Polarization Division Multiplexed Data Transmisison Using Surface Grating VCSELs

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We demonstrate free-space transmission of an aggregate data rate of 16 Gbit/s using polarization division multiplexing with two multimode VCSELs, their polarization being stabilized by monolithic surface gratings.

1. Introduction

Polarization stability of vertical-cavity surface-emitting lasers (VCSELs) is of crucial importance in particular for single-mode devices used in optical communications and optical sensing such as in computer mice.

In recent years, we have shown that an unprecedented level of polarization stability can be reached with surface gratings, which provide a monolithically integrated type of polarization-dependent feedback. Single-mode as well as multimode grating VCSELs have been fabricated in large quantity and have been shown to be polarization-stable with high orthogonal polarization suppression ratio not only for static operation but also under digital and analog modulation, temperature variation, optical feedback, as well as externally applied stress [1]. As a design example, Fig. 1 displays the light outcoupling facet of a manufactured grating VCSEL.

In this article we discuss an application of grating VCSELs in optical communications which we targeted some years ago [2], namely free-space data transmission employing polarization division multiplexing.

2. Free-Space Optics for Interconnection

Full polarization control of surface grating VCSELs is also maintained under high-frequency modulation [3], [4]. Such devices thus also lend themselves to applications in optical communications. Multimode VCSELs with emission in the 850 nm wavelength range are widely used for multimode fiber-based data transmission, where, however, no requirements are put on the polarization behavior. Single-mode fiber transmission demands transverse single-mode VCSEL emission, where polarization switches are very detrimental to the dynamics and noise characteristics. Thus, polarization stability is an important issue in long-wavelength 1.31 and 1.55 μm VCSELs. On the other hand, short-wavelength

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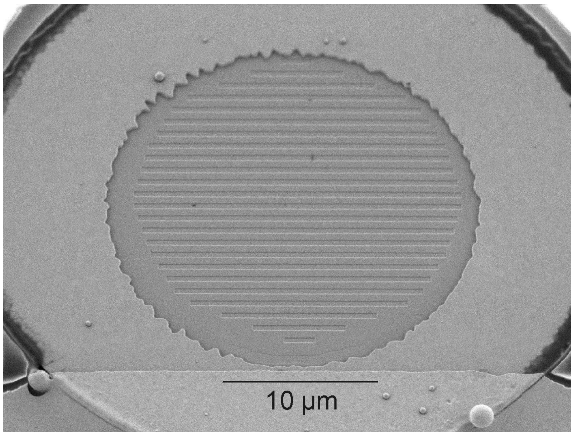

Fig. 1: Scanning electron micrograph of a fully processed VCSEL incorporating a surface grating (from [2]).

850 nm devices are widely used in free-space optics (FSO) equipment [5] for optical interconnection over distances of about 100 m to a few kilometers. In these cases, multimode VCSELs are preferred due to higher output power and thus a more favorable link power budget [6], [7].

Dynamically polarization-stable multimode VCSELs enable polarization division multiplexed data transmission. In this approach, two VCSELs with orthogonal polarizations serve as independently modulated sources of an optical link. The data are sent over a common, ideally polarization-maintaining medium, which is simply air in the case of free-space communication. A particularly compact setup would comprise two orthogonally polarized VCSELs that are monolithically integrated on a single chip and whose emissions are collimated by individual microlenses. At the receiver side, the light is focused on two photodetectors, in front of which two polarizers select the corresponding polarization channel. Applying this technique, the data throughput over a given link can be doubled.

3. Experimental Setup

The functionality of a free-space optics system is demonstrated with the setup shown in Fig. 2. Two grating VCSELs with orthogonal polarization are modulated with the data signal and the inverted data signal of a pattern generator, where the inverted signal is delayed by $(m + 1/2)$ bit periods with m being an integer. The emitted light of the two VCSELs is combined with a polarization-independent beamsplitter, transmitted through a polarizer, and then coupled to a fiber-pigtailed photodetector. The eye diagrams are measured with a sampling oscilloscope. The 860 nm VCSELs used in this experiment have an active diameter of 7 µm, a grating period of 0.75 µm, and a grating depth of 76 nm.

