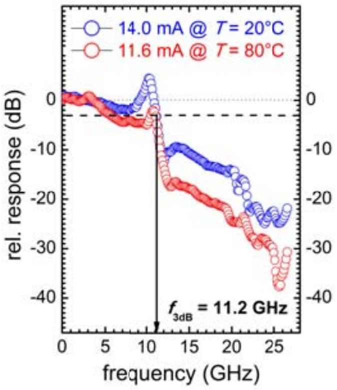

Fig.4: Small-signal modulation response at different temperatures

3. Small Signal Modulation Performance

In order to determine the resonance frequency f_R, the small signal modulation performance was verified on chip-level for various bias-currents. The measurements were performed using an HP8510C vector network analyser with matched and calibrated HP11982A photodiode. The chip was probed with an I67 Cascade microprobe and calibration to the chip-lane was carried out using a Cascade impedance standard substrate. The signal level was chosen in between 0 dBm to -2 dBm depending on incoupling. Fig. 4 presents the measured S_{21}-parameter plotted over the modulation frequency for room-temperature (blue curve) and 80°C (red curve). As can be seen the maximum achievable 3dB-cutoff frequency of 11 GHz is reached for bias currents clearly smaller than the respective roll-over currents and seems to be stable and unchanged over the whole temperature-range.

Conclusions

We presented novel 1.55 µm short-cavity BTJ-VCSELs ($Ø_{BTJ}$ = 5.5 µm) showing record-high single-mode optical output powers exceeding 6.6 mW at room-temperature and 3 mW at 80°C with SMSRs beyond 54 dB over the whole temperature-range. These devices represent promising low-cost light-sources for long-distance data transfer with regard to 100G-Ethernet solutions and optical spectroscopy.

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Tobias Gründl was born in Tegernsee/Bayern Germany, in August 1981. He received the Dipl.-phys. degree in semiconductor physics and nanotechnology from the Technische Universität München, Germany, in 2007. He is currently working towards his PhD degree at the Walter Schottky Institut in Garching, Germany, in the field of gas sensing and optical communications. His research interests include the design and realization of InP-based VCSELs in particular widely tunable (monolithically-integrated) MEMS-VCSELs and the design of SWGs and HCGs.