20 Gbit/s error-free operation of 850 nm oxide-confined VCSELs beyond 1 km of multimode fibre

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R. Safaisini, K. Szczerba, E. Haglund, P. Westbergh, J.S. Gustavsson, A. Larsson, and P.A. Andrekson

Error-free transmission over 1.1 km of OM4 multimode fibre is demonstrated at bit rates up to 20 Gb/s using a narrow spectral width, high speed 850 nm vertical-cavity surface-emitting laser.

Introduction: Vertical-cavity surface-emitting lasers (VCSELs) operating at 850 nm are well suited in data communication applications due to their numerous advantages [1]. Fast data transmission (20 - 25 Gb/s) over longer multimode fibre (MMF) (approaching 1 km) is a growing demand for applications such as intra building links in large office areas and data centers, where longer fibre links are required.

One of the main challenges of high bit rate (BR) transmission over long MMFs arises from their limited bandwidth caused by the effects of chromatic and modal dispersion [2]. One way of achieving longer distance transmission is improving the VCSEL modal properties to reduce its emission spectral width [3, 4].

There have been various efforts on increasing the error free transmission BR and/or distance for 850 nm VCSELs over MMFs. 40 Gb/s back-to-back (BTB) and 35 Gb/s over 100 m of MMF using a 23 GHz modulation bandwidth VCSEL was reported in [5]. Results from attempts at longer distance transmission by reducing the emission spectral width were recently reported for 500 m of MMF using an integrated mode filter [6] as well as 300 m [4] and 603 m [7] of MMF using a quasi-single mode VCSEL at 25 Gb/s. The latter also employed 1 km of MMF to transmit at up to 17 Gb/s [8]. In addition, there is a report on 850 nm VCSEL transmission at 40 Gb/s over 2 km, but using an advanced photonic crystal fibre [9].

Here we present results from our recent work on 20 Gb/s data transmission over 1.1 km of OM4 MMF using a high speed (~20 GHz modulation bandwidth) 850 nm VCSEL with a limited number of emission transverse modes and narrow spectral width. The top distributed Bragg reflector (DBR) reflectivity of the quasi single mode VCSEL was optimized for high output power and low damping of the modulation response. To the best of the authors' knowledge, the BR-distance product is the highest ever reported for a link employing a directly modulated VCSEL and MMF.

VCSEL design and dc measurements: The VCSEL design was optimized for high modulation bandwidth as described in detail in [10]. The epitaxial layers were MOVPE grown on a semi-insulating GaAs substrate. Most of the bottom n-type DBR consists of Si-doped AlAs/AlGaAs layers to facilitate heat transport from the active region by using the high thermal conductivity binary compound. The active region contains five strained InGaAs/AlGaAs quantum wells for improved differential gain [1]. Alternating layers of C-doped AlGaAs with different Al contents were employed as top p-type DBR. The present structure utilizes a multi-oxide scheme to lower the parasitic oxide capacitance. The VCSEL aperture is defined during the device fabrication by wet-oxidizing two 98% Al content layers placed right above the active region in the top DBR, followed by four additional 96% Al content shallow oxide layers for capacitance reduction. VCSELs were fabricated through a standard high speed VCSEL process flow including mesa formation, metal contact deposition, wet oxidation, and planarization. As the last processing step, the reflectivity of the output coupling DBR was reduced to raise the output power and the slope efficiency. This step led to an approximately 40% enhancement in the maximum output power and slope efficiency with only a minimal increase in threshold current. Having a higher launched optical power is crucial for transmission over longer fibres.

The light-current-voltage (LIV) characteristics of a VCSEL with ~3 μm oxide aperture diameter measured at 20°C is presented in Fig. 1. The device show a slope efficiency of 0.64 W/A with 0.19 mA threshold current and a 2 mW maximum output power occurring at 5.7 mA roll over current. The optical emission spectrum of the VCSEL at 2.7 mA is shown in the inset of Fig. 1. The device operated primarily in the fundamental mode with a sidemode suppression ratio >30 dB at bias currents below 1.5 mA and approximately 20 dB at 2.7 mA with 0.29 nm RMS spectral width. This narrow spectral width reduces the effects of chromatic and modal dispersion in the fibre for long distance transmission.

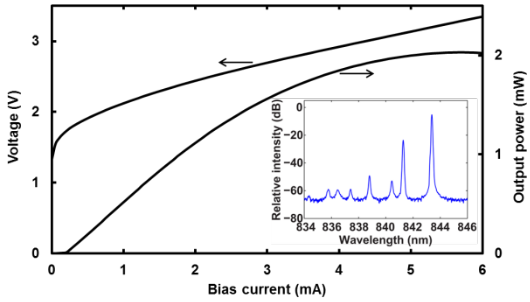

Fig. 1 *LIV characteristics of the ~3 μm aperture VCSEL.*
Inset: Optical spectrum at 2.7 mA.

