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## Ambipolar Carrier Transport of Discotic Liquid Crystalline Phthalocyanine and Its Application for Solar Cells

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Liquid crystalline organic semiconductor is one of the promising materials for electronic device applications, because of the potentially high carrier mobility comparable to that of a-Si ( $0.1 \text{ cm}^2/\text{Vs}$ ). In this paper, we report on a non-peripherally alkyl-substituted phthalocyanine homologue (Fig.1), such as, 1,4,8,11,15,18,22,25-octahexylphthalocyanine ( $\text{C}_6\text{PcH}_2$ ) exhibiting ambipolar characteristics with high drift mobility in both columnar mesogenic and crystalline phases and its application for organic thin-film type solar cells.

$\text{C}_6\text{PcH}_2$  is a low-molecular-weight organic semiconductor and has high solubility for typical organic solvents due to the long substituents.  $\text{C}_6\text{PcH}_2$  exhibits liquid crystalline phase, such as, hexagonal disordered columnar mesophase between 161 and 170 °C.

The carrier drift mobilities estimated by a time-of-flight (TOF) technique in the hexagonal columnar ( $\text{Col}_{\text{hd}}$ ) phase were c.a.  $0.2 \text{ cm}^2/\text{Vs}$  (hole) and c.a.  $0.3 \text{ cm}^2/\text{Vs}$  (electron). The higher mobility in excess of  $1 \text{ cm}^2/\text{Vs}$  could be

observed in the crystalline phase<sup>1</sup>. These values of carrier mobility are independent of the applied field and increased with decreasing temperature. These high carrier mobilities in both  $\text{Col}_{\text{hd}}$  and crystalline phases were measured even in non-homeotropic alignment films, in which the columnar axis is perpendicular to the field direction. This indicates that carriers could be preferably transported along the lateral axis of column and suggests the possibility of new molecular design for the liquid crystalline semiconductor<sup>2</sup>.

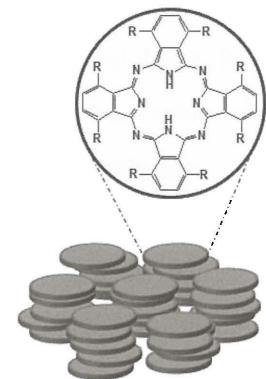


Fig. 1 Molecular structure of phthalocyanine derivative used in this study and its columnar structure.

Organic thin-film solar cells based on a bulk hetero-junction utilizing C<sub>6</sub>PcH<sub>2</sub>, have also been studied.

The blend uniform thin film with the C<sub>6</sub>PcH<sub>2</sub> and 1-(3-methoxy-carbonyl)-propyl-1-1-phenyl-(6,6)C<sub>61</sub> (PCBM) could be fabricated by a spin-coating method. Solar cells with C<sub>6</sub>PcH<sub>2</sub>:PCBM bulk hetero-junction active layer have demonstrated a high external quantum efficiency above 70% in the Q-band absorption region of C<sub>6</sub>PcH<sub>2</sub> as shown in Fig. 2 and a high energy conversion efficiency of 3.1%<sup>3</sup>.

The photovoltaic properties of the solar cell with bulk heterojunction of C<sub>6</sub>PcH<sub>2</sub> and PCBM demonstrated the strong dependence of active layer thickness, and the optimized active layer thickness was clarified to be 120 nm. By inserting MoO<sub>3</sub> hole transport buffer layer between the positive electrode and active layer, the FF and energy conversion efficiency were improved to be 0.50 and 3.2%, respectively<sup>4</sup>. The tandem organic thin-film solar cell has also been studied by utilizing active layer materials of C<sub>6</sub>PcH<sub>2</sub> and poly(3-hexylthiophene) and the interlayer of LiF/Al/MoO<sub>3</sub> structure, and a high  $V_{oc}$  of 1.27 V has been achieved<sup>4</sup>.

C<sub>6</sub>PcH<sub>2</sub> is available as a dopant for conventional organic thin-film solar cells with an bulk hetero-junction active layer composed of poly(3-hexylthiophene) (P3HT) and PCBM. The improvement of long-wavelength sensitivity in P3HT:PCBM bulk hetero-junction solar cells by doping C<sub>6</sub>PcH<sub>2</sub> has been succeeded<sup>5</sup>.

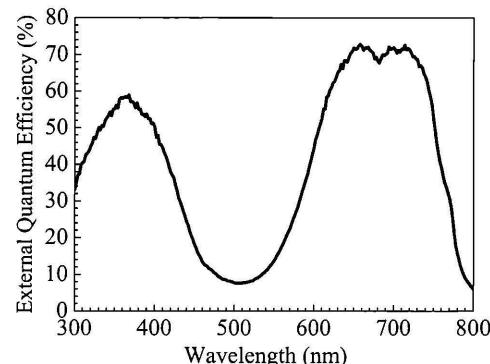


Fig. 2 EQE spectra of the solar cell with structure of ITO/PEDOT:PSS/ C<sub>6</sub>PcH<sub>2</sub> : PCBM/ Al, the composite ratio of which is 2 : 1 in weight.

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