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The structural and optical properties of InGaAs/GaAs MQW

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$In_xGa_{1-x}As$/GaAs multi quantum well (MQW) structure was grown using Molecular Beam Epitaxy (MBE) system. The structural analysis was performed by high resolution X-ray diffraction (HRXRD) method. The fringes in the Rocking curves show that the layer homogeneity and high crystal quality was achieved. In addition, the thickness of the quantum well and the In composition of the quantum well layer was obtained from the rocking curve simulation. The temperature dependent optical characterization was performed using photoluminescence (PL) method. The forbidden band gap energy and the In composition was obtained from room temperature PL results. The peak energy shift, activation energy and the full width at half maximum values (FWHM) were also obtained from temperature dependent PL measurements. At low temperatures below 77K, broadening of the full width at half maximum and a shifting of PL peak were observed.

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1. Introductıon

The As-based III-V group semiconductor quantum well (QW) structures such as $Al_xGa_{1-x}As$, $In_xGa_{1-x}As$ have been extensively studied due to the applications in optoelectronic and microelectronic devices [1-7]. Progress of epitaxial growth techniques as MBE and epitaxial growth on suitable substrates (GaAs, InP, etc.) is one of the key issues to achieve complex materials such as quantum wells (QWs), quantum dots (QDs), superlattices (SLs) etc. and high quality materials in the view of: (1) defect density that penetrates through the active layer and causes non-radiative recombination, (2) surface roughness that causes the alloy separation and optical emission broadening [8-10], (3) undesired strain that causes the relaxation with the formation of the dislocations at the interfaces [11] can degrade the electrical and optical properties of the devices. To produce the quantum-confined structures as lasers, solar cells that need the strain in the structures, the InGaAs is used instead of AlGaAs on GaAs substrates due to having the larger lattice constant difference [12], substrate transparency [11] and longer wavelengths.

The aim of this study is to optimize the $In_xGa_{1-x}As$ MQW structures on GaAs substrates for the device applications as quantum well infrared photodetectors (QWIPS) and optical fiber telecommunication lasers. In this paper, we have presented the detailed metamorphic growth and the structural and optical characterization of $In_xGa_{1-x}As$/GaAs MQW structures. The structures were grown using V80-H solid source MBE system. The structural characterization was performed using high resolution X-ray diffraction (HRXRD) system and the temperature dependent optical characterization was performed using photoluminescence (PL) system.

2. Experimental procedure

The $In_xGa_{1-x}As$/GaAs MQW structures was grown on epi-ready semi-insulating (SI) (100)-oriented GaAs substrate using V80-H solid source MBE system. The reconstruction and growth rate of the surface were determined by RHEED oscillations. The schematic structure of the grown $In_xGa_{1-x}As$/GaAs MQW is given in Fig. 1.

Prior to the growth the substrate was cleaned using acetone, methanol and deionized water for the removing of the organic impurities. In MBE system, firstly intrinsic i-GaAs buffer layer with 500 nm thickness was grown on GaAs substrate to provide the lattice match between the substrate and the epilayers and prevent the migration of defects and the impurities from substrate to the as grown epilayers. 1 μm thick Si-doped n-GaAs contact and 50 nm intrinsic i-GaAs spacer layers were grown. 5 nm thin Si-doped (7.2×10^{17} cm^{-3}) n-InGaAs well and 50 nm i-GaAs quantum barrier (QB) layers were grown on the spacer layer. This process was repeated 9 times to complete the growth of active region. The sample was completed by growth of 500 nm thickness n-GaAs contact layer.

The structural and optical analyses of the $In_xGa_{1-x}As$/GaAs samples were performed using Bruker-AXS-D8-Discover high resolution X-ray diffractometer and Horiba Jobin Yvon Fluorolog-3 photoluminescence (PL) system. In PL measurements, the He-Cd laser with 325 nm wavelength and 55 mw output power was used as an excitation source.

Fig. 1. The schematic structure of an $In_xGa_{1-x}As/GaAs$ *MQW.*

The sample emission was detected using LN_2 cooled InGaAs detector with 800-1600 nm spectral range. Temperature dependent PL measurements were carried out in the 12-77 K temperature range using closed cycle He cryostat. In mole fraction was obtained using high resolution x-ray diffraction and photoluminescence measurements.

3. Results and discussion

The nine period $In_xGa_{1-x}As/GaAs$ MQW structure was grown by MBE system. The structural characterization of the structure was carried out using HRXRD. The experimental w-θ rocking curve and the fit curve that was the simulation of the experimental data using LEPTOS program was given in Fig.2. The satellite peaks that appear in the figure occur due to the interference of the light at the interfaces. The existence of these peaks can be attributed to the high crystal quality and the layer homogeneity [13]. The narrow intense peak that positioned at 33^o was attributed to GaAs substrate peak while the other periodic peaks positioned at the right and the left sides of this peak can be attributed to InGaAs quantum well layers.

