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Gating effect in the I-V characteristics of iodine doped polyacetylene nanofibers

J. G. Park [a], G. T. Kim [a, b], V. Krstic [b], S. H. Lee [a], B. Kim [a], S. Roth [b], M. Burghard [b], Y. W. Park [a, c, *]

a. *School of Physics and Condensed Matter Research Institute, Seoul National University, Seoul 151-742, Korea*
b. *Max-Planck-Institut für Festkörperforschung, Heisenbergstraße 1, D-70569, Stuttgart, Germany*
c. *National High Magnetic Field Laboratory, Florida State University, Tallahassee, Florida 32306, USA*

Abstract

The I-V characteristics of iodine doped polyacetylene (PA) nanofibers were measured as function of temperature. Platinum electrodes on top of SiO_2 substrates were used to prevent reaction with iodine dopant. The distance between the two electrodes is approximately 100 nm. Upon iodine doping, non-ohmic I-V characteristics are observed. The gate dependence shows the charge carrier to be hole with a mobility $\mu_{FET} \sim 4.4\times10^{-5}cm^2/Vs$ at 233K.

Keywords : Polyacetylene, nanofiber, electrical transport, FET.

1. Introduction

Nanowire structures are investigated for their electrical properties and device characterizations[1-5] due to their low dimensionality and potential use of nanodevices. Polymers and oligomers are also good candidates for nanowire structures. There are several reports on transport measurements on this kind of nanowires in nanoscale: poly(3-octylthiophene)[6] and phthalocyanine[7] and benzene-1,4-dithiol molecule[8] using mechanically controllable break junction.

Previous reports on ultrathin 'Durham' route polyacetylene films had shown the field-enhanced conductivity[9]. We reported the transport measurements of PA fiber network which showed significant change in conductivity and magnetoresistance[10]. Here we present the gate dependence of I-V characteristics in PA nanofibers.

2. Sample preparation

Networks of PA nanofibers were prepared with diluted Ziegler-Natta catalyst[11]. After exposure to acetylene, the catalyst was thoroughly washed with toluene to obtain purified, low density PA. Using centrifugation, the toluene was first replaced by 2-propanol, which was in turn replaced by a 1:1 mixture of 1 wt. % aqueous solution of sodium dodecyl sulfate (SDS) and Triton X-100, respectively. After disintegration of the PA network by ultrasonic treatment, one droplet of dispersion was placed on the substrate equipped with four Pt electrode lines separated by ~ 100 nm. Prior to nanofiber deposition, the substrate surface was modified with 3-(aminopropyl) triethoxysilane. The heavily n-doped (As+) silicon wafer with a thermally grown oxide layer of 300 nm thickness served as a back gate.

3. I-V characteristics and gate dependence

From the Scanning Force Microscope (SFM) image, there are two pair of PA nanofiber connections between the electrodes as shown in the upper inset of Fig. 1. (A) is a thick PA nanofiber (~ 20 nm) and (B) is a thin PA nanofiber (~ 4.4 nm). The room temperature conductivity of PA nanofiber in the ohmic region is $\sigma \cong 0.1–0.01 S/cm$. Fig. 1 shows I-V characteristics of the thick PA nanofiber (A). I-V characteristics are different from that of

* Corresponding author. Tel: +82-2-880-6607; fax: +82-2-873-7037; E-mail: ywpark@phya.snu.ac.kr

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conventional semiconductor transistors[12] or other organic FETs[13,14], which show saturation behavior. The lower inset of Fig. 1 shows that the resistance change of nanofiber (A) upon iodine doping is similar to that for bulk PA. The gate dependence of conductance of nanofiber (A) is shown in Fig. 2(a) and the gate voltage dependence in the I-V characteristics of nanofiber(B) is shown in Fig. 2(b). The current is enhanced at negative gate voltage and suppressed at positive gate voltage. Similar gate voltage dependence was also observed in carbon nanotube FETs[3]. This proves that the charge carrier is hole in the iodine doped PA nanofiber.

