PDP13

Low Dispersion Penalty at 10 Gb/s, Over 75 km, Using a Quantum-Well-Intermixed Electroabsorption-Modulator/Widely-Tunable Laser Transmitter

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Abstract: 10Gb/s low power penalty (<0.5 dB) error-free transmission was achieved through 75km using a high-performance widely-tunable EAM/laser transmitter operating under negative chirp conditions. An integration-oriented quantum-well-intermixing process was employed for the realization of these devices.

OCIS codes: (140.5960) Semiconductor lasers; (140.3600) Lasers, tunable; (250.5300) Photonic Integrated Circuits

1. INTRODUCTION

For the first time, a widely-tunable transmitter demonstrating negative chirp performance at 10 Gb/s has been fabricated using a simple, robust quantum-well-intermixing (QWI) processing platform. The transmitter consists of a quantum-well electroabsorption modulator (QW-EAM) monolithically integrated with a widely-tunable sampled grating (SG) DBR laser. Less than 0.5 dB power penalty was measured for transmission at 10 Gb/s through 75 km of standard fiber. The QWI process allows for the circumvention of the traditional processing complexity necessary for the integration of negative chirp EAMs with diode lasers.

Electroabsorption-modulated lasers are candidate sources for optical metropolitan area network applications, as they are compact and potentially low-cost. The monolithic integration of EAMs with widely-tunable lasers allows for inventory reduction and wavelength agile functionality. A common method used to realize this integration employs an offset QW epitaxial architecture, in which the QW active region is grown on top of a bulk waveguide. For EAM definition, the QWs are selectively etched away and an upper cladding regrowth is performed [1]. This process produces Franz-Keldysh type modulators with a positive chirp factor, not suitable for 10 Gb/s transmission through standard fiber over distances required for metro networks. If QWs are used in the EAM, the quantum confined stark effect can be exploited, and negative chirp factors can be achieved. Power-penalty-free transmission through over 100 km of standard fiber using QW EAMs has been reported [2]. The traditional method for the realization of monolithically integrated QW-EAM/laser involves the selective removal of the as-grown waveguide/multiple QW (MQW) region followed by the regrowth of waveguide/MQW material with the desired band edge. This tedious method is commonly referred to as butt-joint regrowth [3]. Although the butt-joint regrowth process does allow each integrated component to possess a unique band edge, the difficulty associated with matching thickness and achieving the desired composition to avoid reflection and loss at the interface is great. Another technique used to realize multiple band edges across a wafer is selective area growth. However, as discussed in [4] the abruptness of the transition region is limited by the surface diffusion of the growth constituents, which may be on the order of tens of microns. Additionally, the optical mode overlap with the MQW may not be ideal in all sections due to the thickness variation. The relatively simple QWI process employed in this work enables for the precise placement of the band-edge of each component within the device, allowing for blue-shifted QWs to remain in the modulator while leaving the axial waveguide undisturbed.

2. EXPERIMENT

The device architecture (Fig. 1a dark outline) consists of two adjacent parallel buried ridges, which can function independent of one another with the lower ridge operating as an optical transmitter. The transmitter consists of a five section widely tunable sampled-grating (SG) distributed Bragg reflector (DBR) laser followed by an EAM. The 5 sections of the SG-DBR laser are, from left to right in Fig. 1a; backside absorber, rear mirror, phase, gain, and front mirror. The phase and mirror sections function to tune the wavelength of the laser [5]. The lithographically defined mirrors make the SG-DBR laser ideal for monolithic integration since no facets are required for operation.

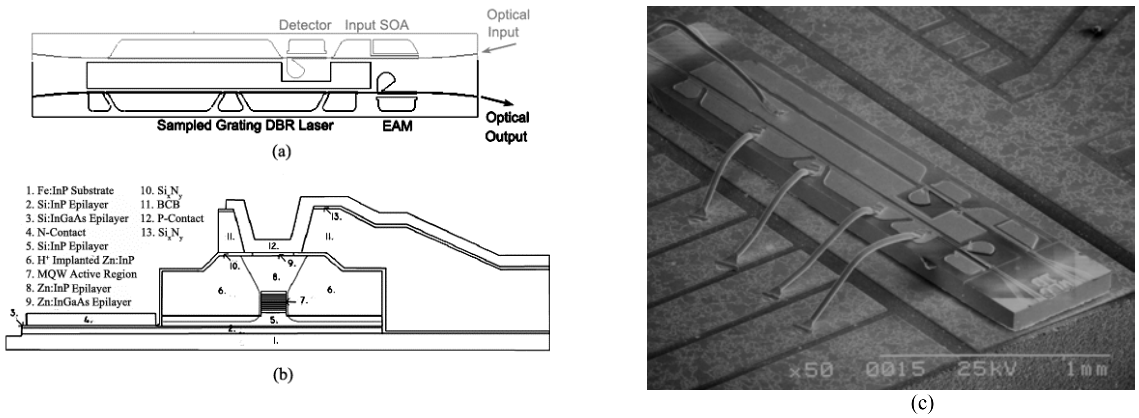

FIGURE 1. (a) Top view schematic of the device architecture, where the transmitter device used in this work is shown with a dark outline. (b) Cross- sectional schematic of modulator sections (c) Electron micrograph of completed transmitter device mounted on a carrier.

