Electrical transport through 60 base pairs of poly(dG)-poly(dC) DNA molecules

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(Received 27 November 2001; accepted for publication 12 June 2002)

We report electrical transport through 60 base pairs of poly(dG)-poly(dC) DNA molecules. The DNA solution is dropped on two metal electrodes with the gap of 20 nm. The current–voltage characteristics measured between the electrodes exhibits clear staircases, which are reproducible over repeated measurements. The size of the observed staircases is consistent with the energy gap obtained from a tight binding calculation.
[DOI: 10.1063/1.1498862]

Electrical transport through DNA molecules has attracted much interest recently, in view of understanding their energy structure and due to potential applications to nanometer-scale molecular electronic devices.[1–7] Synthesized DNA double helix is an artificial nanometer-scale material, which has the diameter of 2 nm and adjustable length of base pair sequence from a few nanometers to several micrometers.[3] Long DNA chain can be viewed as a one-dimensional quantum wire.[4] In addition, stable geometric structures, unique assembly properties, and four bases (guanine, cytosine, adenine, and thymine) combinations open up interesting possibilities for nanodevice engineering.[4–6,8]

Electron transfer within DNA molecules is most essential for device application and much effort has been made for better understanding the transport mechanism.[7,9–12] Interesting transport data have been reported in the last couple of years. Fink *et al.*[13] have measured a linear current–voltage ($I-V$) characteristic of the micrometer-scale DNA ropes. Porath *et al.*[14] have observed $I-V$ characteristics with a clear gap of about 2 eV from the individual 10.4-nm-long free-standing DNA molecules. These two studies show conducting and semiconducting behavior of DNA molecules, but clear mechanism of the transport is still controversial.[15–18] In this letter, we report direct measurements of electrical conduction through 60 base pairs of poly(dG)-poly(dC) DNA molecules (20.8 nm long) between two metal electrodes with nanometer separation.

DNA[19] synthesis was achieved by heating at the temperature of 97 °C (melting point of the 60 base pairs of poly(dG)-poly(dC) DNA is 95.9 °C) for 5 min and natural cooling to room temperature. The DNA synthesis was identified by several techniques such as ultraviolet spectroscopy, mass spectrometry and gel electrophoresis. For the preparation of DNA solution, the poly(dG)-poly(dC) DNA molecules were diluted with 18.2 MΩ deionized water to the concentration of 25 μM. A 1 $\mu\ell$ droplet of dilute DNA solution was carefully positioned on the center of the electrodes using a Hamilton syringe. After waiting for 10 min until the water evaporated, the device was dried using N_2 gas. The dried DNA film makes contact to the metal electrodes by physical adsorption.[20]

A standard e-beam lithography and liftoff process was employed for the fabrication of nanometer scale electrodes. The substrate was a silicon wafer covered with a 200-nm-thick SiO_2 insulating layer. The nanometer-scale electrode pattern was transferred by a thermal evaporation of 5 nm Ti (for adhesion), and 10 nm Au. The minimum feature size of the defined electrode gap was 20 nm. Figure 1(a) shows a schematic diagram of the experimental setup and Fig. 1(b) is an example of our nanopattern having a gap of 20 nm. The $I-V$ characteristics were measured in air and at room temperature.

Figure 2 shows the room temperature $I-V$ and the differential conductance–voltage ($dI/dV-V$) characteristics measured from the electrodes with the gap of 30 μm after dropping the DNA solution is performed. The width of the electrode was 60 μm. Almost linear behaviors are observed both in the $I-V$ and the $dI/dV-V$. The inset shows the $I-V$ measured from the same electrode after dropping DI water and drying procedure. The current in the same bias voltage range only shows the background of ~10 pA. This value is similar to the one measured before DI water dropping.

Figure 3 shows the $I-V$ and the $dI/dV-V$ characteristics measured from the electrodes with the gap of 20 nm after dropping the diluted DNA solution. There are clear staircases in the $I-V$ and maxima are observed in the $dI/dV-V$. The separations between the positions of the observed maxima (−2.1 V, −0.6 V, 2.3 V, and 4.0 V denoted by A, B, C, and D, respectively) are 1.5, 2.9, and 1.7 V. The inset shows the $I-V$ measured between the 20 nm gap electrodes after dropping the DI water. It again shows the background. We have

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