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Performance of Low-Loss and Low-Cost Optoelectronic Module with Polynorbornene Waveguide for 10-Gbps Data Transmission.

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1. Introduction

In recent years, optoelectronic (O/E) modules with optical interconnection between chips, boards, and both of them are expected for high-speed and high-density data transmission. Several module structures have been proposed for increasing the performance of data transmission [1]. For example, "Terabus" with a silicon carrier is known to be a successful O/E module for 10-Gbps data transmission [2]. However, the fabrication processes such as TSV (through-Si via) formation are quite complicated.

On the other hand, we have proposed a O/E module with rigid/flex printed circuit board (PCB), as shown in Fig. 1. The module consists of 48 channels waveguide, four 1 x 12 vertical-cavity surface-emitting laser diodes (VCSELs), four 1 x 12 photo diodes (PDs), two driver integrated circuits (ICs) and two transimpedance amplifiers/limiting amplifiers (TIA/LAs)). The structure is very simple and can be fabricated by standard packaging technologies. We have previously reported low-loss polynorbornene (PNB) waveguides (0.029 dB/cm at 830 nm), micromirror formation by an excimer laser and 10-Gbps data transmission of the PNB waveguide [3].

In this paper, we demonstrate 10-Gbps data transmission using the testing flexible O/E module in which a transmitter (Tx) consisting of VCSELs and driver IC and a receiver (Rx) consisting of PDs and TIA/LA are assembled to a flexible PCB with the PNB waveguide and the micromirror, as shown in Fig. 2(a).

2. Experimental

12-cm-long PNB waveguide arrays were formed by our proprietary "Photo-addressing" technique [4]. Micromirrors were formed by ArF excimer laser ablation. Two VCSELs (1 x 4 channels), a driver IC, two PDs (1 x 4 channels), and a TIA/LA were flip-chip bonded to a flexible PCBs. Then, the flexible PCBs were precisely attached to the waveguide with a flip-chip bounding machine using passive alignment to the micromirror. Propagation loss of the waveguide was determined by a cut-back method.

3. Results and Discussions

Fabrication of Flexible O/E module

Figure 2(b) shows a photograph of overall flexible O/E module with Tx and Rx. Figure 2(c) shows a top view of the magnified Tx part of the module. Figure 2(d) shows a cross-sectional image of PNB waveguide's channels. The thickness, width, and pitch of the core layer were respectively set at 40 μm, 40 μm, 62.5 μm. Propagation loss of the waveguide was found to be 0.043 dB/cm.

Micromirror's Coupling Efficiency and Tolerances

Prior to the VCSEL assembly to O/E module, the micromirror's coupling loss between the VCSEL on flexible PCB and the 12-cm long waveguide was measured by scanning the VCSEL along the propagation direction (in y direction). Figure 3 shows the relative coupling loss as a function of the offset in the y direction. The tolerance of coupling loss within 1.0 dB was about ±10 μm. As seen from Fig.3, micromirror's coupling efficiency was maximized at approximately 6 um offset in anti-propagation direction from the mirror center.

10 Gbps Data Transmission Test

Differential signals with a data rate of 10 Gbps were generated by a pulse pattern generator and transmitted through an evaluation board to each Driver IC and VCSEL. Emitted light at a wavelength of 850 nm was reflected and guided into a 12-cm long waveguide via micromirror. The propagated light was received by PD. The output electrical signals amplified by TIA/LA were detected from an oscilloscope using co-axial cables, as shown in Fig. 4(a).

Figures 4(b)-4(e) show eye diagrams which were detected at Rx's channel 3. Each diagram was measured in individual emitting condition. Channels labeled "Emitted" mean continuously inputting light from VCSELs to PDs. In any cases, 10 Gbps data transmitting were successfully demonstrated without deformation of eye diagram.

Inter-Channel Crosstalk Properties

To evaluate inter-channel crosstalk, we calculate crosstalk detected at a channel by transmitting from the adjacent channels. Figure 5(a) shows top view of two VCSELs array (1 x 4 channels) mounted on a flexible PCB. Crosstalk is defined by the following expression (1), where $P_{o,n}$ is detected power at channel n, $P_{i,m}$ is the input power at the VCSEL channel m adjacent to channel n, and A_n is the propagation loss of channel n.

$$Crosstalk_{m,n} = -10 \log\left(P_{o,n} / P_{i,m}\right) - A_n \qquad (1)$$

Each value of inter-channel crosstalk at 850 nm after propagation through the 12-cm long waveguide was measured as shown in Fig. 5. As seen from Fig.5, each value of crosstalk to Ch 5 (top) or Ch 6 (bottom) was sufficiently larger than propagation loss A_5 (4.12 dB) or A_6 (3.48dB). The values larger than 20.0 dB mean "low crosstalk".

4. Conclusions

Testing O/E modules where two 1 x 4 VCSELs/PDs were mounted on flexible PCBs made by standard fabrication techniques are demonstrated successfully. We confirmed that coupling loss could decrease 1.0 dB by 6 μm offset of VCSEL's emitting aperture to anti-propagation direction from the mirror center. The modules exhibited low propagation loss and capability of 10-Gbps data transmission with low inter-channel crosstalk was demonstrated. In next work, it will be confirmed that a conceptual O/E module with four 1 x 12 optical interconnection channels and conventional rigid/flex PCBs can achieve a good performance by applying these results.

