EAM-integrated DBR-LD with 16-channel and 100-Gbps/λ PAM-4 modulation

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Abstract: An EAM-integrated DBR-LD is reported using a novel waveguide structure for efficient wavelength tuning, and a 16-channel 100-Gbps/λ PAM-4 operation with a grid of 150 GHz near 1290 nm are achieved successfully.

1. Introduction

Wavelength-tunable lasers also capable of modulating channel signals in wavelength division multiplexing (WDM) systems have drawn considerable attention in recent years [1,2]. In particular, they have can potentially offer some cost and convenience advantages like an inventory reduction and an auxiliary management and channel control when they are utilized as a replacement for wavelength-fixed sources in the networks which are very critical in price, operational management, and network scalability issues (i.e., mobile front-haul (MFH) of radio access networks) [3,4]. An electro-absorption modulator (EAM)-integrated distributed Bragg reflector-laser diode (DBR-LD) with a single grating mirror is one of the most suitable candidates in these networks [5] compared with a directly modulated LD, it can be easily upgraded in modulation rate and format owing to its higher bandwidth and more linear electro-optic (EO) response, respectively. As for its wavelength tuning, many research groups have used a current injection into the core layer [6] and/or a thin-film heater [7,8] as a tuning element. While the former has a limited tuning range and an electrical crosstalk-coupling between the DBR and other sections, the latter provides a wide tuning range, but must improve the tuning efficiency.

Recently we reported an EAM-integrated DBR-LD supporting a 56-Gb/s pulse amplitude modulation level four (PAM-4) signal per wavelength and a 16 channel operation at a spacing of 150 GHz near 1290 nm [9]. In this device, an optical waveguide structure which can effectively confine the heat produced by the heater in the DBR section was introduced firstly, showing improvement of more than three times in tuning range. The waveguide structure was fabricated to have a reverse-mesa (RM) shape by using an InP selective wet-etchant [10,11] without any sacrificial layers. From this result, we believe the EAM-integrated DBR-LD can be effectively used as a low-cost, a high energy-efficient, and easy-to-make tunable source for the next-generation MFH systems based on multichannel WDM interface. For the EAM-integrated DBR-LD with the RM structure, we recently improved the bandwidth of EAM without reducing its length. In this paper, we report a 16-channel operation at a rate of 100 Gb/s PAM-4 with a module including the fabricated LD chip.

2. Device structure

Figure 1 show a schematic view of the fabricated EAM integrated DBR-LD comprised of a gain, a phase control (PC), a DBR, an EAM, and a spot size converter (SSC). Under InGaAsP material system, the multiple quantum wells of gain and EAM sections were designed for their quantized energy-level differences to have 1.3 and 1.24 μm, respectively, and the bandgap wavelengths of passive core and grating layers were 1.15 and 1.2 μm, respectively.

In this device, the waveguide of the gain, PC, and DBR sections were made in a form of the etched-mesa buried-hetero-structure (EMBH) [12] and that of the EAM was in a shape of the deep ridge. In the work, the width of EAM waveguide was reduced to decrease its RC time constant while its length was kept the same as that of previous work [8]. After the waveguide fabrication and benzo-cyclobutene (BCB) processes, Pt-based thin film heaters were implemented on top of the waveguides in the tuning sections, DBR and PC, and then the RM structure was fabricated with a SiNx etching mask below the EMBH by using a Br-based InP selective wet etchant which could produce waveguide with (111)A facet sidewalls when the EMBH pattern was formed in the [011] orthogonal direction on an (100) InP.

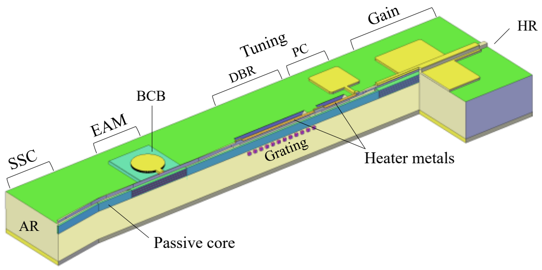

Fig. 1. Schematic view of the EAM-integrated DBR LD

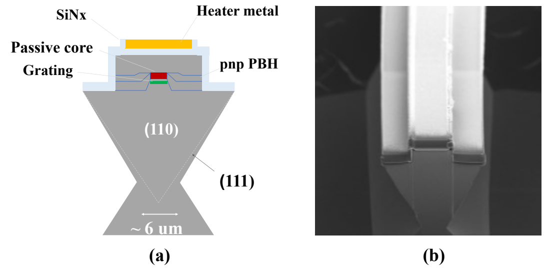

Fig. 2. (a) Schematic view and (b) SEM picture of the fabricated waveguide in the DBR section

Figure 2 show a schematic cross-sectional view and a corresponding scanning electron microscope (SEM) picture of the RM structure in the DBR section. In the etching test, the lateral and vertical etch rates of the etchant were obtained to about 0.65 μm/min and 1.5 μm/min, respectively. After the chip fabrication, front and rear facets are anti-reflection (AR)- and high reflection (HR)-coated to suppress the residual reflection from the output facet and to enhance the output power, respectively.

3. Experimental results of EAM-integrated DBR-LD

The fabricated LD chip was mounted on the chip-on-carrier (CoC) with a 50 Ω-matching resistor and electrical lines including a high-speed transmission line (i.e., grounded coplanar waveguide) and control lines, after wire-bonded, and tested under the thermos-electric cooler (TEC) temperature of 40 °C. A typical threshold current and a slope efficiency of the chip are measured to be about 12 mA and about 0.11 W/A at a current of 50mA, respectively. A 3 dB modulation bandwidth was obtained to be more than 40 GHz at a bias voltage of -1 V after being calibrated with the photodiode effect from the measured electro-optic (EO) response.

