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 channel was doped with phosphorous (P) atoms by thermal diffusion with concentration \(N_D \approx 1 \times 10^{18} \text{ cm}^{-2}\). The smallest devices have a channel width of \(\sim 20 \text{ nm}\) and length of \(\sim 40 \text{ nm}\), while channel thickness is \(<5 \text{ nm}\). 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.

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 \(T \sim 9 \text{ K}\) for small source-drain bias \((V_D = 5 \text{ mV})\) 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).

References


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