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Electrical Transport Properties of Au-Doped DNA Molecules

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1. Introduction

In molecular-scale systems, deoxyribo nucleic acid (DNA) is one of the most promising materials because they have several unique advantages [1]. One of the interesting properties is that the length can be engineered by the number of base pairs, and therefore, it makes useful as interconnection application for the nanometer-scale circuit. Chemical modification at both ends of DNA molecules can also lead to self-assembled contacts between metal and DNA nanowires. However, works on the electrical conducting behavior of DNA is still controversial and the measured conductivity of DNA was not so high. In order to overcome these difficulties, several studies have been carried out to fabricate metallic nanowires using DNA molecules by chemical deposition of thin metallic film onto DNA molecules [2]. These DNA template nanowires show good conductivities, however control over the conductivity by changing the amount of Au has been difficult. In this paper, we report on the successful formation of Au doped DNA molecules, which have high conductivity and the electrical transport properties of this molecules. The detailed analysis of the chemical composition shows that there is a strong possibility of controlling conductivity in our case.

2. Experiments

Gold doped DNA molecules were prepared as follows. The DNA molecules from Salmon were purchased from Sigma (model number 1656). The average length of the DNA is around 0.7 μm (~2000 base pairs). Dopant chemical, hydrogen tetrachloroaurate (III) trihydrate ($HAuCl_4{\cdot}3H_2O$), is purchased from Aldrich and used without further purification. The DNA molecules were dissolved in 10mM (pH 5.6) acetate buffer (0.13mg/ml, 1μM), and underwent shaking incubation for 24 hours at room temperature. The aqueous stock solutions of 25.4mM $HAuCl_4{\cdot}3H_2O$ was also prepared. The mixture of 0.63 ml of the $HAuCl_4{\cdot}3H_2O$ solution and 10ml of the DNA solution was incubated at 40°C for 72 hours. The conjugation of Au atoms to the DNA molecule was analyzed by Fourier transform infrared spectroscopy (FTIR) and X-ray photoemission spectroscopy (XPS).

A standard electron beam lithography and lift-off process was employed for the fabrication of metal electrodes with a gap of 300 nm on SiO_2/Si substrates. The electrode pattern was transferred by a thermal evaporation of 5 nm-thick Ti and 10 nm-thick Au. An aqueous solution of Au doped DNA is deposited on electrodes during a few seconds. After removing DNA droplet by nitrogen gas, DNA remained fixed in between electrodes. The current was measured using a voltage source (Keithley 230) and a precision preamplifier (DL instruments 1211) at room temperature. The system noise level was less than 1 pA.

3. Results and Discussion

During the incubation, Au from chemicals is binding to the DNA bases. The FTIR and XPS measurements have been carried out to identify the binding site of Au in DNA bases. Figure 1 shows the FTIR spectra of DNA with and without $HAuCl_4{\cdot}3H_2O$ incubation process. The carbonyl vibration band of the bases is shifted from 1695 cm^{-1} to 1676 cm^{-1} after incubation process. It clearly indicates the chemical binding between Au and carbonyl group of DNA bases [3]. The inset in Fig. 1 shows the chemical structure of Au binding to the DNA base. The XPS data shows Au and carbonyl group binding energy of 535 eV, which is consistent with the FTIR data. From the chemical composition in this experiment, the ratio of Au atoms and DNA bases is calculated to be 1:5. It means that one of the carbonyl groups in five DNA bases can combine with an Au atom. This suggests that the amount of Au, and as a result,

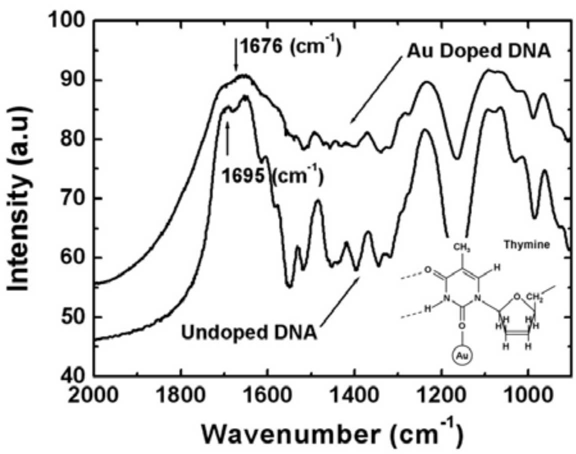

Fig. 1 FTIR spectra of DNA molecules with and without $HAuCl_4{\cdot}3H_2O$ incubation process.

