Nanocrystal growth and improved performance of small molecule bulk heterojunction solar cells

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1. Introduction

To enhance the performance of organic photovoltaic (OPV) cells, preparation of organic nm-sized pillar arrays is fascinating since significantly large area of a donor/acceptor heterointerface having continuous conduction path to both anode and cathode electrodes can be realized. In this study, we grew phthalocyanine crystalline nanopillar arrays. We optimized the pillar density by tuning crystal growth condition in order to apply it to OPV cells. Improved performance from organic bulk heterojunction (BHJ) solar cells composed of a blend of phthalocyanine and fullerene is demonstrated. We found that the parallel growth of π-stacked nanocrystals of phthalocyaiane resulted in high OSC performance and a high power conversion efficiency of 4.1 % was obtained.

2. Result and Discussion

Since a thin-film organic solar cell (OSC) composed of a single donor-acceptor heterojunction with a power conversion efficiency (η) of 0.95% was reported by Tang in 1986,[i] organic photovoltaics have attracted considerable attention on account of their potential for low-cost solar energy conversion. Substantial research has been devoted to improving the characteristics of OSCs. Particularly in the last few decades, rapid advances have been made in the performance of OSCs with, e.g., the development of bulk heterojunction (BHJ) structures.[ii iii]

Recently, Li and Forrest[iv] demonstrated that amorphous chloroaluminum phthalocyanine (ClAlPc) is a promising donor for BHJ configurations. The ionization potential of solid ClAlPc is moderately high, and the highest occupied molecular orbital (HOMO) level lies at about -5.4 eV relative to the vacuum level,[v] which is an advantage for achieving a high open-circuit voltage (V_{OC}) in OSCs. On the other hand, Pfuetzner *et al.* used an attractive blend of the acceptor C_{70} with zinc phthalocyanine (ZnPc) in BHJ structures.[vi] Due to the superior absorption properties of C_{70} compared to those of the conventional fullerene C_{60}, a fairly high η of 2.87% was achieved for the ZnPc:C_{70} BHJ cell. Pfuetzner *et al.* have also reported that the performance of ZnPc:C_{60} BHJ cells improved when they were prepared at high substrate temperatures.[vii] These previous reports provide us with beneficial insights for the development of small molecule-based OSCs.

In this study, the performance of BHJ cells composed of a blended layer of ClAlPc and C_{70} that takes advantage of the superior electronic and optical characteristics of ClAlPc and C_{70} was investigated. Substantial improvements in η, the fill factor (FF) and the short-circuit current density (J_{SC}), are observed for BHJ cells containing ClAlPc and C_{70} that were prepared at higher temperature. X-ray diffraction (XRD) and atomic force microscopy (AFM) analyses provide evidence of a gradual transition of the phase of ClAlPc changing from amorphous to a π-stacked form as the substrate temperature is increased during BHJ deposition. The correlation of the nanostructural changes in the blended layer with the markedly improved OSC performance is discussed.

The growth of π-stacked ClAlPc nanocrystals occurs in ClAlPc:C_{70} BHJ layers deposited at high temperatures, which facilitates percolative transport of charge carriers. By *in situ* heating of the substrate up to 390K during blend deposition, the FF and J_{SC} of the resulting BHJ cells are increased significantly. Accordingly, a highly improved η of 4.1 % (on average 3.9 %) is obtained, which is over 32 % higher than that of the BHJ cell produced at room temperature. These results indicate that the performance of thin-film OSCs can be enhanced by appropriate control of molecular structural order.

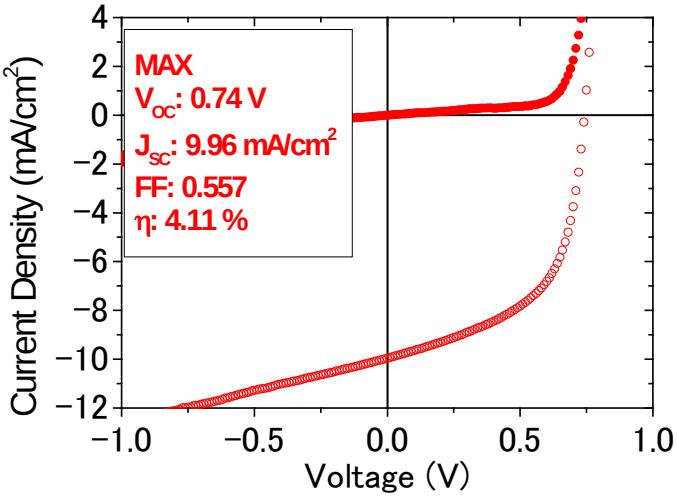

FIG1. OSC characteristics of ClAlPc/C_{70} based device

3. References

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