


## 2008 年中央研究院「年輕學者研究著作獎」得獎人簡介

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得獎著作名稱：(請以申請時之格式填入)

1. Chu-Jung Ko, Yi-Kai Lin, and Fang-Chung Chen\* “Microwave annealing of polymer photovoltaic devices” **Adv. Mat.** 19, 3520 (2007).
2. Chu-Jung Ko, Yi-Kai Lin, Fang-Chung Chen\*, and Chi-Wei Chu ”Modified buffer layers for polymer photovoltaic devices” **Appl. Phys. Lett.** 90, 063509 (2007).
3. Fang-Chung Chen\*, Li-Jen Kung, Tung-Hsien Chen and Yung-Sheng Lin “Copper phthalocyanine buffer-layer to enhance the charge injection in organic thin-film transistors”**Appl. Phys. Lett.** 90, 073504 (2007).

得獎著作簡介：(2000字左右)

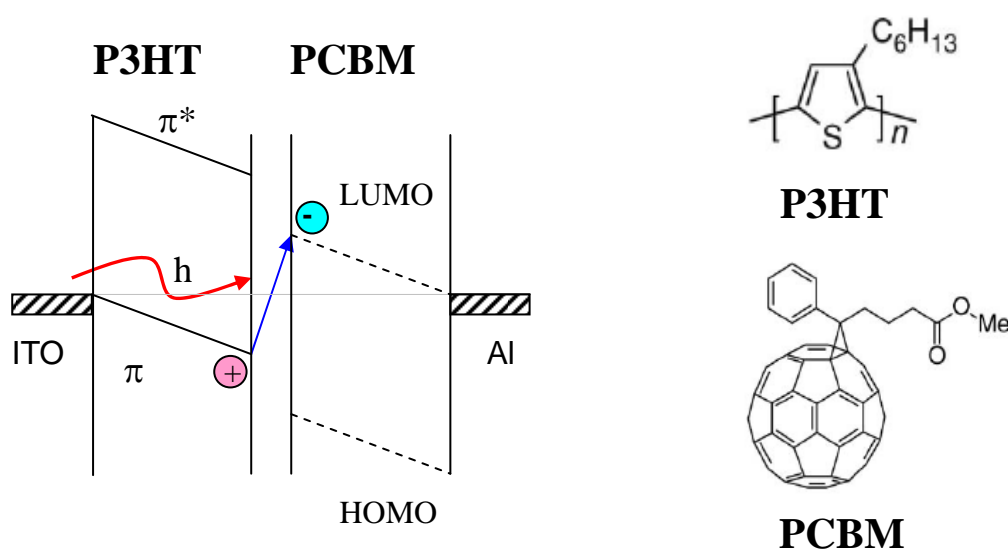
傳統的有機物質，例如日常生活中常用的塑膠材料，常被認為缺乏導電性，因此這些絕緣物質的應用多侷限於包裝及電器用品之外殼等用途上。例如在電子工業上，電線或電纜通常需要一層絕緣包裝以防止觸電，而現今於電腦中的半導體晶片也需要這些絕緣特性良好的物質提供適當的封裝，才可有穩定的操作功能，現代人的日常生活已無法缺少這些有機絕緣材料。

然而，在 1976 年發現導電高分子後，已打破了人們對有機材料的傳統印象。例如第一個發現的高導電高分子聚乙烯，其導電度在以碘蒸氣處理後最高可以增加至原來  $10^9$  倍之多，這些有機材料的導電度可利用類似無機半導體的摻雜方式控制，今日，有機材料應用於電子或光電領域已有不少的產品問世，如最成熟的有機電激發光元件顯示器已於幾年前上市，這些有機電子元件因為重量輕、製程溫度低、成本低以及具有可撓曲性，已受到很大的矚目，在未來低階但低價格的可攜式或可拋棄式的電子產品中將有很大的發展空間，例如可撓性顯示器、無線電電子標籤、智慧卡片與可攜式太陽能電池等，都是很有潛力的產品應用。

