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2MeV-He Ion Channeling Studies of MOVPE-grown GaInNAs Single Quantum Wells

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Abstract

The channeling technique of 2-MeV He^+ ions is applied to analyze the lattice structure of GaInNAs quantum wells sandwiched by GaAs barrier layers. The structure-sensitive channeling measurements reveal that the GaInNAs layer contains significant lattice distortion even after post growth annealing at high temperatures. However, there exist no well-defined point defects such as tetrahedral interstitials. Our results suggest that the interstitial In atoms diffuse by annealing effect and we roughly estimate that the interstitial In atoms reduces the fraction by ~10 % after annealing. Therefore, we

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demonstrate that the drastic improvement of optical characteristics originates from the In diffusion by the annealing.

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Key Words: GaInNAs quantum well, RBS/channeling, lattice strain

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Introduction

The GaInNAs system is attracting increasing interests owing to the fact it can be grown on GaAs substrates, and has potential application to low-cost and un-cooled long wavelength light emitters such as 1.3 μm laser diodes. The epitaxial growth of GaInNAs layers has been attempted by using metal-organic vapor phase epitaxy (MOVPE) as well as molecular beam epitaxy (MBE), and fairly good crystalline quality was confirmed in both cases. Kondow et al [1] first proposed the GaInNAs material system, grew the alloy by MBE and detected a photoluminescence peak in the long-wavelength range at room temperature. Many studies have shown that the GaInNAs can be improved in its photoluminescence and other properties by annealing, but its reason is not known. The MOVPE-grown GaInNAs/GaAs quantum well structures were characterized by using x-ray diffraction (XRD), secondary ion mass spectrometry(SIMS), photoluminescence(PL) and photoreflectance (PR) spectroscopes [2,3].

In the present study we apply 2 MeV-He^+ ion scattering to analyze the as-grown and annealed GaInNAs/GaAs as well as GaInAs/GaAs quantum structures. Also we perform the so-called tri-angulation, i.e. the angular scan profile measurements about three major axes, that is sensitive to the lattice distortions and defects.

Experimental results and discussion

The single quantum well (SQW) samples were grown on GaAs(001) substrates by low pressure MOVPE with horizontal reactor. As shown in Fig.1, the buffer layer is 200 nm GaAs, the active layer is 7 nm $Ga_xIn_{1-x}N_yAs_{1-y}$, and the cap layer is 90 nm GaAs. This thick cap layer was deposited to approach the real device structure. We prepared three samples A,B and C for this study. Sample A was grown at 525 ˚C and its composition is (x,y)=(0.74, 0), i.e. this is GaInAs SQW without N. Sample B and C has the composition (x,y)=(0.70, 0.01) and (0.69, 0.01), respectively, and both were grown at 510 ˚C. After the growth, only sample C was thermally annealed at 670 ˚C for 10 min. The annealing was done in tertiarybutylarsine (TBA) ambient which is the best atmosphere to improve the GaInNAs properties.

The ion dosage was fixed at 20 μC per one spectrum measurement. The scattered α particles were detected by a conventional detector located at a scattering angle of 168˚. In the channeling measurements, we selected three major axes, <001>, <011> and <111>.

Figure 2 shows typical RBS/channeling spectra from sample B. Only the higher energy part is shown for clarity. The In signal can be seen at a scattering energy of about 1.73 MeV. Hereafter we notice only the scattering intensity from In and As+Ga as indicated as Region of Interest (ROI) 1 and 2 in Fig.2. Although the random spectrum seems featureless, the <011> channeling spectrum shows small bumps in ROI2. As will be discussed later, these bumps reflect a poor crystalline quality of the active layer. Figure 3 shows enlarged channeling spectra and compares two cases, one is when the ion beam is aligned to the normal <001> axis and the other is to the non-normal <011> axis. The In scattering intensity is quite different from each other, as well as the surface As+Ga scattering intensity. The <111> aligned channeling spectrum seemed very similar to the <011> case in every aspect, therefore not shown in Fig.3.

Angular scan profiles for all samples are shown in Fig.4. The scattering yield means the integrated total counts in ROI1 and 2 in Fig.2. The As+Ga normalized yield shows the conventional channeling dip in every profile, though the minimum yield (χ_{min}) is deeper in the normal <001> case than the <011> and <111> non-normal cases. The In normalized yield, on the other hand, shows asymmetric dip curves.

As shown in Fig.4, the GaInAs sample (sample A) shows almost identical As+Ga and In profiles in the <001> scan, but in the <011> and <111> scans the In profile shows that the channeling dip is negatively shifted and it is significantly shallow. These features of the channeling dip curves are frequently observed for pseudomorphic layers of slightly mismatched systems. According to the lattice parameter mismatch between GaInAs and GaAs substrate, the GaInAs film is strained in compression in the plane parallel to the surface and in tension in the perpendicular direction. In the <011> channeling case, the In dip is shifted by -0.8 deg. with respect to the As+Ga dip.

