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Dual wavelength single waveguide laser diode fabricated using selective area quantum well intermixing

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ABSTRACT

A two-section single stripe laser diode has been fabricated from a strained InGaAs/GaAs single quantum well heterostructure grown on GaAs substrate. The two sections have different band gap energies owing to selective area intermixing that is achieved by rapid thermal annealing of the sample with the two sections capped by silicon oxynitride (SiO_xN_y) and silicon dioxide (SiO_2), respectively. The device is capable of producing laser emission at either 911 or 953 nm wavelengths depending on the current applied to either section of the laser stripe.

1. Introduction

Multiple wavelength emissions from a single aperture laser is useful for many types of spectroscopic applications. Usually this is accomplished by combining the optical beams from multiple lasers using beam-combiners such as waveguide couplers. This leads to unnecessary loss of efficiency and added bulk to the laser system. In this work, we propose and demonstrate a laser diode system that incorporate two sections in tandem. The two sections have different band gap and therefore are able to lase at the wavelength corresponding to the peak of the gain in their respective regions as long as some current is passed through the non-lasing section to keep it above the optical transparency level. A selective area quantum well intermixing process is employed that involves vacancy diffusion through rapid thermal annealing of the sample capped by either silicon dioxide or various silicon oxynitride films. It is shown that the band gap energy of the intermixed QW structure can be effectively controlled by the composition of the dielectric capping film prior to rapid thermal annealing of the sample. Using a single InGaAs/GaAs quantum well system, the peak wavelength of the photoluminescence can be fine-tuned from 975 to 910 nm.

2. Experimental and result

The semiconductor wafer employed in this work is a standard graded-index, separate-confinement-heterostructure, single-quantum-well (GRIN-SCH-SOW) strained InGaAs/GaAs design grown by metal organic chemical vapor deposition (MOCVD) on a n-doped GaAs substrate [1]. The epitaxial structure consists of a 200 nm thick n-doped GaAs buffer layer, followed by a 1 μm thick n-doped $Al_xGa_{1-x}As$ lower cladding layer whose aluminum mole fraction x, is then graded from 0.3 to 0 over a 150 nm layer thickness. The active region consists of an 8 nm thick InGaAs QW between two GaAs barrier layers each 5 nm thick. The top p-doped layers consist of a 150 nm thick graded GaAs-$Al_{0.3}Ga_{0.7}As$ followed by a 1 μm thick

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0	n-GaAs Substrate		Thickness (mm
1	GaAs	buffer layer	0.300
2	$Al_{0.8}Ga_{0.2}As$	n-cladding	1.200
3	$Al_{0.2}Ga_{0.8}As$	buffer layer	0.075
4	GaAs	QW	0.008
5	$Al_{0.2}Ga_{0.8}As$	buffer layer	0.008
6	GaAs	QW	0.008
7	$Al_{0.2}Ga_{0.8}As$	buffer layer	0.008
8	GaAs	QW	0.008
9	$Al_{0.2}Ga_{0.8}As$	buffer layer	0.075
10	$Al_{0.8}Ga_{0.2}As$	p-cladding	1.000
11	GaAs	p-contact	0.100

Fig. 1. Design of the InGaAs quantum well laser structure grown by MOCVD.

