Clear eye opening 1.3µm-25 / 43Gbps EML with novel tensile-strained asymmetric QW absorption layer

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Abstract *We demonstrate 1.3µm-25/43Gbps EML with novel tensile-strained asymmetric quantum well absorption layer. Clear eye opening was achieved under high output power condition (>+5dBm) both before / after 10km normal SMF transmission up to 43Gbps.*

Introduction

Electro-absorption modulator (EAM) integrated distributed feedback laser diode (DFB-LD) (EML) is a key component for next generation optical transmission systems such as 100-Gigabit Ethernet[1-3] (100GbE: 4x 25Gbps on 4 wavelength), because of its advantages such as high speed and low chirp characteristics, and compactness to use in optical transponder. High speed and low chirp operation are needed under high output power in 1.3µm wavelength, and the key to achieve these requirements lies in design of the quantum well (QW) absorption layer of EAM, which determines extinction ratio, chirp, and their tolerance under high output power condition.

In this paper, we describe a 1.3µm-25 / 43Gbps EML with novel tensile-strained asymmetric QW absorption layer. Clear eye opening and high extinction ratio (>8dB) was achieved under high output power condition (>+5dBm) both before / after 10km normal SMF transmission up to 43Gbps.

Device fabrication and design

Fig.1 shows the schematic drawing of the 1.3µm-25 / 43Gbps EML. The device consists of a 465µm-long InGaAsP DFB-LD, a 120µm-long InGaAsP EAM, and an electrical isolation region. The entire layer structure was grown by metalorganic chemical vapour deposition (MOCVD) technique on n-type InP substrate. We have already reported the improvement of 40Gbps eye opening and chirp characteristics by employing InGaAsP/InGaAsP tensile-strained asymmetric QW absorption layer[4,5] , and we also applied this method to the 1.3µm-25 / 43Gbps EML.

Fig. 2 (a) shows the excitonic properties of asymmetric QW EAM. Insertion of the low-barrier layer on the n-type side of the well layer makes the wavefunctions of the holes more localized to the p-type side of the well layer, and this results in fast quenching of an absorption peak of exciton absorption and fast red shift of the absorption edge. As shown in Fig. 2 (b), these behaviours enhance negative contribution to the change of the refractive index of the EAM absorption layer, thus the small chirp operation can be achieved without any penalty on extinction ratio.

In addition, enhanced contribution of electron light-hole exciton absorption due to tensile-strain in the well layers reduces effective lifetime of the photo-generated holes. In general, frequency response and chirp characteristics of EAM's are deteriorated by photo-generated electric charges (usually holes) piled up in QW's. They cause screening of electric field in QW's. To overcome these problems, it is effective to reduce the lifetime of photo-generated holes and thus to enhance sweep out of the photo-generated holes from QW. As mentioned in the reference[4,5], the tensile-strained asymmetric QW absorption layer will be a good candidate to overcome these problems.

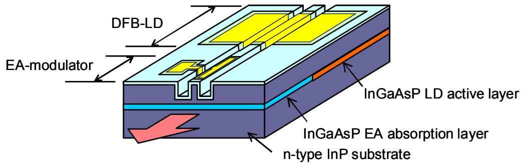

Fig. 1: Schematic drawing of 1.3µm-25 / 43Gbps EML

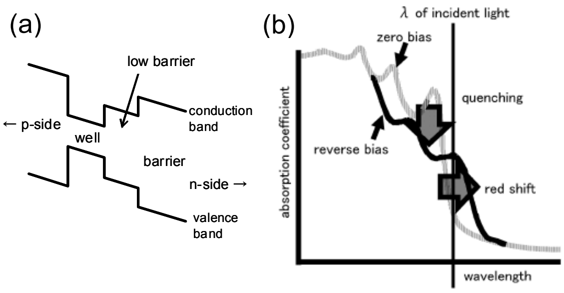

Fig. 2: (a) Band diagram of asymmetric QW absorption layer used for our 1.3µm-25 / 43Gbps EML (left)
(b) Schematic model of the absorption spectrum of a small-chirp EAM (right)

Frequency response and waveforms

We compared the frequency response (S_{21}) between tensile-strained asymmetric QW EAM and conventional compressive-strained symmetric QW EAM. Fig. 3 (a) shows the frequency response of the tensile-strained asymmetric QW EAM at several conditions. Output power of the EML at EA bias voltage=0V was set to +8dBm, and then EA bias voltage was applied to extinguish the output power to +5dBm, +3dBm and +1dBm, respectively. As shown in Fig. 3 (a), the 3dB-down bandwidth was about 40GHz and it shows no obvious deterioration between each EA bias condition.

