Characterization of Active Layer and Electrical Properties of P3HT-based Organic Field-Effect Transistors

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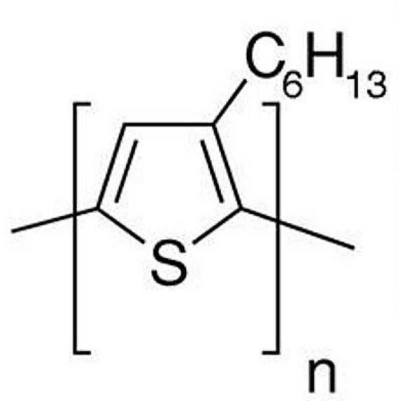
Abstract

Organic field-effect transistors (OFETs) exhibit unique properties, such as being flexible, easy to fabricate, and suitable for large-area processing. Conjugated polymers have been widely applied as semiconducting layers of OFETs. Poly(3-hexylthiophene) (P3HT) is a kind of representative polymeric semiconductor. Besides the π-π conjugated structure, P3HT also has a planar structure of thiophene ring, improving the regularity of the polymer and leading to promising electronic properties. In this study, P3HT films are cast on devices via spin coating. Ultraviolet-Visible Light spectroscopy (UV-Vis) is used to characterize the aggregation of P3HT in the solid state. It shows transition peaks in 605 nm and 550 nm, representing 0-0 and 0-1 transitions, respectively. The charge carrier mobility of devices is around 0.03 cm2 V-1 s-1. The P3HT-based OFETs are successfully fabricated, providing fundamental insights that contribute to the future development and commercialization of organic semiconductors.

Introduction



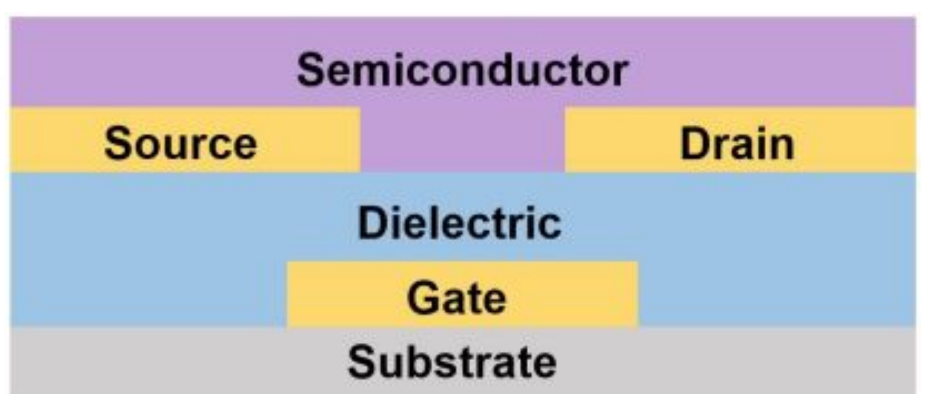


Fig. 1: Chemical structure of P3HT (left) and a schematic illustration of OFET (right)

- P3HT is a semiconducting material that has a conjugated backbone with an adaptive π-π stacking.
- OFET is a semiconducting device that can serve in integrated circuits, wearable devices, and so on.
- UV-Vis provides information on how well P3HT adapts to its conjugated nature through transition peaks.

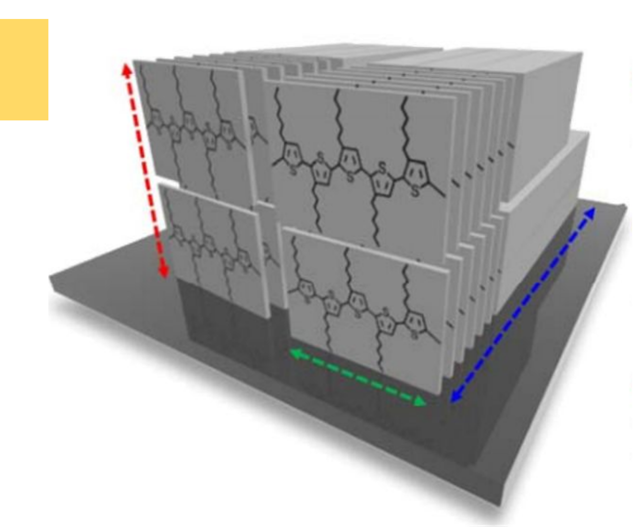


Fig. 2: P3HT edge-on packing structure, with the stacking direction of Intrachain (π conjugation), repeat unit length ~0.38 nm Interchain (π-π stacking), d-spacing ~0.38 nm Alkyl stacking, d-spacing ~1.6 nm

Experiment

1. Dissolve P3HT in chloroform with 5 mg/mL concentration.
2. Clean OFET wafers with acetone, methanol, and isopropyl alcohol.

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1. Prepare the solution at 55°C while stirring for 30 minutes.
2. Clean the wafers through plasma for 15 minutes.

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Perform spin coating by dropping 45 μL of solution onto precleaned wafers or glass slide.

