Quantum media conversion from a photon to an electron spin

H. Kosaka\textsuperscript{1,2}, H. Shigyou\textsuperscript{1}, T. Inagaki\textsuperscript{1,2}, Y. Mitsumori\textsuperscript{1,2}, K. Edamatsu\textsuperscript{1}
T. Kutsuwa\textsuperscript{2}, M. Kuwahara\textsuperscript{2}, K. Ono\textsuperscript{2,3}, Y. Rikitake\textsuperscript{4,2}, N. Yokoshi\textsuperscript{5,2}, H. Imamura\textsuperscript{5,2}

\textsuperscript{1} Research Institute of Electrical Communication, Tohoku University, Sendai 980-8577, Japan
E-mail: kosaka@iee.tohoku.ac.jp
\textsuperscript{2} CREST-JST, 4-1-8 Honcho, Kawaguchi, Saitama 332-0012, Japan
\textsuperscript{3} Low Temperature Physics Laboratory, RIKEN, Saitama 351-0198, Japan
\textsuperscript{4} Department of Information Engineering, Sendai National College of Technology, Sendai 989-3128, Japan
\textsuperscript{5} Nanotechnology Research Institute, AIST, Tsukuba 305-8568, Japan

1. Introduction

Spin is a fundamental property of electrons and plays an important role in information storage. For spin-based quantum information technology, write (preparation) and read-out (measurement) processes of the electron spin state should be coherent. However, both the traditional write and read-out processes were projections to up/down spin states, which do not preserve spin coherence. We have recently demonstrated that we can transfer the polarization coherence of light to the spin coherence of electrons in a semiconductor quantum nanostructure [1], and we can also read out the prepared coherence of the electron spin optically by the developed tomographic Kerr rotation (TKR) method [2,3]. In these demonstrations, it was important to set the g-factor of an electron to be nearly zero. We have also demonstrated that the spin coherence of a single electron trapped in a gate-defined quantum dot, where the g-factor of electrons is tuned to nearly zero, can be electrically manipulated with a microwave applied to the gate utilizing electric-dipole spin resonance (EDSR) [4]. The fabricated quantum dot with a point contact as a charge sensor evidenced that a single electron is actually created by the absorbed photon in the dot [5]. We have also theoretically shown that two-electron coherence can be manipulated and measured via spin-flip tunneling with the help of the spin-orbit interaction [6]. Furthermore, we have shown that the full Bell-state measurement needed for the quantum repeater can even be achieved with help of g-factor engineering and g-factor switching [7].

2. Principle of quantum media conversion

Figure 1 shows the operating principles of the spin coherence transfer (write) and the TKR (read). The principle of TKR is the exchange interaction (singlet state selection) between the target electron and the probe electron created virtually by the probe light. The electron spin state tomography is based on the reverse mapping of the electron spin states onto the photon states, or partial state swapping, through the virtual excitation of a charged exciton. The polarization state tomography of the scattered light thus results in the spin state tomography of the electron interacting with the photon (Fig. 2a). In other words, we can exchange the quantum information between the electron and the photon through elastic scattering. These demonstrations were also carried out in a condition where the up/down spin basis states of electrons remained degenerated under an in-plane magnetic field. As this condition ensures the energy conservation between photons and electrons, the entire Poincare sphere representing the polarization states of photons can be mapped onto a Bloch sphere representing spin polarization states of electrons. The developed tomographic Kerr rotation method enables the density matrix tomography of coherent spin states of electrons, even when the spin does not precess around the applied magnetic field, i.e., the spin is frozen. The frozen spin faithfully maintains the coherence transferred from photons encoded in their polarization.

3. Experimental demonstration of spin state transfer and spin state tomography

Figure 2a shows the time trace of the Bloch vector of electrons whose spin state is transferred from photons in the superposition state of D. The reconstructed density matrix of the electron spin state with and without calibration...
Rabi oscillation

interaction.

initial preparation originating in the electron-hole exchange
degenerate
tions in one scheme based on the resonant scattering in a

maximally superposed case is 0.86±0.03, which is close to unity.
The fidelity degradation is due to spin decoherence after the

tron spin created by a circularly polarized light is unity

assumed that the initial degree of polarization of the elec-
state as a reference (white bars) are shown in Fig. 2b. We

(white bars), we estimate that the fidelity of the spin

coherence transfer from photons to electrons in the max-

anti-bunching nature of the 1st captured electron and the

efficiency of 27%, excluding the coupling efficiency esti-

demonstrated that the device serves as a single

photon to single electron converter with the con-

electron g-factor is designed to be zero, which enables the ideal

spin state transfer from a photon to an electron. Another

important feature is that a quantum point contact serves as

an electron counter in the vicinity of the dot to count the number of electrons in the dot. This electron
counter ensures the fidelity of the quantum media-

cation by the post-selection of the conversion event. We

succeeded to demonstrate that the device serves as a single

Photon

Fig. 3, Experimental demonstration of single photon to single
electron conversion. (a) SEM image of the device. QPC: quantum
point contact. (b) Histogram of the electron-capture events
detected by the QPC as a function of light exposure time.

3. Single photon - electron conversion in a quantum dot

We demonstrated that a single photon creates a single
electron in a semiconductor and detected by the charge [5].
We fabricated a gate-defined single quantum dot consisting of a GaAs quantum well with multiple gates on the top
surface to trap an electron (Fig. 3a). The negatively biased
gates confine only the negatively charged electron created by a single photon with removing the positively charged
hole. The exceptional feature of this device is that the elec-

tron g-factor is designed to be zero, which enables the ideal

spin state transfer from a photon to an electron. Another

important feature is that a quantum point contact serves as

an electron counter implemented in the vicinity of the dot
to count the number of electrons in the dot. This electron
counter ensures the fidelity of the quantum media-

cation by the post-selection of the conversion event. We

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3. 4. Coherent spin manipulation with microwave

Using a similar device with two coupled double quantum

dots (Fig. 4a), we succeeded in demonstrating single-electron spin manipulation by observing the Rabi oscil-
lation in the dot current leaking through the dots as a func-
tion of microwave burst length (Fig. 4b). The importance of
this demonstration is that even an electron with nearly zero
g-factor can be manipulated by microwaves using the elec-
tric-field component instead of the commonly used mag-
netic-field component through the spin-orbit interaction,
and two-spin coherence is measured by the singlet detec-
tion through the Pauli spin blockade. The frozen spin can
never be manipulated by a microwave via the magnetic
field component. Instead, the electrical field component
enables the spin manipulation through the modulation of
the waveform of the electrons in the dot device. [4]

4. Conclusions

The spin coherence transfer and the spin state tomo-

etry demonstrated here will be applicable to the transfer
of a single-particle quantum state and a two-particle entan-
gled state, which is the kind of transfer needed for quantum
information technology. The developed scheme offers a
tool for performing basis-independent preparation and

class of a single electron.

2nd captured electron (Fig. 3b) and polarization selectivity
(not shown) indicate that the photon polarization of a single
electron is successfully transferred to the spin polarization
of an single electron.

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References