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Dopant-atoms have been demonstrated to work as quantum dots (QDs) in Si nano-transistors [1,2]. These systems have the fundamental property of controlling single-electron tunneling (SET), promising low-power consumption for future electronics [3]. Alternatively, they are attractive for quantum computing, which can bring a breakthrough in computation power. For such applications, room temperature (RT) operation is required and a CMOS-compatible, robust fabrication is necessary.

For room temperature SET operation, two main factors are crucial: (i) barrier height ($E_b$); (ii) charging energy ($E_c$). High $E_b$ is needed to suppress thermal activation over the barrier, which can rapidly hide the single-electron tunneling component. $E_c$ must be optimized to preserve Coulomb blockade mechanism ($E_c$~$k_BT$), but also remain lower than $E_b$. These two factors can be tuned by the number and intensity of the coupling of a few donor-atoms.

In recent years, we proposed to selectively dope a small region in a Si nano-channel (Figs. 1(a)-(b)) [4] and thus induce a QD statistically formed by a certain number of P-donors. The probability to find a number of P-donors in a central volume of 10 nm-diameter is shown in Fig. 1(c) for N=1×10^19 cm^-3. Such a-few-donor QD can have deeper ground state and suitable electron localization. In such devices, Coulomb blockade mechanism survives even at room temperature, as shown by the data in Fig. 1(d). This is because the dominant QD is most likely formed by 3 P-donors, with $E_b$ enhanced to >150 meV and $E_c$~100 meV [5]. Although SET operation is not observed at room temperature, this behavior is encouraging for optimization of the design of such a-few-donor QD.

Here, we first study the stability of a-few-donor QD (in this case, 3 P-donors) against fluctuations of donor number and mainly atomistic position. Figs. 2(a)-(b) show different configurations of 3 P-donors in a Si nano-plate, with electron wave function distribution (bottom) at the ground state (for fully ionized systems) obtained by ab initio simulations. As long as inter-donor distance is kept small, it is found that the binding energy and inter-donor coupling remain similar. This suggests that controlling the number of P-donors in a nano-volume can be the main critical factor in determining the properties of a-few-donor QDs for room-temperature operation. Details of this study will be described in the presentation.


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