Letters

A Compact Low-cost 4-channel × 10-Gbit/s Optical Module for Coarse Wavelength Division Multiplexing Links

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Abstract

We have developed a compact low-cost optical module that has four 10-Gbit/s transmission channels of different wavelengths giving a total throughput of 40 Gbit/s. The target applications of the module are short-reach links such as inter-rack connections in POP (point of presence) and WDM (wavelength division multiplexing) access networks. Although 40-Gbit/s laser modulators, photodiodes, and driver LSIs (large-scale integrated circuits) are available, they are still expensive. However, a 10-Gbit/s optical link can be made using cheap direct-modulation laser diodes and low-cost CMOS (complementary metal oxide semiconductor) driver LSIs. Thus, a four-channel CWDM (coarse wavelength division multiplexing) link is the most cost-effective way to achieve 40-Gbit/s transmission. Our module has a compact package size of 33 × 30 × 6.3 mm^3 and is assembled using a simple optical alignment process based on a novel silicon platform technique to reduce the assembly cost. We verified CWDM transmission over a 10-km fiber with a pair of commercial available CWDM multiplexer/demultiplexer filters.

1. Introduction

A CWDM (coarse wavelength division multiplexing) link has great potential to reduce network costs because it can carry multiple applications on an optical fiber and is less expensive than a dense WDM (DWDM) link, which requires costly light sources and expensive optical filters with high wavelength accuracy. These days, the application areas for CWDM links are growing. One example of a new application is the WDM PON (passive optical network) system (**Fig. 1**), which is a point-to-multipoint subscriber access network that provides higher bandwidth than PONs based on time-division-multiplexing. Another application is VSR (very short reach) interconnection in POP (point of presence) (**Fig. 2**). An IA (implementation agreement) for an OC-768 VSR link using four-wavelength CWDM has been published by the Optical Internetworking Forum (OIF) [1]. An example configuration of the CWDM VSR module is shown in **Fig. 3**. This configuration using multiple 10-Gbit/s units will enable a cost-effective 40-Gbit/s module because 10-Gbit/s optical links can be made using cheap direct-modulation laser diodes (LDs) and low-cost CMOS (complementary metal oxide semiconductor) driver LSIs (large-scale integrated circuits).

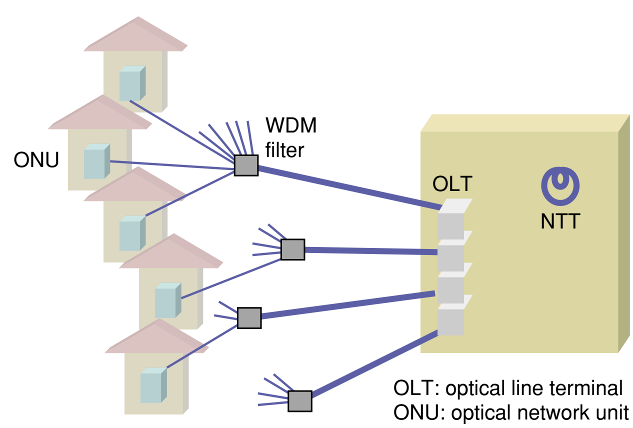

Fig. 1. WDM PON system.

Although CWDM has great potential to reduce the link cost, there is still one major issue. A convention-

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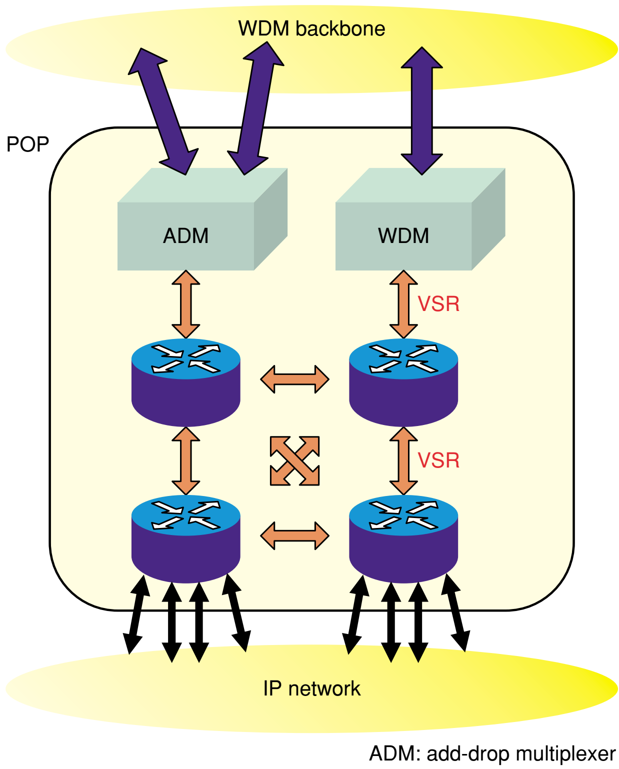

Fig. 2. Typical configuration of a POP (point of presence).

