Overcoming Challenges in Single Electron Charge Detection of Nanoscale Dipoles.

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In our recent study on nanoscale dipole detection[1], a Single Electron Transistor (SET) charge sensor, closely coupled to a metal double-dot (DD) (similar to Fig. 1(a)), detected single electron charging in the DD with an equivalent charge magnitude of about 0.08e. However, about 10% of devices exhibited a much stronger charge magnitude of about 0.3e. Considering the capacitive coupling from the DD to the SET, this increased charge magnitude could not have been the intended charging detection; rather, it must be associated with charging of a metal dot tunnel-coupled to the island of the SET electrometer, effectively functioning as a Single Electron Box (SEB). The presence of this metal dot was a byproduct of the fabrication scheme[2] and was intended to enhance the proximity of the SET electrometer with the dipole system. Hence, understanding the impact of SEBs charging on the charge detection fidelity of SETs becomes paramount.

In prior studies[3], small traps tunnel-coupled to the SET's drain or source and capacitive-coupled to the gate altered the SET's charging behavior. In contrast, we focus on detecting charge objects tunnel-coupled to the SET island with weak capacitive coupling to the source and drain. Careful SET layout design can produce negligible impact from the Single Electron Box (SEB) charging on the intended detection of charged objects (DD). These findings are validated through simulations

Fig. 1(a) illustrates an SEM micrograph of an Aluminum SET with a SEB on the island extension, fabricated by a standard dual-angle shadow evaporation process[2] on a fused silica substrate. To exclusively investigate the impact of SEB charging on the SET, the structure in Fig. 1(b) was designed without the double dot structure of Fig. 1(a). The equivalent circuit of the system of Fig. 1(b) is illustrated in Fig. 1(c). Specific gate bias conditions result in single electron charging within the SEB, modulating the SET's differential conductance. This effect distorts the typical Coulomb Blockade Oscillation (CBO) pattern of the SET at regular intervals in Fig. 2(a), experimentally obtained at 2.7K.

Our simulation of a basic electrostatic charge model[4], illustrated in Fig. 2(b), matches our experiment well. Increasing the SEB-to-island capacitance, $C_{SEB\text{-}i}$, effectively reduces the charging energy of the SEB, resulting in a notable reduction in the magnitude of charge offset caused by SEB charging— observed in the structure of Fig. 1(a). This study illustrates how single electron charging of an SEB at the SET island tip influences conductance and emphasizes proper SET design to mitigate such effects.

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[3] H. George, *et al., Applied Physics Letters, 96*(4), 2010.
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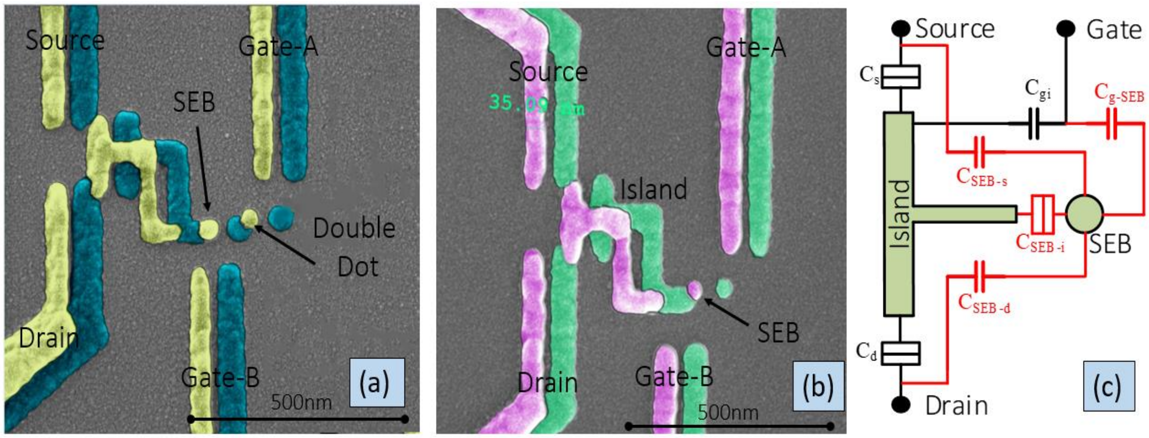

Fig 1: False color SEM micrograph of Aluminum SET with a SEB on island plunger. The colors represent two different angle of Al evaporation (a) With a double dot. (b) Without a double dot. (b) Equivalent circuit schematic of system in Fig 1(b).

