Coherent optical control of a single hole spin

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The spin of a heavy-hole confined to an InAs/GaAs quantum dot is a potential qubit. Compared to an electron spin, the hole is more robust against nuclear spin induced dephasing due to the suppression of the contact hyperfine interaction. A key prerequisite for any qubit is the ability to rotate the pseudo-spin about two axes.

Here we demonstrate the full coherent optical control of a single heavy-hole confined to an InAs/GaAs quantum dot. Larmor precession about an external in-plane magnetic field provides one axis of rotation, whilst the rotation induced by a picosecond laser pulse provides a rotation about the out-of-plane optical axis.

In the experiments, the dot is embedded in the intrinsic region of a ni-Schottky diode. A vertical electric-field is applied such that the electron tunneling is fast (~100 ps) and the hole tunneling is relatively slow (~4 ns), but fast compared to the repetition period of the laser (~13 ns). A magnetic field is applied in Voigt geometry.

The dot is excited by up to three circularly polarized laser pulses. The first, the preparation pulse, resonantly excites the bright neutral exciton with a pulse-area of π. This prepares a spin-polarized electron-hole pair. When the electron tunnels from the dot, it leaves a hole with a Larmor precession synchronized with the preparation pulse. The mechanism is similar to the Hanle effect, and will be discussed in the talk. The final pulse, the detection pulse, has a pulse-area of π and is resonant with the hole-trion transition. The polarization selects either hole spin up or down state creating a trion conditional on the hole-spin, which is detected as a change in photocurrent. Larmor precession of the hole-spin about the external magnetic field is observed by measuring the photocurrent as a function of the time-delay between the preparation and detection pulse. From the Larmor precession we infer that a hole spin with a coherent component has been prepared, and that the hole has an in-plane g-factor of $g_h = 0.079(4)$.

To control both the amplitude and phase of the Larmor precession, a third control pulse is used. This circularly polarized pulse selects the hole-spin up state and drives a hole-trion Rabi rotation through an angle of 2π. If there is no decoherence, the system returns to the hole-spin sub-space having acquired a detuning dependent geometric phase-shift of upto π, rotating the spin about the optical axis, with a gate-time of 14 ps. Experiments demonstrating this optical rotation will be presented.

To summarize, full coherent optical control of a single hole spin is demonstrated using a geometric phase approach and a photocurrent detection technique. Further details of this work can be found in refs. [1], and rival works in refs. [2].

[1] T.M. Godden *et al*, Phys. Rev. Lett. **108**, 017402 (2012); ArXiv 1202.5943
[2] A. Greilich *et al*, Nature Photon. **5**, 702 (2011); K. De Greve et al, Nature Phys. **7**, 872 (2011)