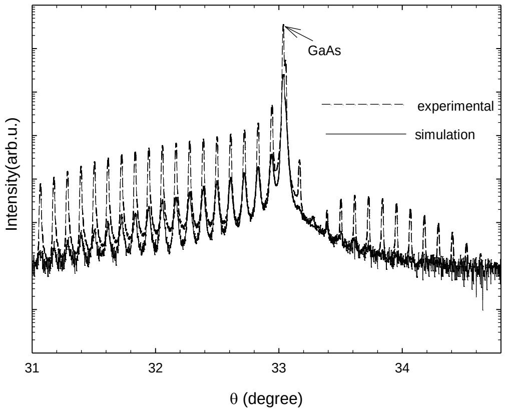

Fig. 2. Rocking curves of $In_xGa_{1-x}As/GaAs$ *MQW structures.*

The quantum well and barrier layer thicknesses and the In composition of the quantum well layers was obtained from the simulation results as 4.3 nm, 46 nm and %25.43, respectively. These results show that the desired thicknesses and the In composition for the $In_xGa_{1-x}As/GaAs$ MQW was achieved. It can be say that InGaAs well layers have compositional homogeneity due to the satellite peaks have not significant broadening [14]

The temperature dependent optical characterization of the $In_xGa_{1-x}As/GaAs$ MQW structures was performed using photoluminescence system. In Fig.3 the spectrum of the emission intensity versus photon energy is given.

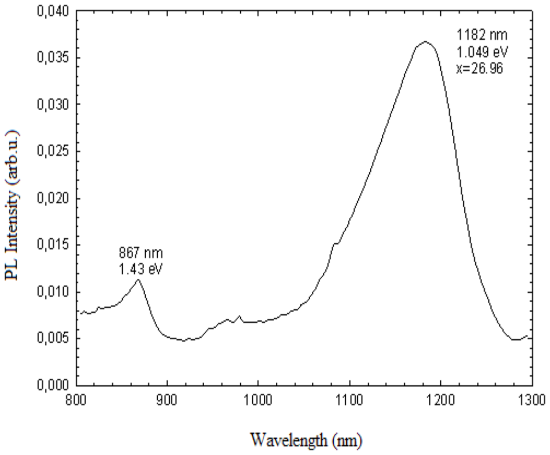

Fig. 3. $In_xGa_{1-x}As/GaAs$ *MQW room temperature PL spectrum.*

As can be clearly seen from the figure, the main two peaks were observed. The most intensive peak that positioned at 1,409 eV represents the band to band transition and originated from the active region of the structure while the other peak that positioned at 1,43 eV corresponds to the PL emission from GaAs layer.

At the high temperature, the transitions from the conduction band to the hole states of the thermalized carriers in the higher energy states have a broadening effect on the PL emission peak. This type broadening was observed for the peak comes from the InGaAs well in high energy regions as seen in Fig.3. The In content of the $In_xGa_{1-x}As$ quantum well layer was also calculated using band to band transition energy and the Vegard Law given below [15]

$$E_g(x) = 1.422 - 1.501x + 0.436x^2 \tag{1}$$

Where $E_g(x)$ is the composition dependent band gap energy in eV and x is the In composition. The In composition was found as %26.96. This value is in good agreement with the HRXRD results.

The temperature dependent PL measurements were also performed at temperature range of 12-77 K to investigate the thermal effecs on the PL emmission The low temperature PL measurement results were given in Fig.4.

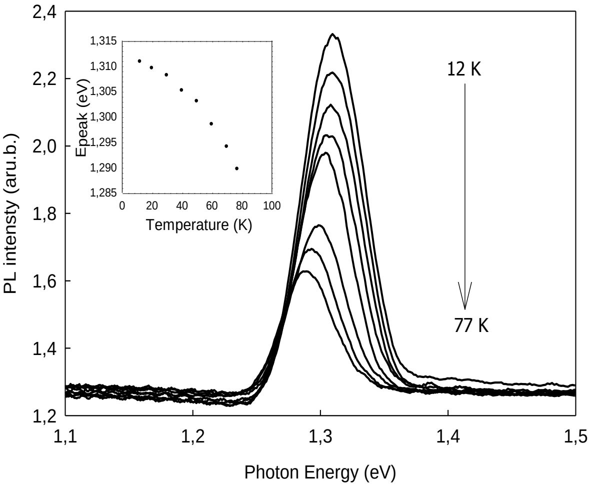

Fig. 4. Temperature dependent PL intensity versus photon energy. The peak energy shift versus photon energy was given as an inset.

As can be clearly seen from this figure, the band gap energy has red-shift as expected. It is known that the electron-lattice interactions have a main role on the shifting of the PL peak position with temperature. The band gap changed from 1.290 eV to 1.311 eV. The peak energy shift versus photon energy was given as an inset of Fig.4

In Fig.5 the Arrhenius plot of the $In_xGa_{1-x}As$/GaAs MQW structure was given. The plot consists of two linear regions as seen in the figure.

