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Transport Spectroscopy of Dopant States in Randomly-Doped Single-Electron Transistors

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Introduction

In recent years, dopant-atom-based single-electron transistors have become important candidates for the next generations of silicon-based nanoelectronics.[1-5] In most works, doping was done using conventional techniques that lead to random dopant distribution. However, the effects of different dopant arrangements on the transport characteristics have not been studied rigorously. In this report, using low-temperature electrical characteristics, we present the transport spectroscopy of discrete electronic states of single or multiple donor systems in randomly-doped single-electron transistors.

Uniformly-doped nano-channel SOI-MOSFETs

Figure 1(a) shows the schematic structure of the SOI-FETs under investigation. The channels were doped with phosphorous (P) atoms by thermal diffusion with concentration $N_D \approx 1\times10^{18}$ cm^{-3}. The smallest devices have the channel width of ~20 nm and length of ~40 nm, while channel thickness is <5 nm. Figures 1(b) and 1(c) illustrate two basic types of possible dopant arrangements in the channel, containing more isolated P donors or randomly clustered P donors.

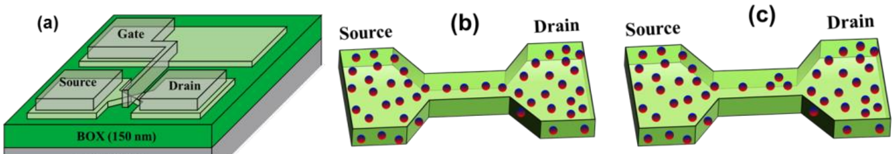

Fig. 1. (a) Schematic structure of P-doped nano-channel SOI-MOSFET. **(b)** and **(c)** Illustrations of two possible dopant distributions in randomly-doped devices: **(b)** relatively isolated P donors; **(b)** randomly clustered P donors in close vicinity.

Low-temperature I-V characteristics of randomly-doped SOI-MOSFETs

Figure 2(a) shows the I_D-V_G characteristics of one type of device at T ~ 9 K for small source-drain bias (V_D = 5 mV) which shows isolated prominent current peaks. If we carefully observe these peaks, we can identify that each of the peaks consist of two subpeaks (inflections), as presented in the inset of the Fig. 2(a). These features most likely indicate single-electron tunneling through the ground and excited states of the single-P-donor quantum dot (QD), as presented in the schematic model of Fig. 2(d). However, in another type of devices, we observed in the I_D-V_G characteristics repetitive series of current peaks, each consisting of a more complex set of subpeaks, as presented in the Fig. 2(b). The most probable origin of these repeated features is the accidental formation of a cluster of phosphorus dopants, closely spaced to each other, giving rise to a more complex density-of-states spectrum, such as schematically illustrated in Fig. 1(d).

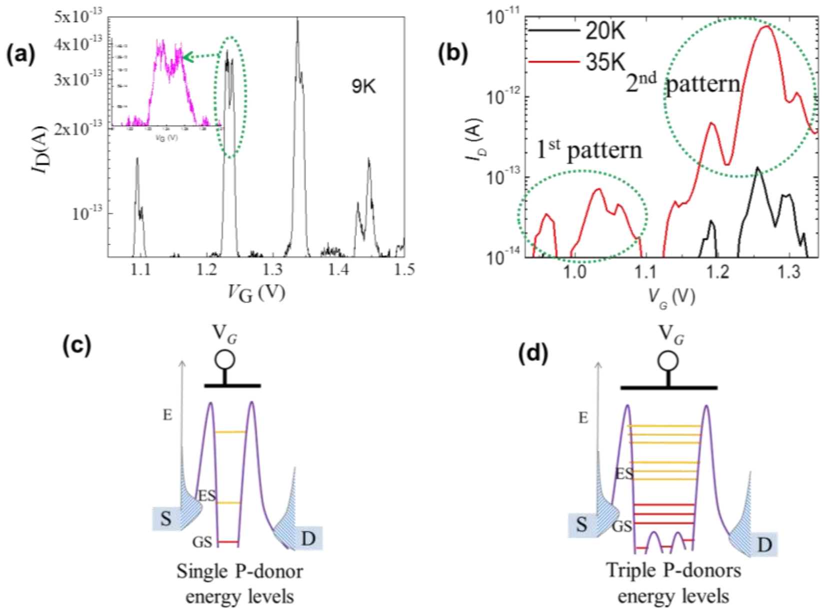

Fig. 2. (a) I_D-V_G characteristics of one type of P doped channel device at T ~ 6 K (V_D = 5mV). **Inset:** The magnified view of the peak indicated by arrow. **(b)** Temperature dependence of I_D-V_G characteristics of another type of devices, with more comlex features, for V_D = 5mV. **(c)-(d)** Schematic representation of energy levels of single and multiple-P donors systems.

References

[1]H. Sellier *et al.*, Phys. Rev. Lett. **97,** 206805 (2006). [2] Y. Ono *et al.*, Appl. Phys. Lett. **90,** 102106 (2007). [3] M. Pierre *et al.*, Nature Nanotechnol. **5,** 133 (2010). [4] M. Tabe *et al.*, Phys. Rev. Lett. **105,** 016803 (2010). [5] E. Hamid *et al.*, Phys. Rev. B **87,** 085420 (2013).