Wider - temperature - range CWDM 100Gbps EML Chip for Data Centers

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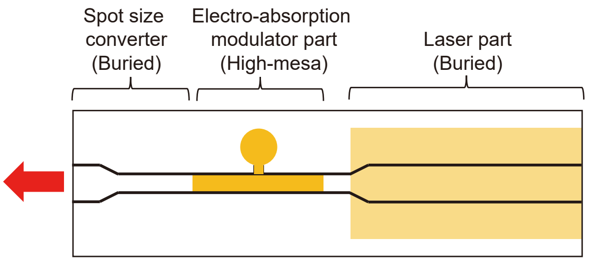
1. Introduction

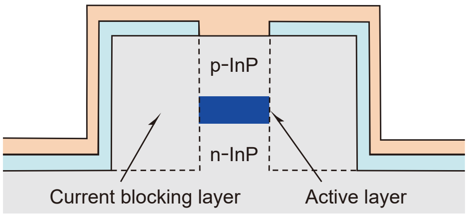
Along with the rapid increase in data communication capacity, data center network communication speeds and capacities continue to increase. Meanwhile, because power consumption is expanding greatly since many transmission devices are being driven and cooled, the demand for low power consumption is extremely strong. Furthermore, reducing the cost of transmission equipment is also extremely important. To handle these issues, using an Electro-absorption Modulated Laser (EML) that does not require temperature adjustment and operates at a wide range of temperatures is effective. A method to realize 400 Gbps data communication using a four-wavelength EML chip operating at 100 Gbps is enacted in an Multi Source Agreement (MSA)(1). The four wavelengths use a Coarse Wavelength Division Multiplexing (CWDM) standard in which the wavelength interval is 20 nm and each wavelength allowable width is 13 nm. Until now, Mitsubishi Electric has developed a single wavelength 50 Gbps EML with a chip temperature range of 25 - 75°C which operates without the need for temperature adjustment, but some data centers are now deemed to require an EML chip which operates at a wider temperature range of T_{LD} = 5 - 85°C with no temperature adjustment. In addition, for 400 Gbps transmission, operation of 100 Gbps per wavelength is required. We developed a semiconductor laser diode chip which is applied as a light source in optical transceivers for 400 Gbps optical fiber communication in data centers. 100 Gbps operation is available in temperatures ranging from 5 to 85°C due to optimized design parameters for the laser diode and modulator sections.

2. EML Chip Design

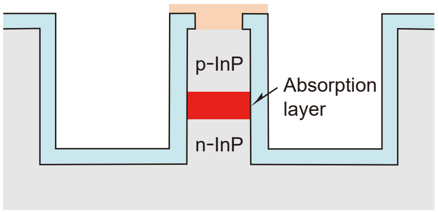
Figure 1 shows the EML device structure. For the laser part, we used a buried heterostructure (Fig. 1(b)) with excellent high temperature characteristics. For the electro-absorption modulator, we decided on a high mesa structure (Fig. 1(c)) possessing high extinction ratio and wide bandwidth characteristics, and the entire device employed our proprietary hybrid waveguide structure which integrated them monolithically (Fig. 1(a))(2). For the 100 Gbps high speed operation here, it is necessary to secure both wide bandwidth and extinction ratio through the reduced capacity of the Electro-Absorption Modulator (EAM). To reduce the capacity and obtain a wide bandwidth, it is desirable to shorten the length of the electro-absorption modulator, but there is a trade-off whereby if the electro-absorption modulator is shortened, the extinction ratio is reduced. The high mesa structure can increase the ratio of optical confinement in the Electro-Absorption (EA) layer compared to other ridge types or buried structures, so it is possible to obtain a high extinction ratio even with a short modulator length. For that reason, here we employed the high mesa structure which can ease the trade-off between the bandwidth and the extinction ratio. The electro-absorption modulator length was made even shorter than the conventional devices and the capacity was reduced, but the design of the extinction ratio that is part of the trade-off satisfied the FR4 standard(1) of the 100 G Lambda MSA. In addition, the fiber coupling efficiency of the single mode fiber was increased by installing a spot size converter following the EAM.



