Challenges in Single-Electron Charge Detection in Non-Abelian Type Quantum Dots Using Single Electron Transistors.

M. I. Rahaman, G. P. Szakmany A. O. Orlov, and G. L. Snider
Electrical Engineering Dept., University of Notre Dame, Notre Dame, IN 46556
gsnider@nd.edu

The detection of spatial movement of unit charges within a nanoscale quantum dot (QD), proposed to exhibit exotic non-Abelian (NA) exchange statistics, is a critical step toward the practical realization of topological quantum computers. Mintairov *et al.*[1] recently reported experimental evidence of NA statistics in self-assembled InP QDs, where a single electron was involved in the creation of a Majorana-bound vortex. This finding opens the possibility of deploying Single-Electron Transistors (SETs) for spatial charge sensing within these QDs.

InP QDs were grown on an InGaP epitaxial layer on a GaAs substrate as per the prescription of Mintairov *et al.*[1] Fig. 1(a) shows a Scanning Electron Micrograph (SEM) of an experimental die, demonstrating site-controlled InP QDs grown on a periodic grid. Al/AlOx/Al metallic SETs were fabricated using the Niemeyer–Dolan technique[2], in close proximity to an InP QD as shown in Fig. 1(b). An SET without any QD, depicted in Fig. 1(c), served as a control/reference device to distinguish the response of SETs with and without InP QDs.

At 300mK, the differential conductance, $G_{SET}(\mu S) = dI_{ds}/ dV_{ds}$, with respect to time, of SET-1 and SET-2 under different photoexcitation are depicted in Fig. 2 (a) and (b) respectively. Photoexcitation was provided by a 650nm wavelength semiconductor red laser operating at room temperature and delivered via a 5m long single-core optical fiber inside the cryostat. The black traces in Fig. 2(a) and 2(b) represent $G_{SET}(\mu S)$ of the two SETs without photoexcitation, demonstrating a stable conductance which is suitable for unit charge detection. Upon applying photoexcitation (0.008μW laser power), both SETs exhibited time-dependent Coulomb Blockade Oscillations (CBOs), where the oscillation frequency increased with the intensity of the laser illumination. These time-dependent CBOs indicate that the illumination generated electron-hole pairs (EHPs) in the substrate. The built-in electric field within the structure separated these electrons and holes, creating a net equivalent gate bias, leading to the observed time-dependent CBOs. As light intensity increased (0.026μW laser power), more EHPs were generated per unit time, thereby increasing the frequency of the CBOs.

We explored a range of light intensities both well below and above the level of power needed to photo-excite an electron in a QD[1]. In that range, no unit charge quantization within the QDs was detected. Since low-temperature photoluminescence (PL) measurements were not available for the sample used, and samples from the same batch showed no detectable PL signal, we speculate that the QDs under investigation had a very short electron lifetime. Consequently, the entire set of experimental observations can be attributed to substrate effects under light illumination. The significance of these results lies in the necessity of carefully accounting for substrate effects in experiments involving quantum dots to ensure measurable outcomes.

---

[1] A. M. Mintairov, *et al., Phys Rev B 111* (2025): 045410.
[2] G. Dolan *et al., Applied Physics Letters*, *31*(5), 337-339, 1977.

