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10 Gb/s REAM-SOA for Low Cost WDM-PON

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Abstract: We demonstrated 10.7 Gb/s REAM-SOA using simplified fabrication process. Good performance at 10.7 Gb/s was obtained with an extinction ratio of > 9 dB and a power penalty of < 1 dB up to 20 km transmission over a 40 nm spectral range.

OCIS codes: (250.5300) Photonic integrated circuits; (060.4510) Optical communications.

1. Introduction

The demand for high bit-rate access networks rapidly grows due to new high bandwidth services. The wavelength division multiplexed passive optical networks (WDM-PONs) is one of promising candidates for the future access networks thanks to its very large capacity, strong security, and high flexibility [1]. However, WDM can be relatively expensive to implement owing to the cost of the specified wavelength sources. In respect to cost effectiveness, the development of colorless source is a key issue in WDM-PON technologies to reduce the system cost dramatically. Various solutions have been proposed for low-speed (≤2.5 Gb/s) colorless source such as injection locked Fabry-Perot laser diodes (FP-LDs) [2] and reflective semiconductor optical amplifiers (RSOAs) [3]. However, future access networks will need higher speed colorless source (10 Gb/s) as bandwidth demand grows. Recently, semi-insulating buried heterostructure (SI-BH) reflective electroabsorption modulator monolithically integrated with semiconductor optical amplifier (REAM-SOA) devices have been successfully achieved at 10 Gb/s [4,5]. Generally, the SI-BH type REAM-SOA is fabricated using four-step metal-organic chemical vapor deposition (MOCVD) growth [5]. In order to decrease the transmitter cost, fabrication process of device should be simplified.

In this work, we demonstrated an integration scheme of a buried ridge stripe (BRS) SOA and a deep ridge modulator using three-step MOCVD. To reduce the coupling loss caused by the lateral misalignment and mode mismatch between BRS and deep ridge waveguide, we have introduced a taper-jointed region at the interface between BRS SOA and deep ridge modulator. In fabricated device, good performance at 10.7 Gbps was obtained with an extinction ratio of > 9 dB and a power penalty of < 1 dB at a 10^{-9} bit error rate (BER) up to 20 km transmission over a 40 nm spectral range.

2. Device Fabrication

Photograph of a fabricated REAM-SOA chip is shown in Fig. 1(a). The length of the REAM is 75 μm. The 1030 μm-long SOA includes an integrated bended waveguide and spot-size converter (SSC) to minimize facet reflection and obtain efficient coupling to a lensed fiber. The SSC was evanescently coupled using double core structure [3]. The device was fabricated by three-step MOCVD. The REAM active layer was composed of eight tensile strained InGaAsP (λ=1.52 μm, ε=-0.38%) wells and lattice-matched InGaAsP barriers (λ=1.15 μm), sandwiched between 0.1 um thick InGaAsP (λ_g=1.15 μm) separated confinement heterostructure (SCH) layers. On the bottom of the lower SCH, a 0.6 μm thick n-doped InP spacer layer and 0.1 um thick InGaAsP (λ_g=1.15 μm) spot size converter (SSC) layer were grown. The multi-quantum well (MQW) has a room temperature photoluminescence (PL) peak at 1470 nm. The butt-coupled SOA active layer consisted of a tensile-strained 0.15 μm thick InGaAsP (λ_g=1.55 μm, ε=-0.2%) layer, sandwiched between 0.1 um thick InGaAsP (λ_g=1.15 μm) separated confinement heterostructure (SCH) layers. After a 1 μm-wide mesa of SOA region was formed by using reactive ion etching (RIE) and slightly wet etching, the wafer was buried by p-InP clad and p^+-InGaAs ohmic layer. And then, a 2 μm-wide mesa of deep ridge REAM region was formed by using RIE etching. As shown in Fig. 1(b), a 150 μm-long taper-jointed region at the interface between BRS SOA and deep ridge modulator was introduced to reduce the coupling loss caused by the lateral misalignment and mode mismatch between BRS SOA and deep ridge modulator, where the width of deep ridge waveguide was varied from 2 μm to 5 μm. A 3 μm-thick polyimide was spin-coated to minimize the capacitance of the bonding pad. The current blocking of BRS SOA and isolation between SOA and REAM were achieved by single-step O^+ ion implantation. The isolation resistance between the SOA and REAM region was measured to be 36.8 kΩ. The rear facet was coated with high reflection (HR) coating, whereas the residual facet reflectivity of front facet with anti-reflection (AR) coating is estimated to be ~ 10^{-5}. The device was sub-packaged with a 50 Ω matching circuit in a temperature controlled mode for static and dynamic properties. All measurements were carried out at 25°C.

