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CGS-MSFSS Project report

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Activity Report

Quantum information science and technology is a rapidly growing field that harnesses the quantum properties of nature to communicate information or perform calculations [ladd2010]. For example, quantum cryptography guarantees the confidentiality of cryptographic keys [bennett1984] and quantum computation promises exponential speedups on certain calculations [shor1994]. However, the fabrication of a universal quantum computer is still an open problem. Single donor atoms in silicon metal-oxide-semiconductor (MOS) devices continue to offer a compelling path for long term goals of quantum computation because of the qubit compatibility with the microelectronics industry and the promise of high fidelity qubit performance partly due to the long coherence properties of donor electrons [witzel2010,tyryshkin2012] and nuclei [steger2012] in silicon.

During the period funded by the MSFSS, I was able to achieve significant progress towards our goal of coupling single donor atoms to quantum dots in a silicon nanostructure. The first major result is the demonstration of a new spin-to-charge electron spin readout mechanism for quantum dots coupled to donors. This readout method produces a charge detector signal that has a higher signal-to-noise ratio and has a longer duration than other known readout methods. This work is being prepared for publication and could be titled “Enhanced latching readout of a triplet state in a hybrid silicon quantum dot and donor system”. This work was also presented at the American Physical Society’s March Meeting 2015. Using this new method, I was able to achieve a second major result. It consists in preparing an initial spin state of the quantum dot and performing quantum manipulations of the spin by utilizing the donor nuclear spin as a driving field for the electron spin quantum bit (or qubit). This breakthrough is a new implementation of the singlet-triplet spin qubit [petta2005] and will lead to very exciting future work involving multiple qubits and the donor nuclear spin. This work should be submitted soon to a high impact journal under the title “Nuclear-driven electron spin rotations in a single donor coupled to a silicon quantum dot”. It should also be presented at the American Physical Society’s March Meeting in 2016.

Hence, this project at Sandia National Laboratories has produced exciting discoveries that will result in two publications and presentations in international conferences. This work will count as some of the prominent results of my Ph.D. program. The project established a good collaboration between Université de Sherbrooke and Sandia National Laboratories in the field of silicon quantum computing by combining Sandia’s world-leading fabrication and measurement capabilities with Sherbrooke’s expertise in qubits. We anticipate that these positive results will be continued in follow-up work.

References:

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Public summary

From January 2015 to July 2015, I was doing research at Sandia National Laboratories in Albuquerque, United States. My work there consisted of performing experimental measurements using Sandia's unique silicon quantum computing platform. The project is about coupling donor spin quantum bits, or qubits, to quantum dots in a silicon nanostructure based on conventional microchip technology. During the project, I devised a new quantum state readout mechanism that allow better, longer lived measurement signals. The measurement (or readout) mechanism is key to any qubit architecture. Next, I was able to demonstrate a quantum manipulation of the two-electron spin states of the coupled donor and quantum dot system. This constitutes a breakthrough for donor spin qubits in silicon because it could enable larger systems consisting of many qubits. This project will lead to publications in scientific journals, presentations in international conferences, and generates exciting new opportunities for manipulating nature at the nanoscale.