Review
of the Ph. D. thesis of Maria Kuznetsova
entitled "Nuclear spin effects in self-assembled quantum dots"
submitted for the degree of Doctor of Philosophy in Physics
at the St. Petersburg State University

The majority of the results are presented for the InAs quantum dots (QDs). InAs self-assembled quantum dots are of great interest for quantum information technologies because they can be grown epitaxially and can be incorporated both into electronic circuits with diodes for control of charge, and into photonic circuits with optical cavities and waveguides for control of photons. Their direct optical band gap suggests exploiting the elementary optical excitation of a QD, the exciton, for quantum information purposes: with the giant optical dipole moment of a semiconductor QD, quantum operations may be performed at a terahertz rate or even faster, giving QDs a great speed advantage over nuclear spins (radio frequency) or electron spins (microwaves).

Unfortunately, the short radiative lifetime of the exciton (of the order of 100 ps) leads to a severe limitation for the application to quantum computation. This problem is solved by doping QDs with a single conduction electron and by encoding the quantum information in the spin degree of freedom of this electron. The spatial confinement in quantum dot protects the electron spins against the primary relaxation mechanisms in bulk, all of which arise from coupling of spin and orbital momenta. Therefore, the electron spin lives for milliseconds or longer and has a coherence time of microseconds at refrigerated temperatures.

However, the electron hyperfine interaction with the lattice nuclei is not screened by confinement, leading to spin decoherence and dephasing, and thus posing severe difficulties for processing quantum information. This problem may be overcome by polarizing the nuclear spins, but the high degree of polarization required, close to 100%, has not been achieved yet.

These facts place the investigations of the electron-nuclei interactions on the very top of the current research field in quantum dots, the field represented by the manuscript of Maria Kuznetsova.

The chapters, presenting gradual understanding and description of different aspects of an electron-nuclei system, organize the dissertation.

First of all, in all experiments author uses a rather novel and robust method for preparation of the spin polarization in the negatively charged QDs, the so called method of a negative circular polarization. The degree of circular polarization of the emitted photons provides then a direct measure of the electron spin projection on the optical axis, and the interaction between nuclei and electrons leads to the change of spin orientation, which is detected by the variation of the polarization. Additionally applied external magnetic fields allow finally the evaluation of the effective nuclear fields seen by the electrons. Although the external magnetic field range where the polarization is observed, is only limited to a small range below 100mT, these method proves itself as an adequate choice.

The chapter 2.2 on the dynamics of nuclear polarization provides comprehensive time-resolved measurements of the longitudinal and transverse (to the direction of applied magnetic field) components of the nuclear polarization. The results of measurements are explained based on the model including the fluctuating nuclear fields and strong quadrupole splitting.

Chapter 2.3 on the role of nuclear spin fluctuations (NSF) discusses further the importance of the NSF in the formations of the Hanle curve measurements. There is a question to both chapters: Can the fluctuating nuclear field components be reduced in that sample using optical excitations and to what extend?

The final chapter describes a method for a resonant nuclear spin pumping by optical means. Here, the strength of the nuclear polarization is found to be sensitive to the phase of the nuclear spin precession of different isotopes with respect to the optical pulses.

Throughout the whole manuscript one sees the importance of quadrupole fields. Can the estimate of the average quadrupole field strength (in mT) be done for the studied sample?

Overall, author demonstrates the knowledge of the literature providing broad spectrum of relevant citations. The presented results are of a very high quality, as it can also be seen by the selection of the publication journals and a number of attended international conferences.

Based on the results, Maria Kuznetsova fully deserves to be awarded to the Ph. D. degree.

Dr. Alex Greilich
TU Dortmund University
Experimental Physics 2
Germany