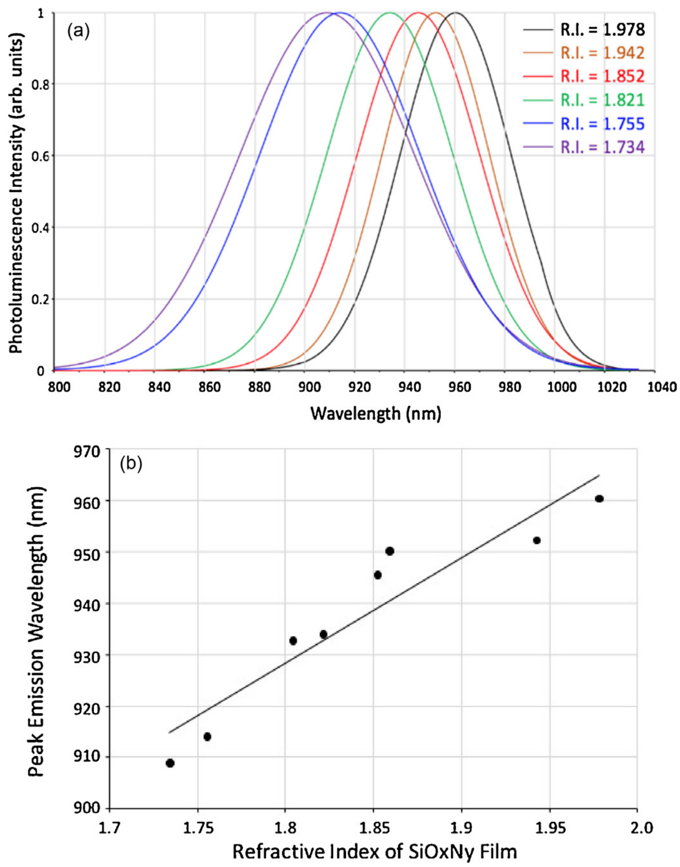

Fig. 2. a PL emission spectra of the QW sample after rapid thermal annealing while covered by different SiO_xN_y films as determined by their refractive indices. Fig. 2b Plot of peak emission wavelengths as a function of the refractive index for different SiOxNy films.

$Al_{0.3}Ga_{0.7}As$ capped by a 200 nm thick p-doped GaAs. The photoluminescence of the sample exhibited a peak at a wavelength of 975 nm. Fig. 1 shows the layer structure of the semiconductor laser material.

In order to characterize the selective area QW intermixing of the structure, several samples were coated with 200 nm thick films of silicon oxynitride of varying composition that were grown at 250 °C in a PlasmaTherm 790 Series PECVD system [2,3]. In order to adjust the relative mole fraction of oxygen to nitrogen in the deposited films, different mass flow rates of NH_3 and N_2O are selected during the PECVD growth process. It was found that the films with a higher nitrogen content tended to have a higher refractive index and therefore the films were tagged according to their refractive index as measured by an ellipsometer [4]. The coated samples were heated at 925 °C for 30 s in a flowing nitrogen atmosphere inside a rapid thermal annealer (RTA) [5]. Photoluminescence (PL) emission spectra from the samples were captured by an Ocean Optics

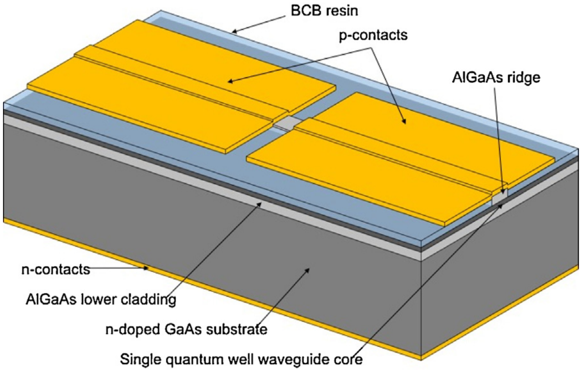

Fig. 3. Schematic of the two-section laser diode device.

