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High-Speed 850 nm VCSEL with 30 GHz Modulation Bandwidth

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GaAs-based 850 nm VCSELs are the standard light source in short-reach high-speed optical interconnects in datacenters and supercomputers. The last few years have seen an impressive increase in VCSEL speed, reaching modulation bandwidths of 28 GHz and single-channel data rates of 57 Gbit/s (non-equalized) and 71 Gbit/s (equalized) under direct NRZ modulation [1-3]. Future optical interconnects will require even faster VCSELs capable of higher-speed transmission at lower energy dissipation. Here we present the results from our new generation of high-speed 850 nm VCSELs, a further development of our previous VCSEL design [1-3].

The epitaxial structure was grown by MOCVD. The active region has strained InGaAs quantum wells for high differential gain. A cavity length of λ/2 is used for the highest longitudinal optical confinement. Transverse optical and current confinement is provided by one primary oxide aperture on each side of the active region. An additional four secondary oxide apertures are used to reduce capacitance. By positioning the primary oxide layers as close as possible to the active region and fine-tuning their position, index guiding is reduced, leading to reduced beam divergence. This also improves the transverse confinement of carriers, resulting in an internal quantum efficiency of 87% (for an 8 µm aperture VCSEL) and a low threshold current of 0.25 mA for a 3.5 µm aperture VCSEL (0.75 mA for the 8 µm aperture VCSEL), see Fig. 1a. The distributed Bragg reflectors (DBRs) feature grading and modulation doping schemes optimized for low free carrier absorption and low resistance [1], resulting in a reduced differential resistance of ~180 Ω for the 3.5 µm aperture VCSEL (50 Ω for the 8 µm aperture VCSEL). The photon lifetime was adjusted to maximize the modulation bandwidth [4]. This enabled a modulation bandwidth exceeding 25 GHz already at 1.8 mA and reaching 30 GHz at 4.1 mA (Fig. 1b). This is the highest modulation bandwidth ever reported for a VCSEL. Because of the small oxide aperture of 3.5 µm, the resonance frequency increases rapidly with current, with a high D-factor of 17.5 GHz/mA^{½} and a maximum resonance frequency of 27 GHz (Fig. 1c). The rapid increase in bandwidth with current is seen in the modulation current efficiency factor (MCEF) of 20.6 GHz/mA^{½} (Fig. 1d). The 8 µm aperture VCSEL reaches a bandwidth of 27 GHz at 13 mA.

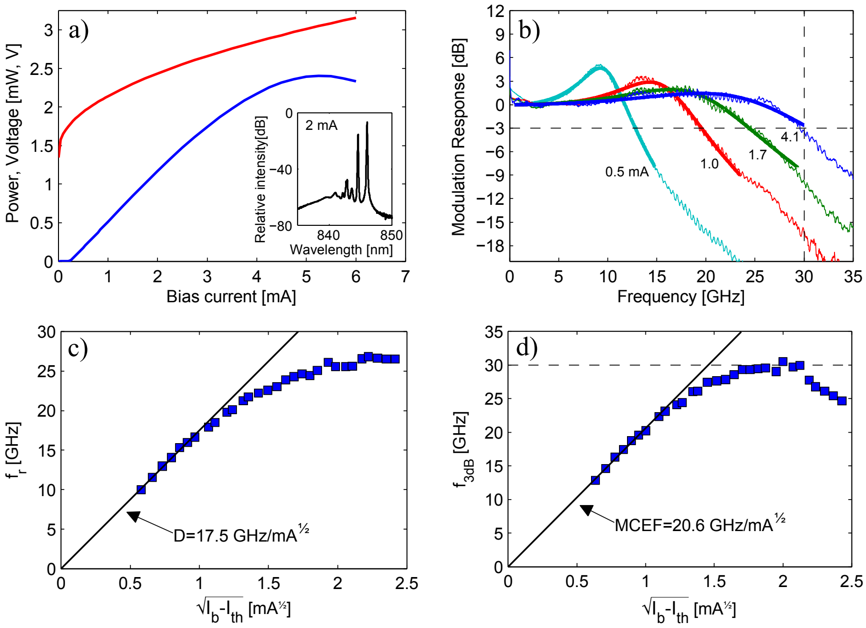

Fig. 1 Characteristics of a 3.5 µm oxide aperture VCSEL. a) Light-current-voltage characteristics and emission spectrum. b) Small signal modulation response (S_{21}) at different bias currents. c) Resonance frequency vs. square root of current above threshold with extracted D-factor. d) Modulation bandwidth vs. square root of current above threshold with extracted modulation current efficiency factor (MCEF).

References

[1] P. Westbergh, R. Safaisini, E. Haglund, J. S. Gustavsson, A. Larsson, M. Geen, R. Lawrence, A. Joel, “High-speed oxide confined 850-nm VCSELs operating error-free at 40 Gb/s up to 85°C,” IEEE Photon. Technol. Lett., **25**, 768-771 (2013).

[2] P. Westbergh, E. P. Haglund, E. Haglund, R. Safaisini, J. S. Gustavsson, A. Larsson, “High-speed 850 nm VCSELs operating error free up to 57 Gbit/s,” Electron. Lett., **49**, 1021-1023 (2013).

[3] D. M. Kuchta, A. V. Rylyakov, F. E. Doany, C. L. Schow, J. E. Proesel, C. W. Baks, P. Westbergh, J. S. Gustavsson, A. Larsson, “A 71 Gb/s NRZ modulated 850 nm VCSEL-based optical link,” accepted for publication in IEEE Photon. Technol. Lett. (2015).

[4] P. Westbergh, J. S. Gustavsson, B. Kögel, Å. Haglund, A. Larsson, ”Impact of photon lifetime on high-speed VCSEL performance,” IEEE J. Sel. Top. Quantum Electron, **17**, 1603-1610 (2011).