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# Enhancement of Light-Harvesting Efficiency in Polymer/ZnO Hybrid Solar Cells by Incorporating Near-IR Dyes

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Hybrid solar cells based on blends of an organic semiconductor and an inorganic semiconductor, such as Si, CdSe, ZnO, and $TiO_2$, have recently become of great interest as an alternative to purely organic solar cells, because they can combine both advantages of the organic and inorganic materials: large absorption coefficients, inexpensive, flexible, and high-throughput productivity for organic materials, and a high carrier mobility, high chemical and physical stability, and a high dielectric constant for inorganic materials. In particular, ZnO is an attractive candidate among various inorganic materials for application of hybrid solar cells, because it has several advantages of high electron mobility and dielectric constant, nontoxic, low-cost, and easy of synthesis by using a variety of techniques. However, the power conversion efficiency (PCE) is still as low as 2–3%. For further improvement in the performance of hybrid solar cells, of particular importance is the enhancement in the light-harvesting efficiency.

In this study, we have studied dye sensitization in hybrid solar cells based on ternary blends of poly(3-hexylthiophene) (P3HT), ZnO and silicon phthalocyanine bis(trihexylsilyl oxide) (SiPc), which can absorb more photons in the near-IR region that P3HT and ZnO cannot harvest. As shown in Figure 1, the short-circuit current density ($J_{SC}$) increased from 2.2 mA $cm^{-2}$ for P3HT/ZnO binary blends without dye to 3.6 mA $cm^{-2}$ for P3HT/ZnO/SiPc ternary blends with a dye fraction of 7 wt%, and then decreased above a dye fraction of 9 wt%. On the other hand, the open-circuit voltage and fill factor were rather independent of the dye fraction up to 9 wt%. As a result, the PCE was improved by a factor of 40%.

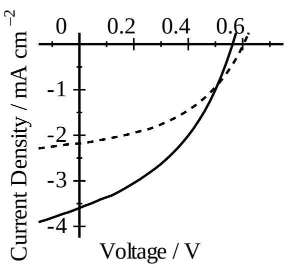


**Figure 1.** *J*–*V* characteristics of ternary hybrid solar cells with a layered structure of ITO|PEDOT:PSS|P3HT/ZnO/SiPc|Al.

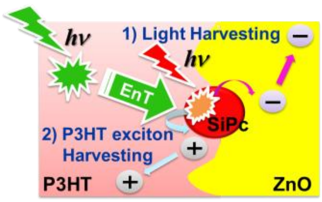


**Figure 2.** Schematic illustration of the light-harvesting and the exciton-harvesting mechanisms in ternary hybrid solar cells.

There are two pathways for the improvement in $J_{SC}$ by incorporation of SiPc. As shown in Figure 2, the first is that SiPc molecules serve as effective photosensitizers, giving rise to the increase in the photocurrent and the second is that SiPc molecules located at the interface of P3HT/ZnO can harvest P3HT excitons by energy transfer because of the large spectral overlap between P3HT emission and SiPc absorption, leading to the enhanced photocurrent generation. Our finding will provide a new approach to developing highly efficient polymer/inorganic hybrid solar cells with dye sensitization.