Short-Cavity 980 nm DBR Lasers with Quantum Well Intermixed Integrated High-Speed EA Modulators

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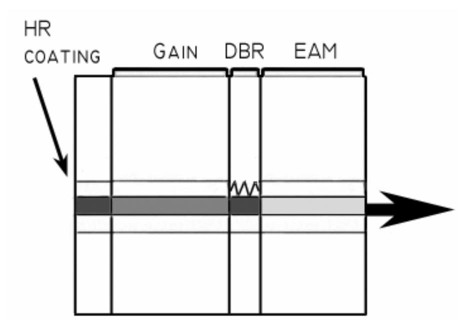
Abstract: Short-cavity, 980nm DBR lasers with integrated EAMs were designed and fabricated using a quantum well intermixing processing platform. RF bandwidths of 16GHz were achieved and open eyes at 10Gb/s were observed with >7dB dynamic extinction.

1. INTRODUCTION

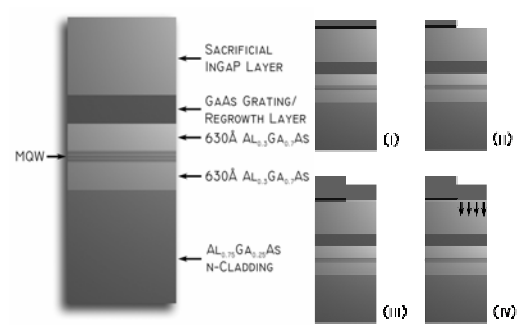
For photonics to replace electronics in applications such as board-to-board and chip-to-chip level interconnects, there is a clear need for increased speed and efficiency. Vertical cavity lasers have demonstrated high efficiencies, but operation to higher data rates is challenging [1]. We have previously demonstrated high efficiency, short-cavity distributed Bragg reflector (DBR) lasers at 1.55 µm with integrated, high bandwidth (25 GHz) electro-absorption modulators (EAM) [2]. By using a quantum well intermixing (QWI) integration platform, the laser and modulator can be simultaneously optimized for high performance. Recently, 980 nm DBR lasers with quantum well intermixed passive sections have been demonstrated with output powers up to 400 mW [3]. Moreover, intermixed quantum well (QW) EAMs have also shown promise to extend data rates up to 40 Gb/s and beyond [4]. Here, we present a short-cavity, 980 nm, DBR laser using a QWI platform in the InGaAs/GaAs/AlGaAs material system, monolithically integrated with a high-speed EAM demonstrating 16 GHz of 3dB bandwidth.

2. DEVICE

The integrated DBR laser-EAM is designed with 3 sections: gain, front DBR mirror, and EAM, as shown in the side-view schematic of Fig. 1a. A high reflectivity (HR) coating is applied to the rear facet. The gain section of the device is 110 µm long designed for low thresholds and high slope efficiency. The front DBR is 20 µm long, and makes use of deep gratings, targeting a coupling coefficient, (κ), of 650 cm^{-1}. The epitaxial base structure consists of 3 InGaAs/GaAs quantum wells centered between two $Al_{0.3}Ga_{0.7}As$ waveguide layers, as shown in Fig. 1b. The upper waveguide also includes a GaAs regrowth layer followed by a sacrificial InGaP layer. An impurity-free quantum well intermixing process described in [5] was used to monolithically integrate high-speed QW-EAMs with the DBR laser. Selective intermixing of the EAM, DBR, and passive regions of the device was achieved by depositing SiO_2 followed by a rapid thermal anneal (RTA) at 850°C. The gain section of the laser was maintained at the as-grown band-edge, λ_{pl} = 977 nm, by applying a surface fluorination treatment to suppress intermixing. Figure 2a shows the photoluminescence (PL) spectra for the two band-edges used for this work; the EAM and passive regions (λ_{pl} = 949 nm) were intermixed 28 nm from the active band-edge. Following QWI, the sacrificial InGaP layer is removed, and first order gratings are patterned using an immersion holography technique and dry etched into the GaAs regrowth layer [6]. Regrowth of the upper p-cladding and p-contact was performed by molecular beam epitaxy [6]. Ridge waveguides 3 µm wide were patterned, benzocyclobutene (BCB) was defined beneath the EAM contacts for low capacitance, and isolation was accomplished by proton implantation. The wafers were thinned, backside metalized, and cleaved into bars. Subsequently, the front and rear facets of cleaved bars were AR and HR-