4. 8 Gbit/s Data Transmission

Figure 3 (top left) shows the optical eye diagram of one of these grating VCSELs without the polarizer in the optical link and with the second laser switched off. The data rate of

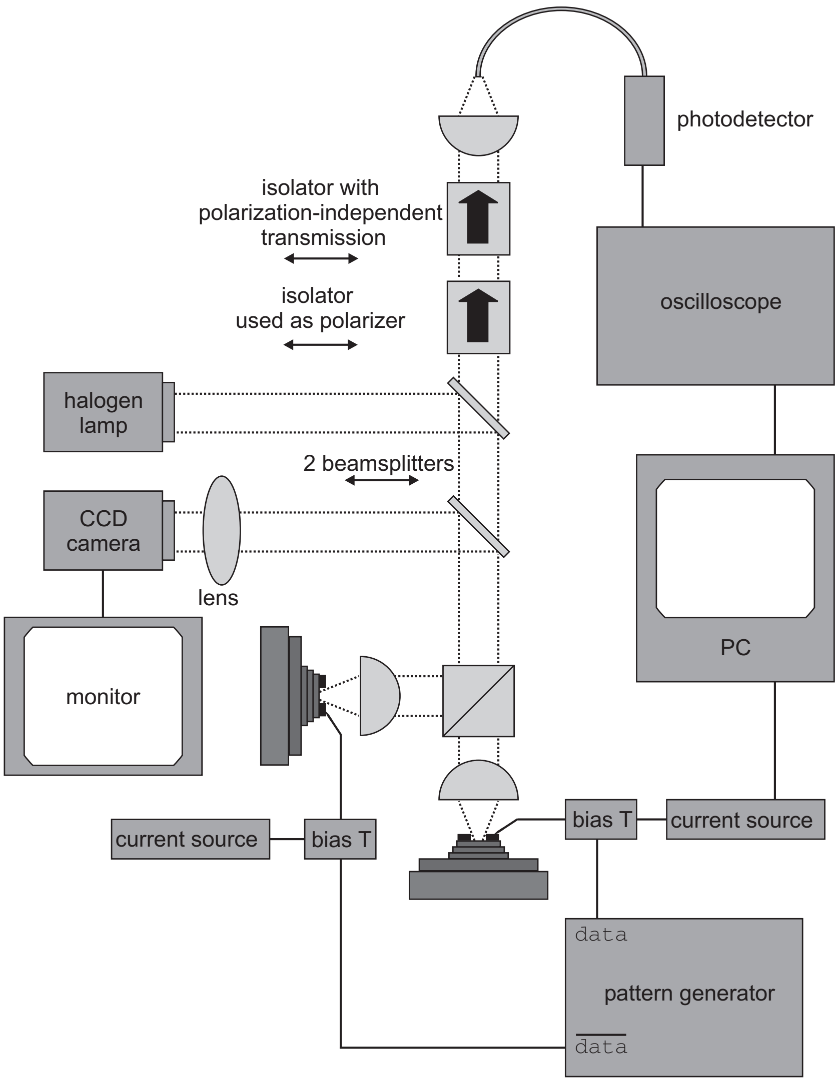

Fig. 2: Measurement setup used to demonstrate polarization division multiplexing. Double arrows indicate components that can be removed from the optical path.

the pseudorandom bit sequence is 8 Gbit/s at a word length of $2^{31} - 1$, the modulation amplitude is 0.7 V_{pp}, and the bias current is 9 mA. The eye is wide open and its quality does not degrade when a polarizer (oriented for maximum transmission) is inserted into the optical path (Fig. 3, bottom left). Even when the second VCSEL with an orthogonal polarization is switched on and is modulated, the optical eye is not distorted (Fig. 3, bottom right), since the signal of the second VCSEL is attenuated by more than 50 dB at the polarizer in front of the detector. The fact that the second VCSEL does not interfere with the original data transmission can also be seen from the bit error rate measurements in Fig. 3 (top right).

