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Impact of Doping Concentration Regimes on Low-Temperature Tunneling in Nanoscale SOI-FETs

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Introduction

Single-electron tunneling via individual dopants has been intensively studied [1-3]. Generally, dopants diffused from source/drain contacts or purposely doped randomly into the channel work as distinct quantum dots (QDs) in tunneling. More recently, precisely-positioned dopants have also been studied [4,5].

In this work, we attempt to obtain a wider overview of the impact of the number of dopants in transport characteristics, covering the regimes of dilute, intermediate, and high doping concentration in channel and leads.

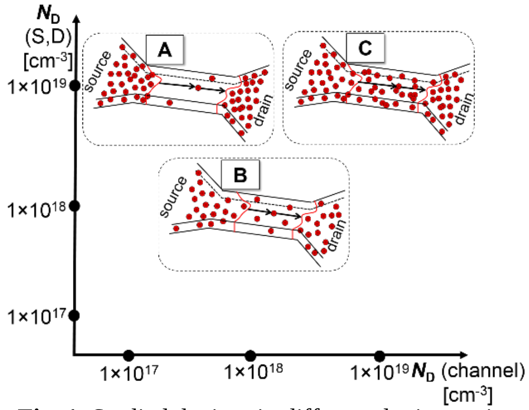

Fig. 1. Studied devices in different doping regimes, mapped as a function of S/D and channel doping.

Doped devices and low-temperature characteristics

The devices that we study are silicon-on-insulator (SOI) MOSFETs, with narrow and thin channels (t_{Si} ~ 10 nm), doped with phosphorus with different concentrations (device **A**: 1-2×10^{17} cm^{-3}; device **B**: ~1×10^{18} cm^{-3}; device **C**: >1×10^{19} cm^{-3}). At the same time, doping concentration in the adjacent source/drain leads was also changed, as illustrated in the schematic diagram of Fig. 1.

For reference devices (with nominally-non-doped channels), we observe, at low T, I_D-V_G characteristics with a relatively abrupt increase of the current (Fig. 2(a)). When the channel is purposely doped with low N_D, several inflections appear, as seen in Fig. 2(b) including a few isolated peaks in some devices. These features may be ascribed to the impact of a small number of P donors in tunneling.

For the regime of intermediate N_D (1×10^{18} cm^{-3}), it has been statistically observed that a significant number of isolated I_D peaks emerge in the low-V_G range [3] (An example is shown in Fig. 2(c)). Since a larger number of donors are expected to be found in the channel, each current peak is likely associated with several different P donors, although formation of few-donor clusters cannot be excluded [6].

When N_D is further increased (as for device **C**), the device is designed effectively as a junctionless transistor. However, at low T, a large number of current peaks dominate transport, as seen in Fig. 2(d). These peaks likely arise from the complex potential landscape realized in the many-dopant channel.

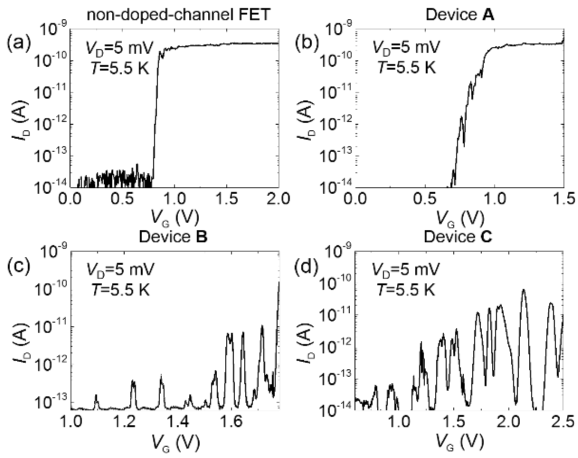

Fig. 2. Low-T I_D-V_G characteristics for different devices: (a) nominally non-doped; (b) low-N_D doped-channel; (c) intermediate-N_D uniformly-doped; (d) highly-doped-channel.

Conclusions

We address and characterize transport through dopant-induced QDs under various regimes of doping. This allows identification of conditions in which a very small number of dopants completely dominate transport. Further study is expected to reveal also the impact of the position of such dopants on the transport properties of nanoscale dopant-atom transistors.

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. Tabe *et al.*, Phys. Rev. Lett. **105**, 016803 (2010). [4] E. Prati *et al.*, Nature Nanotechnol. **7**, 443 (2012). [5] M. Fuechsle *et al.*, Nature Nanotechnol. **7**, 242 (2012). [6] G.A. Thomas *et al.*, Phys. Rev. B **23**, 5472 (1981).