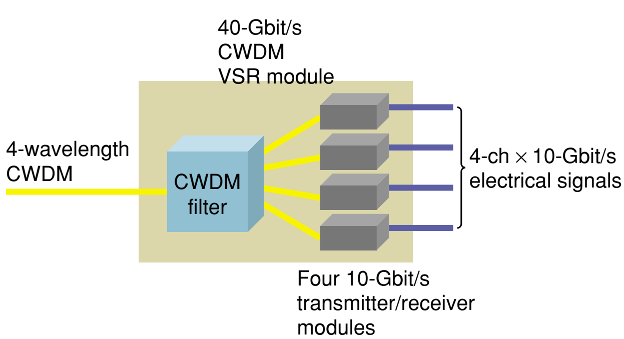

Fig. 3. Example configuration of CWDM VSR module.

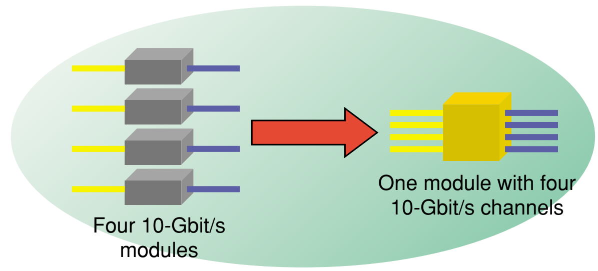

Fig. 4. A compact multi-channel optical module would reduce the number of optical modules and make the system compact.

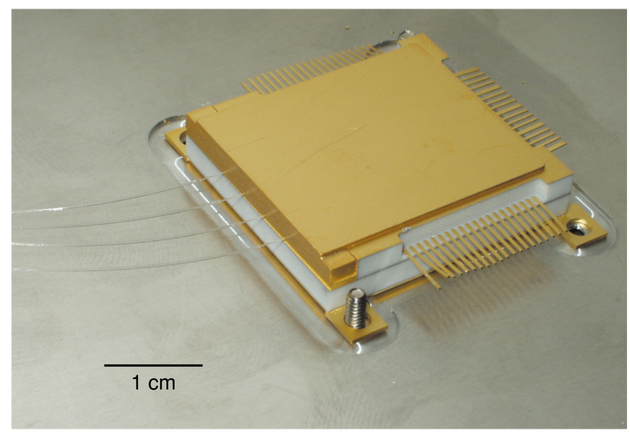

Fig. 5. Photograph of the 4-ch × 10-Gbit/s module.

Table 1. Module specifications.

Data rate per channel	up to 10 Gbit/s
Number of channels	4
Package size	33 mm × 30 mm × 6.3 mm
Output power per channel	>+4 dBm
Receiver sensitivity	–17 dBm
Transmission distance	10 km
Laser diode	Direct-modulation DFB-LD
Photodiode	PIN PD
Wavelengths	1275.7, 1300.2, 1324.7, 1349.3 nm

al CWDM link system requires as many transmitter and receiver modules as there are wavelengths, as shown in Fig. 3. This requires a large amount of board space and results in a high system cost. For applications such as the OC-768 link and optical line terminal (OLT) in the WDM-PON system, a compact multi-channel optical module (**Fig. 4**) would reduce the number of optical modules for the CWDM links and make the system compact and inexpensive.

We have developed compact low-cost 4-ch × 10-Gbit/s optical transmitter and receiver modules for such CWDM applications. Each module has a total throughput of 40 Gbit/s and its volume is only 6.2 cm^3. It is assembled using a simple optical alignment process based on a novel silicon platform technique, which we call the PALC (passive-alignment laser collimator) bench.

