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Electronic transport properties in irradiated C_{60} FNW

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1. Introduction

As for near future electronics devices, there exist many attractive topics for nano-carbon materials, especially, for carbon nano-tubes and C_{60} crystalline whiskers. Since the first report in 1993 [1], several trials on the polymerization due to photo irradiation have been proposed [2-4]. Especially, photo- and electron-beam irradiation are the easy and area selectable method, therefore they have possibility to fabricate the C_{60}-based carbon nanodevices. However, most of them have not been yet examined on detailed electronic transport properties. In this paper, we are discussing the effect of photo-irradiations on the electronic transport properties of C_{60} fullerene nano-whisker (FNW), by investigating the field-effect transistor (FET). Furthermore, the morphology of photo-irradiated C_{60} FNW was observed by scanning electron microscope (SEM).

2. Experimental details

We have investigated the photo-, ultrasonic wave- and microwave- irradiation effects on the electronic transport properties of C_{60} fullerene nano-whiskers (FNW), fine crystalline wires of C_{60} as shown in Fig. 1. It has been studied by observing FET characteristics. In our previous research in thin film of C_{60}, it was clarified that the electrodes for the top contact blocked off the UV-light and polymerization was obstructed underneath the electrodes [5]. Therefore, our C_{60} FNW-FETs were as a bottom-contact configuration, while top-contact organic-FET tends to exhibit good performance compared with bottom-contact structure. The C_{60} FNW-FETs were fabricated with a bottom-contact configuration on heavily *p*-doped Si substrates. Si substrate with a 600 nm thick SiO_2 (as the gate insulator) also serve as the gate electrode. Ti/Au electrodes (20 nm/80 nm thickness respectively) for source and drain were deposited on the Si substrate by electron-beam evaporation. The channel length (L) was 10 μm and the channel width W was 1.0 mm. Subsequently, several C_{60} FNWs were put on the electrodes by resistive heating with the substrate temperature kept at 440 K. Photo-irradiation was performed about 10 hours using the UV-visible light for photolithography at pressure of ~10^6 Torr. Substrate temperature was kept at 300 K during exposure in order to prevent the high temperature (HT) heating arise during photo-irradiation, because polymerized-C_{60} induced by photo-irradiation return to C_{60} monomer by HT heating. The existence of polymerized-C_{60} was confirmed by investigating the solubility in toluene, because C_{60} become insoluble in organic solvent by polymerization. The electrical measurements were performed in the vacuum (~10^6 Torr) as long as there is no description.

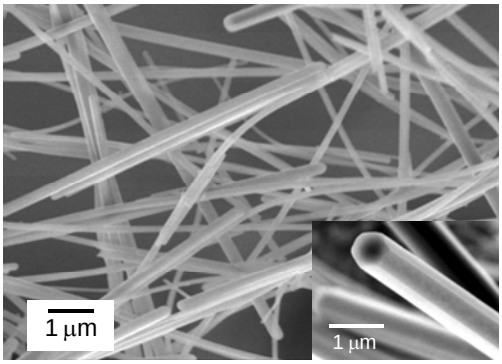

Fig. 1. The SEM photograph of the C_{60} FNW.

3. Results and discussion

Source-drain current (I_{SD}) versus source-drain voltage (V_{SD}) characteristics (I_{SD}-V_{SD}) at several back-gate voltages (V_G) before annealing are shown in Fig. 2 (a) and (b) before and after photo-irradiation, respectively. The field-effect mobilities (μ) estimated by fitting the linear region of the I_{SD}-V_{SD} characteristics are 3.1×10^{-4} cm^2/Vs and 2.6×10^{-5} cm^2/Vs before and after photo-irradiation, respectively. From these results, it has been understood that I_{SD} and field-effect mobility (μ) decreased by about one order after the irradiation. Based on the source-drain current on gate voltage (I_{SD}-V_G at V_{SD} = 10 V) for both before and after photo-irradiations, it is found that the threshold-voltage (V_T) shows to be lowered by photo-irradiation as well as in C_{60} thin film FET [5]. This result indicates that the injection barrier between Au electrode and C_{60} has been changed by photo-polymerization and let to make easy on the carrier injections. However, we have no FET working after exposing the atmosphere but the irradiated effect in C_{60} thin film FET device shows clear I-V characteristics even in after exposing, although the source-drain current value is lower about 10^{-3}~10^{-4} times.

