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Hole transporting electrodeposited PEDOT–polyelectrolyte layers for perovskite solar cells

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S1. Experimental

EDOT was electrochemically polymerized in aqueous solutions consisting of 10 mM EDOT and 20 mM of the following polyelectrolytes[1]: flexible-chain poly(styrenesulfonic acid) (PSSA (Aldrich, M_W 1 000 000, 25 % aqueous solution)) and poly(2-acrylamido-2-methyl-1-propanesulfonic acid) (PAMPSA (Aldrich, M_W 2 000 000, 15 % aqueous solution)), semi-rigid-chain poly(4,4'-(2,2'-disulfonic acid)-diphenylene-iso-phthalamide) (i-PASA), rigid-chain poly(4,4'-(2,2'-disulfonic acid)-diphenylene-tere-phthalamide) (t-PASA) and their sodium salts. Na^+-salts of i-PASA and t-PASA (M_n = 40 000) were synthesized as described in[2]. The synthesis solutions were prepared as described in[1,3]. The EDOT electropolymerization was performed in a galvanostatic (0.05 mA cm^{-2}) regime on ITO-glass substrates from Kavio, and the electrodeposition charge was controlled to be 10 mC cm^{-2}. A platinum foil and a saturated silver–silver chloride electrode were used as counter and reference electrodes, respectively. All the layers with the surface area of 2.75 cm^2 were thoroughly rinsed with deionized water after the synthesis. UV-Vis-NIR spectra of PEDOT layers in the range up to 1300 nm were performed using a UV3101PC spectrophotometer (Shimadzu). The surface morphology and roughness of PEDOT layers was recorded using Enviroscope AFM with a Nanoscope V controller (all by Bruker) in tapping mode.

A solution of PEDOT:PSS (1:6 wt. %) Al 4083 from Ossila referred as PEDOT:PSS(SC) was used to prepare a reference HTL, which was spin-coated at 2000 RPM.

A configuration of the studied PSCs was the following: glass/ITO/PEDOT/Perovskite/C_{60}/BCP/Al. PEDOT-polyelectrolyte layer of 30-40 nm thick on ITO/glass substrate was annealed at 70 °C for 10 min to eliminate water residues. Perovskite was prepared in 1.5 M concentration in anhydrous dimethylformamide (DMF from Sigma-Aldrich) with CH_3NH_3I (MAI, 99.99 % purity from GreatCellSolar) and PbI_2 (ultrapure 99.999 % from Alfa-Aesar)[4]. A 400-nm-thick layer of perovskite was deposited onto the PEDOT layers by centrifugation (5000 rpm, 30 s). 400 μL of toluene (Sigma-Aldrich) were quickly added 5 s after the start of centrifugation. Then, the layers were annealed at 100 °C for 10 min. Thereafter,

thermal vacuum evaporation was used to successively deposit the electron-transport layer of fullerene C_{60} (Ossila Ltd.), blocking layer of 2,9-dimethyl-4,7-diphenyl-1,10-phenanthroline (Sigma-Aldrich), and Al cathode with the thicknesses of 40, 7, and 80 nm, respectively. The thicknesses were determined with a KLA-Tencor D-100 Profiler stylus profile meter. The current–voltage characteristics of the PSC samples were measured with a Keithley 2400 and Oriel 96000 solar simulator (Newport Corp.) at intensity P = 100 mW cm^2 (AM1.5 conditions) in a glovebox with dry atmosphere of argon.

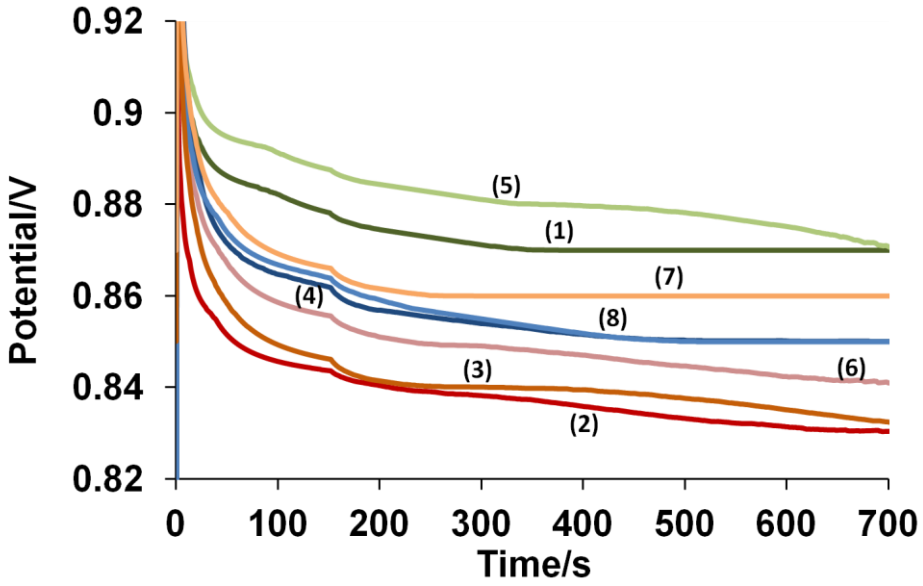

Figure S1 Time dependences of the potential during PEDOT synthesis in galvanostatic mode (0.05 mA/cm^2) in aqueous solutions containing: PAMPSA (1), PSSA (2), i-PASA (3), t-PASA (4), PAMPSNa (5), PSSNa (6), i-PASNa (7), t-PASNa (8).