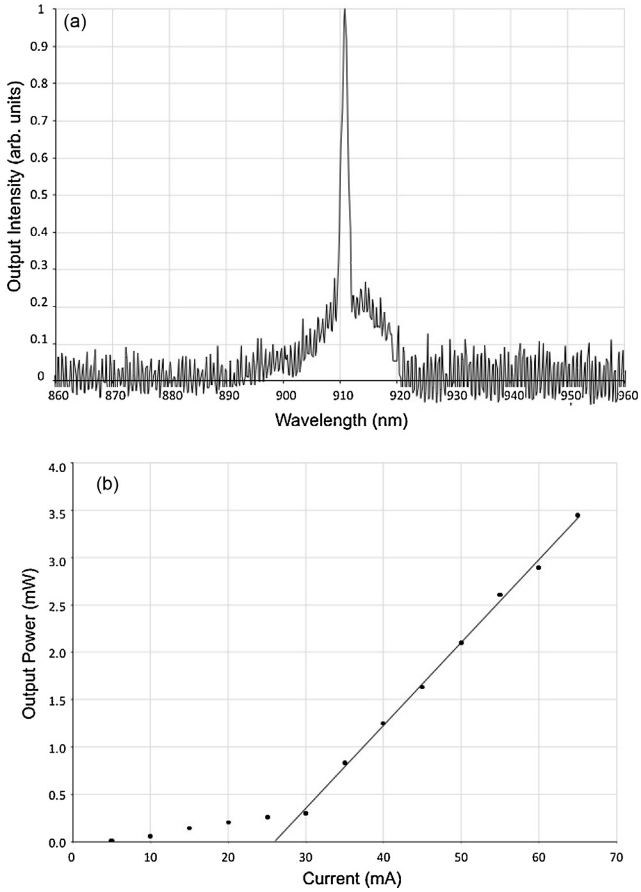

Fig. 4. a The spectrum of laser emission spectrum at 911 nm with 60 mA injected into Section B and 4.5 mA injected into Section A. Fig. 4b The L-I curve as a function of current injected into Section B of the laser diode with 4.5 mA injected into Section A.

USB2000 spectrometer. Fig. 2a shows the PL spectra from the different samples and Fig. 2b shows the peak emission as a function of the refractive index of the cover film. The measurements show that a full control of the emission wavelength from 975 nm to 910 nm is obtained from a semiconductor layer structure that is coated with different films of SiO_xN_y prior to a high temperature rapid thermal annealing.

Two-section single stripe laser diodes are then fabricated using regular photolithographic techniques and wet chemical etching [6]. A small sample of the semiconductor wafer is cleaned with acetone, isopropanol, buffered oxide etch and deionized water and then coated with a 50 nm thick layer of SiO_xN_y that has a refractive index of 1.95 [7]. Using photolithography to mask half of the sample with positive photoresist, the exposed SiO_xN_y is removed by reactive ion etching (RIE). After removal of the photoresist, the sample is coated with a 200 nm thick SiO_2 and then heated at 925 °C for 30 s in an RTA.

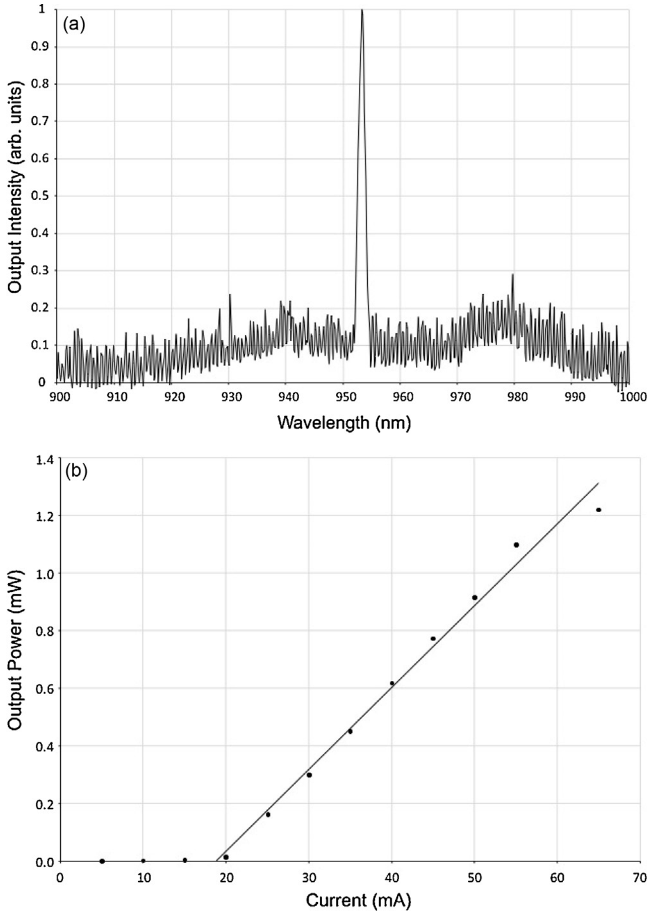

Fig. 5. a The spectrum of laser emission at 953 nm with 60 mA injected into Section A and 3 mA injected into Section B. Fig. 5b The L-I curve as a function of current injected into Section A of the laser diode with 3 mA injected into Section B.

