Quantum Transport of Carbon Nanotube and Bio-Sensor Application

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Abstract :

We have succeeded in observing the coexistence of Coulomb blockade effect and coherent transport of hole in single wall carbon nanotube transistor (CNTFET). The small current oscillation owing to the coherent resonance of the hole overlapped on the large Coulomb oscillation peak. CNTFET is also applied to detect the bio material with high sensitivity.

CNTFET was prepared as follows. An n^+-Si wafer with a thermally grown oxide of 300 nm thick was used as a substrate. The carbon nanotube was grown by thermal chemical vapor deposition from the patterned catalyst of Fe/ Mo/ Si. Co electrodes were deposited for the source and drain, and on the backside of the n^+-Si substrate for the gate. The distance between the source and drain was 73 nm. Thus, back gate type CNTFET was fabricated.

In the drain current-gate voltage characteristics of CNTFET under the drain voltage of 11 mV at 7.3 K, drain current showed periodic peaks and valleys structure with two periodicities. At around gate voltage of V_G=0 V, the large period of ~3 V was observed, which was attributed to Coulomb oscillation characteristic of hole.

At the higher gate voltage region of V_G=-5 V~ 25 V, the small period oscillation of ΔV_G=0.65 V was observed, which was overlapped on the large period oscillation of Coulomb oscillation characteristic. This small period oscillation was attributed to the quantum interference property of hole. From the small period of drain current oscillation of ΔV_G=0.65 V, we could estimate the width of quantum well and obtained the length of cavity of hole L as 55 nm, which was in good agreement with the channel length of the device of 73 nm obtained by the SEM observation. At the further larger applied gate bias, Coulomb oscillation peak becomes unclear and small coherent resonance oscillation becomes dominant. These results could be understood as follows. At low applied gate bias, the Schottky barrier at the source/drain contacts works as tunnel barriers and the device worked as a single hole transistor and showed the clear Coulomb oscillation peaks. At the higher applied gate bias, however, the Schottky barrier height becomes lowered and the tunnel junction resistance becomes smaller than the quantum resistance. That means the Schottky barrier junctions could no more confine the hole inside the nanotube, and Coulomb oscillation peaks becomes disappeared. The Schottky barrier junctions, however, still works as a normal tunnel barrier, and the device shows only the coherent resonance oscillation.

CNTFET was also applied to detect the protein of IgE by using the aptamer/IgE reaction. IgE concentration of 250 *pmol/L* was detected using CNTFET which is the highest sensitivity so far obtained.

We have first succeeded in observing the coexistence of the Coulomb blockade effect and coherent transport of hole in CNTFET and applied CNTFET for the bio sensor.