1060 nm VCSEL for up to 40 Gbit/s Data Transmission

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Abstract: *A GaAs-based 1060 nm VCSEL with strained InGaAs/GaAsP QWs, doped DBRs, a short optical cavity, and multiple oxide apertures is presented. Modulation up to 40 Gbit/s at 25°C and 30 Gbit/s at 85°C is demonstrated.*
Keywords: *Vertical-cavity surface-emitting laser (VCSEL), optical interconnects*

1. Introduction

The short-reach optical interconnects used in datacenters and high performance computing systems are dominated by 850 nm vertical-cavity surface-emitting laser (VCSEL) and multimode fiber (MMF) links with reach up to ~100 m. With large-scale datacenters requiring reach up to ~2 km, VCSEL-MMF links at longer wavelengths are of interest because of reduced chromatic dispersion and attenuation in the MMF. GaAs-based VCSELs are still preferred because of their superior speed and efficiency and it has been demonstrated that the wavelength can be extended to ~1100 nm without compromising reliability [1]. Recently, transmission over 1 km of 1060 nm optimized MMF at 25.78 Gbit/s using a 1060 nm multimode VCSEL with undoped distributed Bragg reflectors (DBRs) and intra-cavity contacts was demonstrated [2]. Here we present a 1060 nm VCSEL with doped DBRs, a short optical cavity and multiple oxide apertures and demonstrate large signal modulation and data transmission at rates up to 40 Gbit/s at 25°C and 30 Gbit/s at 85°C.

2. VCSEL Design and Fabrication

The VCSEL design is similar to that used for our high-speed 850 nm VCSELs [3], but with the strain in the quantum wells (QWs) partially compensated by GaAsP barriers. The AlGaAs/GaAs DBRs with graded composition interfaces are modulation doped and designed for a low electrical resistance-optical loss product. The low index layer in most of the bottom DBR is AlAs for low thermal impedance. A short half-wavelength cavity is used for high optical confinement. The detuning between the gain peak and the cavity resonance is set for a small variation of the threshold current with temperature. To reduce capacitance, we use multiple oxide apertures with two primary apertures for transverse optical and current confinement and four secondary oxide apertures (Fig.1). The primary apertures are positioned at optical field nodes and are thinner than in our 850 nm VCSEL design for weak optical guiding to reduce the spectral width as this is beneficial for long distance transmission. The thinner oxide layers lead to a higher parasitic capacitance and thereby a somewhat reduced modulation bandwidth.

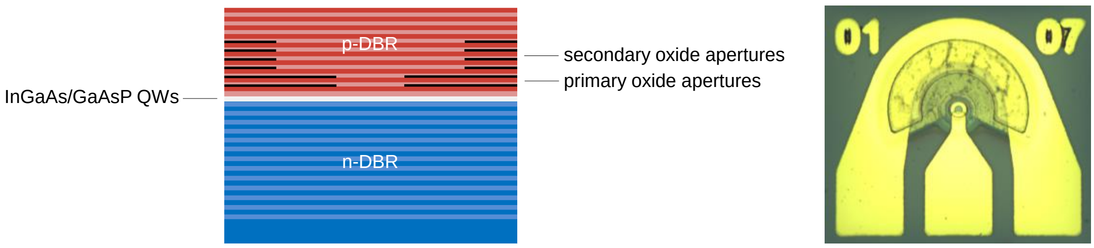

Fig.1 Left: VCSEL design with multiple oxide apertures and strained InGaAs/GaAsP QWs. Right: Microscope image of a fabricated VCSEL.

The epitaxial structure was grown on an undoped GaAs substrate by MOCVD. Standard fabrication techniques were used for deposition and etching of dielectrics, deposition of contact and pad metals, mesa etching, and oxidation. A thick layer of BCB was used under the p-bondpad to reduce the pad capacitance. The diameter of the primary oxide apertures is 4.5 µm. With the phase of the reflection at the surface of the VCSEL having a large impact on the cavity photon lifetime and therefore the VCSEL dynamics, the thickness of the top layer of the top DBR (which controls the phase) was adjusted for a damped high-bandwidth modulation response [4].

3. VCSEL Performance

Static performance characteristics are shown in Fig.2. The output power was measured with a calibrated large-area Ge-photodiode. At 25°C we have a threshold current of 0.51 mA, a slope efficiency of 0.67 W/A, a series resistance of 220 Ω, and a maximum power of 4.6 mW. The emission spectra has an RMS spectral width of $\Delta\lambda_{RMS}$ ~ 0.5 nm, with two dominating transverse modes at ~1056 nm. Increasing the temperature to 85°C led to a shift in wavelength of 5 nm and an increase of the threshold current and differential resistance to 0.65 mA and 230 Ω, respectively. The slope efficiency and maximum power were reduced to 0.57 W/A and 2.8 mW, respectively.

