Up to 10 Gbit/s Data Transmission with 1.3 μm Wavelength InGaAsN VCSELs

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We demonstrate room-temperature data transmission with monolithic InGaAsN/GaAs VCSELs, emitting maximum single-mode optical power of 700 μW at 1304 nm wavelength. Bit error rates of less than 10^{-12} have been achieved for transmission over 20.5 km standard single-mode fiber and 500 m multi-mode fiber at 2.5 Gbit/s and back-to-back transmission at 10 Gbit/s.

1. Introduction

850 nm wavelength vertical-cavity surface-emitting lasers (VCSELs) are currently used as transmitters for short-distance optical links like Gigabit Ethernet or parallel optical links such as PAROLI^{TM} [1]. High beam quality, easy array scaling, on-wafer testability, low power consumption, easy packaging, comparatively low production cost [2] and high-speed modulation capability [3] promote the use of VCSELs for short-distance multi-mode fiber (MMF) based interconnects. At an emission wavelength of 1.3 μm eye-safety restrictions are relaxed compared to 850 nm and standard single-mode silica fibers (SSMF) with higher bandwidth-length products can be used for km-long links in local and metropolitan area networks. By incorporating only 1.8 % fraction of nitrogen into the active quantum wells (QWs), direct band gaps suitable for 1.3 μm transmission can be achieved within the well-known InGaAs/GaAs material system [4]. Thus both high-quality AlGaAs/GaAs distributed Bragg reflectors and the active region can be grown monolithically on GaAs substrates [5, 6, 7]. In this paper we present devices with new record performance as well as data transmission experiments at 2.5 Gbit/s, 5 Gbit/s, and 10 Gbit/s.

2. InGaAsN VCSEL Properties

The active region consists of two 6.5 nm thick InGaAsN QWs which contain about 35 % indium and 1.8 % nitrogen and are separated by 20 nm thick GaAs barriers. We use undoped mirrors and two intracavity contact layers doped with silicon or beryllium for lateral current supply. Current confinement is achieved through a single 15 nm thick AlAs layer incorporated into the p-doped GaAs spacer, which is selectively oxidized to an aperture size of about 4×6 μm^2. The dry-etched top-mesa with a diameter of 15 μm

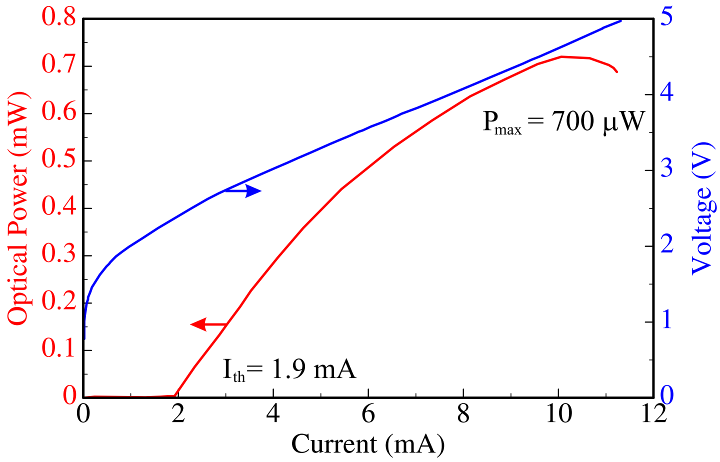

Fig. 1. Output characteristics of a 4×6 μm^2 active area single-mode selectively oxidized InGaAsN VCSEL.

consists of 28 pairs of AlGaAs/GaAs. The diameter of the wet-chemically etched lower mesa is 35 μm. Further details of the structure can be found in [7]. As seen from the continuous wave (CW) output characteristics in Figure 1, the threshold current is 1.9 mA. The maximum output power at room temperature is 700 μW at a driving current of 10 mA. The differential series resistance has a nearly constant value of 280 Ω until thermal roll-over.

