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Carrier Mobility Dependence of Electron Spin Relaxation in GaAs MQWs

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1. Introduction

The spin relaxation of electrons in semiconductor quantum wells is in the picoseconds region, and is of interest to the application for optical devices such as optical switching. It has been reported that the main mechanism of electron spin relaxation in GaAs multiple quantum wells (MQWs) at room temperature (RT) is spin-orbit interaction (SOI) (D'yakonov-Perel' (DP) interaction). This estimation is obtained by experimental results in which the electron spin relaxation τ_s is related to the electron confined energy E as $\tau_s \propto E^{-2.2}$. (DP theory gives $\tau_s \propto E^{-2}$). According to the DP theory, it is expected that τ_s is inversely proportional to the electron scattering time τ_v (or mobility μ). Although τ_v or μ is thus very important factor in the spin relaxation process, few experimental study has been devoted to the electron spin relaxation in terms of τ_v (μ). In this work, we have measured τ_s in GaAs / $Al_{0.4}Ga_{0.6}As$ MQWs at RT, and investigated the electron spin relaxation mechanism, according to the relationship between τ_s and τ_v.

2. Experimental Details

We prepared eight samples of n-type GaAs /$Al_{0.4}Ga_{0.6}As$ MQWs which consist of 60 periods of 7.5nm with different mobility by Molecular Beam Epitaxy. (1) for sample (a)~(c), Si donors were doped in the barrier layers, (2) for sample (d) ~ (f), Si donors were doped in the QWs uniformly, and (3) for sample (g)~(h), Si and Be were doped in the QWs simultaneously. Although quantity of ionized impurity is large, the number of carrier is suppressed: (g) (Si: 1.4×10^{12} cm^{-2}, Be: 7.5×10^{11} cm^{-2}), (h) (Si: 1.4×10^{12} cm^{-2}, Be: 3.0×10^{11} cm^{-2}). For all samples, Hall measurements were carried out to determined n and μ at RT. The transport properties measured at RT are summarized in Table I. In the barrier-doped samples (a)~(c), μ is almost unchanged with n, while μ is decreased by increasing n since ionized impurity scattering is enhanced in the well doped samples (d)~(h). Especially, μ of (g) and (h) is very low since carrier is compensated by Be acceptors. τ_s was evaluated by circularly-polarized pump-probe measurement using Ti-sapphire mode-locked laser tuned at heavy hole-electron excitonic absorption peak of the QWs (~830nm).

3. Results and Discussion

Figure 1 shows the time dependence of the transmission intensity of the probe-beam. Spin-dependent transmittance change with the same circular polarization: (i), opposite circular polarization: (ii). τ_s is obtained from the observed time constant by $\tau = \tau_s / 2$. In Fig. 2, the ralationship between τ_s and μ is plotted. The dashed line shows the fit of all data. We obtained $\tau_s \propto \mu^{-0.61}$. The slope is different from the theoretically expected −1. However, when fitting of the data are made for each doping method separately, the relationship is (1) $\tau_s \propto \mu^{-1.49}$, (2) $\tau_s \propto \mu^{-1}$, and (3) $\tau_s \propto \mu^{-0.97}$, respectively. For the latter two, the slope is close to −1. This result is in tendency consistent with the theoretical prediction based on DP theory $\tau_s \propto \mu^{-1}$, which suggests that the main mechanism of electron spin relaxation in GaAs MQWs at RT is SOI. The origin of the offset between the solid line is not clear at present.

4. Summary

We have measured the electron spin relaxation time τ_s in doped GaAs / AlGaAs MQWs with different electron mobility μ at RT, and investigated the relationship between τ_s and μ. We obtained $\tau_s \propto \mu^{-1}$ from experimental results, which suggests that the electron spin relaxation time largely depends on electron scattering, indicating spin orbit interaction.

Reference

1) M. I. D'yakonov, and V. Yu. Kachorovski, Sov. Phys. Semicond. **20** (1986) 110.

