Effect of dimensionality on the formation of dopant-induced quantum-dots in heavily doped Si Esaki diodes

°**G. Prabhudesai[1,2], M. Manoharan[3], M. Hori[1], Y. Ono[1], H. Mizuta[3], M. Tabe[1], and D. Moraru[1*]**
[1]Research Institute of Electronics, Shizuoka University *E-mail: moraru.daniel@shizuoka.ac.jp
[2]Graduate School of Science and Technology, Shizuoka University
[3]Japan Advanced Institute of Science and Technology (JAIST), Nomi, Japan

Since the first demonstration of quantum mechanical band-to-band tunneling (BTBT) in heavily doped *pn* tunnel (Esaki) diodes about 60 years ago [1], BTBT has remained a main mechanism even in nanowire structures [2]. For future Si nanoscale devices, such Esaki diodes or related tunnel field-effect transistors (TFETs) [3] are promising candidates, relying on BTBT transport through the extended states of the p^+ and n^+ leads. At lower dimensionality, however, the transport mechanism is expected to be strongly affected by the dopant non-uniformity.

Previously, we have reported a strong current enhancement through a facing pair of phosphorus (P) and boron (B) in low-dimensional (2D) Esaki diodes [4]. In this work, we present a more fundamental study on the effect of dimensionality on the potential landscape of Esaki diodes.

For bulk Esaki diodes, the potential landscape near the *pn* junction is formed by the space-averaged long-range Coulomb potentials of a large number of ionized dopants. In nanoscale, however, as the number of dopants is far lower than that in bulk-like (3D) large devices, the long-range potentials of distant dopants is absent. Therefore, at such dimensionality (2D and eventually 1D), potential fluctuations start to become visible leading to the formation of locally deep quantum-dots (QDs). An atomistic dopant distribution and potential landscape for a 2D Esaki diode are shown in **Fig. 1(a)**.

Our statistical studies reveal that these QDs are formed by clusters of ionized dopants near the *pn* junction. These QDs are also found to be mostly isolated from the quasi-metallic p^+ and n^+ leads, a finding which is an *inherently* nanoscale effect. The effective band diagram of the nanoscale Esaki diodes containing such a dopant-induced QD is shown in **Fig. 1(b)**. For low-dimensional devices, it is found that one or a few QDs are formed in a typical structure, as indicated in **Fig. 1(c)**.

We experimentally demonstrate that these dopant-induced QDs mediate SET transport, a first-time observation in Esaki diodes. Further study is underway to correlate the simulation and experiment, and will be discussed in the presentation.

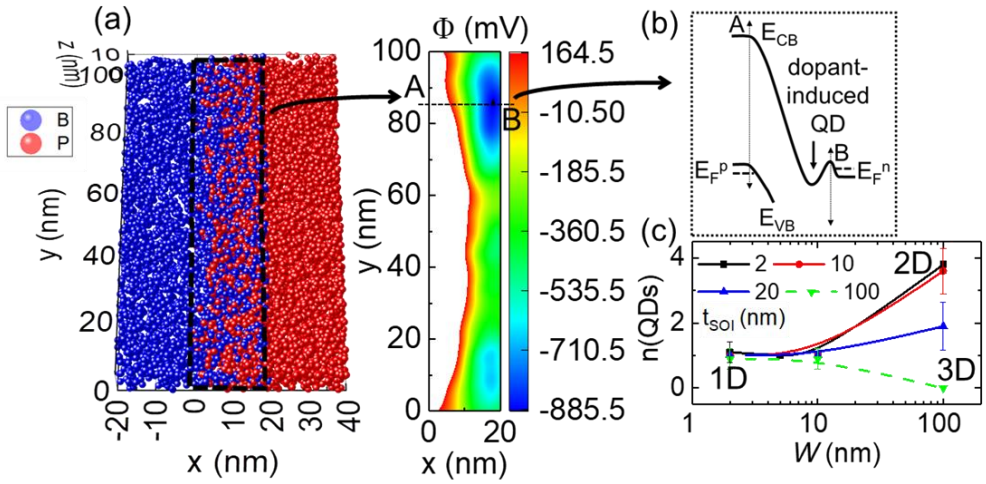

Fig. 1. (a) Simulated dopant distribution (areas outside the black dotted box are quasi-metallic p^+ and n^+ leads) and empirically calculated potential map near the junction (20×100×10 nm^3) of a 2D *pn* Esaki diode. Regions of blue contrast correspond to locally-deep donor-induced QDs. **(b)** Energy band diagram of a nanoscale *pn* Esaki diode with a multiple-dopant-induced QD (along line AB as shown in **(a)**). **(c)** Number of quantum-dots formed as a function of the size of the *pn* junction.

References:

[1] L. Esaki, Phys. Rev. **109**, 603 (1958). [2] H. Schmid *et al.*, Nano Lett. **12**, 699 (2012). [3] A. C. Seabaugh *et al.*, Proc. IEEE **98**, 2095 (2010). [4] M. Tabe *et al.*, Appl. Phys. Lett. **108**, 093502 (2016).