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Electron-Nuclear Spin Coupling in Semiconductor Quantum Wells[1]

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The ability to manipulate and detect nuclear spin orientation is the basis for the science of nuclear magnetic resonance (NMR). An exciting application of NMR is three dimensional magnetic resonance imaging (MRI) microscopy, which recently achieved $4\mu m \times 3\mu m \times 3\mu m$ resolution with a nuclear spin sensitivity of 3×10^{12} protons. In that application and in most MRI applications nuclear spin is used as a non-invasive probe; the net nuclear polarization does not disturb the characteristics of the sample. Quite the reverse can be true in the spintronic systems studied here (where electron spin dynamics are monitered and manipulated). The electron-nuclear hyperfine coupling means, for example, that nuclear polarization can dominate over external magnetic fields in determining the spin precession frequency of electrons in a GaAs quantum well. This strong coupling suggests that we can use spintronic systems as sensitive probes of nuclear spin polarization. Furthermore by controlling electron spin and electron-nuclear spin coupling we can manipulate local nuclear fields. Working in GaAs/AlGaAs coupled quantum wells (CQWs) and parabolic quantum wells (PQWs), we present several approaches for controlling the electron-nuclear spin coupling. By controlling the position of electron spins in a PQW and by controlling the electron nuclear spin coupling between these electron spins and lattice nuclei we produce thin (<10 nm wide) distributions of polarized nuclei. Applying time-varying RF fields across the electrical gates of our samples, we induce local resonant nuclear spin transitions of selected isotopes. Gaining nuclear spin control in these systems may allow us to utilize long nuclear spin coherence times in spintronic application. Also by controlling nuclear spin distributions on nanometer length scales, we can dynamically modify the electron spin environment.

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