240-Gb/s On-Board Optical Transmitters and Receivers

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Abstract: We have developed compact 12-channel, on-board optical transmitters and receivers. The assembly size was 9 mm x 14 mm. Error-free transmission up to 20 Gb/s/ch was achieved, which will enable us to construct a high density optical interconnect.

OCIS codes: (230.0230) Optical devices; (200.4650) Optical interconnects;

1. Introduction

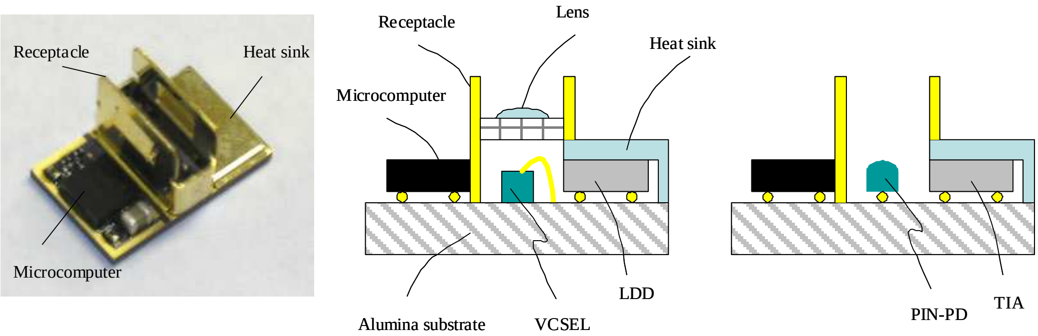
The demand for higher data throughput and higher interconnect densities in servers and routers for IT network systems is growing quickly. To achieve high-speed and high-density interconnects, optical interconnects are promising candidates. To meet the system requirements, first, optical modules need to be densely aligned on boards near the processors to reduce the signal distortion of the electric transmission line. Second, optical modules must be compact. Preferably, they need to be operated with multi-channels at high speed. Third, low power consumption is required from the aspect of heat management.

So far, we have developed a quad 10-Gb/s optical I/O module with 0.85-µm vertical-cavity surface-emitting lasers (VCSELs) [1]. The next-generation transmission rate will be over 10 Gb/s per channel. We expect that a 1-µm-range interconnect will be the high-density interconnect used in the future because 1-µm-range InGaAs/GaAsP quantum well (QW) VCSELs [2] can surpass the performance of 0.85-µm GaAs QW VCSELs due to their higher-speed operation and higher reliability [3,4]. Other factors that give the 1-µm-range VCSELs an advantage in transmission performance over the 0.85-µm devices are the higher eye safety limit and the smaller chromatic dispersion in multi-mode fiber (MMF). For 1-µm-range interconnects, 15-Gb/s x 16-channel operation with 985-nm VCSELs [5] and 10-Gb/s x 12-channel over 600 m error-free transmission [6] were reported. We previously demonstrated 20-Gb/s error-free transmission with 1-µm-range InGaAs/GaAsP QW VCSELs, a single-channel driver IC, and receiver IC between two SERDES devices [7].

In this paper, we describe a new form factor for 12-channel high-speed transmitters and receivers with 1-µm-range VCSELs to satisfy next-generation system requirements. All assembly parts to control the transmitters or receivers were integrated on 9-mm x 14-mm alumina substrates, and their optical receptacles were vertical to the motherboard. These structures, with which two-dimensional module arrays could be formed, were suitable for densely aligning modules near the logic LSIs. Error-free transmission was achieved with these structures at a data rate up to 20 Gb/s. The power consumption per complete link (TX + RX) was less than 14.5 mW/Gb/s including waveform compensation functions.

2. Module Structure

Figure 1 shows a photograph of an assembly as well as conceptual side-views of the transmitter and receiver. The size and appearance of the transmitter and receiver are the same. They are assembled on 9-mm x 14-mm alumina substrates. The transmitter substrate is mounted with a 12-channel laser diode driver (LDD), 1-µm-range VCSELs, a lens array, capacitors, and a microcomputer. The receiver substrate is mounted with a 12-channel transimpedance amplifier (TIA), pin photodiodes (PIN-PDs), capacitors, and a microcomputer. Fiber arrays are attached by the receptacles at a right angle to the substrate. Heat from the LDD and the TIA is dissipated from an upper heat sink. These features of the new form factor are suitable for high-density packaging with LSI. The microcomputers, which have a memory for operating optical devices, will be incorporated into the LDD ICs and TIA ICs in the near future.



(a) (b) (c)

Fig. 1. (a) Photograph of an assembly; (b) conceptual side view of transmitter, and (c) conceptual side view of receiver

The assembly size is expected to be less than 9 mm x 9 mm in the future, which will make it more feasible to mount them more densely with the LSIs on interposers.

The VCSELs have the same oxide-confined structure as conventional 0.85-µm VCSELs. The wavelength was tuned from 0.85 µm to the 1-µm range by adding indium in the GaAs QWs. Intensifying the lateral optical confinement of the VCSELs is an easy way to achieve high-speed VCSELs. Strong lateral optical confinement broadens the spectrum width and reduces the optical coupling tolerance. However, the smaller chromatic dispersion described in the introduction expands the spectrum width that is permissible for MMF transmission. We were able to suppress the coupling loss to the fiber array for the 12-channel transmitter to less than 1 dB by controlling the distance between the VCSELs and lens arrays. The PIN-PD structures were basically the same as PIN-PDs used in 1.3- and 1.55-µm ranges. Our PIN-PDs had an InP-base back-illuminated structure with a monolithically integrated InP lens. They were flip-chip bonded on the substrate. To increase the PIN-PD bandwidth, the capacitance of the PIN structure must be decreased. To decrease the capacitance, the absorption area must be smaller than the MMF diameter, and beam size conversion is required as well as transmitters. The integrated lens expanded the coupling tolerance between the fiber arrays and PIN-PDs.