Transmission experiments: Large signal modulation performance of the VCSEL was evaluated by measuring the eye diagrams and bit error rates (BERs) for BTB configuration and after 500, 800, and 1100 m of MMF. Non-return-to-zero data pattern with a 2^7-1 bits long pseudorandom binary sequence generated by a SHF 12103A bit pattern generator was fed to the VCSEL through a linear SHF 807 amplifier with 24 dB gain in combination with a total of 23 dB attenuation and a 30 GHz SHF 120A bias-T via a high speed probe. The linear amplifier was utilized to suppress unwanted microwave reflections, while its additional gain was mainly cancelled out by the attenuator. The light output was then butt-coupled to a 62.5 μm core diameter MMF by maximizing the coupled power with ~50% coupling efficiency before either launching to a 50 μm core diameter OM4 MMF or directly to a photoreceiver for BTB measurement. The photoreceiver package contains a New Focus 1580 photodiode with 12 GHz bandwidth and an integrated transimpedance amplifier. Use of a photoreceiver package can effectively reduce the noise level and improve the signal quality. However, the available photoreceiver has a limited bandwidth and thus is a limiting factor for measuring at very high BRs. A JDSU OLA-54 variable optical attenuator was placed before the photoreceiver to adjust the received power for the BER measurement. The output signal of the photoreceiver was then used to measure eye diagrams using an Agilent Infiniium DCA-J 86100C 70 GHz digital communications analyzer or to perform BER analysis using a SHF 11100B error analyzer. The VCSEL was biased at 2.7 mA with a peak-to-peak modulation voltage of 0.95 V.

Results and discussion: Inverted eye diagrams for BTB, 500, 800, and 1100 m transmission at 20 Gb/s are shown in Fig. 2. The corresponding BER results are presented in Fig. 3. Open eyes and error-free (BER<10^{-12}) operation at 20 Gb/s were achieved for up to 1100 m of MMF with a power penalty of ~2 dB at 1100 m transmission and a VCSEL energy dissipation of 280 fJ/bit. The BTB sensitivity is within 1 dB of the theoretical performance, accounting for the 12 GHz receiver bandwidth and the resulting intersymbol interference penalty. The eye diagrams after transmission over 1100 m of MMF suggest that fibre dispersion is not a limiting factor and even longer transmission distances should be possible. Unfortunately the received optical power was limited by fibre and connector losses. The reduced VCSEL spectral width directly reduces the effects of chromatic fibre dispersion while it indirectly also reduces the effects of modal dispersion since the quasi single mode VCSEL excites a reduced number of fibre modes. The eye diagrams also show the same amount of noise for both ones and zeros, suggesting that the relative intensity noise (and mode partition noise in particular) is not a limiting factor for these quasi-single mode VCSELs.

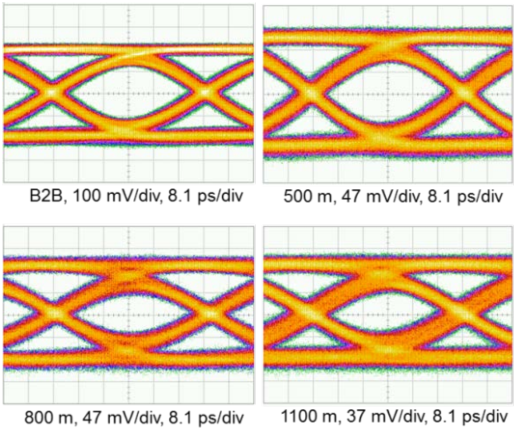

Fig. 2 *Inverted eye diagrams of the received signal after BTB, 500, 800 and 1100 m transmission on MMF.*

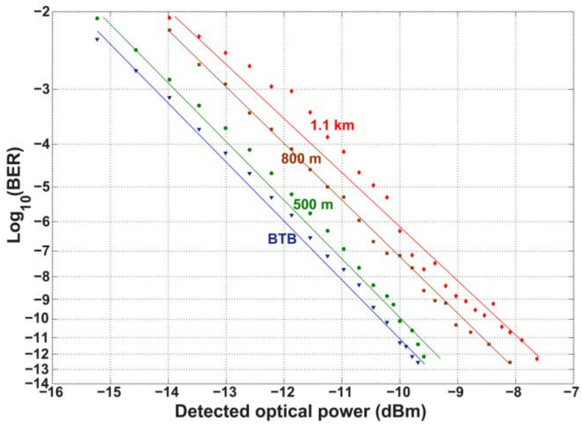

Fig. 3 *BER results obtained for 20 Gb/s transmission over up to 1100 m of MMF.*

Conclusion: A high-speed, oxide-confined, quasi single mode 850 nm VCSEL has been fabricated and used in transmission experiments. Narrow spectral width and high output power allow for 20 Gb/s error-free transmission over 1100 m of MMF as shown by open eye diagrams and BER measurements.

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