Observation of Interdot Coupling Phenomena in Nanocrystalline Silicon Point-Contact Structures

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Nanocrystalline silicon (nc-Si) devices are potential candidates for the development of single-electron transistors (SETs) and quantum information devices compatible with large-scale integration processes. These devices use thin nc-Si films where nanometre-scale crystalline silicon grains 'naturally' form large numbers of silicon quantum dots (QDs), isolated by tunnel barriers formed at thin amorphous silicon or silicon oxide grain boundaries (GBs). The small grain size leads to large electron-confinement and single-electron charging energies, raising the possibility of room-temperature operation of QDs and SETs. The densely-packed nature of the QDs is of also of interest for quantum information processing in silicon.

In this work we study electrostatic 'Coulomb' interactions and coherent electron wave function coupling effects between two adjacent nc-Si grains by using point-contact single-electron transistors (PC-SETs: Fig.1 (left)). The PC-SETs with a very small channel with 30 nm × 30 nm in lateral dimensions were formed on a 40 nm thick nc-Si film with lateral grain size of 20 – 25 nm. The electrostatic potential on the grains are controlled via the bias applied to two side gates. After patterning the PC-SETs, oxidation at 750°C for 60 minutes and annealing at 1000°C were applied, which convert the GBs into a solid tunnel barrier. We observed the switching of the Coulomb oscillation current peaks at 4.2K as we swept the two side gate voltages V_{g1} and V_{g2} (Fig. 1 (right)) [1]. We found that the switching phenomenon is caused by the electrostatic coupling effects between two adjacent parallel nc-Si grains formed in the PC channel, and the gap between the two peak lines in the switching region is determined by the coupling capacitance between the grains.

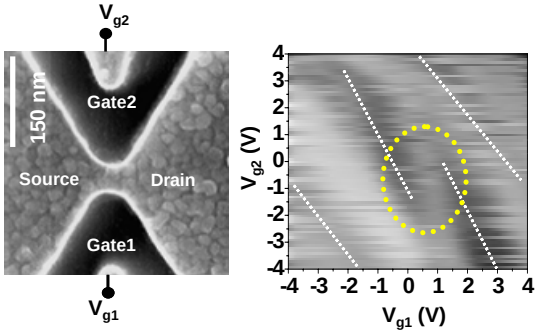

Fig. 1 SEM micrograph of a nc-Si PC-SET (left) and gray scale image of current as a function of two side gate bias voltages V_{g1} and V_{g2}.(right)

Next we adopted oxidation at 750°C for 30 minutes without the following annealing in order for making the GB tunnel barrier more transparent so that the adjacent grains couple each other more strongly. The PC-SETs then exhibited delocalisation of the electron wavefunctions over the coupled grains. Two peak lines in the plot of the device conductance at 4.2K (Fig. 2(left): white dotted lines) show intersecting and splitting (a broken circle with an arrow) caused by electrostatic interactions when the energy levels in the two grains are in resonance [2]. In this strong coupling region, we observed that the characteristics are decomposed into four Lorentzian peaks (Fig. 2(left)) – two main peaks (arrows with '*B*') with two small peaks (arrows with '*A*'). This is attributed to the tunnel coupling across two adjacent grains, resulting in bonding- and anti-bonding-like resonance peaks. These molecular states may be used to realize a Si-based charge qubit.

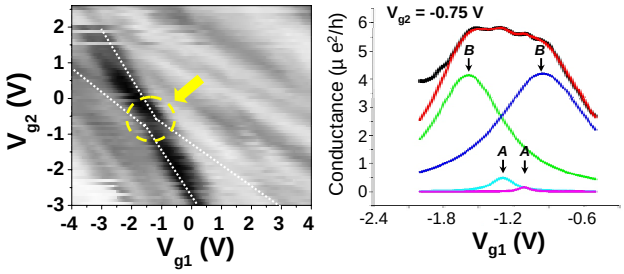

Fig. 2 Two conductance peak lines intersect and split (left) and conductance-V_{g1} curve fitted using four Lorentzian peaks.(right)

References

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[2] M. Khalafalla, Z.A.K. Durrani and H. Mizuta, Appl. Phys. Lett. **85**, in press, Sept. 2004.