2. Module construction

A photograph of the module is shown in **Fig. 5**, and its specifications are shown in **Table 1**. The transmitter and receiver are separate modules and have the same appearance. Each module has four transmission

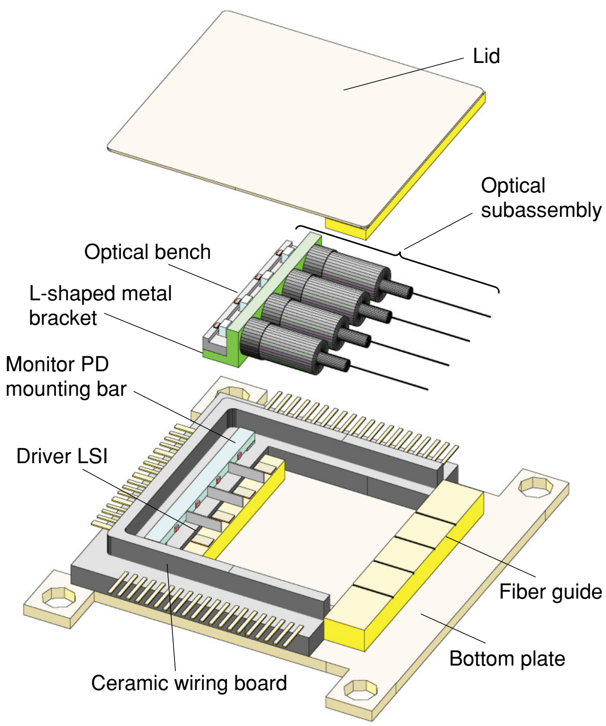

Fig. 6. Exploded view of the transmitter module.

channels, each of which can carry data at a rate of up to 10 Gbit/s. The lasers in the transmitter are direct-modulation distributed-feedback laser diodes (DFB-LDs), and the photodetectors in the receiver are PIN (positive-intrinsic-negative) PDs (photodiodes). The transmitter has LD driver LSIs and monitor PDs. The receiver has transimpedance amplifier (TIA) LSIs. The transmission distance is up to 10 km, which is enough for inter-rack interconnections and most access networks.

There are two different approaches to constructing a multichannel optical module: using device arrays or discrete devices. Optical device arrays and LSI arrays can minimize the size of a multichannel module, but optical device arrays are intrinsically expensive because of their low product yield. On the other hand, single-channel LD drivers and TIAs have a broad market and are getting cheaper. However, 10-Gbit/s driver arrays and TIA arrays are not available yet, and when they are, they will be expensive because of their limited market. The use of single-channel devices has another advantage. It suppresses inter-channel crosstalk, which is a serious issue in arrayed devices, especially for multi-gigabit-per-second transmission. Thus, we chose an independent-channel structure, which uses single-channel optical devices and LSIs.

An exploded view of the transmitter (Tx) module is

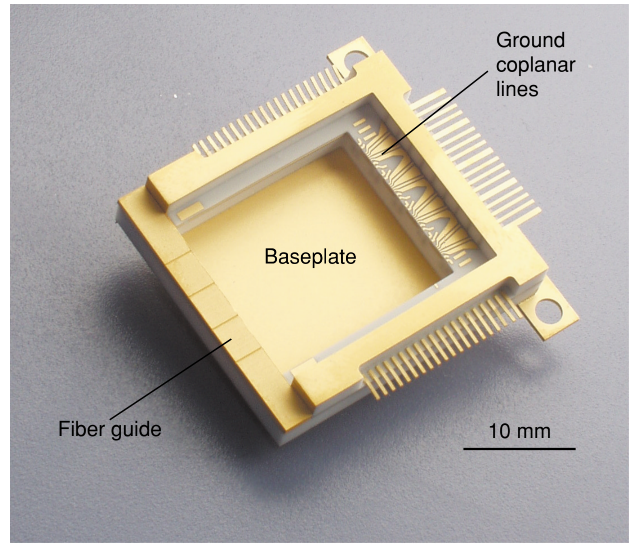

Fig. 7. Photograph of the ceramic-metal hybrid package.

shown in **Fig. 6**. To reduce the cost, we designed it as simply as possible. A Tx optical subassembly (OSA) or receiver (Rx) OSA is assembled in advance and mounted in a package. Optical alignment is completed on the OSA, so the package does not require mechanical accuracy for optical alignment. The driver LSIs or TIA LSIs are mounted on an LSI carrier and connected to the OSA and high-speed signal lines on the ceramic wiring board with gold wires. The LSI carrier is separated from the OSA, so that heat from the LSIs is not conducted to the optical devices. The Tx module has monitor PDs. A monitor PD mounting bar, which contains four monitor PDs, is mounted on the ceramic package to receive back illumination from four LDs.

