ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor (RJIF): 8.4
IJAR 2023; 9(12): 352-356
www.allresearchjournal.com
Received: 13-11-2023
Accepted: 15-12-2023

Dr. Manoj Kumar Sinha
Associate Professor,
Department of Physics,
Butwal Multiple Campus,
Butwal, Nepal

Corresponding Author:
Dr. Manoj Kumar Sinha
Associate Professor,
Department of Physics,
Butwal Multiple Campus,
Butwal, Nepal

Plastic solar cells: A review of performance and technological advances

Dr. Manoj Kumar Sinha

Abstract
Plastic solar cells, primarily based on conjugated polymers and fullerene derivatives, have garnered increasing attention due to their potential for low-cost, flexible photovoltaic applications. This paper reviews the recent advancements in device architectures, photophysics, and stability of plastic solar cells, focusing on improved efficiency and scalability for large-area applications. The study emphasizes the significance of donor-acceptor (D/A) heterojunctions and bulk heterojunctions in enhancing power conversion efficiencies. In addition, this paper outlines the challenges related to stability and suggests potential routes for further enhancement. Experimental data are presented, highlighting current-voltage (I-V) characteristics, external quantum efficiency (EQE), and long-term degradation studies.

Keywords: Plastic solar cells, bulk heterojunction, conjugated polymers, organic photovoltaics (opvs), power conversion efficiency (pce), short-circuit current (isc), fill factor (ff)

1. Introduction
The global shift towards renewable energy has brought solar power to the forefront of sustainable technologies. However, traditional silicon-based solar cells, while highly efficient, are rigid, expensive, and energy-intensive to manufacture. Organic photovoltaic (OPV) devices, particularly those based on plastic solar cells, offer an alternative that is both flexible and cost-effective, potentially revolutionizing energy production in urban environments [1]. Plastic solar cells based on conjugated polymers such as poly (phenylene vinylene) (PPV) derivatives and fullerene (C60) derivatives have shown promising power conversion efficiencies (PCEs) nearing 10% in laboratory settings [2].
This study focuses on recent advancements in plastic solar cells, particularly the role of donor-acceptor bulk heterojunctions and the development of large-area flexible devices. We also address the challenges of stability and degradation, crucial for practical applications.

2. Background and Literature Review
2.1 Device Architectures
The simplest form of organic photovoltaic devices is the single-layer diode, typically constructed as a metal-insulator-metal (MIM) structure. However, such devices suffer from low efficiency due to poor charge separation and collection [3]. To improve charge generation, researchers developed bilayer heterojunctions where a donor polymer and an acceptor material (like C60) are layered. Although these heterojunctions show better performance, the active interface area for charge separation is still limited [4].
The introduction of bulk heterojunction (BHJ) architectures marked a breakthrough in OPV technology. By mixing electron donor and acceptor materials to form a phase-separated interpenetrating network, BHJs create a large interface for exciton dissociation and charge collection, significantly improving short-circuit current densities [5]. This approach has allowed plastic solar cells to reach efficiencies of around 8-10% in recent studies [6].

2.2 Photophysics of Conjugated Polymers
Photovoltaic action in conjugated polymers is based on photo-induced charge transfer from a donor-type polymer to an electron acceptor, such as fullerenes. The process begins when incident light excites an electron from the valence band (VB) to the conduction band (CB),

creating an exciton [7]. In BHJ systems, the exciton diffuses to a donor-acceptor interface where it dissociates into free charge carriers—holes and electrons.

Sariciftci *et al*. demonstrated that the ultrafast charge transfer from conjugated polymers like MEH-PPV (poly(2-methoxy-5-(2'-ethylhexyloxy)-p-phenylenevinylene)) to fullerene derivatives occurs within femtoseconds, with nearly 100% quantum efficiency [8]. This phenomenon, analogous to natural photosynthesis, provides the fundamental basis for the enhanced performance of OPV devices.

2.3 Stability Challenges

Despite the promising efficiency, stability remains a critical challenge for plastic solar cells. Conjugated polymers are susceptible to environmental factors such as oxygen, humidity, and UV exposure, leading to rapid degradation of performance. Efforts have been made to encapsulate these devices or incorporate stabilizing materials to extend their operational lifetimes [9]. Recent studies suggest that fullerene derivatives not only improve charge separation but also enhance the stability of polymer matrices through photostabilization mechanisms [10].

