Control of nuclear spins by quantum Hall edge channels

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Extremely weak interaction of nuclear spins to their environments yields, on one hand, their exceedingly long de-coherence time, but on the other hand, makes their control and detection a nontrivial task. Contriving ingenious means of controlling/detecting nuclear spins is thus an important experimental challenge for exploring the implementation of spintronics, quantum information processing or quantum computation in solid state devices. We show here that spin-split edge channels in the integer quantum Hall effect (IQHE) devices provide a unique tool to (i) polarize, (ii) unitary-transform, and (iii) detect nuclear spins. The number of manipulated nuclear spins is small, on the order of 10^9.

The one-electron energy of a finite two-dimensional electron gas (2DEG) system is quantized into discrete Landau levels (LLs) in strong magnetic fields, where each orbital LL is spin split into spin-up and spin-down Zeeman sub-levels. Due to confining potential, the LLs increase their energies as a boundary of the 2DEG layer is approached and form respective edge channels along the boundary at the Fermi level. By selectively transmitting different edge channels by means of cross-gate biasing technique, one can unequally populate the spin-up edge channel and the spin-down edge channel of the lowest orbital LL in a GaAs/AlGaAs Hall bar device in the $\nu=2$ IQHE regime. Over-populated edge channel (either with spin-up or spin-down) can be chosen by the polarity of the source-drain voltage applied to the device. When the up-spin channel is over populated, for instance, spin-up electrons undergo spin-flip transition to empty states of the spin-down edge channel. Due to the hyperfine interaction [1] this process is accompanied by the down-to-up spin-flop transition in the nuclear spin system, leading to the development of strong dynamic nuclear polarization (DNP) in the region only along the edge channels. The DNP, in turn, induces an effective magnetic field for the electron spin system, again, via the hyperfine interaction. This leads to a change of the resistance of the device, through which the DNP is sensitively detected. By passing radio-frequency (rf) currents through a fine metal strip placed near the edge channels locally generate rf-magnetic fields in the region of DNP. Nuclear magnetic resonance (NMR) as well as the Rabi oscillation of initialized nuclear spins are electrically detected (through the resistance) [2,3]. Free-induction decay as well as the spin-echo experiments have been made, suggesting $T_2 = 80\ \mu s$. In addition, by externally modifying the confining potential via side-gate-biasing technique, the edge channels are shifted side-wise over a 120nm distance, thereby locally probing the spatial profile of the DNP. DNP proved to spread roughly over a 20 nm-wide region (twice the magnetic length). The number of manipulated nuclear spins is suggested to be on the order of 10^9. The spin-split edge channels are thus a powerful tool to (i) efficiently initialize, (ii) unitary-transform, and (iii) sensitively detect nuclear spins.

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