

# Combining Vacuum Deposited with Solution Processed Layers in Organic Solar Cell

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## ABSTRACT

Heterojunction cells are the subject of much current research. They can be differentiated by their production processes: solution processing and vacuum processing. Both production processes have advantages and disadvantages. Solution processed devices have the advantages of monodispersity and simple synthesis, but the use of solution processing is limited to soluble conjugated polymers due to their ability to form a smooth film on spin coated materials and the devices are characterised by lower mobilities due to their disordered structures. Vacuum processing can lead to relatively high throughput and sequential stacking of well-defined layers and extraction of exciton diffusion lengths can be performed. Vacuum processed devices, however, tend to suffer from lower efficiencies.

Our approach is based on combining vacuum deposited active layers with solution processed layers in organic photovoltaic cells using pentacene and buckminsterfullerene.

**Keywords:** heterojunction cells, pentacene, buckminsterfullerene, bathocuproine, calcium

## 1 PENTACENE AND FULLERENE

A key to the successful implementation of organic solar cells is the ability to combine a high charge carrier mobility with cheap, large- area fabrication processes. Up until now the highest mobility has been achieved in small molecule materials with a high crystallinity. One successful small molecule in organic photovoltaic cells (OPVCs) is pentacene, which is a promising donor due to its high carrier mobility[1]. Also it has a long exciton diffusion length and shows strong absorption in the visible region. As n-type materials, buckminsterfullerene has been widely used for its high electron affinity and ability to transport charge effectively.

## 2 EXCITON-BLOCKING LAYER

Insertion of 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (Bathocuproine or BCP) and calcium plays an important role in OPVCs, resulting in an enhanced power conversion efficiency (PCE). BCP and Ca, which are

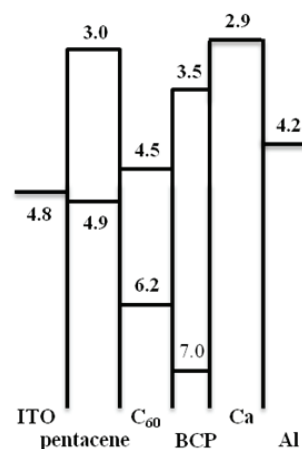


Figure 1 Energy diagram of a device[1]

wide-band-gap materials, act as an exciton-blocking layer (EBL).

They prevent excitons diffusing toward the Al electrode and work as an optical spacer between the active layer and electrode, leading to redistribution of the optical electric field. As the diffusion buffer layers, they play very important roles in OPVCs, which establishes the ohmic contact between the C<sub>60</sub> and Al and prohibits lowering of the work function of the C<sub>60</sub>/Al interface[2].

Exciton quenching can be observed in cell A without any BCP or Ca layer and this S-shaped I-V characteristic can be attributed to a barrier for extraction inside the solar cell. However, improvement in efficiency through cell B with a Ca layer and cell C with a BCP layer has been explained by its exciton blocking properties near the Al electrode like Figure 2. Cell D with both a BCP and a Ca layer showed the most enhanced efficiency but the increased rate is not remarkable. The cells with BCP, Ca, or BCP and Ca showed increased values in all of V<sub>OC</sub>, J<sub>SC</sub>, and FF compared to the cell without any exciton-blocking layer, as shown in Table 1.

	$V_{OC}$ [mV]	$I_{SC}/cm^2$ [mA/cm <sup>2</sup> ]	FF [%]	MP/cm <sup>2</sup> [mW/cm <sup>2</sup> ]
Standard device/Al	223.97	2.81	30.19	0.19
STD/Ca/Al	295.00	5.68	51.95	0.87
STD/BCP(10 nm)/Al	264.83	6.28	49.89	0.83
STD/BCP(10 nm)/Ca/Al	267.34	6.88	51.12	0.94

\*STD device : PEDOT:PSS/pentacene(50 nm)/C<sub>60</sub>(50 nm)/Al

Table 1.  $V_{OC}$ ,  $I_{SC}$ , FF and Efficiency of each device with BCP, Ca, and BCP/Ca

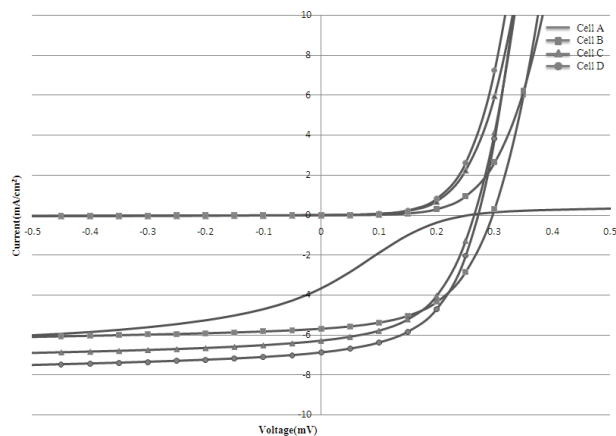


Figure 2 I-V characteristics of devices with Ca/BCP/BCP+Ca layers.

