Overhauser Effect and Anisotropy of Electron Spin g-factor in GaAs / AlGaAs Quantum wells

Tetsu Ito, Wataru Shichi, Masao Ichida, Hideki Gotoh, Hidehiko Kamada, Hiroaki Ando

Abstract:

To investigate the dependence of electron g-factor on magnetic field in GaAs / AlGaAs quantum wells time-resolved photoluminescence measurements under a high magnetic field in different experimental configuration, the magnetic field perpendicular ($g_\perp$) and parallel ($g_\parallel$) to the quantum confinement direction, has been studied. When the angle between the magnetic field and the confinement direction is 45°, the precession frequency varies depending on polarity of magnetic field and the circular polarization type of excitation light (σ^+ or σ^-). We found that these dependences of the precession frequency exhibit main features of Overhauser effect with an effective magnetic field of 0.5 T that nuclear spins react back on electron spin precession and the g-factor value is not affected by the effective magnetic field. The $g_\perp$ and $g_\parallel$ values agree well with the results of four-band $\boldsymbol{k}\cdot\boldsymbol{p}$ perturbation calculations.

Keywords: *quantum well, electron spin g-factor, Overhouser effect.*

1. Introduction

In quantum structures such as quantum wells (QWs) and dots fundamental properties of the semiconductors are altered by quantum confinement effects. Among these properties Landé g-factor of electrons is one of the most sensitive one susceptible to the quantum confinement. The electron Landé g-factor, which represents spin-magnetic field interaction, has been studied in semiconductor structures [1]-[5]. The electron g-factor in QWs exhibits anisotropy, reflecting symmetry of the quantum confinement [2]-[7]. The electron g-factor ($g_\perp$) for a magnetic field perpendicular to the direction of quantum confinement is assessed in the Voigt configuration either by means of time resolved photoluminescence (PL) measurements [2], [5], [7] or by pump-probe optical nonlinear measurements [3]-[4]. To precisely assess the electron g-factor ($g_\parallel$) for the magnetic field parallel to the confinement direction an experimental setup, where the angle between the magnetic field and the confinement direction is 45°, is required [3]. In this paper we will discuss nuclear magnetic effects on the spin precession and the electron g-factor using experimental data obtained in the 45° configuration [3], [4], [7].

2. Experimental

In experiments to assess the quantum confinement effects accurately and systematically under the same conditions we have used a sample, which consists of QWs having different well widths. In this sample each QW consists of GaAs well and $Al_{0.35}Ga_{0.65}As$ barrier layers. Time resolved PL measurements were carried out to observe the electron spin precession under a high magnetic field in Voigt configuration at 4 K. The PL traces are obtained by spectrally integrating around the emission peak using a streak camera. The QW sample was irradiated by 2 ps pulse laser with a photon energy of 1.8 eV, and a repetition rate of 80 MHz. Estimated excitation power density was 240 W/cm^2. The pump pulse is circularly polarized to achieve spin selective excitation. The circular polarization components σ^+ and σ^- in PL were selectively measured by using $\lambda/4$ wave plate and polarizer. Figure 1 shows typical time evolution of optical anisotropy, defined as $\sigma^+ - \sigma^-$, obtained for the QW with 15 nm well width. A simple spin relaxation is observed under no magnetic field as shown in Fig. 1 by dotted line. The spin relaxation time is assumed to be around 800 ps. With increasing the magnetic field we have observed an oscillation caused by electron spin precession. We have estimated the spin precession frequency from the oscillation in the PL time evolution. The precession frequency increases in proportion to the applied magnetic field, as shown in Fig. 2. The electron g-factor values are derived from the proportionality constant for each QW with different well width. The measured g-factor value in Voigt configuration, $g_\perp$ is shown in Fig. 3 as a function of well width with filled circles. Dotted line indicates the g-factor value for the GaAs bulk sample. The observed value is very close to the reported value of -0.44 [1], [8]. The g-factor value increases monotonically with a decrease in the well width crossing the zero level between the well widths of 8 and 6 nm. To precisely assess the electron g-factor ($g_\parallel$) for the magnetic field parallel to the confinement direction we employed an oblique experimental configuration [3]. In the oblique configuration magnetic field was applied so that the angle between the directions (polarities) of quantum confinement and of magnetic field may be 45° or 135°. Figure 4 shows measured precession frequency as a function of magnetic field for the QW with a well width of 15 nm. In negative magnetic field we plotted the precession frequency with negative sign. The precession frequency is proportional to the magnetic field with same proportionality coefficients. However, the precession frequency has difference at the same magnetic field depending on the polarization type of excitation light (σ^+ or σ^-). From the proportionality coefficient the electron g-factors in 45° configuration, g_{45}, has been obtained. The dependence of the $g_\parallel$ value on well width is shown in Figure 3. Here, circularly polarized σ^+ light is used for optical excitation. The values of $g_\parallel$ were assessed based on measured $g_\perp$ and g_{45} values using the relational equation, $g_{\parallel}^2 = 2g_{45}^2 - g_{\perp}^2$ [3]. To explore the physical origin of the dependences of precession frequency on the polarization type, temporal change in the spin precession frequency has been assessed. We performed time-resolved PL measurements in picosecond scale. The PL traces were measured at 0, 10, and 20 minutes after changing excitation polarization from σ^+ to σ^-. Exposure time was 2.5 minutes and applied magnetic field was +3 T. The sample was kept illuminated during the measurements. While the change in the precession oscillation from 0 to 10 minutes was evident, the difference was negligible from 10 to 20 minutes. Since the precession oscillation did not seem to be averaged out in exposure time of 2.5 minutes the response time of this effects is considered to be longer than a few minutes.

