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Fabrication of single electron transistors with molecular tunnel barriers using AC dielectrophoresis technique

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1. Introduction

Recently, the possibility of using chemically synthesized organic molecules has been probed widely. One example could be the single molecule transistor where a single molecule was contacted in between nano-gap electrodes [1]. Such single molecule contact is important but it is still extremely difficult to control the process. In this work, we report the fabrication and characterization of a single electron transistor (SET) with gold nanoparticles bridging two nano-gap electrodes. A self-assembled mono (SAM) layer of organic molecules covering the electrodes function as tunnel barriers between the electrodes and the nanoparticle. The nanoparticles are captured by AC dielectrophoresis and the controllability over the number of captured particles is shown to be much better than direct molecular contact. The measured characteristics of the device shows typical single electron tunneling behaviors.

2. Fabrication and Characterization of Device

Idea

Two important recipes of our transistor fabrication are SAM and AC dielectrophoresis. As shown in the schematic of Fig. 1, the SAM layer of dithiol molecules are formed on Ti/Au electrodes with the gap whose size is comparable to the diameter of Au nanoparticles. Then the nanoparticles are captured in between the electrodes by AC dielectrophoresis [2]. The final device after the capture process is an SET topology where the nanoparticle is bridged between two electrodes by the molecules.

Capture of gold nanoparticles

After cleaning the fabricated nano-electrode with 3:1 mixture of H_2SO_4 and H_2O_2, the formation of 1,8-octanedithiol SAM was followed. Then, after dropping the solution containing Au nanoparticles on the device, AC electric fields are applied between the nano-electrodes. The nanopartilces move due to the dielectrophoretic force and are captured at the gap where the field gradient is maximum. The typical range of applied AC voltege and frequency are 2 ~ 4 V_{p-p} and from kHz to MHz, respectively. Figure 2 shows the SEM image showing that 5 nanoparticles with the diameter of 50 nm are captured in between the electrodes with the gap of 50 nm. Figure 3 shows that two nanoparticles with the diameter 40 nm are successfully captured in between the electrodes with the gap of 50 nm.

Current-Voltage Characteristics

Figure 4 shows the drain current (I_D) as a function of the drain-source voltage (V_{DS}) measured from the device of Fig. 2 at various temperatures (Ts). There is a clear Coulomb staircase and it is smeared out as T increases. Figure 5 shows I_D as a function of the gate bias (V_{BG}) at various V_{DS} values at T = 4.2 K. Periodic Coulomb oscillations are observed with the change of V_{BG}.

3. Conclusions

We have successfully fabricated SETs by capturing Au nanoparticles in between two metal nano-gap electrodes. The electrodes are covered by SAM of dithiol molecules, and they work as tunnel barriers between the nanoparticle and the electrode. The transport data measured from the nanoparticle SET exhibits Coulomb staircase and Coulomb oscillations.

Acknowledgements

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References

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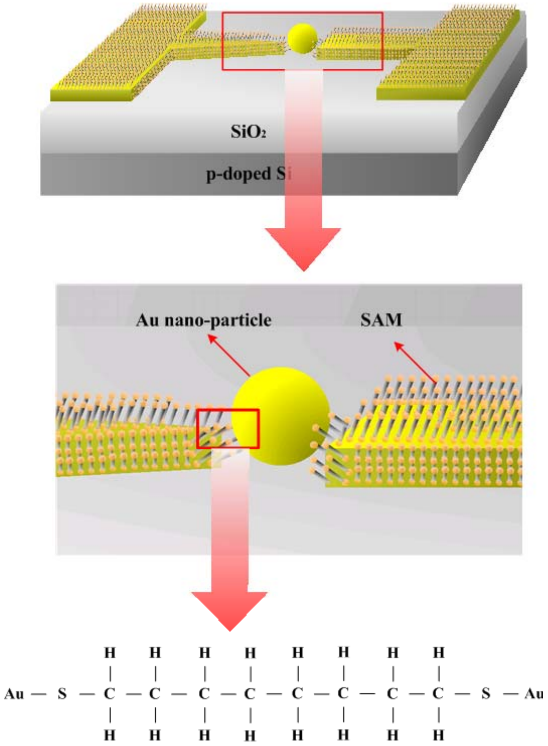

Fig. 1 Schematic of the single electron transistor using SAM and AC dielectrophoresis.

