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Growth and characterization of Si doped InGaAs/GaAs Single quantum well.

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Abstract: *The effect of silicon on In GaAsSi/GaAs quantum well structures is investigated using high resolution X-ray diffraction technique (HRXRD) . The growth of quantum well is studied by surface electron microscopy (SEM). The surface morphology is studied using atomic force microscopy (AFM). It is observed from the AFM images that the roughness increases as Si doping increases. The incorporation of silicon also induces alloy non-uniformity in the quantum well, leading to an increased surface roughness. We found that the FWHM of the rocking curves of Si-doped InGaAs increase with increasing Si concentration, indicating the degradation of the crystal quality with increasing doping level.*

Keywords: *MBE, InGaAs, QW, HRXRD, AFM, SEM.*
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I. Introduction:

Optoelectronics based on very thin layers of semiconductor heterostructures, such as quantum wells (QWs), play an important role in many commercial applications [1]. Recently Indium gallium arsenide (InGaAs) has been the focus of research interest. For the production of semiconductor heterostructures various epitaxial methods are used like liquid phase epitaxy (LPE), chemical vapor deposition (CVD), metal organic chemical vapor deposition (MOCVD), molecular beam epitaxy (MBE), metal organic molecular beam epitaxy (MOMBE), vapor phase epitaxy (VPE) and metal organic vapor phase epitaxy (MOVPE) [2]. For our work, we have grown InGaAs epitaxial layers on commercially available GaAs substrates using molecular beam epitaxy. Molecular beam epitaxy takes place in high vacuum or ultra-high vacuum. The most important aspect of MBE is the slow deposition rate (typically less than 1000 nm per hour), which allows the films to grow epitaxially.

III-V compound semiconductors have been traditionally grown on (100) substrates because of the wide range of growth conditions which results in good epitaxial layer quality and well-established device processing technology [3]. Doping plays an important role in fabrication of most semiconductor electronic, opto-electronic, and all-optical devices, as it allows to engineer free carrier concentrations in various materials. Group III/V semiconductors are mainly doped either by volume-doping, when the dopant is co-deposited during growth of the doped layer or by delta-doping during which growth of a non intentionally doped layer is interrupted to deposit the "delta layer [4]. Although both techniques are rather well known and have been applied to various materials, characterization of doped layers in order to control free carrier concentrations with high accuracy remains a subject of discussion since it is crucial for high performance of certain devices [5]. Silicon has been used as a n-type dopant in many binary, ternary, and quaternary semiconductors, such as GaAs, InP, A1GaAs, A1GalnP, and GaInAs [6]. The spread of Si atoms and their electrical activity depend on the growth temperature and doping concentration [7].

In this work, we present a study of characterization of Si-doped InGaAs SQW grown on GaAs semi insulating substrate. We have grown Si-doped InGaAs SQW by MBE with doping densities 2.3×10^{16} /cm^3 ; 2.5×10^{16} /cm^3 ; 3×10^{16} /cm^3 and 4×10^{16} /cm^3 at a substrate temperature of 580°C.

II. Material and method:

The samples were grown using commercially available semi insulating GaAs substrate wafers. Each was loaded into the growth chamber of an all solid-source MBE machine DCA 450 model. Substrate temperature raised to 600^0C for oxide desorption to take place, once the sporty pattern is observed in RHEED window as shown in figure 1 ,buffer layer is grown after being out gassed in the preparation chamber by opening the Ga cell shutter, buffer layer is grown for to make surface smooth. A 270nm GaAs buffer layer was grown at 580^0C over pressure $3.8\text{x}10^{-8}$ torr., after the removal of the native oxide layer under arsenic overpressure. This was followed by deposition of 9 nm InGaAs doped with silicon. The target silicon composition was $2.3 \text{ x } 10^{16}$cm^{-3}. The substrate was then taken up to 480^0C and a layer of GaAs was deposited, to form a cap layer. For the samples, the arsenic pressure was kept at 7.4×10^{-12}torrs during the period of InGaAsSi deposition, ramping up, and GaAs capping. Then the sample was cooled down rapidly and removed from the MBE growth chamber. Reflection high energy electron diffraction (RHEED) pattern used to study surface reconstruction and growth rate measurement was recorded during the period of InGaAsSi deposition. The structural properties of the samples were investigated by using a Philips X'pert MRD high resolution X-ray diffractometer (HRXRD) and surface morphology was studied using atomic force microscopy (AFM).and Scanning Electron Microscopy (SEM).