On the other hand, Fig. 3 (b) shows the frequency response of the conventional compressive-strained symmetric QW EAM. The condition of the measurement was same as described in Fig. 3 (a). As

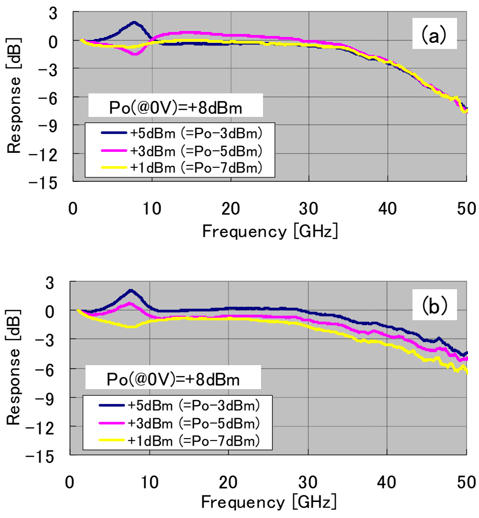

Fig. 3: (a) Frequency response of the tensile-strained asymmetric QW EML (above)
(b) Frequency response of the conventional compressive-strained symmetric QW EML (below)

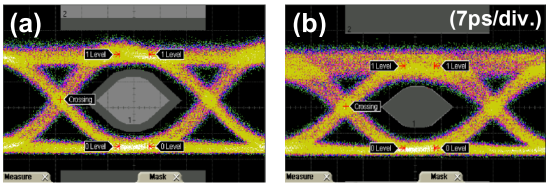

Fig. 4: Optical waveform with 4th Bessel filter of
(a) the tensile-strained asymmetric QW EML (left)
(b) the compressive-strained symmetric QW EML (right)

shown in Fig. 3 (b), the 3dB-down bandwidth deteriorated as the optical output decreased (*i.e.*, the amount of extinction of light increased, therefore the photo-generated carrier increased). The roll-off shown in high extinction condition is attributed to charge pile up effect of holes.

Fig. 4 (a) shows an optical waveform of tensile-strained asymmetric QW EML at the condition that corresponds to the condition "$P_{out\_average}$=+3dBm" shown in Fig. 3 (a). The EML was modulated with a 25.78125Gbps non-return-to-zero (NRZ) pseudo-random bit sequence (PRBS) signal with a length of 2^{31}-1, and the EML chip temperature was 40 deg C. Clear eye opening and high mask margin (=34%) were observed. In contrast, Fig. 4 (b) shows an optical waveform of conventional compressive-strained symmetric QW EML at the condition that corresponds to the condition "$P_{out\_average}$=+3dBm" shown in Fig. 3 (b). Extinction ratio was almost the same as shown in Fig. 4 (a), but obvious deterioration of the waveform was observed. The result shows good agreement with the deterioration of the frequency response.

25 / 43Gbps operation

We have demonstrated 25Gbps / 43Gbps operation using tensile-strained asymmetric QW EML. Fig. 5 (a) shows the back-to-back optical waveform modulated with 25.78125Gbps NRZ 2^{31}-1 PRBS signal. Lasing wavelength was 1308.3nm at EML chip temperature was 40 deg C. Modulated output average power at chip facet was +5.1dBm, dynamic extinction ratio was 8.3dB and mask margin was 50%. Fig. 5 (b) shows the waveform after 10km normal SMF transmission. Clear eye opening was achieved both before / after 10km normal SMF transmission.

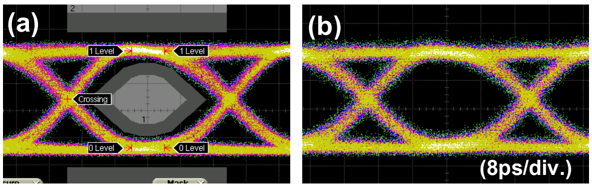

Fig. 5: 25.78125Gbps modulated waveform of the tensile-strained asymmetric QW EML with 4th Bessel filter
(a) Back-to-back (left)
(b) After 10km SMF transmission (right)

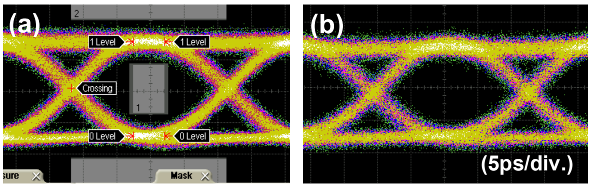

Fig. 6: 43.01842Gbps modulated waveform of the tensile-strained asymmetric QW EML with 4th Bessel filter
(a) Back-to-back (left)
(b) After 10km SMF transmission (right)

We have also demonstrated 43Gbps operation. Fig. 6(a) shows the back-to-back optical waveform (of a different chip described in Fig. 5) modulated with 43.01842Gbps NRZ 2^{31}-1 PRBS signal. Lasing wavelength was1308.3 nm at EML chip temperature was 40 deg C. Modulated output average power at chip facet was +6.1dBm, dynamic extinction ratio was 8.1dB and mask margin was 6%. Fig. 6(b) shows the waveform after 10km normal SMF transmission. Clear eye opening was also achieved up to 43Gbps even in high output power condition.

Conclusions

A 1.3μm-25 / 43Gbps EML with novel tensile-strained asymmetric QW absorption layer was demonstrated. Clear eye opening and high extinction ratio (>8dB) was achieved under high output power condition (>+5dBm) both before / after 10km normal SMF transmission up to 43Gbps. These results indicate that our 1.3μm-25 / 43Gbps EML is applicable in 100GbE (4x25G) system and 40/43G SONET/SDH/OTN systems.

Acknowledgements

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