INNOLUX CORP. v. PATENT OF SEMICONDUCTOR ENERGY LABORATORY CO., LTD.

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Abstract

This lab experiment is designed to help you understand the construction and operation of an **Organic Thin Film Transistor** (OTFT). You will learn the importance of the electrodes, organic layers, and the other infrastructure comprising an OTFT in the process of fabricating and characterizing your own. Starting from the conductive, transparent and interdigitated indium tin oxide (ITO) source and drain electrodes, you will apply an organic layer, P3HT (poly(3-hexylthiophene)), and an insulating layer, PVP (polyvinyl propylene). You will then create a gate structure containing a liquid metal (gallium-indium eutectic) and finalize the assembly using optical adhesive. Finally, you will characterize your OTFT by measuring current vs. voltage data, determining the turn-on voltage, and analyzing the various operation regimes.

Part 1	Part 2	Part 3
Semidondучting and Insulating Layers	Creating the Gate Electrode and the OTFT	Device Characterization

Write-up Instructions

Your lab report (Lab Notebook) will minimally consist of the following *for each part*:

A. Statement of experimental objective
B. Sketches of experimental setup
C. Record of all measurements
D. All requested calculations

The following lab procedure will indicate specifically what to include and where. The purpose of this style of write-up is to force you to keep a technical record of your experiments in the way that many engineers and scientists are required to do (in industry and universities). The lab director(s) will provide you with blank technical notebook sheets in the lab (also available on the website). You are expected to follow the lab notebook guidelines introduced by the lab director(s) (also see the Appendix), and your lab grade will depend both on your experimental procedure and on how well you follow these guidelines. Note that the same pages you use during the lab experiment should also be the ones you complete at home and hand-in as your write-up — do not rewrite them.

materials (polymers, oligomers), hybrid materials (organic-inorganic composites), and small molecules have been employed in the development of TFTs. This same architecture had proved viable when hydrogenated amorphous silicon (a-Si:H) was used as the semiconducting material. Even today, a-Si:H is used for the transistor backplanes in liquid crystal displays (LCD) and OLED displays [1].

Originally, charge carrier mobility was the parameter of focus since it was a key factor limiting any performance breakthrough. As better materials and device structures were discovered, researchers showed that OTFT performance could rival that of a-Si:H TFTs. The development over time of charge carrier mobility is shown in Fig. 1. Note than in a period of fewer than 15 years, mobility of organic semiconductors has improved by five orders of magnitude, rivaling the performance of traditional inorganic devices.

Over the past few decades, several academic and industrial groups have undertaken OTFT research and development, searching for better photoresists, electrode materials and insulators in focused and broad efforts to improve overall semiconducting properties, to bring processing difficulty and constraints to a minimum and to open new application pathways such as large-area printing on common and accessible materials. Current excitement surrounding OTFTs is driven by the ability to print transistor arrays on flexible backplanes for electronic displays, including e-paper, LCDs and OLED displays.

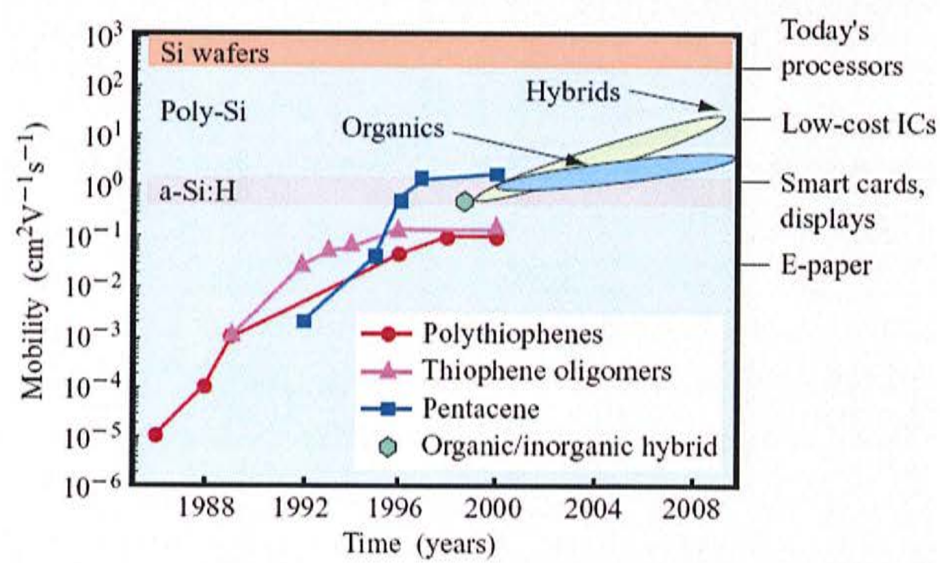


Figure 1. Organic and inorganic semiconductor mobility improvement over time [2].

enhanced—and mobility is improved—through self-assembly and ordering. Additionally, these materials exhibit great mechanical properties such as flexibility, toughness, and the ability to be processed in solution at low temperatures, resulting in new manufacturing processes such as roll-to-roll and ink jet printing. Recently, On/Off current ratios of P3HT and pentacene have reached as high as 10^6 and 10^7, respectively. Additionally, mobilities (see Fig. 2) have been good enough for circuits running at a few MHz and demonstrated with over 1000 transistors.