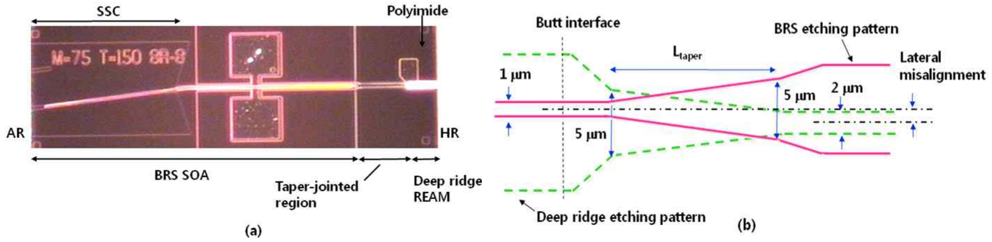

Fig. 1. Photograph of a fabricated REAM-SOA chip (a) and schematic view of taper-jointed region at the interface between BRS SOA and deep ridge modulator (b).

3. Results and Discussion

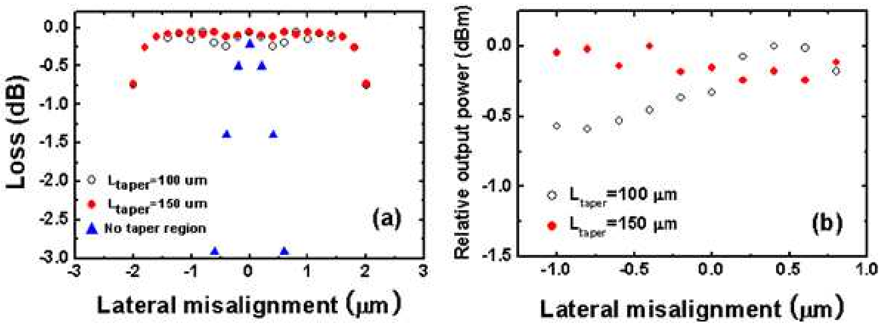

Fig. 2. Calculated loss (a) and relative output power (b) versus intentional lateral misalignment with different lengths of taper-jointed region (L_{taper}).

The deep ridge etching step after formation of SOA waveguide leads to a lateral misalignment. In order to know the lateral misalignment tolerance of taper-jointed region, deep ridge REAM was integrated with BRS SOA without bending waveguide and SSC. An intentional misalignment between two waveguides was varied by 0.2 µm step. Output power of REAM-SOAs without bending waveguide and SSC were measured at 100 mA of SOA. Fig. 2 shows calculated loss and relative output power versus intentional lateral misalignment with different lengths of taper-jointed region (L_{taper}). The calculated loss was simulated using 3-dimensional BPM (beam propagation method, supplied by RSoft Co.). As shown in Fig. 2(a), calculated lateral misalignment tolerance below 0.5 dB excess loss is about ± 1.9 µm in 100 µm-long and 150 µm-long taper-jointed region. However, calculated lateral misalignment tolerance below 0.5 dB excess loss is about ± 0.2 µm in no taper-jointed region. As shown in Fig. 2(b), in in 150 µm-long taper-jointed region, measured lateral misalignment tolerance within 0.5 dB output power variation is larger than ± 1 µm.

The 3-dB ASE bandwidth of REAM-SOA is ~30 nm and ripple is ~ 1 dB at 150 mA of SOA, which indicates the low reflectivity of SOA facet, butt-coupled interface and BRS-deep ridge transition region. The fiber-to-fiber gain of REAM-SOA is ~11.7 dB at 150 mA of SOA. The saturation input power is about -15 dBm. Compared to fiber-to-fiber gain of reflective SOA, the loss of REAM with 150 µm-long taper-jointed region is estimated to be ~7 dB. Fig. 3 shows the output power of the REAM-SOA as a function of reverse biases of REAM. The injection current of SOA was 100 mA. The wavelength and power of input beam was 1550 nm and 0 dBm, respectively. Although the operating voltage of REAM is relatively large due to large detuning (~80 nm) between SOA and modulator, a maximum (minimum) static extinction ratio (ER) is 21 dB (15 dB).

