High Differential Efficiency (>60%) Continuous-Wave Operation of 1.3μm InP-Based VCSELs with Sb-Based DBRs

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Long-wavelength vertical-cavity surface-emitting lasers (VCSELs) operating in the important telecommunications window of 1.3 – 1.6μm are attractive light-sources for short to mid-range optical networks. We have previously demonstrated a monolithic all-epitaxial platform utilizing InAlGaAs active regions and AlGaAsSb distributed Bragg reflectors (DBRs) with excellent results at 1.55μm [1]. Here we demonstrate the first continuous-wave (CW) operation of a 1.3μm InP-based VCSEL with Sb-based DBRs. These devices achieved world-record CW differential efficiencies for long-wavelength VCSELs of greater than 60% at room-temperature (RT). Furthermore, we demonstrate the first high-speed modulation for any long-wavelength VCSEL with Sb-based DBRs. These advancements verify that the Sb-based DBR technology can yield high-performance devices spanning the entire 1.3 – 1.6μm wavelength window.

Fig. 1 shows a schematic of the monolithic all-epitaxial VCSEL structure. The device was grown by solid-source molecular beam epitaxy (MBE) in a single growth step and utilizes a thin (350Å) selectively etched tunnel-junction layer to generate efficient optical and electrical confinement. The AlGaAsSb DBRs provide an index contrast of $\Delta n = 0.4$, comparable to GaAs/AlGaAs DBRs. The cavity contains a five quantum-well active region surrounded by InP layers that facilitate current and heat spreading in the device. The total cavity thickness is 4λ. Fig. 2 displays the CW light and voltage vs. current (LIV) curves for a VCSEL device with an 8μm diameter tunnel-junction aperture. CW operation was observed up to 88°C, with an output power >1.5mW at 20°C. These devices lased single-mode at 1.305μm with a side-mode suppression ratio (SMSR) of 46dB, as shown in Fig. 3.

The thin selectively etched tunnel-junction aperture provided low-loss optical confinement, generating the high differential efficiencies demonstrated in Fig. 4. World-record values were achieved, with 64% at RT and greater than 50% at 50°C. This result is an important advancement towards creating higher power devices with low-required drive-currents. Fig. 5 shows the threshold current vs. stage temperature for the device, indicating that the optimal gain-peak to cavity-mode alignment occurred around 20°C. These devices were designed for optimal RT operation, but improved temperature performance can be expected with a higher gain offset.

In order to demonstrate the high speed capabilities of these devices, they were modulated with a 2^{31}-1 prbs at 3.125Gb/s. Light was coupled directly into a single-mode fiber and then into a 10Gb optical receiver. Open eye diagrams were obtained up to 60°C and are shown in Fig. 6. The extinction ratios were derived directly from the optical bit stream and were >8dB for operation up to 60°C with a peak-to-peak drive voltage of only 800mV. Error-free operation was obtained up to 60°C and the bit error rate (BER) curves are shown in Fig. 7.

In conclusion, we have demonstrated the first CW operation of 1.3μm VCSELs with Sb-based DBR technology and have achieved record-high CW differential efficiencies. High speed modulation was also demonstrated for the first time with this technology. Coupled with previous results at 1.55μm, these results clearly demonstrate this platform's ability to generate high-performance monolithic VCSELs spanning the entire 1.3 – 1.6μm wavelength window.

[1] S. Nakagawa, et al., *Applied Physics Letters*, vol. 78, pp. 1337-1339 (2001).

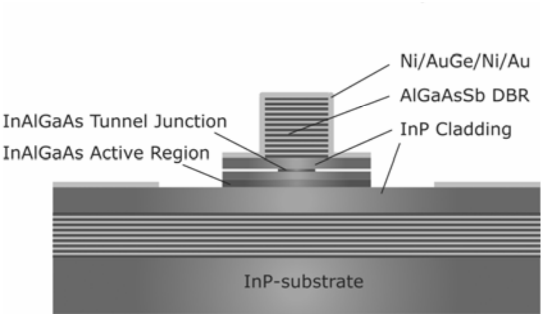

Fig. 1: Schematic of 1.3µm InP-based VCSEL device with selectively etched tunnel-junction aperture.

