High-Speed Datacom VCSELs at 1310 and 980 nm

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Abstract:

Recent progress on VCSELs for datacom applications within the author's group at UCSB will be reviewed. Efforts on 'all-epitaxial, long-wavelength' InP-based devices as well as efficient, small-cavity-volume GaAs-based VCSELs will be included. InGaAlAs/InGaAsSb/InP all-epitaxial wafers processed in a conventional manner are found to provide viable VCSELs across the entire 1300-1600 nm wavelength band, and InGaAs/GaAlAs/GaAs structures with low-loss tapered-oxide apertures have demonstrated low-current, high-data-rate modulation up to 35 Gb/s.

1. Introduction

Although work on novel structures for high-efficiency, high-speed VCSELs began well over a decade ago for such applications as chip-to-chip, board-to-board and computer interconnection[1,2], the commercial world has largely ignored these technologies in favor of simple proton-implanted structures for such applications as multi-mode fiber links and, more recently, mice for computers. However, in the past year or two the chip and computer makers are now clearly acknowledging the need for a more power and space efficient way to transmit 20+ Gb/s data over relatively short distances. Thus, interconnect applications within and between high-end computers are emerging for high-speed, high-efficiency VCSELs. If a universal standard is not required, as in active cables or intra-box applications, 980 nm would appear to be more attractive because of its inherent efficiency and speed potential[3].

For somewhat more conventional data links over distances > 300 m or so, the longer wavelengths in the 1300—1600 nm band are preferred. Here manufacturable VCSELs with characteristics suitable for such applications as FTTH or pico-cell wireless distribution are desired. Recent results show that the entire 1300 – 1600 nm wavelength range can be covered in a common InGaAlAs/InGaAsSb/InP epitaxial VCSEL technology[4]. However, competition from edge-emitters manufactured in well-established factories can only be overcome in very high volume applications where the VCSEL can hope to be a lower cost solution. Obtaining edge-emitter-like characteristics is still a major concern.

2. High-speed, high-efficiency 980 nm VCSELs

Figure 1 illustrates a cross section of the GaAs-based VCSEL design along with its small-signal frequency response. The active region contains three strained InGaAs quantum-wells resulting in emission at 980 nm. Substrate emission is facilitated enabling flip-chip mounting as well as backside integrated microlenses as has been shown in prior work[5]. The strained InGaAs active region provides higher differential gain for higher resonance frequency, higher temperature operation (due to a higher T_0), and potentially higher reliability.

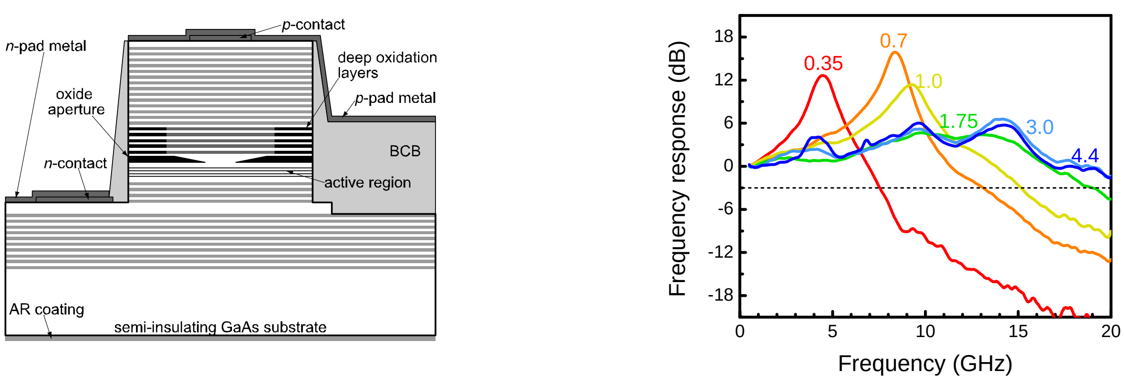

Figure 1. Schematic of tapered oxide VCSEL and frequency response for 3 μm aperture at various bias currents. Maximum cw output power @ 6.8 mA = 3.1 mW; power @ 4.4 mA = 2.6 mW; η_d = 54%.

