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# Dynamics of Hole-Spin Superposition in GaAs/AlGaAs Quantum Wells

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**Abstract**

**Dynamics of hole-spin superposition in GaAs/AlGaAs quantum well was investigated through polarization- and time-resolved photoluminescence (PL) measurement under resonant excitation condition. Creating and evaluating hole-spin superposition are achieved with resonant PL properties, which will crucially contribute to quantum technology with hole-spin quantum bits.**

## 1. Introduction

Electron and hole spin in semiconductor quantum-confinement structure have been investigated for quantum information technology. Especially, hole-spin states are expected as quantum bit because hole-spin states aren't affected by nuclear spin polarization. For applying the hole-spin states to quantum memory, creation and controlling superposition of hole-spin states are important technology. In this study, we have performed polarization- and time-resolved photoluminescence (PL) measurements [1,2] to investigate creation and relaxation of the hole-spin superposition. Created hole-spin superposition is expected to be observable before the superposition is destroyed by phonon scattering by PL measurements under resonant excitation condition. Linearly- and circularly-polarized excitation measurements were performed to create hole-spin states with deferent coefficient and phase of superposition.

## 2. Experimental

In the present study, we used a GaAs/AlGaAs multiple quantum well (MQW). In the MQW sample, each QW consists of GaAs well and $Al_{0.35}Ga_{0.65}As$ barrier layers grown on a [001] GaAs substrate. Each sample consists of 20 wells and the thicknesses of the well layer measured in this study are 4, 8, and 12 nm. Polarization- and time-resolved PL measurements were carried out to observe spin relaxation at 18 K. In the experiment, the MQW samples were irradiated by a Ti-doped sapphire laser with an excitation power of 2 mW. The duration and repetition rate of the laser pulses were 2 ps and 80 MHz, respectively. Circularly and linearly polarization resolved PL measurements were performed. For circularly polarization resolved measurement, the linearly polarized laser pulses were converted to circularly polarized pulses ($\sigma^+$ or $\sigma^-$) using a quarter-wave plate, after which the circularly polarized laser pulses illuminated the samples for selective excitation of spin-polarized electrons and holes. The circularly polarized components in the PL signal emitted from the samples were selectively measured using a quarter-wave plate and a polarizer. For linearly polarization resolved measurement, the linearly polarized laser pulses were illuminated to the samples for selective excitation of superposition of electron and hole spin. The linearly polarized components in the PL emitted from the samples were selectively measured using a half-wave plate and a polarizer. The temporal changes in the intensity of the circular and linear components were measured with a streak camera.

## 3. Results and Discussion

Figure 1 shows time traces of PL intensity of co- (black thick curve) and cross-circular (red thin curve) components. Peak of PL (1.570 eV) was separated from scattering of excitation laser light as shown in the inset. Excitation photon energy was 1.573 eV and was 2.6 meV larger than exciton energy. Intensity difference between co- and cross-circular components was clearly observed. Figure 2 shows time traces of PL intensity of co- (black thick curve) and cross-linearly (red thin curve) components. When excitation photon energy is close to exciton energy (1.573 eV), intensity difference was clearly observed as shown Fig.2 (a). However, the difference was not observed in non-resonant excitation condition (1.584 eV) as shown Fig.2 (b).

To discuss how spin polarization is formed by circularly- and linearly-polarized excitation light we calculated time traces of degree of polarization; $(I_+ - I^-)/(I^+ + I^-)$ from polarized PL components ($I^+$, $I^-$) and plotted them in Fig.3. The time trace of degree of polarization was fitted by single and double exponential decay for linearly (blue curve) and circularly (green curve) polarization resolved measurements, respectively as shown thick curves in Fig.3. Shorter lifetime of double exponential decay fitting in circularly polarization resolved measurement was close to the lifetime obtained by linearly polarization measurements. Well width dependence of them is shown in Fig. 4. They almost didn't depend on well width and are around 30 ps.

In linearly polarization measurement, hole-spin superposition is easily decayed by non-resonant excitation condition because of complex band structure of valence band. Observed lifetime would reflect lifetime of hole spin which mainly determined by effect of band mixing in valence band. So hole-spin superposition is observed only by resonant excitation condition and the lifetime almost doesn't depend on well width as shown in Fig. 4. In circularly polarization measurement, hole-spin polarization would remain by resonant excitation condition. So first decay component was observed in resonant excitation condition and the lifetime was close to hole-spin life time. Slow decay component in circularly-polarization measurements is considered to be electron-spin lifetime.

