III-N-V 半導体におけるアニール効果の放射光を用いた硬X線光電子分光法による研究
Analysis on the annealing effect of III-N-V semiconductors by hard X-ray photoelectron spectroscopy using synchrotron radiation

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Abstract

We compare bulk sensitive hard x-ray photoelectron spectra of an GaInNAs/GaNAs multiple quantum well samples before and after annealing. We observe a peak at around 6614 eV close to As2$p_{3/2}$ for as-grown sample, which vanishes after annealing. That can be considered to be related to the reduction of O related defects or N antisites or interstitials by the annealing. We observe In peak of buried GaInNAs layer 15 nm deep inside the material, which show an energy shift towards smaller binding energy side after annealing. In contrast, Ga, As and valence band edge does not show the behavior. That suggest the atomic rearrangements of In.

Key Words： Hard x-ray XPS, Semiconductors, Optical-fiber communications, GaInNAs, Anneal

Introduction：

Group III-nitride-arsenides (III-N-V) are promising materials for 1.3 and 1.55 μm telecommunications optoelectronic devices on GaAs substrates, or a monolithic electronic/optical integrated circuits on Si. It has been shown that annealing significantly improves the optical properties of those materials, but it also results in a blueshift of the band gap which is usually undesirable for long wavelength application. The blueshift has been mostly attributed to the atomic rearrangement of N and In.[1] Recent progress of third-generation synchrotron light sources enables delivery of unprecedented high photon flux with energy of around 7 keV. These sources can make high-energy and high-resolution x-ray photoelectron spectroscopy (XPS) accessible. The larger escape depth of photoelectrons with higher kinetic energy will facilitate studies of electronic structures and/or chemical states of bulk materials, nanoscale buried layers and their interfaces since the contribution to the detection of signal from the surface region will be small. Then, we study the annealing effect of III-N-V materials using hard x-ray XPS.

Experiment：

We study the annealing effect of a III-N-V semiconductor GaInNAs by hard x-ray XPS, at SPring-8 BL46XU. The system utilizes hard X-ray (6-8 keV) from high brilliant synchrotron radiation, achieving a probing depth of as deep as around 20 nm that enables to observe electronic states inside the material non-destructively and making the measurement bulk-sensitive. A sample contains 10-periods GaInNAs multiple quantum wells (MQWs) having 14 nm $GaN_{0.005}As_{0.995}$ barrier layers sandwiching 8 nm $Ga_{0.64}In_{0.36}N_{0.045}As_{0.955}$ QWs. Hence, we can detect the information from both the top $GaN_{0.005}As_{0.995}$ barrier and the buried $Ga_{0.64}In_{0.36}N_{0.045}As_{0.955}$ QW. We compare the spectra of the sample before and after annealing.

Results and discussion：

Figure 1 (a) shows wide range XPS spectra of the MQWs . Due to the large X-ray energy, we could detect the peaks of strong binding energy, enabling the successful detection up to As2*s* peak. Figure 1(b) shows the spectra around As2$p_{3/2}$ for the as-grown and annealed samples. Specifically, we observe a peak at around 6614 eV for as-grown sample. In contrast, the peak was vanished after annealing. The peak can be

related to As-N or As-O bonding. Consequently, annealing presumably removes those bonding configurations, corresponding to the reduction of O related defects or N antisites / interstitials.
Due to the large x-ray energy, we could successfully detect a peak related to In of GaInNAs layer buried 15 nm deep from the surface, which is usually not accessible by conventional XPS. Figure 2 shows spectra around (a) In3*p* and (b) Ga3*d*/In4*d* for the sample before and after annealing. It should be pronounced that the peak related to In shows a shit of their peak energy toward higher kinetic energy side, corresponding to the peak shift toward lower binding energy side. In contrast, the other peaks of As, Ga and valence band edge do not show such energy shift. This can mean that atomic arrangements surrounding In were modified by the annealing. We can not observe clear spectra from N because of its small ionization cross section for the high x-ray energy. Nevertheless, that could reflect the atomic rearrangements between In and N as have been reported [1] .