Figure 1 also illustrates the use of a tapered oxide aperture[6]. This design acts more like an ideal intra-cavity lens and greatly reduces the optical loss, thereby enabling the use of much smaller cavity volumes. The aperture's tapered point also greatly reduces the stress that tends to exist at the tips of oxide apertures with blunt ends. This also should aid in improved reliability, especially with InGaAs quantum-well actives which inhibit defect clustering. The current VCSEL results have primarily been the result of reducing the cavity volume without adding noticeably to the optical mode loss. Resistance and capacitance have also been improved, but multimode operation is probably the primary limiting issue at present. Nevertheless, the frequency response shows a low current bandwidth/root-current figure-of-merit of MCEF = 16.8 GHz/mA$^{1/2}$, about as high as ever obtained in larger area, higher power dissipation devices[7].

Figure 2 shows the eye diagram and Bit-Error-Rate at 35 Gb/s, which indicates error-free operation at 10^{-11} BER. This is the highest error-free data rate and highest data-rata per mW of power dissipation ever obtained from any VCSEL[8]. If the issues identified above, e.g., multimode operation, can be addressed, data rates exceeding 40 Gb/s may be possible.

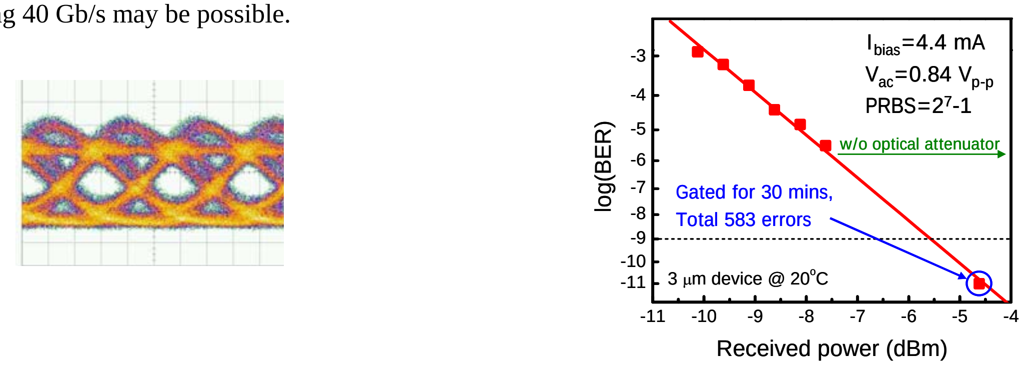

Figure 2. Eye diagram and Bit-Error-Rate at 35 Gb/s. Power dissipation @ 4.4 mA = 10 mW, or 3.5 Gbs/mW.

3. All-epitaxial 1310 nm results

Figure 3 shows a cross section of the 1310 nm InP-based device along with its cw light-current characteristics for a 6.5 μm aperture[4]. About double this cw power was obtained with larger apertures. Similar 1550 nm devices were demonstrated several years ago using the same basic technology platform[9]. As illustrated the device uses two n-type InP intra-cavity contacts for low thermal and electrical resistance with a thin (35 nm) n^+/p^+ tunnel junction placed at a null of the standing wave above the half-wavelength, 5-QW active region. The tunnel junction layers are selectively etched to form a thin aperture for lateral current and photon confinement. The epitaxially-grown DBR mirrors consist of undoped, lattice-matched InGaAsSb layers, which have an index contrast comparable to the AlGaAs layers used in many 850 nm VCSELs. This configuration provides relatively low internal optical losses (~ 7 cm^{-1}). The observed 20°C differential quantum efficiency is higher than 60% for aperture diameters larger than 6 μm. The 3dB small signal bandwidth was measured to be 4.5 GHz at 20°C, dropping to 3.5 GHz at 60°C [10].