This work employs a modified ion-implantation enhanced QWI process described in [4], as the fabrication platform. In this process, vacancies are created by ion implantation into an InP buffer layer over the MQW active region. During a high temperature anneal, the vacancies are diffused through the MQW region, promoting the interdiffusion of group V-atoms between the wells and barriers. The interdiffusion reshapes the QW profile by distorting the QW/barrier interface. The result is a shift in the quantized energy levels in the well, and hence a shift in the band edge energy.

3. PROCESS

The epitaxial base structure and cross-sectional device architecture is illustrated in Fig. 1b and an electron micrograph of the completed device is shown in Fig. 1c. The MQW active region, consisting of 15 InGaAsP 8.0 nm compressively strained (0.6%) QWs and 8.0 nm tensile strained (0.3%) InGaAsP barriers, is centered within a 1.1Q waveguide. Using the intermixing process described in [4] and illustrated in Figure 2a, the EAM and passive section band-edges were blue-shifted such that the peak photoluminescence wavelengths were 1510 nm and 1450 nm, respectively. The photoluminescence results are shown in Fig. 2b.

4. RESULTS

The SG-DBR lasers demonstrated low threshold currents of 13mA, with output powers of 10mW at a gain section current of 100mA. At this operating point, a side mode suppression ratio (SMSR) greater than 35 dB was achieved. The EAM (175 um) demonstrated over 40 dB of DC extinction for wavelengths of 1558, 1570, and 1580

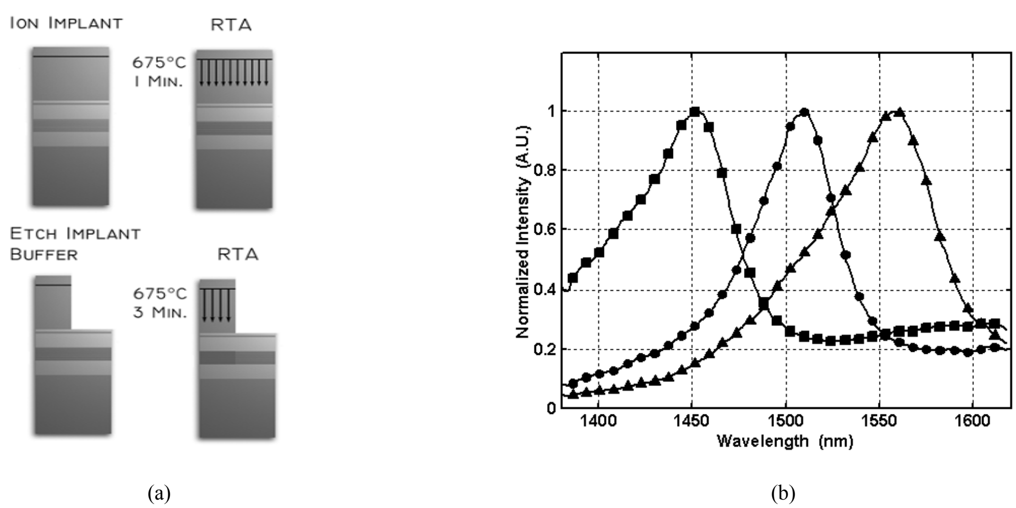

FIGURE 2. (a) Schematic of intermixing process. From left to right on top; ion implantation followed by rapid thermal annealing. From left to right on bottom; selective removal of vacancy point defects required for blue-shifting, followed by an additional anneal (b) Photoluminescence spectra of active section (triangles), modulator section (circles), and passive sections (squares).

