Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.768-769

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X-ray Resonant/Off-Resonant Scattering of Fractional Monolayer AlAs/GaAs Superlattices

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1. Introduction

The heterostructures in III-V semiconductors with ultrashort-period superlattices, which may be called as 'digital alloys', have significant advantages for the new devices with the high performance in both the electrical and the optical properties [1], because the energy band-gap can be controlled with changing the constitution steeply at interfaces. The superlattices (SL) of $(\mathrm{GaAs})_m/(\mathrm{AlAs})_n$ have been studied intensively [2]. The period lengths (*n*+*m*) in these SL, however, have only integral number, *i.e.* 'digital' number, in a unit of monolayer (ML), and most of periods are more than 2 ML. This is because that much interest has been focused on the crossover of the transition between TYPE II and TYPE I, which occurs in the period of about 10 ML in the case of $n = m$ [2,3]. We have focused on the SL structures grown by molecular-beam epitaxy (MBE) that have the period length of less than 2 ML and/or of the 'fractional' number in ML unit. Our results of the optical studies show that the photoluminescence (PL) energies of the SL with period of fractional ML are well explained by the Kronig-Penny model [4]. The SL structure, however, is still to be cleared in the case of such short period.

In this paper, we report the structural analyses using synchrotron radiation. The x-ray resonant/off-resonant scattering measurements have been made on $(\mathrm{GaAs})_m/(\mathrm{AlAs})_n$ with the period of fractional ML fabricated by the shutter-control in MBE growth. The experimental results are discussed with comparison to simulations.

2. Experimental

The layer configurations of $(\mathrm{GaAs})_m/(\mathrm{AlAs})_n$ in the samples are shown in Table. I. Samples were fabricated on the GaAs (001) substrate. The growth in the SL structure was designed as followed; (1) the ratio of layer thickness for all the samples is fixed as GaAs : AlAs = 7 : 3. (2) the numbers of periodical cycles, Γ, is set as the total thickness of SL region equals to 1000 ML(~ 280 nm).

The x-ray resonant / off-resonant scattering measurements have been performed at room temperature at BL13XU in SPring-8/JASRI. The incident x-rays were monochromated by $\mathrm{Si}(111)$ and were applied to the samples, which were set at the center of the multi-axes goniometer. The scattering rays were counted by a NaI scintillation detector. The $(0\,0\,L)$ scattering profiles in reciprocal space were obtained by $\theta - 2\theta$ scan both in the non-resonant region, 8.05 keV, and in the resonant region around Ga K-edge, 10.37 keV.

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3. Results

The $(0\,0\,L)$ profiles measured are shown in Fig.1(a) and (b). The satellite peaks originated from the SL periodicity have been observed in these profiles for samples (i) and (ii). However, no satellites are found for sample (iii). This may be due to that the atomic fluctuation at the interface in each layer is significant in sample (iii). From the position of satellite peaks, the period lengths were estimated as 9.85 ML and 1.69 ML for samples (i) and (ii), respectively. The calculated profiles based on the kinematical model in only one dimension (z-axis: growth direction) are also shown in Fig.1. The positions of satellite peaks show good agreement between experiments and calculations. This result verifies the possibility that the SL structure with the periods of the 'fractional' number monolayer can be fabricated with an arbitrary designation, even if the thickness of one of components is less than 1 ML.

The averaged lattice constants 5.6697 Å of SL region in sample (i) were evaluated from the relation of the peaks from the SL phase and the GaAs substrate. From the differences of lattice constants between SL and the substrate, the constituent ratio of Al:Ga was deduced as 0.28:0.72 using the Poisson's ratio of AlAs, 0.32.

The $\theta - 2\theta$ profiles around $(0\,0\,4)$ reflection were measured at several incident x-ray energies near the Ga K-edge. The energy dependences of the intensities of peaks

Table I SL configurations of $(\mathrm{GaAs})_m/(\mathrm{AlAs})_n$ SL in this study. Γ gives the number of cycles; one cycle means a set of the growth of a GaAs layer and an AlAs layer.

Sample	(Design)				(XRD)
	m	*n*	*m*+*n*	Γ	*m*+*n*
(i)	7.0	3.0	10.0	100	9.85
(ii)	1.2	0.5	1.7	588	1.69
(iii)	0.9	0.3	1.3	769	−

originated from both the SL region and the substrate are plotted in Fig. 3. The peak intensities of SL in each sample show slowly changing with energy, while those from the substrate show the large reduction at the absorption edge due to the resonant effect of Ga atom [5]. In order to estimate atomic composition at III site, we have analyzed the reduction ratio of peak intensities between the SL and the substrate. In the analysis, it was assumed that the scattering intensity is proportional to the square of the scattering factor, $|F|^2$, i.e. with no dynamical effect. The deduced values of Al concentration are 0.53, 0.82, and 0.82 for sample (i), (ii), and (iii), respectively, which are quite different from the designed value of 0.3. This may be due to the dynamical effect, which is not negligible when a scattering object is close to a perfect single crystal like the samples in this study. More accurate estimation of Al concentration is expected by means of the analysis with both the kinematical and the dynamical effects.

