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光ファイバー通信用(Ga,In)(N,As)系半導体におけるアニール効果のXAFS法による研究
Analysis on the annealing effect of fiber-optics application (Ga,In)(N,As) semiconductor by XAFS

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We study annealing effect of GaInNAs/GaNAs multiple quantum wells by depth-resolved/ polarization dependent extended x-ray absorption fine structure. The radial distribution function around Ga and In atom shows that the system around In, corresponding to inside the QW, is more strongly microscopically distorted compared to GaNAs barrier. After annealing, the peak intensity of the Ga-As related peak increased, and the In-As related peak decreased. That can be due to the effect of atomic rearrangement of those materials. The x-ray beam polarization dependency suggests that the atomic rearrangement occurs anisotropically.

Key Words： XAFS, Semiconductors, Optical-fiber communications, GaInNAs, Anneal

Introduction：

Group III-nitride-arsenides are promising materials for 1.3 and 1.55 μm telecommunications optoelectronic devices and 1.0 eV materials for solar cells grown on GaAs substrates. It has been shown that annealing significantly improves the optical properties of this material system, but it also results in blueshift of the emission which is undesirable for long wavelength application. The blueshift has been mostly attributed to the atomic rearrangement of N and In.[1] The origin of the blueshift is the focus of this study and here we try to analyze its microscopic atomic structure by advanced X-ray absorption fine structure measurements.

Experiment：

We study the annealing effect of GaInNAs by depth-resolved extended x-ray absorption fine structure (EXAFS). The local structure around Ga and In atoms of 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. The measurement was carried out at SPring-8 BL37XU. Using linearly polarized x-ray whose electric field was set to be both horizontal and vertical to the sample, we obtain the information of the anisotropy of the local structure. The In K-edge result contains the information solely from the QWs. In contrast, we carry out surface sensitive measurement to resolve the information from the substrate for Ga K-edge measurement. The result contains the information stemmed from top 40 nm of the sample, corresponding to the two periods of the barries and QWs.

Results and discussion：

Figure 1(a) and (b) shows the radial distribution function (RDA) around Ga and In atom, respectively, obtained from EXAFS measurements. Both the curve shows strong 1st nearest neighbor peak at around 2.1 Å corresponding to those binding to As. The representative difference between those curve is that we can observe a peak related to second nearest neighbor at around 4 Å for the curve around Ga atom shown in Fig. 1(a), but not around In in Fig. 1(b). This indicates the system around In, corresponding to inside the QW, is much more microscopically strongly distorted compared to GaNAs barrier. It suggests the existence of large amount of N will largely modify the surrounding local atomic structure. In fact, N atoms over 5% can affect for most of second nearest neighbor of group III atoms in the system.

After annealing, the intensity of the Ga-As peak increased in Fig. 1(a) and the In-As peak decreased in Fig. 1(b). That can be due to the effect of atomic rearrangement, enhancing the configurations of In-N bonding. [1]

Fig. 2(a) shows polarization direction dependency of the In- K-edge RDA on the sample. We have measured the spectra varying the incident x-ray polarization direction as indicated in the figure, showing the difference between in-plane direction (corresponds to the incident x-ray polarization of //[110] and [-110]) and out-plane/growth direction (//[001]). As seen in Fig. 2(b), the annealing induced decrease of In-As peak intensity is more pronounced for the direction of parallel to in-plane direction. That suggests the anisotropic annealing-induced atomic rearrangements.

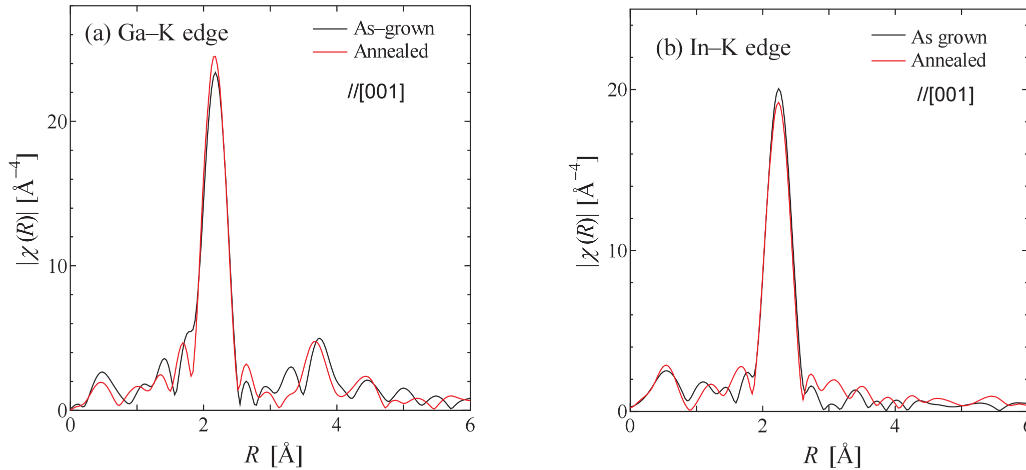

Fig. 1 Radial distribution function of (a) Ga K-edge: top 40 nm from surface including both GaInNAs and GaNAs information, and (b) In K-edge: from the 10 layers of GaInNAs QWs. The indicated direction shows the incident x-ray linear polarization at the measurement.

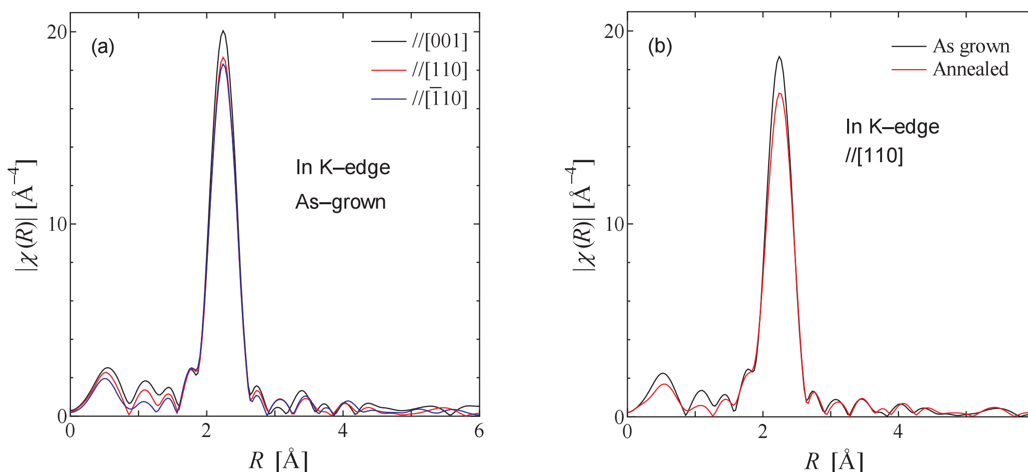

Fig. 2 Radial distribution function for the In K-edge from top 40 nm: including both GaInNAs and GaNAs information, and (b) In K-edge including solely the information from the 10 layers of GaInNAs QWs. The indicated direction shows the incident x-ray linear polarization at the measurement.

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).