Single Electron Transport Simulations in Silicon Nanochains
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Abstract: We carry out simulations of Coulomb staircases observed experimentally in the current-voltage (I-V) characteristics of single Si nanochains at room temperature [1]. The nanochains consist of Si nanocrystals (SiNCs) ~10 nm in diameter, separated by ~5 nm SiO2 barriers. Coulomb staircases characteristics can be simulated using a multiple tunnel junction (MTJ) model (Figure 1 (a)) [2]. Here, the SiNCs form charging islands, isolated by tunnel barriers at the SiO2 regions (Figure 1 (b)). Figure 1 (c) shows SEM image of a nanochain. Figure 1 (d) shows the I-V characteristics of a nanochain containing 7 SiNCs, similar to experimentally measured devices. We simulate these characteristics using an MTJ with equal junction capacitances (C), varying values of junction resistances (R1, R2,…..,Rn), and equal SiNC to substrate capacitances C0. Simulations show that the C0 plays an important role in reduction of the threshold voltage, as shown in Figure 1 (e). As C0 increases, a greater proportion of the source-drain voltage (VDS) across the nanochain drops across the first tunnel junction, due to the voltage divider formed by the first junction capacitance C, and the first stray capacitance C0, in parallel with the equivalent capacitance of the rest of the MTJ [3]. The charging energy of the first junction is overcome at lower voltages, leading to a lower onset of current. The simulations demonstrate that a random variation in the tunnel junction resistances leads to clearer Coulomb staircases. A 60% variation in resistances gave the best fit to our experimental results.

Fig 1: (a) Equivalent circuit diagram of a nanochain device (b) Schematic diagram of a nanochain (c) SEM image of a nanochain (d) Experimental and simulated I/V characteristics of a nanochain device (e) Simulated effect of gate capacitance on threshold voltage.