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Highly Conductive PEDOT:PSS Electrode Treated with Polyethylene Glycol for ITO-free Polymer Solar Cells

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At least one electrode should be transparent in optoelectronic devices like solar cells and light emitting diodes to harvest or emit light. Currently, Indium Tin Oxide (ITO) is widely used as the standard transparent electrode; however, ITO is not an ideal electrode due to its limited availability, high cost and other technical drawbacks (1). Among alternatives, conductive polymer poly(3,4-ethylene dioxythiophene) (PEDOT) doped with poly(styrene sulfonate) (PSS) is quite promising as a next-generation transparent electrode (2). However, pristine PEDOT:PSS has very low conductivity to be used as an electrode and several efforts are going to enhance its conductivity by more than three orders of magnitude (3 and 4). Here we used different molecular weight polyethylene glycol (PEG) and enhanced the conductivity from 0.3 S/cm to 805 S/cm while treatment with ethylene glycol (EG) gave only 640 S/cm (Fig. 1). Higher molecular weight and longer chain PEG gives better screening between PEDOT and PSS chains and leads to better conductivity enhancement than small molecule EG. The conductivity was further enhanced to 1100 S/cm by combining PEG and methanol treatment. PEGs with molecular weight higher than 400 have low mobility to impart the required screening effect and hence the conductivity enhancement is less. Increase in carrier concentration by three orders of magnitude after PEG and EG treatment is the main reason for the conductivity enhancement. PEG treated films have also transmittances as high as 93% while ITO has lower than 88%. Through FTIR, XPS and AFM investigation, the mechanism for the conductivity enhancement is found to be charge screening between PEDOT and PSS followed by phase separation and reorientation of PEDOT chains leading to bigger and better connected particles. PEG forms hydrogen bonding with hygroscopic PSS and enhances the conductivity stability. The presence of PEG on the films surface affects the polymer solar cell (PSC) device performance and 2% PEG concentration gave the best efficiency for all molecular weight PEGs. PSC devices with PEG treated PEDOT:PSS anodes showed power conversion efficiency of 3.62% while those treated with EG showed 3.51% and the ITO counterpart showed 3.73% (Fig. 2 and Table I).

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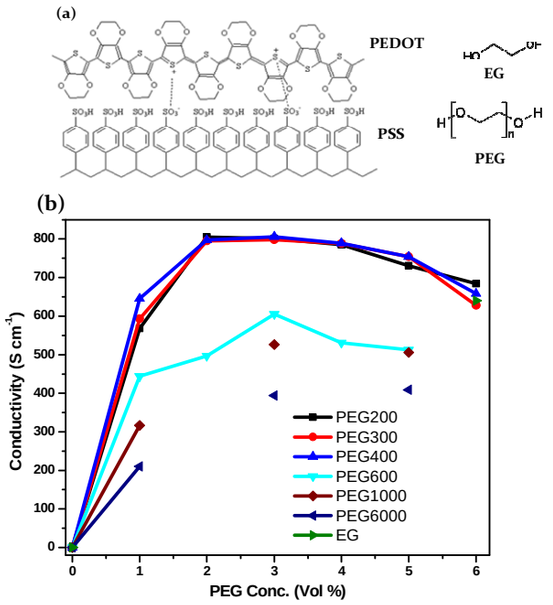

Fig. 1 (a) Chemical structure of PEDOT:PSS, EG and PEG. (b) Conductivities of PEDOT:PSS treated with different molecular weight PEG with different concentrations.

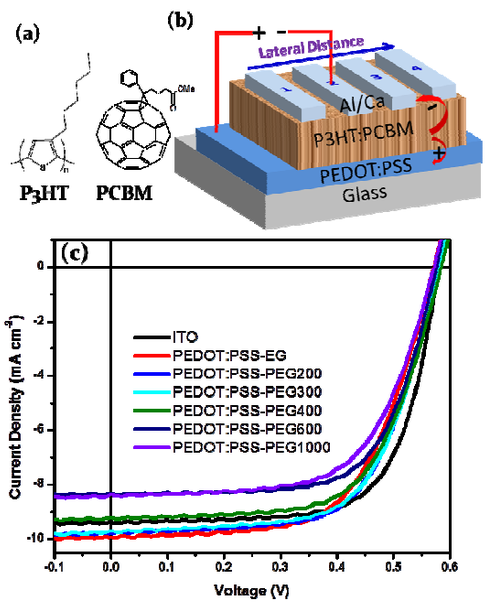

Fig. 2 (a) Chemical structures of active layer chemicals. (b) Device architecture of the ITO-free PSC. (c) J-V curves of PSCs with ITO and PEDOT:PSS treated with 6% EG and 2% PEG anodes.

Table I Photovoltaic performances of PSCs with ITO and PEDOT:PSS treated with 6% EG and 2% PEG anodes extracted from J-V curves.

Anode	J_{SC} (mA cm^{-2})	V_{OC} (V)	FF (%)	PCE (%)
ITO	9.38	0.58	68.56	3.73
PEDOT:PSS-EG	9.85	0.58	61.44	3.51
PEDOT:PSS-PEG200	9.80	0.58	63.69	3.62
PEDOT:PSS-PEG300	9.73	0.58	63.61	3.59
PEDOT:PSS-PEG400	9.22	0.58	64.14	3.43
PEDOT:PSS-PEG600	8.32	0.58	66.11	3.19
PEDOT:PSS-PEG1000	8.37	0.58	62.21	3.02