Efficient, High-Speed VCSELs for Optical Interconnects

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Abstract: The demand for efficient optical sources at high data rates is growing as the need for more interconnects and interconnect density grows in both data centers and high-performance computers. Novel vertical-cavity surface-emitting lasers (VCSELs) continue to be investigated for these applications. We conclude that more highly-strained, higher In-content devices on GaAs are a good choice because of their higher inherent efficiency, modulation speed, and reliability. A new three-terminal configuration is also being studied with some unique characteristics.

As the performance of microprocessors scales and the capacity of data centers increases, optical interconnects are recognized as superior to conventional electrical interconnects due to their low-power consumption, small size, weight, and superior bandwidth over significant path lengths [1]. Driven by this demand, high-speed, high-efficiency, high-reliability VCSELs are gaining increasing interest in such applications worldwide, and performance breakthroughs continue to occur. In fact, these new markets may eclipse existing markets for VCSELs and change the rules (standards) in the future. For example, Fig. 1 illustrates the growth of optical interconnect channels within single high-performance computers, showing that a single machine now has as many interconnects as the total worldwide volume of parallel optical channels in other applications.

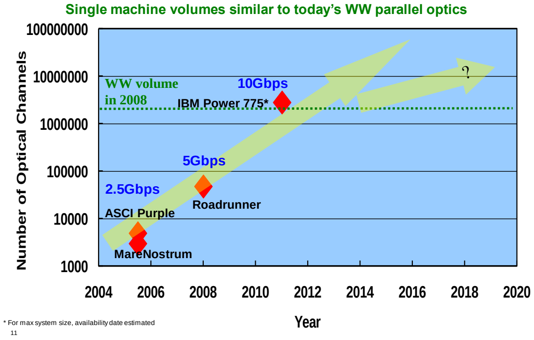

Figure 1. Number of optical interconnect channels within a single computer vs. time[1].

Highly-strained quantum-well gain regions are now well known to provide nearly all of the characteristics needed to advance VCSELs to the next level of performance and quality to meet the new challenges[2-5]. As indicated in Fig. 2 they provide high-gain, high-differential gain (high speed), and hold the promise of high reliability.

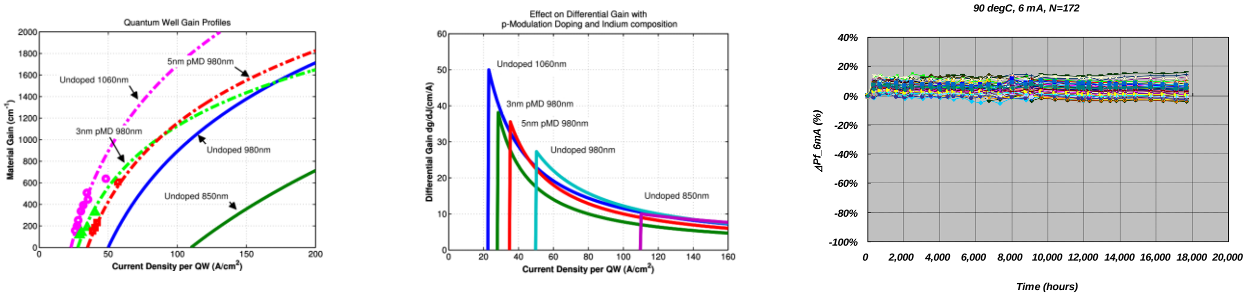

Figure 2. Material gain and differential gain, dg/dJ, versus current density per quantum well[3] together with accelerated aging data for 1060 nm VCSELs from Furukawa via IBM[1]

Co-incidental to these improvements with the addition of In to the GaAs quantum wells is an increase in the emission wavelength from 850 nm to the 950 – 1100 nm range. Unfortunately, this has caused some heartburn amongst both users and suppliers as the old standards for datacom fixed the wavelength at 850 nm. Many would like to continue to stay at 850 nm to be compatible with existing applications. However, because the new data center and next generation computing applications will probably dwarf the volume of all of the prior VCSEL datacom applications [1], past standards as well as the desire to have a common product architecture may not be as relevant for these new markets.

Furthermore, it should be noted that there are a few advantages of having the longer wavelength emitters as outlined in Fig. 3: a) The GaAs substrate becomes transparent—this enables backside emission and simpler assembly/packaging techniques, including backside collimating microlenses on the chip; b) The eye-safe power threshold is approximately doubled; and c) The inherent fiber dispersion can be reduced to less than half [3].