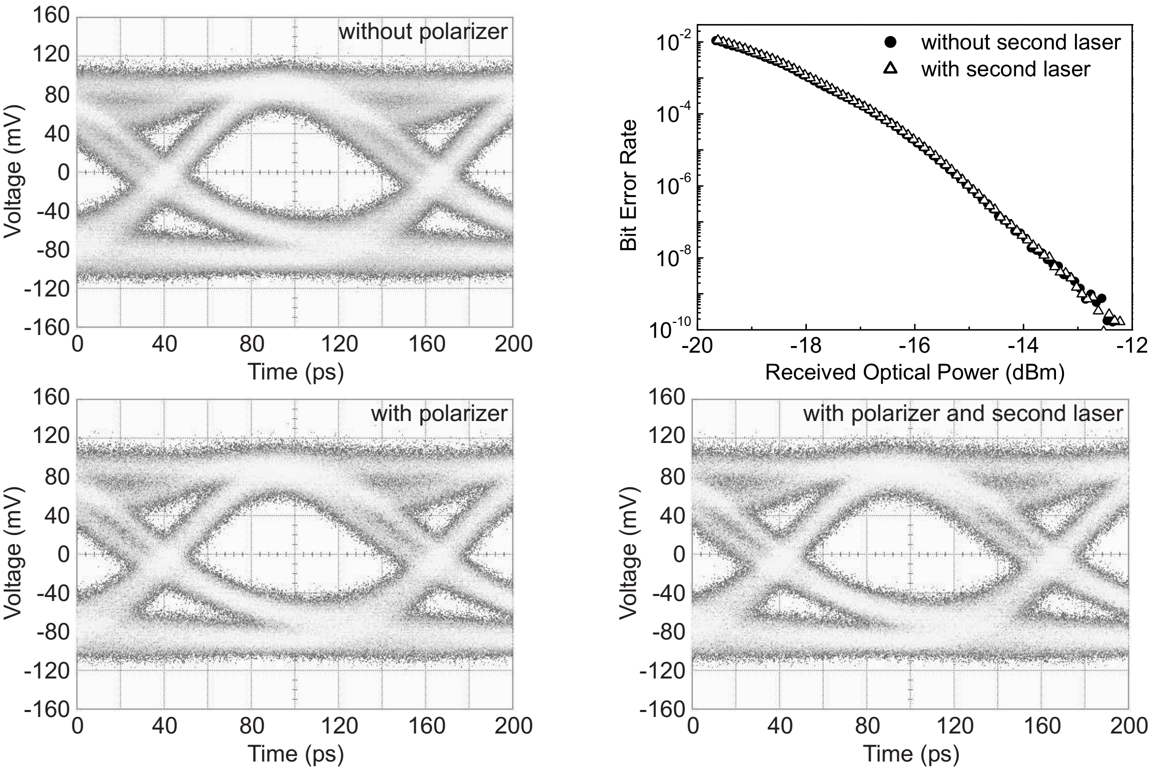

Fig. 3: Optical eye diagrams of surface grating VCSELs at a data rate of 8 Gbit/s. Channel 1 VCSEL before (top left) and after (bottom left) the insertion of the polarizer in Fig. 2 as well as with the orthogonally polarized channel 2 VCSEL switched on (bottom right). Bit error rate characteristics corresponding to the bottom left and right eye diagrams (top right).

5. Polarization Channel Selection

In the setup described above, just one detector and one polarizer are used. One of the two polarization channels is selected by rotating the polarizer, as can be seen in Fig. 4. The orientation of the polarizer is varied between 0° and 90° with respect to the [011] crystal axis. Comparing the eye diagrams for 0° and 90°, one can see the displacement of the two polarization channels by half a bit period, as mentioned above. The eye diagrams in both channels are clearly open. An aggregate data rate of 16 Gbit/s could be easily achieved by adding a second detector. Likewise, this experiment would also work with two adjacent (e.g., 250 μm distance) grating VCSELs on a single chip. It has been shown before that orthogonal grating orientations of such devices result in orthogonal light output polarization [8]. This approach was not chosen here because of the lack of appropriate optics that — in a practical system — has to shape the output into a joint free-space beam with a given divergence angle.

