OPTICAL PROPERTIES OF DIFFUSED AlGaAs/GaAs MULTIPLE QUANTUM WELLS AND THEIR APPLICATIONS IN HIGH POWER LASER

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Abstract

We will present results for an $Al_{0.24}Ga_{0.76}As/GaAs$ diffused multiple quantum well with five periods of 100/100 Å thick well/barrier layers grown in between $Al_{0.24}Ga_{0.76}As$ guiding layers and cladded on top by a 1μm thick p-$Al_{0.44}Ga_{0.56}As$ layer and on the bottom by an n-$Al_{0.44}Ga_{0.56}As$ layer of equal thickness, on a n^+-GaAs buffer layer and n^+-GaAs substrate. Vacancy enhanced QW diffusion is employed where a 2000 Å thick layer of SiO_2 is deposited on top of the diffused multiple quantum well structure. Photoluminescence measurement and photovoltage measurement at room temperature show that after rapid thermal annealing for 30 sec at 1000 °C to 1040 °C, a bandgap shift of 30 nm is obtained for the exciton edge. Further, this technique is applied to a ridge waveguide laser structure to make two windows for high power output up to 36 mW. This device shows that the diffusion process may have practical applications.

Introduction

Impurity free vacancy diffusion (IFVD) is a simple way to control the mixing in quantum wells [1]. Multiple quantum wells (MQW) intermixing using IFVD has been becoming very attractive recently for modifying optical properties of materials as this method is able to tune the bandgap of the MQW wafer and at the same time it can be used for making window structures for high power laser operation.

Diffused multiple quantum wells (DF-MQW) can be obtained by intermixing the alloy composition of barriers and the wells through their heter-interfaces. In an AlGaAs/GaAs system, SiO_2 is selectively capped on the MQW structure to enhance the intermixing. The sample then undergoes Rapid Thermal Annealing (RTA) at temperatures above 850 °C for 30 sec. These procedures induce the out-diffusion of Ga into the capping SiO_2 layer which results in the generation of vacancies in the QWs, enhancing the interdiffusion of Al and Ga atoms, so that the diffusion coefficient becomes larger. The resulting increase in bandgap can be evidenced by the blue shift of photoluminescence (PL) measurement and photovoltage measurement.

DF-MQW can be applied to high power lasers with quite a few advantages [2]: (1) An increase in the band shift to shorter wavelengths of the band edge can be obtained, thereby improving the operation of the high power lasers. (2) DF-MQW can be easily obtained by using the existing fabrication technologies.

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High output power lasers are receiving a lot of attention for several different applications [3,4] such as free-space communications, optical storage, high-density optical disk memory systems and high-speed laser beam printers. The optical output power of semiconductor lasers is however limited by catastrophic optical damage (COD) [3-6] which results from local degradation of laser mirrors by laser light absorption in depleted regions as a consequence of thermal runaway. Moreover, larger threshold current is necessary for high power lasing operation. Consequently, the thickness of the active layer has to be increased and lower output power will be obtained [5]. Thus the COD threshold optical power density has to be increased to cater for high power laser operation. There are two possible solutions to increase the COD threshold optical power density: (1) Increase the lasing cavity stripe width or (2) use 'window' structure. The former method has the problem of instability and nonfundamental far-field patterns [3]. The latter method was proposed to have the property of less absorption adjacent to the mirror surface since evidence shows that decrease in adjacent mirror absorption will increase the COD threshold optical power density [5].

The 'window' at two ends of the sample are produced by using IFVD on the sample. The size of the 'window' is controlled by the size of the SiO_2 cap. IFVD and annealing promote the degree of interdiffusion of Ga and Al atoms, which results in a modification of bandgap energy and thus the refractive index . This implies that a tunable operation wavelength and high laser output power can be obtained. The 'window' structure therefore provide a mean to improve the reliability of the device by reducing facet degradation.

In this work, we report full steps of fabrication procedures and the use of IFVD to obtain the diffused AlGaAs/GaAs MQW. We also present the results of PL measurement and photovoltage measurement of the diffused AlGaAs/GaAs MQW for determining the 'window' performance in the high power ridge waveguide laser diode. In addition, limitation on the maximum output power has been determined.

Fabrication and Experiment

Undoped AlGaAs/GaAs MQW structure was grown on a n^+-GaAs buffer layer and n^+-GaAs substrate by Molecular Beam Epitaxy (MBE) in this experiment as shown in Fig. 1. The MQW consisted of five periods of alternating $Al_{0.24}Ga_{0.76}As$/GaAs layers with both of the $Al_{0.24}Ga_{0.76}As$ barriers and GaAs QWs having equal thickness of 100Å. The MQW was surrounded by $Al_{0.24}Ga_{0.76}As$ guiding layers. It was then cladded on the top by p-$Al_{0.44}Ga_{0.56}As$ (Be doped) and on the bottom by n-$Al_{0.44}Ga_{0.56}As$ (Si-doped) layers of equal thickness of 1 μm.