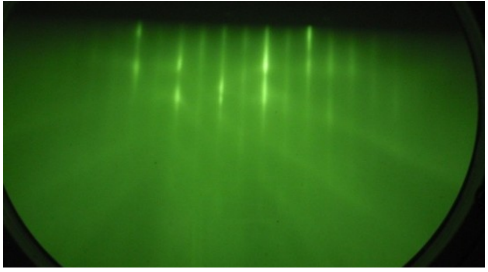


Figure.1. RHEED pattern after the growth of GaAs buffer layer

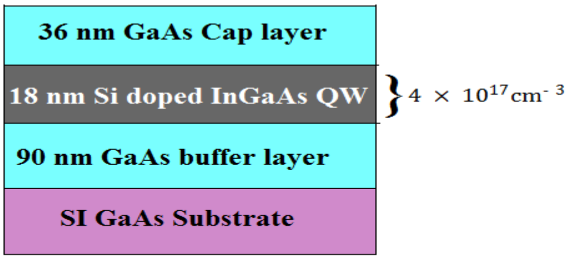


Figure.2. Schematic structure of InGaAsSi/GaAs SQW

III. Result and Discussion:

i. High Resolution X-ray Diffraction (HRXRD) Analysis

The elemental compositions in the QW samples were determined by the HRXRD (004) ω/2θ curves shown in Figure.3 .In each curve, the relatively narrow and strong peak comes from the GaAs substrate, while the broad and weak peak corresponds to the strained InGaAsSi/GaAs QW. The HRXRD intensities of the layer peaks are relatively weak, implying that the samples may be partly relaxed. The HRXRD spectra indicate that as the concentration of Si increases the layer peak shifts towards the lower angles.

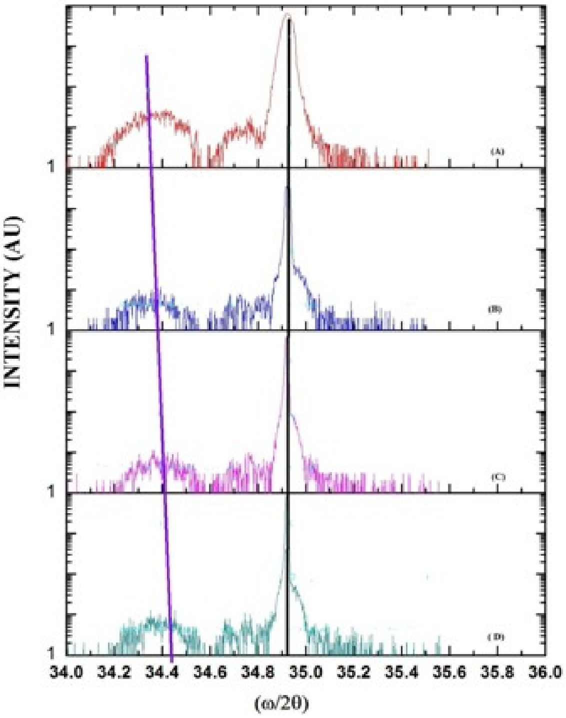


Figure 3. High resolution x-ray diffraction (HRXRD) spectra of Si doped InGaAs/GaAs With Si concentration (A) 4×10^{16} /cm^3 (B) 3×10^{16} /cm^3 (C) 2.5×10^{16} /cm^3 (D) 2.3×10^{16} /cm^3

ii. Scanning Electron microscopy (SEM) analysis:

Figure 4 shows the cross-sectional view of scanning electron microscopy image for Si doped InGaAs/GaAs SQW. The image brings information about uniform distribution of the layers, however the measurement of the thickness of subsequent layers is difficult.