All dynamic measurements were performed as a following. The seed light of continuous beam (CW) light from tunable laser passed through REAM-SOA via variable optical attenuator (VOA), polarization controller (PC), and circulator. The modulation speed was 10.709 Gb/s with pseudorandom data of a 2^7-1 nonreturn-to-zero bit sequence. Dynamic properties of REAM-SOA was little dependent on pattern length. Modulated output beam passed through an erbium-doped fiber amplifier (EDFA) and band-pass filter before a receiver and sampling oscilloscope. The DC bias and AC modulation amplitude of REAM was fixed at -3 V and 4.3 V_{pp}, respectively. The SOA current was adjusted in the range 85~100 mA. The input power was fixed at 0 dBm. As shown in Fig. 4, good performance at

10.7 Gb/s was obtained with an extinction ratio of > 10 dB and a power penalty of < 1 dB at a 10^{-9} bit error rate (BER) up to 20 km transmission over a spectral range of 40 nm.

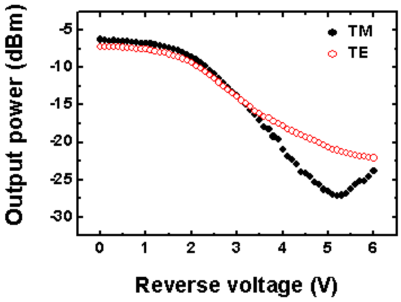

Fig.3. Output power of the REAM-SOA as a function of reverse biases of REAM. The SOA current was 100 mA.

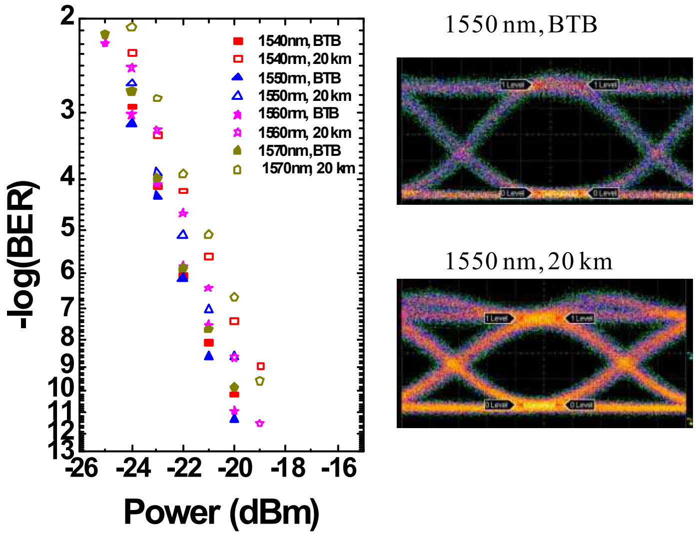

Fig.4. Output power of the REAM-SOA as a function of reverse biases of REAM. The SOA current was 100 mA. The inset shows eye patterns.

4. Conclusion

We fabricated monolithic integration of deep ridge REAM and BRS SOA using three-step MOCVD growth and RIE process. In spite of nonself-aligned processing, a relatively wide tolerance for misalignment in the fabrication process was obtained by introducing a taper-jointed region, which should make the fabrication process more reproducible. Good performance at 10.7 Gb/s was obtained with an extinction ratio of > 9 dB and a power penalty of < 1 dB at a 10^{-9} bit error rate (BER) up to 20 km transmission over a spectral range of 40 nm.

References

[1] G. Talli, and P. D. Townsend, "Hybrid DWDM-TDM long-reach PON for next-generation optical access," J. Lightwave Technol. **24**, 2827-2834 (2006)

[2] X. Cheng, Y. J. Wen, Y. Dong, Z. Xu, X. Shao, Y. Wang, and C. Lu, "Optimization of spectrum-sliced ASE source for injection-locking a Fabry-Perot laser diode," IEEE Photon. Technol. Lett. **18**, 1961-1963 (2006).

[3]D. C. Kim et al, "2.5 Gbps direct modulation of reflective semiconductor optical amplifier for wavelength division multiplexing passive optical network colourless sources," Jap. J. App. Phys. **48**, 120209 (2009).

[4]E. K. MacHale et al, "Extended-Reach PON Employing 10Gb/s integrated reflective EAM-SOA," in *ECOC*2008, Th.2.F.1.

[5]D. Smith, I. Lealman, X. Chen, D. Moodie, P. Cannard, J. Dosanjh, L. Rivers, C. Ford, R. Cronin, T. Kerr, L. Johnston, R. Waller, R. Firth, A. Borghesani, R. Wyatt and A. Poustie, "Colourless 10Gb/s reflective SOA-EAM with low polarization sensitivity for long-reach DWDM-PON networks," in *ECOC*2009, 8.6.3.