Full-Duplex Bidirectional Optical Data Transmission over 50 µm-Core Graded-Index Multimode Fiber with Monolithically Integrated Transceiver Chips

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We present bidirectional data transmission experiments in half- and full-duplex mode at 1 Gbit/s data rate over 500 m graded-index multimode fiber with VCSELs and MSM photodiodes as parts of a novel GaAs-based monolithically integrated transceiver chip.

1. Introduction

For a wide range of interconnect applications, bidirectional optical data transmission in the Gbit/s range is very desired. Monolithically integrated transceiver (Tx/Rx) chips for 850 nm wavelength operation have recently been presented [1], which consist of a vertical-cavity surface-emitting laser diode (VCSEL) and a metal–semiconductor–metal photodiode (MSM PD) and are suited for coupling to a 100 µm core diameter fiber. Nevertheless, owing to the applied lithographic process, they are not well suited for standard graded-index multimode fibers (MMFs) with smaller core. A new generation of chips (Fig. 1) presented in this article is based on a completely revised and simplified process technology. Due to a significant reduction of the VCSEL diameter, the detection area is increased and a centered laser diode can be realized for Tx/Rx chips with 110 µm diameter, which drastically enhances coupling tolerances between chip and fiber. Even quasi error-free full-duplex 1 Gbit/s bidirectional data transmission over a 500 m-long MMF with 50 µm core diameter is possible and shows the high potential of the given approach for various low-cost datacom applications.

2. Transceiver Chip Fabrication

The monolithically integrated transceiver chip contains all layers necessary for signal generation and reception. The MSM PD layer structure includes a 1 µm-thick GaAs absorption layer and is grown on top of the VCSEL layers. More information on the layer sequence is available in [2]. To access the highly p-doped cap layer of the VCSEL, the detector layers within the resist-protected photodiode area are selectively removed by citric acid solutions. The process is terminated at an AlAs etch-stop layer which is subsequently removed by hydrofluoric acid. A dry-etch process is applied to define the VCSEL mesa, during which the photodiode is protected by photoresist. The new design allows the photodiode metallization on a planar surface. Since edge effects are avoided, the device spacing can be reduced and decreased finger width as well as narrower interdigital spacing are more feasible. The circular trench in Fig. 1 separates VCSEL and photodiode and is subsequently filled with polyimide. Only one metallization step is required to contact both the p-side of the VCSEL and to put bondpads on the surface. A small polyimide stripe from the previous lithographic step provides a resistance of several 10 MΩ between VCSEL and photodiode top metallization. The PD diameter equals 110 µm. It is well suited for fibers with up to 100 µm core diameter which shall be centered in front of the device. Tx/Rx chips with both centered and off-centered VCSELs have been processed.

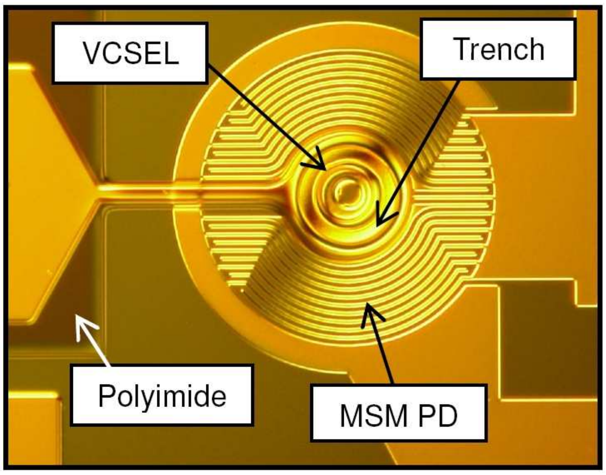

Fig. 1: New-generation transceiver chip with 110 µm diameter containing a centered VCSEL. The 1 µm PD fingers are separated by 2 µm interdigital spacings [3].

3. Effective Responsivity and Coupling Efficiency

We investigate the conditions for butt coupling to a MMF with 50 µm core diameter and a numerical aperture of 0.2. As indicated in Fig. 2, the MMF is scanned in y-direction over a PD with 1.5 µm finger width and 2.5 µm spacing, at a constant distance between fiber and PD of $\Delta z = 50$ µm. The effective responsivity reaches values of as high as 0.35 A/W for ±40 µm lateral offset, where the fiber almost entirely faces the PD area (see inset). With a centered fiber, the effective responsivity is much increased with higher distance between fiber and chip. As seen in Fig. 3, a peak value of 0.26 A/W is found at 380 µm displacement.

The VCSEL-to-fiber coupling efficiency amounts to approximately 70 % for a centered laser diode, where Fresnel losses are included. The 3-dB decay occurs at $\Delta z = 150$ µm. At a constant distance of 50 µm between VCSEL and fiber, the 3-dB decay is found at ±20 µm lateral displacement. Thus, using butt coupling, a tradeoff exists between high input coupling and high effective responsivity.

