High-speed tapered-oxide-apertured 980 nm VCSELs supporting data rates up to 30 Gb/s

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Abstract: High-speed 980 nm VCSELs with tapered oxide apertures were designed and fabricated. The devices show >20 GHz bandwidths for bias currents between 2 and 4 mA. Open eyes up to 30 Gb/s are also demonstrated.

1. INTRODUCTION

Recently, vertical-cavity surface-emitting lasers (VCSELs) have received considerable interest for their potential applications in optical interconnects [1]. VCSELs are very attractive for short-distance interconnects due to their small footprint, ease of fabrication in arrays, and high-speed operation at low power consumption. Although the fastest VCSELs have shown 30 Gb/s operation and bandwidths of 24 GHz at a 1.1 µm wavelength [2], these devices use buried tunnel-junctions and require regrowth. This not only reduces the manufacturability but also adds extra costs. Here we report high-speed, tapered-oxide-apertured 980 nm VCSELs which can be easily fabricated. The taper angle is increased to reduce the mode volume and improve the high-speed performance. The devices show > 20 GHz bandwidth for bias currents between 2 and 4 mA and open eye diagrams up to 30 Gb/s.

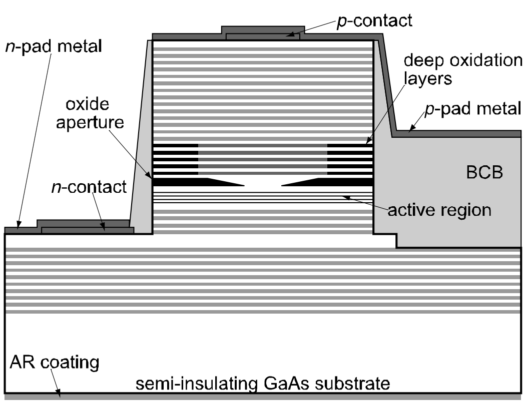
2. DEVICE

The structure used in this work is *n*-intracavity, bottom-emitting, tapered-oxide-apertured 980 nm VCSEL as shown in Fig. 1(a). The bottom mirror is an 18-period AlGaAs/GaAs distributed Bragg reflector (DBR). The 5/4λ thick *n*-contact layer is placed at the 5^{th} period to reduce the loss and provide better longitudinal mode confinement. The top mirror has a 30-period AlGaAs/GaAs DBR. The Aluminum fraction of the first 5 periods DBR is increased from 85% to 93% to form deep oxidation layers for reducing capacitance [3]. Tapered oxide aperture with a 4 µm taper length and a thickness of 1/2λ is used to simultaneously achieve better mode confinement and low optical scattering loss. The doping scheme of the *p*-mirror is also optimized to reduce the series resistance without introducing too much loss. The pad capacitance is reduced by (a) removing the *n*-contact layer (RF ground) beneath the *p*-pad metal (RF signal), (b) applying Benzpcyclobutene (BCB) between these two layers, and (c) shrinking the pad dimension to 40×70 µm as shown in Fig. 1(b). Details of the device structure and process can be found in [4].

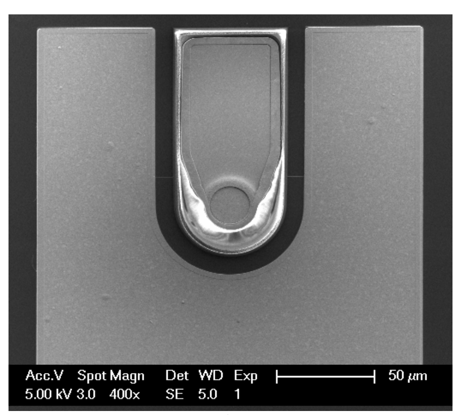
3. RESULTS

Figure 2(a) shows the voltage, output power against current (L-I-V) curves for a 3 µm diameter device. The device has a very low threshold current of 0.155 mA and a differential quantum efficiency of 53 %. The threshold voltage is only 1.48 V, 220 meV larger than the quasi-Fermi level separation. This low threshold voltage is the consequence of the optimized doping scheme and the low threshold current. The series resistance is approximately 220 Ω and the peak wall-plug efficiency is 30%. The maximum output power achieved is 3.6 mW.