2) A. Tackeuchi, Y. Nishikawa, and O. Wada, J. Appl. Phys. **68** (1996) 797.

TABLE I Transport properties of measured at room temperature in GaAs MQWs

	Doping configration		Electron concentration μ (10^{11}cm^{-2}/well)	Mobility n (cm^2 / Vs)
(1)	Si	(a)	4.7	4200
	barrier-doped	(b)	2.6	4700
		(c)	1.4	4600
(2)	Si	(d)	6.0	2500
	well-doped	(e)	2.4	2800
		(f)	0.4	3500
(3)	Si, Be	(g)	4.7	800
	well-doped	(h)	9.8	1500

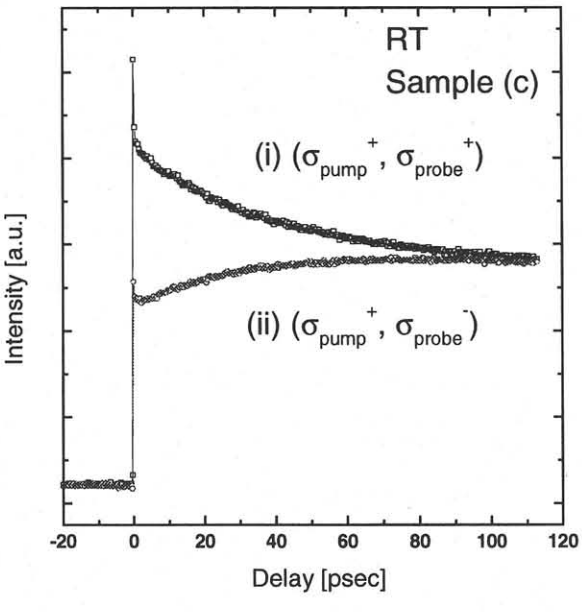

Fig. 1 Time dependence of the transmission intensity of σ^+ probe beam when the sample is excited by (i) σ^+ and (ii) σ^- polarized pump beam.

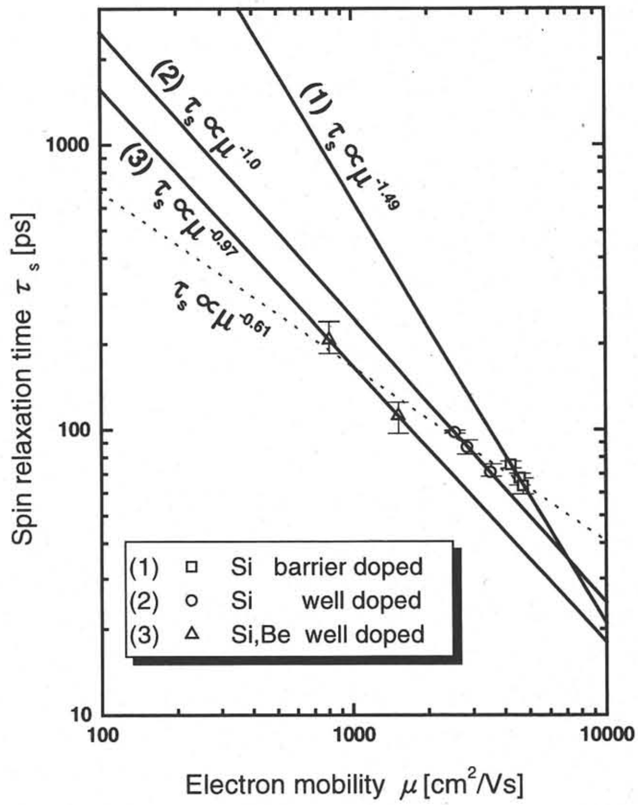

Fig. 2 Mobility (μ) dependence of the spin relaxation time τ_s for sample (a)～(h). Solid lines are fitting curves for the data of samples with the same doping configuration. The dashed line is a fitting curve for all samples.