我的研究主要在有機電子元件中的高分子太陽能電池與場效電晶體。三篇相

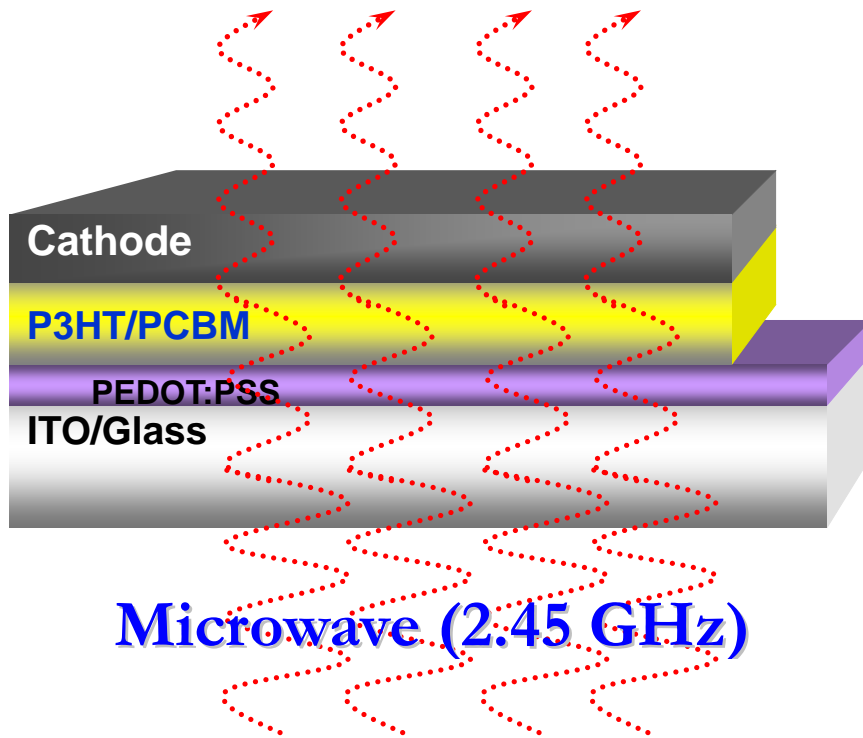
關的著作簡介如下。隨著石化能源的需求增加、價格攀昇與地球暖化效應加劇，再生能源相關的研究也漸受重視，再生能源中的太陽能為乾淨且取之不盡的能源，而在太陽能相關技術中，高分子太陽能電池因有機會提供低價的能源來源，因此也受到很大的矚目。目前高效率的高分子太陽能電池都以異直接面的方式製作，通常是混合一具軛高分子與碳六十而成(圖一)，兩者有不同的能階，因此當照光時，將發生超快的光誘導電荷轉移的現象，之後產生之電子與電洞經由碳六十與高分子分別傳導至電極。此兩種材料形成一交錯網路而有很大的接觸面積，因此可確保有高效率的極子分離，而產生電子與電洞。因為薄膜型態將影響電荷分離與傳導的效率，兩材料之間的相分離結構對太陽能電池有很大的影響。

薄膜型態的控制，目前多數主要皆以加熱(或退火)的方式製作，所謂的退火，簡單來說就是經由加入能量的方式而使得薄膜內部結構改變的過程，而一般加熱將導致高分子鏈產生自身排列的結果，使得電荷跳躍更容易，因此電荷之遷移率，即電荷於電場中的移動速度，經退火後變高，而電池的內電阻變小後，能量轉換效率即變大。然而一般加熱方式都是經由加熱板等傳導的方式，能量容易散失，特別是對於製作產生能源的電池來說，並不希望耗掉太多能源。