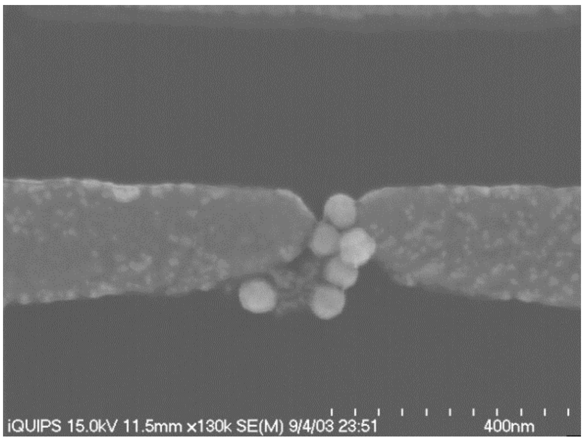

Fig. 2 SEM image of an SET fabricated by AC capturing five Au nanoparticles. The diameter of the Au nanoparticle is 50 nm and the gap between two electrodes is ~ 50 nm.

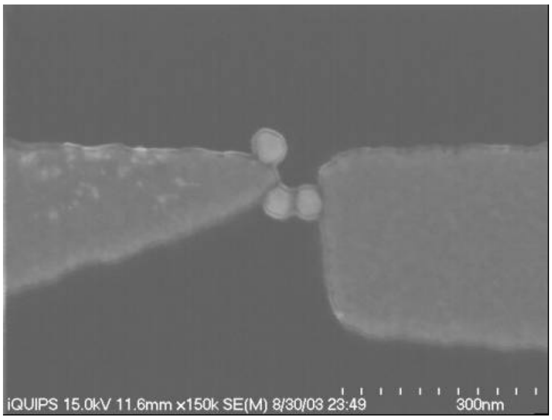

Fig. 3 SEM image of an SET fabricated by AC capturing two Au nanoparticles. The diameter of the Au nanoparticle is 40 nm and the gap between two electrodes is ~ 50 nm.

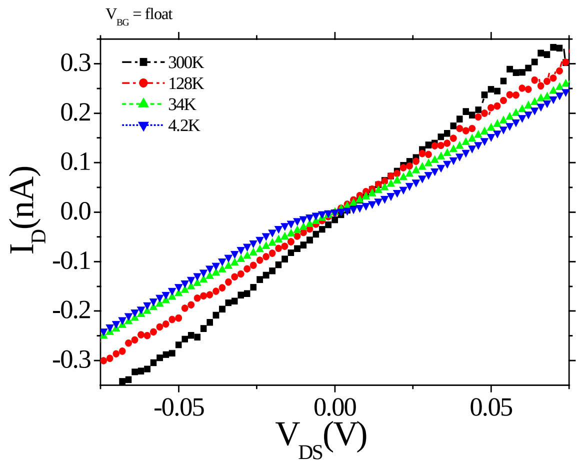

Fig. 4 I_D – V_{DS} characteristics measured from the SET of Fig. 2 at various Ts.

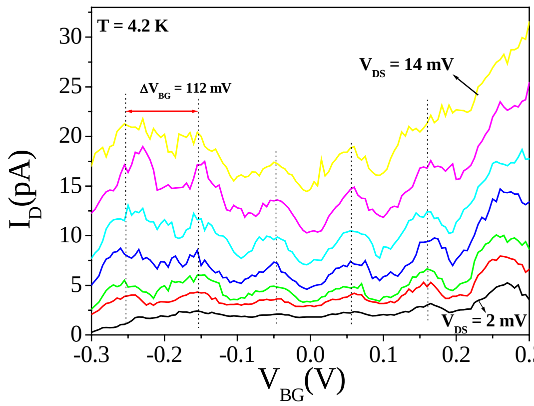

Fig. 5 I_D – V_{BG} characteristics measured from the SET of Fig. 2 at T = 4.2 K.