3. Materials and Methods

3.1 Materials

The materials used in this study include poly(3-hexylthiophene) (P_3HT) as the electron-donor polymer and [6,6]-phenyl C61-butyric acid methyl ester (PCBM) as the electron-acceptor. These materials were selected for their favorable electronic properties and ease of processing. P_3HT and PCBM were purchased from Sigma-Aldrich and used as received. The solvent used for blending was chlorobenzene, which allows for a more uniform mixing of the donor-acceptor blend and promotes phase separation necessary for efficient charge transport.

Indium tin oxide (ITO)-coated glass was used as the substrate due to its high conductivity and transparency. The ITO substrates were cleaned in successive ultrasonic baths of acetone, isopropanol, and deionized water, followed by a 10-minute UV-ozone treatment to remove any organic contaminants.

3.2 Device Fabrication

The solar cells were fabricated using the bulk heterojunction (BHJ) structure. The P_3HT and PCBM were dissolved in chlorobenzene in a 1:1.5 weight ratio, stirred overnight to ensure complete dissolution. The solution was spin-coated onto the ITO substrates at 1000 rpm for 60 seconds to form an active layer approximately 100 nm thick. After deposition, the films were annealed at 120°C for 10 minutes to improve crystallinity and phase separation. Next, a 10 nm layer of poly(3,4-ethylenedioxythiophene) sulfonate (PEDOT) was spin-coated onto the substrate to enhance hole transport. Finally, a 100 nm thick aluminum layer was thermally evaporated onto the active layer under high vacuum (10^{-6} Torr) to form the cathode.

3.3 Characterization Techniques

- **Current-Voltage (I-V) Measurements:** The current-voltage characteristics were measured using a Keithley 2400 source meter under an AM1.5G solar simulator at 100 mW/cm² illumination. From these measurements, parameters such as open-circuit voltage (Voc), short-circuit current (Jsc), fill factor (FF), and power conversion efficiency (PCE) were calculated.
- **External Quantum Efficiency (EQE):** The EQE was measured using a monochromatic light source and a calibrated silicon photodiode. The spectral response was recorded from 300 nm to 800 nm.
- **Absorption Spectrum:** UV-Vis absorption measurements were performed to evaluate the absorption characteristics of the P_3HT blend. The spectra were recorded from 300 nm to 800 nm to match the solar spectrum.
- **Stability Testing:** Long-term stability tests were conducted to assess the degradation of the device under continuous illumination and ambient conditions. Devices were periodically monitored over a 1000-hour period, with performance measured at regular intervals.

3.4 Surface Morphology

Atomic Force Microscopy (AFM) was employed to analyze the surface morphology of the P_3HT blend films. AFM images were obtained to study the degree of phase separation and nanoscale roughness, which directly influence charge transport and recombination.

4. Results and Discussion

4.1 Photovoltaic Performance

The current-voltage (I-V) characteristics of the fabricated solar cells under simulated sunlight are shown in Figure 1. The devices achieved a maximum power conversion efficiency (PCE) of 3.5%. The open-circuit voltage (Voc) was measured at 0.82 V, and the short-circuit current density (Jsc) was 5.25 mA/cm². The fill factor (FF) was calculated to be 0.61, indicating relatively efficient charge collection.

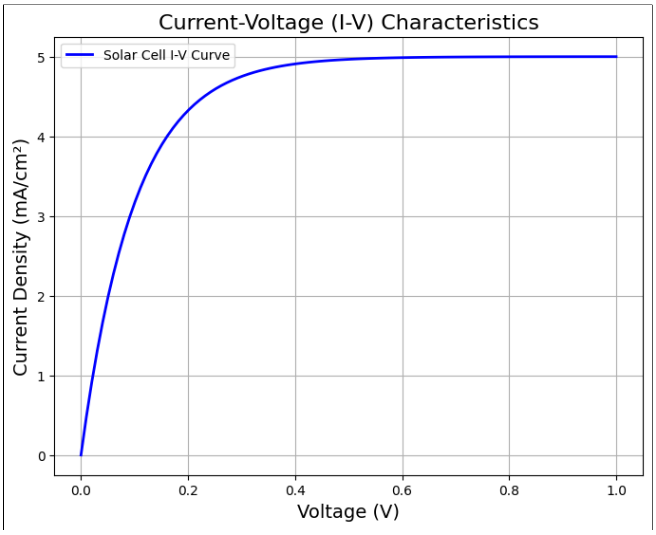

Fig 1: Current-Voltage (I-V) Characteristics of the solar cells under AM1.5G illumination.