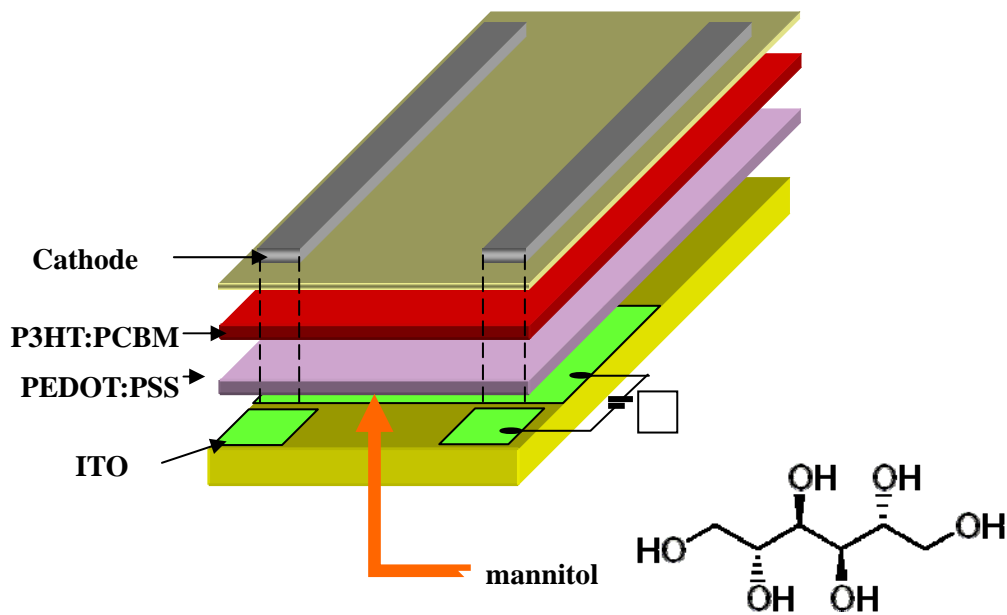
圖一、光誘導電荷分離之示意圖與高分子 P3HT 及碳六十衍生物的化學結構。

我們首度以獨步全球的微波方式進行元件之退火(圖二)，微波是一個非接觸性且快速的加熱法，因為不同的材料通常具有不同的微波吸收係數，因此微波可以對材料選擇性地加熱，而通常電子元件中均含有絕緣、半導體或導體等不同特性的材料，微波吸收係數通常都不同，因此微波退火將可增加能量利用率。研究結果顯示微波退火90秒後，元件即可達3.6%的效率，從內標準的溫度量測法中，也可得知微波可以選擇性地對元件中的有機主動層與金屬電極加熱，因此大幅增加了退火步驟的效率，本研究成果已發表於 *Adv. Mat.* 19, 3520 (2007)。



