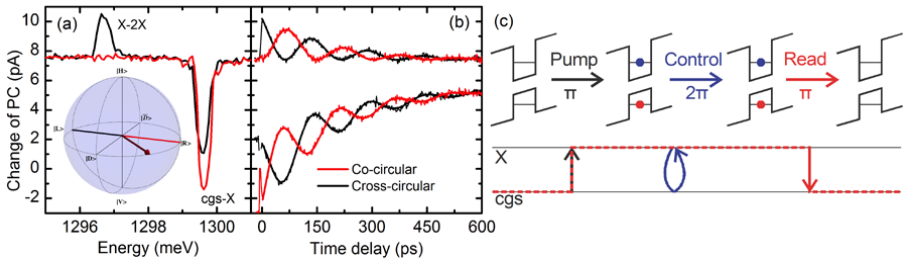
Resonant optical initialization, control and readout of a spin qubit with near unity fidelity

K. Müller[1], R. Ripszam[1], T. Kaldewey[1], M. Bichler[1], G. Koblmüller[1], G. Abstreiter[1] and J.J. Finley[1]

[1]*Walter Schottky Institut and Physik Department, TU Muenchen, Garching, Germany*

Ultrafast photocurrent spectroscopy provides exquisite sensitivity to probe charge and spin dynamics as well as coherence properties of individual quantum dot nanostructures [1-2]. Here, we demonstrate how a precisely timed sequence of three monochromatic ultrafast (~2-5 ps) optical pulses with a well-defined polarization can be used to (i) prepare an arbitrary superposition of exciton spin states in an individual InGaAs quantum dot photo-diode, (ii) arbitrarily control of the spin-wavefunction without an applied magnetic field and (iii) read-out with high fidelity the quantum state in an arbitrary basis simply by detecting a strong (~2-10 pA) electric current flowing in an external circuit [3]. The results obtained show that the combined preparation, control and read-out of the spin quantum state can all be performed with a near-unity (>97%) fidelity.

Due to the finestructure splitting of self-assembled quantum dots, the neutral exciton forms a spin qubit with two energy eigenstates that can be addressed using the linear optical polarizations H and V (inset figure 1). Therefore, arbitrary superposition spin states can be initialized by directly mapping the polarization of a resonant ps-duration laser pulse to the exciton spin Bloch sphere. In pump-probe spectroscopy experiments this exciton spin can be read out by either the spin selectivity of the conditional absorption of the biexciton transition (2X) or the spin-selectivity of the stimulated emission (X). As an example we present in figure 1(a) pump-probe spectra for pumping the exciton with R polarized light and probing the spin state with R and L polarizations and in (b) the temporal evolution of the peaks. Clearly, the spin selectivity of the conditional absorption of 2X and stimulated emission of X can be seen in (a) and fully modulated antiphased oscillations resulting from the spin precession in (b). In this contribution we present the arbitrary initialization of an exciton spin and the projection readout along arbitrary axis.



Arbitrary, high fidelity coherent optical control is achieved by applying an additional 2π-pulse with a precisely defined polarization in resonance with X between initialization and readout (figure 1c). This control pulse does not affect the population of the X state but induces precise rotations of the exciton spin state. We demonstrate arbitrary coherent control of the exciton spin state using a single resonant ps-duration laser pulse. Thereby, the fidelity of the control is again near unity, limited to >97% by the ~100fA readout noise in the photocurrent signal. Our methods are fully applicable to other optically addressable quantum emitters and have strong potential for scaling to more complex systems such as molecules and spin-chains.

[1] K. Müller et al. Phys. Rev. Lett. 108, 197402 (2012)
[2] K. Müller et al. Phys. Rev. B 85, 241306(R) (2012)
[3] K. Müller et al arXiv:1212.2993 (2012)