References

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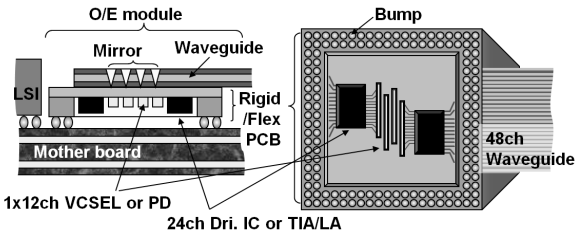

Fig. 1 Conceptual O/E module with four 1 x 12 interconnection channels.

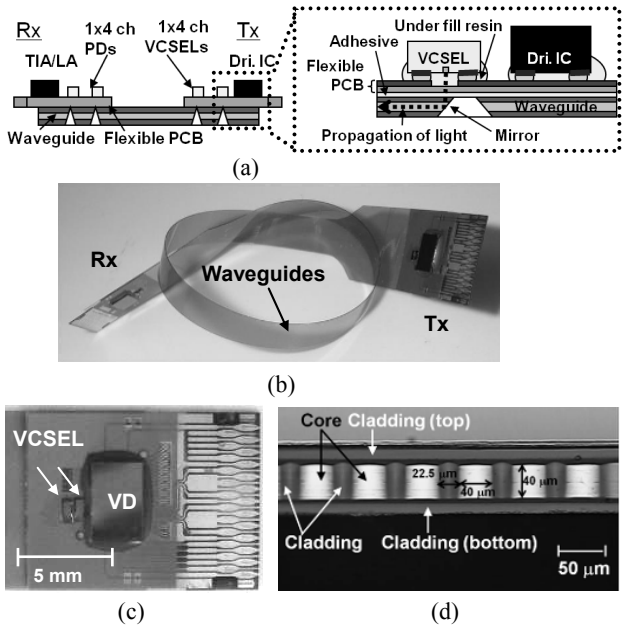

Fig. 2 (a) Testing O/E module with two 1 x 4 interconnection channels, (b) overall flexible O/E module (c) top view image of Tx part, and (d) cross-section image of high-density waveguide.

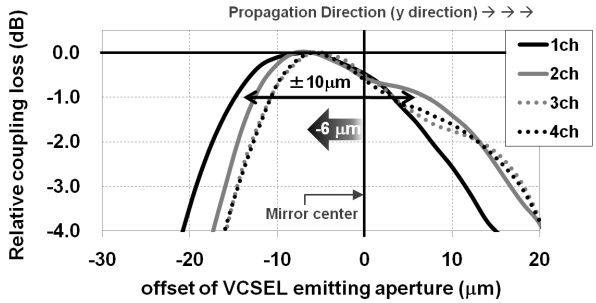

Fig. 3 Micromirror's coupling loss measurement of scanning a VCSEL in y direction.

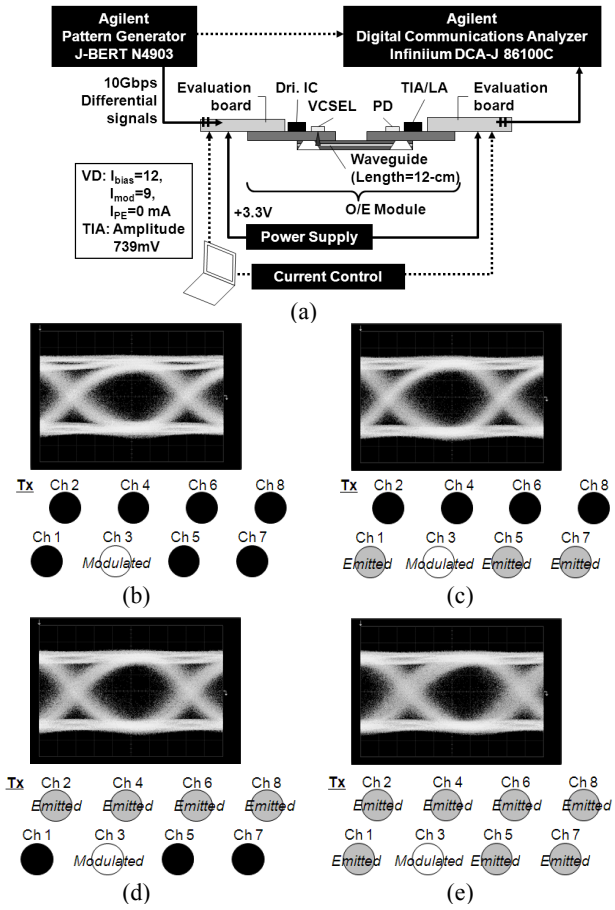

Fig. 4 10 Gbps data transmitting measurement. (a) set-up and (b) to (e) eye diagrams.

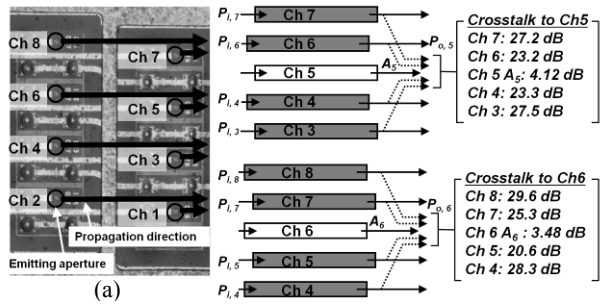

Fig. 5 Inter-channel crosstalk properties and (a) mounted side view of a VCSEL.