圖二. 元件結構及微波退火之示意圖。

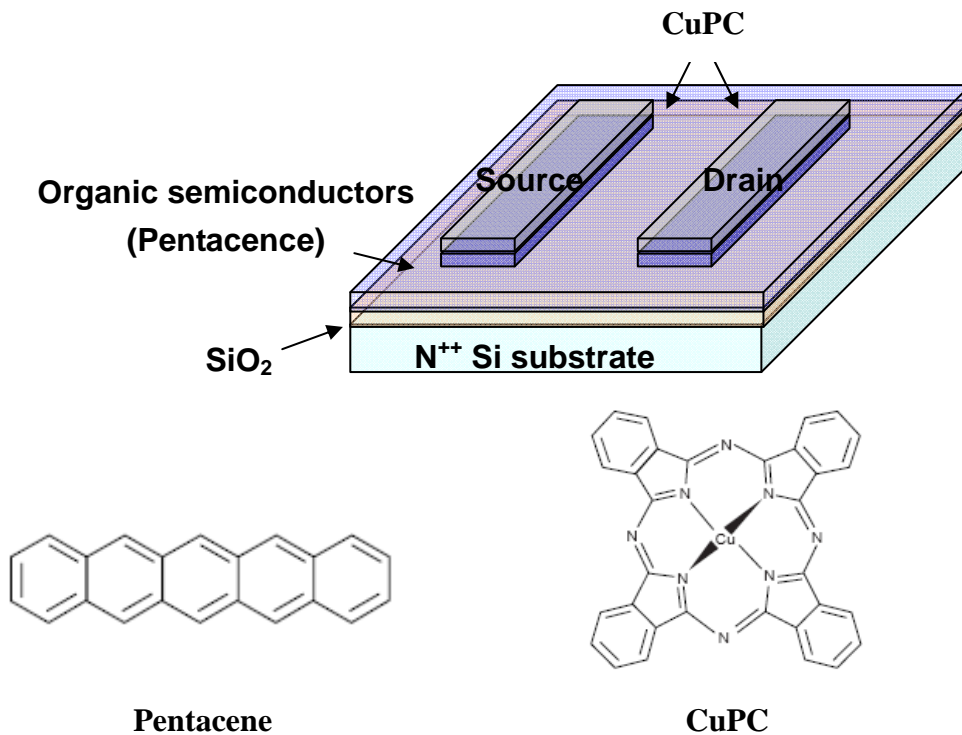
太陽能電池的內電阻來源有界面電阻與材料本身電阻等(圖三)，有別於多數相關研究均專注於有機主動層的方向，我們則加入甘露醇於高分子緩衝層 PEDOT:PSS 中，利用減低緩衝層中的電阻，進一步的降低元件的內電阻，而成功地製作出能量轉換效率高達 5.2% 的有機高分子太陽能電池元件，此效率已達國際一流的水準，相關論文已發表於 **Appl. Phys. Lett.** 063509 (2007)。



圖三. 元件結構及甘露醇之化學結構。

有機薄膜電晶體可利用一閘極之電壓控制於源極與汲極之間的電流大小。我們使用一高摻雜的矽基板為閘極，二氧化矽為絕緣層，五環素為半導體層，當在閘極加一電壓之後，即產生場效電荷，因電荷濃度的改變，因而使得半導體的導電度產生變化，因此，半導體層的導電度可以藉由閘極的電壓控制，換句話說，當源極與汲極有電位差時，兩極間的電流可以以閘極電壓控制。

而一般元件之源/汲極電極與有機半導體的界面電阻並不小，將會影響元件的電性，因此我們發現，利用有機物如銅苯二甲藍(copper phthalocyanine, CuPC)等修釋源/汲極電極，因降低界面電阻，可提升元件特性，電荷遷移律可以增加一倍，我們推測當金蒸鍍在 CuPC 上時，會在界面引出表面能階(surface states)，藉著這些能階，電洞可更容易注入元件，進而降低界面電阻，將可提升整體元件的特性，相關論文已發表於 *Appl. Phys. Lett.* 90, 073504 (2007)。




圖四. 元件結構及五圓環與銅苯二甲藍之化學結構。

### 評審簡評：

陳方中教授的研究興趣主要在高效益有機電子元件的發展，研究主題包括高分子發光二極體；有機太陽電池；有機薄膜電晶體等。陳教授在他早期的研究，對增加高分子發光二極體的量子效益上有非常重要的貢獻。他在有機光伏 (photovoltaic) 電池的研究，提出利用混合離子高分子電解質的方法來增強光電轉換效益的概念，也得到重要成果。此次陳教授獲得中研院年輕著作獎的工作，主要是探討應用微波處理方式來改善有機光伏電池的製程，進而提高光伏效益，此一工作成果領先國際上的相關研究。這個成果有極高的後續潛力應用在有機電子元件的發展。總體而言，陳方中教授在有機光電元件、有機電子的研究著有成效，是國內有極高研究發展潛力的年輕學者。

