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Natural Superlattice Disordering in GaInP/AlGaInP by Ultra-Low Energy Ion Exposure

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In this paper we demonstrate a new method for band gap engineering. We use ordered GaInP/AlGaInP samples which can be transformed into disordered material by Rapid Thermal Annealing (RTA). In photoluminescence (PL), the disordered state reveals a higher band gap by a value of 100 meV. An Electron Cyclotron Resonance (ECR) ion source was used for an ultra-low Ar^+ ion impact. We found a reduction of the minimum RTA temperature necessary for disordering by 250 °C. This reduction depends systematically on the ECR and RTA parameters. A possible application of this technique might be the fabrication of non-absorbing mirrors in GaInP/AlGaInP lasers.

1. INTRODUCTION

The material system GaInP/AlGaInP can be grown in a state where alternating monolayers of GaP and InP along (11-1)- or (1-11)-planes are formed. Such an ordered structure reveals a smaller band gap by a value of 100 meV in photoluminescence (PL) compared to the disordered state with statistically distributed In and Ga ions in the planes mentioned above. An ordered → disordered transition can be used to fabricate non-absorbing mirrors in GaInP/AlGaInP lasers if the effect propagates to a depth of 1 μm and more.

2. ION INDUCED DISORDERING

We used an ordered single quantum well (SQW) structure with L_z = 8 nm at a distance SQW - surface of D = 80 nm. The as grown PL spectra of the SQW and the $(Al_{0.33}Ga_{0.67})In_{0.5}P_{0.5}$ barrier are depicted in Fig. 1a. This structure can be disordered by using Rapid Thermal Annealing (RTA) (Fig. 1b: annealing temperature T_{RTA} = 925 °C, annealing time t_{RTA} = 60 sec). As a minimum temperature for this RTA process we found T_{RTA} = 875 °C.

Using an Electron Cyclotron Resonance (ECR) ion source to perform a low energy Ar^+ ion exposure[1)] (30 eV, 20 min) this temperature can be significantly reduced (Fig. 1c: T_{RTA} = 650 °C, t_{RTA} = 60 sec). By the Ar^+ ion exposure, defects[2)] are created in a layer a few nanometers thick beneath the sample's surface. During the RTA process the defects are propagating towards the

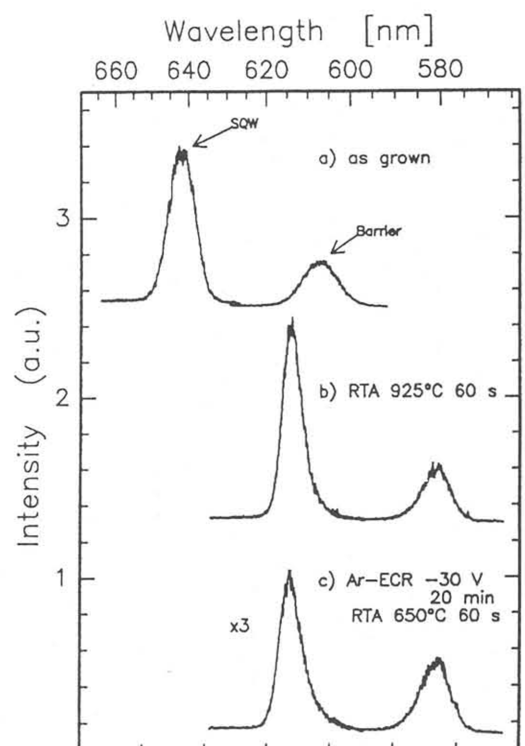

Fig. 1:
Photoluminescence (PL) spectra of a 8 nm GaInP single quantum well structure (SQW) and the $(Al_{0.33}Ga_{0.67})_{0.5}In_{0.5}P$ barrier after different processing:

a) as grown sample
b) RTA (925 °C, 60 s)
c) Ar^+ ion exposure (30 eV, 20 min) + RTA (650 °C, 60 s)

