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# Thermal Annealing Effect in GaInNAs Thin Films Estimated by X-ray Absorption Fine Structure Spectroscopy

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## 1. Introduction

GaInNAs is a III-nitride compound semiconductor and a very promising material for near infrared devices which can be fabricated on GaAs substrates [1-2]. However, thermal annealing, which is required to improve its crystal quality and luminescent efficiency, causes reduction of the N contents and enlargement of the bandgap energy [3-4]. Nitrogen out-diffusion [4] and shortened Ga-N bond length [5] due to the annealing has been investigated as a reason of the annealing effect by other researchers. The annealing effects consist of two material behaviors. One is that the peak photoluminescence (PL) intensity rises with increasing annealing temperature. The other is that by increasing annealing temperature the PL peak shifts shorter wavelength. We have considered site-exchanges that affect PL peak intensity and peak energy would also occur in GaInNAs by the annealing [6-8]. Our first experimental investigation on the change of short-range order in GaInNAs thin films has been done by using X-ray absorption fine structure (XAFS) spectroscopy at room temperature [6]. In this study, we examined the change of atomic alignments around In atoms by the comparison between as-grown and thermally annealed GaInNAs samples by using low-temperature XAFS spectroscopy. Clear structural change that is supposed to relate to In-N bonds has been observed owing to the low-temperature measurements and comparison between experimental and simulated results can be possible.

## 2. Experiments

The samples were grown on GaAs (001) substrate by using molecular beam epitaxy with an electron cyclotron resonance (ECR) plasma source. The growth temperature was 480°C and GaAs growth rate was about 0.5μm/hr. $N_2$ gas flow rate was 1.0 sccm and the incident power of 2.45GHz microwave was 300W. The thickness of GaInNAs layer was 0.3μm, which was grown on undoped 0.5μm GaAs buffer layer. Figure 1 shows X-ray diffraction ω-2θ curves of the (004) peaks from GaAsN and GaInNAs films. The GaAsN film was prepared for the estimation of N content of the GaInNAs layer. As a result, N and In contents can be described as $Ga_{0.78}In_{0.22}N_{0.013}As_{0.987}$ estimated by Fig.1. Thermal annealing was carried out in the MBE growth chamber at 600°C for 1 minute under As irradiation.

Low temperature (30K) fluorescence XAFS measurements around In-K edge (27.9keV) were carried out at BL01B1 at SPring-8 in Harima (Hyogo Prefecture), Japan. A liquid nitrogen cooled 19 elements Ge detector with an Al filter was used for detecting the X-ray fluorescence from the sample. The samples were cooled down to around 30K by using He closed flow cryostat.

## 3. Results and Discussions

Figure 2 shows the measured radial distribution function around In atoms of the as-grown and the annealed GaInNAs samples (solid lines). The peaks labeled with A, B, and C can be clearly observed than in our first XAFS

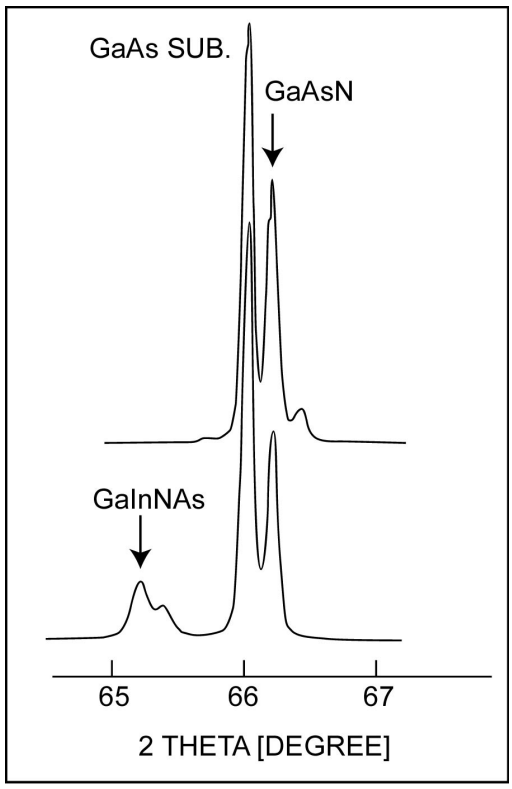


Fig.1 X-ray diffraction 2θ-ω curves of the (004) peaks from a GaAsN and GaInNAs films on GaAs.

experimental results [6-8]. Suppressing thermal vibration of atoms in GaInNAs samples by the cooling enables these peaks clearly to be derived.

Also in Fig. 2, simulated results for two models of bond alignments of (a)In-As-Ga and (b)In-N-Ga are shown (broken lines). The peaks labeled with B and C originate in the second neighbor Ga atoms of the model (a). This is the most alignment in the GaInNAs samples because of dilute nitrogen composition. The peak A, which appears only in the annealed sample, can be considered to originate in the second neighbor Ga atoms of the model (b) in comparing with the simulated results. The growing of peak A by the annealing means the increase of the number of the atomic alignment of model (b) in the GaInNAs samples. These results show that the considered phenomena in GaInNAs samples are the following two cases : (1) the number of In-N bonds increases and (2) bond length is shortened drastically due to the annealing. Calculated results on the total energy of crystal structure with different local atomic alignments are necessary to obtain a clear explanation on the interpretation of these experimental results.

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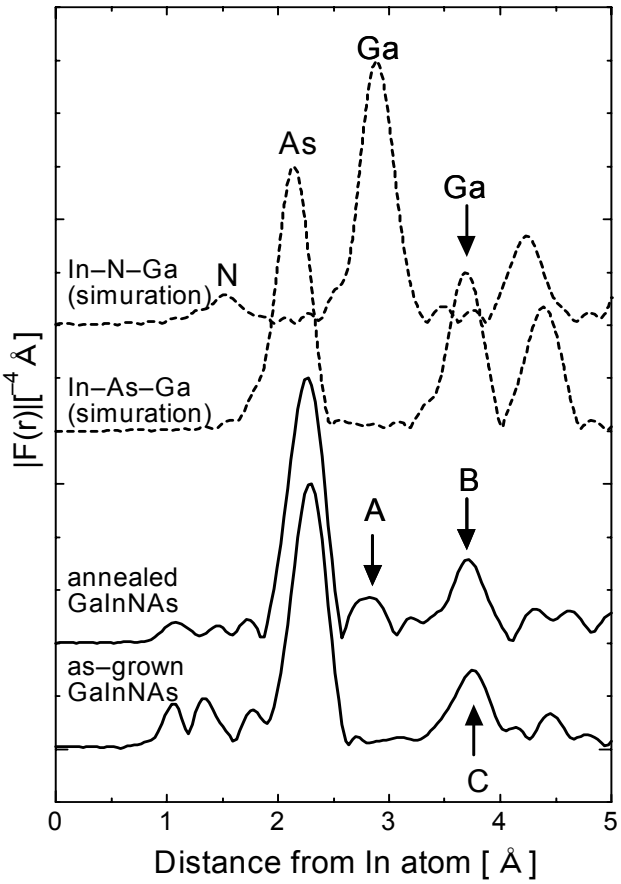


Fig. 2 : Solid lines show radial distribution function around In atoms of the as-grown and the annealed GaInNAs samples. Broken lines show simulated results for two models of bond alignments of (a)In-As-Ga and (b)In-N-Ga