2.1 Package

A photograph of the ceramic-metal hybrid package is shown in **Fig. 7**. A ceramic wiring board and a metal fiber guide with fiber grooves are soldered to a metal base plate. The OSA and the LSI carrier are placed on the baseplate. The wiring board contains ground coplanar lines for 10-Gbit/s signals and feed-through electrodes that allow hermetic sealing. The package is designed to be easy to seal. The fiber feed-through is hermetically sealed just by placing metalized fibers in the grooves of the fiber guide and soldering the lid on; the whole package is sealed at the same time. The S-parameters of the package are shown in **Fig. 8**. The –3 dB bandwidth of S21 is greater than 20 GHz, and S11 is better than –15 dB at 10 GHz, so the package can handle 10-Gbit/s signals.

2.2 Optical subassemblies

A simple optical coupling structure is the most effective way to reduce the cost of the module because the dominant cost is for optical alignment. We have developed new Tx and Rx OSAs using a silicon technique that greatly simplifies optical alignment. Details are given below.

2.2.1 Tx OSA

We chose a two-lens optical configuration for the Tx OSA to obtain high coupling efficiency because the output power of a CWDM Tx module must be higher than that of a non-CWDM module to compensate for optical loss of CWDM filters. A high coupling efficiency also enables us to reduce the laser current and the power to the laser drivers. This results in lower power consumption, which helps with thermal management. However, the alignment process for two-lens optics is much more complex than that for single-lens optics. To simplify the alignment, we invented a new optical platform for the Tx OSA, which we call the PALC bench (**Fig. 9**) [2]. It consists of a silicon optical platform, four LDs, and four 1st lenses. The LDs and 1st lenses are mounted on the platform by a passive alignment process. The silicon optical platform has four lens pockets for the 1st lenses and four electrode patterns to mount LDs. The LDs are mounted on the electrode pattern by flip-chip bonding and a visual alignment technique having positional accuracy within 1 µm [3]. The lens pockets are made by cutting the silicon bench with a dicing saw. The 1st lenses, which have a cubic shape are put in the lens pockets and pushed against the pocket walls, so they are aligned mechanically by the edges of the pockets. These lens pockets enable us to mount the 1st lenses without a complex active alignment process. A schematic of the Tx OSA is shown in **Fig. 10**. The PALC bench and four fiber-with-lens assemblies are mounted on the L-shaped metal bracket. Four fiber-with-lens modules are mounted using an active alignment technique, which does not require submicrometer accuracy because the ±1-dB tolerance of the fiber-with-lens module is nearly ±10 µm. This wide tolerance comes from the large beam size emitted from the PALC bench, which is over 500 µm, and drastically reduces the time required for active alignment. A photograph of the complete Tx OSA in the package is shown in **Fig. 11**. The Tx OSA is soldered onto the package baseplate and connected electrically to the driver LSIs with gold wires.

2.2.2 Rx OSA

A schematic of the Rx OSA, which has four Rx optical benches, is shown in **Fig. 12**. Each bench consists of a silicon platform with a V-groove, a fiber with an angled facet, and a PD. The PD is mounted on the silicon bench using a visual alignment process.

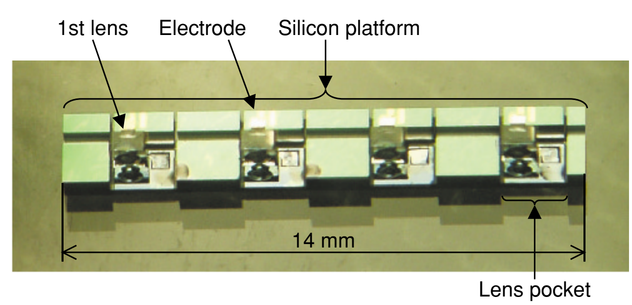

Fig. 9. Passive alignment laser collimator (PALC) bench.

