Fabrication And Characterisation of Bandgap Tuned Lasers in GaAs/AlGaAs Quantum Well Structures Using Pulsed Laser Irradiation

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Abstract

We report the use of Q-switched Nd:YAG laser irradiation technique to enhance the interdiffusion of Ga-Al, and hence the quantum well intermixing (QWI), in GaAs/AlGaAs double quantum well (DQW) structures. Multiphoton interactions with carriers lead to phonon emission; the phonons interact with lattice thus generating point defects, which diffuse during subsequent annealing stage in a rapid thermal processor (RTP) and cause intermixing. This QWI technique is essentially impurity free and potentially high resolution. 3μm wide ridge waveguide lasers were fabricated from the intermixed and control samples. A differential bandgap shift of up to 40meV have been observed between the intermixed and the as-grown lasers. Parameters, such as threshold current density, internal quantum efficiency, material loss, and transparency current density were extracted from the light-current (L-I) characteristics of the lasers cleaved to different cavity lengths. Compared to as-grown devices, it was found that the bandgap tuned lasers exhibited a small increase in the threshold current density, and negligible change in the slope efficiency.

Introduction

One of the most powerful technique for fabrication of the photonic integrated circuits (PICs) involve the ability to alter the bandgap of multi-quantum well (MQW) well structure after growth by disordering. Disordering of DQW can also be used to shift the gain envelope of as-grown material, thus allowing laser with a range of tuned wavelengths to be fabricated from a single wafer.

In recent years various techniques have been developed for selectively intermixing QW structures in semiconductors. These include Impurity Induced Disordering (IID) and Impurity Free Vacancy Disordering (IFVD) [1]. However, these processes tend to alter the crystal structure. IID decreases the crystal purity and IFVD has limited selectivity and brings about bandgap shift over almost all part of wafer, especially in GaInAs/GaInAsP system. Another recently developed technique is called Photo-absorption Induced Disordering (PAID). It uses preferential absorption of laser photons in QW to generate free carriers. A variation of PAID technique having a better spatial resolution have been developed in GaInAs-GaInAsP structures.

This involves irradiating the MQW material with high energy Q-switched Nd:YAG laser pulses [2]. Measurements of the spatial resolution of this technique show it to be better than 20μm [3].

In this paper, we report the use of Q-switched Yd:YAG laser irradiation technique to enhance the interdiffusion of GaAs/AlGaAs DQW structures. We show that the P-PAID QWI produces high optical quality material, which can be used to fabricate bandgap-tuned lasers. We also report the charcterisation of the developed lasers.

Experiment

The DQW laser sample used in this experiment was grown by metal-organic vapor phase epitaxy (MOVPE). The laser was fabricated with a separate confinement

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heterostucture. (SCH). The DQW region was undoped and consisted of two 10 nm wide GaAs quantum wells, seperated by a 10 nm $Al_{0.2}Ga_{0.8}As$ barrier. The top and bottom $Al_{0.2}Ga_{0.8}As$ barriers were 0.1μm thick. The upper and lower cladding $Al_{0.4}Ga_{0.6}As$ layers were doped to $5x10^{17}$ cm^{-3} using carbon and silicon.,0.9 and 1.5 μm thick respectively. The top contact epitaxial layer consisted of 0.1μm of GaAs doped with $5x10^{18}$ cm^{-3} of zinc.

and 3μm.. Figure 1 gives the diagrammatic view of the laser structure.

The control sample was that sample that was not exposed to laser but was subjected to RTP cycles. The control and the as-grown samples were also used to compare results obtained from the P-PAID sample lasers. The three sample lasers were tested under pulsed current condition

