1.3-µm, 50-Gbit/s EADFB Lasers for 400GbE

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Abstract: We have developed 1.3-µm, 50-Gbit/s EADFB lasers for future 400Gbit Ethernet. 10- and 40-km SMF transmission with clear eye openings over 14-nm wavelength range under 50-Gbit/s operation are demonstrated for the first time.

OCIS codes: (140.5960) Semiconductor Laser; (230.3120) Integrated optics devices

1. Introduction

Due to the recent demands for huge data capacity in data communications systems originating from, for example, cloud computing and communications between data centers, the data rate required in local area networks (LANs) is becoming higher and higher. To meet this requirement, 100Gbit Ethernet (100GbE) was recently standardized in 2010 [1]. In 100GbE, a multi-lane LAN-WDM system is employed, in which 25-Gbit/s×4 lane signals with the 4.5-nm wavelength spacing around 1.3-µm are used. For the transmitter, four-lane light sources with the modulation speed of 25 Gbit/s are, therefore, required with their optical multiplexer. Directly modulated lasers (DMLs) and electroabsorption modulators integrated with DFB lasers (EADFB lasers) are promising candidates for the light sources and have been intensively studied [2]-[7]. DMLs are easy to fabricate and the power consumption is small; however, the extinction ratio (ER) is not so large. Although EADFB lasers need a more complex fabrication process and have larger power consumption than DMLs, large ER is easily obtained and their eye patterns are very clear.

The data rate of the next Ethernet will be 400-Gbit/s (400GbE). As in 100GbE, multi-lane transmission will be indispensable. If we want to transmit data over some tens of kilometers, the wavelength should be 1.3-µm as in 100GbE due to the low chromatic dispersion of SMF. Regarding the serial data rate, some configurations are possible, for example, 25-Gibt/s×16, 40-Gibt/s×10, and 50-Gibt/s×8. For 50-Gbit/s modulation, advanced modulation formats, such as differential quadrature phase shift keying (DQPSK) based on Mach-Zehnder modulators, are also possible together with on-off keying (OOK) format. Each configuration has its own pros and cons in terms of the size, cost, power consumption, and so on. Within these configurations, 50-Gbit/s OOK is one attractive candidate since the size of whole transmitter (including their optical multiplexer) will be medium compared with other candidates. For 50-Gbit/s OOK modulation, the use of DMLs seems to be difficult and EADFB lasers are promising for future 400GbE system.

In this work, we developed 1.3-µm, 50-Gbit/s EADFB lasers for 400GbE. The use of InGaAlAs-based quantum wells (QWs) for the electroabsorption modulators (EAMs) reduces the hole pile-up during the modulation due to their small valence band offset and thereby enables the high-speed modulation. We demonstrate 10- and 40-km SMF transmission with sufficient dynamic ER (DER) under 50-Gbit/s operation over 14-nm wavelength range with the clear eye openings. The presented results show that EADFB lasers will be key building blocks for the future 400GbE transmitter.

2. Device design and structure

For high-speed modulation with EAMs, the sweeping of holes in the valence band is a key factor. Therefore, material systems with small valence band offset, ΔE_v, are preferred since the holes generated by absorption of light are easily swept out, and hence there is less hole-pile-up during the modulation. Also, conduction band offset, ΔE_c, should be large to ensure large ER, which is important for long-distance transmission. Large ΔE_c provides better overlap between the conduction- and valence-band wavefunctions under bias voltage, making the absorption coefficient larger. We used InGaAlAs-based QW since it is the ideal material system to obtain small ΔE_v and large ΔE_c [8]. In addition, a tensile strained QW is used to obtain large ER [3],[4].

