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Polymer Field Effect Transistors of Polyfluorene Prepared by Evaporative Spray Deposition using Ultradilute Solution

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1. Introduction

The evaporative spray deposition using ultra-dilute solution (ESDUS) technique is a polymer thin film preparation method having significant four advantageous features; 1) non-vacuum process, 2) pixel size deposition with simple shadow masks, 3) device fabrication of polymers showing very low solubility, 4) layer-by-layer deposition of polymers soluble to a same solvent. Recently we demonstrated that polymer light-emitting diodes (PLEDs) with a polymer stacking layered structure were fabricated by ESDUS, resulting drastic improvement in the device performance [1-3].

The ESDUS apparatus is schematically illustrated in Figure 1. The sample solution of a concentration around 1 ppm is nebulized into air and made into an aerosol with the particle size of around 10μm. The aerosol is transported by nitrogen carrier gas from the first chamber to a nozzle facing a substrate in the second chamber. During the transportation, the solution particles shrink with the evaporation of the solvent. The substrate is held on a ceramic heater with a thermocouple settled on an x-y positioner stage. The particles containing the appropriate amount of the solvent are deposited onto the substrate while keeping the distance from the nozzle constant for homogeneous deposition. The flatness or thickness of the resulted films can be controlled by the spraying rate, chamber temperature and substrate temperature.

The organic films prepared by ESDUS are formed by the deposition of the particles. Therefore, the growth process of the films should be very different from those by conventional methods such as spin-coat. Although PLEDs and photovoltaic cells prepared by ESDUS showed better or almost identical device performance compared with those by spin-coat, those devices are sandwiched structure, i. e. 100 nm of short and vertical carrier transportation. It is worth to compare ESDUS films with spin-coat films in a device with long and horizontal carrier transportation. In the present study, the organic field effect transistors (OFETs) prepared by ESDUS and by spin-coat were compared.

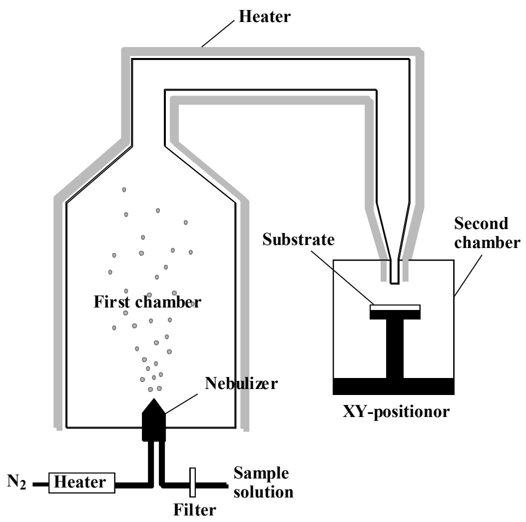

Fig. 1 Schematic illustration of ESDUS apparatus

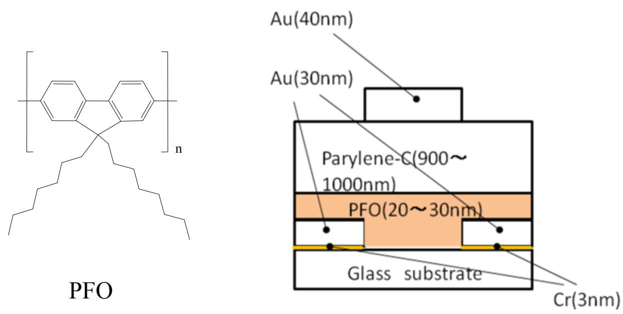

Fig. 2 Molecular structure of PFO and device structure of top-gate FET prepared in this study

2. Experimental

We prepared a polymer film of poly(9,9-dioctylfluorene), PFO, (Fig. 2, Sumation, Inc.). The spin-coated films were formed on a glass substrate using 1.2 wt% xylene solution. The ESDUS films were deposited onto precleaned glass substrates using THF solution of PFO at the concentration of 3×10^{-4} wt% with the substrate temperature of 80 °C. The films on glass substrates were used for spectroscopic investigation. For FET fabrication, chromium/gold source-drain electrodes

(W=5mm L=75μm) were vacuum-deposited on a glass substrate before polymer film preparation. Parylene-C insulator layer was formed onto the polymer film by chemical vapor deposition, followed by sputtering gold gate electrode.(Fig. 2) The surface morphology and the film thickness were determined by atomic force microscopy (AFM) (Nanopics 100, SII)

