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# Characterization of columnar-shaped InAs/GaAs quantum-dot structures using grazing incidence X-ray diffraction

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## 1. Introduction

In development of a quantum dot (QD) devices, it is important to acquire the information on the detailed QD structure. A cross-sectional scanning tunneling microscopy (XSTM) is a powerful tool for acquiring the information on atomic accuracy, but it is destructive inspection and advanced equipment is needed for the measurement [1]. A grazing incidence X-ray diffraction (GIXD) measurement is effective nondestructive evaluation, but a synchrotron radiation institution has been required [2]. In this work, we succeeded in GIXD measurements using the equipment for labs, and performed characterization of the columnar-shaped InAs/GaAs QD structures.

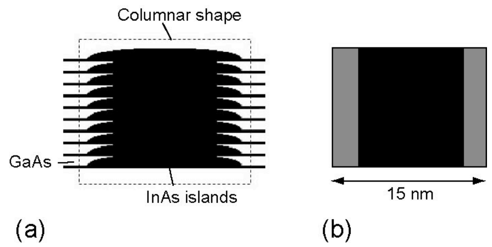


Figure 1 (a) Schematic of columnar shaped QD in cross section, and (b) a model used in our simulation..

## 2. Experiments

In the columnar-shaped QD, the stacked InAs QDs are directly piled up as shown in Figure 1(a) to form a single QD on GaAs substrate [3]. Since multiple stacking growth is carried out, multiple wetting layer is formed in the circumference of the columnar-shaped QD. Near the perimeter of QD is not touching directly upper and lower QDs, and this is a transition domain between the InAs core and a surrounding multiple wetting layer. We prepared four types of samples where the number of QD stacking varied from 9 to 32.

GIXD measurements were performed to evaluate the columnar-shaped QD structure. Figure 2 shows the experimental setup. Incidence X-ray beam was put in the very small angle about a total-internal-reflection angle to a (001) plane surface. Most of the incidence was reflected at the surface plane. We set the samples so that diffraction might occur in (220) plane. The diffracted X-ray beam was detected by the imaging plate (IP) as two-dimensional information.

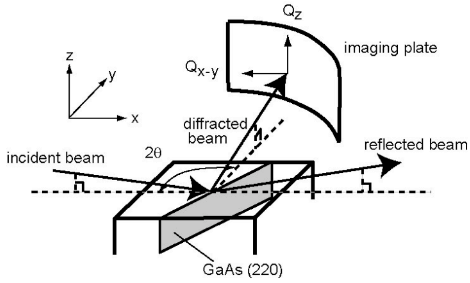


Figure 2 Schematic of GIXD measurement.

## 3. Results and discussion

Figure 3 indicates the IPs of four kinds of samples in the GIXD measurements. The n denotes the number of QD stacking during the formation of columnar-shaped QD. The deepest signal is diffraction of GaAs (220). Since the sizes of the sample used for measurement differ, absolute intensity is various. The signal extended in the direction of x-y at the upper right of a GaAs (220) peak is considered to be diffraction from columnar-shaped QD. The extension is increasing with the increase in the number of QD stacking.

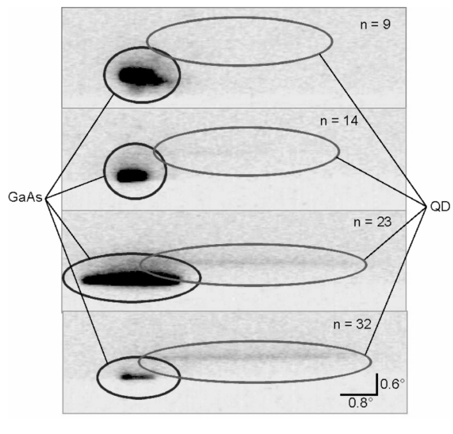


Figure 3 Imaging plate around GaAs (220) signal in four samples in which the number of QD stacking varies.

By converting the data on IP into rocking curve, the difference smong samples becomes still clearer. Figure 4 indicates the diffraction intensity in linear as a function of diffraction angle converted from the signals on IP. The signals were integrated around the QD in z-axis. Therefore, GaAs (220) peak is not necessarily highest. Diffraction peaks of QD were observed at the smaller angle to the GaAs peak. The spectrum reflects the distortion and composition inside the sample. The internal structure of sample can be known in analyzing the QD-related diffraction peak in detail.