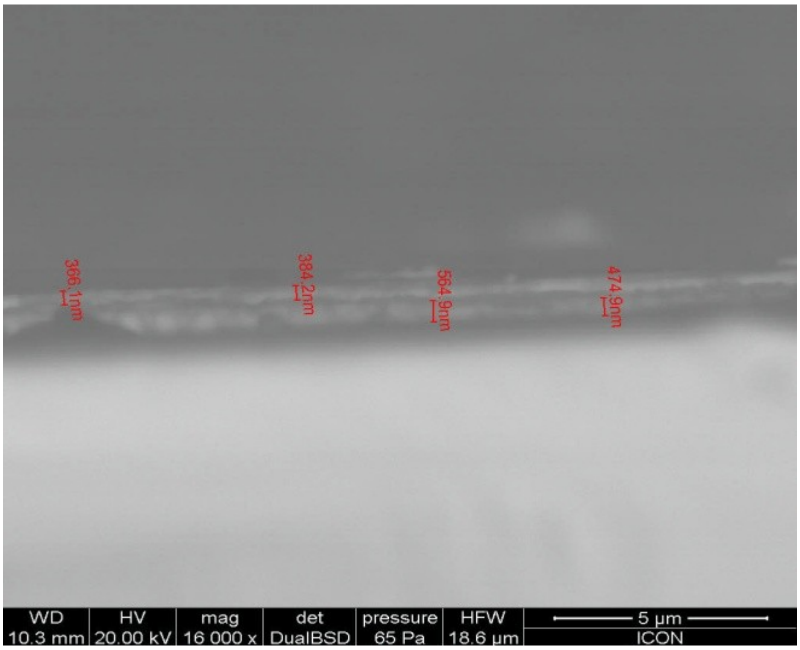


Figure 4. SEM image of an InGaAsSi SQW

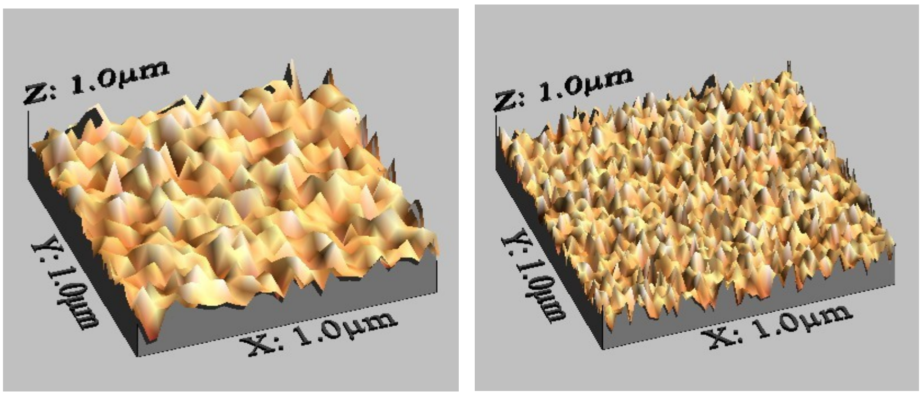
iii. Atomic force microscopy (AFM) analysis:

An atomic force microscope (AFM) is widely used now for a surface morphology control of semiconductor device structures. At the same time, surface roughening originates partly from the defects in the inner layers and, therefore, the AFM may be used as a sensitive technique for a layer structure transition analysis.

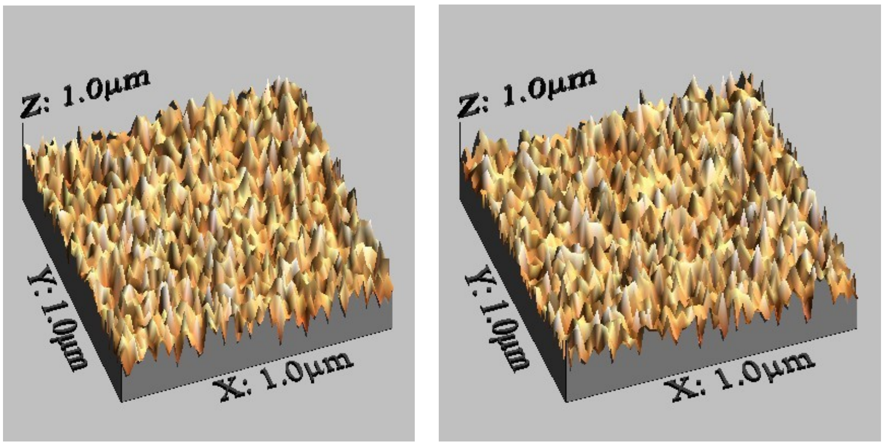
Literature on surface morphology studies is very limited for Si doped InGaAs/GaAs SQW structures. The surface morphology of the structures (3 D images) is shown in figure 5(A, B, C, D) with root mean square (rms) roughness value as high as 0.2533.

Sr.No	Si concentration	Roughness
1	4×10^{16} /cm^3	0.2533
2	3×10^{16} /cm^3	0.2486
3	2.5×10^{16} /cm^3	0.2417
4	2.3×10^{16} /cm^3	0.2416

Table 1: Roughness with reference to Si Concentration



(A) **(B)**



(C) **(D)**

Figure 5: AFM images of Si doped InGaAs/GaAs with Si concentration (A) 4×10^{16} /cm^3 (B) 3×10^{16} /cm^3 (C) 2.5×10^{16} /cm^3 (D) 2.3×10^{16} /cm^3

IV. Conclusions:

In GaAs quantum well doped with Si are successfully fabricated which can be used as active materials in various optoelectronics devices. Observed XRD patterns very well confirm the quantum well. This is complemented by the results obtained from SEM image. As the silicon doping increases the surface roughness increases. The results confirm that AFM analysis of surface makes it possible to establish the critical layer transition in the inner thin layers of a structure.

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