Development of 10Gbit/s EMwL-TOSA

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Lately the broadband service, which provides image distributions via the Internet, is rapidly becoming a prevalent feature in homes. Due to this situation the amount of communication traffic carried by optical networks is increasing at a rate that exceeds figures expected from the Moore's Law[1], resulting in an increasing demand for transmission systems that offer transmission speeds of 10Gbit/s in the telecommunications, data communications and storage fields.

There are a number of industry standards (MSA: Multi Source Agreements) for transponders used for optical transmitter and receiver at 10Gbit/s. Each of these standards has specifically stipulated external dimensions, pin arrangements and functions. Transponders of a relatively large type, such as the conventional “300-pin MSA” or the relatively compact and power saving XENPAK (10-Gigabit Ethernet Transceiver Package) or the XFP (10-Gigabit Small Form Factor Pluggable) are all in demand within the market. As a matter of fact, the electric power consumption and module footprint of the XFP are approximately one-tenth those of the 300-pin MSA[2, 3]. Expansion for the adoption of the XFP is expected in the future, as it can be used in board designs without any concern for the selection of communication protocol, such as SONET for telecommunications, Ethernet for data communications or Fiber Channel for storage.

We have thus far developed a compact butterfly module[4] (OL5160M) by loading the EMwL device (EMwL:Electroabsorption modulator integrated with laser diode) and the driver IC into a single package, for the purpose of providing an optical transmission light source at the core of the 300-pin MSA transponder used for a transmission range of 40km.

We developed the EMwL-TOSA (EMwL Transmitter Optical Sub-Assembly) as the light source for the XFP and achieved a performance with favorable transmission characteristics that satisfactorily meet the requirement specifications of the XFP, as shown below. It features a distributed penalty of 1dB or less for single mode fiber (SMF) transmissions in a 50km range with an element operating temperature of 45 degrees Celsius, which performs a 10Gbit/s-NRZ modulation with an optical extinction of 10dB or more and average optical output of 0dBm or more.

This paper will first describe the changes in the operating temperature of the EMwL devices in order to respond to the low power consumption requirements that are becoming an issue for board designs using the XFP, followed by the design of a compact TOSA module that fits into the limited mounting space available inside the XFP and finally an introduction to the characteristics of the module that has been developed. In order to implement procedures to lower the power consumption the design for the operation of the EMwL device was altered from operating at 25 degrees Celsius to operating at 45 degrees Celsius, thereby reducing the burden on the thermo electronic cooler (TEC) that maintains the temperature of the EML at a constant level. Furthermore, in consideration for mounting the module into the XFP, the external dimensions of the package were made compatible with the XMD (10Gbit/s Miniature Device) - MSA[5]. A new single lens system was adopted to miniaturize the module dimensions and a flexible printed circuit board (FPC) was used for the terminals.

Device Structure and Design

The structure of the fabricated EMwL device is shown in **Figure 1**. The electro-absorption (EA) is monolithically integrated with laser diode (LD). Since the epitaxial growth of both EA and LD sections are performed separately using butt-joint technique, it is possible to optimize the core structure design of both sections individually, making 45 degrees Celsius operation easier. For waveguide structure, polyimide embedded ridge structure is incorporated, which is sutable for high-speed operation due to its low parasitic capacitance in comparison with conventional embedded structure.

A multi-quantum well distributed feedback-type (MQW-DFB) structure was adopted for the LD section and the quantum well layer of the MQW active layer as well as the barrier layer were optimized to make it possible to obtain large optical outputs even in high temperatures (45 degrees Celsius).

In the EA section the well layer and barrier layer of the MQW absorption layer were optimized to make it possible to obtain a high optical extinction ratio and low chirp by using an effect that enlarges the shift quantity at the edge of absorption at low voltages (Quantum-Confined Stark

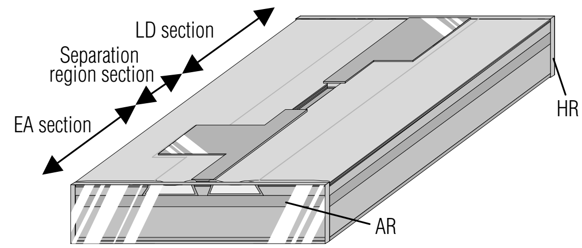


Fig. 1 Schematic structure of EMwL chip

Effect, QCSE effect).

The difference between the band gap wavelength of the EA and the laser wavelength of the LD (detuning) is important for operations at 45 degrees Celsius. It is necessary to set the detuning amount for the design of operations at 25 degrees Celsius, whereas the detuning for the design of operations at 45 degrees Celsius must be identical with consideration for the temperature dependency of the laser wavelength (0.1nm/degree Celsius) and the temperature dependency of the band gap wavelength of the EA (0.7 to 1nm/degree Celsius). With this device the band gap wavelength for the design of operations at 25 degrees Celsius in the EA section was set to approximately 15nm in the short wavelength side to obtain epitaxial growth conditions for an optimum detuning amount (**Figure 2**) at 45 degrees Celsius.

