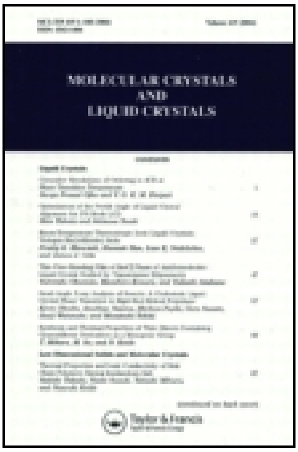

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Improvement of the Solar Efficiency of Polymer Solar Cells by using 1, 3, 5-Trichlorobenzene as Co-solvent

Viruntachar Kruefu [a d] , Chanitpa Khantha [b] , Pusit Pookmanee [c d] & Sukon Phanichphant [e]

[a] Program in Materials Science, Faculty of Science, Maejo University, Chiang Mai, Thailand

[b] Department of Chemistry, Faculty of Science, Chiang Mai University, Chiang Mai, Thailand

[c] Department of Chemistry, Faculty of Science, Maejo University, Chiang Mai, Thailand

[d] Nanoscience and Nanotechnology Research Laboratory (NNRL), Faculty of Science, Maejo University, Chiang Mai, Thailand

[e] Materials Science Research Center, Faculty of Science, Chiang Mai University, Chiang Mai, Thailand

Version of record first published: 12 Sep 2012.

To cite this article: Viruntachar Kruefu , Chanitpa Khantha , Pusit Pookmanee & Sukon Phanichphant (2012): Improvement of the Solar Efficiency of Polymer Solar Cells by using 1, 3, 5-Trichlorobenzene as Co-solvent, Molecular Crystals and Liquid Crystals, 566:1, 170-174

To link to this article: http://dx.doi.org/10.1080/15421406.2012.701919

Mol. Cryst. Liq. Cryst., Vol. 566: pp. 170–174, 2012
Copyright © Taylor & Francis Group, LLC
ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2012.701919

Improvement of the Solar Efficiency of Polymer Solar Cells by using 1, 3, 5-Trichlorobenzene as Co-solvent

VIRUNTACHAR KRUEFU,[1,4,*] CHANITPA KHANTHA,[2]
PUSIT POOKMANEE,[3,4] AND SUKON PHANICHPHANT[5]

[1]Program in Materials Science, Faculty of Science, Maejo University, Chiang Mai, Thailand
[2]Department of Chemistry, Faculty of Science, Chiang Mai University, Chiang Mai, Thailand
[3]Department of Chemistry, Faculty of Science, Maejo University, Chiang Mai, Thailand
[4]Nanoscience and Nanotechnology Research Laboratory (NNRL), Faculty of Science, Maejo University, Chiang Mai, Thailand
[5]Materials Science Research Center, Faculty of Science, Chiang Mai University, Chiang Mai, Thailand

Bulk-heterojunction (BHJ) solar cells utilizing P3HT:PCBM composite using 2.5, 3.5, 5.5 and 7.5 mg of 1, 3, 5-trichlorobenzene (TCB) as co-solvent were fabricated. The co-solvent method can induce a good quality of P3HT:PCBM thin film nanostructure, leading to enhanced absorption. With the optimized TCB quantity, the power conversion efficiency (PCE) achieved with the solar cell was up to 15% better than that attained by a similar device without the presence of TCB. The devices load with and without Niobium doped ZnO Nanoparticles (Nb/ZnO NPs) produced by flame spray pyrolysis (FSP) were also compared.

Keywords Nb-doped ZnO; 1, 3, 5-trichlorobenzene; polymer solar cells; flame spray pyrolysis

Introduction

Many research groups have developed solar cells based on P3HT and conjugated fullerene composites [1–3] and/or Nb/ZnO NPs [4–5]. Although much progress has been achieved, with several reported polymer solar cell devices providing power conversion efficiencies of 3−6%, there remains room for improvement. The types of solvent and the production of the active materials can also enhance the performance by improving the nanoscale morphology of the interpenetrating donor:acceptor materials [1]. The different device geometries and interface morphologies need to be evaluated for the purpose of trapping more light, dissociating excitons more efficiently and increasing electron mobility in conjugated polymers [1]. To the best of our knowledge, we investigated the effect of co solvent (TCB) adding (0–7.5 mg) on the morphology and performance of bulk heterojunction organic solar cells

