980 nm DBR Lasers Monolithically Integrated with EA Modulators for Optical Interconnect Applications

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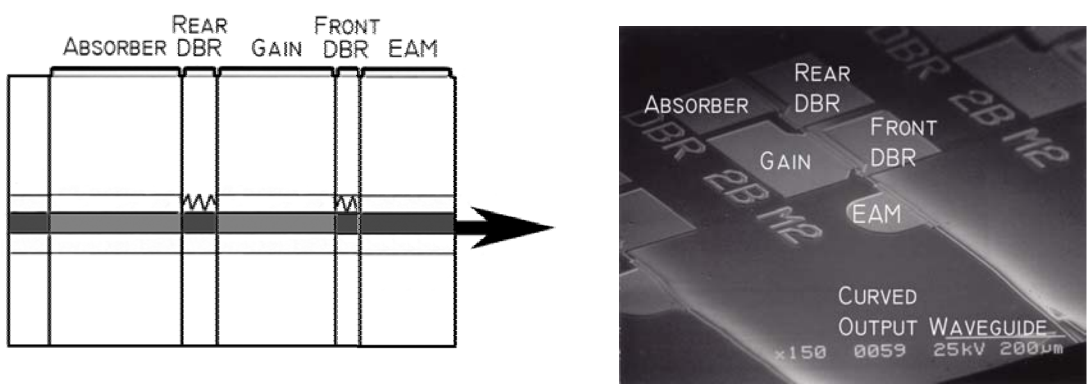
Abstract: Short-cavity InGaAs/GaAs/AlGaAs lasers with first order DBRs and integrated EAMs were fabricated using a quantum well intermixing process. >5mW output was achieved at 45mA. DC extinction was >15dB at -1.5V with efficiencies up to 20dB/V.

OCIS codes: (140.5960) Semiconductor lasers; (250.5300) Photonic Integrated Circuits

1. Introduction

The rapidly increasing complexity of modern computing systems has led to a demand for higher clock frequencies over longer path lengths. Meeting the bandwidth and path length requirements of modern computer systems is becoming increasingly difficult using traditional electrical connections. For this reason, chip to chip optical interconnects (C2OI) are being considered as promising candidates for replacement of electrical interconnects in future computing systems [1]. In addition to having high bandwidth-path length products, optical interconnects exhibit low cross talk, are free from electro-magnetic interference (EMI), and promise lower delay times than their electrical counterparts.

Highly efficient short cavity integrated DBR (distributed Bragg reflector) laser/EAM (electro-absorption modulator) transmitters for C2OI applications have previously been demonstrated at 1550 nm using quantum well intermixing (QWI) [2]. Quantum well intermixing has been demonstrated as an elegant technique for integration of photonic ICs at both 1550 [3] and 980 nm [4]. In the high temperature environment of modern IC's, 980 nm technologies will be required. In this paper we describe the fabrication of novel, short cavity, integrated DBR laser/EAM transmitters operating at 980 nm. The devices are fabricated using a unique QWI technique to monolithically integrate multiple band edges on chip. In addition, a novel immersion holography technique was used to obtain first order 980 nm Bragg reflectors. The devices exhibit single mode operation and have excellent extinction characteristics.

