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

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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. **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 °C). 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 °C. 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 °C.

(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 Al0.28Ga0.72As barriers as shown in Fig. 3(a). Sample A and B were grown without interface growth interruption on (100) and (110) GaAs substrates,
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 $\tau_s$ 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 interface roughness can induce spin relaxation via the DP SIA term due to the potential fluctuation resulted from the suppression of the SIA term of the DP process. An improvement of the interface morphology, which may be due to the electron spin relaxation in (110) GaAs/AlGaAs QWs. Spin relaxation time can be increased by improvement of the interface morphology. Fig. 5 shows $\tau_s$ dependence on the temperature for the samples B and D. By fitting with the least-square method, $\tau_s$ 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.

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, $\tau_s$ 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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References