Electrical Detection of Spin Coherence of $^{31}$P Qubits in Silicon at Very High Magnetic Fields

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Introduction

Phosphorus ($^{31}$P) doped silicon (Si:P) is a technologically important material with possible uses in spintronic and quantum information processing devices [1]. One way to understand the properties of this material is by investigation of spin-dependent electronic transitions which influence transport and recombination and thus, the conductivity. Whilst studies of this type have been performed on Si:P at low magnetic fields [1], no systematic investigation had been undertaken at high magnetic fields above $B_0 = 8$T. The goal of the work presented here was to carry out pulsed electrically detected magnetic resonance (pulsed EDMR) experiments at high magnetic fields in order to better understand the nature of electronic processes that may be utilized for coherent electrical spin readout devices.

Experimental

We used the quasi-optical homodyne and heterodyne spectrometers in the EMR facility to perform EDMR at $B \sim 8.5$ T (frequency $= 240$GHz), operating in a microwave chopping mode or microwave pulsed mode. The voltage change across a (111) crystalline bulk silicon device with a doping of $[^{31}P] \sim 10^{15}$ cm$^{-3}$ was recorded.

Results and Discussion

Figure 1 displays data indicative of our most important results: (a) An EDMR spectrum recorded at $T = 1.3$K shows a very pronounced signal due to the hyperfine split $^{31}$P resonance. The measurement shows that EDMR at highest electron spin polarization produces strongest so far recorded EDMR signals [2]. The data also reveals that the intensities of the $^{31}$P hyperfine lines differ significantly. This observation led to the discovery that a fast Overhauser relaxation induces negative hyper-polarization of $^{31}$P nuclei in silicon [4]. Figure 1(b) displays a comparison of Hahn-Echo decays detected with pulsed EDMR and conventional pulsed mm-wave detection. The data shows that the mm-wave detected spin coherence is not compromised by the electrical detection. The electrically detected coherence time is the longest so far detected (of any electrical detection scheme in any material system) [3].

Conclusions

We have achieved the demonstration of EDMR at the highest magnetic fields reported to date [2], the demonstration of a proposed $^{31}$P spin readout mechanism utilizing spin traps in silicon and the demonstration of the longest electrically detected spin coherence time using this mechanism [3]. Furthermore, we have discovered a new method for fast nuclear polarization, which may have application ranging from quantum information processing to magnetic resonance imaging [4].

Acknowledgements

We acknowledge support from the NHMFL Visiting Scientist Program. A portion of this work was performed at the National High Magnetic Field Laboratory, which is supported by NSF Cooperative Agreement No. DMR-0654418, by the State of Florida, and by the DOE.

References