The GaInNAs layer, on the other hand, exhibits very contrasting features as shown in the middle column of Fig.4. The <001> angular scan is similar to the GaInAs case, but in the <011> and <111> angular scan curves we clearly identify the In channeling peaks and dips. A channeling peak indicates that the target atoms are located far away from the lattice site of the host material as the interstitials or random clusters. However, since the sample has a thick cap layer the ion steering effect may be possible [4,5]. This effect influences the angular scan profiles to result in, for example, an asymmetric dip curve or large scattering yield near the channel center. In this interpretation, the <011> angular scan profile of sample B has a dip at -1.0 deg. The <111> angular scan also exhibits the channeling peak near the center and the dip at -1.2 deg. The In atoms in the GaInNAs alloy are perfectly registered to the host GaAs lattice when viewed from the <001> direction, but a fraction of them are not registered in the <011> and <111> directions. The fraction of nonrandom or registered In atoms, f_{nr}, can be calculated by $f_{nr} = (1-\chi_{In})/(1-\chi_{GaAs})$, where χ_{In} and χ_{GaAs} are the minimum yields of In and As+Ga scattering intensity, respectively [6]. In the present case, however, since the χ_{In} near the center is too large, we consider that the flux peaking effect must be taken into account. This effect has been estimated by the computer simulation based on the continuum model in a diamond lattice structure to be ~2 times near the channel center [7]. Therefore we modify the equation to be $f_{nr} = (1-\chi_{In}/2)/(1-\chi_{GaAs})$. Applying this equation to the present results, we roughly estimate f_{nr} of about 70 % for the <011> direction, which agrees fairly well with the medium energy ion scattering (MEIS) result of 77 % [8].

The effect of annealing on the atomic structure of GaInNAs alloy can be assessed from the last column of Fig.4. The scan profiles and peak heights show small modifications suggesting diffusion of some In atoms due to the annealing. By the same calculation as described above, the fraction of diffused In atoms is estimated to be 10 % at most in the <011> direction. Also the χ_{In} at the dip position is slightly deeper after annealing than before. All of these results suggest the In atoms diffusion by the annealing effect.

Conclusion

We have studied the GaInNAs/GaAs single quantum well structures using 2 MeV-He^+ ion RBS/channeling technique. Channeling angular scan measurements showed a deep channeling dip in the <001> direction, and characteristic channeling peaks and dips in the <011> and <111> directions. These results indicate that the GaInNAs alloy contains largely displaced In atoms in contrast to the elastically strained structure of the GaInAs/GaAs SQW. The lattice location of In atoms is certainly not well-defined interstitial. After annealing, the channeling profiles showed the modification suggesting the In diffusion. Therefore, our results indicate that the drastic improvement of optical characteristics originate from the In diffusion by the annealing.

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Figures captions

Fig. 1. Sample structure and various ion beam incident directions.

Fig. 2. RBS/Channeling spectra from as-grown GaInNAs sample (sample B). Aligned spectrum is shown for the He^{+} ions incidence along the <011> axis.

Fig. 3. Comparison of <001> and <011> channeling spectra. The In and surface Ga+As region is enlarged.

Fig. 4. Tri-angulation results of GaInAs, as-grown GaInNAs and annealed GaInNAs.