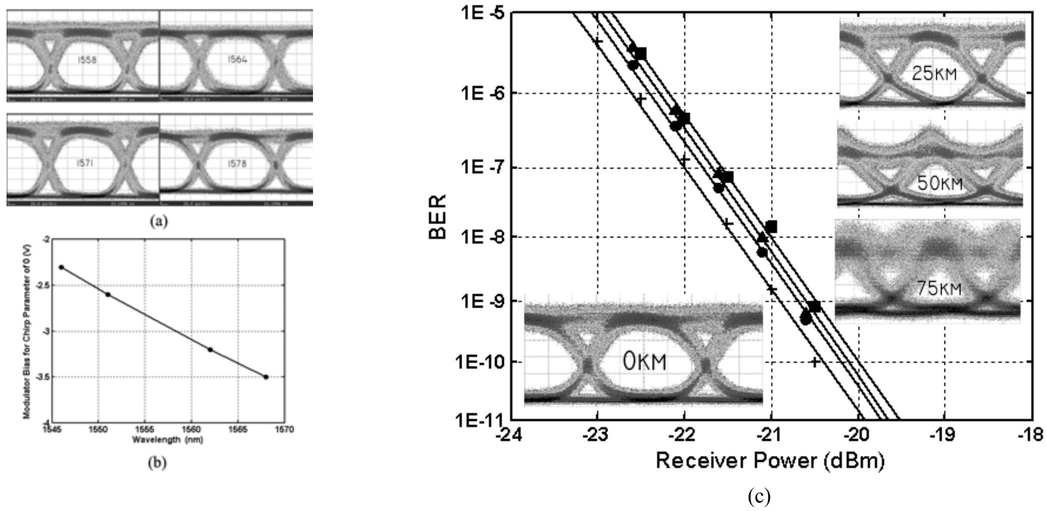

FIGURE 3. (a) Back-to-back eye diagrams from transmitter at wavelengths of 1558 nm, 1564 nm, 1571 nm, and 1578 nm. (b) Reverse bias zero chirp crossing point as a function of laser wavelength (c) BER curves and respective eye diagrams for back-to-back (cross), and transmission through 25 km (circles), 50 km (triangles), and 75 km (squares) of fiber at a wavelength of 1564 nm.

nm, with efficiencies greater than 20 dB/Volt. The 3dB bandwidth of the same modulator was greater than 19 GHz. 10 Gb/s eye diagrams were taken over the tuning range of the SG-DBR laser demonstrating RF extinction ratios greater than 10 dB using driving voltages between 2.4 V and 3.4 V. The small-signal chirp parameter was characterized using the fiber-response method described in [6]. Fig. 3b shows the wavelength dependency of the small signal zero-chirp parameter bias point, varying from –2.3V at 1546 nm to – 3.5V at 1568 nm.

Transmission experiments at 10 Gb/s were performed using a non-return to zero (NRZ) pseudo-random-bit-sequence (PRBS) of 2^{31}-1. A booster erbium doped fiber amplifier (EDFA) was used to launch optical powers on the order of 30 mW through Corning SMF-28 fiber. A variable optical attenuator was used to regulate the optical power into a non-preamplified receiver. Bit error rate (BER) curves through 25, 50, and 75 km of fiber at a wavelength of 1564 nm are shown in Fig. 3c. Error-free operation was achieved through 75km of fiber with a power penalty of less than 0.5 dB, while transmission through 100km of fiber resulted in a significantly larger power penalty. The low power penalty at 75 km confirms the negative effective chirp operation for large signal modulation, as indicated by small-signal chirp measurements. The shaping of the eye diagrams due to dispersion is clearly seen inset in Fig. 3c where the optical eye diagrams are shown after transmission through fiber. The noise performance for transmission through 75km is limited by the signal attenuation of the fiber and the noise of the oscilloscope optical receiver.

5. CONCLUSION

For the first time, a high performance widely-tunable EAM/laser transmitter operating under negative chirp conditions demonstrated error-free low-power-penalty operation through 75 km of standard fiber at 10 Gb/s. The transmitters demonstrated a 3dB bandwidth over 19 GHz and an RF extinction greater than 10 dB. This work was made possible by the use of a simple, robust QWI processing platform for the monolithic integration of blue-shifted QW-EAMs with SG-DBR lasers.

6. REFERENCES

[1] Y Akulova, G. Fish, P Koh, C. Schow, P Kozodoy, A. Dahl, S. Nakagawa, M. Larson, M. Mack, T. Strand, C. Coldren, E. Hegblom, S. Penniman, T. Wipiejewski, L. Coldren, "Widely Tunable Electroabsorption-Modulated Sampled Grating DBR Laser Transmitter" IEEE *J. Sel. Topics in Quantum Electron*., vol. 8, November/December, 2002

[2] K. Morito, R. Sahara, K. Sato, and Y. Kotaki, "Penalty Free 10 Gb/s NRZ Transmission over 100 km of Standard Fiber at 1.55 um with a Blue-Chirp Modulator Integrated DFB Laser" ," *IEEE Photon. Technol. Lett*., vol. 8, pp.431-433, 1996.

[3] J. Binsma, P. Thijs, T. VanDongen, E. Jansen, A. Staring, G. VanDenHoven, and L. Tiemeijer, "Characterization of Butt-Joint InGaAsP Waveguides and Their Application to 1310 nm DBR-Type MQW Ganin-Clamped Semiconductor Optical Amplifiers," IEICE Trans. Electron., vol. E80-C, pp. 675-681, 1997.

[4] E. Skogen, J. Raring, J. Barton, S. DenBaars, and L. Coldren, "Post-Growth Control of the Quantum-Well Band Edge for the Monolithic Integration of Widely-Tunable Lasers and Electroabsorption Modulators," IEEE *J. Sel. Topics Quantum Electron*. To be published 2004.

[5] V. Jayaraman, Z. Chuang, and L. Coldren, "Theory, Design, and Performance of Extended Tuning Range Semiconductor Lasers with Sampled Gratings," *IEEE J. Quantum Electron*., vol. 29, pp. 1824-1834, 1993.

[6] B. Dvaux, Y. Sorel, and J.F. Kerdiles, "Simple Measurement of Fiber Dispersion and of Chirp Parameter of Intensity Modulated Light Emitter," *IEEE J Lightwave Technology,* vol. 11, no. 12, pp. 1937-1940, (1993).