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1. Characterize electrical properties of OFETs with the probe station.
2. Use the UV-Vis spectrometer to record the absorption spectra of films on glass slides.

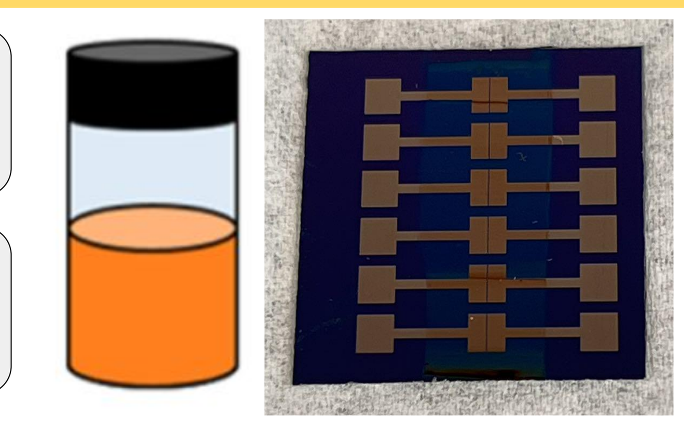

Fig. 3: Illustration of well-mixed P3HT solution (left), and an OFET with P3HT active layer (right).

Results & Discussion

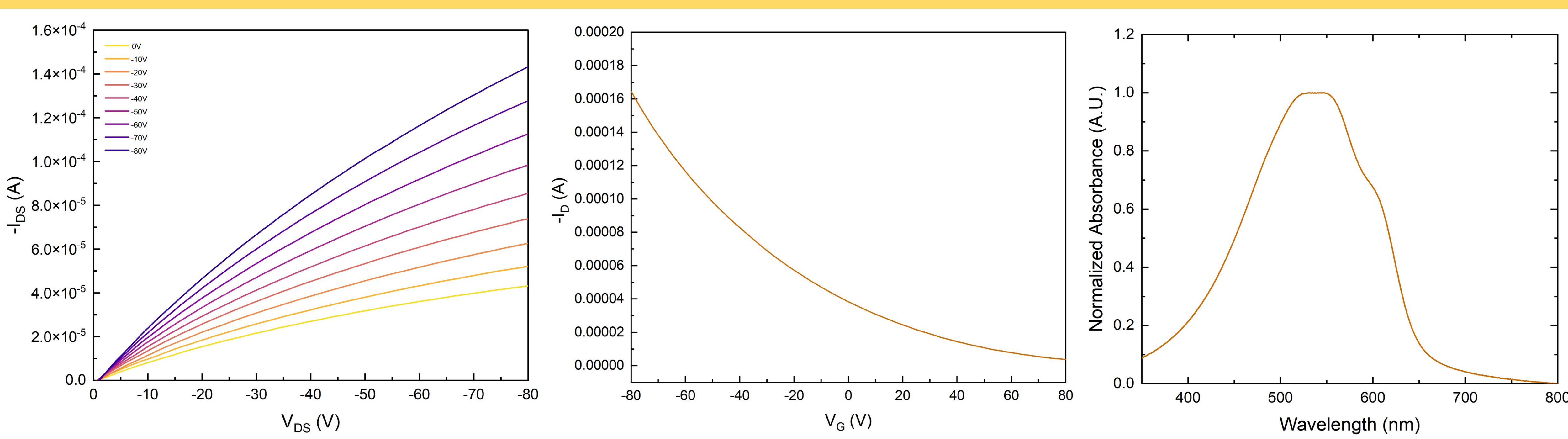

Fig. 4: Output characteristics (left), transfer characteristics (middle), and UV-Vis spectrum (right) of P3HT films cast by spin coating.

I_{DS} = drain-source current, I_D = drain current [ampere] ; V_{DS} = drain-source voltage, V_G = gate voltage [volts]

- Output curves show the saturation drain-source current at maximum drain-source voltage drop (-80 V) when different gate voltages are applied.
- Transfer curves show the change in drain current with respect to change in gate voltage at maximum drain-source voltage (-80 V).
- Average charge mobility through spin coating is 0.03 $cm^2 V^{-1} s^{-1}$. Calculated through the following equation: $I_D = \frac{W}{2L} C_i \mu (V_G - V_{Th})^2$
- Absorption bands at 605 nm and 550 nm represent the 0-0 and 0-1 transitions of P3HT respectively.
- 0-0 transition (605 nm) associates with intrachain interactions (see *Fig.* 2). Higher 0-0 peak signifies greater intrachain interaction, longer conjugation length, and better planarization of the polymer backbone.
- 0-1 (550 nm) transition associates with interchain interactions (see *Fig.* 2).

Future Work

- Apply alternative deposition methods (e.g. blade coating) that should supposedly improve charge mobility by facilitating the orientation of aggregates.
- Blend P3HT with other polymers to increase the crystallinity and tune the film morphology to improve the electrical properties.
- Additional characterizations such as Raman, AFM, and GIWAXS: they provide a clearer insight into the film morphology, molecular stacking, and crystalline regions.
- Other polythiophene derivatives may be good candidates for active layer materials.

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