## 2008 Academia Sinica Research Award for Junior Research Investigators

<p>Name: Fang-Chung Chen</p> 	<p>Education:</p> <p>Bachelor in Chemistry, National Taiwan University, (1992~1996)</p> <p>Master in Chemistry, National Taiwan University (1996~1998)</p> <p>Ph. D. in Materials Science, University of California, Los Angeles (2000~2003)</p> <p>Employer(s)/Job Title(s):</p> <p>Assistant Professor, Department of Photonics and Display Institute</p>
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### Award publications :

1. Chu-Jung Ko, Yi-Kai Lin, and Fang-Chung Chen\* “Microwave annealing of polymer photovoltaic devices” **Adv. Mat.** 19, 3520 (2007).
2. Chu-Jung Ko, Yi-Kai Lin, Fang-Chung Chen\*, and Chi-Wei Chu ”Modified buffer layers for polymer photovoltaic devices” **Appl. Phys. Lett.** 90, 063509 (2007).
3. Fang-Chung Chen\*, Li-Jen Kung, Tung-Hsien Chen and Yung-Sheng Lin “Copper phthalocyanine buffer-layer to enhance the charge injection in organic thin-film transistors” **Appl. Phys. Lett.** 90, 073504 (2007).

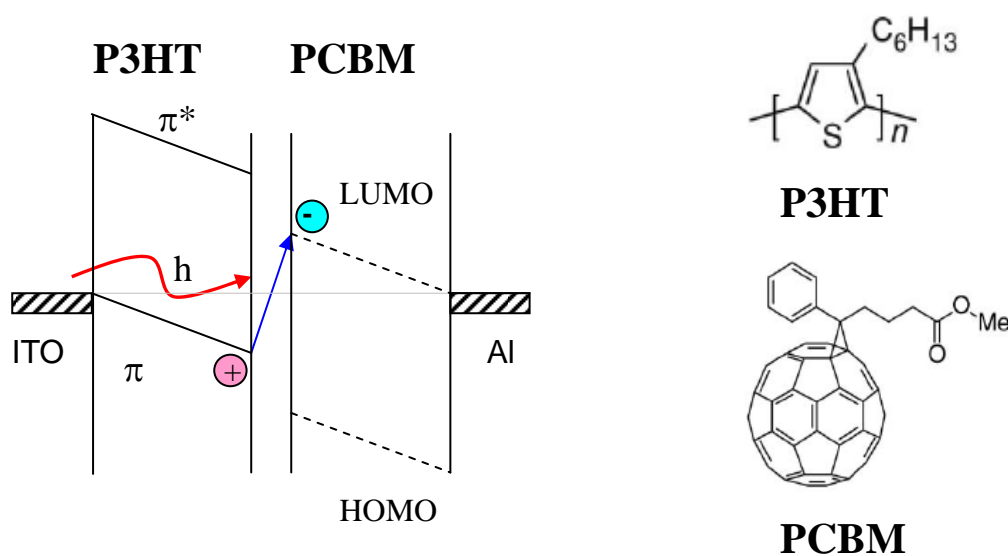
### Summary of the Award publications ( around 2000 words ) :

Plastics, composed of organic molecules, are usually considered as insulators, which do not conduct electricity. Traditionally, these materials are either used as passive insulators or as encapsulants, especially in electrical industry. For examples, electric cords and wires are conventionally coated with plastics to avoid electric shock. Modern semiconductor chips also rely on these materials to support proper packaging. Plastics have been already indispensable to our daily life.

However, since the discovery of conducting polymers, the traditional view point has been changed. Polyacetylene, the first highly conductive polymer, becomes  $10^9$  times more conductive than it is originally after treatment of iodine vapour. The conductive of these modern organic materials could be controlled by the “doping” process, which is analogy to the doping of traditional inorganic semiconductors. Currently, electronic products, in which organic materials play an active role, have

been realized. The most mature product is organic light-emitting diodes displays, which has been commercial available several years ago. These organic devices are receiving increasing attention because their favorable properties, such as light weight, fabrication at low temperature, low cost, and mechanical flexible, are attractive for some low-performance, low-cost electronic products which address the needs for disposable and portable devices in the future. Besides flexible displays, radio-frequency identification tags, smart cards, and portable solar cells are also potential applications.

