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Effect of Growth Interruption on Electron Spin Relaxation in (110)-Oriented GaAs/AlGaAs Quantum Wells

Satoshi Iba, Hiroshi Fujino, Toshiyasu Fujimoto, Shinji Koh and Hitoshi Kawaguchi
Graduate School of Materials Science, Nara Institute of Science and Technology
8916-5 Takayama, Ikoma, Nara 630-0192, Japan
Phone: +81-743-72-6176, Fax: +81-743-72-6183, e-mail: i-satoshi@ms.naist.jp

1. Introduction

Recently, in semiconductors, spin devices such as spin-FET and -LED become a focus of interest. Spin dynamics has to be characterized in order to realize the spin devices. One of the significant factors in spin dynamics is electron spin relaxation time. Long spin relaxation time is beneficial for the manipulation of the spin states of electrons. In order to obtain long spin relaxation time, it is necessary to understand spin relaxation mechanisms in detail. It is well known that the dominant spin relaxation mechanism at room temperature in zinc blende semiconductors such as GaAs is D'yakonov-Perel' (DP) mechanism [1, 2]. In the DP process, electron spin relaxation in GaAs/AlGaAs quantum wells (QWs) derives from two types of inversion asymmetry: (1) the bulk inversion asymmetry (BIA) and (2) the structural inversion asymmetry (SIA). Regarding (1), H. Ohno *et al.* demonstrated dramatically long spin relaxation time in (110)-oriented GaAs/AlGaAs QWs due to the suppression of the DP process through decrease of the BIA term [3]. Regarding (2), it is considered that improvement of hetero-interface morphology may increase spin relaxation time due to the suppression of the DP process through decrease of the SIA term [4]. Recently, increase of spin relaxation time in (110)-oriented GaAs/AlGaAs QWs grown with interface growth interruption (GI) was reported [5]. However, effect of growth interruption on electron spin relaxation was not fully understood. Then, in order to investigate correlation between the hetero-interface roughness and electron spin relaxation time, we fabricated GaAs/AlGaAs QWs on GaAs (110) substrates using molecular beam epitaxy (MBE) with interface growth interruption and evaluated electron spin relaxation time in (110) QWs.

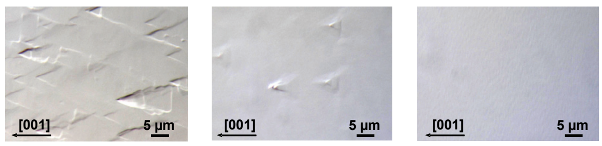
2. Experiments

All the samples were grown by solid source MBE. The surface morphology of the grown films was observed by an optical microscope and the crystallinity was evaluated by X-ray diffraction (XRD) measurements. Electron spin relaxation time was measured using polarization- and time-resolved PL measurements. A mode-locked Ti: Sapphire laser with the pulse width of ~70 fs and the repetition rate of 80 MHz was used as a pump laser and carriers were excited only in the QWs with a pump intensity of 3 $\mu J/cm^2$. In the measurements, a circularly-polarized pump pulse was incident to the sample and the time evolution of the PL intensity was measured using a streak camera.

2. Results and discussion

For the characterization of spin dynamics, high quality of QW is required. Since the window of MBE growth conditions on GaAs (110) substrates is narrower than GaAs (100), we first optimized the growth condition varying growth rate (0.5, 1 μm/h), As/Ga flux ratio (40, 80) and growth temperature (430, 480, 530 ºC). 500 nm-thick GaAs films were grown on (110) GaAs substrates using above 12 growth conditions. The surface morphology of the grown films is shown in Fig. 1. Although triangular defects were seen on the surface of the film grown at high growth temperature, good surface morphology was obtained for the sample grown at low temperature. In Fig. 2, the results of XRD measurements are shown. Except the samples grown with growth rate of 0.25 μm/h and As/Ga flux ratio of 80, full width at half maximum (FWHM) of the XRD rocking curves became the minimum at the growth temperature of 480 ºC. Considering both the surface morphology and the crystallinity, we determined the best growth condition as follows: growth rate of 0.5 μm/h, As/Ga flux ratio of 80 and growth temperature of 480 ºC.

(110)-oriented GaAs/AlGaAs QWs were fabricated using the optimized growth condition. All the samples consisted of twenty-period 6-nm-thick GaAs QW layers separated by 20-nm-thick $Al_{0.28}Ga_{0.72}As$ barriers as shown in Fig. 3(a). Sample A and B were grown without interface growth interruption on (100) and (110) GaAs substrates,



(a) (b) (c)

Fig. 1 Surface morphology of the film grown at (a) 530 ºC, (b) 480 ºC and (c) 430 ºC observed by an optical microscope.