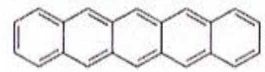
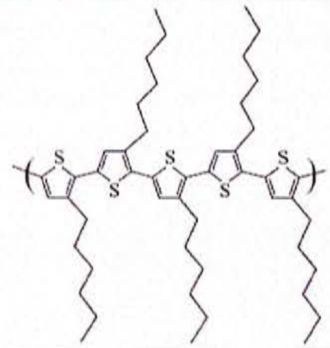
Semiconductor	*Representative chemical structure*	*Mobility* ($cm^2V^{-1}s^{-1}$)
Silicon	Silicon crystal	300–900
	Polysilicon	50–100
	Amorphous silicon	~1
Pentacene		~1
Regioregular poly(3-hexylthiophene)		10^{-1}

Figure 2. Common semiconductor materials, their chemical structure and mobility data [2].

As it will be employed and applied in our lab, P3HT is miscible in certain solvents and exhibits moderate but repeatable charge carrier mobility when layers are spin-cast. The polymer chains align themselves as shown in Fig. 3 where **a** and **b** represent the spacing among neighboring chains. The quality of the P3HT layer is dependent upon the materials at its interface(s) and the method with which it is applied.

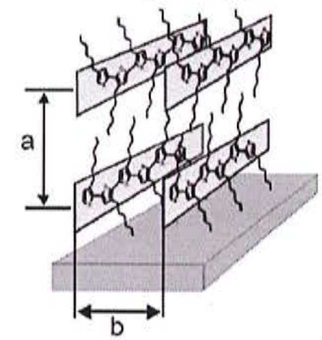


Figure 3. Structure of P3HT following spin-casting.

Aside from the semiconductor itself, the gate insulator material and electrode architectures are of great importance in OTFTs. A common device layout employs a bottom-gate architecture as depicted in Fig. 4(a). In short, the application of the insulator and the interface between it and the semiconductor greatly affects the overall device performance. An additional as shown in Fig. 4(b). This pattern effectively increases the channel width, thus leading to higher currents. In addition, by applying the insulator as the top layer, we can use a liquid metal (gallium-indium (GaIn) eutectic) as the gate electrode in an unpatterned, single contact point.

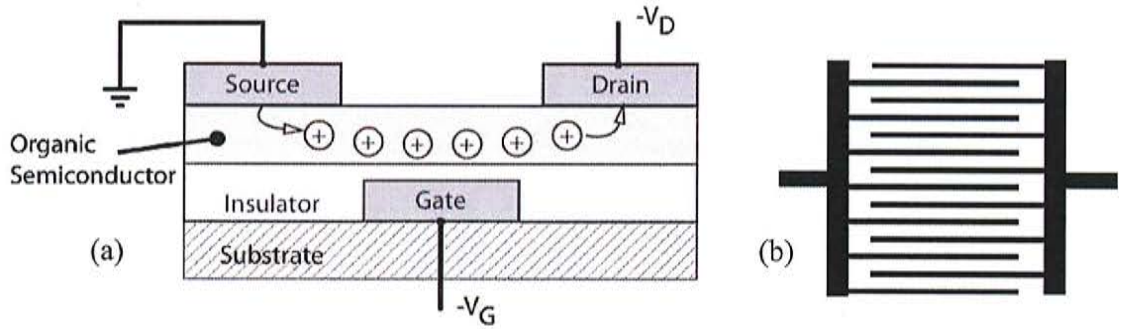


Figure 4. (a) Diagram of a bottom-gate OTFT device showing the path of charge carriers from source to drain; (b) Interdigitated pattern for source and drain electrodes.

OTFT Operation and Characterization

An inorganic metal-insulator-semiconductor field-effect transistor (MISFET) is a three-terminal device in which the source and drain contact the bulk semiconductor solid with the gate separated by an insulator. Proper doping creates p-n junctions in the bulk and an applied voltage on the gate can create an inversion region beneath the gate insulator within which charge carriers move between source and drain, providing a current modulated by the magnitude of the gate voltage. OTFTs are similar in that current between the source and drain electrodes can be modulated by the gate voltage. However, the semiconductor in an OTFT is just as the name implies, a thin film, not a bulk solid. Additionally, there are no p-n junctions. Instead, the metal electrodes easily inject charge into the semiconductor meaning the operation of the device, i.e. the regime in which current enhancement is appreciable, occurs in accumulation, not in inversion.

Current in an OTFT, as shown in Fig. 4(a), arises from two processes: a bulk current that is present even without an applied gate voltage and a field-effect current that increases as a potential appears on the gate electrode, causing accumulation of carriers in the semiconductor. Because of this, an *n*-channel OTFT contains an *n*-type semiconductor and a *p*-channel OTFT contains a *p*-type semiconductor.

Characterization of an OTFT and its operating regimes is similar to that of a MISFET in that the important measurements concern the drain current. Figure 5(a) presents drain current vs. drain-source voltage for a P3HT OTFT with a grounded source electrode. A transition in the current as it approaches the saturation regime is especially apparent in the V_{GS} = -40 V curve. Additionally, the application of negative drain and gate voltages and a resultant negative drain

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