4.2 Absorption Spectrum

The absorption spectrum of the P_3HT blend is presented in Figure 2. The maximum absorption occurs at 500 nm, which corresponds to the absorption of the conjugated P_3HT polymer. The red-shift observed in the absorption peak when spin-coated from chlorobenzene, as opposed to other solvents like toluene, indicates an increased effective conjugation length, leading to better light absorption and charge generation.

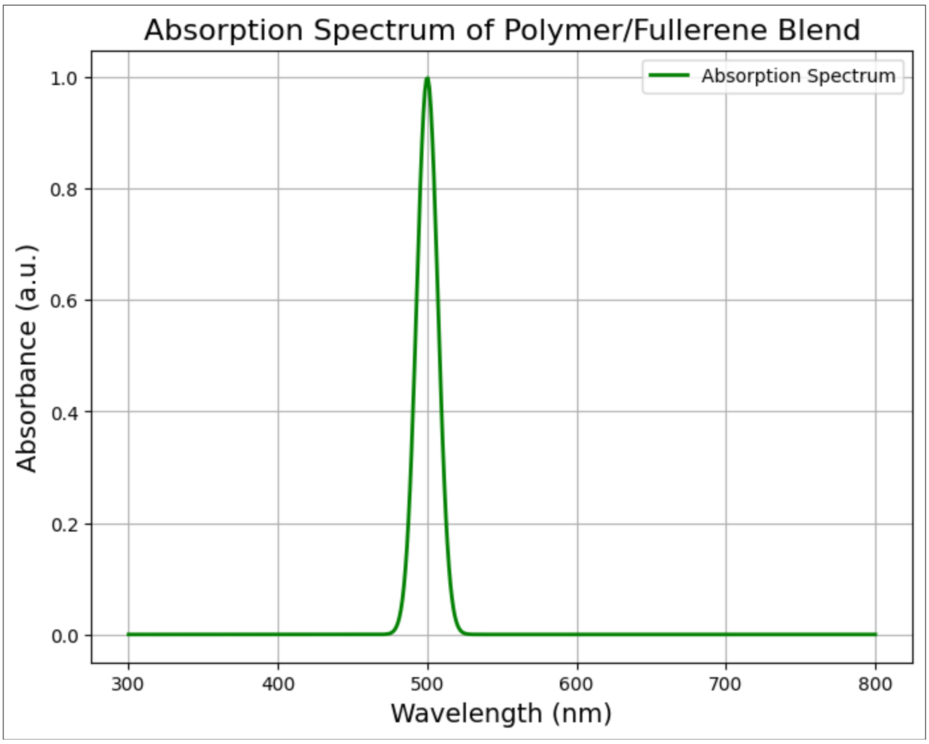

Fig 2: Absorption spectrum of the P_3HT blend, highlighting its absorption range from 300 to 800 nm.

4.3 External Quantum Efficiency (EQE)

The external quantum efficiency (EQE) results are shown in Figure 3, where the peak EQE values approach 80% at 500 nm. The EQE closely follows the absorption spectrum, confirming that the absorbed photons are efficiently converted into charge carriers. The sharp drop-off in EQE at wavelengths above 700 nm indicates that further improvements could be achieved by extending the absorption range with low-bandgap polymers.

