Coupling between single photons and single electron spins via angular momentum transfer in quantum dots

Akira Oiwa
The Institute of Scientific and Industrial Research, Osaka University

Spin-selective optical interband excitation, which creates the spin polarization and detects the spin dynamics, has contributed to the considerable progresses for studying spin physics and controlling spins in bulk and structured semiconductors. Though the angular momentum transfer from a single photon to a single electron spin is an elemental process of the spin-selective excitation it has not been fully studied because of the difficulties to detect single photons and single electron spins. Gate-defined lateral quantum dots (QDs) are, however, suitable to detect a single electron spin in a single-shot manner [2)] and the coherent manipulation of single electron spins has been extensively studied in such QDs. [3,4)] Indeed we have realized the detection of single photoelectrons in a single quantum dot with a charge sensing technique.[5)] Moreover, the coherent coupling between single electron spin states and photon polarization states would allow us to investigate a quantum correlation between light and spin in solids and would contribute to long distance quantum communications. Here we show that single photoelectron spins can be discriminated by Pauli effect and the angular momentum of circularly polarized single photons can be transferred to single electron spins in lateral GaAs double QDs. These results manifest that photons can be coupled to electron spins in the electrically tunable QDs.

Double QDs with a metal mask were fabricated in $Al_{0.33}Ga_{0.67}As$/GaAs quantum wells (see Fig.1). The light source was a wavelength-tunable pulsed Ti:Sapphire laser. First we show that the interdot tunneling between the two QDs offers a robust detection scheme of the single photoelectrons trapped in the double QD. The interdot tunneling of a trapped single photoelectron can be clearly detected because the amplitude of the interdot tunneling signal obviously exceeds the noise level of the charge sensor current. [6)] In two-electron regime, the interdot tunneling timescale of the photoelectrons strongly depends on the relative spin orientation (either parallel or anti-parallel) between two QDs due to Pauli exclusion principle, enabling us to discriminate the single photoelectron spin with a high distinguishability more than 90% (see Fig. 2). Finally by changing the incident photon polarization, the probability of the anti-parallel spin configuration smoothly changes from left-handed to right-handed circularly polarization through liner polarization, indicating distinctly the angular momentum transfer from single photons to single electron spins in double QDs.

We also discuss the feasibility of the coherent transfer from single photons to single electron spins. This can be achieved by designing both electron and hole g-factors appropriate to the theoretical proposal[7)] and by a spin tomography measurement technique with a rotation of the transferred single electron spin. The coherent transfer provides a route to realize quantum repeaters. Furthermore, introducing an entangled photon pair source would realize the novel experiments of non-local entanglement between a local spin and one of the entangled photons.

Author acknowledge the collaborations with T. Fujita, K. Morimoto, H. Kiyama, G. Allison, M. Larsson, S. Teraoka and S. Tarucha in University of Tokyo and A. Ludwig, A. D. Wieck in Ruhr-Universität Bochum. This work was supported by Grants-in-Aid for Scientific Research A (No. 25246005), "Quantum Cybernetics" project, FIRST program, QuEST Grant No. (HR-001-09-1-0007), IARPA, MEXT Project for Developing Innovation Systems.

Reference

1) *Semiconductor Spintronics and Quantum Computation*, D. D. Awschalom, D. Loss and N. Samarth, Springer, New York 2002.
2) J. M. Elzerman et al., Nature **430**, 431 (2004).
3) M. Pioro-Ladriere *et al.*, Nature Phys. **4**, 776 (2008).
4) R. Brunner *et al.*, Phys. Rev. Lett. **107**, 146801 (2010).
5) A. Pioda *et al.*, Phys. Rev. Lett. **106**, 146804 (2011).
6) T. Fujita *et al,* Phys. Rev. Lett. **110**, 266803 (2013).
7) R. Vrijen and E. Yablonovich, Physica E **10**,569 (2001).

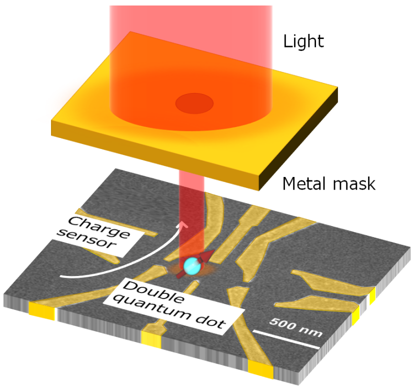

Fig. 1 Schematic of the photon irradiation on to the lateral double quantum dot which is covered with an optical mask with a center aperture.

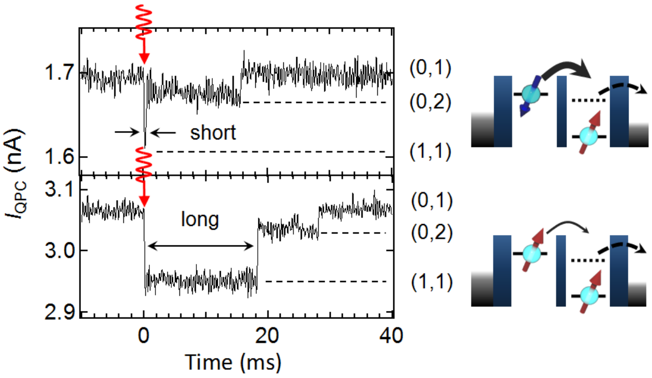

Fig. 2 Example traces of single-shot single photoelectron spin detection measured at 750 mT. Top (bottom) shows the detection of anti-parallel (parallel) photoelectron spin configuration, respectively.