Small Molecule Thin Film Solar Cells With Active Layers Composed Of Copper Phthalocyanine (CuPc) And Fullerene (C$_{70}$)

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Abstract. We have grown organic solar cells through bilayer structure using copper phthalocyanine (CuPc) as the donor material and fullerene (C$_{70}$) as the acceptor. In this article, we demonstrate power conversion efficiency of 1.47% for the bilayered solar cells composed of CuPc and C$_{70}$. Successful tuning of the thickness of the individual layers was carried out to obtain the optimum solar cell parameters. It has been found that efficiency of the bilayer devices depends primarily on the individual layer thickness and thermal annealing of the devices. Overall, bilayer structure is suitable when the active layers are insoluble in most of the commonly available solvents.

Keywords: Bilayer solar cells, thermal annealing, film thickness  
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INTRODUCTION

Organic electronics has been emerging as important contenders of the modern day electronics due to their potential for low cost, ease of fabrication and also their compatibility with flexible substrate [1]. Most of the fabrication techniques till date involved the use of either the bulk heterojunction route or the bilayer structure for the realization of organic solar cells. In the bulk heterojunction solar cells, the active layer is a blend of electron donor and electron acceptor materials. On the other hand, bilayer heterojunction comprises of active layers of electron acceptor layers on top of an electron donor layers. Such a bilayer structure has been demonstrated by Tang et al in 1986 [2]. A combination of copper phthalocyanine and perylenetetracarboxylicacid bis-benzimidazole to form a p–n heterojunction was successfully demonstrated by Tang et al. Among the family of Phthalocyanines, CuPc has been widely used because of their high carrier mobility and strong absorption coefficient (\(\alpha > 10^5\) cm$^{-1}$). It is a well known organic semiconductor with p-type conduction. The conduction in this material mainly arises from the relative distribution of carrier traps. These phthalocyanines when combined with materials having high electron affinity, such as C$_{60}$ or perylene derivative, lead to an efficient photo induced charge transfer process thus leading to a photocurrent. It is expected that the fullerenes C$_{60}$ and C$_{70}$ exhibit remarkably different performances when used as active channel layers for thin film transistors. This is due to the structural modification in fullerene C$_{70}$ route or the bilayer structure for the realization of organic solar cells. In the bulk heterojunction solar cells, the active layer is a blend of electron donor and electron acceptor materials. On the other hand, bilayer heterojunction comprises of active layers of electron acceptor layers on top of an electron donor layers. Such a bilayer structure has been demonstrated by Tang et a which is slightly elongated compared to C$_{60}$. Hence, as an n-type counterpart we have used C$_{70}$ which offers a much higher absorption compared to conventional C$_{60}$. Hence, in this article, we report on photovoltaic properties of an efficient solar cell based on bilayer structures of polycrystalline CuPc as donor and C$_{70}$ as an acceptor. The thickness dependence of individual layers on the performance of the devices is also discussed. The device structure used in the present investigation and the corresponding energy level diagram of the materials is shown in figure 1.

RESULTS AND DISCUSSION

Figure 1 shows the device structure and the corresponding energy levels of the active layer components. It has been widely accepted that the open
circuit voltage (Voc) can be directly correlated to the difference between the HOMO level of the donor and the LUMO level of the acceptor [3]. However, due to morphological changes of the active layers, in practical cases, the observed Voc will be slightly lower than the ideal values. Such a phenomena was also observed in our case wherein a Voc of 0.48 V was obtained, which corresponds to a slight deviation from the difference between HOMO energy level of CuPc and LUMO energy level of C70. Electrical characteristics of a device with a geometry of ITO/PEDOT:PSS/CuPc/C70/Al are presented in Figure 2. In the case of bilayer structures it is believed that the CuPc molecules allow the hole transport and the asymmetric C70 molecules form a percolation path for the transport of electrons to the cathode. Dependence of short circuit current and other solar cell parameters such as Voc, FF are analyzed as function of CuPc thickness and the data are presented in Figure 2. It was found that the CuPc thickness is a major factor determining the short circuit current density of the device. And there was an increase in Jsc from 0.6 to 6.5 mA/cm² as the thickness of CuPc increased from 7.5 nm to 40 nm. It is also possible that at lower thicknesses the charge transport between the hole and electron transport layers is highly unbalanced leading to poor device performances. With increase in thickness of the CuPc, the grains tend to grow, resulting in better crystallinity as well as improved mobilities.

**FIGURE 1:** (a) Bilayer device structure and (b) corresponding energy levels

It has been observed that under the illumination of AM 1.5 radiation, the devices exhibited a maximum current density of 6.5 mA/cm², an open circuit voltage of 0.48 V, and a fill factor of 0.48. Overall it resulted in a power conversion efficiency of 1.47 % for the active layer thicknesses of 40 nm each for CuPc and C70. It is also worth noting that the thickness of C70 was varied and the optimized thickness was found to be 40 nm. For comparison, devices were also fabricated with CuPc and C60 and PCE of 0.41% was resulted with a current density of 1.8 mA/cm².

The absorbance of the bilayer active layer films were measured by a UV-VIS spectrophotometer in the wavelength range 300 to 800 nm. Figure 3 shows the absorption spectra of the active layers with different thicknesses of CuPc (15 to 50 nm) for a fixed thickness of C70 (40 nm). It is well known that the absorption edge of CuPc is around 600 nm and from the figure it is observed that the absorption around this wavelength and beyond 600 nm increase with increase in CuPc thickness, which intern favors carrier absorption in these wavelength regimes. Such increased carrier absorptions lead to the increase in the short current densities as shown in Figure 2.

**FIGURE 2:** (a) Device parameter variation with thickness of CuPc and (b) corresponding I-V characteristics under illumination.

**FIGURE 3:** Absorption spectra of the bilayers of CuPc and C70 at different CuPc thicknesses.

We have demonstrated a bilayer solar cell structure ITO/PEDOT:PSS/CuPc/C70/Al. It was found that the optimized CuPc thickness for the 1.47 % solar cell was 40 nm. Further improvement in the conversion efficiency could be achieved by inserting cathode materials of lower work functions and efforts are underway in that direction.

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**REFERENCES**