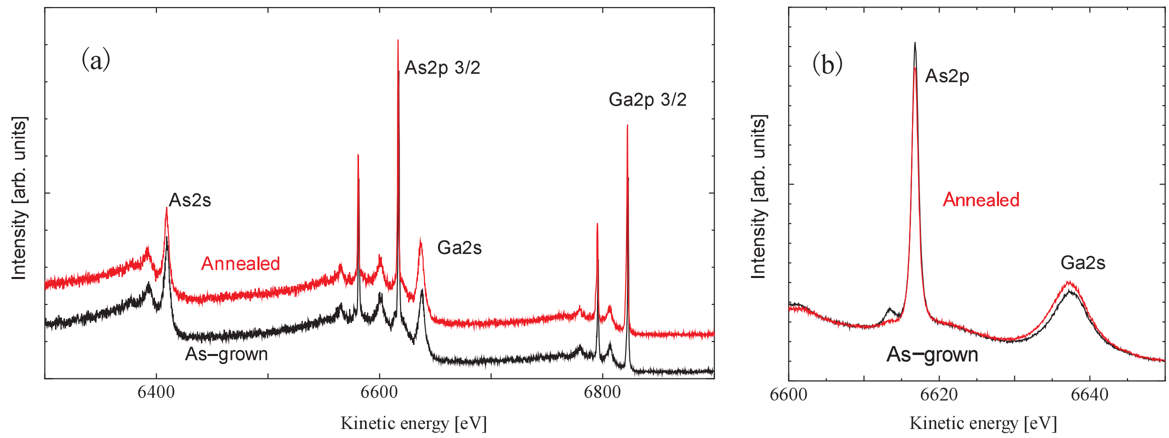

Fig. 1 (a) Wide scan and (b) around As2*p* spectra for as grown and annealed samples.

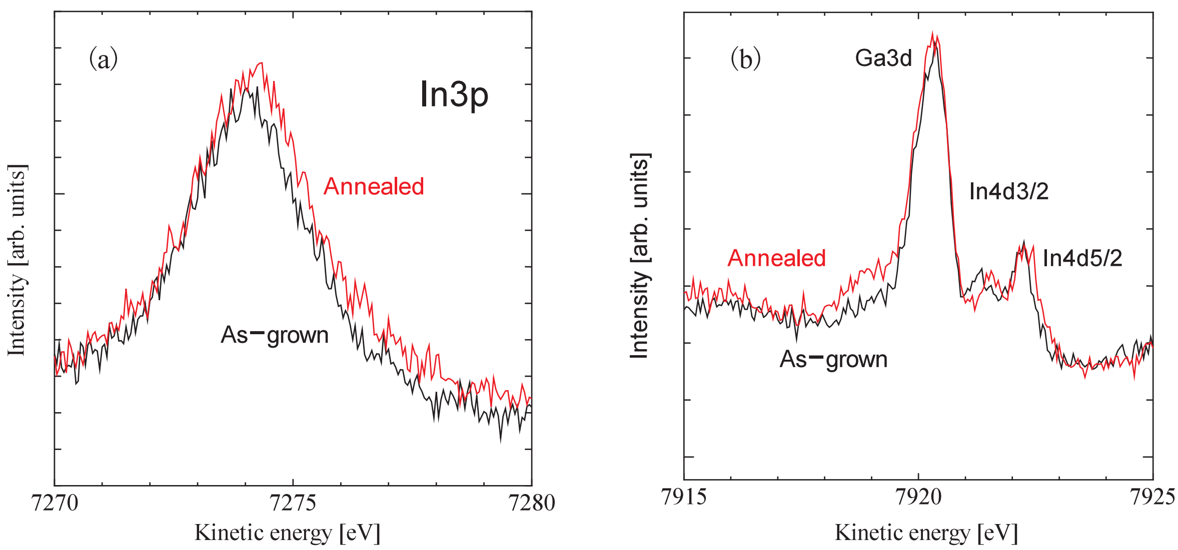

Fig. 2 XPS spectra around (a) In3*p* and (b) Ga3*d*/In4*d* for as-grown and annealed samples.

Future issues :

Here we report the preliminary result of XAFS measurement on our sample. The measurement was successfully carried out. We will proceed further precise analysis on the results including theoretical approach.

Reference :

[1] Lordi et. al, Phys. Rev. Lett. 90, 145505 (2003).