Spin Qubits in Silicon – Advantages of Dressed States

A. Laucht1, R. Kalra1, S. Simmons1, J. P. Dehollain1, J. T. Muhonen1, G. Tosi1, F. A. Mohiyaddin1, S. Freer1, F. E. Hudson1, K. M. Itoh2, D. N. Jamieson3, J. C. McCallum3, A. S. Dzurak1, and A. Morello1

1 Centre for Quantum Computation and Communication Technology, School of Electrical Engineering & Telecommunications, UNSW Australia, Sydney, New South Wales 2052, Australia
2 School of Fundamental Science and Technology, Keio University, 3-14-1 Hiyoshi, 223-8522, Japan
3 Centre for Quantum Computation and Communication Technology, School of Physics, University of Melbourne, Melbourne, Victoria 3010, Australia

*a.laucht@unsw.edu.au

Keywords: Quantum Bit, Dressed States, Electron Spin Resonance

Abstract

A single electron spin in silicon is dressed by a microwave field to create a new qubit with tangible advantages for quantum computation and nanoscale research.

Introduction

Coherent dressing of a quantum two-level system has been demonstrated on a variety of systems, including atoms [1], self-assembled quantum dots [2], and superconducting quantum bits [3]. It is used to gain access to a new quantum system with improved properties - a different and tuneable level splitting, faster and easier control, and longer coherence times. Here, we present coherent dressing of a single electron spin bound to a 31P donor in isotopically purified silicon. The electron spin already constitutes a two level quantum system with extremely long coherence times of $T_2^{\text{CPMG}}=0.5$ s [4] and excellent control fidelities of 99.95 % [5], figures of merit that are on a par with the best solid-state quantum bits realized.

Methods and Results

In our work we investigate the properties of the dressed, donor-bound electron spin in silicon, and probe its potential for the use as quantum bit in scalable architectures. Here, the two dressed spin-polariton levels constitute the quantum bit. We observe a Mollow triplet [1] in the excitation spectrum (see Fig. 1), and demonstrate full two-axis control of the driven qubit in the dressed frame with a number of different control methods. We present coherent control with an oscillating magnetic field, an oscillating electric field [6], by frequency modulating the driving field, or by a simple detuning pulse. We measure coherence times of $T_{2p}^*=2.4$ ms and $T_2^\text{Hahn}=9$ ms, one order of magnitude longer than those of the undressed qubit [7]. Furthermore, we demonstrate that the dressed spin can be driven at Rabi frequencies as high as its transition frequency, making it a model system for the breakdown of the rotating wave approximation [8].

Figure 1. Dressing a single electron spin in silicon. The upper panel shows Rabi oscillations of the resonantly driven electron spin. The Rabi frequency is $\Omega=252$ kHz. The lower panel shows the observation of a Mollow triplet. Here, the electron spin was coherently rotated by $21\pi$, while a second microwave source with -26dB less power was scanned over the resonances to acquire the spectrum.

DOI: 10.17648/bwsp-2017-69955
Acknowledgments

This research was funded by the Australian Research Council Centre of Excellence for Quantum Computation and Communication Technology (project number CE110001027) and the US Army Research Office (W911NF-13-1-0024). We acknowledge support from the Australian National Fabrication Facility, and from the laboratory of Prof. Robert Elliman at the Australian National University for the ion implantation facilities. The work at Keio has been supported in part by FIRST, the Core-to-Core Program by JSPS, and the Grant-in-Aid for Scientific Research and Project for Developing Innovation Systems by MEXT.


DOI: 10.17648/bwsp-2017-69955