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Bandgap Tuning in InGaAs/InGaAsP Laser Structure by Quantum Well Intermixing

Jongbum Nah†, and Patrick LiKamWa

College of Optics and Photonics, University of Central Florida, Orlando, FL32816-2700, USA

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We report the selective area bandgap tuning of multiple quantum well structures by an impurity free vacancy induced quantum well intermixing technique. A 3dB waveguide directional coupler was fabricated in the disordered section of an intermixed quantum well sample as a demonstration of photonic device applications.

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I. Introduction

In future optical communication systems, there will be increasing demand for the monolithic integration of photonic devices that can perform higher levels of functionalities such as wavelength conversion, packet routing and switching, signal reconditioning etc.. To realize photonic integrated circuits, spatial control of the optical and electrical properties of the underlying materials is required. Several techniques such as selective regrowth and selective area epitaxy[1,2] have been investigated for this goal. An alternative approach is the selective-area quantum well intermixing (QWI) that changes the position of the absorption edge.[3,4] The post-growth modification of the optical properties of QWs is a very promising technique for the realization of monolithically integrated devices. To date, a number of QWI techniques have been reported including impurity-induced disordering,[5] impurity-free vacancy-induced disordering,[6] ion implantation-induced inter-diffusion,[7] and several laser-induced disordering processes.[8] Impurity-free vacancy-induced disordering is usually implemented by the deposition of a dielectric film coating followed by a rapid thermal annealing. InP-based structures have attracted increasing interest in electronic, optoelectronic and photonic devices for optical communication in the 1.55 μm wavelength band.

In this study, the intermixing of 1.55 μm laser structures at various annealing temperatures has been investigated by photoluminescence (PL) measurements. In the experiments, the SiO_2 dielectric cap layer is grown by plasma enhanced vapor phase deposition (PECVD) on top of the sample and a rapid thermal annealing (RTA) process is then applied. As the vacancies diffuse from the cap into the MQW structure, the constituent elements of the QWs interdiffuse and the compositional profile of the QW is changed resulting in a shift of the electronic levels in the QWs.

A ridge waveguide 3dB directional coupler was fabricated in the intermixed region of the samples as preparatory work towards a photonic integrated device/circuit.

II. Experiments

A quantum well laser structure grown by MOCVD is used as test samples for the intermixing experiments. The active layer consists of seven 1% compressively strained InGaAs quantum wells with a thickness of 7 nm and lattice matched InGaAsP barriers with a thickness of 14 nm. The upper and lower confinement layers are 70 nm undoped InGaAsP layers with an optical bandgap corresponding to a wavelength of 1.18 μm. The 1.5 μm thick InP upper cladding layer is Zn doped with a doping concentration of 2×10^{18} cm^{-3}. The structure was covered with 100 nm InGaAs cap layer.

A 200 nm thick SiO_2 film was grown on top of the samples by plasma enhanced chemical vapor deposition (PECVD). The samples were processed by rapid thermal annealing at 800°C, 830°C, and 850°C for 40 sec in a flowing N_2 ambient. The photoluminescence were measured with the samples at room temperature and using a CW Nd : YAG laser as the optical pump.

For the selective area intermixing, SiO_2 film was deposited on 4 mm x 4 mm sample. Then a strip 500 μm wide and 4 mm long was opened in the deposited SiO_2 film near the center of the sample using conventional photolithography and wet chemical etching by buffered HF acid. The sample was then annealed at 830°C for 40 sec in a flowing nitrogen am-

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† E-mail: jnah@mail.ucf.edu

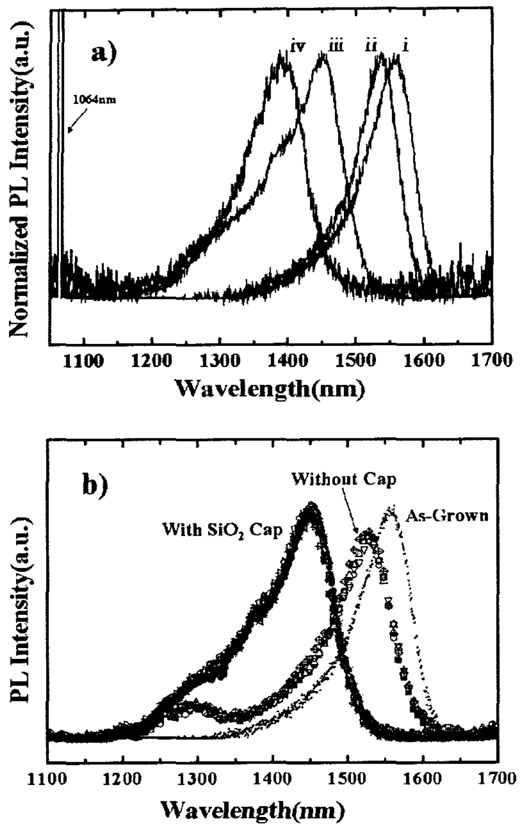

Fig. 1. a. Photoluminescence results: (i) as grown, (ii) annealed at 800°C, (iii) 830°C, (iv) 850°C. b. Multiple superimposed spectra from several intermixed and un-intermixed regions of the sample annealed at 830°C for 40 second.

bient. In order to verify the areal uniformity of the quantum well intermixing, photoluminescence was measured at many different locations (intermixed and non-intermixed) selected randomly.