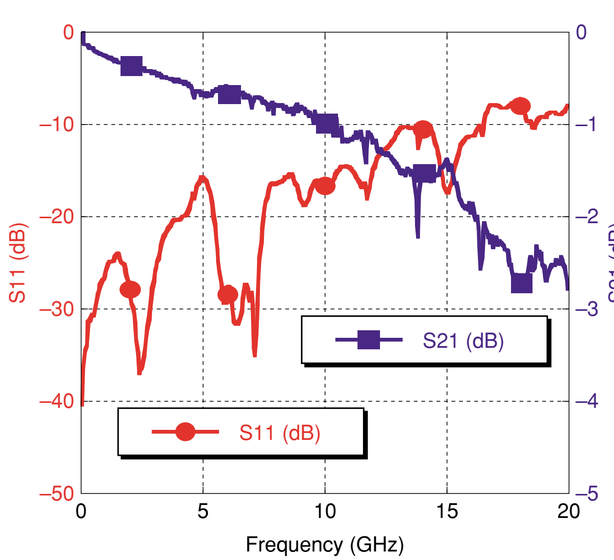

Fig. 8. S-parameters of the package.

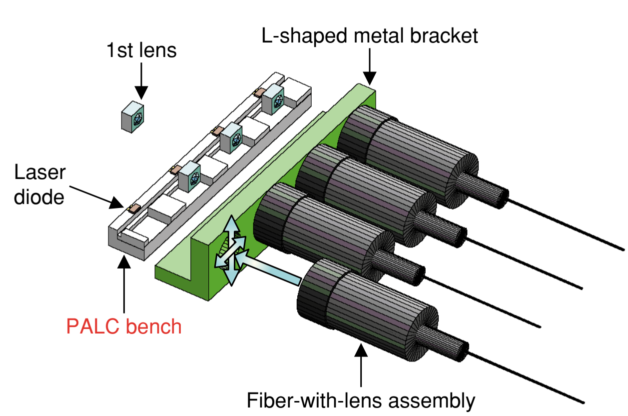

Fig. 10. Transmitter optical subassembly (Tx OSA).

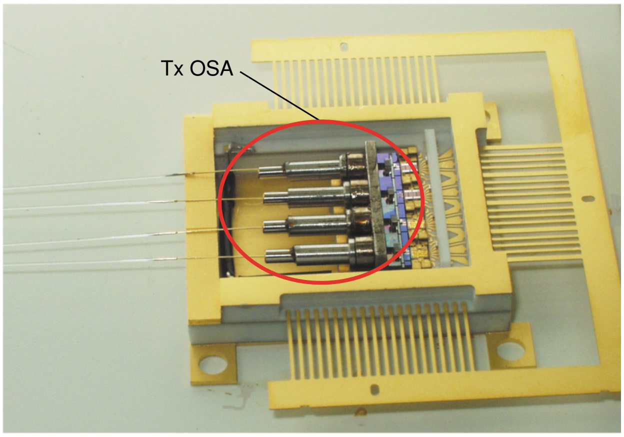

Fig. 11. Tx OSA mounted in the package.

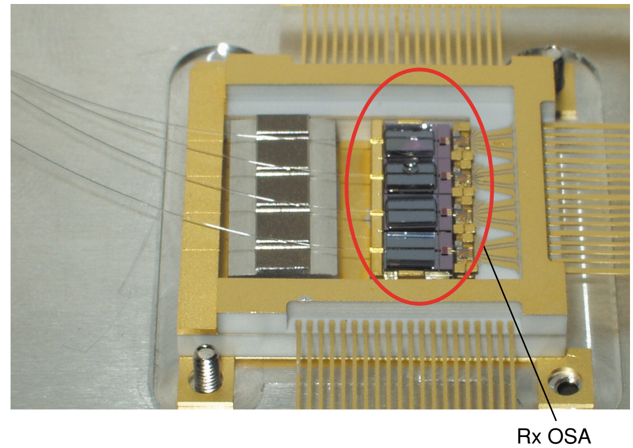

Fig. 13. Rx OSA mounted on the package.