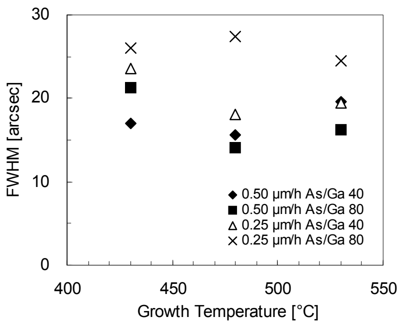
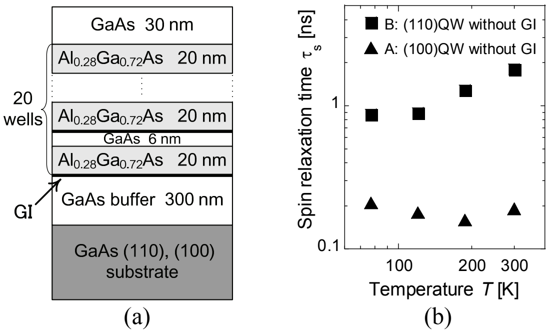


Fig. 2 FWHM of (220) XRD rocking curves plotted as a function of growth temperature.



(a) (b)

Fig. 3 (a) Schematic structure of the QWs and (b) temperature dependence of τ_s for the sample A (solid triangle: (100) QWs without GI) and B (solid square: (110) QWs without GI).

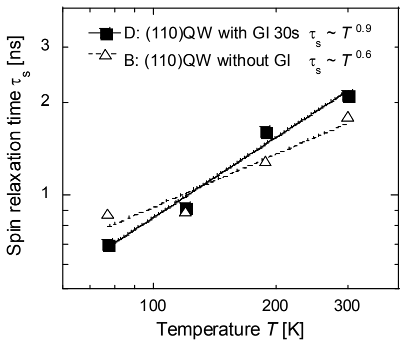
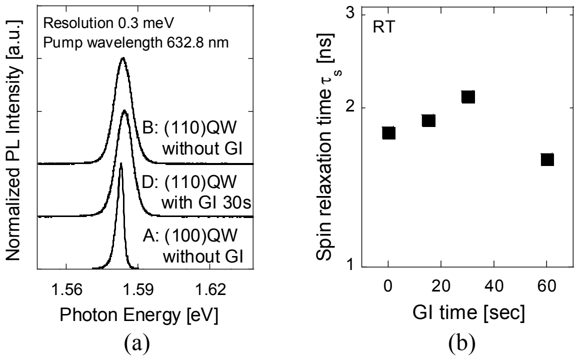


Fig. 5 Temperature dependence of τ_s for the sample B (without GI) and D (with GI 30s). τ_s of the sample B and D is proportional to $T^{0.6}$ and $T^{0.9}$, respectively.

respectively. Sample C, D and E were grown on (110) GaAs substrates with 15-, 30- and 60-second-interface growth interruption before the growth of the barrier layers, respectively.

Fig. 3(b) shows electron spin relaxation time plotted as a function of temperature of the sample A and B. The spin relaxation time τ_s in the (110) QWs was about 1.8 ns, which was almost 10 times longer than that of (100) QWs. Another feature was the temperature dependence of the spin relaxation time. For (100) QWs, the spin relaxation time increased with decreasing temperature. On the other hand, the spin relaxation time in the (110) QWs decreased with decreasing temperature as previously reported [3].

Next we investigated correlation between hetero-interface roughness and electron spin relaxation. An SIA term due to the potential fluctuation resulted from the interface roughness can induce spin relaxation via the DP process. In order to obtain longer spin relaxation time, we tried to form flat hetero interfaces by utilizing growth interruption before the growth of barriers, varying the growth interruption time. Fig. 4(a) shows the PL spectra of samples A, B and D. The FWHM of the PL peaks for samples A-E were 3.2, 8.6, 8.0, 7.9 and 8.6 meV, respectively. The decrease of the FWHM of the PL peaks corresponds to the improvement of the interface morphology. Fig. 4(b) shows τ_s dependence on the growth interruption time at room temperature. We found that τ_s increased with increasing GI time and τ_s of the sample D with GI 30s was 2.1 ns. However τ_s decreased with further increasing GI time up to 60s. The results indicated that the (110) QW with narrower FWHM of PL showed longer τ_s. The long τ_s may derive from the suppression of the SIA term of the DP process by improvement of the interface morphology. Fig. 5 shows τ_s dependence on the temperature for the samples B and D. By fitting with the least-square method, τ_s is found to be proportional to $T^{0.6}$ for the sample B as reported in Ref. 3, while $T^{0.9}$ for the sample D, which can be understood as a difference of the electron spin relaxation mechanism due to the different interface morphology.



(a) (b)

Fig. 4 (a) PL spectra of sample A, B and D. In the PL measurements, a He-Ne laser was used as a pump. (b) Growth interruption time dependence of τ_s for samples B-E.

3. Conclusions

We investigated the effect of interface growth interruption during MBE growth on electron spin relaxation in (110)-oriented GaAs/AlGaAs QWs. By utilizing 30-second-interface growth interruption before the growth of barrier layers, τ_s increased from 1.8 ns to 2.1 ns. From the results, it is concluded that there is a considerable correlation between the hetero-interface morphology and electron spin relaxation in (110) GaAs/AlGaAs QWs. Spin relaxation time of (110) QWs can be increased by improvement of the interface morphology, which may be due to the suppression of the SIA term of the DP process.

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