A 2 μm width ridge waveguide 3 dB directional coupler was fabricated with an intermixed quantum well sample that was rapid thermal annealed at 830°C for 40 sec using photolithography and wet chemical etching. The total device length was 1.5 mm. The length of the coupling region was 260 μm and gap separation between the ridge waveguides was 1 μm. The optical wave guiding was investigated using a home-built Erbium doped fiber laser operating at 1.55 μm with an output power of 1 dBm.

III. Results

The normalized PL spectra in figure 1.a shows that the degree of the blue shift in the position of the PL peak increases as the annealing temperature is increased. However, the increase in bandgap shift due to the increase in annealing temperature is also accompanied by weaker and noisier PL spectrum that is attributed to an increase in the level of defect generation. Some reports attributed the dominant process of intermixing in InGaAs QWs by encapsulating dielectric films to anion (group V) vacancy diffusion.[9] Figure 1.b. shows the superimposed PL data taken across the sample in several intermixed and un-intermixed locations showed good areal uniformity and selectivity. The PL data for the as-grown sample shows that only a small degree of intermixing occurs in the region that was not covered by the SiO_2 cap.

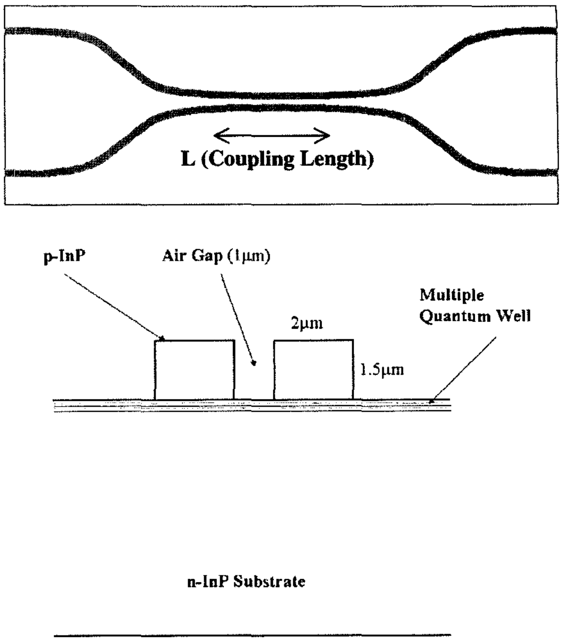

Fig. 2. Schematic representation of the device structure

Schematic drawings of a 3 dB optical waveguide directional coupler and of the cross sectional view of the coupling part are shown in figure 2. In figure 3 the photograph of a device output facet is shown. The laser beam that is launched by the end-fire coupling method into one of the input waveguides is guided and then partially coupled to the adjacent waveguide in the coupling section. At the output of the device the optical power is equally split between the two waveguides as shown in figure 3.b. The increase in the optical bandgap allowed the low-loss optical waveguiding of TE polarized light at 1.55 μm wavelength. The device also showed polarization insensitivity as the polarization of input light was changed from TE to TM.

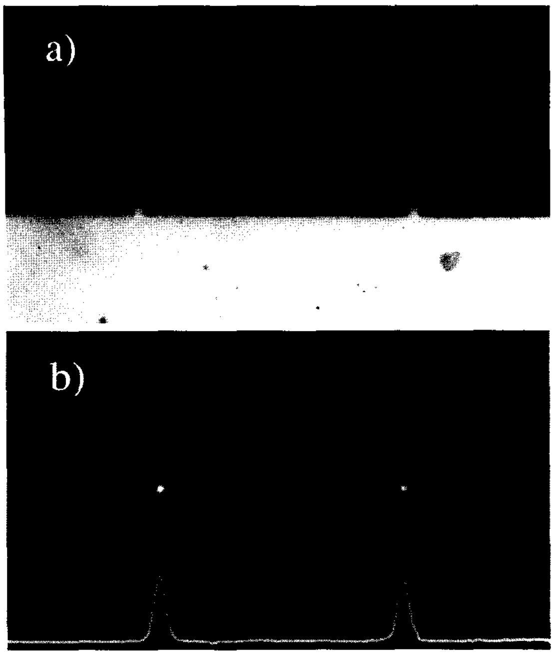

Fig. 3. a) Photograph of the device output facet. b) The near-field output profiles of the directional coupler with light launched into one input waveguide

IV. Conclusion

We have demonstrated the post-growth modification of the bandgap energy of QW structures by an impurity-free vacancy-induced disordering intermixing technique. The intermixing process is highly reproducible and produces uniform-areal bandgap alterations. Simple photolithographic etching of the top SiO_2 film is employed to achieve area- selectivity that is very important for photonic integration.

A low-loss 3-dB waveguide directional coupler has been demonstrated as preparatory work for photonic integrated circuit research.

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