

Novel Vertical-Cavity Surface-Emitting Lasers

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Abstract: Novel vertical-cavity surface-emitting lasers (VCSELs) were developed in both diode and triode forms. Three-terminal devices demonstrated either a field-induced charge-separation mechanism for gain modulation or angular control of a lateral current injection for polarization switching, and both show promise for increased transmission capacity with VCSEL sources.

As the performance of microprocessors scales and the capacity of data centers increases, optical interconnects are recognized superior to conventional electrical interconnects due to their low-power consumption, small size, weight, and superior bandwidth over significant path lengths. Driven by this demand, high-speed, high-efficiency VCSELs remain interesting to researchers worldwide and performance breakthroughs continue to occur.

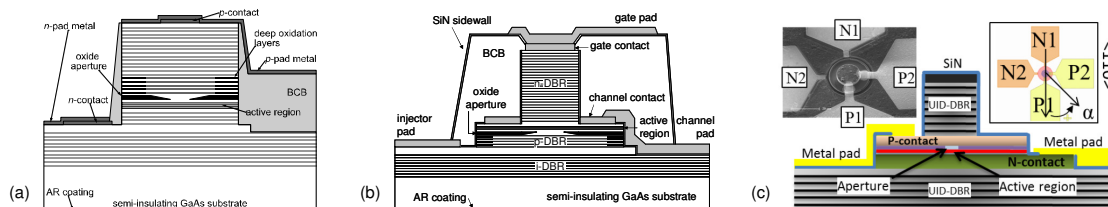


Fig. 1. (a) State-of-the-art 980nm diode VCSEL. (b) Field-Induced Charge-Separation Laser. (c) High-Extinction Polarization VCSEL.

We designed and fabricated state-of-the-art 980nm diode VCSELs (Fig.1a), which utilized an optimized p-DBR mirror design and deep oxidation layers to minimize parasitic effects [1]. These devices are capable of above 35Gb/s error-free operation and >20GHz small-signal bandwidth (Fig. 2a). Based on the same design rules, we further developed field-induced charge-separation lasers (FICSLs), which introduce an extra-terminal to the diode VCSEL to be a new modulation lever (Fig. 1b) [2]. By varying the bias voltage on the gate terminal, the overlap of electrons and holes in the quantum well can be modulated without changing the bias current of the p-n junction. Simulations have shown that this novel direct gain-modulation mechanism enhances the bandwidth, and the static as well as the rf characteristics of 1st generation FICSLs have been measured experimentally (Fig. 2b).

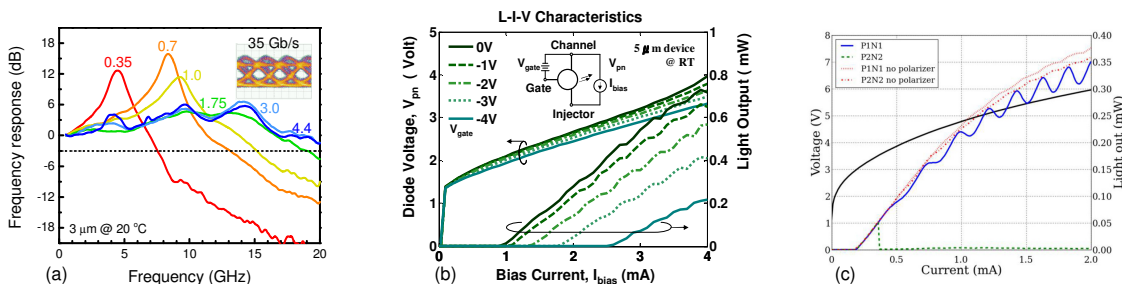


Fig. 2. (a) State-of-the-art 980nm diode VCSEL showing >20GHz small-signal bandwidth and 35Gb/s error-free operation. (b) Gate voltage modulation of a FICSL. (c) >21dB extinction between orthogonal polarizations in a High-Extinction Polarization VCSEL.

Another innovative approach to encrypt more information into each bit is through polarization control by using not only light intensity to encode data but also output polarization as well. We developed a high-extinction polarization VCSEL with orthogonal metal pads for current injection and Deuterium (D⁺) implantation for current isolation (Fig. 1c) resulting in >21dB extinction between orthogonally polarized modes, which is the highest-ever reported (Fig. 2c) [3].

Ongoing research in the Coldren group includes optimizing the FICSL design to address the parasitic effects, and further improving diode VCSELs by incorporating highly-strained as well as p-type modulation-doped quantum wells to increase the differential gain, which is essential to increasing data rates [4].

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- [4] L. A. Coldren, Y.-C. Chang, Y. Zheng, and C.-H. Lin, *Photonics Soc. Summer Top. Proc.*, paper TuD2.1, Playa Del Carmen, (July, 2010).