A SiO_2 layer of 2000Å was deposited on the surface of the sample by sputtering. The obtained sample was then put in a quartz box for RTA at temperatures ranging from 1000 °C to 1040 °C for 30 sec in flowing nitrogen at a rate of 2.5 litre/min. After annealing, the SiO_2 cap was removed in a buffered HF solution.

PL measurements were performed at room temperature. Blue shift of about 30 nm from 849.4 nm to 818.6 nm was obtained which implies that a good tunable operation wavelength has been achieved. Room temperature photovoltage measurements was also used to measure the blue shift of the bandgap. These two measurements show the tuning of bandgap by quantum wells intermixing.

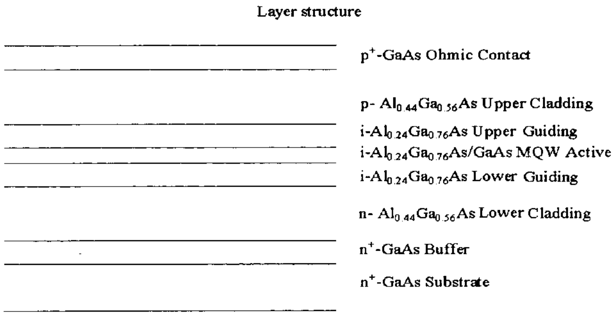

Fig. 1. Schematic diagram of the diffused multiple quantum wells structure.

The high power ridge waveguide laser diode has the same structure as the as-grown sample, but the window structure has been adopted to its ends and p^+-GaAs ohmic contact was deposited, as shown in Fig. 2. The ridge is 5 μm wide and 1.1 μm deep. Light outr t power versus current characteristics are obtained to determine the maximum output power and the threshold current.

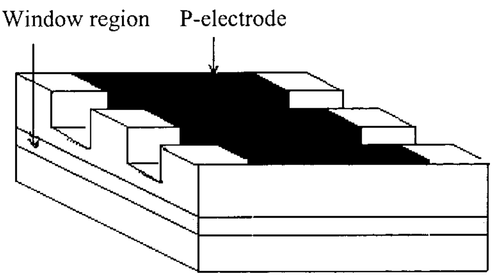

Fig. 2. Schematic diagram of the high power ridge waveguide laser with window structure.

Results and Discussion

PL spectra was used for monitoring the degree of compositional disordering and the transition energy between the first heavy hole and electron states in the AlGaAs/GaAs system. The PL measurements at room temperature are shown in Fig. 3. For the as-grown sample, Fig. 3 curve (a), an emission peak at 849.4 nm and a lower emission peak of shorter wavelength of 843 nm has found due to heavy hole (HH) and light hole (LH) excitonic transitions respectively. Fig. 3 curve (b) is the PL spectrum of sample after RTA at 1000 °C for 30 sec. The highest emission peak has shifted to a lower wavelength of 832.5 nm. The shoulder peak has disappeared. It is due to the broadening of PL spectrum. Such phenomenon shows the intermixing of the barriers and the wells which tunes the bandgap of the material. Fig. 3 curve (c) refers to another sample treated under RTA at 1020 °C for 30 sec. Its emission peak has shifted to 829.4 nm with broadening. The broadening can be explained by the increased intermixing of the well and barrier layers together with the well width fluctuation [7].

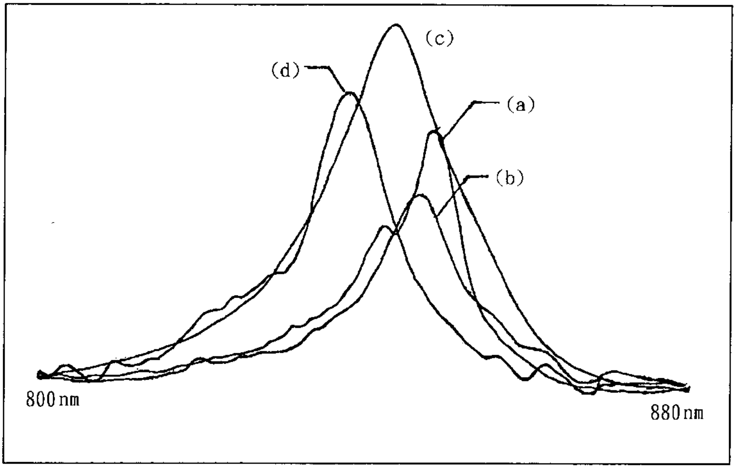

Fig. 3. Photoluminescence spectra of the DF-MQW sample, for (a) the as-grown sample, (b) RTA at 1000 °C shows a blue shift of 16.9 nm, (c) RTA at 1020 °C and (d) RTA at 1040°C show larger blue shift up to 30.8 nm.