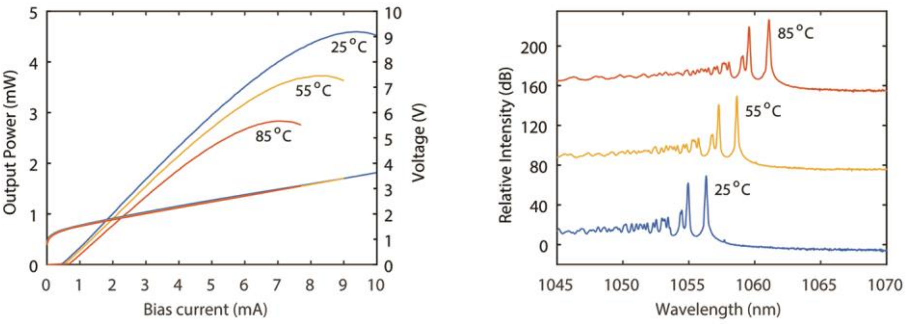

Fig.2 Left: Output power and voltage vs. current at 25, 55, and 85°C. Right: Emission spectra at 4 mA.

The small signal modulation response (Fig.3) was measured with a Rohde & Schwarz ZVA 67 GHz vector network analyzer and a 28 GHz Picometrix DG-32xr photodetector. A lens system was used to couple the output light from the VCSEL into a multimode fiber (MMF) after which it was attenuated and fed to the detector. At 25°C the maximum 3 dB bandwidth is 21 GHz at 4 mA bias current. At 85°C it is reduced to 17 GHz at 3.7 mA. From 25 to 85°C the *D*-factor is reduced from 11.7 to 9.3 GHz/mA^{½}, with a maximum resonance frequency of 22 GHz at 25°C. The *K*-factor is constant over temperature at 0.18 ns. With a parasitic pole frequencies of ~11 GHz the speed is to a large extent limited by the capacitance over the thin oxide layers.

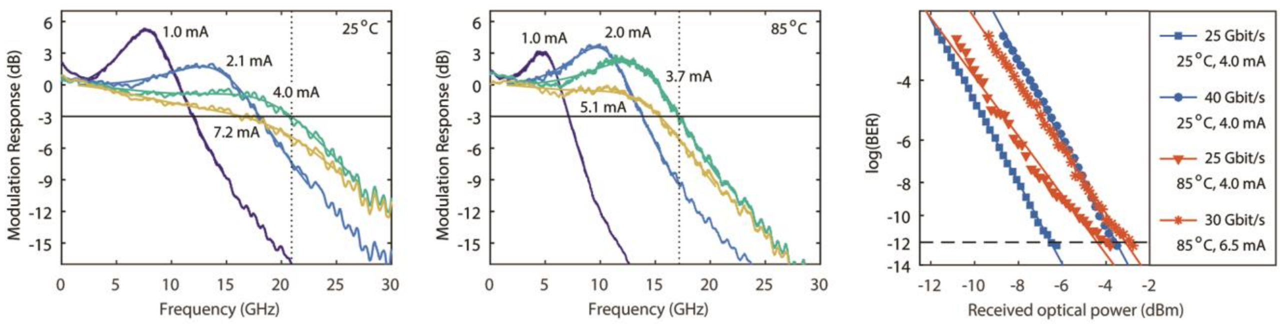

Fig.3 Left and middle: Small signal modulation response at 25 and 85°C.
Right: Data transmission at 25 and 40 Gbit/s at 25°C and 25 and 30 Gbit/s at 85°C.

Large signal modulation and back-to-back data transmission experiments were conducted using an SHF 12103A bit pattern generator (PRBS with word length 2^7-1, non-return-to-zero, 380 mV_{p-p}), the lens system, short (2 m) MMFs, a variable optical attenuator, and the Picometrix detector followed by a DC-block, a 55 GHz amplifier (22 dB), and an SHF 11100B error analyzer. Error-free transmission was achieved up to 40 Gbit/s at 25°C and 30 Gbit/s at 85°C (Fig.3). Zero errors were received for 6 Tb of transmitted data, reaching a very high confidence level.

4. Conclusion

The design and performance of a 1060 nm VCSEL intended for long distance transmission over MMF have been presented. With strained InGaAs/GaAsP QWs, doped DBRs, a short optical cavity, and multiple oxide apertures, the VCSEL can be modulated for data transmission at rates up to 40 Gbit/s at 25°C and 30 Gbit/s at 85°C.

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