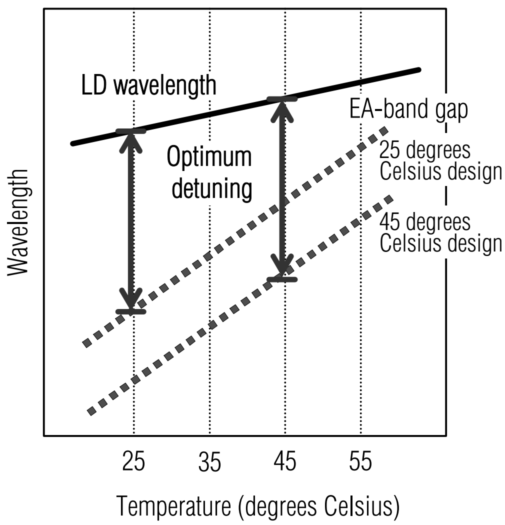


Fig. 2 Schematic diagram of temperature dependency of detuning

Configuration of TOSA Module

The configuration of the developed EMwL-TOSA module is shown in **Figure 3**, while the external appearance of the module is shown in **Photo 1**. An EMwL device for operations at 45 degrees Celsius, photo diode (PD) for the monitor, thermistor for stabilizing the temperature of the EMwL device, compact TEC and lens are all built into the package. An LC receptacle was used for the section that fits together with fiber, to accommodate the XFP. Furthermore, if the SC receptacle is adopted, the design can also be applied to the XENPAK.

The dimensions of the module package, excluding the FPC and receptacle section, are 9.5mm × 6mm × 6mm, a volume that is one-fifth the size of our conventional products, which is necessary to accommodate the XFP transponder module.

The notable aspects of the module design include (1) the design of a flexible substrate FPC, (2) the change of the optical coupling system from the conventional double-lens system to a single-lens system, due to the small size of the module and the adoption of a compact TEC.

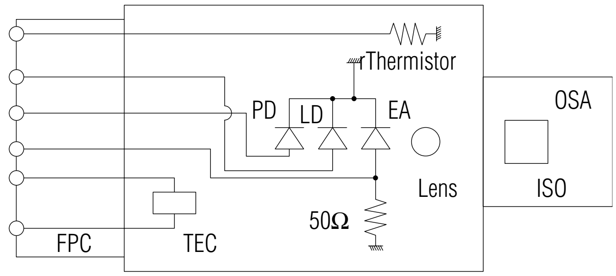


Fig. 3 Configuration of module

Photo 1 External appearance photograph of module

In conventional packages the electrode output of a package is provided by metal leads to the circuit board of the transponder, however, the FPC is used with the XMD-MSA. The characteristics of the FPC have an impact on the high-speed characteristics and therefore, it is particularly important to have the impedance matching without increasing the transmission losses on the signal lines. A favorable matching was obtained by optimizing the “width” of the signal lines.

The optical coupling efficiency of the conventional double-lens system is high, however, adoption of such a system is not possible due to the constraints of module size. In order to ensure that a high optical coupling efficiency is possible even with a single-lens system, an aspherical surface lens, which is optimum for this purpose, was adopted.

DC Characteristics

DC characteristics of the prototyped EMwL-TOSA are described. Typical current-optical output characteristics (I-L characteristics) are shown in **Figure 4**.

The threshold current (Ith) is 25mA at the LD section when the EMwL operating temperature is 45 degrees Celsius, while the optical output is 3.5mW (@80mA). These are adequate characteristics for obtaining an average optical output of 1mW, which is required by the 10Gbit/s transponder.