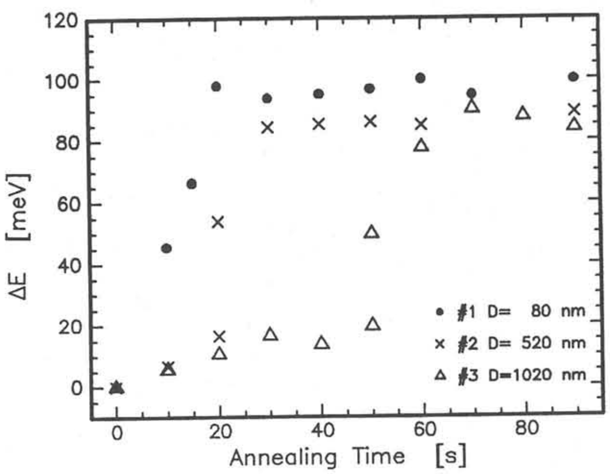

Fig. 2:
Shift ΔE of the PL peak energy as a function of the annealing time (Ar^+ ion exposure (30 eV, 60 min) + RTA (650 °C) for samples #1-3 with increasing distance D (80, 520, and 1020 nm, resp.) of the SQW to the surface

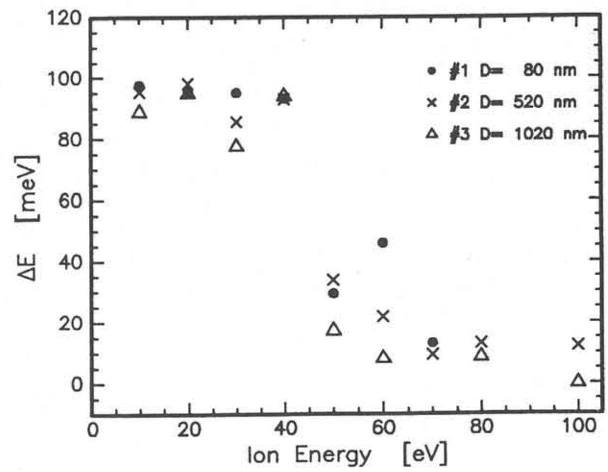

Fig. 3:
Shift ΔE of the PL peak energy as a function of the Ar^+ ion energy (ion exposure: 60 min + RTA (650 °C, 60 s), samples as in Fig. 2)

SQW. When they reach the SQW in a sufficient concentration the disordering can occur at a reduced RTA temperature. The intensity is reduced only by a factor as small as 3 (Fig. 1c). As can be seen in Fig. 1 c) as well, the energy shifts of the SQW and the barrier line, respectively, are nearly the same. This fact shows that the reason for the line shift is not intermixing of SQW and barrier material but an ordered → disordered transition. This result was confirmed by Secondary Ion Mass Spectroscopy (SIMS), performed under conditions for high depth-resolution (energy of the primary ions = 3 keV, angle of incidence = 70° off the normal incidence, low current density). Monitoring the Al-signal, we did not find any difference in the Al-concentration when we compare an as grown sample with a disordered sample as in Fig. 1 c). Therefore, we do not have a significant contribution of intermixing to the shift of the PL peak in energy.

The process of defect propagation can be seen very clearly in Fig. 2: To obtain a spatial resolution, a series of three samples (#1-3) with varying location of the SQW beneath the surface (D = 80, 520, and 1020 nm, respectively) was subject to an Ar^+ ion exposure with 30 eV for 60 min. For the order → disorder transition to occur, an increasing minimum annealing time t_{RTA} with increasing depth D of the SQW was found.

As shown in Fig. 3 the ion energy must not exceed 40 eV to make disordering at reduced temperature possible. With the ion energy above 40 eV the onset of sputtering as a competitive process inhibits the deposition of a sufficiently high concentration of defects in a surface-near layer because this layer itself is removed simultaneously. The fact that a high ion dose at very low ion energy (< 40 eV) is crucial for this method of material processing implies the necessity to use an ECR ion source.

3. LATERAL BAND GAP ENGINEERING

A masked sample with stripes down to 2 μm in width was used for lateral structuring by selectively disordering the non-masked parts of the sample. This possibility together with an effective depth of the method of more than 1 μm as found in Chapter 2 could lead to an application of this technique for the realization of non-absorbing mirrors in GaInP/AlGaInP lasers.

4. SUMMARY

In summary, an ECR ion source with Ar^+ ions at ultra-low energies (< 40 eV) has been used to establish a new technique for lateral bandgap engineering by inducing the ordered → disordered transition in GaInP/AlGaInP.

5. REFERENCES

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