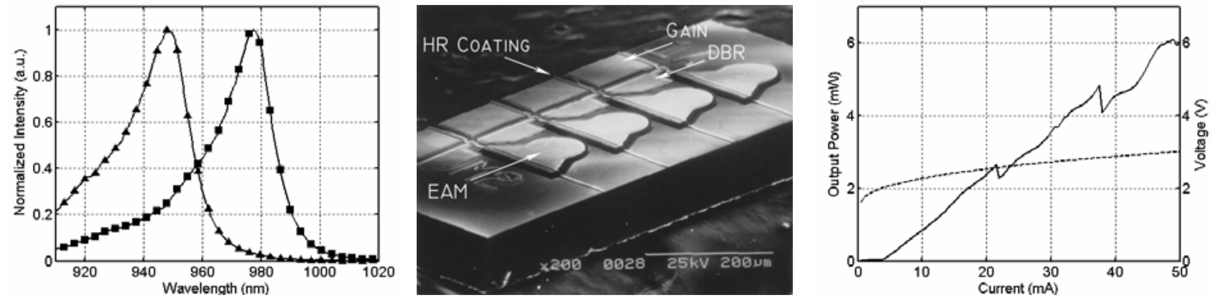


(a)



(b)

FIGURE 1. (a) Side view schematic of the integrated short-cavity DBR laser-modulator, illustrating the Gain, DBR, and EAM sections. (b) Epitaxial base structure. To the right illustrates the intermixing process used: (i) surface fluorination followed by SiO_2 deposition; (ii) removal of the SiO_2 and fluorination layer; (iii) deposition of a second SiO_2 layer; (iv) RTA to drive vacancies down through the multiple quantum well active region.



(a) (b) (c)

FIGURE 2. (a) PL spectra for device shown in this work. Symbols indicate active region photoluminescence (squares) and EAM/passive section photoluminescence (triangles). (b) SEM of a fabricated 4-element DBR laser-modulator. (c) Room temperature continuous wave light (solid) and voltage (dashed) characteristics of the integrated DBR laser-modulator.

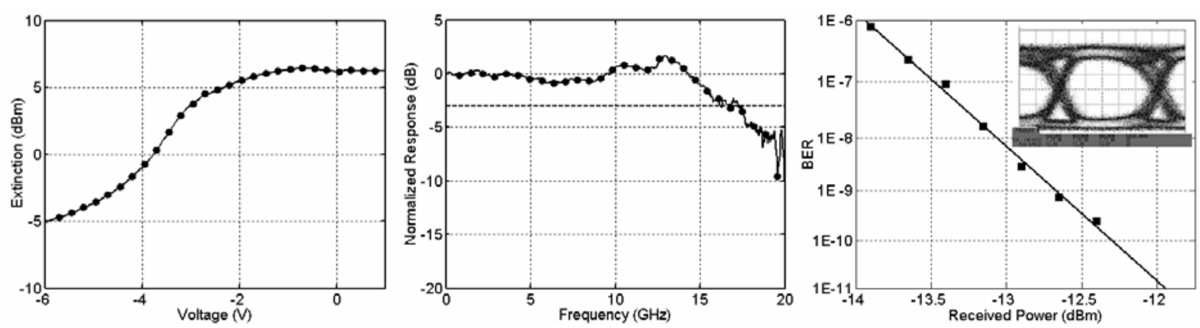
coated, respectively. Finally, the devices were mounted onto AlN carriers and wire-bonded to RF pads for high-speed testing. A scanning electron micrograph (SEM) of a fabricated 4-element array is shown in Fig. 2b.

3. RESULTS

The DBR laser had a threshold current of 5 mA and demonstrated output powers up to 6 mW at a gain section current of 50 mA, as shown in Fig. 2c. We expect to see higher output powers upon improving the low injection efficiency of these devices. The 125 µm long integrated EAM exhibited over 10 dB of optical extinction with 5 dB/V efficiency, and the small signal 3dB modulation bandwidth was measured to be 16 GHz, as shown in Fig. 3a and 3b, respectively. Large signal digital modulation experiments were performed at 10 Gb/s using a nonreturn to zero pattern and a pseudorandom-bit-sequence of 2^{31}-1. Open eye diagrams were achieved with 7.7 dB dynamic extinction at a DC bias of -2.5 V and a 3 V peak-to-peak swing. Corresponding bit error rate (BER) curves is plotted in Fig. 3c, demonstrating error-free operation at 10^{-9}. Higher data rates were not able to be tested due to equipment limitations.

4. CONCLUSION

We have demonstrated short-cavity DBR lasers emitting at 980 nm with integrated QW-EA modulators fabricated using a QWI platform. The integrated QWI EAMs demonstrated 16 GHz bandwidth and error-free operation at 10 Gb/s, with further optimization possible for increased high-speed performance. With QWI, the band-edge of each section of the device can be individually optimized, resulting in monolithic integration of lasers with high-performance QW-EAMs.



(a) (b) (c)

FIGURE 3. Performance characteristics of a 125 µm long QWI EAM: (a) DC optical extinction, (b) 3 dB modulation bandwidth of 16 GHz, and (c) BER curve and open eye diagram at 10 Gb/s.

5. REFERENCES

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