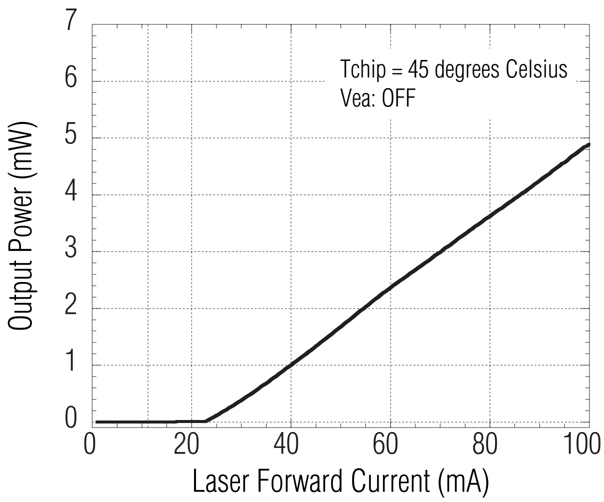


Fig. 4 I-L characteristics

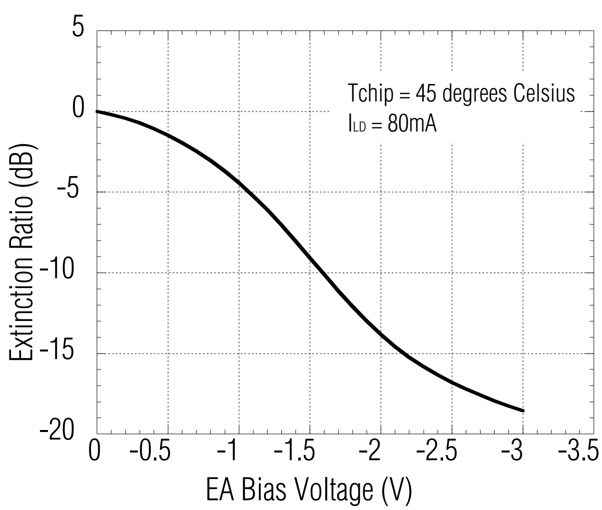


Fig. 5 Optical extinction characteristics

Figure 5 shows the reverse bias dependency of the optical extinction characteristics at the EA section when the LD current is constant (80mA). Optical extinction ratios of 14dB for 0V to -2V and 18dB for 0V to -3V have been obtained, which satisfy the dynamic optical extinction ratio of 10dB for 10Gbit/s of modulation voltage at 2Vpp.

Modulation and Transmission Characteristics

The SMF-50km transmission characteristics for 10Gbit/s-NRZ modulation of the EMwL-TOSA are described next. The transmission characteristics evaluation system used for this evaluation is shown in **Figure 6**. The bit rate was 9.95328Gbit/s of the SONET standard and the signal string was a pseudo-random binary sequence (PRBS) 2^{31}-1, which is made up of 31 rows of random signals. Moduration voltage applied to the EMwL-TOSA was set to 2Vpp. The operating

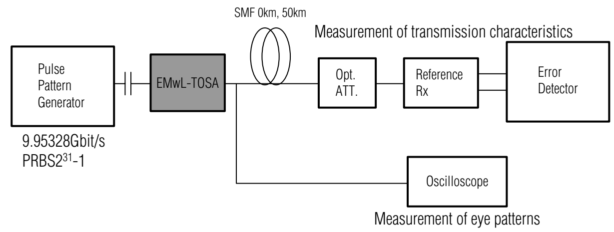


Fig. 6 Transmission characteristics evaluation system

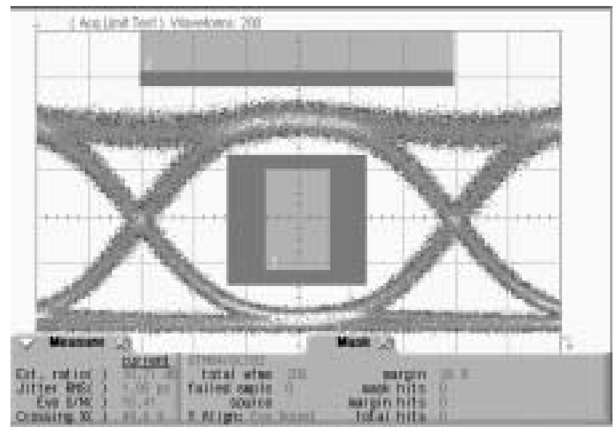


Fig. 7 (a): 0km transmission waveform

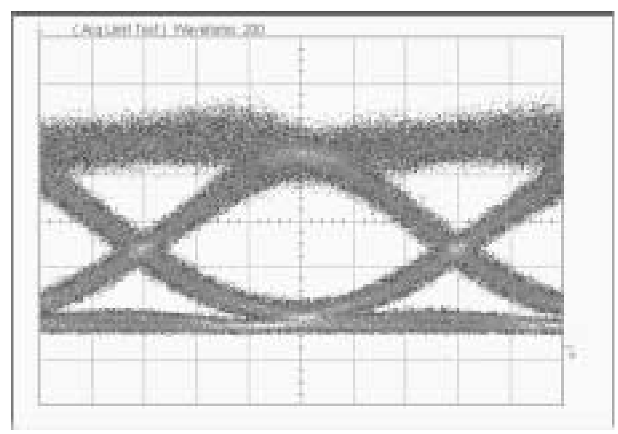
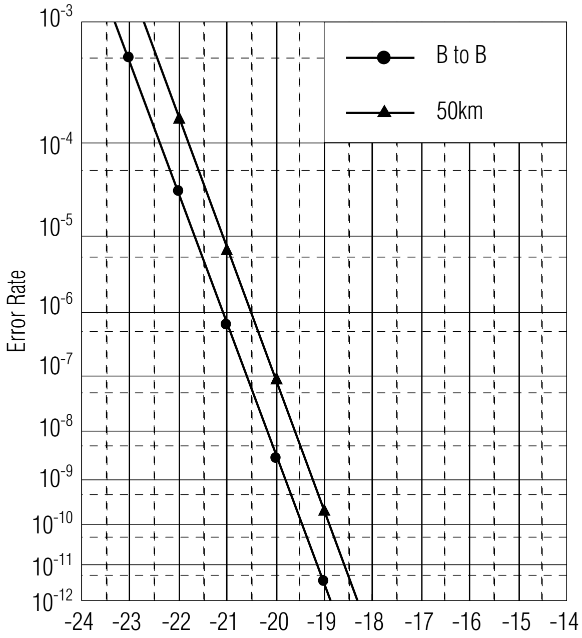