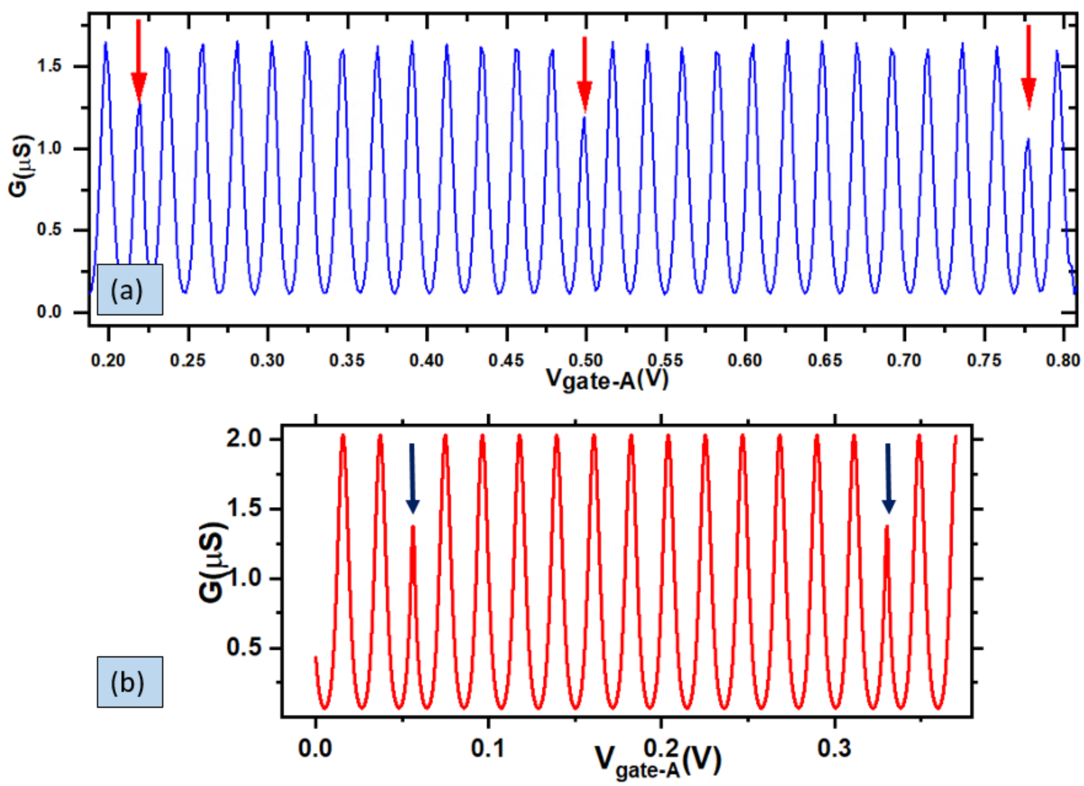

Fig 2: (a) Experimental Coulomb Blockade Oscillation (CBO) of the SET shown in Fig. 1(b). Differential conductance, G(S), dI_{ds}/dV_{ds}, plotted while sweeping $V_{gate\text{-}A}$ at 2.7K with gate-B grounded for V_d =0V. Red arrows highlight change in conductance due to single electron charging in SEB. (b)Simulated CBO of Fig. 1(c) with arrows pointing the change of conductance due to SEB charging with C_{gi}=0.118aF, C_s=39.7aF, C_d=16aF, $C_{g\text{-}SEB}$=0.0236aF, $C_{SEB\text{-}s}$= $C_{SEB\text{-}d}$= 1.55aF, $C_{SEB\text{-}i}$=4.72aF.