

## Nanofiber Aligned within Ordered Conducting Polymer TFT

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### Abstract

*We report the preparation of novel nanofiber organic semiconductors that can be utilized as the active channel materials in the field effect transistors (FETs). The nanofibers produced by the electrospinning reveals the excellent performances (mobility  $\sim 0.16 \text{ cm}^2/\text{V}$ ) due to their highly ordered molecular packing in the polymer matrix.*

### 1. Introduction

Organic thin-film transistors (OTFTs) are promising alternative materials due to their large-area applicability, compatibility with plastic substrate, and solution processability [1]. Despite a myriad of such merits, molecular design of high-performance materials, synthesis of air-stable materials, contact resistance, and understanding of carrier transport mechanism remain the challenging issues in this field. To date, there have been a variety of approaches to prepare the organic semiconductors including physical vapor transport, interfacial self-assembly, spincoating, electrochemical polymerization, jet printing, and electrospinning that produces the one- and/or two-dimensional morphologies. The one-dimensional organic nanofiber semiconductors are of particular interest because they show the extraordinary electrical, optical, and chemical properties compared with two-dimensional counterparts. Self-assembled  $\pi$ -conjugated molecules into wire nanostructures shows relatively high charge-carrier mobilities due to high degree of molecular orientation. Furthermore, nano-sized wires can be integrated and woven in a desirable way to fabricate the wearable devices.

Electrospinning process is one of the simplest and the most versatile methods that can produce the polymer nanofibers [2]. Depending upon the various

experimental parameters such as molecular weight, applied voltage, solvent, and viscosity, it is possible to fabricate the nanofibers with desirable morphologies. Field effect transistors using electrospun conducting polymers nanofibers have been demonstrated by several groups. In general, these types of nanofibers are blends with another polymer due to the difficulty in electrospinning of conducting polymer alone. However, the morphological control of active component that is the key to the device performance has not been intensively studied in fabrication of FET devices with electrospinning process.

In this work, we use the low-molecular-weight material with  $\pi$ -conjugated molecular structure that can be self-assembled and aligned within a conducting polymer nanofiber matrix as an active material in a FET device. We present the performances of this device and possible explanations of charge transport.

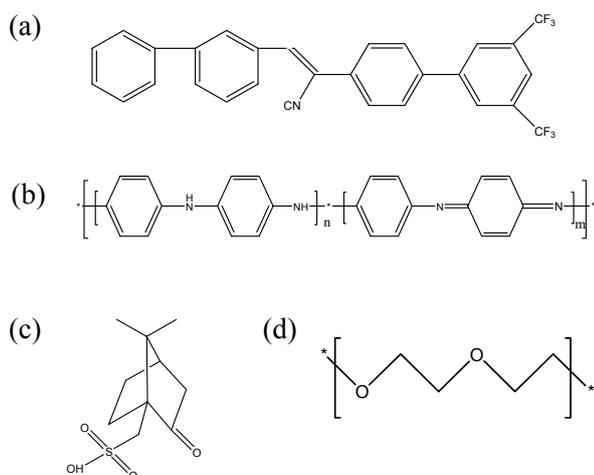
### 2. Experimental

Emeraldine base polyaniline (PANI, Mw 65,000, 100 mg) doped with camphosulfonic acid (CSA, 130 mg) and polyethylenoxide (PEO, Mw 1,000,000, 10 mg) are dissolved in chloroform (10 ml) for 4 hours. In a separate batch, 1-cyano-trans-1,2-bis-(3',5'-bis-trifluoromethyl-biphenyl)ethylene (CN-TFMBE) was dissolved in chloroform. Two solutions were mixed for 1 hour and filtered with 0.45  $\mu\text{m}$  PTFE filter. For an electrospinning setup, 0.5 ml of a mixed solution was ejected through the syringe needle (22 gauge) at a speed of 0.18 ml/h. Nanofibers formed at 10 kV were deposited on the patterned silicon substrate. The substrate was attached on the rotating drum (5000 rpm) so that the deposited fibers can be aligned in a certain direction. Images of nanowires were taken using confocal laser scanning microscope (Olympus

OLS 3000). For a measurement of FET characteristics, precision semiconductor parameter analyzer (Agilent 4156C) was used under ambient conditions.