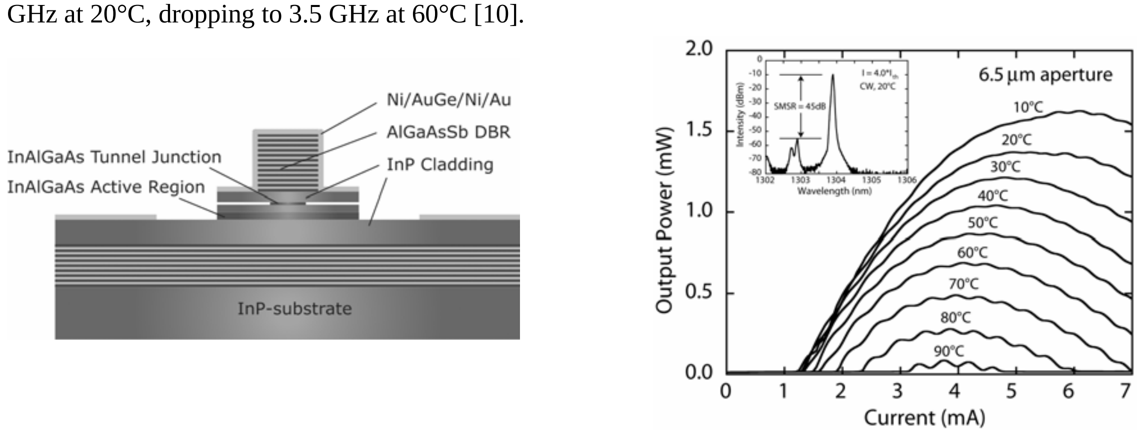

Figure 3. Schematic and L-I characteristics for InP-based 1310 nm VCSEL.

Figure 4 gives the eye diagrams and BER from 20 to 60°C. Open eye diagrams were obtained up to 60°C. The extinction ratios remained > 8dB for operation up to 60°C with a peak-to-peak drive voltage of only 800mV. The results illustrate viable operation at data rates of at least 3.125 Gb/s. Relatively straight-forward modifications to reduce parasitics and mode volume should provide ~ 10 Gb/s.

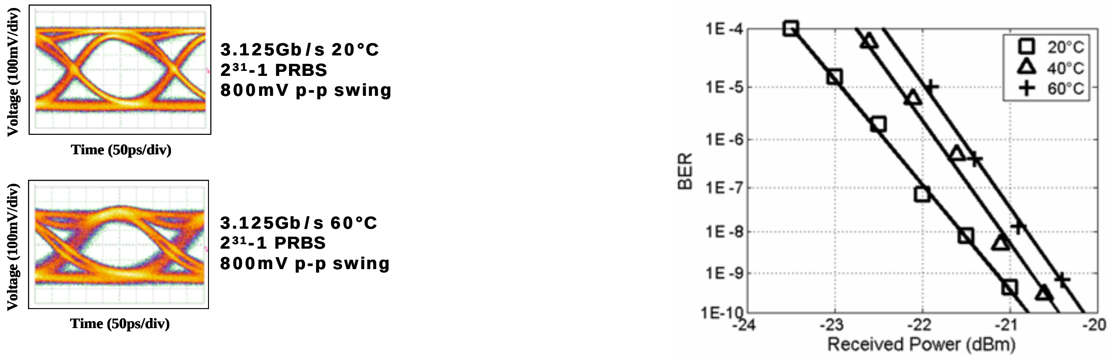

Figure 4. Eyes and BER for 1310 nm VCSEL at 3.125 Gb/s[10].

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Larry A. Coldren is the Fred Kavli Professor of Optoelectronics and Sensors at the University of California, Santa Barbara, CA. He received the Ph.D. degree in Electrical Engineering from Stanford University in 1972. After 13 years in the research area at Bell Laboratories, he joined UC-Santa Barbara in 1984 where he now holds appointments in Materials and Electrical & Computer Engineering, and is Director of the Optoelectronics Technology Center. In 1990 he co-founded Optical Concepts, later acquired as Gore Photonics, to develop novel VCSEL technology; and in 1998 he co-founded Agility Communications, later acquired by JDSU, to develop widely-tunable integrated transmitters.

At Bell Labs Coldren initially worked on surface-acoustic-wave devices and then later on tunable coupled-cavity lasers using new reactive-ion etching (RIE) technology that he created for the then emerging InP-based materials. At UCSB he has worked on novel multiple-section tunable lasers, a variety of related photonic ICs, and high-efficiency vertical-cavity surface-emitting lasers (VCSELs), both at short and long wavelengths. His work has always involved developing new materials growth techniques (by MBE and MOCVD) as well as the necessary fabrication technology.

Professor Coldren has authored or co-authored over 800 papers, 5 book chapters, 1 textbook, and has been issued 61 patents. He has presented dozens of invited and plenary talks at major conferences; he is a Fellow of the IEEE, OSA, and IEE, the recipient of the 2004 John Tyndall Award, and a member of the National Academy of Engineering.