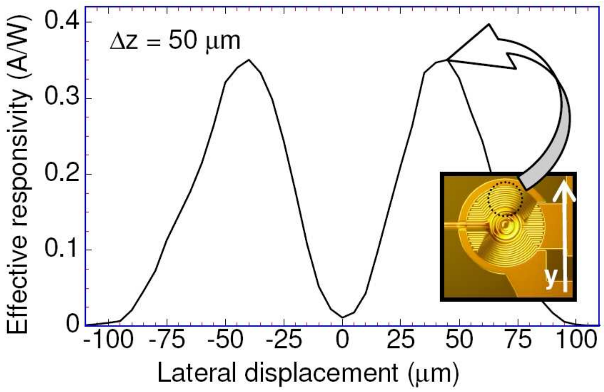

Fig. 2: Effective responsivity of a Tx/Rx chip with a centered VCSEL under lateral displacement of a butt-coupled ($\Delta z = 50\,\mu\text{m}$) MMF with 50 μm core diameter.

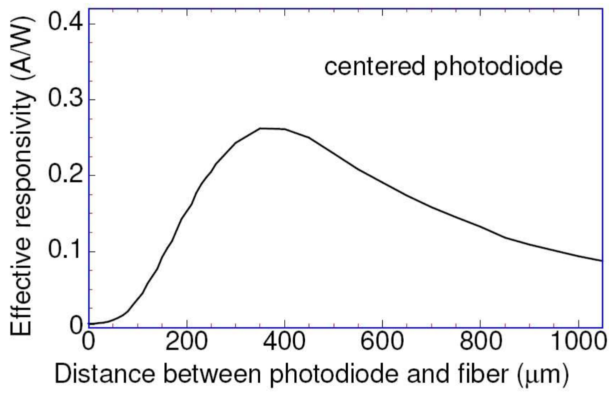

Fig. 3: Effective responsivity for a variation of the distance between PD and MMF, corresponding to 0 μm lateral displacement in Fig. 2.

4. Digital Data Transmission

For bidirectional data transmission, one butt-coupled Tx/Rx chip at each fiber end is used, i.e., there are no optics between chip and fiber and the distance is about 50 μm. Each transceiver chip consists of a 110 μm MSM PD with 1.5 μm finger width and 2.5 μm spacing and an oxide-confined VCSEL with a 3-dB bandwidth exceeding 5 GHz. For data transmission experiments in half-duplex mode, one VCSEL is modulated, while the other one is biased above threshold. Optimum alignment is achieved if the photocurrent at each side is maximized. To control the received AC signals simultaneously, the "data" and "data-not" outputs of the pattern generator are used and both PD signals are monitored on an oscilloscope. Low-pass filters with $f_{3\,\text{dB}} = 1100\,\text{MHz}$ are employed at each side during all experiments. The half-duplex eye diagrams have been recorded by turning off one of the modulation signals. Regarding the coupling efficiencies, the position of the VCSEL was somewhat off-center with respect to the fiber axis. At this position, the effective responsivity of the PD was 0.1 A/W, indicating a loss of about 5 dB at each PD side. The eye diagrams for transmission of a non-return-to-zero pseudo random bit sequence of $2^7 - 1$ word length at 1 Gbit/s data rate over 500 m MMF with 50 μm core diameter show a large eye opening, indicating error-free transmission (Figs. 4a and b). The eye diagrams slightly differ in shape since the VCSELs have different active diameters. Even in full-duplex mode at 1 Gbit/s, error-free data transmission is enabled (Fig. 4c). The reduced eye opening and increased noise are mainly due to electrical crosstalk on the same chip and reflections from the opposite chip, producing far-end optical crosstalk.

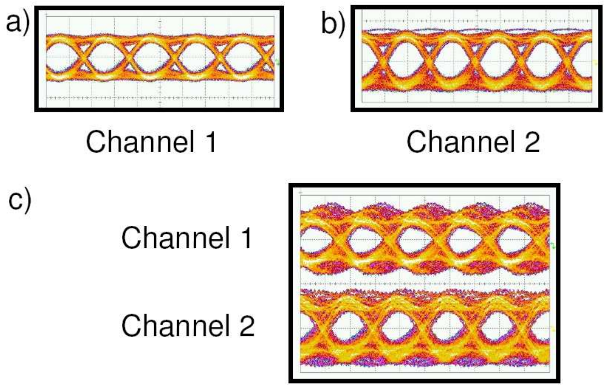

Fig. 4: Eye diagrams for bidirectional data transmission at 1 Gbit/s data rate over 500 m of 50 μm core diameter MMF in half-duplex mode (a and b) and full-duplex mode (c).

5. Conclusion

We have developed a new generation of 850 nm wavelength transceiver chips. Centered VCSEL placement allows direct butt coupling or the use of, e.g., simple ball lens optics. With butt coupling conditions, 1 Gbit/s data have been sent over 500 m of 50 μm MMF even in full-duplex mode. Future generations of smaller chips are targeted to provide improved coupling tolerances.

References

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[2] M. Stach, F. Rinaldi, M. Chandran, S. Lorch, and R. Michalzik, "Bidirectional optical interconnection at Gb/s data rates with monolithically integrated VCSEL–MSM transceiver chips", *IEEE Photon. Technol. Lett.*, vol. 18, pp. 2386–2388, 2006.

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