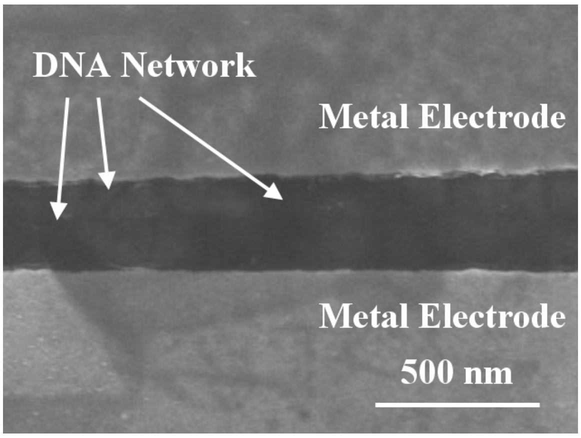

Fig. 2 SEM image of Au doped DNA molecules on the metal electrodes. The DNA molecules are connected in between two electrodes with network structure.

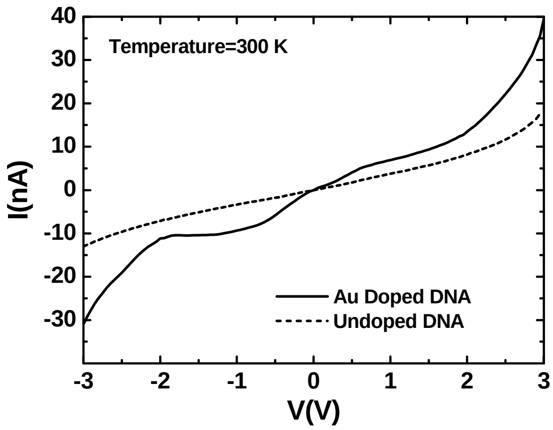

Fig. 3 I-V characteristics of undoped (dotted line) and Au doped (solid line) DNA molecules in between metal electrodes at room temperature.

the conductivity can be increased by increasing the concentration of the $HAuCl_4 \cdot 3H_2O$ solution.

Figure 2 is the scanning electron microscope (SEM) image of Au doped DNA molecules on the metal electrodes. It is not easy to identify clearly, however, DNA makes a network structure in between two electrodes. The thickness of the DNA typically ranges from 20 to 100 nm.

Figure 3 shows typical room temperature current-voltage (I-V) characteristics of undoped and Au doped DNA molecules. The sample with undoped DNA shows almost monotonic increase of the current with the increase of the bias in the measured range. The sample with Au doped DNA exhibits wide and clear staircase. In addition, the conductivity of Au doped DNA is increased more than twice compare to that of undoped DNA. It is difficult to determine the conductivity of DNA quantitatively because of a variety of DNA thickness and geometry. However, the conductivity of Au doped DNA is always higher than that of undoped DNA over repeated measurements. Other template nanowires showed only linear I-V curve [2] and this is contrasting to our observations. High conductivity and clear staircase structure from Au doped DNA is attributed to the Au doping. We don't know the exact role of Au atoms in DNA molecules, however, Au can help the charge transfer between the DNA bases. Moreover, Au doping will be a promising technique to control the conductivity of DNA molecules.

4. Conclusions

We have investigated electrical transport properties of Au doped DNA molecules. Au doping was carried out by incubation process of the mixture of $HAuCl_4 \cdot 3H_2O$ and DNA solution. Au binding to the DNA bases was identified using FTIR and XPS measurements. From the I-V characteristics, Au doped DNA exhibit higher conductivity than undoped DNA, which indicates the effect of doping.

Acknowledgments

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