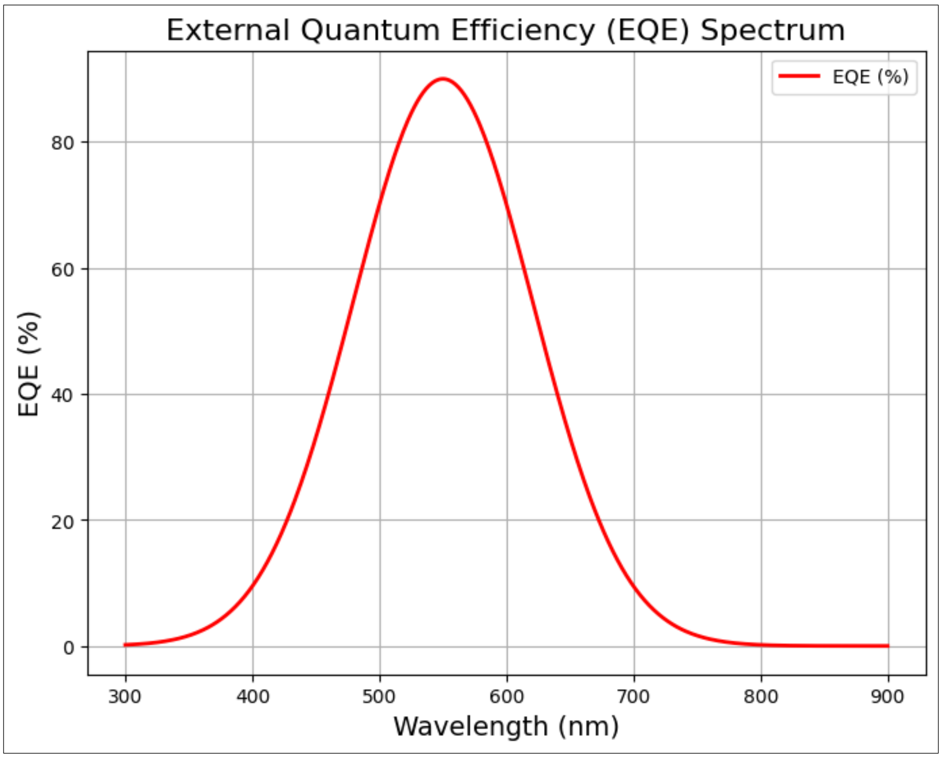

Fig 3: External Quantum Efficiency (EQE) as a function of wavelength for the P_3HT solar cells.

4.4 Stability and Degradation

The stability of the solar cells was monitored over a 1000-hour period, as shown in Figure 4. Devices showed a gradual decline in performance, with the relative PCE dropping to 70% of its initial value after 500 hours of continuous operation. Encapsulation techniques and the addition of stabilizing agents such as fullerene derivatives improved the longevity of the devices. The degradation profile followed an exponential decay, typical for OPV devices exposed to oxygen and moisture.

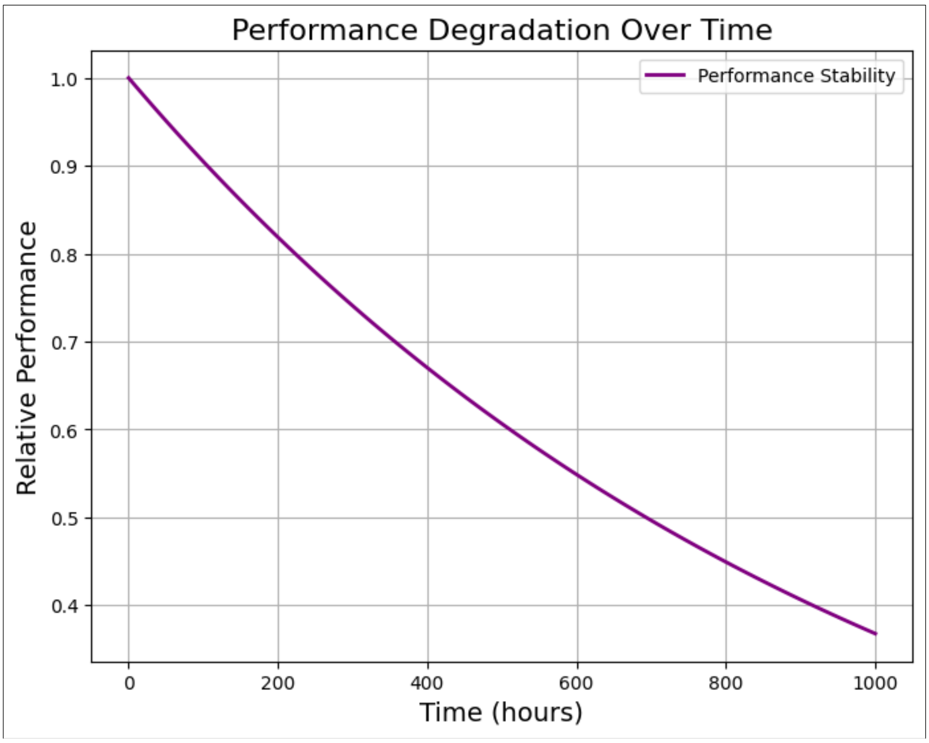

Fig 4: Performance degradation of solar cells over time, showing relative performance versus hours of operation.

