Inelastic single-electron tunneling assisted by confined phonons observed for suspended silicon double quantum dots

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This paper presents the first experimental observation of inelastic single-electron tunneling through silicon-based suspended double quantum dots (SDQDs) mediated by confined phonons. The SDQDs with two side gates (see Fig. 1) were fabricated on a 50-nm-thick heavily-P-doped silicon-on-insulator (SOI) substrate by using EB lithography and ECR-RIE. The SiO_2 layer under the film was etched out by hydrofluoric acid, and then the SDQDs were thermally oxidized to passivate the device surface and reduce the SDQDs dimensions [1]. Bias voltages applied to the two side gates, V_{g1} and V_{g2}, control the electro-chemical potentials of the individual DQDs. A single electron tunnels through DQDs elastically when the chemical potentials align.

Figure 2 shows the drain-to-source current measured at 120 mK with V_{ds} = 200 µV as a function of V_{g1} and V_{g2}. We observed typical characteristics for a serial DQDs structure [2], e.g. two sets of charging lines at the crossing of which appears a pair of triangular regions where the current is enhanced. However, for some range of gate voltages, the DQDs characteristics are far more complicated and may suggest the presence of an extra dot in the structure that may be formed due to random-dopant induced potential fluctuations. In order to analyze the DQDs characteristics and the inelastic current, we carefully chose one of the overlapped triangles which is not affected by the charging line of the extra quantum dot. Figure 3 shows the drain-to-source current curve in the triangular region at V_{ds} = 500 µV, which is fitted well by eight peaks. The largest peak centered at $\Delta E = 0$ corresponds to elastic tunneling, and the peaks centered at $\Delta E > 0$ correspond to inelastic tunneling. We calculated the phonon spectral density for the SDQDs structure by using a model which consists of a suspended SOI film sandwiched with SiO_2 layers and a cylindrical structure for the DQDs [3]. By comparing the experimental results in Fig. 3 and the calculated spectral density, we found that the relatively large peak observed at ΔE = 260 µeV (shown by a red arrow) is attributed to a group of sharp peaks in the spectral density caused by an enhancement of the electron-phonon interaction in the SDQDs. The other peaks observed at ΔE = 100 µeV, ΔE = 180 µeV and ΔE = 390 µeV also agreed well with the simulation results. These results allow us to envisage the possibility of tailoring the electron-phonon interaction in SDQDs.

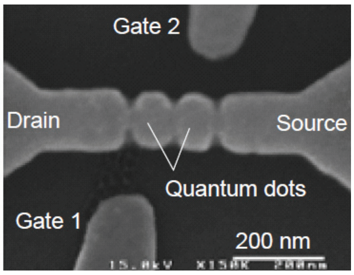

Fig.1 A SEM image of a fabricated SDQDs device.

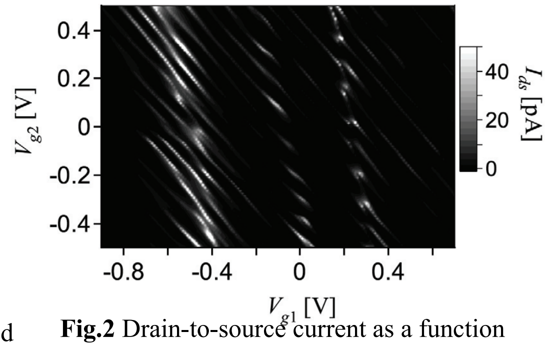

Fig.2 Drain-to-source current as a function of two side-gate voltages.measured at 120 mK with V_{ds} = 200 μV

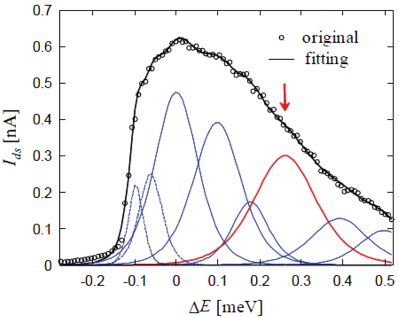

Fig.3 Drain-to-source current versus energy difference between SDQDs measured around the charge triple point.

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