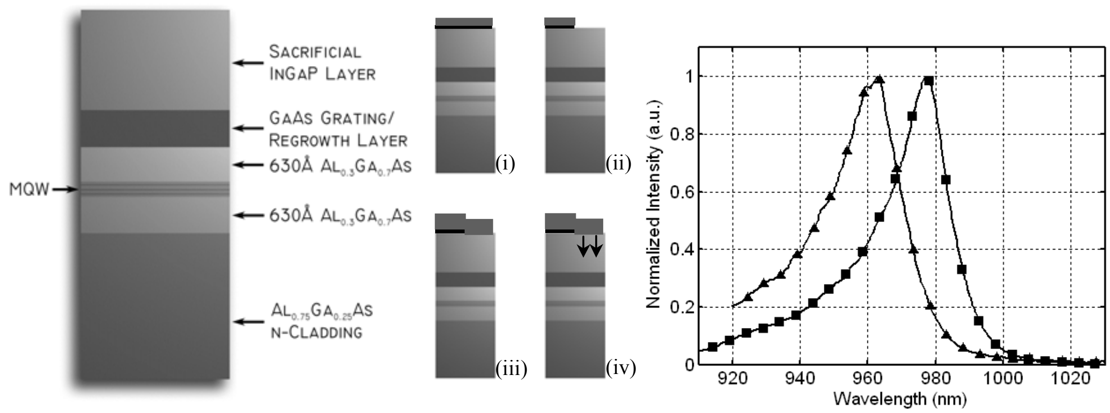


(a) (b)

FIGURE 1. (a) Side view schematic and (b) electron micrograph of the completed short-cavity DBR laser, illustrating the monolithic integration of the Gain, front and rear DBRs, and EAM sections along with a curved output waveguide.

2. Experiment

Short cavity (110 μm) DBR lasers with first order gratings were designed with 48 μm rear mirrors and 16 μm front mirrors. The laser was integrated with a 125 μm EAM by way of a quantum well intermixing process compatible with regrowth [4]. QWI allows for selective blue shifting of the semiconductor band edge so that each component of the transmitter can be optimized individually. The first order 980 nm gratings, which require a pitch of approximately 151 nm, were fabricated by an immersion holography technique, which was developed to avoid the expensive and time consuming process of Ebeam lithography. A curved waveguide makes an angle of 8º with the output facet, thereby minimizing unwanted reflective feedback. A side-view schematic and scanning electron micrograph of the device are shown in Fig. 1a and 1b, respectively.



(a) (b)

FIGURE 2. (a) The left shows the epitaxial base structure. The right illustrates the intermixing process used for band edge optimization in this work: (i) surface fluorination followed by SiO_2 deposition; (ii) patterning of the SiO_2 and fluorination layer; (iii) deposition of the second SiO_2 layer; and (iv) rapid thermal annealing to drive vacancies down through the multiple quantum well active region. (b) Normalized photoluminescence spectra for the active (squares) and EAM (triangles) band edges of the device.

3. PROCESS

The epitaxial base structure, as shown in Fig. 2a, was grown on a silicon-doped GaAs substrate by Molecular Beam Epitaxy (MBE). The structure contained an $Al_{0.75}Ga_{0.25}As$ n-cladding region below a multi-quantum well (MQW) active region centered within an $Al_{0.3}Ga_{0.7}As$ waveguide. The MQW consists of 3 InGaAs 8 nm compressively strained quantum wells, separated by 8 nm GaAs barriers. Following the active region, a 65 nm GaAs layer was grown, which serves as part of the grating layer as well as an aluminum-free regrowth interface layer. Finally, a 300 nm sacrificial InGaP layer completed the base structure.

The quantum well intermixing process, as illustrated in Fig. 2a, begins with a surface fluorination treatment of the sacrificial InGaP layer using an SF_6 plasma. A 100 nm layer of SiO_2 is then deposited by plasma enhanced chemical vapor deposition. The SiO_2 is lithographically patterned and etched in BHF so that it only remains where the as-grown band edge is desired. Developer is used to strip the fluorination layer from the semiconductor in regions not protected by the SiO_2. A second, 200 nm layer of SiO_2 is then deposited. In regions where the fluorination layer was removed, the SiO_2 creates vacancies in the InGaP buffer layer. In regions where the fluorination layer remains, the SiO_2 is unable to interact with the semiconductor. The vacancies created in the non-fluorinated parts of the semiconductor are driven into the multiple quantum well active region by rapid thermal annealing at 850 ºC for a time of 5'45". The vacancies promote the diffusion of atoms across the well/barrier interfaces, thereby altering the shape of the quantum wells and producing a blue shift of the band edge. Fig. 2b shows photoluminescence spectra from the as-grown (active) and intermixed (modulator) regions of the device. The active band edge is at λ_{pl} = 977 nm, and the modulator band edge is at λ_{pl} = 963 nm.

