Effect of tunnel resistance modulation on single-electron tunneling in selectively-doped Si nano-transistors

°A. Afiff[1,2,3], A. Udhiarto[3], H. Sudibyo[3], D. Hartanto[3], M. Tabe[1] and D. Moraru[1,2*]
[1]Research Institute of Electronics, Shizuoka University *E-mail: moraru.daniel@shizuoka.ac.jp
[2]Graduate School of Science and Technology, Shizuoka University
[3]Faculty of Engineering, University of Indonesia

Silicon transistors are the key building blocks of present-day electronics, but they become affected by the individuality of dopants or dopant clusters in nanoscale. A number of studies have focused on the effects of dopants as quantum dots (QDs) mediating single-electron tunneling (SET), as a fundamental mode of operation for Si nano-transistors [1].

Recently, we fabricated selectively-phosphorus-doped Si transistors in silicon-on-insulator (SOI) substrates in order to form a deep donor-QD, with large tunnel barriers. Device structure and potential profile are shown in **Fig. 1**. This allowed us to observe SET even at high temperatures (T~150 K) because the thermally-activated electrons are effectively cut off by the high tunnel barriers [2]. The SET signatures at low bias emerge as Coulomb diamonds in the stability diagrams as T is increased.

In this work, we analyze the behavior of these devices at low T, but increasing the bias range. As V_D is increased, Coulomb diamonds emerge at lower gate voltages, with higher extensions in V_D as V_G is made more negative. (**Fig. 2(a)** shows an experimental results at T=5.5 K.) The observation of these Coulomb diamonds confirms the presence of deep states of donor-QDs in the channel.

The increasing opening of these diamonds with reducing V_G can be attributed to several factors, such as: (i) gradually increasing tunnel resistance (R) at lower V_G; (ii) the presence of more than one QD in the channel; or (iii) gradually enhanced electron localization at lower V_G (increasing charging energy). **Fig. 2(b)** shows a simulated stability diagram for a single-QD based on the orthodox theory of Coulomb blockade [3], considering model (i), i.e., the modulation of the tunnel resistance by the voltage (indicated in **Fig. 2(b)**). The reasonable matching between experiment and simulation suggests that the tunnel resistance modulation is a critical factor in the single-electron tunneling operation of these devices. However, further study is under way to fully clarify the models and will be discussed in the presentation.

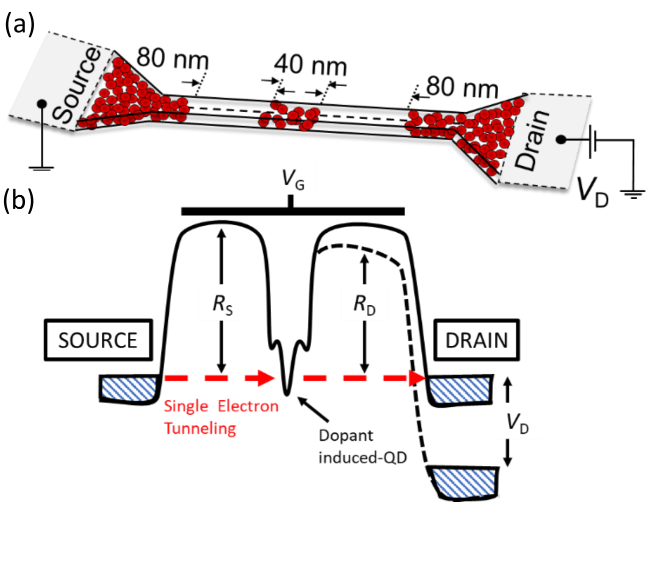

Fig. 1. (a) Schematic illustration of a nano-FET, with a selectively-doped area in the center of the channel. (b) Potential profile of the selectively-doped nano-FET. Drain bias and gate voltage can modulate the tunnel resistances.

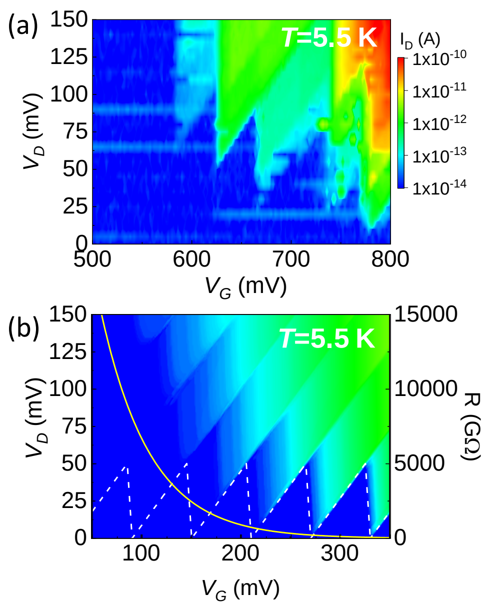

Fig. 2. Low-temperature stability diagrams of: (a) selectively-doped nano-FET from experimental results; (b) simulated single-QD system with tunnel resistance modulated by gate voltage (yellow curve).

[1] P. M. Koenraad and M. E. Flatté, Nature Mater. **10**, 91 (2011). [2] A. Samanta *et al*., Appl. Phys. Lett. **110**, 093107 (2017). [3] M. H. Devoret and H. Grabert, *Single charge tunneling: Coulomb blockade phenomena in nanostructures* (NATO), 1991.