Fig. 3 curve (d) shows the sample under RTA at 1040 °C for 30 sec. Its PL spectrum shifts further to the left, from 849.4 nm to 818.6 nm, giving 30.8 nm blue shift for its sample. The degree of intermixing depends on the annealing temperature. From the measurements, intermixing is enhanced with increasing temperature.

To verify the above result, photovoltage measurements have been performed using different samples treated at different RTA temperatures, and shown in Fig. 4. The spectra shown in the figure are the as-grown sample and those at different RTA temperature for 30 sec. Three absorption edges can be observed where the one at longer wavelength represents the band gap [8]. Such absorption edge has the trend of shifting to shorter wavelength as the annealing temperature increases. The as-grown sample has an absorption edge at 851 nm (1.458 eV) in Fig. 4 curve (a). If RTA is applied at 1000 °C for 30 sec in Fig. 4 curve (b), blue shift of absorption edge to 839 nm (1.479eV) results. For higher temperatures 1020 °C in Fig. 4 curve (c) and 1040 °C in Fig. 4 curve (d), the blue shift is enhanced up to 38 nm and 30 nm respectively. Thus, bandgap enlargement can be characterized by the blue shift of absorption edge. However, the measured absorption edge wavelength at 1020 °C is shorter than at 1040 °C. Such result is unexpected and which may be due to an error in measurement.

The high power ridge waveguide laser diode used in this experiment adopts the DF-MQW structure as the windows at the two ends. Fig. 5 shows the light output power versus current characteristics of high power ridge waveguide laser diode. Fig. 5 curve (a), shows the output power of a window structure laser diode with a threshold current at 85 mA and maximum power of 36 mW. For the conventional laser diode without the window structure,

Fig. 5 curve (b), a lower threshold current at 60 mA and maximum power at 30 mW result. The increase in higher output power is due to the tuning of the bandgap at the output window as a result of the intermixing of MQW which blue shifts the output wavelength. Also, the threshold

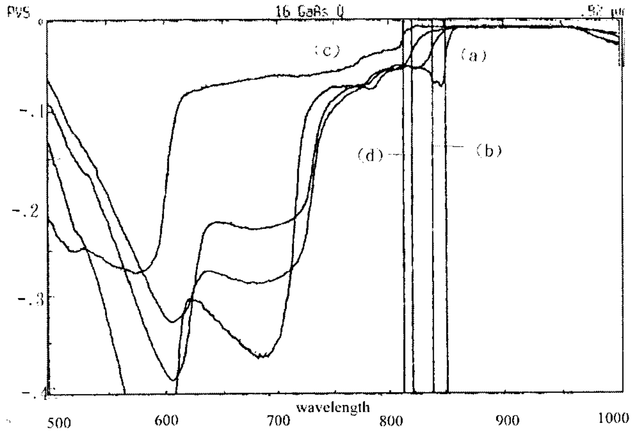

Fig. 4. Photovoltage spectra recorded at room temperature. The curves (a), (b), (c) and (d) represent the as-grown sample, RTA at 1000 °C, 1020 °C and 1040 °C respectively.

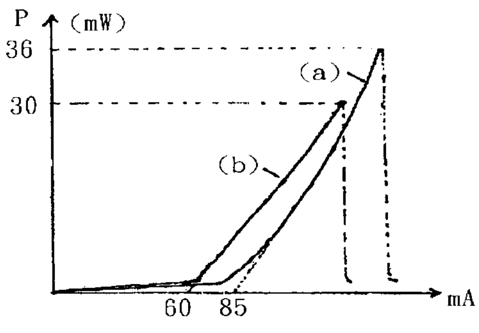

Fig. 5. Light output power (P) versus current curve characteristics of the high power ridge waveguide laser diode. (a) is the laser diode with window structure and (b) conventional laser diode without window structure.

COD power is observed to increase by 20% showing the potential of the window structure made by IFVD technique to obtain high power laser output.

Conclusion

Diffused multiple quantum wells can be easily obtained by IFVD under RTA at about 1000 °C for achieving a good tunable operation wavelength range. Results presented here show such ability by a large blue shift of more than 30 nm at an annealing temperature of 1040 °C. This diffused QW structure has been utilized to produce a window for high power ridge waveguide laser diode with an enhanced COD threshold power up to 20%. Therefore, the DF-MQW window structure made by IFVD technique is a very attractive technology to produce high power output in lasers.

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