6. Conclusion

We have demonstrated the feasibility of using transverse multimode surface grating VC-SELs for free-space data transmission over independent data channels with orthogonal

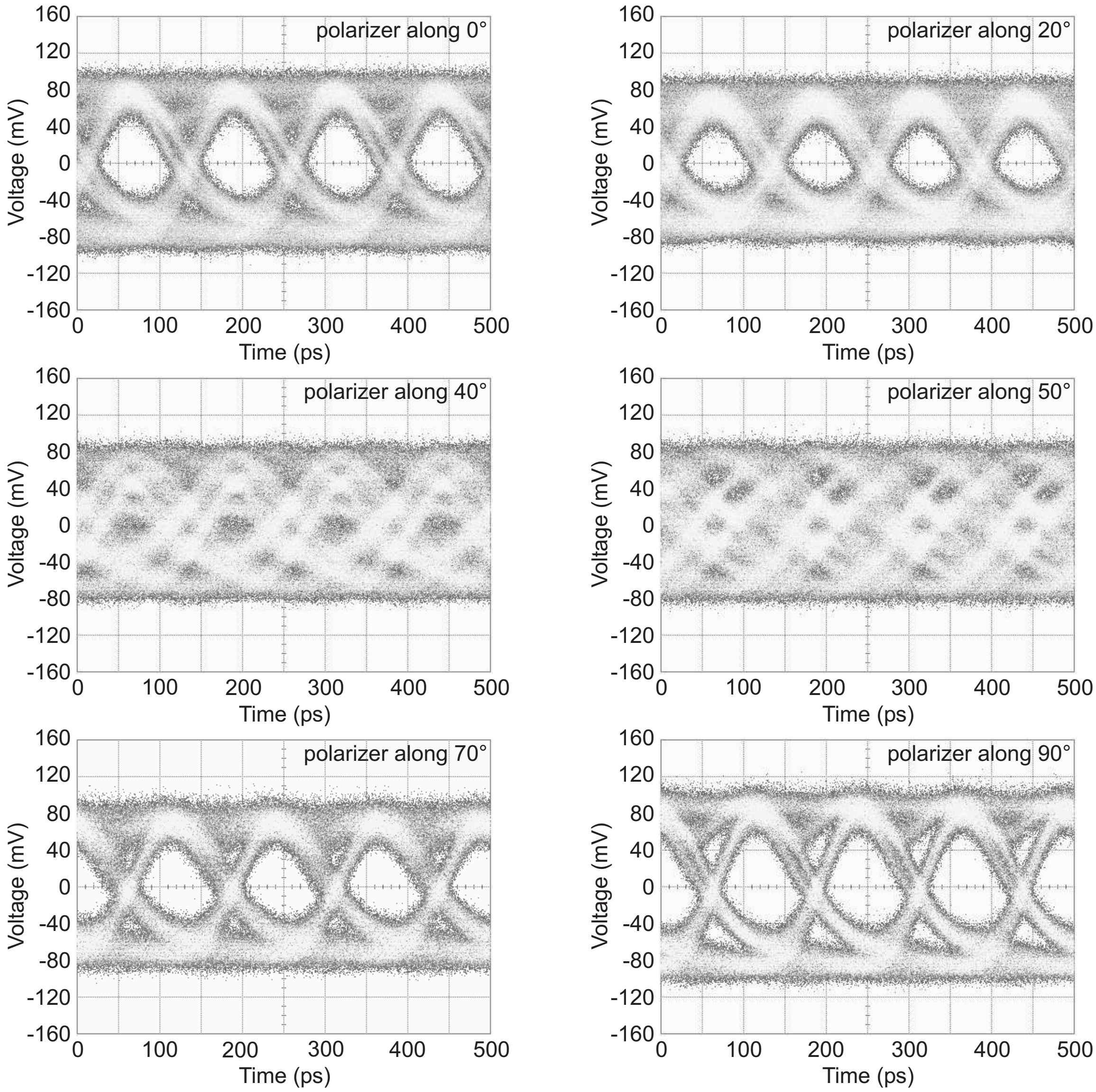

Fig. 4: Optical eye diagrams recorded for a free-space polarization division multiplexed optical link using two orthogonally polarized grating VCSELs that are simultaneously modulated at 8 Gbit/s data rate. The orientation of the polarizer is indicated in each graph. The VCSELs and the modulation conditions are the same as in Fig. 3.

polarization. The aggregate data rate of 16 Gbit/s was limited by the particular chip design of the VCSELs and not by the surface grating technique. For practical applications in existing VCSEL-based FSO transceivers, beam combination optics adapted to an integrated two-laser transmitter chip need to be developed. On the receiver side, two detection units behind a shared main collimation lens have to be used. The induced power penalties due to the finite orthogonal polarization suppression of low-cost polarizer foils or due to static or dynamic rotational misalignment between both transceiver units must also be investigated.

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