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Transport via dopant-quantum-dots fabricated by thermal diffusion through nano-masks

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Introduction

In recent years, we have been studying dopant-atom devices that work by single-electron tunnelling via single dopant atoms as quantum dots (QDs) [1]. These devices can offer a broad functionality range, also based on a different transport mechanism as compared with scaled-down conventional transistors. Recently, the field of single-dopant devices has been steadily developed and advanced through several breakthrough studies [2-6].

Ii should be noted, however, that, in most devices, the dopants were introduced in the channel with conventional doping techniques, in random positions, and devices exhibiting single-dopant characteristics were picked up for more detailed study. Only a few works addressed directly the control of dopants, either in number, using single ion implantation [7], or in position, with atomic manipulation using scanning tunnelling microscope tips [8]. These are, however, state-of-the-art techniques, which are not fully suitable for CMOS fabrication.

In this work, we propose and demonstrate fabrication of dopant-based devices, with the dopant position controlled using precisely patterned doping masks.

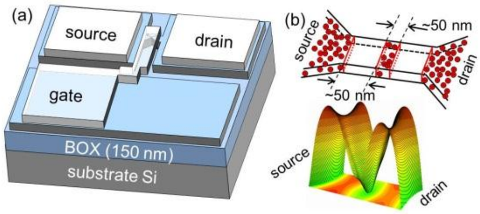

Fig. 1. (a) Structure of an SOI-MOSFET studied. (b) Top: FET channel selectively doped in nanoscale using thermal diffusion process. Bottom: possible potential landscape induced by localized donors.

Fabrication and electrical characteristics of selectively-doped SOI-FETs

The nanoscale channel of silicon-on-insulator (SOI) transistors [Fig. 1(a)] was selectively doped with phosphorus (P) within an area of ~30 nm in width, using a thermal diffusion process. The doping process is self-aligned, so that the dopant-quantum dots have a well-determined position relative to the leads, as shown in Fig. 1(b). Different from our previous works [1,4,6], doping concentration was higher ($N_D \cong 5 \times 10^{18}$ cm^{-3}), so average distance between P donors is <5 nm. This increases the probability of forming multiple-donor QDs within the selectively-doped area when several P donors are located near each other.

Electrical characteristics were measured for these devices, starting from low temperatures (T > 6 K), as shown in Fig. 2. Current peaks ascribed to tunnelling via dopant-QDs can be observed. The impact of the localized doping can be understood by comparison with uniformly-doped and nominally-undoped-channel FETs (not shown here), fabricated with the same fabrication process. The peaks also exhibit a noticeable sub-structure, which reflects the density-of-states inside the QD.

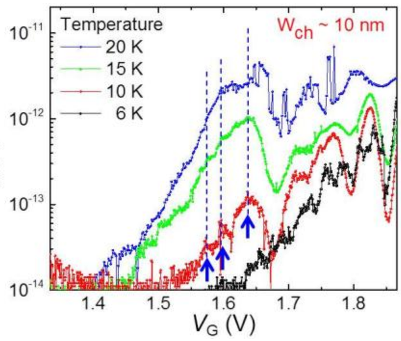

Fig. 2. I_D-V_G characteristics for a selectively-doped nano-FET at low T (T > 6 K). The low-V_G current peak reveals a clear sub-structure, with several inflections (as indicated by arrows), at the lowest temperatures.

These results provide information about the interaction between neighbouring dopant atoms, which may accelerate further development of dopant-based devices and technology.

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