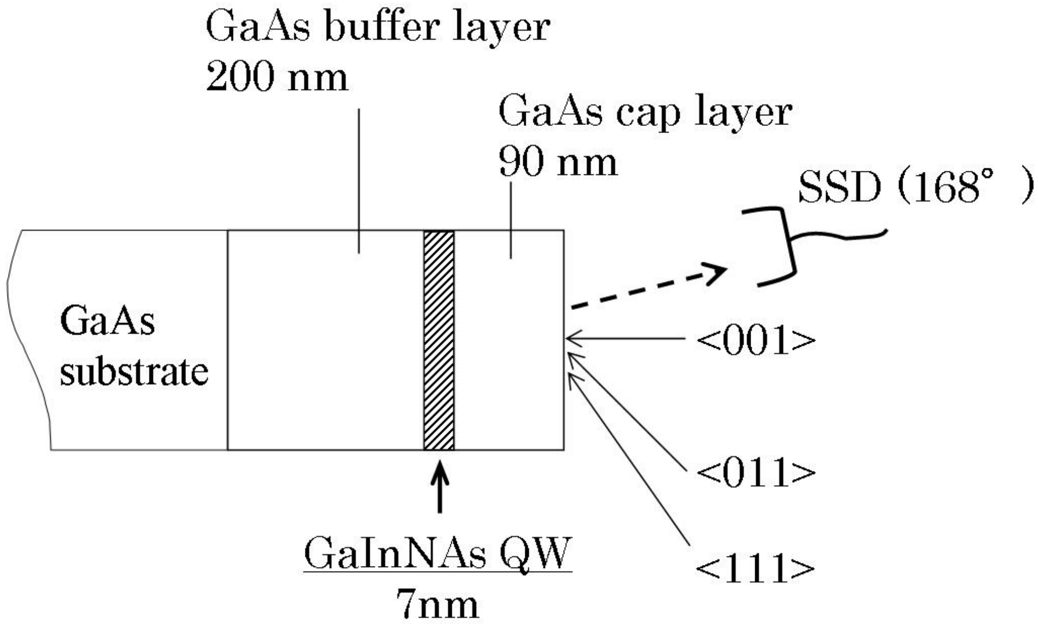
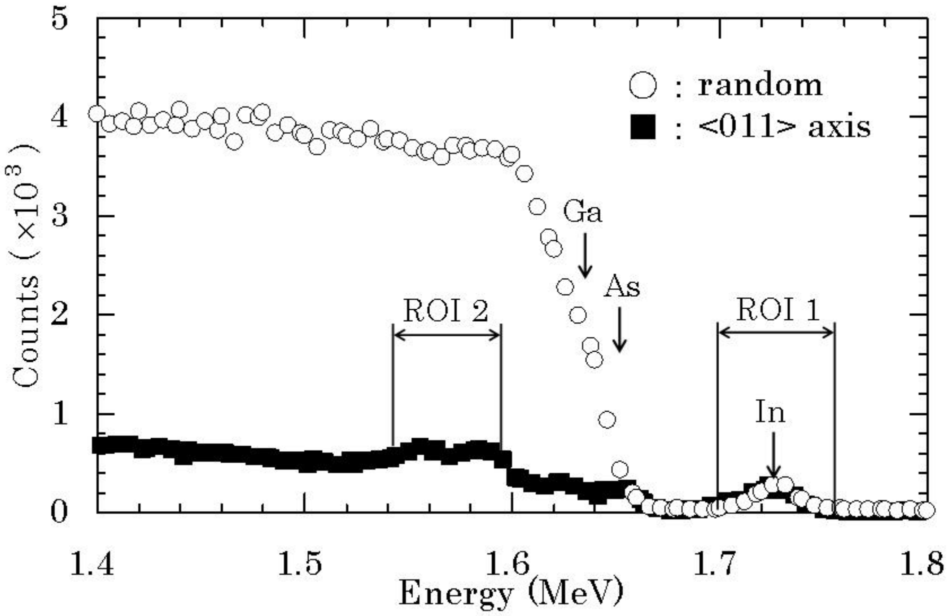

GaAs buffer layer
200 nm
GaAs cap layer
90 nm
SSD (168°)
GaAs
substrate
<001>
<011>
<111>
GaInNAs QW
7nm

Figure 1



5
4
3
2
1
0
Counts (×10³)
○ : random
■ : <011> axis
Ga
As
ROI 2
ROI 1
In
1.4
1.5
1.6
1.7
1.8
Energy (MeV)