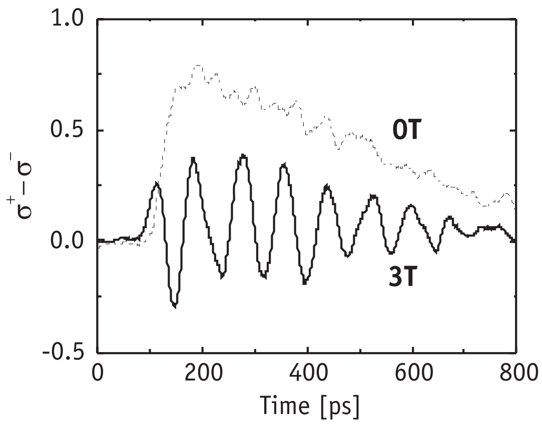

Fig. 1. Time traces of optical anisotropy, defined as $\sigma^+ - \sigma^-$, measured for the GaAs/$Al_{0.35}Ga_{0.65}As$ QW with a well width of 15 nm.

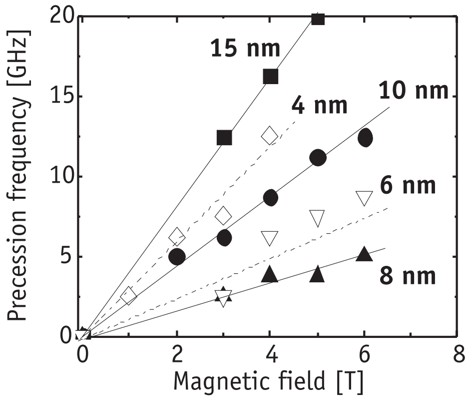

Fig. 2. Precession frequency as a function of magnetic field for various well widths of GaAs/$Al_{0.35}Ga_{0.65}As$ QWs.

3. Discussions

In general nuclear spin effects and electron-electron spin interaction are well known that affects the precession frequency. Especially the nuclear spin alignment induced by the Overhauser effect gives considerable effects to the precession frequency through hyperfine interaction [3], [4]. In the oblique configuration a net electron spin component $\mathbf{S}_{\parallel}$, parallel to the applied magnetic field, persists over the lifetime of the spin precession. The hyperfine interaction $A\mathbf{I}\cdot\mathbf{S}_{\parallel}$ between the net electron spin and the nuclear spin builds up a nuclear spin alignment $\langle\mathbf{I}\rangle$. This reacts back on the electron spins as an effective magnetic field $\mathbf{B}_N = A\langle\mathbf{I}\rangle / g_e\mu_B$, which modifies the total magnetic field experienced by the electron spins. Here μ_B is the Bohr magneton. When the electron g-factor g_e is negative and the hyperfine interaction constant A is positive, as in the GaAs / $Al_{0.35}Ga_{0.65}As$ QW having 15 nm well width, the direction of effective field is anti-parallel to the nuclear spins. The precession frequency lowering caused by the change in the excitation polarization from σ^+ to σ^- (Fig. 4) is consistent with the main feature of effective magnetic field. From the intercept of the fitted lines in Fig. 4 the effective magnetic field of $\mathbf{B}_N$ = 0.5 T is evaluated. The time scale of building up of nuclear polarization caused by the Overhauser effect, is reportedly from a few minutes to several ten of minutes [3], [4]. The observed transient change in the precession oscillation is also within this time region.