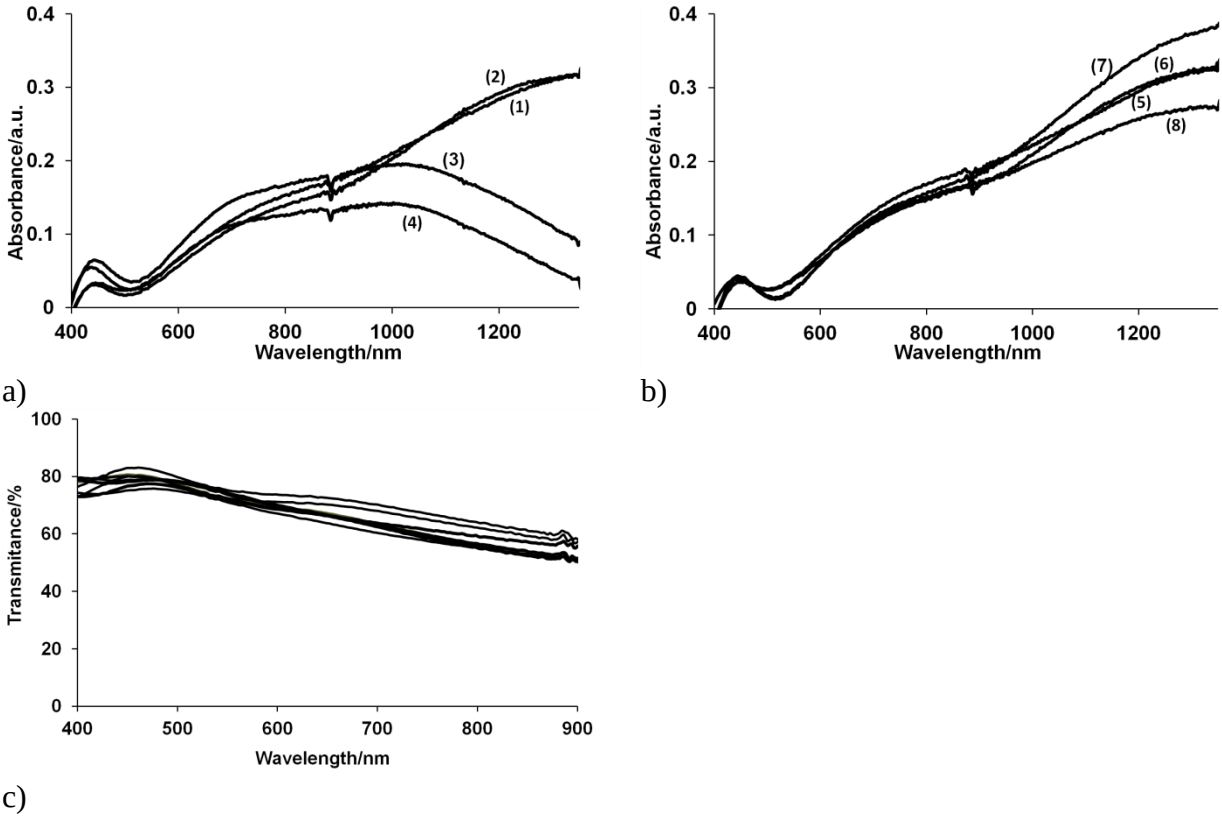

Figure S2 Absorption spectra of the layers of PEDOT complexes with acid form of PE (a): PAMPSA (1), PSSA (2), i-PASA (3), t-PASA (4) and salt form of PE (b): PAMPSNa (5), PSSNa (6), i-PASNa (7), t-PASNa (8). Transmission spectra of PEDOT layers (c).

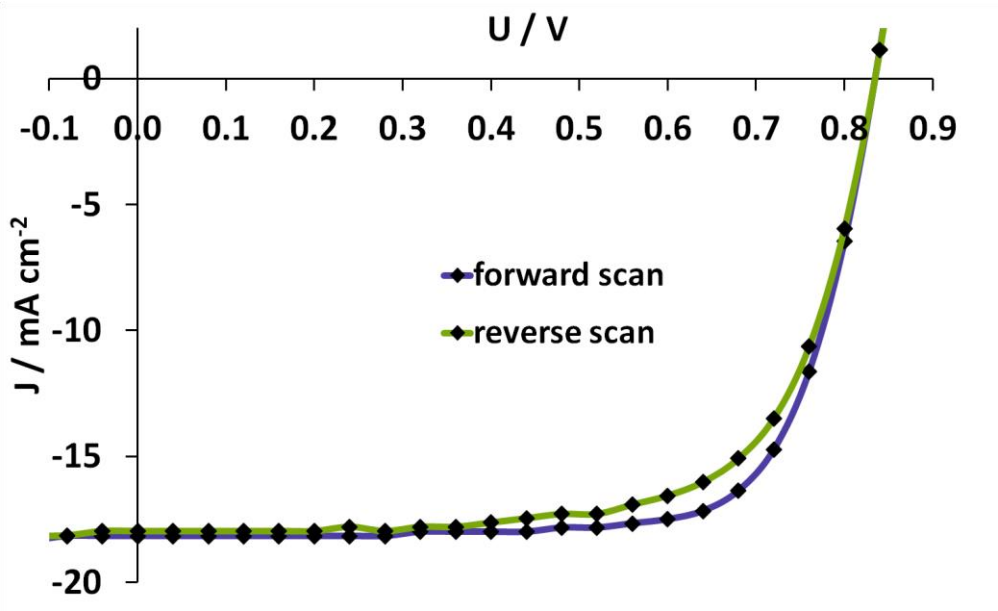

Figure S3 Current density versus voltage characteristics for the best device based on electrodeposited PEDOT-t-PASA.

References

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