---

[*]Corresponding Author to V. Kruefu, Tel.: +668 6 9203399. E-mail: v_viruntachar@hotmail.com

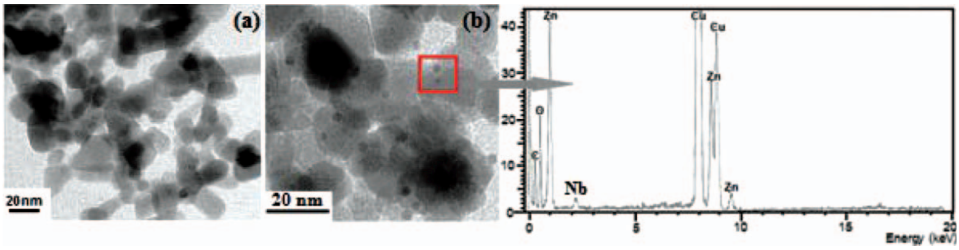

Figure 1. (a) TEM bright-field image of pure ZnO and (b) TEM bright-field image and EDS analysis of 3 mol% Nb/ZnO NPs.

made using the polymer (P3HT) blend with the fullerene (PCBM). Bulk heterojunction solar cells utilizing a P3HT:PCBM composite loaded with 3 mol% Nb/ZnO NPs by using TCB as co-solvent were also reported.

Experimental

Fabrication of our BHJ solar cells was reported in our previous work [4–5]. In this work, an PEDOT:PSS film was spin coated onto the ITO glass substrate, which was then dried in a vacuum oven at 100°C for 25 min. The blend solution of P3HT/PCBM ratio of 1.0:0.7 (wt/wt%); with 15 mg of P3HT blend 10.5 mg of PCBM [4–5] and TCB at 0, 2.5, 3.5, 5.5 and 7.5 mg in chlorobenzene 1 ml. The blend solution was spin coated on top of the PEDOT:PSS film. Finally, the substrates were transferred to a vacuum chamber to evaporate 1.5 nm of lithium fluoride and 100 nm of aluminum as top electrode. The active area of these devices is 0.28 +/− .04 cm^2. After completion, the devices were annealed for 7 min. at 150°C [5]. Nb/ZnO NPs containing 3 mol% Nb were synthesized by flame spray pyrolysis (FSP) [4] and were prepared in 1-butanol to achieve a concentration of 15 mg mL^{-1}. The last device was prepared by adding 30 vol% of 3 mol% Nb/ZnO solution [4–5] and TCB 5.5 mg to 1.0:0.7 (wt/wt%) P3HT:PCBM solution.

The Current-Voltage (*J*-*V*) characteristics of the produced devices were tested with a calibrated solar simulator with an intensity of 100 mW cm^{-2}. External Quantum Efficiency (EQE) measurements were performed using a Hitachi F-4500 fluorescence spectrophotometer with an AM 1.5 filters. The morphology of the films after annealing at 150°C for 7 min. were examined using atomic force microscope (AFM) system [5].

Results and Discussion

TEM bright-field image of FSP-made pure ZnO and 3 mol% Nb/ZnO NPs are shown in Figure 1. The ZnO particle sizes and morphology were spherical, hexagonal and rod-like. From the TEM studies, the average size of the hexagonal type of 3 mol% Nb/ZnO NPs was found to be 5–20 nm. EDS analysis of 3 mol% Nb/ZnO NPs to confirm the Nb deposited on ZnO support.