My research in the field of “organic electronics” centers on the polymer solar cells and field-effect transistors. Three research papers are introduced as followings. Continuous growth in world energy consumption, declining fossil reserves, and increasing climate change concerns have led to an enormous increase in demands for alternative and economical energy sources. Solar energy is one of the renewable sources, which are clean and naturally replenished. Among the solar energy technologies, polymer photovoltaic devices have received much attention recently, because they could offer a potentially inexpensive way to produce electricity from sunlight. The most efficient polymer solar cells have a so-called “heterojunction” structure prepared through the blending of conjugated polymers (electron donors) and fullerenes (electron acceptors) (Figure 1). The conjugated polymers and fullerenes have different electrical energy levels. Upon illumination, ultra-fast photo-induced charge transfer from conjugated polymers to fullerenes occurs. Subsequently, the holes and electrons move towards the electrodes through polymers and fullerenes, respectively. These two materials form a randomly interpenetrating network with a large interfacial area, which ensures the highly efficient dissociation of excitons (electron and hole pairs). Because the morphology, the precise structure of the polymer-fullerene blend, controls the efficiency of charge separation as well as charge transport, it plays an important role in determining the efficiency of the solar cell.



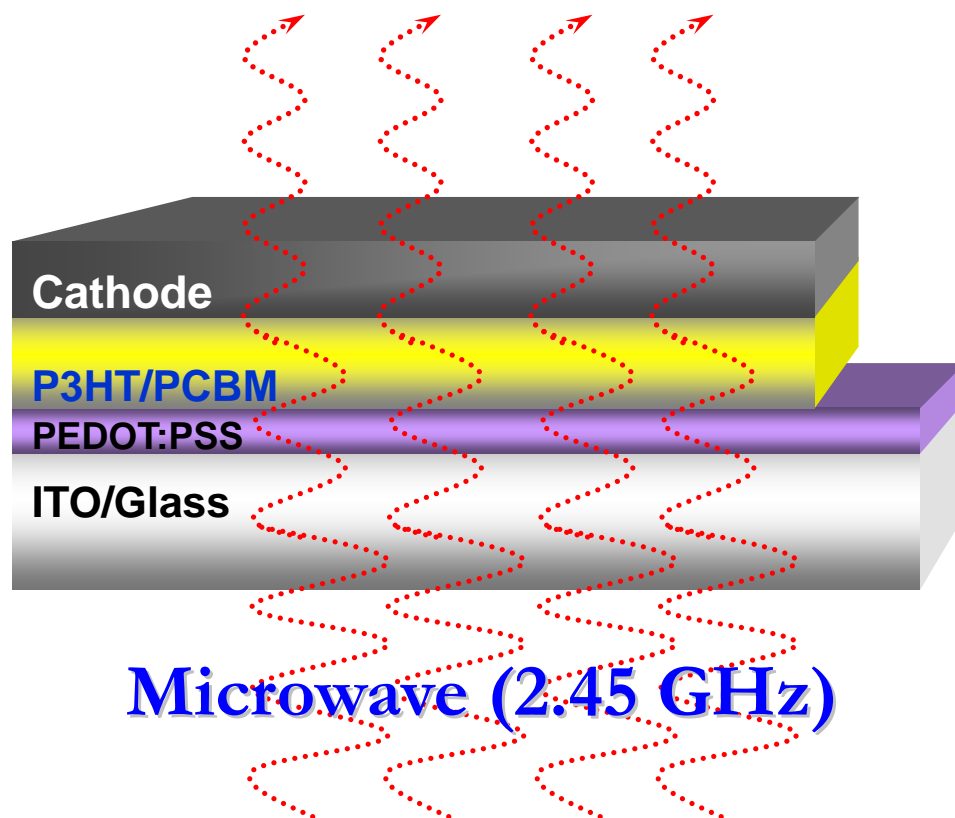
**Figure 1.** Scheme of the process of photo-induced charge transfer and the chemical structure of poly(3-hexylthiophene) (P3HT) and [6,6]-phenyl-C-61-butyric acid methyl ester (PCBM).