### 3. Results and discussion

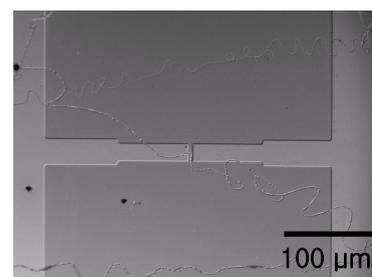
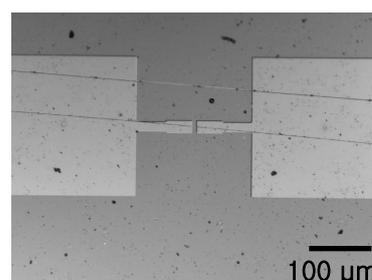
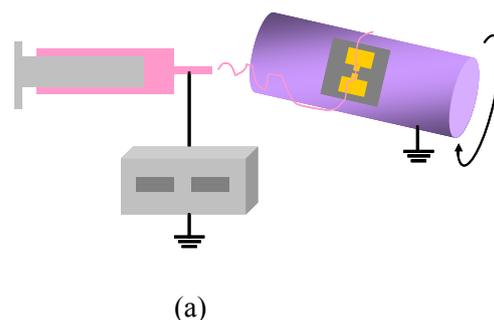
CN-TFMBEs are the low-molecular-weight materials that can spontaneously form the aggregates as nanofibers due to their strong dipole-dipole interactions (Figure 1(a)) [4]. Electrical and optical properties of these nanofibers have been published elsewhere [3, 4]. PANI is one of the most widely used conducting polymers due to its ease of synthesis, simple doping/dedoping chemistry, and environmental stability. Because of the difficulty of electrospinning of PANI alone, several researchers demonstrated the fabrication of electrospun PANI fibers by mixing it with PEO and PMMA [5]. We also attempted the electrospinning of PANI with different combinations polymers and observed that the mixture of PANI (doped with CSA) and PEO gives the most consistent results in terms of morphologies and electrical properties (Figure 1).



**Fig. 1. Chemical structures of blend components used in electrospinning process (a) CN-TFMBE, (b) PANI, (c) CSA, and (d) PEO**

Figure 2(a) presents a schematic view of electrospinning process. Figure 2(b) shows a representative nanofiber of CN-TFMBE/PANI blends deposited on the Au electrodes by the electrospinning; the number of fiber can be controlled by the electrospinning time. The diameter of fibers was measured to be  $410 \pm 90$  nm. In contrast to nanofibers

without CN-TFMBE (Figure 2(b)), the existence of CN-TFMBE enables the fiber to be more rigid, giving rise to the highly straightened morphology without entangled part that is occasionally found in PANI/PEO fibers. It is probably due to the spontaneous formation of rigid CN-TFMBE wire inside of the PANI/PEO fiber matrix during the solvent evaporation in the electrospinning processes. The orientation of individual fiber was adjusted using the rotating drum. Depending on the substrate orientation with respect to the rotating direction of the drum and rotating speed, the alignment of fibers could roughly be controlled. As the rotating speed increases, more fibers tend to be deposited closer to the parallel direction of drum rotation. In this way, we could increase the possibility of fiber to be deposited on the small region ( $5 \mu\text{m}$  (W)  $\times$   $20 \mu\text{m}$  (L)) of Au electrodes and thus precisely control the number of fibers.