This process results in two sections of the semiconductor sample with different band gap energies related to the degree of quantum well intermixing. The QW in the region of the sample that was covered by SiO_xN_y (Section A) is intermixed less than in the region covered by SiO_2 (Section B). Positive photoresist is spun on top of the SiO_2 and 3 μm wide stripes that run across the two different intermixed sections are delineated using contact mask photolithography [8]. The unwanted SiO_2 and SiO_xN_y layers are removed by RIE and the waveguide ridge is formed by etching the GaAs contact layer and top AlGaAs cladding layer [9]. After removing the photoresist, the whole sample is then spin-coated with a thick layer of bisbenzocyclobutene (BCB), an insulating protective resin [10,11]. After curing the BCB in a nitrogen flowing oven for 2 h at 250 °C, the solidified BCB is etched back by RIE until about 350 nm of the top SiO_2 coated waveguide is uncovered. The SiO_2 and SiO_xN_y are then removed by RIE and negative photoresist is spun on the surface followed by photolithography to define 30 μm wide channel openings centered around the waveguide stripes. 10 nm of titanium, followed by 4 nm of zinc followed by 300 nm of gold contact metals are deposited by vacuum thermal evaporation [12]. The unwanted metals are removed by lift-off by dissolving the photoresist in acetone leaving 30 μm wide p-contact metals covering the whole length of the waveguides. A 4 μm wide gap is etched in the contact metal at the interface between the two intermixed sections using photolithography and gold etch consisting of potassium iodide and iodine solution [13]. After sample is cleaned, the metals are annealed at 430 °C for 30 s. The substrate is then lapped down and polished to a thickness of 120 μm and then coated with 4 nm of nickel followed by 20 nm of germanium and 200 nm of gold by vacuum thermal evaporation to form the n-contact layer [14]. The contacts are finally annealed at 430 °C for 30 s [15]. The sample is cleaved to a total length of 1450 μm with 650 μm of the waveguide length in Section B. Fig. 3 shows a schematic of the two-section laser diode.

The device is then mounted p-side up on a copper header and tested on a waveguide alignment setup. A 25X microscope objective lens is used to capture the light emitted from either of the cleaved facets and focus it into the end of an optical fiber that is connected to a spectrometer to monitor the emission spectrum. A power meter is then positioned in the laser beam path to measure the light output power as a function of injected current.

Fig. 4a shows the emission spectrum of the light output from the device with 60 mA injected into the Section B of the laser device and 4.5 mA injected into Section A. The laser emission at 911 nm indicates that the structure of original QW in

Section B has been altered considerably. Fig. 4b shows the light output as a function of the injection current. The L-I curve was obtained by gradually increasing the current that is applied to the section under test while a fixed 4.5 mA current was applied to the other section. The threshold current for that combination is 26 mA with a current slope efficiency of 0.18 W/A.

Fig. 5a shows the emission spectrum from the same device with 60 mA injected into Section A of the device and 3 mA injected into Section B. In this case, the laser emission is at 953 nm indicating confirming that the QW in Section A is intermixed to a lesser extent than that in Section B. Fig. 5b shows the light output as a function of the injection current and indicates a threshold current of 19 mA and a current slope efficiency of 0.056 W/A.

3. Conclusions

A two-section single waveguide laser diode has been demonstrated that can lase at two different wavelengths depending on the current injected into the two separate sections. The measurements of the laser L-I responses indicate that the intermixing process does not cause significant deterioration of the active region to an extent that causes laser action to cease and therefore is encouraging for other active devices incorporating multiple selectively intermixed QW regions are feasible.

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