Nuclear magnetic resonance in single quantum dots

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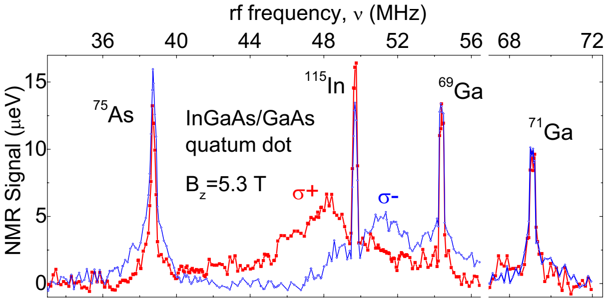
Much new solid state technology for single-photon sources, detectors, photovoltaics and quantum computation relies on the fabrication of strained semiconductor nanostructures. Development of such devices depends on techniques allowing structural analysis on the nanometer scale. However, commonly used microscopy methods are destructive, leading to the loss of the important link between the obtained structural information and the electronic and optical properties of the device. A possible solution is development of non-invasive nuclear magnetic resonance (NMR) techniques. Since most nuclei used in optically active III-V semiconductor nanostructures possess quadrupole moments, optically detected NMR (ODNMR) so far proved difficult in semiconductor nano-structures due to significant strain-induced quadrupole broadening of the spectra. As a result control of nuclear spins using NMR has only been achieved in strain-free nanostructures, like GaAs/AlGaAs semiconductor quantum dots (QDs) [1-3].

Here, we develop new high sensitivity techniques that move ODNMR to a new regime, allowing high resolution spectroscopy of as few as 10^5 quadrupole nuclear spins [4]. Furthermore, related techniques allow the study of coherent dynamics of nuclear spins: inhomogeneous spectral broadening is found to lead to suppression of nuclear spin magnetization fluctuations thus extending spin coherence times.



The dramatic enhancement of sensitivity achieved in our ODNMR technique is based on the use of broadband radio-frequency (rf) excitation, with specially designed spectral pattern. Using this approach, NMR spectra with rich structure are measured on single InGaAs/GaAs and InP/GaInP QDs. In InGaAs QDs contribution from all four isotopes can be resolved (see Fig.). Sharp peaks originate from transitions between +1/2 and -1/2 spin states unaffected by strain; their amplitudes provide information on chemical composition of the dot within the volume sampled by a single electron. Broad spectral bands appearing on both sides of the indium peak originate from satellite transitions (that involve nuclear spin levels with projection >3/2 or <-3/2). The shape and linewidths of these bands reflect magnitude and distribution of strain inside the quantum dot.

The new ODNMR methods have potential to be applied for non-invasive investigations of a wide range of materials containing quadrupole nuclei beyond single nano-structures. Such techniques will also directly address the task of understanding and control of nuclear spins on the nanoscale, one of the central problems in quantum information processing.

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[2] M. N. Makhonin *et al*, Phys Rev B **82**, 161309 (2010)
[3] M. N. Makhonin *et al*, Nature Materials **10**, 848 (2011)
[4] E. A. Chekhovich *et al*, ArXiv:1112.4079v1 (2011)