Fig. 7 (b): 50km transmission waveform

temperature of the EMwL was set to 45 degrees Celsius, while the module case temperature was set to 25 degrees Celsius and the LD drive current was set to 80mA.

Figure 7 (a) and (b) respectively indicate (a) Back-to-Back optical output waveforms (B-to-B: 0km transmission) and (b) optical output waveforms after a 50km transmission (dispersion of 800ps/nm). The Fourth Bessel-Thomson filter was used for the evaluation of the optical output waveforms.

The standard is clearly satisfied as the optical extinction ration of 10.7dB and average optical output of 0.5dBm have been obtained for the B-to-B optical outputs



Tchip = 45 degrees Celsius, ILD = 80mA, Bit rate = 9.95328Gbit/s.

Fig. 8 Bit error rate characteristics

with a mask hit margin of 30% even under conditions where the FPC is mounted. Further, the OC-192/STM-64 standardized by the ITU was selected for the transmission mask.

Figure 8 shows the bit error rate characteristics for B-to-B and 50km transmissions. The dispersion penalty (DP) when the error rate is 1×10^{-12} is approximately 0.6dB, which means that a favorable result was obtained by far exceeding the required specification of 1.5dB.

The temperature dependencies of the average optical output, optical extinction ratio and dispersion penalty are shown in **Table 1**. Favorable characteristics were obtained in a wide range from -5 degrees to 75 degrees Celsius. **Figure 9** shows the module power consumption when the package case temperature was changed from -5 degrees to 75 degrees Celsius. The temperature was controlled by the TEC to ensure that the EMwL operating temperature was 45 degrees Celsius. The figure shows that the electric power consumption of 1.0W or less was attained in a wide temperature range from -5 degrees to 75 degrees Celsius. The electric power consumption was kept to about one-third in comparison to conventional modules.

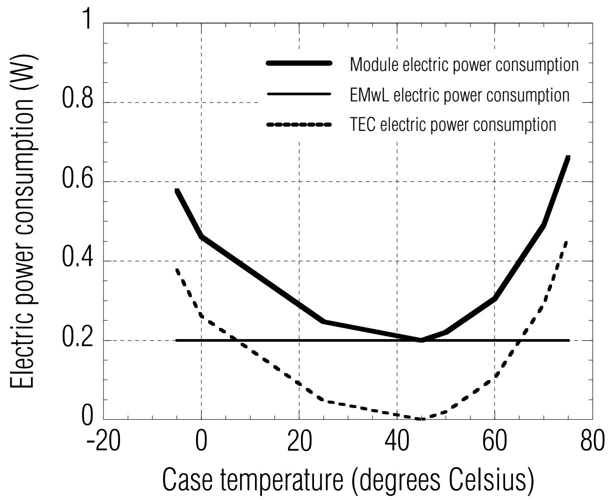
Table 1 Temperature characteristics of EMwL-TOSA

Parameter	Case temperature (degrees Celsius)		
	-5	25	75
Average optical output (dBm)	0.40	0.50	0.48
Optical extinction ratio (dB)	10.65	10.70	10.73
Dispersion penalty (dB)	0.62	0.59	0.63

Bit rate = 9.95328Gbit/s with constant Im value.

Conclusion

We succeeded in developing an EMwL-TOSA that complies with the XMD-MSA standard, which is used as the light source of the XFP, a compact 10Gbit/s transponder for 40km transmissions. It incorporates favorable characteristics with an average optical output of 0dBm or more, an optical extinction ratio of 10dB or more, a DP of 0.6dB and a maximum electrical power consumption of 1W or less for temperatures from -5 degrees to 75 degrees Celsius, which were achieved through the design of an EMwL device that operates at 45 degrees Celsius, the design of a single-lens optical coupling system that accommodates compact packages and the adoption of a compact TEC.



Tchip = 45 degrees Celsius, ILD = 80mA, Bit rate = 9.95328Gbit/s.

Fig. 9 Module electric power consumption

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