Electron Spin Qubits and Spin-Photon Interface Using Quantum Dots

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Manipulating and detecting photons, and electron spins have been intensively studied for implementing qubits in information transmission, and computing, respectively. Quantum state transfer or quantum media conversion (QMC) between these qubits is a strong requirement for constructing a comprehensive quantum network. Electron spin qubits with quantum dots (QDs) have recently been demonstrated using various techniques, and to scale up the qubits will be crucial as the next step. On the other hand, this achievement is motivating study on the photon-spin QMC in QDs, but the experiments have just started. In this talk I will review our recent progress in making multiple spin qubits and single photon-electron interface with QDs.

Electron spin resonance (ESR) is the fundamental concept of spin qubits, in which two Zeeman states are defined by a static magnetic field and superposed by an ac magnetic field. To manipulate individual electron spins in QDs in a scalable manner, both magnetic fields must be local to each QD. We have developed a technique of using a micro-magnet and ac electric field to meet this requirement. A micro-magnet placed on top of each QD is magnetized by application of external in-plane magnetic field to generate a field gradient out-of-plane and an excess in-plane field at the dot. Application of an ac electric field to the dot oscillates an electron inside to generate a local ac magnetic field only experienced by the electron. In addition, the ESR condition depends on the external magnetic field as well as the micro-magnet induced in-plane field. We use a double QD integrated with a micro-magnet to observe cw ESR peaks and Rabi oscillations of two individual spins, and extend the technique to triple QDs.

One of the prerequisites to implement the photon-spin interface is to detect a single photon-generated electron and reset it in a time scale faster than the spin-flip time in a controlled manner. We use a QD and a quantum point contact charge detector to demonstrate single-shot detection of single electrons generated by single photons. The photo-generated electron can be ejected from the dot in the tunable time range from shorter to longer than the spin-flip time. We then use a spin-dependent tunnel coupling of the dot to the leads in the spin-resolved edge states to distinguish the spin orientation of photo-generated electrons. We find that this technique works well for the short resetting time of photo-generated electrons.