The structure of our EADFB lasers are similar to those reported in the past [3],[4]. The layer structures of the DFB laser and EAM were grown by metal-organic vapour-phase epitaxy (MOVPE). To optimize each structure separately, a butt-joint technique was used to connect them. A ridge-waveguide structure was employed to simplify the fabrication process. After the ridge-waveguide had been formed, to increase the modulation bandwidth, benzocyclobutene (BCB) was used to bury the side of the ridge and a small bonding pad was evaporated for the

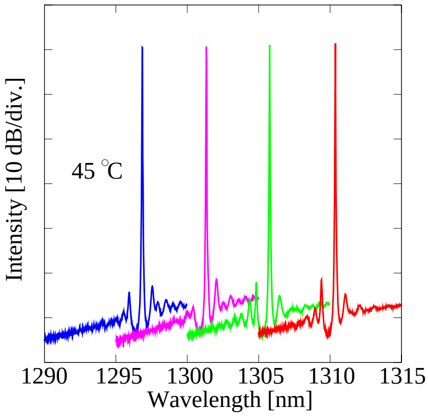


Fig.1. Lasing spectra

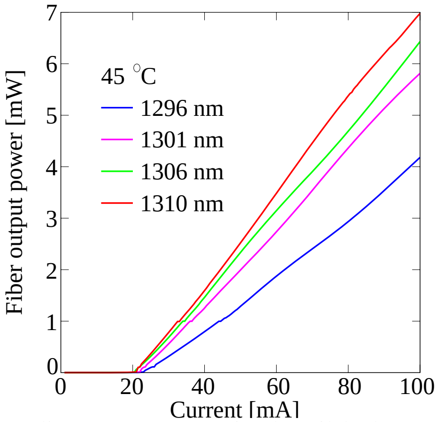


Fig. 2. Fiber output power as a function of injection current.

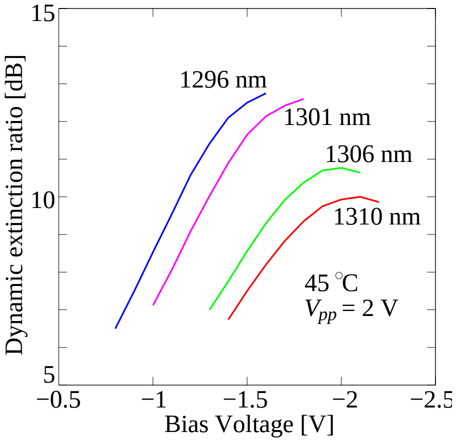


Fig.3. DER as a function of the bias voltage.

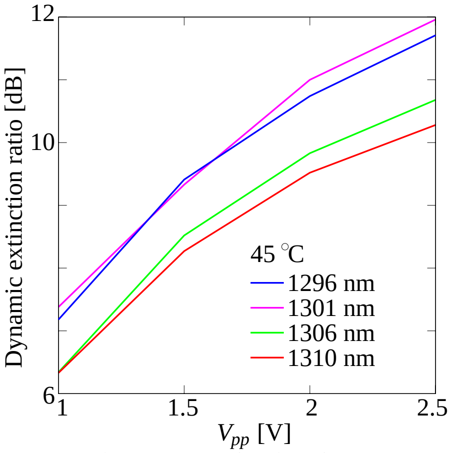


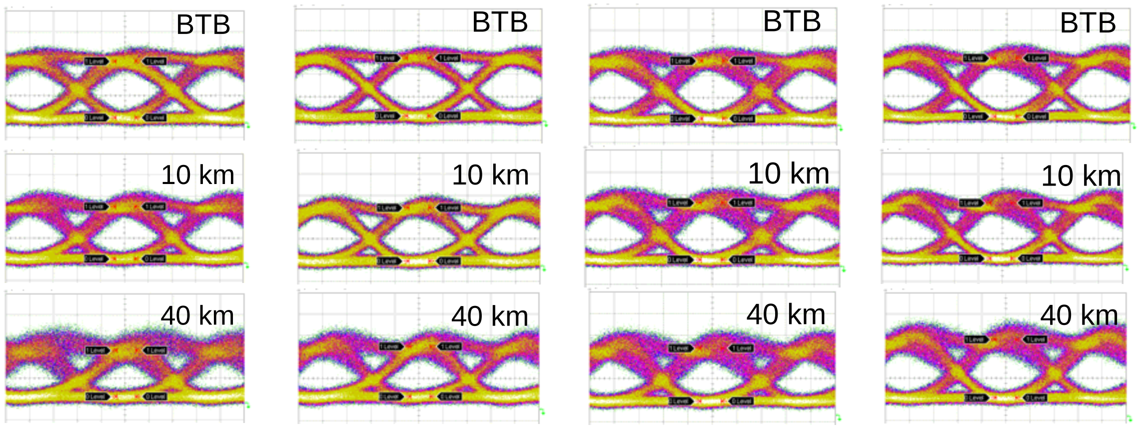
Fig. 4. DER as a function of V_{pp}.