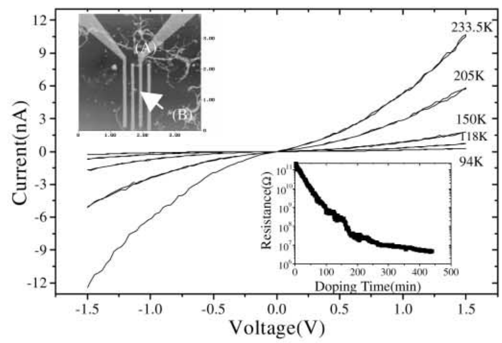

Fig. 1. I-V characteristics of thick PA nanofiber (A). Upper inset shows SFM image of nanofibers on top of Pt electrodes. (A) is a thick PA nanofiber (~ 20 nm) and (B) is a thin PA nanofiber (~ 4.4 nm). Lower inset shows change of resistance upon iodine doping.

4. Field effect mobility

Gate dependent I-V characteristics are more significant in thin PA nanofiber than in thick fiber. Previous results on organic FET of oligothiophene[14] showed that the gate voltage affects only one or two monolayers (~ 5 nm). Considering the diameters of the PA nanofiber (A) (~ 20 nm) and (B) (~ 4.4 nm), the gate effect is more significant in nanofiber (B).

To estimate the field effect mobility, we modified the equation of ref.[4,13] for the p-type organic FET in linear region,

$$\frac{g_d}{\sqrt{-g_m}}\sqrt{\frac{LV_d}{ZC_i}} = -\sqrt{\mu}(V_g - V_0) \qquad (1)$$

where g_d is the channel conductance, g_m is the transconductance, L is the channel length, Z is the channel width, V_d is the bias voltage, C_i is the capacitance per unit area and μ is mobility. From this relation, the slope of the lefthand side vs. gate voltage (V_g) gives the square root of mobility and the intercept gives the threshold voltage (V_0). From inset of Fig. 2(b), mobility is determined to be $4.4\times10^{-5}cm^2/Vs$ at 233K. From equation (1), one finds V_0=75.4V. This positive threshold voltage confirms that the charge carrier in iodine doped PA nanofibers is hole.

In summary, we measured I-V characteristics of iodine doped PA nanofibers. Current enhancement was found at negative gate voltage. From the gate dependence, we conclude the charge carrier to be hole with a mobility $\mu_{FET}\sim 4.4\times10^{-5}cm^2/Vs$ at 233K.

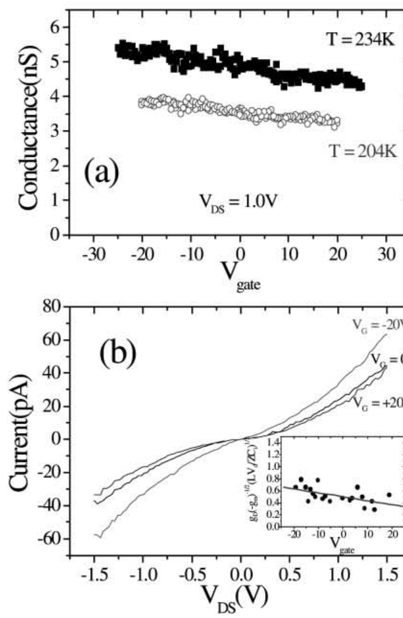

Fig 2. (a) Gate dependence of conductance of PA nanofiber(A) at T=234K and T=204K with V_{DS}=1.0V. (b) Gate dependent I-V characteristics of PA nanofiber(B) at T=233K. Inset shows plot of lefthand side of eq. (1) vs. Vg. From the guided line, the estimated mobility is $4.4\times10^{-5}cm^2/Vs$ There is a clear current enhancement at negative gate voltage

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