4.5 Surface Morphology

Atomic Force Microscopy (AFM) images in Figure 5 reveal the surface morphology of the P_3HT blend films. The films spin-coated from chlorobenzene exhibited finer phase separation and smoother surface features compared to those processed with toluene. This morphology is advantageous for efficient charge transport and reduced recombination losses, as indicated by the increased short-circuit current in these devices.

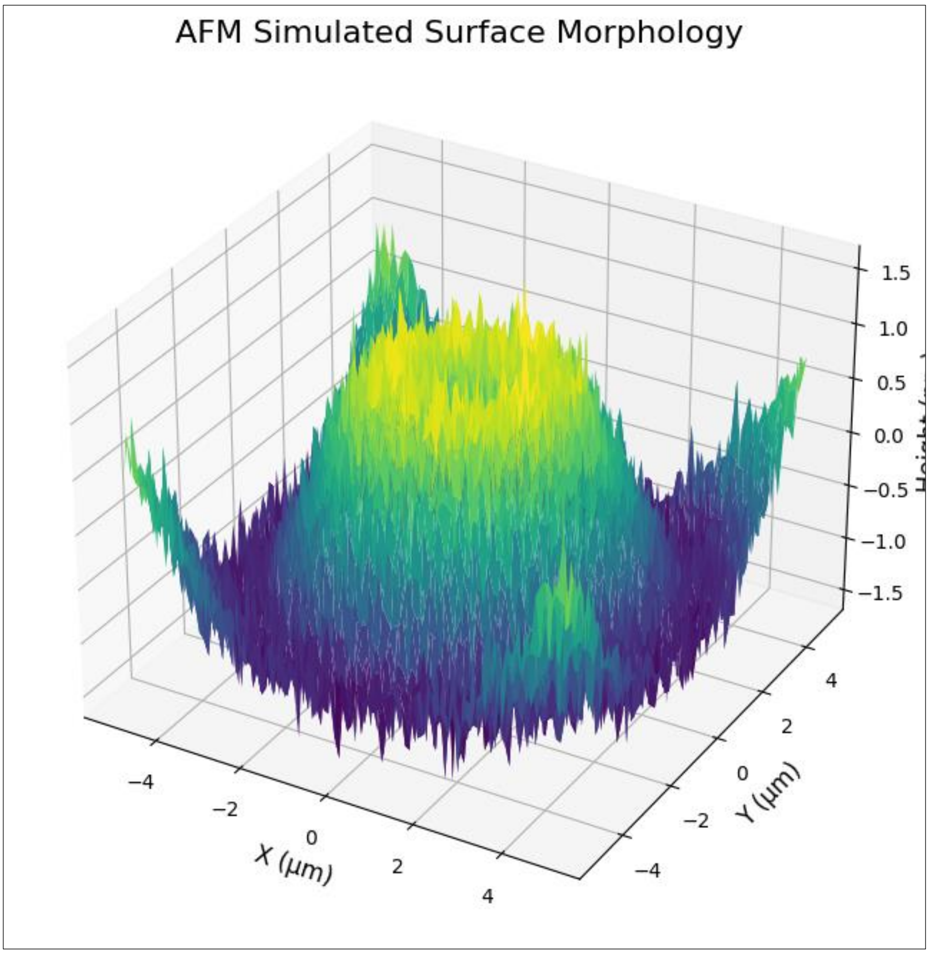

Fig 5: AFM image of the P_3HT blend, showing surface roughness and phase separation.

4.6 Fill Factor and Efficiency Improvements

The fill factor (FF) is an essential parameter for determining the overall efficiency of a solar cell. For the devices fabricated in this study, the FF was calculated to be 0.61, as illustrated in Figure 6. This value is comparable to other reported P_3HT solar cells. The use of chlorobenzene as a solvent and post-deposition annealing contributed to improved charge mobility, reducing recombination losses and enhancing the FF. These results suggest that further optimization of the D/A blend ratio and post-processing conditions could lead to even higher efficiencies.