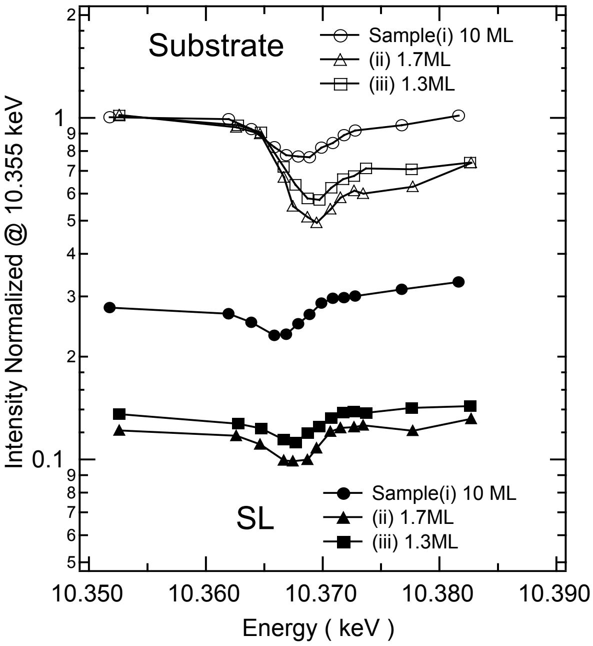

Fig. 2 Energy dependences of (0 0 4) peak intensities of each samples at the energy around Ga K-edge, 10.367 keV. Solid marks gives for the peak originated from SL region and vacant marks for the peak from the substrate.

3. Conclusions

We investigated the layer structures in SL samples of $(GaAs)_m/(AlAs)_n$ with the period, $n+m$, designed as 10, 1.7, and 1.3 ML by means of x-ray resonant/off-resonant scattering method. The satellite peaks in $(0\,0\,L)$ profiles, which are originated from the period length of 9.85 and 1.69 ML were observed. This suggests that the thickness of each layer in SL is the fractional ML and there is no atomic flatness at the interfaces. The energy dependence of $(0\,0\,4)$ peak intensities around Ga K-edge shows the reduction due to the resonant effect of Ga atom. The Al concentrations, which were estimated from the ratio of the peak intensities between SL region and the substrate, without the dynamical effect, are not coincident to the designed value 0.3.

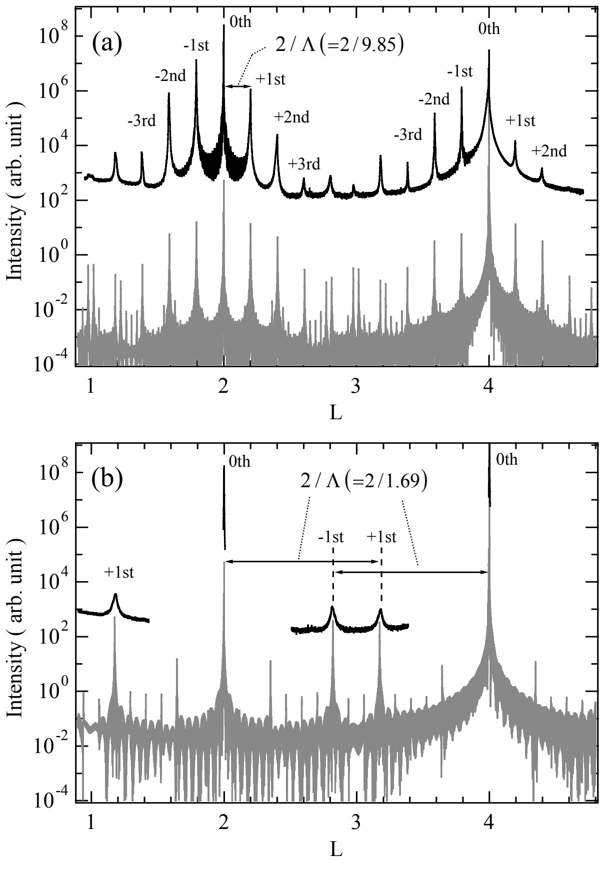

Fig. 1 (a) (0 0 L) profiles in $(GaAs)_m/(AlAs)_n$ in sample (i) : the periodic length Λ (= $n+m$) is 9.85 ML. (b) sample (ii) : Λ = 1.69 ML. Experimental results and the calculated are shown in upper and lower areas in each figure, respectively.

Acknowledgements

The synchrotron radiation experiments were performed at SPring-8 with the approval of Japan Synchrotron Radiation Research Institute (JASRI) as Nanotechnology Support Project of the Ministry of Education, Culture, Sports, Science and Technology. (Proposal No. 2004B0372-ND1d-np-Na / BL-No.13XU)

References

[1] S. Koshiba, J. Crystal Growth **201-202** (1999) 810
[2] W. Ge, J. Lumin. **59** (1994) 163
[3] G. Li, Phys. Rev. B **40** (1989) 10430
[4] K. Fujii, Extended Abstract of the 65th Fall Meeting of The Japan Society of Applied Physics and Related Societies, **3** (2004), 1545
[5] Y. Watanabe, Trans. JIM **29** (1988) 81