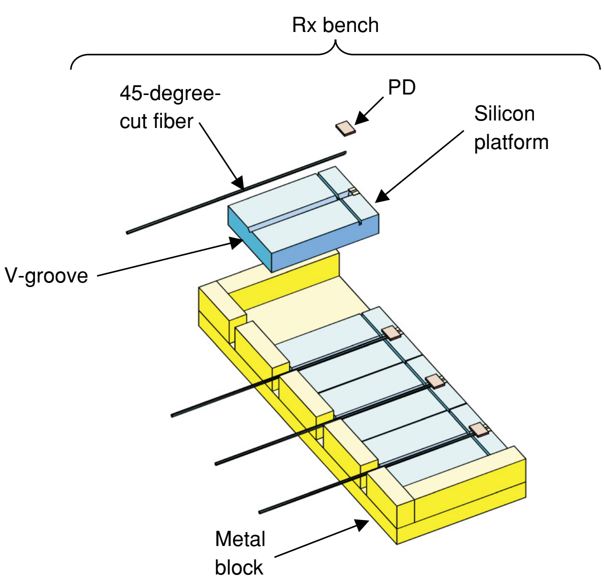

Fig. 12. Rx OSA.

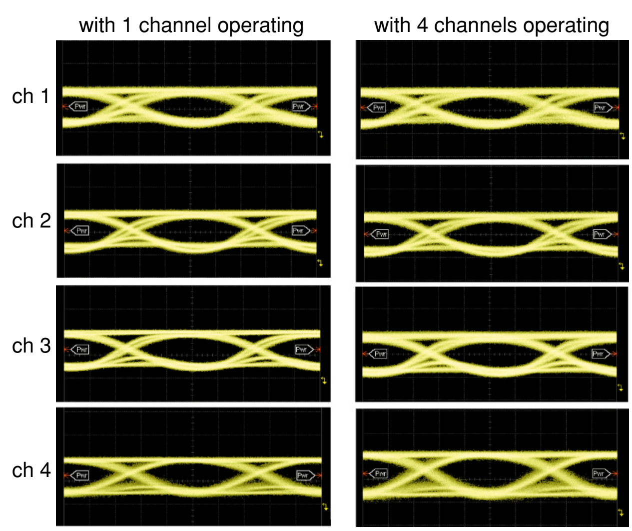

Fig. 14 . Eye diagrams for the Tx module.

The fiber is aligned along the V-groove. Input signal light is reflected at the angled facet of the fiber and thereby coupled to the PD. This simple configuration makes the Rx OSA module inexpensive. The complete Rx OSA mounted on the package is shown in **Fig. 13**. The Rx OSA is also connected to the TIA LSIs with gold wire after being soldered onto the baseplate.

3. Evaluation results

Filtered eye diagrams for the Tx module at 10 Gbit/s with a pseudorandom binary sequence (PRBS) 2^{23}–1 pattern are shown in **Fig. 14**. The left column shows eye diagrams when only one channel was operating, while the right one shows eye diagrams when all the channels were operating. The diagrams all show good eye openings, and the waveforms are almost the same regardless of the number of channels operating. These results show that crosstalk is quite low, even at 10 Gbit/s.

Figure 15 shows eye diagrams for the receiver for input power of –20 dBm without signals on the adjacent channels (a), when the input power to the adjacent channel was also –20 dBm (b), and when it was –10 dBm (c). Even when the power to a neighboring channel was 10 dB higher than that to the observed channel, very little jitter due to crosstalk was

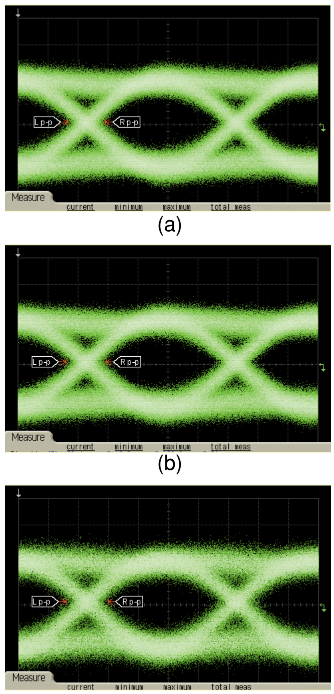

Fig. 15. Eye diagrams of Rx output in 10-Gbit/s operation. Received power of the observed channel was –20 dBm. (a) No input on the disturbance channel. (b) –20 dBm on the disturbance channel. (c) –10 dBm on the disturbance channel.

observed. These results demonstrate that the crosstalk in the module is quite low.