Finally we discuss the anisotropy in the electron g-factor. The calculated results obtained by four-band ***k·p*** perturbation method [6] are shown in Fig. 3 with solid curve ($g_{\perp}$) and dashed curve ($g_{\parallel}$). The trend of the experimental results is well reproduced by the theoretical analysis. The anisotropic electron g-factor in QWs can be attributed to the spin dependent coupling efficiency of valence states to conduction electron states *via* ***k·p*** perturbation [6].

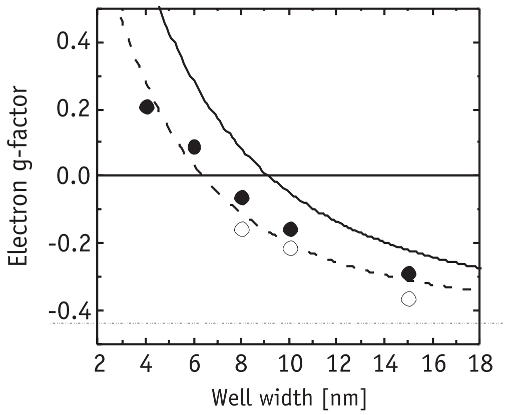

*Fig. 3. Measured values of $g_{\perp}$ (filled circles) and $g_{\parallel}$ (open circles) as a function of well width for GaAs / $Al_{0.35}Ga_{0.65}As$ quantum wells. Solid and dashed curves are calculated $g_{\perp}$ and $g_{\parallel}$ values, obtained by using four-band **k•p** perturbation theory.*

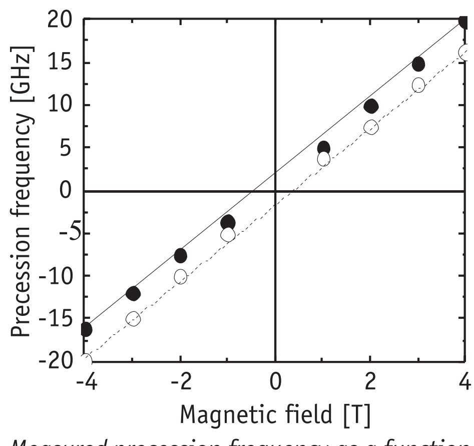

Fig. 4. Measured precession frequency as a function of magnetic field for the GaAs / $Al_{0.35}Ga_{0.65}As$ quantum well with a well width of 15 nm. The + and – signs mean the polarity of the magnetic field. Filled and open circles are the results for the excitation light of circular polarization σ^+ and σ^-, respectively.

4. Conclusion

We have studied the dependence of electron spin g-factor on magnetic field in GaAs / AlGaAs QWs by time resolved PL measurements. In the 45° configuration we have found that precession frequency varies depending on the polarity of applied magnetic field and the circular polarization of the excitation light. These dependences of precession frequency can be explained by the Overhauser effect with an effective magnetic field of 0.5 T. The values of $g_{\perp}$ and $g_{\parallel}$ are qualitatively reproduced by a four-band $\boldsymbol{k{\cdot}p}$ perturbation calculations. Our results indicate that the nuclear field effects are observed not only in the pump-probe nonlinear measurements but also in simple PL measurements at oblique configuration as an effective magnetic field. When we evaluate the electron g-factor from the proportionality factor in the dependence of the precession frequency on external magnetic field, the effect of the nuclear field is not affect on the electron g-factor.

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