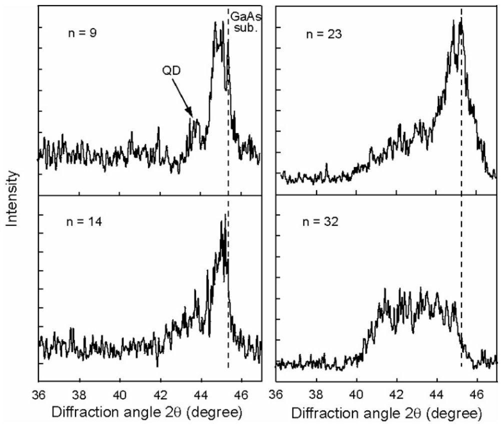


Figure 4 Measured GIXD spectra of four samples with various stacking number of QDs.

Figure 5 shows the Full width at half maximum (FWHM) and center position of QD-related peaks in Figure 4 as a function of n. It is clearly appears that the FWHM increased and peak position decreased as the stacking number increased. This result suggests a systematic change of sample structure.

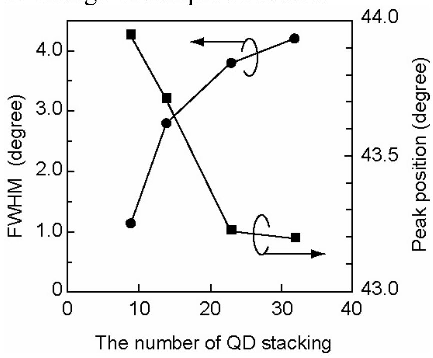


Figure 5 FWHM and peak position of measured diffraction peak as a function of QD stacking number .

To analyze the obtained rocking curves, we performed simulations of the curves. We first calculated the strain field in the QD sample using the finite element method [4]. In the calculation, the columnar-shaped QD was modeled as shown in Figure 1(b), where the QD has InAs core and surrounding cylindrical InGaAs transition domain. The multiple wetting layer was modeled as a single quantum well. Then, based on the structural parameters of the elements, XRD spectra were calculated with dynamical theory.

Indium composition and width of the transition domain was considered as fitting parameters. Figures 6(a) - 6(d) indicate the FWHM and peak position of calculated XRD spectra as a function of the fitting parameters. As indium composition of transition domain increases, FWHM increases and peak position decreases. As width of transition domain increases, FWHM decreases and peak position increases. These tendency is common among all QD stacking numbers.

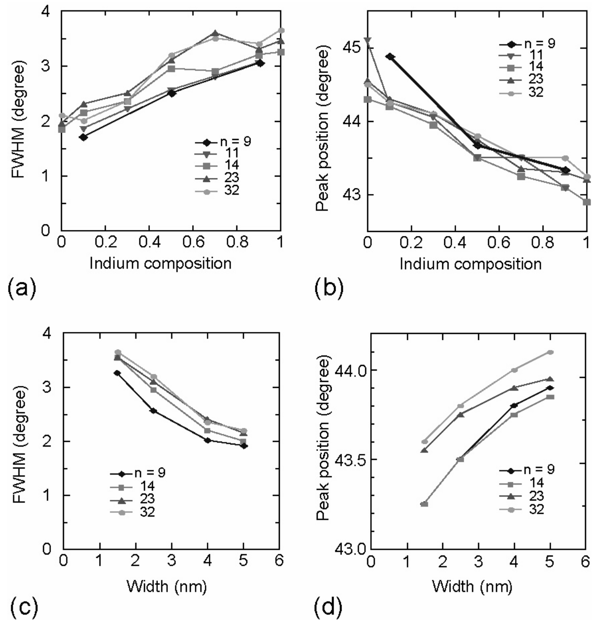


Figure 6 Calculated (a) FWHM and (b) peak position of diffraction peak as a function of indium composition of transition domain. Calculated (c) FWHM and (d) peak position as a function of width of transition domain.

After the simulation, we found that, as the number of stacking increases, the indium composition of the transition domain increases and its width decreases. The results suggest that the InAs core grew with the increase of stacking number.

## 4. Conclusions

We realized GIXD measurement with the equipment for labs, and performed structure evaluation of the columnar-shaped QD. Using IP for a detector, we successfully observed that QD-related signals appeared around a GaAs (220) peak and varied with the number of QD. We calculated distribution of strain field in the samples based on the finite element method, and simulated the XRD spectra. Measurements were fitted by the calculations using the simple model which divides the columnar-shaped QD into an InAs core and an InGaAs transition domain. We found that the core was expanded according to the increase of the number of QD stacking. The GIXD measurement with the equipment for labs will enhance the development of QD devices.

## References

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