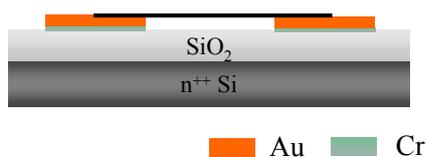
**Fig. 2. (a) Electrospinning Set up and confocal laser scanning microscopic images of electrospun nanowire of (b) CN-TFMBE/PANI-PEO and (c) PANI-PEO on the electrodes**

Figure 3 represents the FET device structure and transistor characteristics of an electrospun nanofiber blend. The current ( $V_{DS}$ ) between two electrodes increases as the magnitude of negative voltage ( $V_g$ ) of gate increases, demonstrating nanofiber acts as p-type semiconductor (Figure 3(a)). Threshold voltage ( $V_{th}$ ) and transconductance ( $g_m$ ) were determined to be -78 V and 1.45 nS (at  $V_{DS} = 10$  V), respectively. In a saturation regime, a hole mobility was calculated to be  $\sim 0.16$  cm<sup>2</sup>/V for the given capacitance ( $2.3 \times 10^{-16}$  F) of the device using the following relation.

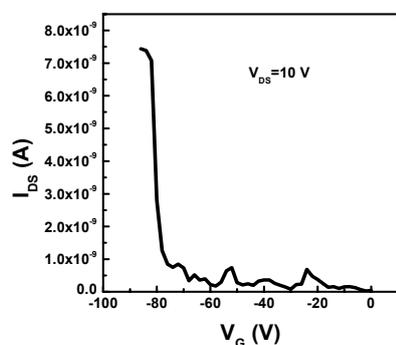
$$I_{DS} = \frac{\mu C}{2L^2} (V_G - V_{TH})^2 \quad (1)$$

where  $\mu$ , C, and L are the mobility, the dielectric capacitance, and the fiber length, respectively.

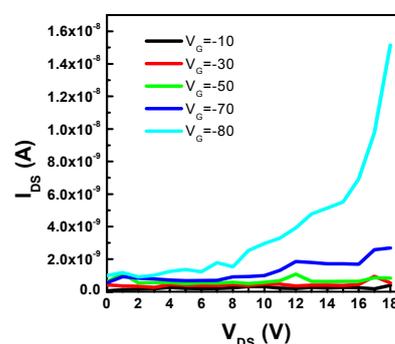
This high mobility value for this device is attributed to the spontaneous nanofiber formation of CN-TFMBE that is aligned in a direction parallel to the PANI/PEO fiber formation. In addition, the ability of aligning the matrix polymer (PANI/PEO) on the electrodes may enhance the carrier mobility for multiple wires compared with random wire network structure because the matrix polymer guides the effective direction of carrier movement.



(a)



(b)



(c)

**Fig. 3. (a) Schematic description of field effect transistor (FET) device structure and (b)  $I_{DS}$ - $V_{DS}$  and (c)  $I_{DS}$ - $V_G$  characteristics of PANI/CN-TFMBE blends nanowire**

#### 4. Summary

We demonstrate that p-channel organic nanofibers prepared by electrospinning of the conducting polymers blends exhibit the excellent behavior as a field-effect transistor (FET). High mobility value of 0.16 cm<sup>2</sup>/Vs has been obtained by the alignment of nanofibers in the electrospun polymers on the electrodes. Optimization of assembled nanostructures and further treatment such as thermal annealing and TFT measurement in a vacuum environment may improve the device performances, which remains the future studies. We expect that nanofiber FET will be available for disposable and wearable sensor in the near future.

#### 5. References

1. A. L. Briseno, C. B. Mannsfeld, S. A. Jenekhe, Z. Bao, and Y. Xia, *Materialstoday*, **38-47**, 11 (2008).
2. D. Li, and Y. Xia, *Adv. Mater.*, **1151-1170**, 16, (2004).
3. B. K. An, D. S. Lee, J. S. Lee, Y. S. Park, H. S. Song, and S. Y. Park, *J. Am. Chem. Soc.*, **10232-10233**, 126 (2004)
4. J. H. Kim, Y. Jung, J. W. Chung, B. K. An, and S. Y. Park, *Small*, **804-807**, 5 (2009)
5. N. J. Pinto, A. T. Johnson, A. G. MacDiarmid, C. H. Mueller, N. Theofylaktos, D. C. Robinson, and F. A. Miranda, *Appl. Phys. Lett.*, **4244-4246**, 83 (2003)