

Photoluminescence and Electroluminescence of Organic Solar Cells

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Introduction

Organic solar cells are promising candidates for utilising solar energy due to their adjustable chemical structure and ease of processing for large area photovoltaic panels.^{1,2} Based on organic semiconductors commonly in organic/polymer blends with band-gap from 1.4 eV to 3 eV,¹ these materials absorb a small fraction of the solar spectrum. One approach to overcome this limitation is by stacking cells of different band-gaps in tandem. However, new materials and devices with a narrower band-gap require careful design,^{2,3} and understanding the diffusion dynamics is required to enhance the efficiency of the solar cells. Development of new and efficient organic devices has also been limited due to poor stability even after the encapsulation to protect from oxidation.⁴ In this note, the extensively studied blend Poly(3-hexyl)thiophene-2,5-diyl: [6,6]-phenyl C₆₁ butyric acid methyl ester (P3HT: PCBM) is characterised via steady-state and time-resolved spectroscopy.

Methods and Materials

Photoluminescence excitation, emission and electroluminescence spectra were measured using an FLS980 Fluorescence Spectrometer equipped with a 450 W Xe lamp and double excitation and emission monochromators. Gratings blazed at 250 nm and 750 nm were used on the excitation and emission arms, respectively. Higher diffraction orders were filtered by the integrated long wave-pass filters in the FLS980. A photomultiplier tube detector (PMT-980) and an NIR-PMT (PMT-1700) were used.

For time-resolved measurements, a picosecond pulsed diode laser (EPL-445) and a Ti-Sapphire laser (Coherent Verdi G10, 10W and Mira 900, 200 fs, 76 MHz) were used. The Ti-Sapphire output was passed through a pulse picker resulting in repetition rate of 4.75 MHz and then frequency doubled to provide excitation at 445 nm. The fluorescence emission was detected by a micro-channel plate PMT detector (MCP-PMT). All three required detectors were simultaneously fitted in the ports available in the FLS980.

Poly(3-hexyl)thiophene-2,5-diyl (P3HT) and [6,6]-phenyl C₆₁ butyric acid methyl ester (PCBM) in 1:1 were dissolved in o-dichlorobenzene (Sigma-Aldrich, 240598) in a 17 mg/ml solution and stirred for 12 h at 50°C.⁵ This solvent was used due to its high boiling point at 180°C to assist structural ordering upon drying and further improve charge transport.⁶

The solution was spin-coated on quartz discs for 30 s at 1000 rpm, left for 2 h to cool down in a culture dish and finally annealed at 150°C for 10 min. To prevent exposure to air, the coated films were encapsulated with UV-cured epoxy on a quartz slide. The solution preparation, spin coating, annealing of the samples and encapsulation were done inside the glovebox at 0.1 ppm H₂O and O₂.

Results - Discussion

Figure 1 displays the normalised excitation and emission spectra of the air-exposed and encapsulated P3HT: PCBM samples. The emission spectra are similar before and after encapsulation with peaks at 720 nm. However, the excitation spectra of the air-exposed sample monitored at 720 nm, display the main peak at 600 nm and a shoulder around 450 nm, as well as additional peaks at 220 nm and 280 nm for the encapsulated sample originating from the epoxy used. The excitation spectra agree with absorbance spectra with absorption from PCBM from 200 nm-400 nm and at 400 nm-600 nm from P3HT.^{7,8}

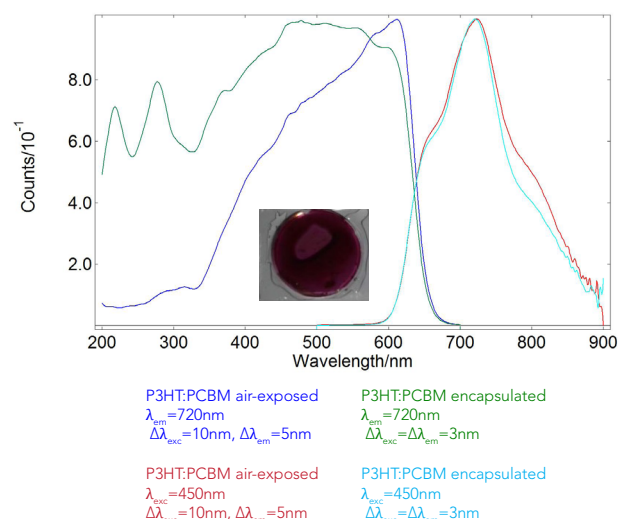


Figure 1: Excitation and emission spectra of air-exposed and encapsulated P3HT: PCBM solar cells. The inset displays a photo of the encapsulated solar cell.

The fluorescence decays of the P3HT: PCBM samples are shown in Figure 2. The decay of the air-exposed sample was fitted in a single exponential of lifetime 46.84 ps which is significantly lower than the encapsulated sample with 647.20 ps. The lifetime of the encapsulated sample agrees with this of pristine P3HT,^{3,9} which indicates that in this sample the polymer has not been quenched by PCBM.

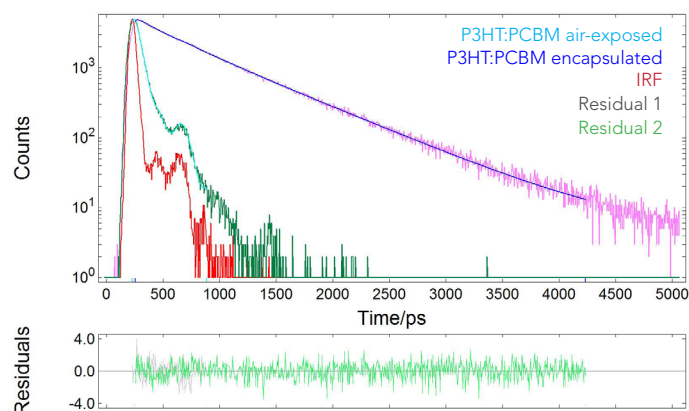


Figure 2: Fluorescence decays of air-exposed and encapsulated P3HT: PCBM solar cells.

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The normalised electroluminescence (EL) spectra of the encapsulated sample at different driving currents are shown in Figure 3. A blue-shift of the spectrum is observed for increasing injection current, associated with increased population of higher energy states.¹⁰

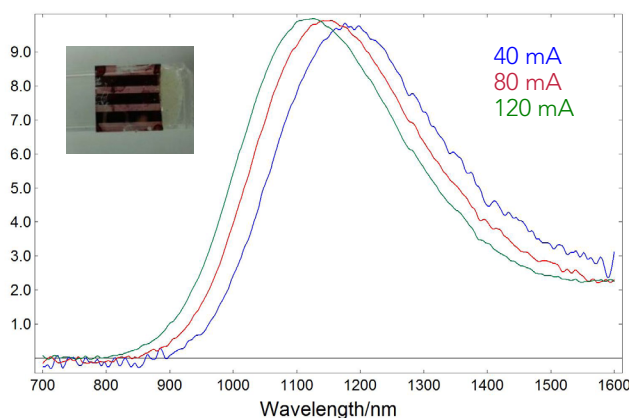


Figure 3: Electroluminescence spectra of encapsulated P3HT:PCBM device. In the inset, a photo of the encapsulated device is shown.

Conclusion

P3HT:PCBM solar cells have been characterised via photoluminescence and electroluminescence spectroscopy. The photoluminescence excitation spectra are in agreement with the absorption spectra. Time-resolved measurements in the picosecond range revealed the quenching state of the fullerene by the polymer, which is essential for the development of organic solar cells with new materials. In addition, a blue-shift of the electroluminescence spectrum is observed for increasing current injection.

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