Figure 2 shows the *J*-*V* characteristics of P3HT:PCBM bulk-hetero junction solar cells blends with various TCB concentrations (mg). The best performance, with a short-circuit current density $J_{sc} = 9.51$ mA/cm^2, a fill factor FF = 0.539, an open-circuit voltage $V_{oc} = 0.682$ V and a resulting efficiency of 3.39%, could be reached for a cell blended with a TCB concentration of 5.5 mg/ml and annealed at 150°C for 7 min. This yielded a 15%

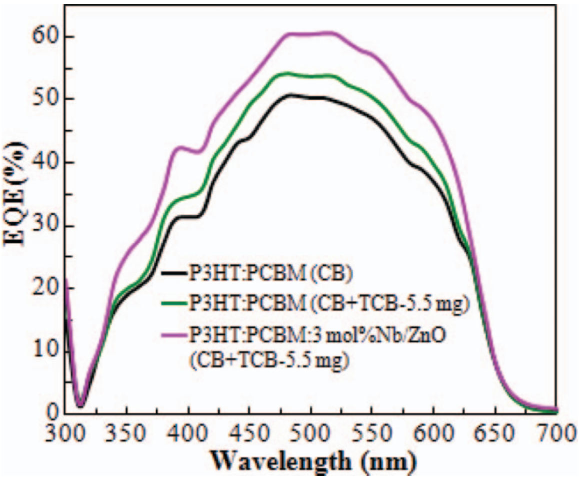

Figure 2. *J–V* characteristics of P3HT:PCBM bulk-hetero junction solar cells blends with various TCB concentrations and P3HT:PCBM:3 mol%Nb/ZnO blends with TCB at 5.5 mg.

improvement over the devices obtained under the same conditions but without the inclusion of TCB. The FF of all devices was within what would be expected for standard devices made with this P3HT and annealed for 7 min.

The *J-V* measurement of P3HT:PCBM:3 mol% Nb/ZnO blend with TCB at 5.5 mg was also shown in Fig. 2. Nb/ZnO NPs synthesized with 3 mol% concentration of niobium were then used to investigate the effect of NPs on the photovoltaic characteristics of devices. From the data summarized in Table 1, there is an increase in the short-circuit current density and a fill factor for Nb/ZnO doped devices. We have demonstrated that doping P3HT:PCBM BHJ solar cells with certain amounts of Nb/ZnO NPs resulted in efficiency increases via increases in primary photon conversion. Possible sources for this increase have been suggested [4–5].

Figure 3 shows external quantum efficiency (EQE) spectra of the photovoltaic devices with and without TCB as a co-solvent. The EQE measurements show an increase in photon collection, and thus photocurrent, across all absorbed wavelengths. A maximum of 55% in the region around 510 nm can be seen for the photovoltaic cell with 3 mol% Nb/ZnO NPs.

Table 1. Solar cells characteristics of P3HT: PCBM blends both with and without added TCB and P3HT:PCBM:3 mol%Nb/ZnO bulk-hetero junction solar cells blends added with TCB (5.5 mg)

Samples	V_{OC} (V)	J_{SC} (mA/cm^2)	FF	η (%)
P3HT:PCBM (CB)	0.660	8.94	0.506	2.90
P3HT:PCBM (CB+TCB-2.5 mg)	0.666	8.94	0.535	3.09
P3HT:PCBM (CB+TCB-3.5 mg)	0.678	9.15	0.548	3.30
P3HT:PCBM (CB+TCB-5.5 mg)	0.682	9.51	0.539	3.39
P3HT:PCBM (CB+TCB-7.5 mg)	0.672	9.28	0.555	3.36
P3HT:PCBM: 3 mol%Nb/ZnO (CB+TCB-5.5 mg)	0.682	10.20	0.567	3.83

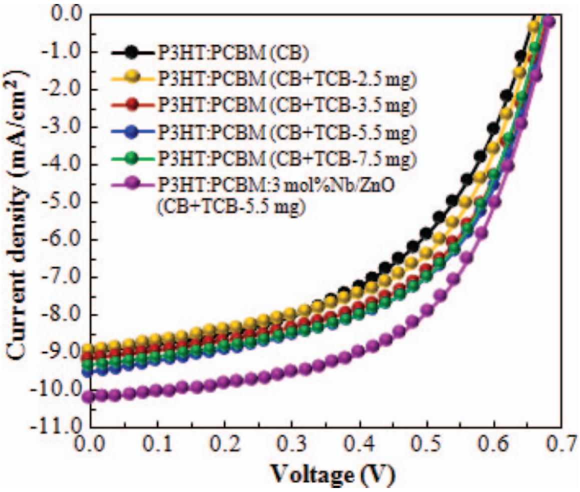

Figure 3. EQE spectra of P3HT:PCBM blends with and without added TCB at 5.5 mg and P3HT:PCBM:3 mol%Nb/ZnO blends with TCB at 5.5 mg.