The control of morphology is usually achieved by thermal annealing (heating). The heat treatment usually causes the self-organization of polymer chains, facilitating the charge hopping. Therefore, the charge mobility, the drift velocity of charge carriers to the applied electric field, becomes larger, resulting in lower internal resistance of the solar cell and higher power conversion efficiency. However, thermal annealing is conventionally implemented through thermal conduction methods, such as the use of hotplates or thermal ovens, the energy loss and low efficiency of energy usage during such processes can be problematic.

In our work, we use microwave heating, which is a non-contact and rapid heating process to annealing the polymer solar cells (Figure 2). Because the degree of microwave absorption depends on the rotation of the dipoles of a material, microwave annealing can be used to heat materials selectively. Since typical electronic devices usually composed of different materials, from insulators and semiconductors to conductors, the absorption efficiency of each material is usually different. Therefore, it is a potential approach toward enhancing the efficiency of energy usage. Our results suggested that the power conversion efficiency of the devices increased upon increasing the microwave irradiation time, reaching a maximum of 3.6% within only 90 s. *In situ* temperature probing suggested that the microwaves could penetrate the anode, including the ITO glass substrate and the PEDOT:PSS buffer layer, without any loss of energy, whereas the organic active layer and the cathode were both heated. The selectively heating method can enhance the energy usage efficiency for the



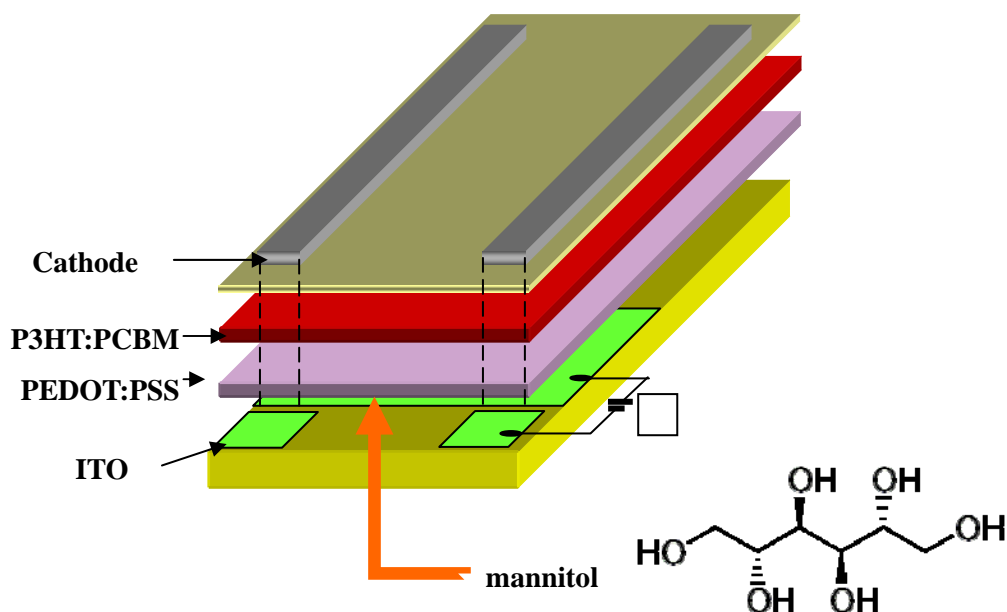
preparation of the polymer solar cells. This work has been published in **Advanced Materials** 19, 3520 (2007).



