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Using nuclear magnetic resonance to explore the physics of nuclear spins in semiconductor quantum dots.

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When semiconductor quantum dots (QDs) are considered in the context of implementing solid-state quantum computer, it is inevitable that hyperfine interaction (HI) has to be considered. [1, 2]. The most important model system associated with HI is the so called "central spin" problem that describes single electron or hole spin (trapped in a QD) interacting via HI with a large (10^4-10^6) number of nuclear spins, which also interact with each other via dipole-dipole interaction. The key challenge is to understand how HI affects the coherence of the central spin, and find the conditions under which electron spin coherence can be significantly extended. Although all Hamiltonians of the central spin problem are well known, when realistic properties of a QD are taken into account (e.g. inhomogeneous strain and finite electron wavefunction confinement) it becomes almost impossible to solve. As a result many aspects of nuclear spin physics in QDs still lack understanding.

In this talk I will discuss the use of nuclear magnetic resonance (NMR) as a tool for studying nuclear spin system in semiconductor QDs (with a particular focus on III-V dots). In the first part of the talk I will demonstrate the unique capacity of NMR by reviewing some recent results obtained with this technique. For example the recent measurement of the hole hyperfine constants with chemical-element sensitivity enabled observation of a considerable contribution of the *d*-symmetry orbitals into the valence band states, which significantly modifies hole hyperfine Hamiltonian, making HI non spin-conserving [3]. Furthermore we have demonstrated that NMR on QDs can be used as a powerful structural analysis tool making it possible to probe chemical composition and elastic strain distribution within the volume of a single QD in a noninvasive manner [4].

In the second part of my talk I will present the results of the most recent experimental work done in Sheffield. I will show how NMR can be used to study nuclear-nuclear interactions in self-assembled QDs. Such interactions are responsible for random fluctuations of the nuclear field acting on the central spin and thus set an upper limit on the coherence time of the central spin [1]. For strain free GaAs (bulk, quantum wells and lattice matched GaAs/AlGaAs QDs) the timescale of the dipole-dipole interaction can be easily estimated as ~200 μs which agrees well with experiment [1, 2] However, for self-assembled QDs (e.g. InGaAs/GaAs) the task of predicting nuclear spin bath dynamics is much more complex, due to the presence of strong inhomogeneous quadrupole effects [1]. Here we were able to measure the intrinsic coherence time of the nuclear spins in individual QDs: we found T_2 ~2 ms for ^{71}Ga spins and T_2 ~5.5 ms for ^{75}As. Such pronounced increase of the nuclear T_2 is attributed to the effect of quadrupole interaction that leads to partial freezing of the flip-flops between nuclear spins. Our results suggest that millisecond-scale electron spin coherence is possible in principle in strained QDs, setting up a new milestone on the road towards scalable solid-state quantum computer.

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