

Polymers for New Energy Technologies: Organic Photovoltaics

Introduction

Photovoltaic cells, more commonly known as solar cells, are named after the chemical process of converting light into electricity. The use of photovoltaic (PV) materials is a promising solution to global energy needs. Currently, commercial solar cells use silicon or another inorganic semiconductor as the photoabsorber material. With these materials, power conversion efficiencies of ~18-22% for commercial cells and up to ~47% for research cells have been achieved.¹ However, inorganic solar cells face several challenges including high cost and difficulty of manufacturing, and a relatively brittle and fragile nature.

Due to these downsides, other PV materials are under investigation to achieve the goal of low-cost, lightweight, flexible solar cells. Organic photovoltaics (OPVs), which use polymers or small organic molecules for light absorption and charge transfer,² are the leading candidates. OPV polymers can be made from widely available, relatively eco-friendly raw materials and can be produced on large scales using simple techniques such as solution processing or vapor deposition. Moreover, their band gaps can be fine-tuned or tailored by molecular engineering (i.e., by changing length, functional groups, etc.).³

Organic solar cells face their own hurdles, including lower (but commercially viable) efficiencies of ~3-10% for commercial cells and ~18% as a record,¹ and performance instability and degradability due to environmental factors such as light and heat. Despite these issues, OPVs are expected to play a major role in the solar market due to their low cost. Current research is therefore largely focused on improving efficiency of OPV polymers.

Here we discuss how nanoscale characterization, specifically with the atomic force microscope (AFM), can aid in the improvement of organic photovoltaics (Figure 1).

Tailoring Morphology to Improve Efficiency

The polymer films used in organic solar cells are prepared by solution processing, whereby a polymer is first dissolved in solvent from which a film is created from the solution by spin coating, drop casting, doctor blading, or a similar method. Numerous variables in the preparation process are known to affect the

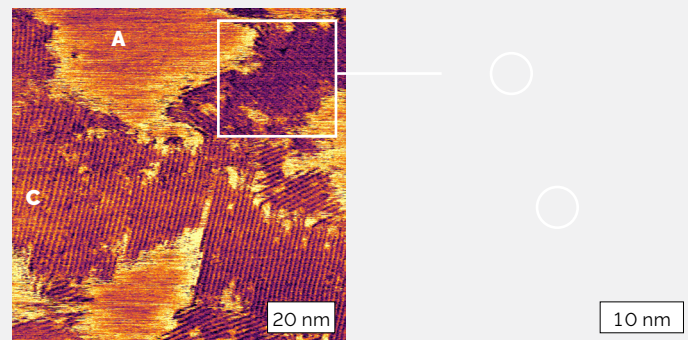


Figure 1: AFM images of polythiophene (ADS306PT) morphology reveal (left) crystalline (C) and amorphous (A) domains and (right) the regular chain structure of a crystalline region containing a few defects (circled). Images represent tapping-mode phase and were acquired on the Jupiter XR AFM in ambient conditions.

electronic properties and performance of the film produced. Elucidating how each variable affects the resulting film will enable better control of the fabrication process, leading to improved efficiency.

For example, the conjugated polymer poly(3-hexylthiophene) (P3HT) is a common donor material for OPV photoabsorber layers. P3HT assembles into nanofibers upon crystallization from solution, and the ease of assembly can be tuned by adjusting parameters such as molecular weight, regioregularity, and concentration. However, this tuning also impacts crystallization and thus efficiency: higher crystallinity is known to translate into higher charge carrier mobility, which in turn results in higher conversion efficiency. Therefore, a deeper understanding is needed of the crystallization process and what conditions affect its outcome. In this way, processes can be tailored to achieve the desired crystalline morphology and improve device performance.

AFMs enable virtually nondestructive characterization of polymer morphology with micro- and nanoscale spatial resolution. Most AFMs can evaluate larger morphological features such as phase segregation and domain size and shape, but only newer AFMs with the highest resolution and lowest noise can assess the local crystallinity of polymers.

The ambient conditions AFM images of drop casted Polythiophene (ADS306PT) shown in Figure 1 were acquired on Jupiter XR. Besides revealing molecular