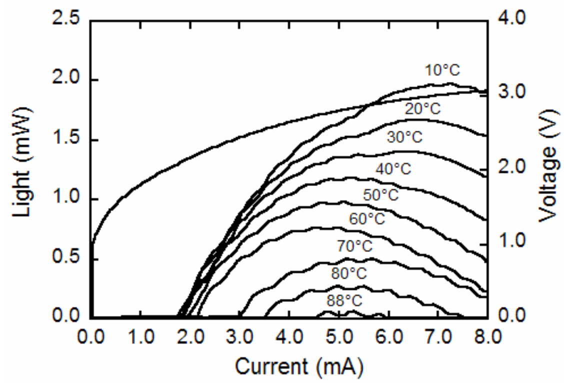

Fig. 2: CW LIV curves for bottom-emitting VCSEL with 8µm aperture at various temperatures showing operation up to 88°C.

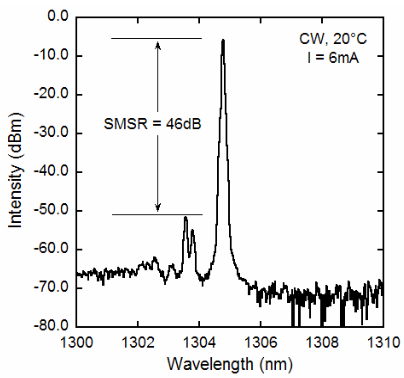

Fig. 3: CW lasing spectrum showing emission at 1.305µm and a 46dB SMSR.

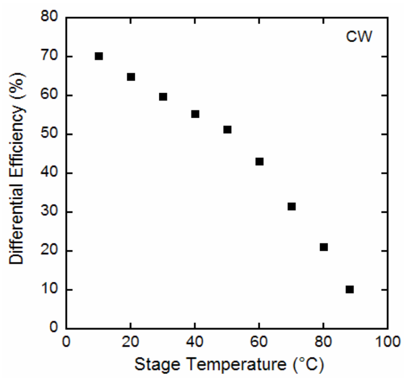

Fig. 4: Differential efficiency vs. stage temperature showing differential efficiency over 50% at 50°C.

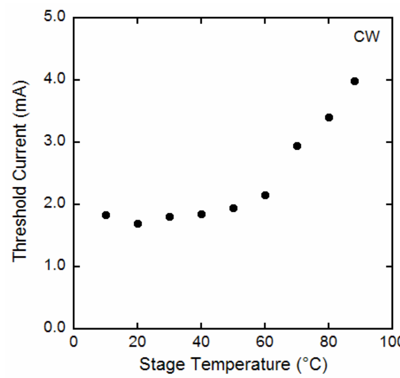

Fig. 5: Threshold current vs. stage temperature for VCSEL device optimized for RT performance.

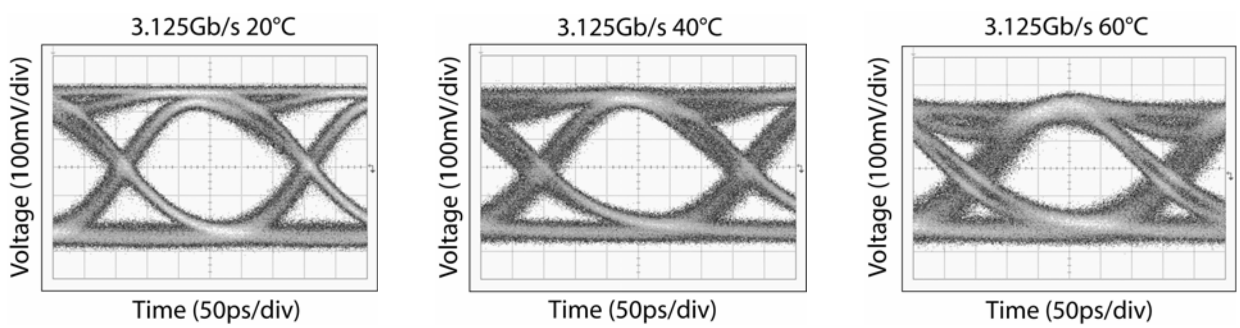

Fig. 6: Eye diagrams at 3.125Gb/s for 20, 40, and 60°C. Extinction is >8dB up to 60°C with a drive voltage of 800mV.

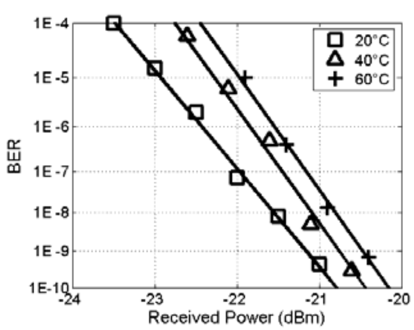

Fig. 7: BER curves at 20, 40, and 60°C for a 2^{31}-1 prbs showing error-free operation up to 60°C.