### 3 EFFECT OF CONDUCTIVE LAYER

PEDOT:PSS is a transparent and conductive polymer and is precoated onto the ITO surface. Devices depending on a PEDOT:PSS layer show different I-V characteristics both under dark current and illuminated conditions as shown in Figure 3.

	$V_{oc}$ [mV]	$I_{sc}/cm^2$ [mA/cm <sup>2</sup> ]	FF [%]	MP/cm <sup>2</sup> [mW/cm <sup>2</sup> ]
STD(on ITO)/BCP/Ca/Al	315.81	6.61	52.25	1.09
STD(on PEDOT:PSS) BCP/Ca/Al	267.34	6.88	51.12	0.94

Table 2.  $V_{OC}$ ,  $I_{SC}$ , FF and Efficiency of each device with the ITO/PEDOT:PSS and the ITO anode

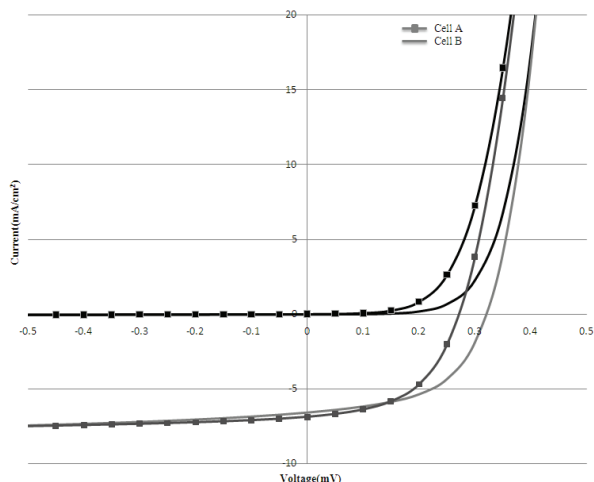


Figure 3. Effect of the PEDOT:PSS layer on the I-V characteristics of anode/50 nm pentacene/50 nm C<sub>60</sub>/10 nm BCP/Ca/Al, where the anode is either the ITO/PEDOT:PSS (cell A, squares), or the ITO (cell B, solid line). Black lines represent I-V curves taken in the dark, while gray lines represent I-V curves taken under AM 1.5G illumination.

Cell A was grown on bare ITO, while for cell B, the ITO was precoated with PEDOT:PSS. The insertion of the PEDOT:PSS layer leads to an increase in the dark current. The cell with a PEDOT:PSS layer has a higher short-circuit current but a lower open-circuit voltage compared to the cell without a PEDOT:PSS layer. A large difference in efficiency is not observed. These higher short-circuit current and lower open-circuit changes can be explained by the higher work function of the PEDOT:PSS layer compared to that of ITO [3] and the different morphology of pentacene grown on ITO to that grown on PEDOT:PSS[4].

### 4 INSERTION OF SOLUTION PROCESSED LAYER

Figure 4 shows the PV devices with the structure ITO / pentacene(50 nm) / (PCBM:P3HT) / C<sub>60</sub>(50 nm) / BCP(10 nm) / Ca / Al produced with a combination of vacuum processing and solution processing.

Pentacene, C<sub>60</sub>, and BCP films are grown at high temperature, ranging from 100°C to 300°C in high vacuum ( $-1 \times 10^{-6}$  Torr) and the PCBM:P3HT film is spun casted under N<sub>2</sub> atmosphere.

The insertion of solution processed layer PCBM:P3HT will create a bulk heterojunction, in which excitons are generated close to the second material, leading to efficient photocarrier generation[5].

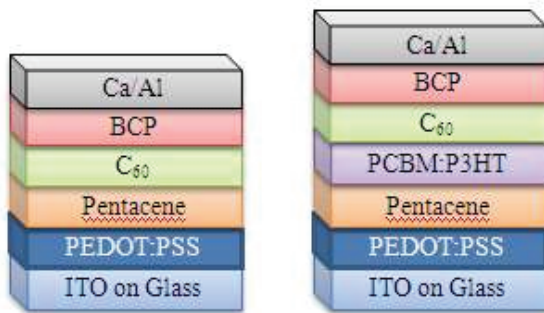


Figure 4. Schematic device structure

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