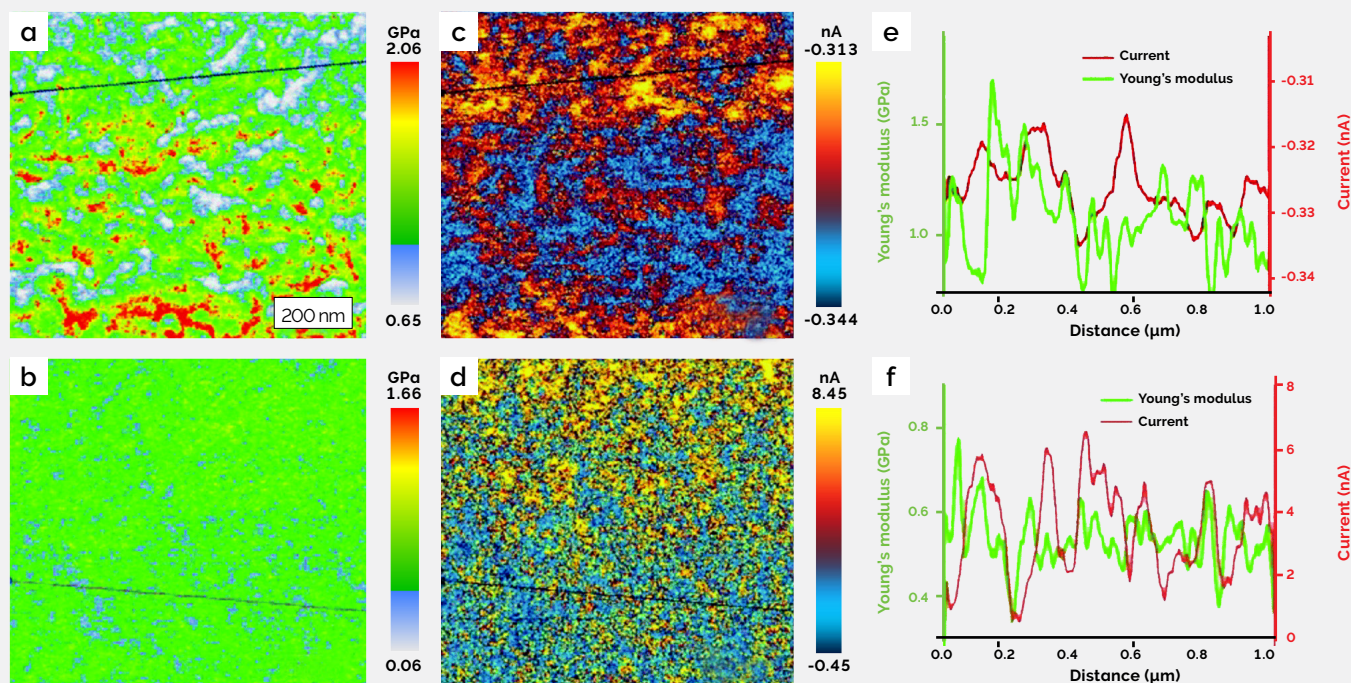


Figure 5: a) and b) Young's modulus maps for pristine and doped P3HT films, respectively. c) and d) Nanoscale maps of current for the same films, respectively. Acquired in Fast Current Mapping mode on the Cypher ES with the Dual Gain ORCA module. e) and f) Profiles corresponding to the black lines in images (a-d) enable comparison of mechanical and electrical response at the same sample position. The data shown are reused under fair use from the original article cited in Ref. 7.

contained both crystalline and amorphous regions. Further comparison of the modulus maps and their histograms, shown in Figures 4e and 4f, revealed that doping did not affect the modulus of amorphous regions. However, the lower modulus values observed in crystalline regions of doped films suggested that the dopants were mainly present in crystalline regions.

In addition, simultaneous mapping of film current, morphology, and modulus was performed and is shown in Figure 5. Maps of local current for pristine and doped films, shown in Figures 5c and d, indicated that doped films conducted about 30 times more current than undoped ones. The current maps were also compared to the co-localized modulus maps shown in Figures 5a and 5b. Line section profiles like those in Figures 5e and 5f revealed that higher current corresponded to higher modulus, suggesting higher conductivity in crystalline regions for both types of films.

Comparing the nanomechanical and nanoelectrical data to results obtained with other tools further confirmed these findings. Considering the entire body of data led to the conclusion that dopant sites were preferentially located in the crystalline domains, which exhibited higher conductivity. Results like these illustrate how correlating AFM measurements can

provide insight into tuning the electrical properties of conjugated polymer films on the nanoscale. In this way, they can help optimize polymeric materials to improve the efficiency of OPVs.

Summary

Polymer materials hold tremendous promise for many next-generation energy technologies including organic photovoltaics. Realizing a future of low-cost renewable energy based on OPVs, however, requires further research to enhance their efficiency. Asylum Research AFMs provide a wide range of valuable capabilities for this purpose. They can characterize structure down to molecular-chain level at speeds high enough to capture dynamic processes, in relevant environments such as organic solvents under perfusion. Moreover, Asylum Research AFMs can measure localized mechanical and electrical properties to help uncover relationships between structure, properties, and performance. These capabilities and more make AFM characterization an increasingly indispensable step for OPV research.