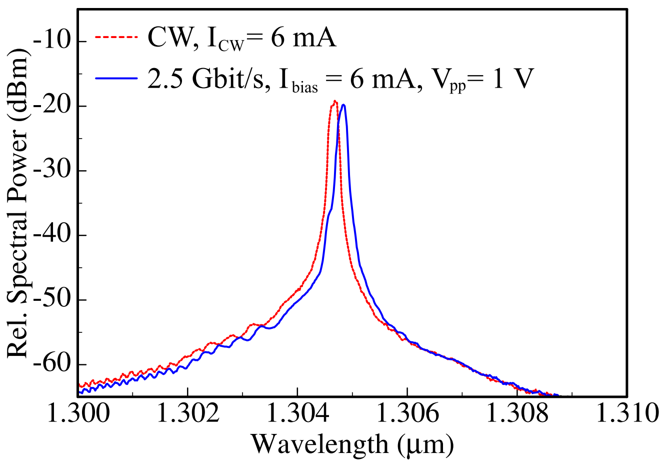

Fig. 2. Spectra at CW and modulated operation with V_{pp}=1 V at 6 mA bias current.

The lasing wavelength shifts from 1302.5 nm at an operation current of 2 mA to 1306.1 nm at 10 mA. Single-mode and single-polarization emission is maintained at a side-mode suppression ratio of more than 35 dB up to a driving current of 9 mA. At 6 mA bias and digital modulation with V_{pp}=1 V the laser also remains single-mode and shows only a wavelength shift of 0.1 nm versus CW mode as shown in Figure 2.

3. Dynamic Properties and Data Transmission Results

From small-signal modulation measurements as indicated in Figure 3 we have deduced a modulation efficiency of 3.7 $\mathrm{GHz}/\sqrt{\mathrm{mA}}$ and a maximum 3 dB modulation frequency of 5.4 GHz at a driving current of 7 mA.

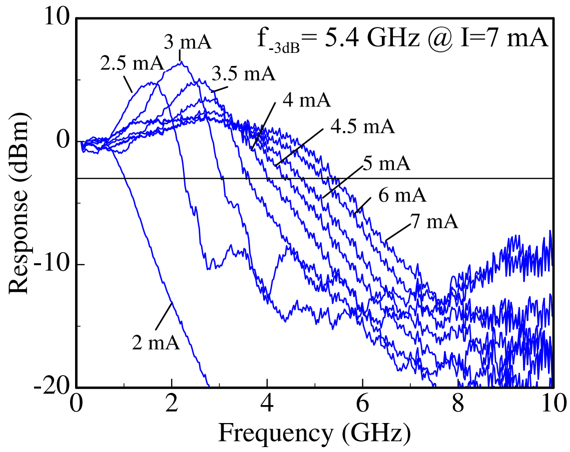

Fig. 3. Small-signal frequency response of a 4×6 μm^2 active area InGaAsN VCSEL for various bias currents.

Transmission experiments have been carried out at 2.5 Gbit/s with a pseudo-random bit sequence (PRBS) of $2^7 - 1$ word length. The VCSEL was biased at 6 mA and modulated with 1 V_{pp} from a 50 Ω impedance driver, corresponding to an average output power of –4 dBm and a measured optical extinction ratio of 6.4 dB. An avalanche germanium photodetector with a bandwidth of 2 GHz was employed for detection

