Volume Manufacturable High speed 850nm VCSEL for 100G Ethernet and Beyond

Laura M. Giovane\textsuperscript{a}, Jingyi Wang\textsuperscript{a}, M.V. Ramana Murty\textsuperscript{a}, Ann Lehman Harren\textsuperscript{a}, Hsu-Hao Chang\textsuperscript{a}, Charlie Wang\textsuperscript{a}, David Hut\textsuperscript{a}, Zheng-Wen Feng\textsuperscript{b}, Thomas R. Fanning\textsuperscript{b}, Aadiya Sridhara\textsuperscript{b}, Sumtro-Joyo Taslim\textsuperscript{b}, and Jason Chu\textsuperscript{b}

\textsuperscript{a}Avago Technologies, Fiber Optics Product Division, 1320 Ridder Park Dr., San Jose, CA 95131, USA
\textsuperscript{b}Avago Technologies, Fiber Optics Product Division, 1150 Depot Rd., Singapore
laura.giovane@avagotech.com

Abstract: This paper reviews the technology used to enable commercial deployment of VCSELs at 25-28G and some of the device challenges that need to be addressed to enable the next generation of data rates.

OCIS codes: (250.0250) Optoelectronics; (140.7260) Vertical cavity surface emitting lasers

1. Introduction

Over the last two decades the performance of vertical cavity surface emitting lasers (VCSELs) has kept pace with the ever-increasing demands of high performance computing, data centers and storage networks. Successive generations of VCSELs along with other components have enabled multi-mode transceivers to dominate short-reach optical channels by offering an attractive combination of low cost, performance, reliability and power efficiency. The design of the current generation of 25-28G VCSELs, which supports among others the 100G Ethernet and 32Gb Fibre Channel PI-6 standards, must meet a challenging set of specifications for bandwidth, noise, spectral width and reliability over-temperature and with sufficient manufacturing margin to enable volume manufacturing and commercial viability. The InGaAs quantum well is behind many of the fastest 850nm VCSELs reported in the literature\cite{1}, and some VCSEL manufacturers have adopted the InGaAs quantum well (QW) to enable the 25-28G generation of commercial data communication VCSELs\cite{2,3}.

As the industry turns to developing the technology associated with the next generation of optical links to enable 50Gb/s per optical channel many strategies have been proposed including multi-level coding at 25 Gbaud such as 4-level pulse amplitude modulation (PAM-4). These approaches will clearly put new demands on the dynamic performance of the VCSEL. This paper will review the 25G performance and highlight the VCSEL technology development that is needed and progress being made to support the next generation optical link demands.

2. 25-28Gbs 850nm VCSELs

The adoption of InGaAs QW to support bit rates higher than 25Gbs is motivated by the improvement in differential gain of pseudo-morphically strained InGaAs over GaAs. The improved differential gain directly results in improved modulation current efficiency factor (MCEF) and relaxation oscillation frequency ($f_r$) at a given current density. The use of the InGaAs QW does pose challenges and requires substantial epitaxy process development to enable the quality of the InGaAs gain material across the wafer, high speed devices and wear-out reliability\cite{3,4}. Figures 1a-c show the performance characteristics of a typical 7μm oxide aperture Avago Technologies 25G VCSEL. High temperature 75°C power of over 2mW is possible at a typical drive current of 7.5mA. The RMS spectral width at 7.5mA is 0.45nm, which insures compliance with the 100G Ethernet and 32G Fibre Channel standard specifications. The S21 response indicates that the f-3dB bandwidth is in excess of 18GHz and is typically fairly invariant over the temperature range from 5°C to 75°C. The extracted $f_r$ of the VCSEL exceeds 16GHz.

Although it would be straightforward to achieve a higher bandwidth design by reducing damping, eye quality suffers as damping is decreased. As reported by other researchers\cite{2,6}, bandwidth alone is not the only relevant metric in predicting the large signal responses. To achieve optimal eye quality and limit jitter the VCSEL
design must have sufficient damping to suppress the relaxation oscillation even though this might come at the expense of bandwidth. The InGaAs QW enables the bandwidth and performance with significant process margin. Figure 1d shows the bandwidth trend chart for parts sampled from a year of production material. The outstanding reliability of these same VCSELs has been reported[3].

3. 25Gbaud-50Gb/s PAM-4 Signaling:

Multilevel modulation schemes such as PAM-4 have been proposed to extend the reach of multimode fiber at high bit rate[7,8]. The PAM scheme promises more data throughput for a given bit period than non-return to zero (NRZ), but it requires more overall power and lower noise to deliver the required bit-error-rate (BER) performance. Furthermore, similar to NRZ modulation where underdamped VCSELs create more jitter and overshoot and undershoot, underdamped VCSELs will impair the PAM-4 eye, causing vertical closure of the eyelets between the different logic levels.

Using Avago’s 25-28G production VCSEL technology as a baseline, we modified the design to improve the differential gain, dG/dN and the confinement factor, G. These design changes have enabled a VCSEL with a relaxation oscillation frequency of over 19GHz. Figure 2a shows the room temperature S21 response as a function of bias. Figure2b and c show the eye diagrams at 28Gb/s and 40Gb/s respectively. The inherent speed of the VCSEL is sufficient to give an open 40 Gb/s eye. Figure 2d shows the 27 Gbaud PAM-4 eye. The suppressed relaxation oscillation apparent in the S21 helps to minimize the vertical eye closure in the PAM-4 eye.

4. Summary:

The volume manufacturing of 25-28Gb/s VCSELs has been enabled by developing a robust InGaAs QW based process. Further refinements on the basic design will enable the next generation of 50 Gb/s per channel devices.
PAM-4 signaling, like NRZ, requires an optimization in the VCSEL damping to minimize impairments from the relaxation oscillation.

Figure 2a: S21 response of PAM-4 VCSEL at room temperature for bias conditions from 3-10mA. The bandwidth at 7.5mA is 20GHz. 2b) 28Gb/s VCSEL eye at room temperature and 7.5mA bias shown with a 32G Fibre Channel mask with 43% margin. 2c) 40Gb/s VCSEL eye at 8.5mA, shown with a scaled 25Gb Ethernet mask with 25% margin. 2d) PAM-4 eye: arbitrary waveform generator (AWG) driven VCSEL and 5-tap equalization.

5. References:


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