Figure 2

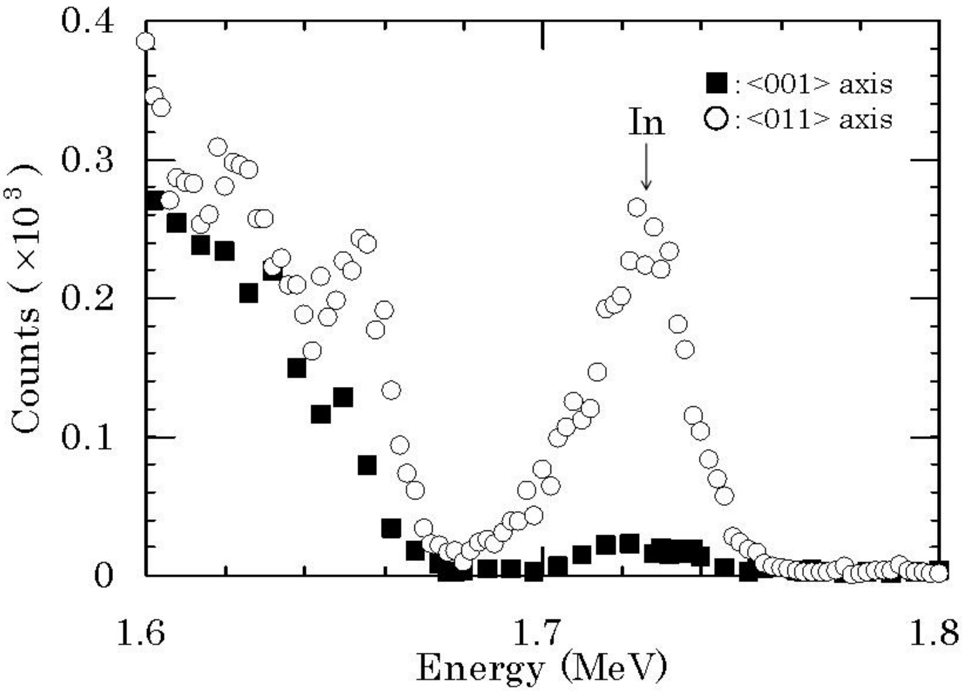


Figure 3

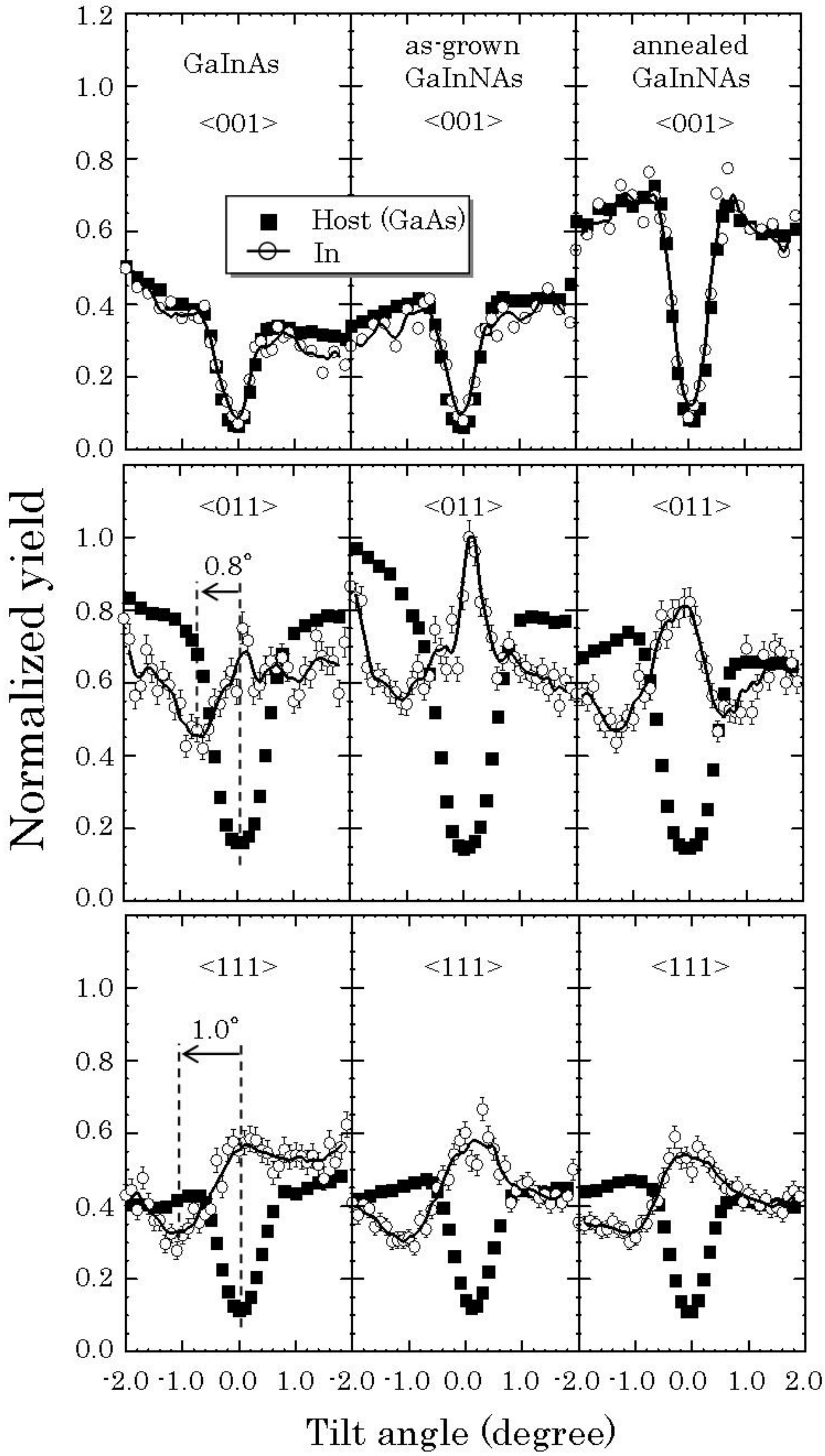

GaInAs
as-grown GaInNAs
annealed GaInNAs
<001>
<011>
<111>
Host (GaAs)
In
0.8°
1.0°
Normalized yield
Tilt angle (degree)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-2.0 -1.0 0.0 1.0 2.0

Figure 4