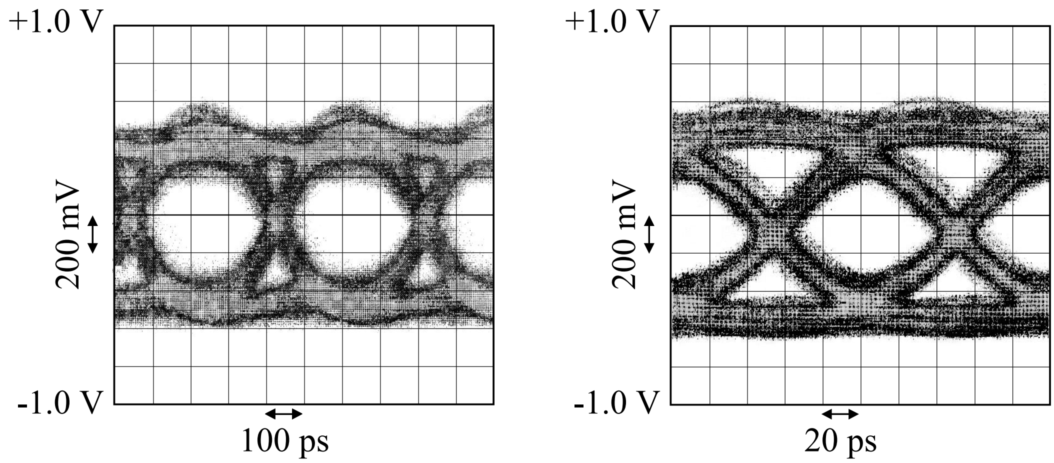

Fig. 4. Eye diagrams recorded for a BER of 10^{-12} after 20.5 km SSMF transmission with 2.5 Gbit/s data rate (left) and for BTB testing with 10 Gbit/s (right).

The eye diagrams in Figure 4 are wide open and symmetric and are displayed for transport of 2.5 Gbit/s data rate over 20.5 km SSMF (left) and 10 Gbit/s for back-to-back (BTB) transmission (right). Minimum measured bit error rates (BER) are below 10^{-12} as shown in Figure 5. For BTB transmission at 2.5 Gbit/s data rate the minimum received optical power for a BER of 10^{-12} is –29.0 dBm and since fiber dispersion is negligible at 1.3 μm, the measured power penalty after 20.5 km of SSMF is only 0.5 dB compared with 4.5 dB power penalty for transmission over 500 m MMF with 50 μm core diameter. For 5 Gbit/s transmission, an InGaAs pin-diode with 9 GHz bandwidth together with a suitable 3 GHz Bessel filter was used. Again the VCSEL was driven with 6 mA bias current and 1 V_{pp} which leads to an optical extinction ratio of 6 dB. For BTB and 10 km SSMF transmission with a BER of 10^{-12}, the minimum received optical power is –19.1 dBm and –18.5 dBm, respectively. Without 3 GHz filtering we were able to demonstrate 10 Gbit/s BTB transmission. In order to obtain the necessary modulation frequency range, the bias current had to be increased to 8 mA. As inferred from Figure 5 for a BER of 10^{-12}, a minimum received optical power of –10.4 dBm is necessary. Unfortunately, under modulation at 8 mA bias current, the donut-shaped next order transverse mode is excited, prohibiting a suitable transmission over the single-mode fiber.

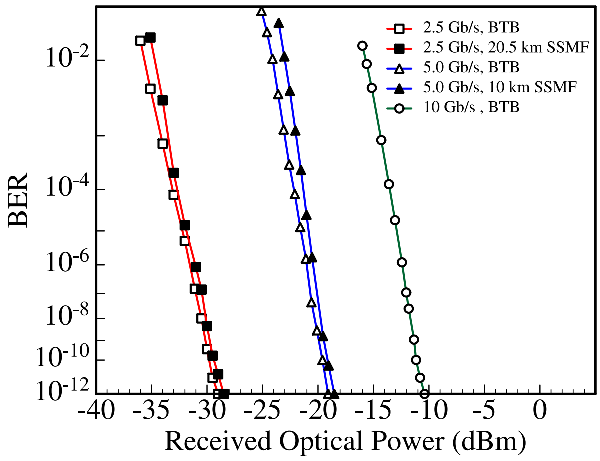

Fig. 5. BER characteristics for $2^7 - 1$ word length PRBS 2.5 Gbit/s data rate transmission over 500 m MMF, 20.5 km SSMF and for BTB testing, 5 Gbit/s BTB and over 10 km SSMF and 10 Gbit/s BTB.

4. Conclusion

We have fabricated and characterized new monolithic InGaAsN VCSELs emitting single-mode at 1.3 μm wavelength. The devices are suitable for error-free data transmission at 2.5 Gbit/s, 5 Gbit/s, and 10 Gbit/s over distances of 20.5 km SSMF, 10 km SSMF, and BTB, respectively. At a data rate of 2.5 Gbit/s, we have also compared the transmission behavior between 500 m MMF and 20.5 km SSMF. All presented results clearly demonstrate the excellent prospects of 1.3 μm wavelength VCSEL sources as the key elements for low-cost datacom applications.

5. Acknowledgment

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