The frequency responses of a 3 µm diameter device are shown in Fig. 2(b). An electrical –3 dB frequnecy of 20

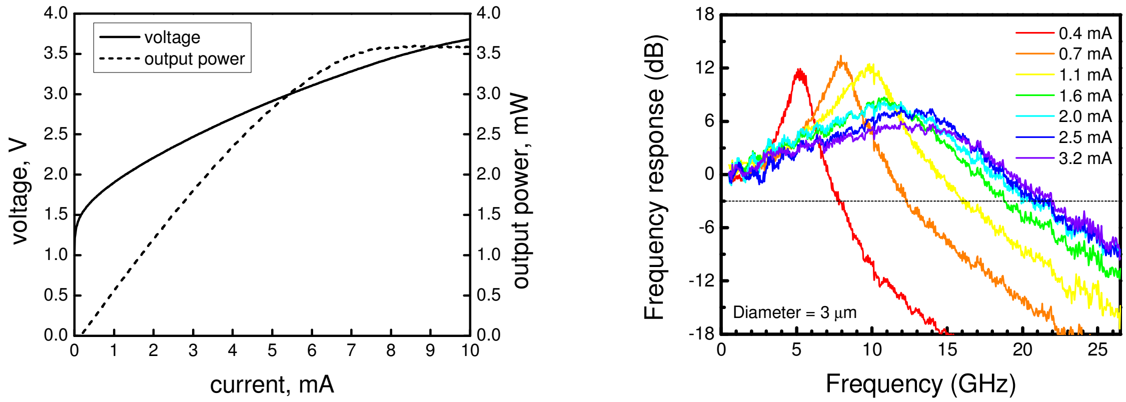


(a)



(b)

FIGURE 1. (a) Schematic cross-section of VCSEL, and (b) top view scanning electron micrograph (SEM).



(a) (b)

FIGURE 2. (a) L-I-V curves, and (b) frequency responses for a 3 μm diameter device. The estimated Gaussian 1/e mode diameter is 2.8 μm.

GHz is achieved at a bias current of 2 mA. The maximum modulation bandwidth is ~21.5 GHz at a bias current of 3.2 mA. The modulation current effeciency factor (MCEF) of this device is 16.8 GHz/√mA and ties with the highest reported value for QW VCSELs [5]. This high MCEF is the consquence of the low threshold current and the strong mode confinement.

Large signal modulation was also performed to evaluate the feasibility of these devices for optical interconnect applications. The NRZ signal (PRBS 2^{31}-1) from the pattern generator was amplified using a SHF 806E amplifier with 26 dB gain and combined with the DC bias through a 65 GHz bias tee. The combined signal was then attenuated using a 6 dB attenuator and fed to the devices. The optical signals were measured using Agilent 86109A oscilloscope with an internal 30 GHz photodiode. The measured eye diagrams at 20, 25, and 30 Gb/s are shown in Fig. 3. The estimated bias currents for these eyes are 4~5 mA. As shown in the figures, eye diagrams at 20 and 25 Gb/s are clearly open, and eye diagram at 30 Gb/s is still open with some limitation on the time window. Bit error rate (BER) measurement was performed and error-free operation up to 15 Gb/s was achieved, mainly limited by the bandwidth of the photoreceiver used.

4. Conclusion

High-speed, tapered-oxide-apertured 980 nm VCSELs were designed and fabricated. These devices show decent DC performance and achieve >20 GHz modulation bandwidth at bias current 2~4 mA. Open eyes up to 30 Gb/s is demonstrated and operation at this data rate can be expected with a better receiver.

5. References

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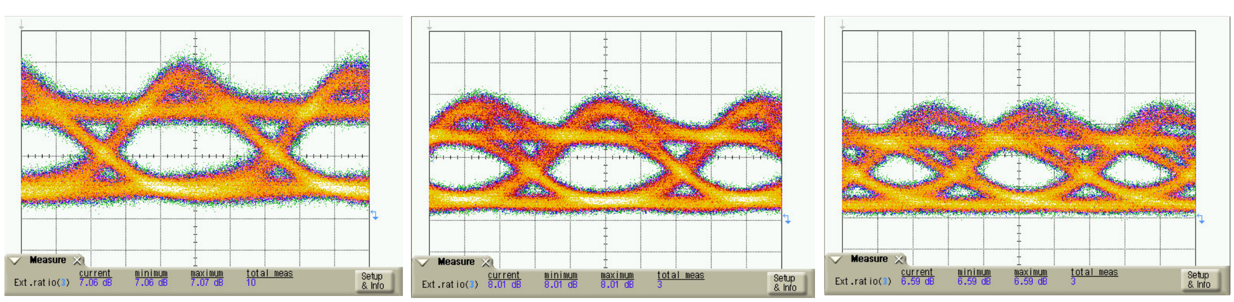

(a) 20 Gb/s, extinction ratio=7 dB (b) 25 Gb/s, extinction ratio=8 dB (c) 30 Gb/s, extinction ratio=6.6 dB

FIGURE 3. Optical eye diagrams measured by Agilent 86109A with a 30 GHz internal photodiode. The bias currents are estimated to be 4~5 mA. The time scale is 10 ps/Div.