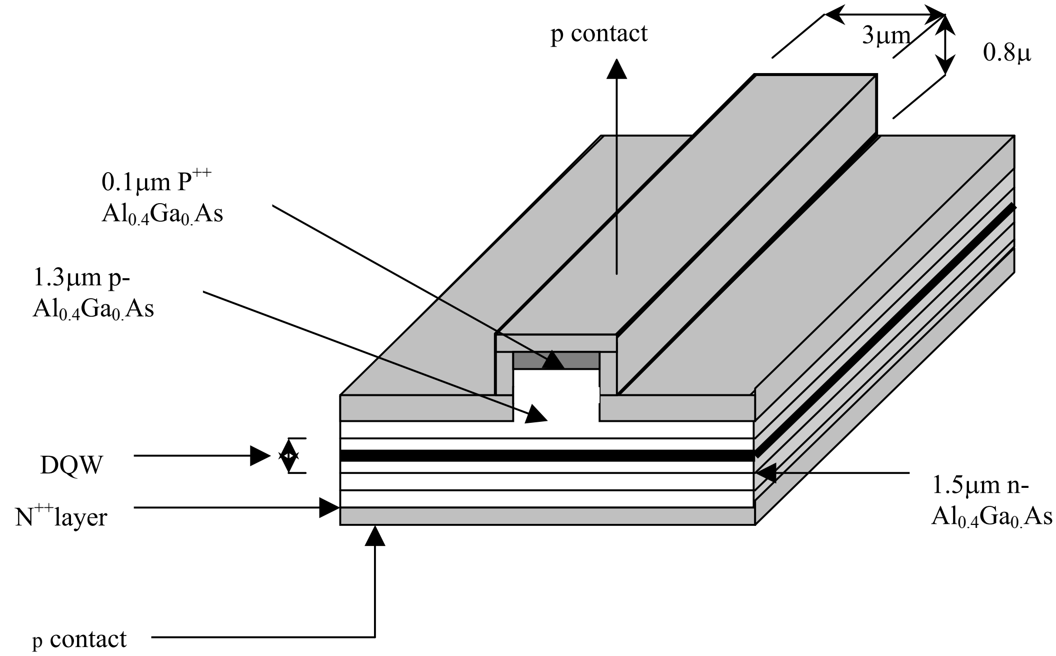


Figure **1** : Ridge waveguide double quantum well GaAs/AlGaAs laser

A Q-switched Nd:YAG laser with a pulse repetition rate of 10Hz and average pulse fluence of 1.25 mW, operating at a wavelength of 1.06 μm was used to irradiate the sample normal to the surface. The intermixing stage was carried out using a RTP. The samples were placed face down on a piece of fresh GaAs and another piece of GaAs was placed over the back to provide an As over pressure. Photoluminescence (PL) measurement was carried out at 77K to study the bandgap shift after the intermixing..

3μm wide ridge waveguide lasers were fabricated from the P-PAID intermixed sample, the control and also the as-grown sample. The ridge was dry-etched to a depth of 0.8μm, 1.0μm

at room temperature to characterise the intermixed laser and for comparison of parameters obtained. The pulse width of the current was 400nm and the repetition cycle was 1 kHz.

Results and Discussion

Samples were exposed to varying period of time and annealed at 925 ^{0}C for 60 seconds. The variation of bandgap shift to the laser exposure time was observed and it was seen that the sample exposed to larger number of pulse seemed to exhibit less intermixing. Transmission Electron Microscopy (TEM) studies showed that the point defects at higher irradiation coalesced to form extended defects such as dislocation loops [4]. Such loops being stable trap point defects inhibits the intermixing of Ga and Al.

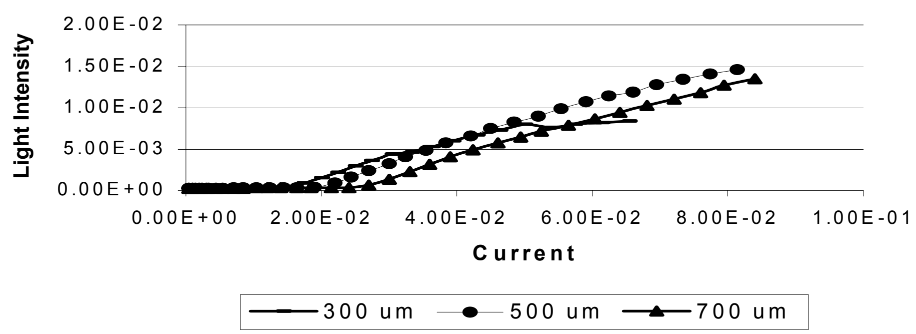
The process of QWI can be explained as follows. Laser irradiation created point defects by generating hot carrier plasma which then emits a sufficiently high concentration of phonons that the crystal structure is disrupted [5]. For the Nd:YAG laser , the photon energy is below the bandgap of any part of GaAs-AlGaAs structure. . These point defects then could subsequently diffuse and induce QWI during the RTP stage. The wavelength of P-PAID sample laser was seen to have been decreased by about 25 nm, while that of the control (sample without irradiation) shifted about 10 nm under similar RTP condition, compared to the as-grown laser. This wavelength shift is undesirable and can be prevented by the use of intermixing mask like p-doped SiO_2.

The control sample parameters are not tabulated as the data obtained associated with it are not valid. It can be seen that threshold current density (J_{tr}) of the intermixed lasers increased by a slight margin. The change in the slope efficiency and internal quantum efficiency (η_I) was found to be insignificant. The small change in the threshold current density is probably related to the depletion of As, since the sample were only proximity capped during the annealing [6]. Hence this fault can be corrected using the dielectric caps during the annealing process.

Conclusion

This report successfully demonstrates the use of P-PAID technique to induce QWI in GaAs-AlGaAs structures and the use of these intermixed samples to form bandgap tuned lasers of high optical quality.

Figure 2 Variation of Threshold current with cavity length



The characterisation of the laser made from the P-PAID sample was done using the conditions given in the previous section and is compare to that of as-grown laser. The variation of threshold current with cavity length as predicted by theory is shown in Figure 2. Table 1 gives the parametric values obtained.

Sample	Threshold Current Density (infinite length)	J_{tr}	η_I	Loss(cm^{-1})
As-grown	221	65	72	15.9
P-PAID	230	67	68	15.6

Table 1 Laser parameters of the as-grown and P-PAID sample

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