2. Results and discussion

PFO is widely investigated as an electroluminescence material. It is known that PFO takes some thin film phases. Among the phases, β-phase, where the main chain takes fully extended planar zigzag conformation[4], gives longest absorption peak and highest PL quantum yield.[5]

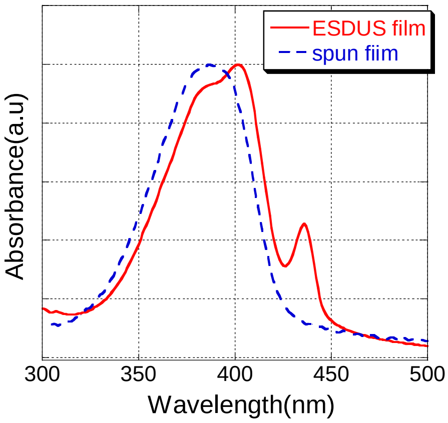

Fig. 3 Absorption spectra of PFO films formed on glass substrates by ESDUS (solid line) and spin-coat (dashed line).

Interestingly, the PFO film prepared by ESDUS showed significant peak at 435 nm, characteristic of β-phase, while the spun film showed no side peak indicating an amorphous phase. The PL quantum yield of the ESDUS film and spun film were 48% and 24 %, respectively. The polymer should take the more stable extended zigzag conformation during the film growth in ESDUS process.

The output characteristics of the FETs prepared by ESDUS and spin-coat were shown in Fig. 6. In the saturation regime, drain current is modeled with the standard FET equation [6]. The field effect hole mobility (μh), on/off and threshold voltage (Vth) were summarized in table 1.The device characteristics were in a same order. Since ESDUS film is formed by deposition of aerosol particles, the film might contain more defects in the molecular arrangement.

Table 1 FET characteristics of PFO films

	on/off	μh (cm^2/Vs)	Vth (V)
ESDUS	7.7×10^2	$(2.3\pm0.9)\times10^{-4}$	-59.1
spun	2.3×10^3	$(4.7\pm1.1)\times10^{-4}$	-38.6

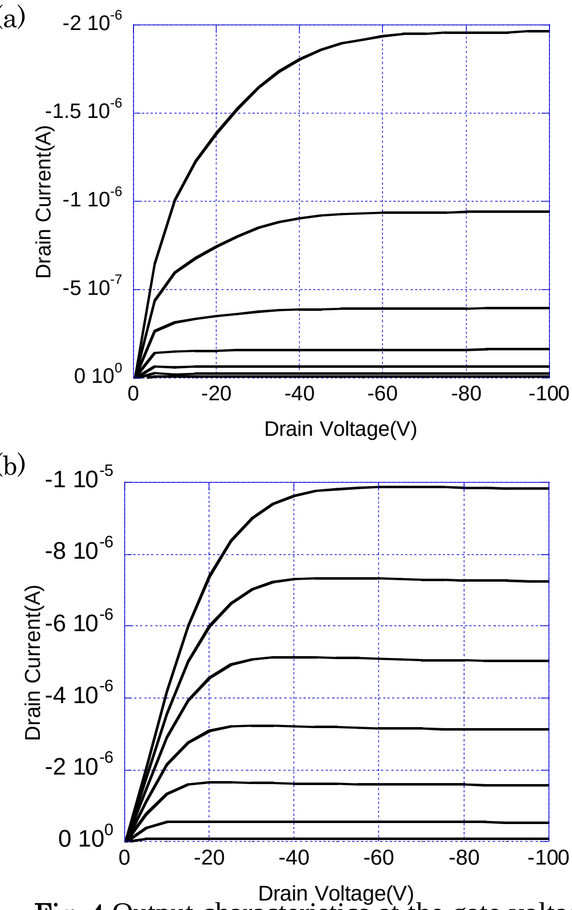

Fig. 4 Output characteristics at the gate voltage =0 to -100 V of PFO FETs prepared by (a) ESDUS and (b) spin-coat

The extended conformation favorable for carrier transport and the unfavorable defects can result in the device characteristics.

4. Conclusions

PFO takes energetically favorable conformation during film growth process in ESDUS, while spin-coat provides only amorphous as deposition. ESDUS can be used for investigation of electric properties dependent of the polymer conformation in a film.

Acknowledgements

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