High-Speed Buried Tunnel Junction VCSELs with High Operation Temperature

- Invited Paper -

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Abstract

1.55- μm vertical-cavity surface-emitting lasers with reduced parasitics and superior modulation bandwidth in excess of 10-GHz at 85°C are realized. Bit-rates of 17-Gb/s are demonstrated at room temperature, and error-free 12.5-Gb/s is achieved up to 85°C.

Introduction

High-Speed vertical-cavity surface-emitting lasers (VCSEL) with internal bandwidths exceeding 20 GHz have been presented recently emitting in the near infrared spectrum [1-2]. As this waveband can only be used for short distances up to 300 m, there has been a great effort in developing long-wavelength, high-speed VCSELs with steady progress [3-7].

Especially, long-wavelength VCSELs with buried tunnel junction (BTJ) have shown promising results and record-high modulation bandwidths.

In the near future, the market demands cost-effective 100G Ethernet solutions. Consequently, higher laser bandwidth is demanded for the projected data-rates, favourably provided by a cost-effective device at long wavelengths and high temperatures that range up to 85°C for uncooled operation.

In this paper we present high-speed long-wavelength BTJ VCSELs with superior bandwidths up to 85°C.

Low Parasitics Design

The lasers under investigation were grown by molecular beam epitaxy on InP substrate. The high-speed 1.55 μm VCSEL structure is an improved version of the device described in [4], with optimized active region, detuning, mirror-reflectivities and doping levels. The schematic layout of the laser chip is shown in Fig. 1. BCB is used as low-dielectric constant passivation, eliminating contact pad capacitances. For high laser bandwidth and sufficient gain at elevated temperatures, the active region is composed of 7 heavily strained (2.5% compressive strain, pseudomorphic) InAlGaAs quantum wells near the borderline of critical layer thickness. For the presented device, the threshold current was designed to be lowest at 60°C heat-sink temperature. This was achieved by a large mode-gain offset resulting in negative T_0 values. Due to the BTJ, which allows the elimination of nearly all p -conducting material with higher electrical resistances and optical losses, a

Fig. 1. Schematic cross-section of a high-speed 1.55 μm InP-based BTJ VCSEL. The device is mounted epi-down on an electroplated gold pseudo-substrate. The InP substrate is removed while manufacturing. Both n - and p -contact can be accessed on top. Contact-pad capacitances are minimized.

differential series resistance as low as 40-50 Ω has been achieved, impedance matched to electrical drivers.

As the parasitic response of our VCSELs can be well modeled by a first-order equivalent circuit [5], a three-pole filter function including relaxation-oscillation frequency f_R , intrinsic damping γ and parasitic roll-off f_P describes the response of our VCSEL well, allowing several intrinsic parameters, to be extracted. Constant terms in Eq. (1) are the differential quantum efficiencies η_d of laser and detector.

$$H(f) = \eta_{d,L} \eta_{d,PD} \cdot \frac{f_R^2}{f_R^2 + j \frac{\gamma}{2\pi} f - f^2} \cdot \frac{1}{1 + j \frac{f}{f_P}} \quad (1)$$

Even though our devices in reference design [4] showed excellent high-speed behaviour for small chip diameters, the bandwidth of devices with larger semiconductor chips were still clearly limited by device parasitics. By reducing the doping levels of the blocking diode next to the BTJ from 5 to $1 \cdot 10^{17} \text{ cm}^{-3}$, the parasitic capacitance was significantly lowered, boosting the modulation bandwidth from below 7 GHz to 9 GHz.

Modulation Performance

VCSELs are characterized by very high carrier and photon densities in the optical resonator causing a damped modulation response. Consequently, low parasitics are especially important for VCSELs as the smaller relaxation oscillation overshoot cannot compensate a parasitic roll-off. In Fig. 2, a superior modulation per-

Fig. 2. Small-signal modulation performance of 1.55 μm VCSEL with improved modulation bandwidth and temperature range. At 25°C modulation bandwidth in excess of 12 GHz can be stated and even at elevated temperatures of 85°C 10 GHz modulation bandwidth is available. Scatters: measured data; solid lines: fit to Eq. 1. *LIV*-characteristics given as inset.

formance can be identified over a wide temperature range. The 3-dB bandwidth exceeds 12 GHz at 25°C, is 11 GHz at 55°C and 10 GHz at 85°C. The *LIV*-performance is given as an inset showing more than 2.5 mW at room temperature and 1 mW at 80°C. A detailed investigation of intrinsic laser parameters clearly demonstrated a lowered *K*-factor from 0.4 to 0.3 ns, yielding an improvement of the damping limit [6]. With a shortened laser cavity, photon lifetimes could be further reduced yielding a 15-GHz bandwidth [7].

Large-Signal Performance

The VCSELs presented here were especially designed for uncooled operation with superior and constant rating rather than peak-performance at a certain fixed temperature. As demonstrated in Fig. 3, error-free data-transmission at 12.5-Gb/s up to 85°C is feasible. Open eyes at 12.5 and 17-Gb/s clearly state the potential for 100G Ethernet applications.

Conclusions

In this paper we present our 1.55 μm BTJ-VCSELs with improved high-speed and high-temperature performance. Internal parasitics have been drastically reduced by redesign of doping-levels. Modulation bandwidth at 5 mA is sufficient for 12.5-Gb/s over a temperature-range from 0-85°C at output powers around 1 mW. Internal relaxation oscillation frequencies could also be improved by higher differential material gain from highly strained quantum-wells. At room temperature we present a record-high modulation bandwidth above 12 GHz demonstrating data-rates of 17-Gb/s for 100G Ethernet.

Fig. 3. Large-Signal modulation performance of the VCSEL presented in Fig. 2. Error-free data-transmission at 12.5-Gb/s at 85°C is demonstrated. (2^7-1 PRBS, BTB). Inset eye diagrams recorded at 12.5 and 17-Gb/s data-rates are both wide open. Eye diagrams were recorded at 25°C.

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