Interactions of individual dopants and macroscopic quantum dots in weakly-doped nanoscale SOI-FETs

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Introduction

Dopant-based transistors, in which individual dopants or coupled dopants play the role of quantum dots (QDs), have important advantages as atomic-scale devices [1-3]. For extending the range of applications, an important regime of study is related to the interactions of individual dopants and larger, macroscopic QDs [4,5] in the channel of the same device [6]. Here, we present preliminary data suggesting tunnel coupling between discrete P donors and macroscopic QDs in the nanoscale channel of Si transistors.

SOI-FETs with low-concentration channels

We fabricated silicon-on-insulator field-effect transistors (SOI-FETs) with the channel doped with different doping concentrations, N_D [4]. Here, we focus on devices doped with the lowest $N_D \approx 1\text{-}2\times10^{17}$ cm^{-3}, with channels having a cross-section of approximately 10×10 nm^2. A schematic illustration of the channel of such a device is shown in Fig. 1. In these devices, the heavily-doped source and drain leads are "bridged" by a small number of P donors. A macroscopic QD is likely to be formed in such nanostructured channel, either by the clustering of a number of P donors or by a geometric modulation of the channel.

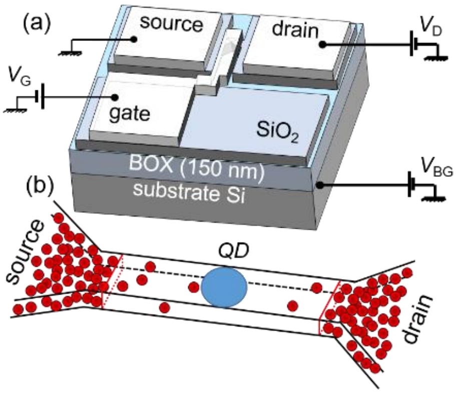

Fig. 1. (a) SOI-FET structure and I-V measurement setup. (b) An illustration of dopant distribution nearby a macroscopic QD.

Current modulations at low temperature

At low temperatures, current transport is dominated by single-electron tunneling through QDs formed in the narrow channel. Representative I_D-V_G characteristics exhibiting such behavior are shown in Fig. 2. In these characteristics, a quasi-periodic distribution of fine peaks can be observed. These peaks with small periodicity in V_G can be most likely ascribed to single-electron tunneling via a macroscopic QD, which can accommodate a relatively large number of electrons.

Another essential effect (marked in the figure) refers to the modulation of current intensity in different ranges of gate voltage. A single modulation (envelope) has been ascribed to resonant coupling in a system formed by a single dopant and a larger QD [6]. Here, different modulations may be associated with different P donors, located at various positions within the channel of the device.

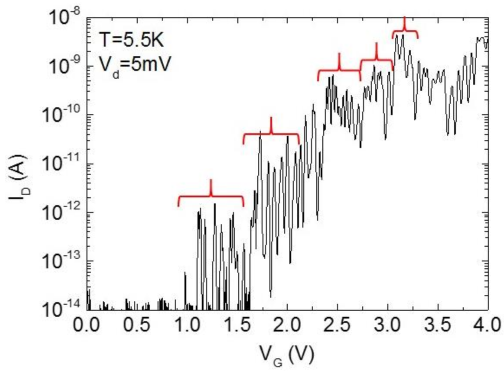

Fig. 2. Low-temperature (5.5 K) I_D-V_G characteristics for a low-N_D SO-FET. Modulations of current peak intensity may be related to interactions of individual dopants and larger QDs.

Conclusions

We study the interaction of discrete donors and macroscopic QDs in tunneling-transport for low-concentration-doped SOI-FETs. Single P donors, located in the narrow FET channel, can modulate the tunneling current through macroscopic QDs. Further analysis will aim at clarifying the importance of dopant position on transport characteristics.

References

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