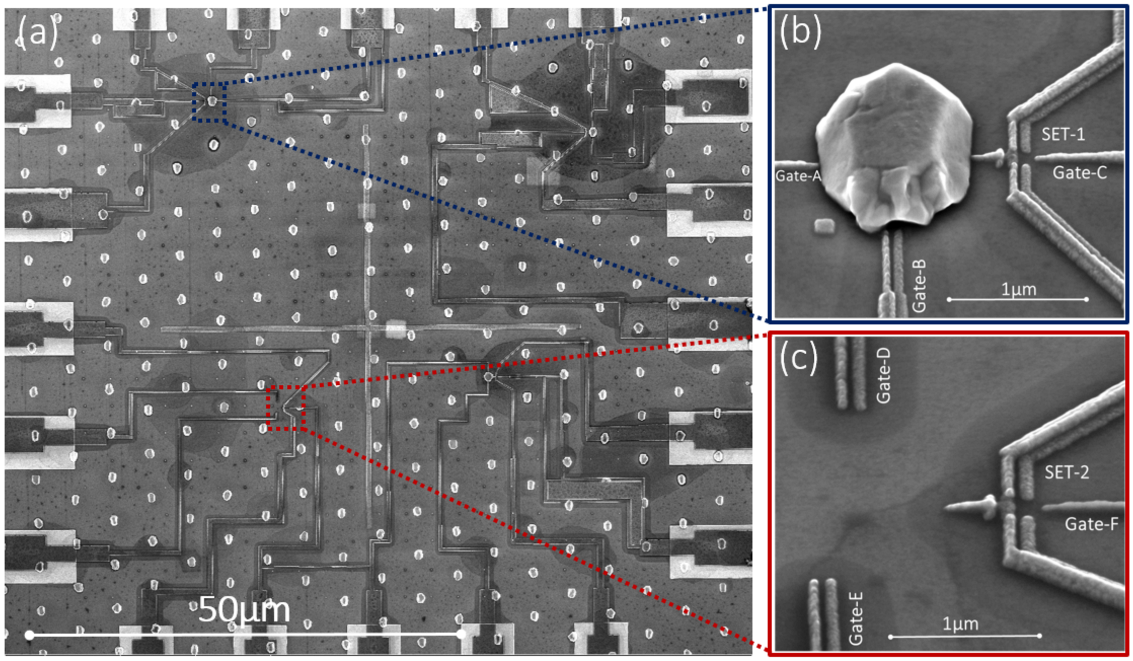

Fig 1: (a) SEM micrograph of an experimental die. InP quantum dots with an InGaP cap layer on top were grown at defined locations. (b) SEM micrograph of SET-1 integrated in close proximity to an InP quantum dot with an InGaP cap layer on top. The small square is an aluminum fiducial mark used for alignment purposes. The gates labeled as gate-A through gate-C were used for supplying DC voltage. (c) SEM micrograph of SET-2 without any nearby quantum dot. The gates labeled as gate-D through gate-F were used for supplying DC voltage.

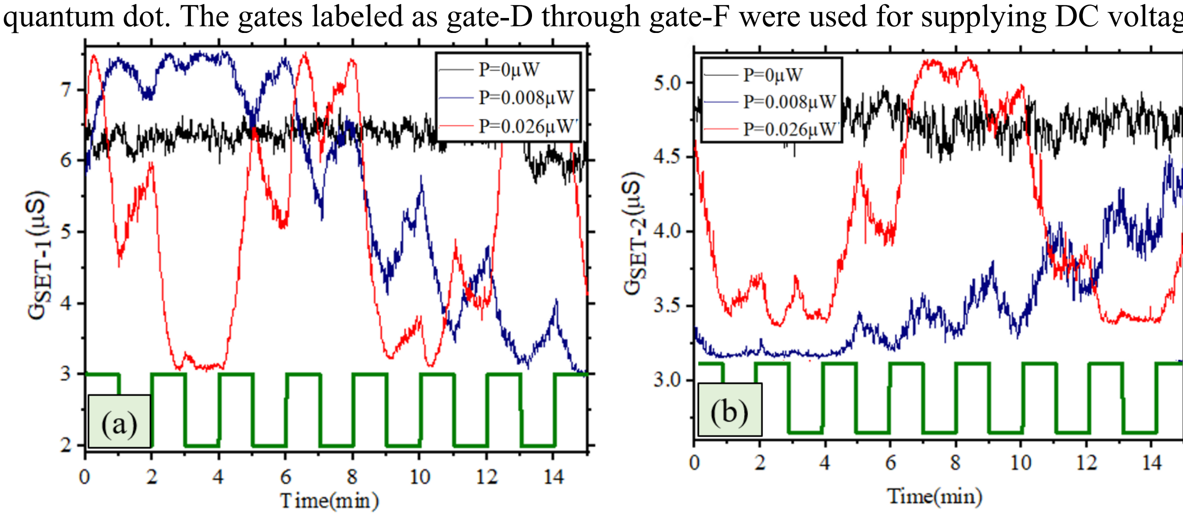

Fig 2: Differential conductance, G_{SET}(µS), of (a) SET-1 and (b) SET-2 as a function of time measured at 300mK. G_{SET}(µS) was measured using standard low-frequency lock-in amplifier. The sample was illuminated with pulses from a semiconductor red laser (650 nm wavelength) delivered through an optical fiber. The pulses had a duty cycle of 50%, with an on-time of 60 seconds, and were applied continuously throughout the experimental time. The green trace at the bottom in both figures, shown with arbitrary magnitude, represents the laser pulses. The output power of the laser was 0µW, 0.008µW and 0.026µW, measured at room temperature.