Development of Next Generation Data Communication VCSELs

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Abstract: This paper reviews the advancement in VCSEL technology at Broadcom to support the next generation of 850nm multi-mode data communication links at channel bit rates beyond 100Gb/s. © 2020 The Author(s)

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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. As the industry prepares for PAM-4 modulated optical links at baud rates greater than 50Gbd, challenges for directly modulated VCSEL-based multi-mode links need to be addressed. The most significant of these challenges is the inherent limit of the directly modulated laser's relaxation-oscillation frequency. Other challenges include the VCSEL's electrical parasitics, thermal rollover/ junction temperature management, relative intensity noise (RIN) performance and an array of impairments that limit the potential link length including fiber bandwidth, chromatic dispersion and mode partition noise (MPN) penalties. Numerous reports of 850nm VCSEL modulation at 50GBd for both OOK and PAM-4 schemes chart the path forward for directly modulated VCSELs [1-3].

2. 100G VCSEL Design Principles and Performance

Building on Broadcom's existing design for 25GBd VCSELs, we have designed VCSELs to optimize the relaxation-oscillation frequency, a fundamental metric of VCSEL performance, by maximizing both the differential gain, dg/dN, of the InGaAs quantum wells and improving the confinement factor, Γ. The relaxation-oscillation frequency increases with increasing current density, however, in high temperature environments, the relaxation-oscillation typically will saturate or even rollover at high current densities as the high junction temperature of the VCSEL mitigates the improvements from increased current density. Improving the VCSEL's thermal resistance lowers the junction temperature and is essential to achieve maximum high temperature relaxation-oscillation frequencies. Equally significant is the impact of decreased junction temperature on the VCSEL's wear-out lifetime, which follows an Arrhenius model.

Figure 1 shows the S21 response of the new VCSEL design over a range of bias currents. At 5°C (Figure 1a) the bandwidth exceeds 30GHz, the frequency limit of the small-signal measurement setup. Thermal effects reduce the bandwidth of the device by about 2GHz at 75°C (Figure 1b). The extracted relaxation-oscillation frequencies at 9mA are 28GHz and 24GHz at 5C and 75C respectively. At 75°C and 9mA bias, the relaxation-oscillation frequency is limited by thermal effects, where among other things differential gain, dG/dN decays as temperature rises with increasing current density. Still higher bandwidths could be achieved by decreasing the K-factor thus reducing damping. However, for large signal modulation, eye quality can suffer as damping is decreased [4,5]. Improvements in bandwidth must be matched with improvements in the relaxation oscillation frequency.

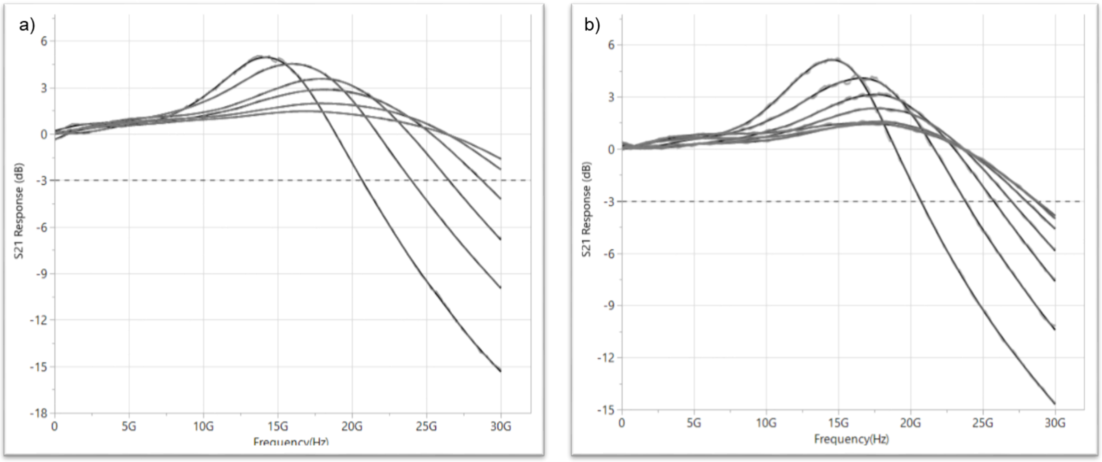

Figure 1: S21 response of VCSEL at 5C a) at 5C and b) at 75C. DC bias currents range from 3 to 9mA.