(a) Top view of entire chip



(b) Cross-sectional view of buried LD



(c) Cross-sectional view of high-mesa EAM

Fig. 1 Schematic structure of hybrid-waveguide EML

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Normally, the absorption layer is formed by a multiple quantum well. Turning the light on and off is controlled using a phenomenon (quantum confined stark effect) in which the light's absorption spectrum shifts to the long wavelength side due to the application of an electric field across the quantum well. As in Fig. 2, light from the laser part which is incident on the Electro-Absorption layer passes through when there is no electric field, but when an electric field is applied, the band gap narrows to allow light to be absorbed. Figure 3 shows an overview of the electro-absorption modulator's absorption spectrum. In the absence of an electric field, the absorption coefficient of the laser oscillator wavelength is small and so the light passes through with almost no absorption; but, when an electric field is applied, the light's absorption spectrum shifts to the long wavelength side due to the quantum confined stark effect, the absorption coefficient for the laser oscillator wavelength increases, and so the light is absorbed. The electro-absorption modulator's characteristics vary widely depending on the first peak (the exciton absorption peak) of the absorption spectrum in the absence of an electric field and on the laser oscillator wavelength detuning quantity (hereinafter, referred to as "⊿λ"). In the normal range, the smaller ⊿λ, the greater the extinction ratio and the lower the optical output, and the larger ⊿λ, the smaller the extinction ratio and the higher the optical output. To attain the desired characteristics across a broad temperature range, it is necessary to set this ⊿λ appropriately, but it is difficult to achieve the characteristics across a wide temperature range because the laser oscillator wavelength changes by around 0.1 nm/°C in response to the Electro-Absorption spectrum changing by around 0.5 nm/°C. At the low temperature side, ⊿λ becomes large, so it is necessary to increase the voltage applied to attain the desired extinction ratio, but if a large voltage is applied, there is the issue that the exciton absorption peak collapses and the extinction ratio is reduced. Here, these issues are resolved by devising the absorption layer's multiple quantum well design and designing ⊿λ appropriately. At the high temperature side, there is the issue that the laser's optical output is reduced, but even when operating at a high temperature of 85°C by devising a current blocking layer structure, we have ensured that the desired optical output can be attained.

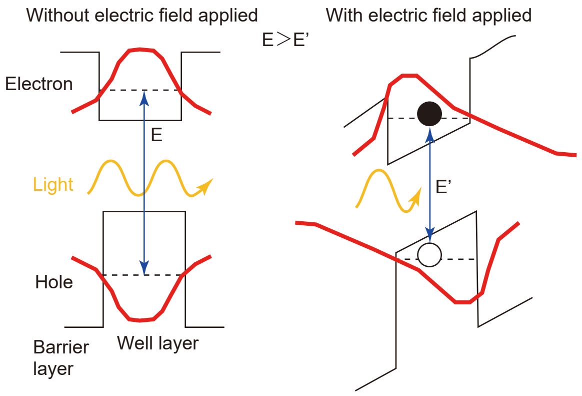

Fig. 2 Quantum confined Stark effect

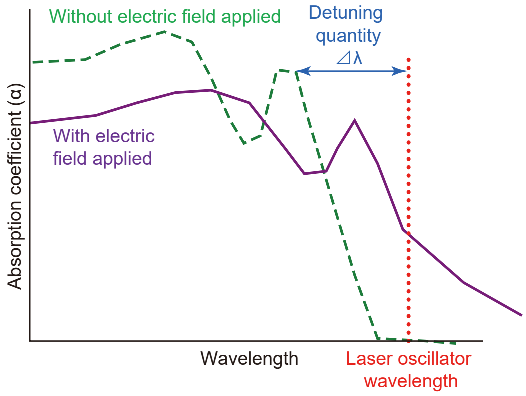

Fig. 3 Qualitative diagram of absorption spectra

3. EML Evaluation Result

Table 1 shows EML's target specification and evaluation results. Figure 4 shows the frequency response characteristics (S21) of the product developed here (1311 nm wavelength band chip). The measurements were made by contacting an Radio Frequency (RF) probe directly with the submount on which the chip was implemented. The operating conditions are: chip temperature T_{LD} = 5°C, LD current (I_{op}) =

Table 1 Product target specification and evaluation results

Item		Target specification	Evaluation result	
			5°C	85°C
Emission wavelength	L0	1264.5~1277.5nm	1267.5nm	1274.4nm
	L1	1284.5~1297.5nm	1287.4nm	1294.6nm
	L2	1304.5~1317.5nm	1307.5nm	1314.6nm
	L3	1324.5~1337.5nm	1327.4nm	1334.4nm
3dB cutoff frequency		≧35GHz	53GHz	48GHz
Optical modulation amplitude (chip facet)		≧5dBm	8.0~8.6dBm	5.3~7.6dBm
Extinction ratio		≧3.5dB	4.7~5.3dB	7.0~7.3dB
TDECQ		≦3.4dB	2.4~2.7dB	1.4~2.5dB

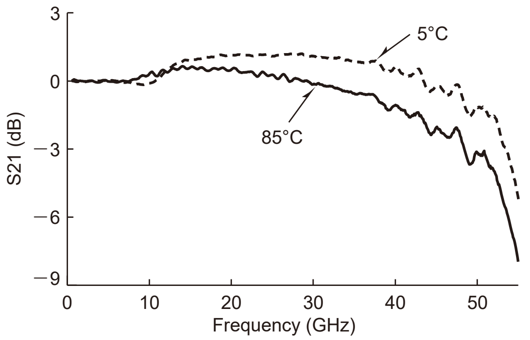

Fig. 4 Experimental result of frequency response

40 mA, EA offset voltage (V_{EA}) = –2.5 V, T_{LD} = 85°C, I_{op} = 120 mA, V_{EA}= –1.5 V. To operate the device at 100 Gbps, a passband of 35 GHz or more is required in general, and the product developed here attains a sufficient bandwidth for 100 Gbps transmission, with 53 GHz at 5°C and 48 GHz at 85°C.

