High-Performance Low-Cost Optical Link at 850 nm with Optimized Standard Singlemode Fiber and High-Speed Singlemode VCSEL

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Quasi error-free 9 Gbit/s data transmission experiments are presented over 1 km of ITU-T G.652 compliant 9 µm core diameter singlemode fiber with high bandwidth at 850 nm using a high-speed singlemode VCSEL.

1. Introduction

Multimode fibers (MMFs) optimized for data transmission at 850 nm wavelength are increasingly referenced and used by applications, cabling, and fiber standards [1]. Such fibers enable the lowest total system cost for interconnect distances between 150 m and 600 m by using vertical-cavity surface-emitting laser (VCSEL) transceivers at speeds up to 10 Gbit/s. It would be of much interest to extend the cost benefit of short-wavelength VCSELs to longer distances of up to a few kilometers while exploiting the standard singlemode fiber (SMF), which is so far the cheapest and most widely used fiber on the market. However, currently available VCSELs emit in multiple transverse modes which is very beneficial to meet the encircled flux conditions (as specified in the 10-GbE standard) for the power launched into a MMF. The latter intend to avoid the region close to the fiber axis which often shows a rather poor differential mode delay (DMD) behavior. Obviously, the coupling efficiency of multimode VCSEL emission into SMFs is very low. Another limit in using VCSELs with SMFs is imposed by the poor modal bandwidth of a standard SMF at 850 nm. In this paper it is shown how these drawbacks can be overcome by using a singlemode VCSEL and a specially designed SMF, optimized for 850 nm operation. With this combination, transmission up to 9 Gbit/s is demonstrated over 1 km of G.652 compliant fiber. The work has been presented at ECOC 2004 [2].

2. Fiber Description

ITU-T G.652 compliant singlemode fibers are optimized for operation above 1310 nm and usually feature a very low intermodal bandwidth in the wavelength region around

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850 nm, where at least the LP_{01} and LP_{11} modes are well guided by the core. Two-mode fiber systems based on intermodal delay equalization have been widely studied [3]-[6] in order to address several different applications. Various refractive index profiles have been suggested to achieve zero-modal dispersion at 1300 nm [5] or in the 800 to 900 nm wavelength range [6]. The fiber used in the experiments achieves equalization at 850 nm through careful optimization of a slightly graded profile, capable of yielding G.652 compliant characteristics in the 1260 to 1625 nm region. Typical intermodal delay at 850 nm is less than 0.3 ps/m over a wide wavelength range, which inherently guarantees a 3 dB worst-case modal bandwidth higher than 1000 MHz · km. The feasibility of quasi error-free transmission using such a fiber at 1.25 Gbit/s over 2 km and at 155 Mbit/s over 7.4 km while employing commercially available multimode VCSELs has already been demonstrated in previous papers [7],[8]. Nonetheless, so far, the lack of high-bandwidth singlemode VCSELs has prevented the exploration of higher bit rates.

3. Singlemode VCSEL Operation Characteristics

For the purpose of this study, oxide-confined 850 nm GaAs based VCSELs with optimized singlemode behavior have been fabricated. As shown in Fig. 1 (left), the lasing threshold is found at 0.5 mA and 1.6 V. Maximum singlemode and multimode output powers are 3.1 mW and 4.3 mW, respectively.

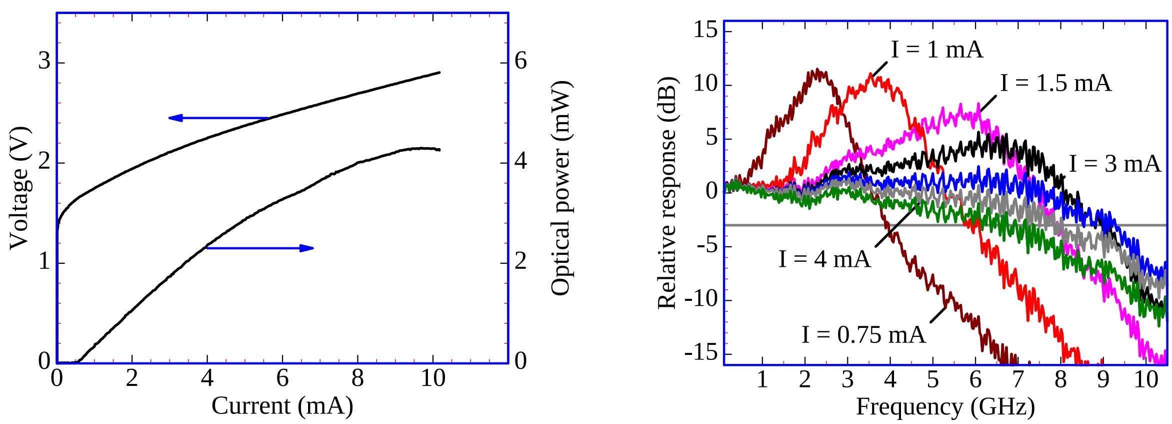

Fig. 1: CW operation characteristics (left) and small-signal frequency response curves of the oxide-confined GaAs singlemode VCSEL (right).