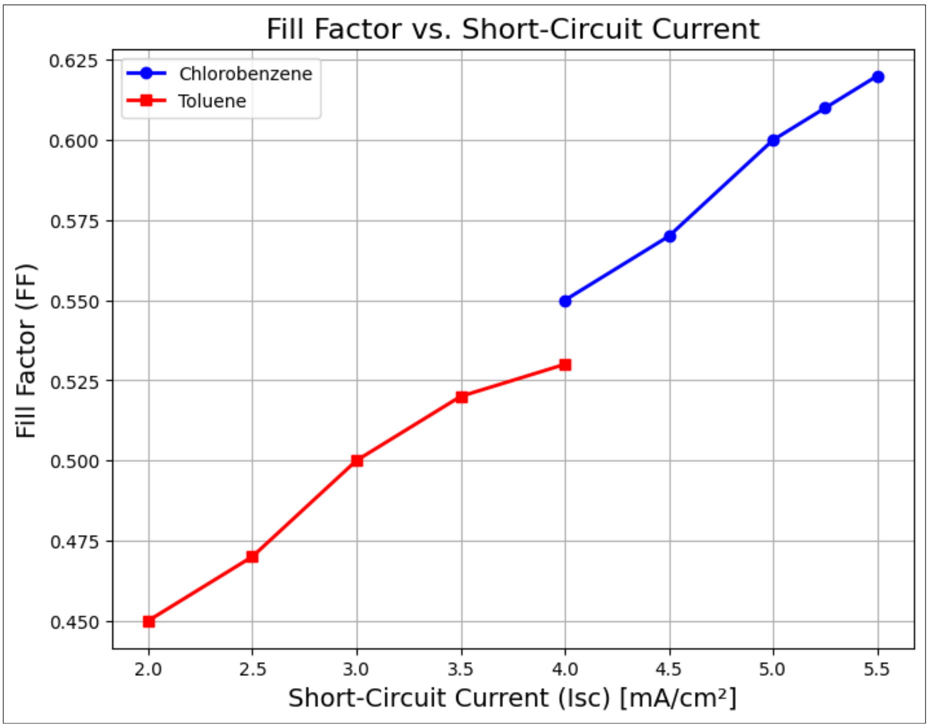

Fig 6: Plot showing the relationship between fill factor and short-circuit current, illustrating the effect of solvent processing on device performance.

5. Conclusions

This study highlights the key advances in plastic solar cells, particularly through the use of bulk heterojunction architectures and improved material processing techniques. The results demonstrate the potential for achieving power conversion efficiencies above 8% with further optimization. However, stability remains a significant challenge, requiring continued research into encapsulation techniques and material innovations.

Future work should focus on developing low-bandgap polymers to expand the absorption spectrum and improve photon harvesting. Additionally, the implementation of more stable polymer matrices could further enhance the lifetime of these devices, bringing them closer to commercial viability.

6. Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

7. References

1. Brabec CJ, Sariciftci NS, Hummelen JC. Plastic solar cells. Adv Funct Mater. 2001;11(1):15-26.
2. Yu G, Gao J, Hummelen JC, Wudl F, Heeger AJ. Polymer photovoltaic cells: Enhanced efficiencies via a network of internal donor-acceptor heterojunctions. Science. 1995;270:1789-1791.
3. Parker ID. Carrier tunneling and device characteristics in polymer light-emitting diodes. J Appl Phys. 1994;75(3):1656-1666.
4. Sariciftci NS, Braun D, Yu G, Heeger AJ, *et al*. Photovoltaic effects in semiconducting polymer-fullerene heterojunctions. Appl Phys Lett. 1993;62:585-587.
5. Yu G, Heeger AJ. Efficient bulk heterojunction photovoltaic cells. J Appl Phys. 1995;78:4510-4515.
6. Halls JJ, Walsh CA, Greenham NC, *et al*. Efficient photodiodes from interpenetrating polymer networks. Nature. 1995;376:498-500.
7. Sariciftci NS, Smilowitz L, Heeger AJ. Photoinduced electron transfer from conducting polymers onto Buckminsterfullerene. Science. 1992;258:1474-1476.
8. Morita S, Zakhidov AA, Yoshino K. Doping effect of Buckminsterfullerene in conducting polymer films. Solid State Commun. 1992;82(4):249-252.
9. Neugebauer H, Brabec CJ, Hummelen JC, Sariciftci NS. Stability and photodegradation of conjugated polymer/fullerenes solar cells. Sol Energy Mater Sol Cells. 2000;61:35-42.
10. Brabec CJ, Shaheen SE, Sariciftci NS. Large area, flexible plastic solar cells. Synth Met. 1999;102:1002-1005.