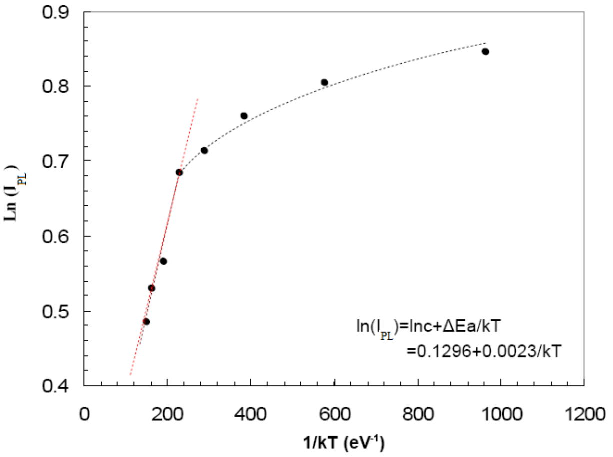

Fig. 5. Arrhenius plot of the $In_xGa_{1-x}As$/GaAs MQW structure.

The activation energy of the electrons that are confined in the quantum well region was calculated using the slope of the linear region of Arrhenius plot obtained by the relation is given by [7]

$$I = I_0\left[1+\frac{1}{c+\Delta E_a/kT}\right] \tag{2}$$

The activation energy was found as 2.3 meV and decrease with decreasing temperature. This energy is quite lower than the electrons and heavy hole’s energies of 91 and 104 meV for InGaAs quantum wells reported in Ref. 7. Thus, this behaviour was attributed to the lower confinement energy of the electrons positioned in quantum wells.

The temperature dependent full width at half maximum (FHWM) change was done in the temperature range of 12-77 K and the temperature dependent FHWM values was given in Fig.6. The FHWM values were found as 54.75 and 47.27 meV of 12 and 77 K, respectively. As seen from the figure, the FHWM values decreased upto 70 K. This abnormal behaviour, FHWM decrease with increasing temperature, can be attributed to the thermal runaway of the carriers from the InGaAs quantum wells or the tunneling of the carriers into the barriers. If the thermal energy is in the same order of electron’s exciton binding energy, the generated free carriers due to the dissociation of excitions tunnel into the barriers or escape from the quantum wells to find the localized energy minumum. Thus, the decrease of the free electrons cause the decrease of FHWM. The FHWM value increases as expected after 70 K due to the alloy scattering [16-19].

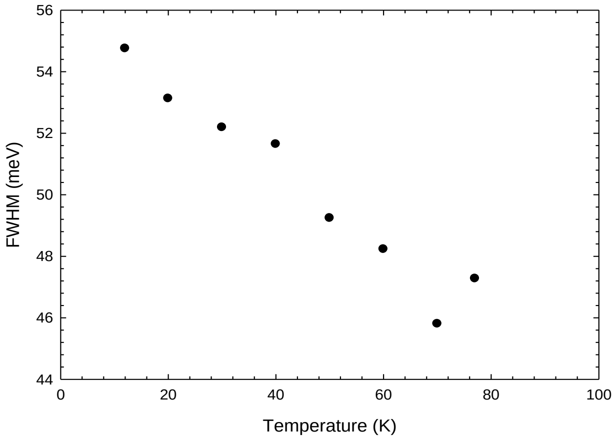

Fig. 6. Temperature dependent FHWM values for $In_xGa_{1-x}As$/GaAs MQW structure.

4. Conclusions

In this study $In_xGa_{1-x}As$ MQW structure was grown on semi insulating (SI) GaAs substrate using MBE system. The structural characterization was performed using HRXRD and the simulation was done using LEPTOS progam. According to simulation results, the quantum well and barrier thicknesses and the In composition of the quantum well layers was obtained as 4.3 nm, 46 nm and %25.43, respectively. In addition to the structural characterization, the temperature dependent optical characterization was performed using photoluminescence system to understand the emission nature of the active layer and also to find the In composition. The In composition was found as %26.96. The In compositions obtained from HRXRD and PL results are in a good agreement and shows that the desired structure was growth. In addition to In composition, the peak energy shift, the activation energy of the electrons and the full width at half maximum values was found from PL measurements. The peak energy shift with increasing photon energy was found that there is a red shift as expected. The activation energy of the electrons was calculated as 2.3 meV from the Arrhenius plot. The decrease of the activation energy with decreasing temperature was attributed to the lower confinement energy of the electrons positioned in quantum wells. The FHWM value decreases with increasing temperature upto 70 K, while increases with increasing temperature above 70 K. This abnormal behaviour upto 70 K was attributed to the thermal runaway of the carriers from the InGaAs quantum wells or the tunneling of the carriers into the barriers. The broadening of the FWHM above 70 K, the increasing of the FWHM with increasing temperature, was attributed to alloy scattering.

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