The K-factor has also been shown to impact relative intensity noise (RIN) of the VCSEL;[5] for comparable relaxation oscillation frequency, higher K-factors result in lower bandwidths but also lower RIN. In order to improve both noise and bandwidth performance, the relaxation-oscillation frequency must be maximized over temperature. The relative noise intensity for VCSELs of the optimized design is shown in Figure 2(a). The RIN noise decreases with bias because the relaxation-oscillation frequency is also increasing with bias. Because of the RIN trade-off with bandwidth, the ultimate design of the 100G VCSEL should account for the overall all noise performance of the link. The bandwidth can be maximized while keeping the transmitter RIN below critical levels for the link.

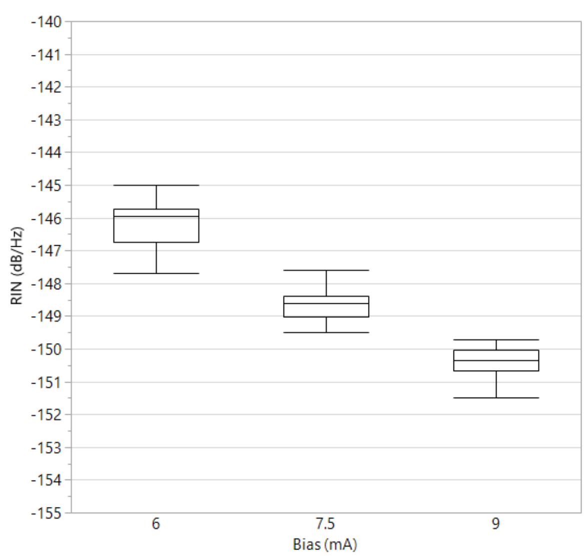

Figure 2: Relative intensity noise performance of 10 VCSELs. The measurement is done at room temperature under DC bias with no back reflection and with a Keysight 86105D sampling scope.

Figure 3 shows an equalized waveform from a 9mA biased VCSEL modulated at 53.125 Gbd with a PRBS13Q PAM-4 signal. A three-tap, T-spaced (T is the symbol period) pre-emphasis is used on the drive signal from a Keysight M8040A pattern generator. The optical waveform is captured using the Keysight 86105D receiver with a

38.3 GHz SIRC (system impulse response correction) filter. A five-tap, T-spaced feed-forward equalizer is used to reduce the inter-symbol interference (ISI) introduced in the optical waveform. The equalized waveform has a sufficiently small transmitter and dispersion eye closure (TDECQ) penalty for error-free transmission in a multi-mode fiber link with forward error correction (FEC) as defined in IEEE Standard 802.3bs. A 70m long worst case OM4 fiber is expected to have a combined modal and chromatic dispersion 3 dBo bandwidth of about 36 GHz. The impact of transmission over such a fiber was simulated by introducing a fourth-order Bessel-Thompson filter of 18.6 GHz before the equalizer and resulted in only a small increase in TDECQ penalty.

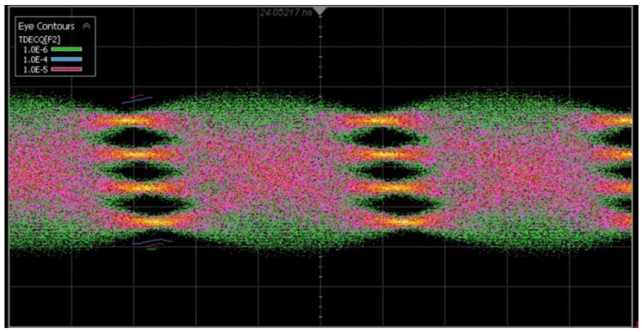

Figure 3: Equalized waveform from a VCSEL modulated at 53.125 Gbd.

3. Summary:

The next generation of 100Gb/s VCSEL-based 850nm multi-model links will require optimization of the relaxation oscillation frequency. VCSELs have been fabricated with relaxation-oscillation frequency at 24GHz at 75°C. Noise performance is less than -145dB/Hz. Reliability testing is on-going.

4. References:

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