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高分子太陽能電池元件光吸收增益之探討

Light Harvesting Schemes for Improving the Performance of Polymer Solar Cells

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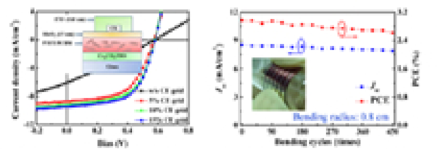
研究重點

本研究論文著重於有機高分子太陽能電池元件 (Organic photovoltaics, OPVs)光吸收增益之探討，其主動層材料為poly(3-hexyl thiophene) (P3HT)及[6,6]-phenyl C_{61}-butyric acid methyl ester (PCBM)，透過光學結構設計及奈米光學的應用，提升元件內太陽光的吸收，進而提升太陽能電池的元件效率。此外，本論文也探討有機材料電荷轉移能態 (Charge transfer states)的光學特性，其可吸收長波長的光子，有助於延伸有機太陽能電池元件對太陽光譜的吸收範圍。同時，本研究也衍生發展出可撓曲元件及具生物醫療功能之近紅外光雷射驅動 (Near-infrared laser-driven, NIRLD)有機太陽能電池元件。

研究成果

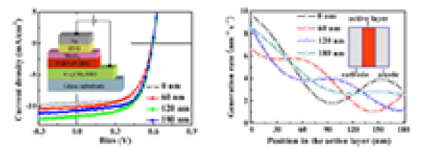
首先，我們開發出高效能的半透明有機高分子太陽能電池元件，此可應用在堆疊式或串接式的元件結構，使其可吸收更廣泛的太陽放射光譜，進而提升元件的功率轉換效率。我們進一步利用此透明電極的結構，發展出高效率的上照光有機太陽能電池元件，並完成以金屬薄片為基板的可撓曲太陽能電池元件。另外，我們利用銦錫氧化物 (Indium tin oxide, ITO)作為光學間隔層 (Optical spacer)，藉由光學干涉效應調整元件內光場的分佈，在適當的光學間隔層厚度條件下，可以產生有利於提升元件光電流的激子分佈狀態，減少激子在電極界面的消散效應，並增加有效激子的數目，進而提升倒置式有機太陽能電池的元件功率轉換效率。同時，我們利用了表面電漿子 (Surface plasmons)的特殊光學特性來提升有機太陽能電池的元件效率，在陽極緩衝層內加入金奈米粒子激發侷域性表面電漿共振，此現象可在金屬奈米粒子周圍產生局部電場增益，使得元件內的激子產生率及激子分離率上升，進而增加有機太陽能電池元件的光電流及填充係數。最後，我們探討了電荷轉移能態的光學特性，此能態存在於P型/N型異質界面結構中，具有吸收長波長的光子的特性，有助於延伸有機太陽能電池元件對太陽光譜的吸收。據此，我們也成功發展出以近紅外光雷射驅動之有機太陽能電池元件，可以有效地將980 nm雷射光轉換成電能，由於生物組織對於980 nm近紅外光具有高透光性，可將此元件置於人體組織內作為具生物醫療功能性的奈米元件之無線電源，同時此應用也為有機太陽能電池領域開創一個新的研究方向。

Semi-Transparent OPVs



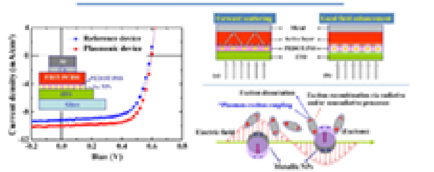
We demonstrated inverted semi-transparent OPVs, in which the hole and electron carriers were collected by the top (MoO_3/ITO) and bottom (ITO/Cs_2CO_3) electrodes. Incorporating Al counter electrode (CE) grids effectively reduced the device resistance, thereby enhancing the power conversion efficiency (PCE). The OPV containing an Al CE grid with a shadow fraction of 15% exhibited high transparency (up to 73%) and remarkable PCEs (3.3%). Based on this top electrode configuration, we further realized flexible OPVs on metal foils. These OPVs exhibited excellent PCEs (ca. 3%) in conjunction with superior mechanical flexibility and device air stability.

Interference-Enhanced OPVs



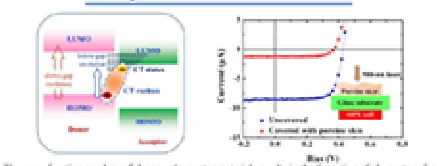
We used ITO, a transparent conducting oxide, as an optical spacer to improve the performance of inverted polymer solar cells. The optical interference effect resulted in spatial redistribution of the optical electric field in the devices. Although the degree of light absorption in inverted cells was not increased, the resulting favorable distribution of photo-generated excitons probably decreased the level of exciton quenching near the electrodes. As a result, the introduction of the ITO optical spacer at an appropriate thickness increased the short-circuit current density and the overall device efficiency.

Plasmonic-Enhanced OPVs



We explored the effect of gold nanoparticle (Au NPs)-induced surface plasmons on the performance of OPVs. The overall device efficiency of these OPVs was improved after blending the Au NPs into the anodic buffer layer. The addition of Au NPs increased the rate of exciton generation and the probability of exciton dissociation, thereby enhancing the short-circuit current density and the fill factor. We attributed the improvement in device performance to the local enhancement of the electromagnetic field originating from the excitation of the localized surface plasmon resonance.

Charge Transfer States in OPVs



The wave function overlaps of donor and acceptor materials results in the formation of charge transfer (CT) states, which can harvest long-wavelength photons. Direct excitation through CT states might open up new avenues for harvesting the long-wavelength spectrum of solar irradiation. We therefore investigated the photophysical properties of CT excitons in P3HT/PCBM blends. We also used the P3HT/PCBM OPVs converting 980-nm light into electrical power. Because of the high transparency of biological tissue toward 980-nm light, these near-infrared laser-driven (NIRLD) OPVs might be a promising wireless electrical source for biological nanodevices for use within the human body.

研究生活與心得

學生在交通大學光電研究所博士班就讀期間，致力於有機薄膜太陽能電池的研究，研究重點著重在有機太陽電池元件內光吸收增益的方案設計，並於2010年獲得國科會三明治計畫獎學金補助，前往德國馬克斯普朗克固態研究所進修，從事奈米電漿光學於光電元件應用的研究，在此機構學習最尖端的科學新知，期勉自己成為優秀的研發人才。

很榮幸研究成果獲得『中技社科技論文獎』的肯定，此殊榮使我對往後的研究工作更具信心與熱情，並期許自己能在綠能產業的研發工作上做出最大的貢獻。獲得此殊榮，首先感謝我的指導教授陳方中博士對我不斷的指導與鼓勵，以及實驗室夥伴們的協助與貢獻。最後感謝我的家人在我求學過程中的陪伴與支持，使我可以無後顧之憂地投入在研究工作上，此榮耀屬於您們。

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