Micro-magnet techniques for implementing spin qbits with quantum dots

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Advanced nanofabrication technologies of semiconductor devices have enabled us to control the properties of just a few electrons confined to small structures, i.e. quantum dots (QDs), and thereby to apply such QDs for implementing quantum computation. In this respect, manipulation and detection of charge and spin degrees of freedom in QDs are the core of study. To date electron spin qubits or units of quantum information have been demonstrated using various techniques with QDs, and it is now getting crucial to prepare multiple spin qubit system as the next step. We have recently proposed and demonstrated a micro-magnet technique for making spin qubits with QDs, which may meet the requisite for the qubit multiplication[1,2]. I will talk about the micro-magnet technique for double QDs in realizing advanced spin qubit operations: two individual spin qubits, two-qubit gates, and non-destructive spin readout.

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 a.c. magnetic field normal to the static field. However, the conventional ESR can only apply for a large ensemble of spins, not for single spins. To manipulate individual electron spins in QDs in a scalable manner, both magnetic fields must be local to each QD. A combined technique of a micro-magnet and an a.c. electric field (or microwave field) meets this requirement. A micro-magnet placed on top of QDs, when magnetized in-plane by application of an external in-plane magnetic field, imposes two static stray fields: a laterally grade out-of plane field and a small in-plane field. Oscillation of an electron inside the dot driven by a microwave field can generate an a.c. magnetic field local to the dot. On the other hand the in-plane field and external field are added up to generate a total in-plane field also local to the dot and therefore enable ESR local to each dot. We apply this technique for a double QD to demonstrate two individual spin qubits[3] and a two-qubit gate for modulating and detecting a spin entangled state as a fraction of the output[4]. We show that our micro-magnet technique may be useful to prepare multiple qubits in a row up to more than 25[5]. Furthermore we apply the same technique to realize non-destructive spin readout[6].

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