Physical Review B - Condensed Matter and Materials Physics 2014 vol.90 N21

Efficient dynamic nuclear polarization of phosphorus in silicon in strong magnetic fields and at low temperatures

Järvinen J., Ahokas J., Sheludyakov S., Vainio O., Lehtonen L., Vasiliev S., Zvezdov D., Fujii Y., Mitsudo S., Mizusaki T., Gwak M., Lee S., Vlasenko L.
Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia

Abstract

 Efficient manipulation of nuclear spins is important for utilizing them as qubits for quantum computing. In this work we report record high polarizations of 31P and Si29 nuclear spins in P-doped silicon in a strong magnetic field (4.6 T) and at temperatures below 1 K. We reached 31P nuclear polarization values exceeding 98% after 20 min of pumping the high-field electron spin resonance (ESR) line with a very small microwave power of 0.4 μW. We evaluate that the ratio of the hyperfine-state populations increases by three orders of magnitude after 2 hours of pumping, and an extremely pure nuclear spin state can be created, with less than 0.01 ppb impurities. A negative dynamic nuclear polarization has been observed by pumping the low-field ESR line of 31P followed by the flip-flip cross relaxation, the transition which is fully forbidden for isolated donors. We estimate that while pumping the ESR transitions of 31P also the nuclei of Si29 get polarized, and polarization exceeding 60% has been obtained. We performed measurements of relaxation rates of flip-flop and flip-flip transitions which turned out to be nearly temperature independent. Temperature dependence of the 31P nuclear relaxation was studied down to 0.75 K, below which the relaxation time became too long to be measured. We found that the polarization evolution under pumping and during relaxation deviates substantially from a simple exponential function of time. We suggest that the nonexponential polarization dynamics of 31P donors is mediated by the orientation of Si29 nuclei, which affect the transition probabilities of the forbidden cross-relaxation processes.

http://dx.doi.org/10.1103/PhysRevB.90.214401