 Fr-2L

Optical control of individual magnetic atoms in a semiconductor quantum dot

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The decrease of the structure size in semiconductor electronic devices and magnetic information storage devices has dramatically reduced the number of atoms necessary to process and store bits of information. Information storage on single magnetic atoms would be an ultimate limit. Diluted magnetic semiconductors combining high quality semiconductor structures and the magnetic properties of Mn atoms (S=5/2) offer the possibility to couple magnetic atoms through their exchange interaction with carriers and are model systems for the study of these devices.

With quantum dots doped with Mn atoms, the optical probing of a single atomic spin in a solid state environment become possible using optical micro-spectroscopy techniques: The state of a photon emitted or absorbed by a II-VI semiconductor quantum dot containing an individual Mn atom is directly related to the spin state of the atom. This is due to the exchange interaction between the confined electron-hole pair and the Mn spin: the electron-hole pair acts as an effective magnetic field along the quantum dots' growth axis that lifts up the degeneracy between the six (2S+1) Mn spin states. Depending on the Mn spin orientation, the recombination of an injected electron-hole pair emits a photon with a given energy and polarization. An individual Mn atom embedded in a II-VI semiconductor quantum dot may act as an optically addressable spin based memory. The next step would be to control the coupling between such ultimate memories: a carrier mediated interaction between two Mn spins inserted in the same quantum dot is one step towards this challenging goal.

In this talk, we will show how the photons emitted by an individual CdTe/ZnTe quantum dot containing one or two Mn atoms can be used to probe the dynamics of the Mn spins. We will also discuss how the resonant optical injection of spin polarized carriers can be a tool to control these localized spins. After a description of the spin structure of the system formed by the interaction between a controlled number of confined carriers and one or two Mn spins [1], we will present photon correlation [2] and time resolved optical pumping experiments [3] on individual quantum dots allowing probing the dynamics of these few interacting spins. Finally, we will show that under a strong resonant optical field, the energy of any spin state of one or two Mn atoms can be independently tuned using the optical Stark effect [4]. Each optical transition in a Mn-doped quantum dot behaves like an isolated two-level quantum system well described in a dressed atom picture. In the ground state, the laser induced shift could be used for a coherent manipulation of the spin of the Mn atoms.

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