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Persistence of single-donor effect up to room temperature in SOI-MOSFETs

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Introduction

Single-dopant-atom transistor is one of the promising candidates for future generations of nanoelectronics.[1-5] However, most characteristics of individual dopant-atom have been studied at cryogenic temperatures. In terms of applications, room-temperature operation is essential. At room temperature, the impact of individual dopants has been typically observed as threshold voltage (V_{TH}) fluctuations in the electrical characteristics of transistors.[4,6] Recently, we observed that, in nanostructured-channel SOI-FETs, new current peaks emerge at high temperatures (100 K) due to single-electron tunneling via a single dopant.[7] This was ascribed to the enhancement of the donor's ionization energy due to a strong dielectric confinement. In this report, we focus on the hump features that appear at more negative gate voltages (V_G) relative to the peaks. These humps can be observed at high temperatures and persist up to room temperature, suggesting that they are due to deep-energy dopant-induced quantum dots.

Results and Discussion

Figure 1(a) shows the schematic structure of the SOI-FETs under investigation. The channel was doped with phosphorous (P) atoms ($N_D \approx 1\times10^{18}$ cm^{-3}). The smallest devices have channel width of ~20 nm and length of ~40 nm, while channel thickness was only 2 nm. Figure 1(b) shows an SEM image including also discrete donor distribution.

In order to clarify the transport mechanisms, we measured the I_D-V_G curves from low temperatures (T = 20 K) to room temperature (T = 300 K), as shown in Fig. 1(c). As previously reported,[7] we observed the emergence of new peaks at intermediate temperatures. These new peaks were ascribed to tunneling via deep-energy P donors. Moreover, we can see different features at more negative V_G's as distinct humps, appearing at 120 K (blue curve) and at 200 K (green curve). It is important to note that these humps persist even up to room temperature. The origin of these humps can be studied from Arrhenius plot analysis at the peak and hump regions, as shown in Fig. 1(d). For the peak, three different regions can be observed (marked as (i), (ii), (iii)). At low T (region (iii)), transport is dominated by single-electron tunneling. With increasing T, thermally-activated transport becomes important (region (ii)) and eventually it becomes the dominant transport mechanism (region (i)). For the hump, we observed only two different regions, indicated by (i) and (ii), i.e., thermally-activated transport and mixed transport regime. This behavior is similar to the one observed for the peak, suggesting that the hump may also be due to donor-induced QD. This QD may be either due to individual or grouped donors, with deeper ground-state energies as indicated by the calculated actiation energies in Fig. 1(d). This can justify the persistence of the features even at room temperature.

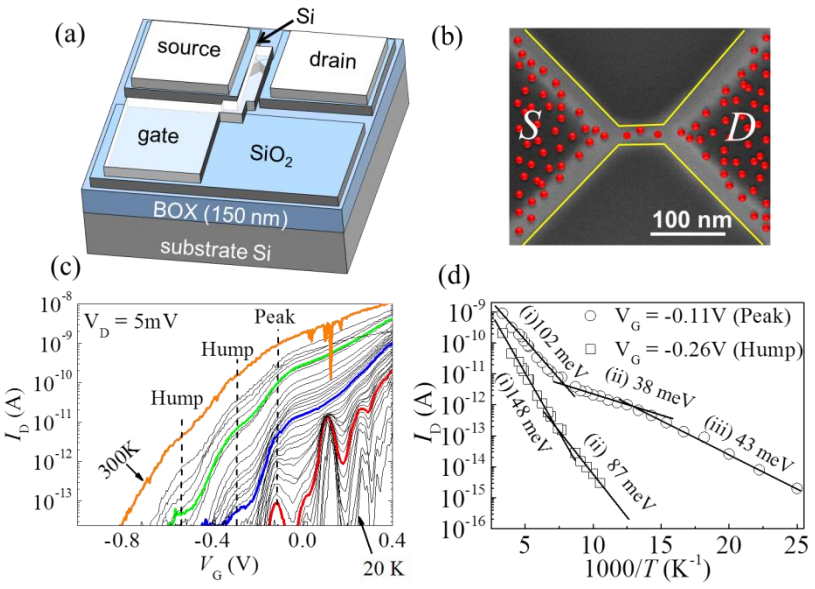

Fig. 1. (a) Schematic structure of P-doped nano-channel SOI-MOSFET. **(b)** SEM image for one smallest device. **(c)** Temperature dependence of I_D-V_G characteristics (V_D = 5mV). **(d)** Representative Arrhenius plot for a peak and hump region. Calculated activation energies are indicated on the plot.

References [1]H. Sellier *et al*., Phys. Rev. Lett. **97**, 206805 (2006). [2]G. P. Lansbergen *et al*., Nat. Phys. **4**, 656-661 (2008). [3]Y. Ono *et al*., Appl. Phys. Lett. **90**, 102106 (2007). [4]M. Pierre *et al*., Nat. Nanotechnol. **5**, 133-137 (2010). [5]M. Tabe *et al*., Phys. Rev. Lett. **105**, 016803 (2010). [6]T. Shinada *et al*., Nature, 437, 1128 (2005). [7]E. Hamid *et al*., 73rd JSAP Fall Meeting, 14p-F4-5 (2012).