EAM to increase the electrical bandwidth. A λ/4 shifted grating was used for the laser section, and the facets for the DFB laser and EAM were coated with anti-reflective films. Each chip was separately packaged in a butterfly module. All the chips were fabricated from the same wafer and have the same layer structure other than the grating pitch.

3. Device performance

Figure 1 shows the lasing spectra of our fabricated devices. All the measurements were done at 45 °C. Lasing occurs around 1.3 μm with 4.5-nm wavelength spacing. Since there is no information about the wavelength for 400GbE, we tentatively evaluated the characteristics of the devices for four LAN-WDM lanes used in 100GbE. The side-mode-suppression ratios are over 50-dB. Hereafter, we discriminate the devices by their lasing wavelengths. Figure 2 shows the output power of the modules as a function of injection current. The threshold currents are very uniform and about 20 mA. For the devices the lasing wavelengths of 1301, 1306, and 1310 nm, around 8-dBm output powers were obtained. Slight degradation in output power for the device with 1296 nm wavelength can be attributed to the larger coupling loss of the module.

Figure 3 shows the DER as a function of the bias voltage to the modulator for 50-Gbit/s modulation. The voltage swing, V_{pp}, is a constant value of 2 V. For shorter wavelength, the DER is larger since the detuning is small. By setting the bias voltage to the optimum value, DER larger than 9-dB is obtained over a 14-nm wavelength range with the same EAM structure, which is compatible with 100GbE (For example, 4- and 8-dB DERs are required for 10- and 40-km 100GbE). Another important issue for Ethernet transmitters is power consumption. To reduce the power consumption, reducing the voltage swing is effective. Figure 4 shows the DER of EADFB lasers as a function of V_{pp}. The bias voltages to the modulators are 1.24, 1.44, 1.7, and 1.85 V for the lasing wavelengths of 1296, 1301, 1306, and 1310 nm, respectively. With only 1-V voltage swing, DERs larger than 6-dB are obtained over a 14-nm



(a) (b) (c) (d)

Fig. 5. 50-Gbit/s eye diagrams.

wavelength range. Since a tensile-strained InGaAlAs QW provides a large ER and steep extinction curve, it is suitable for low-voltage operation.

Using the devices, we performed a transmission experiment. V_{pp} for EAMs was 2 V. Non-return to zero (NRZ), 2^{31}-1 pseudo-random bit stream (PRBS) signal was used. The modulation speed for each EADFB laser was 50-Gbit/s. Figures 5 (a)-(d) show eye-diagrams for BTB configuration, and after 10- and 40-km SMF transmission. Even after the transmission, the eyes are still clear and open, indicating the applicability of our EADFB lasers for 400GbE. It should be noted that if the wavelength spacing used in 400GbE is 400 GHz (half of 100GbE), expanding the operation to eight wavelengths is straight forward since presented devices cover 14-nm wavelength range for 50-Gbit/s operation.

4. Conclusion

We developed 50-Gbit/s, 1.3-µm EADFB lasers for 400GbE and demonstrated 10- and 40-km SMF transmissions under 50-Gbit/s operation over 14-nm wavelength range with clear eye openings for the first time. The DERs for four lanes are over 9 dB and 6 dB for V_{pp} = 2 and 1 V, showing the possibility for low-driving voltage operation. The proposed devices will be the key building blocks for future 400GbE transceiver.

5. References

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