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ハイブリッド量子ナノシステムへ向けたカーボンナノチューブ

Carbon nanotubes for hybrid quantum nanosystems

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A quantum processor, such as shown in Fig.1, could be an example of the hybrid quantum nanosystems, where various qubits (quantum bits), such as the superconducting qubits and the spin qubits, are communicating each other through a resonant cavity which works as a quantum bus. The superconducting qubit may be good for logic, while the spin qubit may be good for memory. A strong quantum mechanical coupling between each qubit and the resonator has to be realized (A dotted line in Fig.1). The processor may send and receive optical photons to communicate with outside world (quantum I/O interface). For this, a frequency conversion between microwave frequencies and optical frequencies are needed because most of the existing qubits rely on microwave frequencies. Carbon nanotubes are attractive for building blocks of the quantum processor. It could be used for the spin qubit with long spin coherence time because it is made of the carbon atom, a majority of which does not contain nuclear spins. For the compound semiconductor based spin qubits, the nuclear spins in the host atoms are the main decoherence source. The simple shell structures in the carbon nanotube quantum dots are advantageous to realize a single spin in the quantum dot (Fig.2). Besides, an energy gap of the carbon nanotubes in the optical communication frequencies makes the material attractive for the quantum I/O interface that converts the microwave frequency in the cavity to the optical frequency in the optical fiber. Of course, there are a lot of challenges for the carbon nanotubes in this application. Device fabrication is a practical challenge. The strong spin coupling with a cavity photon may not be easy in the carbon nanotube because the spin orbit interaction is small, which is being used to couple the spins and the electric field in a cavity. Figure 3 shows an InSb quantum dot placed in a superconducting coplanar waveguide cavity to realize the coupling between the spin and the electric field through the strong spin orbit interaction in the InSb (It may not be an ideal material for the spin qubit because of the nuclear spin problem). Somehow, the spin-charge conversion needs to be done for the carbon nanotube spin qubit. We will also show optical emission from the single-wall carbon nanotube quantum dots and its coherent control toward the quantum I/O interface.

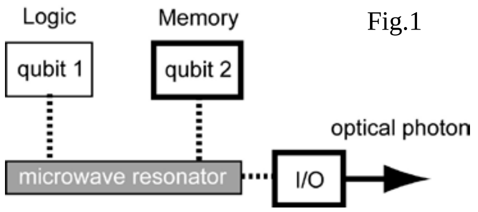

Fig.1

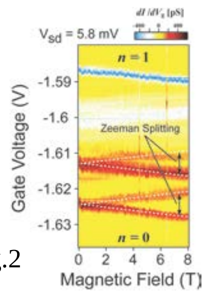

Fig.2

Fig.3