The bias current for the small-signal as well as data transmission experiments was chosen as 3 mA, where the differential resistance amounts to 154 Ω. As illustrated in Fig. 1 (right), the 3-dB bandwidth is then maximized at 9 GHz, which makes the device capable for 10 Gbit/s data transmission. At the receiving end, a multimode fiber pigtailed InGaAs pin-photoreceiver with above 8 GHz bandwidth was used.

4. DMD and Digital Data Transmission

In order to get quantitative insight into the modal delay properties of the SMF, the DMD characteristics at 850 nm wavelength have been determined. Here, a 5 µm core diameter singlemode fiber is scanned over the 9 µm SMF input at a distance of about 10 µm (in accordance with the IEC pre-standard 60793-1-49, Sect. 3.3.) and the impulse response at the output end is recorded for each offset position. A gain-switched 850 nm singlemode VCSEL delivering pulses with less than 40 ps full width at half maximum is employed for this purpose. The results in Fig. 2 (left) reveal that the DMD is below 0.1 ps/m, which clearly enables data rates in the range of 10 Gbit/s.

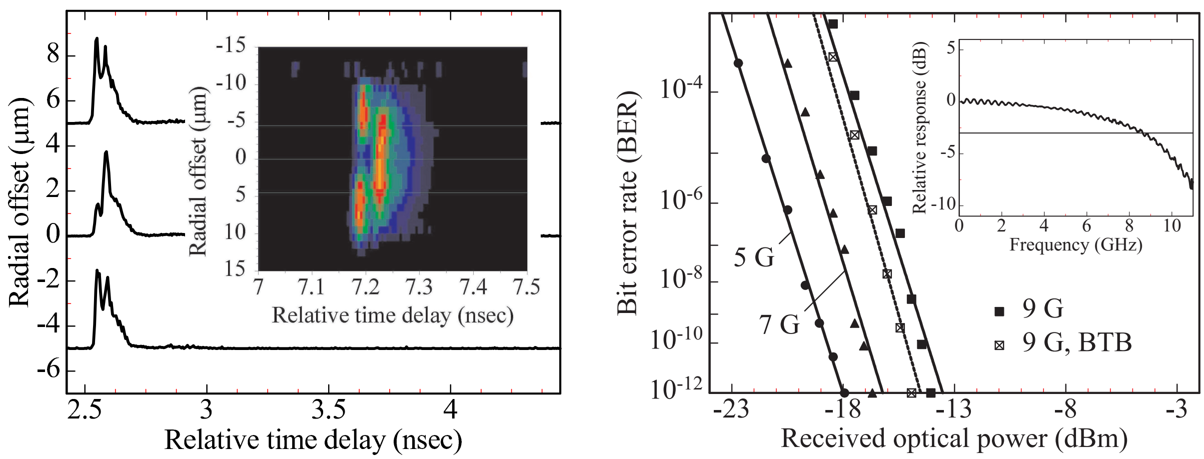

Fig. 2: DMD characteristics for the 1 km-long SMF (left) and BER characteristics for 1 km SMF transmission at data rates of 5, 7, and 9 Gbit/s (right). The inset shows the small-signal fiber response.

Data transmission experiments have been carried out under non-return-to-zero $2^7 - 1$ and $2^{31} - 1$ word length pseudo random bit sequence modulation using the aforementioned singlemode VCSEL driven with $U_{\mathrm{pp}} = 0.6$ V. Figure 2 (right) summarizes the obtained bit error rate (BER) curves for $2^7 - 1$ word length. With the longer word length, power penalties of 1.7 and 1.9 dB are observed at data rates of 5 and 7 Gbit/s, respectively. Low-frequency cut-offs of electronic components have probably prevented 9 Gbit/s transmission in this case. The power penalty versus back-to-back (BTB) operation is about 0.9 dB at a BER of 10^{-12} for the transmission of the 9 Gbit/s signal. There is almost no power penalty versus BTB operation for the transmission of data rates below 7 Gbit/s. The observations are in agreement with the small-signal measurement results of the fiber which are depicted in the inset in Fig. 2 (right). These show a bandwidth–length product of 9 GHz · km, so that the VCSEL might appear as the limiting factor of the high-speed data transmission.

5. Conclusion

For the first time, quasi error-free transmission of a 9 Gbit/s digital data signal at 850 nm over a specially designed standard singlemode fiber of as much as 1000 m length has been demonstrated by means of a high-speed singlemode VCSEL.

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