The LDDs and TIAs were fabricated using a SiGe-BiCMOS process. The supply voltages are 3.3 V. Both transmitters and receivers have equalizer functions to reduce jitter. Differential 100-Ω transmission lines connect the inputs (outputs) of LDD (TIA) circuits to bond pads aligned on the back side of the aluminum substrates.

3. Performance

High-speed optical measurement was carried out on separate evaluation boards. The evaluation boards were prepared using circular printed wire boards (PWBs) and were equipped with a socket for the high-frequency component, which connected the optical modules to the PWBs. Twelve pairs of 50-mm differential, 100-Ω microstrip transmission lines connected the socket to 24 surrounding SMA connectors. The S21 of the microstrip transmission line and the socket at 10 GHz were respectively 2.5 dB and 0.6 dB.

Figure 2 plots the dependence of extinction ratio on modulation conditions. In the bias current range up to 10 mA, the f3dB bandwidth of the VCSEL increased as the bias current was increased. To obtain an extinction ratio of more than 4 dB and to achieve a high speed of 20 Gb/s, we selected 8 mAp-p for the modulation current and 6 mA for the bias current. Figure 3 plots the extinction ratio (ER) for all transmitter channels. The ERs for all channels were over 4 dB. The rise time (20-80%) was 19 ps, and the fall time (80-20%) was 29 ps.

Transmission experiments were carried out at a rate of 20 Gb/s using a 2^7-1 PRBS pattern. We used 50 m of GI50 MMF for transmission. Figure 4 shows the bit error rates (BER) and a typical eye diagram. A clear eye opening was obtained as the receiver eye pattern. Overshoot of the eye pattern was due to receiver equalization. Error-free operation was obtained for all channels. The minimum optical power was less than –8 dBm at the BER of 10^{-12}. The power consumption per complete link (TX + RX) was less than 14.5 mW/Gb/s.

Table I shows the results of transmitter reliability tests. All tests were carried out after a thermal history corresponding to 10 times the reflow process. In the failure column, the numerator indicates the number of failed channels, and the denominator is the number of total channels. The tests showed the transmitters had good reliability against the stresses of bias current, temperature, and humidity.

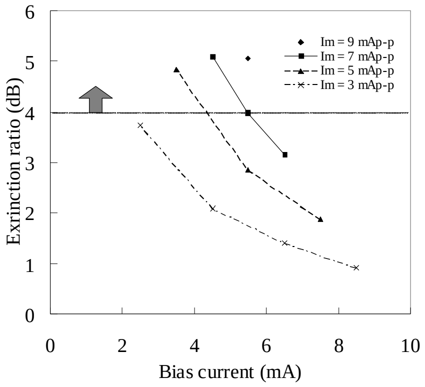


Fig. 2. Dependence of extinction ratio on modulation conditions

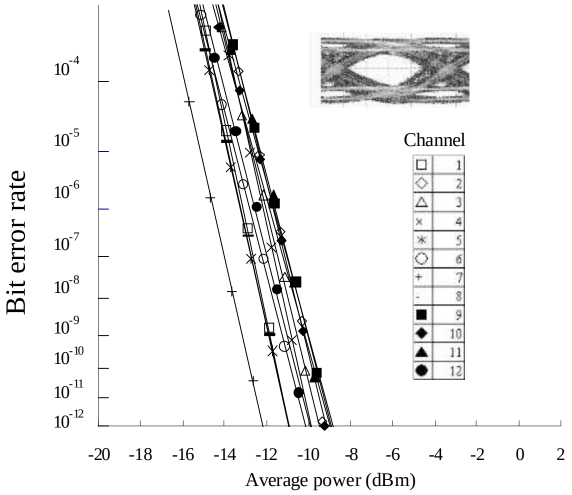


Fig. 4. Bit error rates and typical eye diagram at data rate of 20 Gb/s

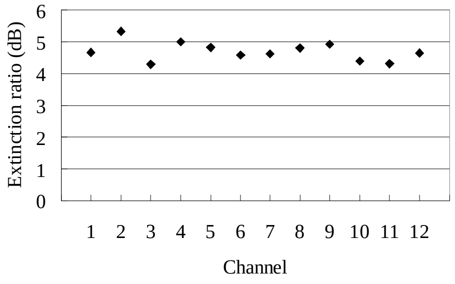


Fig. 3. Extinction ratio for all 12 transmitter channels

Table I

Results of transmitter reliability test

	Condition	Failure
High temperature operation	1000 h, 100°C, 10 mA 1000 h, 120°C, 10 mA	0/29 0/11
Biased damp heat	85°C/85%RH, 5 mA, 1000 h	0/12
Temperature cycling	-40-85°C, 500 cyc.	0/12
Damp heat storage	85°C/85%RH, 1000 h	0/9

4. Conclusions

We have developed 1-μm-range high-speed transmitters and receivers. They support an aggregate data rate of 240 Gb/s through 12 TX and 12 RX channels that each operates up to 20 Gb/s. The assembly structure is suitable for high-density packaging. These results indicated that our transmitters and receivers are useful for constructing high-density interconnects.

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