A block diagram of the CWDM transmission evaluation system is shown in **Fig. 16**. Optical outputs from the four-wavelength Tx module were wavelength-division multiplexed by a commercially available CWDM multiplexer (MUX) module and transmitted on a single-mode fiber. The transmitted WDM signal was demultiplexed by a CWDM demultiplexer (DEMUX) module and received by the Rx module. The spectrum of the Tx output after the CWDM MUX module is shown in **Fig. 17**. There are four peaks, which correspond to the channel output wavelengths.

The bit-error-rate (BER) characteristics at 10 Gbit/s are shown in **Fig. 18**. At a BER of 10^{-12}, the received power was –17 dBm. This indicates that the sensitivity of the receiver module is high enough. In addition, all the lines nearly overlap regardless of the transmission distance and number of operating channels. From this result, we can conclude that the module is suitable for transmission over a distance of 10 km and that the crosstalk is very low.

4. Conclusion

We have developed a compact low-cost optical module for CWDM applications. It has four 10-Gbit/s transmission channels of different wave-

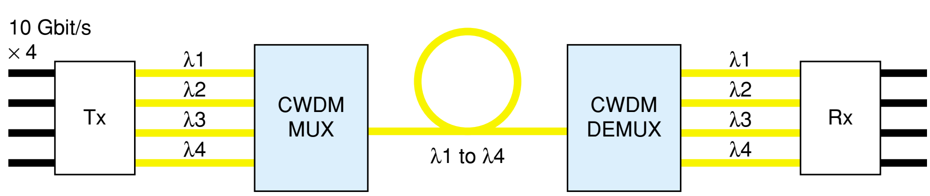

Fig. 16. Block diagram of the CWDM evaluation system.

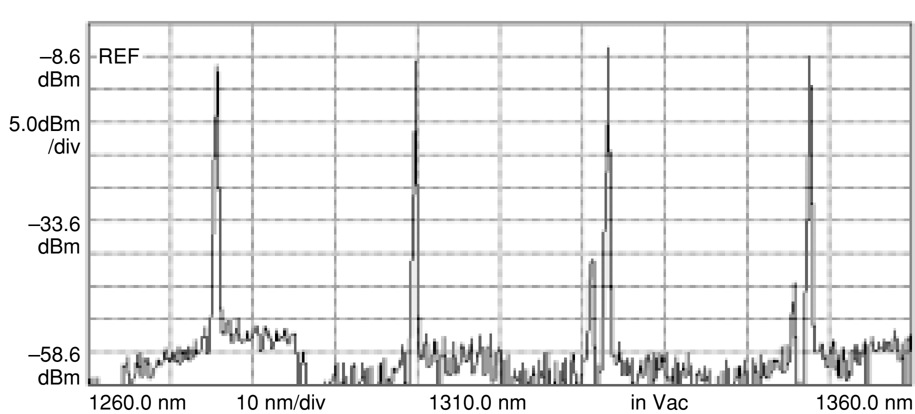

Fig. 17. Tx output spectrum after the CWDM MUX module.

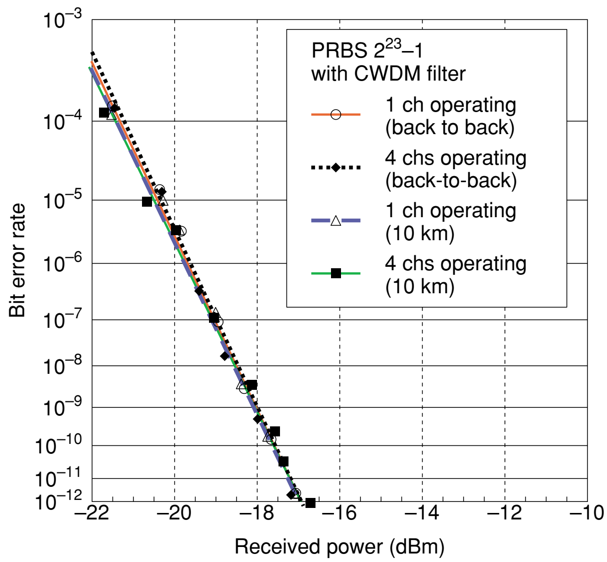

Fig. 18. Bit-error-rate characteristics for CWDM transmission.

lengths giving a total throughput of 40 Gbit/s. We designed the new transmitter and receiver OSAs to reduce the assembly time and cost. We verified that the module is suitable for 40-Gbit/s 10-km CWDM transmission.

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