Figure 3 show superimposed tuning spectra of 16 channels with a channel grid of 150 GHz under 100 Gbps PAM-4 operation. In this measurement, each channel wavelength was set by adjusting the DBR and PC currents (i.e., coarse and fine tunings) at a constant gain current and its peak power variation was obtained to be within less than 1.7 dB. All channels showed dynamic single mode (DSM) operations with the side mode suppression ratios (SMSRs) of over 40 dB, which gradually decrease with the increase of channel number. For this result, the degradation of SMSR can be though to be related to the longitudinal temperature non-uniformity which makes the Bragg wavelength deviated from the lasing condition across the cavity.

Figure 4 show the normalized output power as a function of the EAM bias voltage, namely static extinction ratio (ER), for several channels. As the channel increases, the ER appears to be slowly decreasing with the reverse-bias. We think this is mainly due to the increase of the detuning between the lasing wavelength and EAM absorption peak wavelength as well as slight reduction of efficiency in quantum confine stark effect. In the experiment, a bias voltage was adjusted from -1.8 to -2.3 V with the increase of channel number in order to make the EAM operated at a linear region in the ER curve. The 100 Gbps PAM-4 electrical signal with the pseudorandom binary sequence (PRBS) pattern of 2^{15}-1 was generated using a pulse pattern generator (Anritsu MU196020A), and amplified by a broad band amplifier.

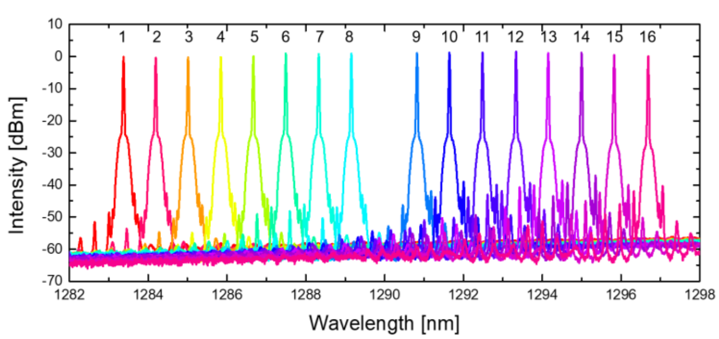

Fig. 3 Superimposed tuning spectra for 16 channels under 100Gbps PAM-4 operation.

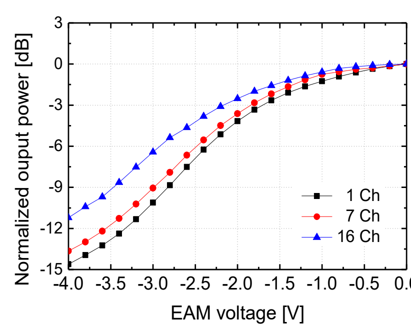

Fig. 4 ER curve for ch. 1, 7, and 16.

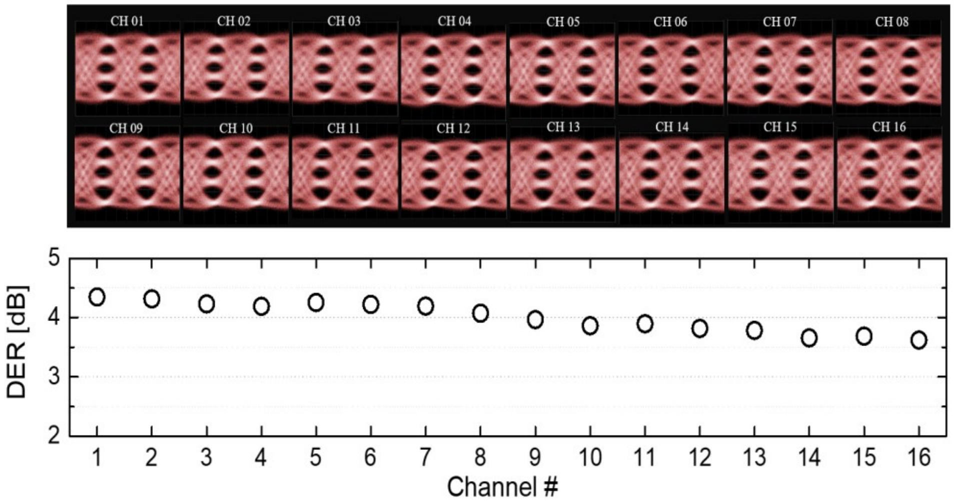

Fig. 5. 16 channel 100 Gbps PAM-4 eye patterns (upper) and outer DERs at 2Vpp (lower)

The signal was combined with a DC bias through a Bias-Tee, and applied to a transmission line on a CoC through a RF probe. An optical signal from the DBR-EAM LD was directly received by a digital communication analyzer (DCA, Keysight N1030A). Figure 5 shows the measured 16 channel 100 Gbps PAM-4 eye patterns and their outer dynamic ER (DER). The receiving filter bandwidth of 37.3 GHz was used in this measurement and the modulated peak-to-peak voltage (Vpp) of the EAM was set to be 2 V. The measured eye patterns showed clear eye openings and DERs of more than 3.5 dB for all channels.

4. Conclusion

The EAM-integrated DBR laser didoes with the RM structure for high tuning efficiency was developed, and stable DSM spectra of 16 channels with the grid of 150 GHz under the 100 Gbps PAM-4 modulation were obtained successfully. Based on these results, we conclude that the EAM-integrated DBR-LD can be used as a promising light source for the next generation MFH systems.

5. Acknowledgements

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