Electric-field-assisted formation of an interfacial double-donor molecule in Si nano-transistors

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Introduction:

In recent years, many reports showed that dopant atoms can act as ultra-small quantum dots (QDs) in nanoscale transistors [1-5]. However, the range of applications can be greatly extended if neighboring dopants can be coupled via an interface, allowing tunability of dopant-based systems. In this report, we show electric-field-assisted merging of two donor-induced interface wells into a system that can be labeled as an interfacial double-donor molecule.

Nanoscale SOI-FETs with different doping concentrations:

In order to observe different regimes of inter-donor coupling, we fabricated silicon-on-insulator field-effect transistors (SOI-FETs, as shown in Fig. 1(a)) with channels doped with different concentrations. Fig. 1(b) shows a possible dopant distribution for the case of $N_D \approx 1\times10^{18}$ cm^{-3} (device A), while Fig. 1(c) depicts the case of $N_D > 1\times10^{19}$ cm^{-3} (device B). For this latter type, selective doping technique was used to avoid formation of highly conductive channels as in junctionless transistors. Electric field in the thin Si channel is tuned by V_{FG} and V_{BG}.

Formation of donor-molecule systems:

Figures 1(d) and 1(e) show the low-temperature contour plots of the second derivative of I_{DS} in the V_{FG} - V_{BG} plane for representative devices of each type. Current peaks appear as darker traces in these plots. A prominent change of slope for these traces is observed at a certain positive V_{BG} and is ascribed to the flat-band condition [6].

Most importantly, for device A, sudden shifts of the current traces as marked by rectangles can be observed. According to our analysis, these shifts indicate merging of two neighboring donor-induced potential wells at the Si/SiO_2 interface. This is illustrated by the potential landscapes shown as insets. As electric field is increased, the donor-induced wells expand and suddenly merge, thus forming an interfacial double-donor molecule.

For device B, due to the doping pattern, it is expected that multiple-dopant clusters are formed in the channel [7]. In Fig. 1(e), a complex pattern of traces, including a number of anti-crossing features, can be observed. These are ascribed to single-electron tunneling transport via serial-coupled QDs. In this case, molecular behavior of the multiple-dopant system can be observed without assistance of an interface.

Summary: These findings represent a basic experimental step in controlling the formation of interfacial multiple-donor molecular systems. Such systems can work as basic units for a variety of dopant-based applications, ranging from quantum computing to dopant-based transistor operation.

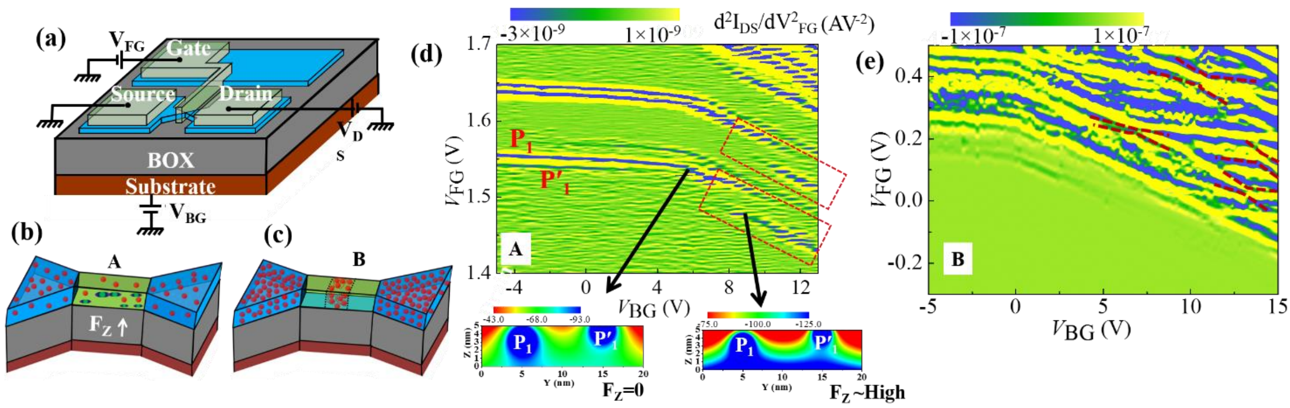

Fig. 1. (a) Bird's eye view of an SOI-FET. **(b)-(c)** Schematic dopant distribution in the channels of low- and high-concentration devices, respectively. Formation of interfacial dopant molecule under electric field is also depicted. **(d)-(e)** Contour plots of second-order derivative of I_{DS} in a V_{FG}-V_{BG} plane for low- and high-concentration devices, respectively. Lower panel of **(d)** shows potential landscapes of a double-donor system under different electric fields.

References

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