Figure 5 shows the optical waveform during Back-To-Back (BTB) 53.125 Gbaud Pulse Amplitude Modulation -4 (PAM4) modulation operation for each wavelength band at chip temperatures of 5°C and 85°C. The measurements were made by contacting an RF probe directly with the submount on which the chip was implemented. The operating conditions are: baud rate of 53.125 Gbaud, EML modulation voltage amplitude (V_{pp}) of 1.0 V, I_{op} = 30 mA @ 5°C and 120 mA @ 85°C. The EA center bias (V_c) is as shown in the respective diagrams. In the chip end output, we attained an Optical Modulation Amplitude (OMA) of 8.0 - 8.6 dBm @ 5°C, and of 5.3 - 7.6 dBm @ 85°C, an extinction ratio during modulation (Ex) of 4.7 - 5.3 dB @ 5°C,7.0 - 7.3 dB @ 85°C, TDECQ 2.4 - 2.7 dB @ 5°C, and 1.4 - 2.5 dB @ 85°C, an so we achieved the target specification with a broad temperature range with a chip temperature of 5°C and 85°C.

4. Conclusion

We developed a CWDM 4-wavelength 100 Gbps EML chip operating at chip temperatures from 5 to 85°C, and we attained excellent characteristics that satisfied the target specification. Due to this, the optical transceiver, which is a system component in data centers, does not require a Thermo Electric Cooler (TEC) for temperature adjustment of the EML, though it was required with previous products, and can reduce the power consumption and cost in data centers.

References

(1) 100G Lambda MSA https://100glambda.com/

(2) Morita, Y., et al.: 1.3 μm 28 Gb/s EMLs with Hybrid Waveguide Structure for Low-Power-Consumption CFP2 Transceivers, Optical Fiber Communication Conference/National Fiber Optic Engineers Conference 2013, America, paper OTh4H.5 (2013)

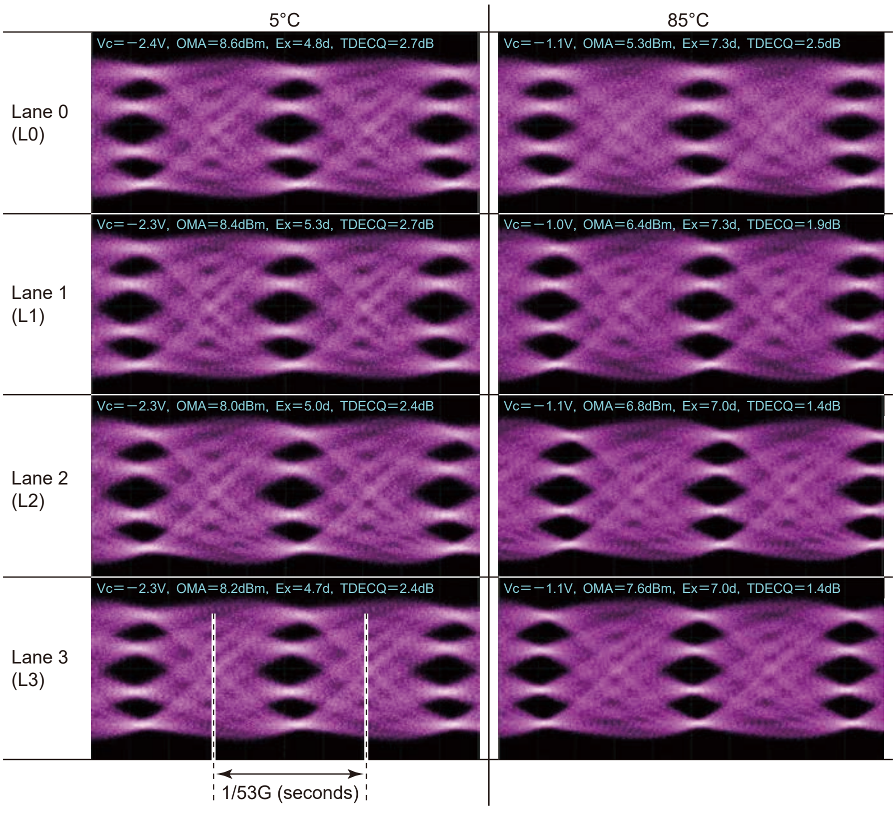

Fig. 5 53.125 Gbaud PAM4 eye diagrams