There is a prominent increase at 385 nm, corresponding to the probable band gap of 3.2 eV of ZnO. AFM topography images indicate the smoother film surface of the P3HT:PCBM when TCB was used as the co-solvent in the blend, as shown in Fig. 4. Film as prepared from CB+TCB-5.5 mg, the surface is rather smooth with r.m.s. roughness of 0.725 nm, while the film prepared from CB shows r.m.s. ~ 1.882 nm. The surface of film was smoother with the addition of TCB at 5.5 mg/ml, which in turn improved the organic/cathode contact.

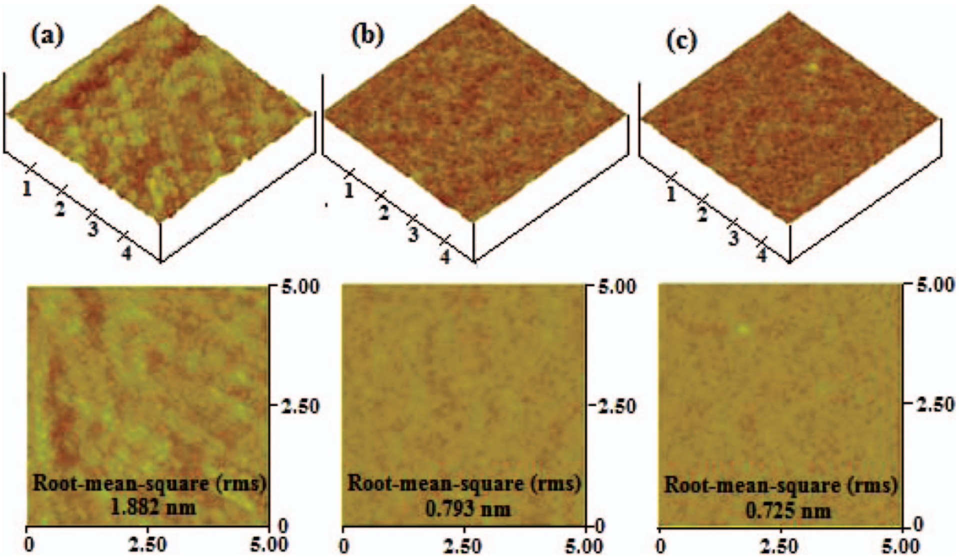

Figure 4. AFM images of P3HT:PCBM spin coated from (a) CB, (b) CB+TCB-3.5 mg and (c) CB+TCB-5.5 mg after annealed at 150°C for 7 min.

The power conversion efficiency of such fabricated solar cells was higher than that of cells formed without TCB solvent.

Acknowledgements

The authors gratefully acknowledge Program in Materials Science, Faculty of Science, Maejo University, Thailand; the Royal Thai Government, Ministry of Science and Technology, Thailand; Materials Science Research Center, Faculty of Science, Chiang Mai University, Thailand; Financial Support from the Thailand Research Fund Through the Royal Golden Jubilee Ph.D. Program, Thailand and the Center for Nanotechnology and Molecular Materials, Wake Forest University, USA.

References

[1] Keawprajak, A., Piyakulawat, P., Klamchuen, A., Iamraksa, P., & Asawapirom, U. (2010). *Sol. Energy Mater. Sol. Cells*, *94*, 531–536.
[2] Beek, W. J. E., Wienk, M.M., & Janssen, R. A. J. (2006). *Adv. Funct. Mater.*, *16*, 1112–1116.
[3] Wang, M., & Wang, X. (2008). *Sol. Energ. Mater. Sol. C.*, *92*, 766–771.
[4] Kruefu, V., Peterson, E., Khantha, C., Siriwong, C., Phanichphant, S., & Carroll, D. L. (2010). *Appl. Phys. Lett.*, *97*, 053302.
[5] Kruefu, V., Khantha, C., Peterson, E., Carroll, D. L., & Phanichphant, S. (2011). *Mol. Cryst. Liq. Cryst. Sci. Technol.*, *538*, 15–19.