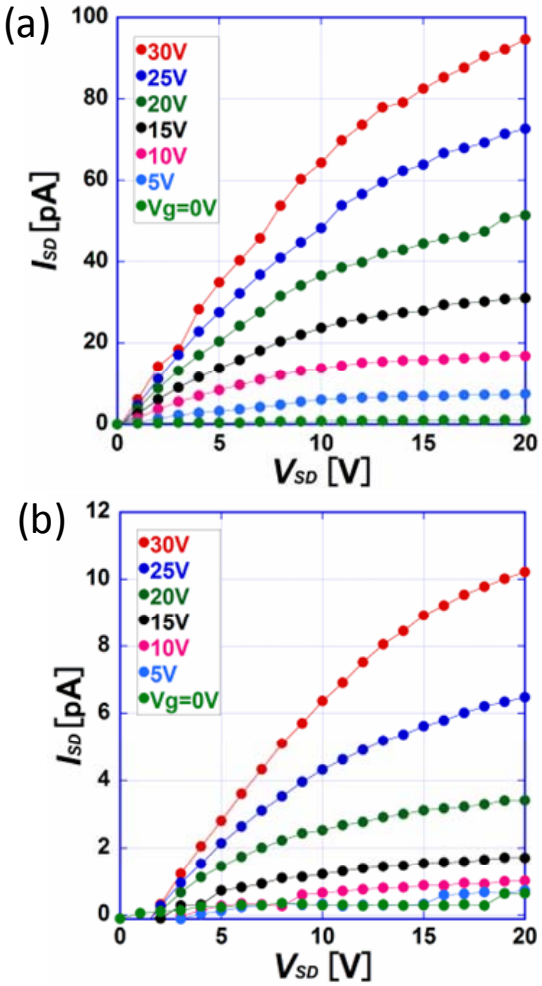

Fig. 2. I_{SD}-V_{SD} characteristics of the C_{60} FNW-FET for before (a) and after photo-irradiations (b) are shown, the V_G is varied from 0 to 30 V and the mobility decreases by about one order of magnitude after the irradiation.

Finally, the morphology of our C_{60} FNW after photo-irradiation was investigated using SEM. As a result of the comparing before and after irradiations, a certain small cracks were observed in the case of thin FNW as shown in Fig. 3 (a). These clacks are not observed in a case of the thick C_{60} FNW as shown in Fig. 3 (b). It can be considered that the intermolecular distance of C_{60} is shortened by the polymerization. Therefore, it may consider that this shrinkage caused by such cracks, and must consequently leads to the decrease in I_{SD} and μ.

4. Summary

The FET characteristics of C_{60} FNW were investigated before and after photo-irradiation. It have been understood that the I_{SD} clearly decreased after photo-irradiation and the μ decreased from 3.1×10^{-4} cm^2/Vs to 2.6×10^{-5} cm^2/Vs. Also, it has been clarified by the SEM investigation that photo-irradiated C_{60} thin film has a few cracks in the case of thin wire, but in the case of thick one there is no crack. Therefore, we can not determine the origin of the decrease of I_{SD} and μ. After photo-irradiation, the threshold voltage seems to be lowered. Furthermore, photo-irradiated C_{60} thin film shows the FET characteristics after exposure to the atmosphere, but C_{60} FNW-FET does not work well in the atmosphere because O_2 in the air may obstruct the electron transport in C_{60} devices. Therefore, we need further more studies in order to clarify the electronic transport effect on the polymerization effect on C_{60} FNW-FET.

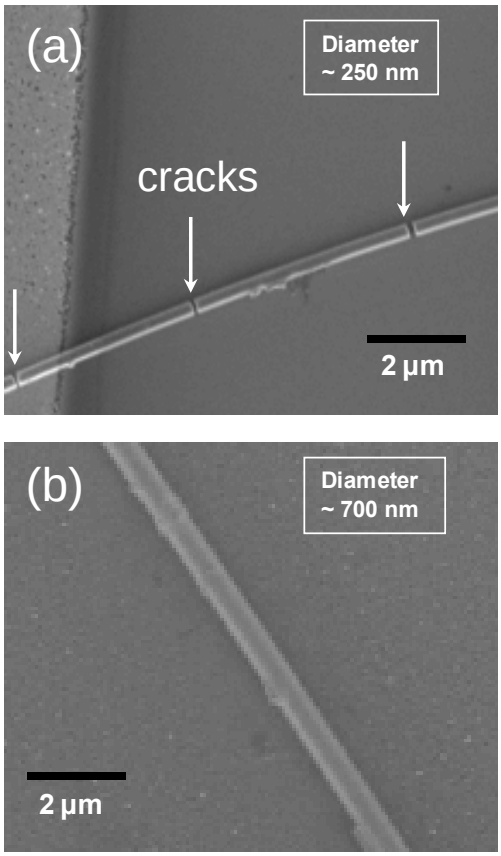

Fig. 3. The SEM photographs of C_{60} FNW samples, thin one (a) and thick another (b) after photo-irradiation. A few cracks can be observed in the thin sample (a).

Acknowledgments

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