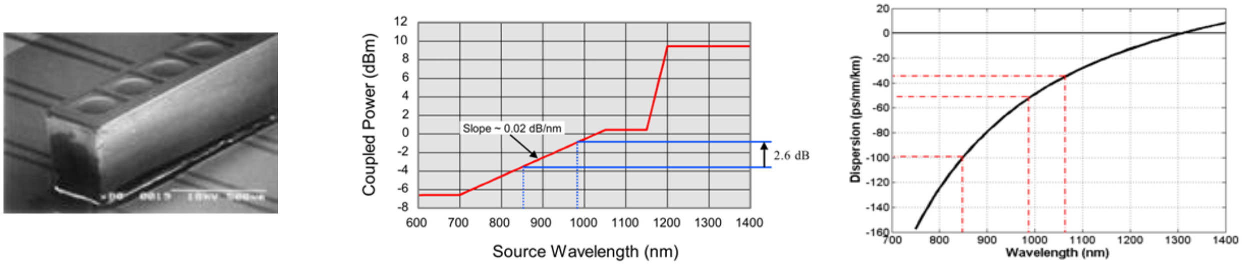

Figure 3. a) Flip-chip mounted 980 nm VCSEL with etched backside microlenses; b) eyesafe allowable optical power levels; c) fiber material dispersion[3]

As illustrated in Fig. 4, we have designed and fabricated 980nm diode VCSELs, which utilized an optimized p-DBR mirror design and deep oxidation layers to minimize parasitic effects [6]. These devices had >20GHz small-signal bandwidth and operated above 35Gb/s error-free with 10 mW of power dissipation (or 286 fJ/bit). They also were incorporated within record-efficiency IBM optical interconnect links [1].

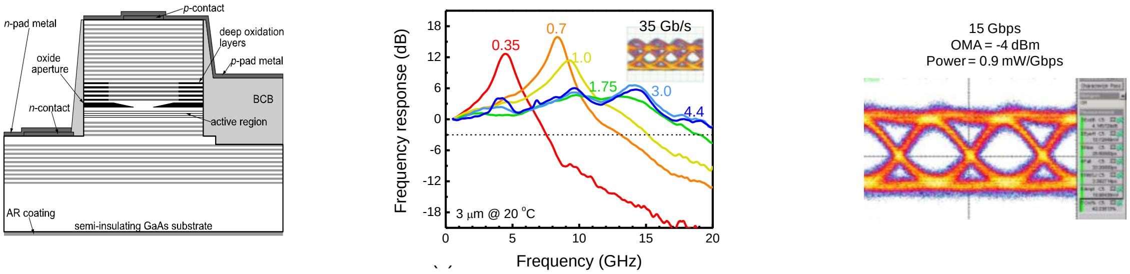

Figure 4. 980 nm VCSEL; frequency response & eye diagram @ 35 Gb/s; transmitter eye with CMOS driver (IBM)

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. 5) [7]. 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.

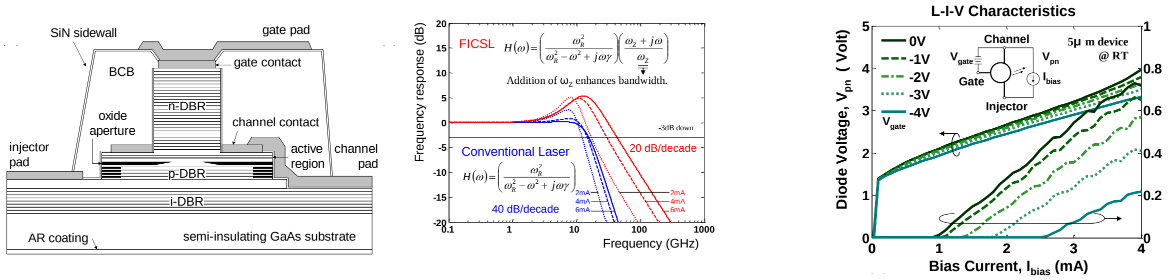

Figure 5. Field-Induced-Charge-Modulation VCSEL; theoretical frequency response compared to conventional laser; experimental gate voltage modulation[7].

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