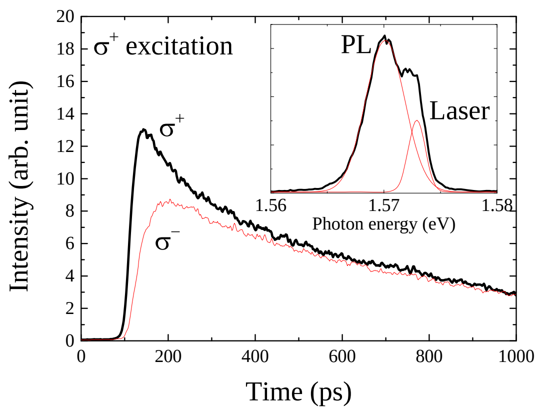


Fig. 1 Time traces of PL intensity of co- (black thick curve) and cross-circular (red thin curve) components. Inset indicates measured PL spectrum of co-circular component (black thick curve) and results of two peaks fitting (red thin curve).

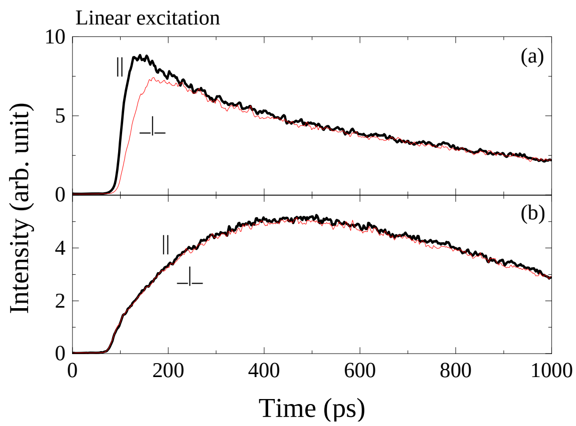


Fig. 2 Time traces of PL intensity of co- (black thick curve) and cross-linearly (red thin curve) components. Excitation photon energy were (a) 1.573 eV and (b) 1.584 eV.

## 4. Conclusions

Hole-spin superposition is observed by polarization- and time-resolved PL measurements. Creation and relaxation of hole-spin state with different coefficient and phase of superposition, which corresponds to hole-spin state in Bloch sphere, was found to be observable in PL measurements using linearly- and circularly polarized pump light under quasi-resonant excitation condition. Fundamental knowledge obtained by present study will contribute to advance in quantum information technology with hole-spin quantum bit.

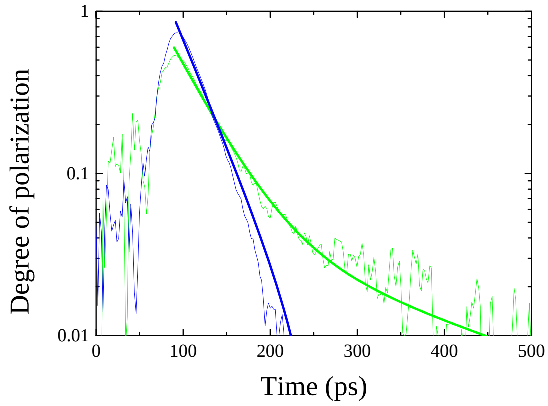


Fig. 3 Time traces of degree of polarization excited by circularly (thin green curve) and linearly (thin blue curve) polarized light. Thick curves indicate results of single and double exponential decay fitting for linearly and circularly-polarization resolved measurements, respectively.

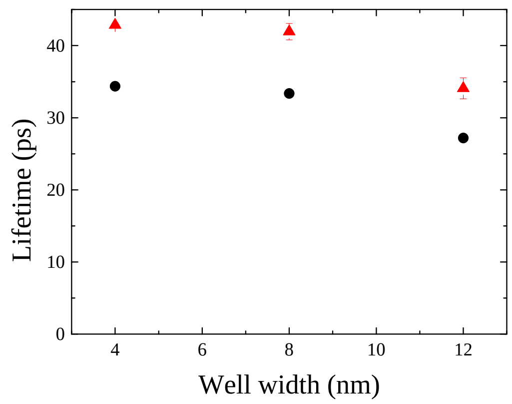


Fig. 4 Well width dependence of lifetime excited by linearly (black circles) and circularly (red triangles) polarized light. Shorter components in circularly-polarization resolved measurement are indicated in this figure.


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## References


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