**Figure 2.** The device structure and the microwave annealing process.

Technically, major contributions to the internal series resistance include the bulk resistance, including the bulk resistance of organic layers (P3HT:PCBM), PEDOT:PSS and electrodes (ITO and cathode metals) and the contact resistance, originating from the interface between the electrodes and the active layer (Figure 3). While most of related researches center on the investigation and development of the organic active layer of the solar cells, we found that the buffer layer, poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate) (PEDOT:PSS), has great influence on the device efficiency.

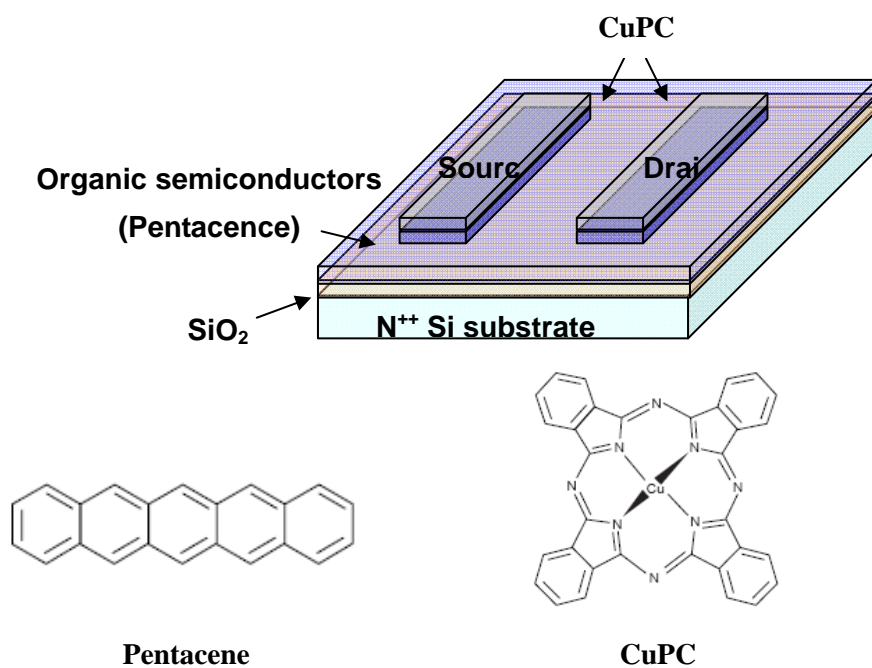
Improved power conversion efficiency, up to 5.2%, has been observed by reducing the resistance of PEDOT:PSS after doping of mannitol (Figure 3). The device improvement is owing to the reduction of series resistance of the PEDOT:PSS. The extreme high power conversion efficiency is among the highest values reported in organic solar cells. This work has been published in **Applied Physics Letter** 90, 063509 (2007).



**Figure 3.** The device structure and the chemical structure of mannitol.

An organic thin-film transistor is a device, which can control the current flow between the source and drain electrodes by applying a voltage on the third gate electrode (figure 4). In our work, heavily doped Si wafer was used as the gate electrode and the substrate. 200 nm thermal SiO<sub>2</sub> was served as the gate insulator. An organic semiconductor, pentacene, was thermally evaporated on the gate dielectric. Upon applying a bias on the gate electrode, field-induced charges are generated. Because the concentration of free charge carriers is altered, the conductivity of the semiconductor layer changes. Therefore, the conductivity of the semiconductor could be controlled by the gate bias. While a bias is applied between the source and drain electrodes, the current flow can be also controlled by the gate voltage.

The contact resistance of OTFTs between the source/drain electrodes and the organic semiconductors is usually quite significant. To solve the problem, we found that the performance of organic thin-film transistors can be improved by inserting one thin layer of copper phthalocyanine (CuPC) at the interface. The contact resistance of the device was reduced by using the CuPC buffer layer. The device mobility was improved by almost one-fold after the modification. It is concluded that the Fermi level pinning at the induced surface states at the Au/CuPC interface contributes to the improvement. This work has been published in **Applied Physics Letter** 90, 073504 (2007).



**Figure 4.** The device structure of a OTFT and the chemical structure pentacene and CuPC.