Radio-Frequency Capacitive Gate-based Sensing for Silicon CMOS Quantum Electronics

Research Abstract

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This thesis focuses on implementing radio frequency (rf) reflectometry techniques for silicon quantum electronics. This field has great potential for applications such as quantum computing, high-precision sensing and meteorology. I have investigated three aspects of rf reflectometry in state-of-the-art silicon silicon complementary metal-oxide-semiconductor (CMOS) nanowire field effect transistor (NWFET).

First, a high-sensitivity capacitive gate-based charge sensor has been developed for fast, accurate and scalable techniques for quantum state readout in CMOS based quantum computing. The external matching circuit was optimized to detect capacitive changes in the high frequency resonator. A new circuit topology is used where superconducting niobium nitride (NbN) inductor is connected in parallel with a single-gate NWFET resulting in resonators with loaded Q-factors in the 400-800 range. For a resonator operating at 330 MHz, a charge sensitivity of 7.7 $\mu e/\sqrt{\text{Hz}}$ is obtained and, when operating at 616 MHz, I get 1.3 $\mu e/\sqrt{\text{Hz}}$.

Second, this new circuit topology for the resonator is used with a dual-gate Si NWFET. This dual gate device geometry gave access to a double quantum dot (DQD) system in few electron regime. The spin-state of the two electron DQD system is read out using Pauli spin blockade between joint singlet S(2,0) and triplet $T_-(1,1)$ states at finite magnetic field B. The singlet-triplet relaxation time T_1 = 1 ms is measured standard homodyne detection techniques.

Thirdly, the capacitive gate sensor is used to implement a primary thermometer that allows probing the local temperature of a single electron reservoir in Si NWFET. The thermometer is based on cyclic electron tunneling between a system with discrete energy levels and a single electron reservoir. The cyclic electron tunneling was driven by embedding the device with the rf capacitive gate sensor which in turn allows us to read the thermometer dispersively. I found that the full-width-half-maximum of the resonator phase response depends linearly with temperature via well-known physical law by using the ratio k_B/e between the Boltzmann constant and the electron charge.