The critical role of interfaces in Si/SiGe quantum dot qubits: valley splitting and radiation impacts

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Interfaces and other atomic-scale materials features are critical to the operation, properties, and robustness of Si/SiGe quantum dot qubits. In this talk I discuss two important examples. First, the atomic-scale structure of the quantum well in Si/SiGe heterostructures plays the dominant role in determining the valley splitting. This splitting, which arises from a coupling between the two z-valleys in the silicon band structure, determines the energy gap that protects spin-up and spin-down qubit states. If the valley splitting is small, the qubits fail. While the interface between the quantum well and the upper quantum well barrier by itself does cause some valley splitting, recent results demonstrate a new method: silicon quantum wells containing short wavelength oscillations in the concentration of added germanium atoms can significantly increase the valley splitting. Second, there are deeper, buried defect layers that in principle can trap charges induced by external radiation. I will discuss recent experiments that imitate such radiation impacts in Si/SiGe quantum devices using fiber optic illumination on the back of the wafer to deposit energy and induce bursts of electron-hole pairs deep in the bulk of the wafer. We find that some of the generated charge – mostly negative charge (electrons) – migrates to the top region of the wafer and shifts the offset charge of quantum dot qubits. We are able to identify abrupt jumps in the offset charge that appear to arise from trapping of individual electrons. Based on the magnitude of the jumps in the offset charge, the charge trapping occurs within a few hundred nanometers of the qubit. Importantly, the device can be very stable both before and right after the single-charge trapping, as we demonstrate by turning off the optical illumination as soon as a charge jump is observed.

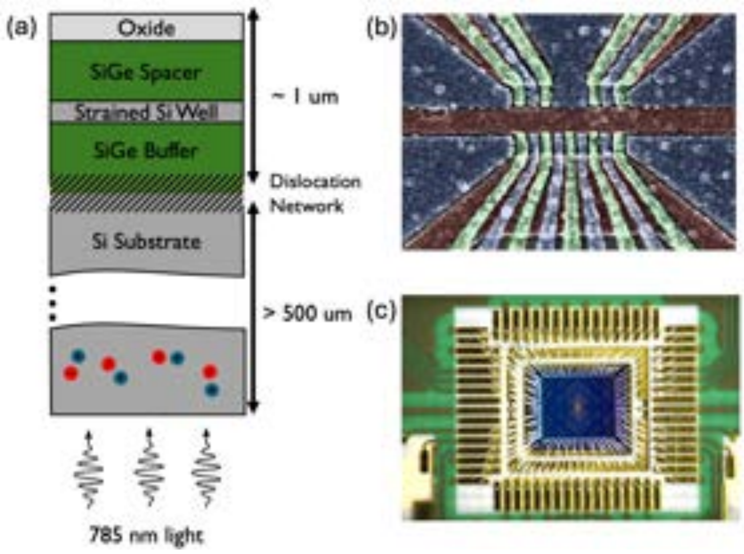

Figure 1 (a) A prototypical Si/SiGe qubit heterostructure showing (i) a buried defect layer formed during epitaxial growth aimed at producing (ii) relaxed SiGe, (iii) a tensile-strained Si quantum well, and (iv) a top barrier and oxide layer. The many interfaces present are essential to qubit operation and resilience. Experiments are performed using (b) overlapping gate devices fabricated at UW-Madison and (c) Tunnel Falls devices fabricated at Intel Corporation.