Following quantum well intermixing, the sacrificial InGaP layer is removed, and gratings are patterned and etched in the GaAs layer. Standard holography techniques using our HeCd 325 nm UV laser cannot produce Bragg gratings with the 151 nm pitch necessary for first order 980 nm DBR gratings. Immersion holography is therefore used to obtain the desired pitch. In this process, photoresist is first spun onto the sample, and a thin layer of index matching fluid is used to adhere the sample to a prism. By this method, the holographic grating pitch is reduced by a factor of n, where n is the index of the prism. The gratings are then etched into the GaAs using inductively coupled plasma. An MBE regrowth of the $Al_{0.75}Ga_{0.25}As$ upper p-cladding filled in the gratings to achieve a high index contrast; this was then capped with a highly doped GaAs p-contact layer. Ridge waveguides, 3 µm wide, were patterned and etched. Ti/Pt/Au p-metal contacts were patterned, the wafer was thinned, backside metalized, and the devices were cleaved into bars.

4. RESULTS

Figure 3a shows voltage and optical output power as a function of injection current for the DBR laser operating CW. A low threshold current of 9 mA was measured, and output powers greater than 5 mW were achieved with a gain section current of 45 mA. The optical output power is significantly decreased by attenuation due to the long waveguide associated with the curved output waveguide. The devices demonstrated single mode lasing at 978 nm with >30 dB side mode suppression, as shown in Fig. 3b. Figure 3c presents the DC modal extinction characteristics of the EAM with the laser biased at 40 mA. Greater than 15 dB optical extinction was measured at a reverse bias of -1.5 V. High extinction efficiencies were exhibited, with a maximum efficiency of 20 dB/V at a bias of -1 V.

5. CONCLUSION

Short cavity, 980 nm monolithic integrated laser/modulator devices have been designed, fabricated, and tested. Immersion holography, a faster, simpler, and more cost effective approach compared to Ebeam lithography, was used to obtain first order 980 nm Bragg gratings. The devices were fabricated using QWI for the monolithic integration of the DBR laser and EAM components. The lasers exhibited excellent single mode characteristics, and the 125 µm modulator demonstrated >15 dB DC extinction and high extinction efficiencies.

6. REFERENCES

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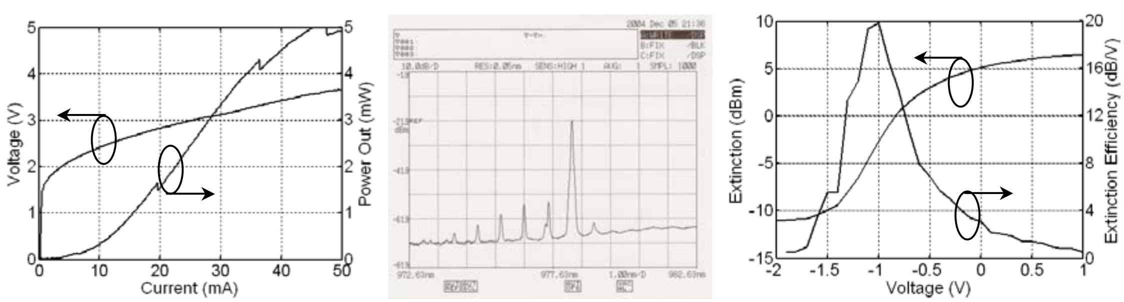

(a) (b) (c)

FIGURE 3. (a) CW voltage vs. injection current and optical power through the modulator vs. injection current. (b) CW lasing spectra showing emission at 978 nm with greater than 30 dB SMSR. (c) DC optical extinction of a 125 µm modulator showing more than 15 dB at -1.5 V. Extinction efficiencies of up to 20 dB/V are found at a –1 V bias.