Supplementary Information

Room-temperature solution processed SnO_x as electron extraction layer for inverted organic solar cells with superior thermal stability

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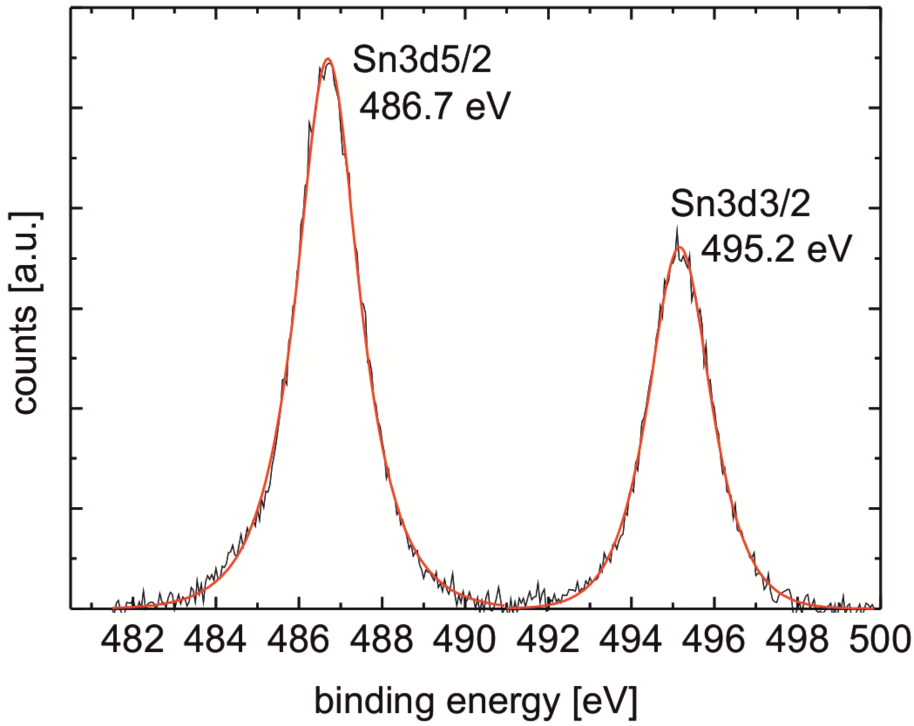

Figure S1: XPS spectrum of the Sn3d peaks of a pristine SnO_x layer. The peaks have been fit using a Gauss-Lorentz profile.

Electronic Supplementary Material (ESI) for Journal of Materials Chemistry

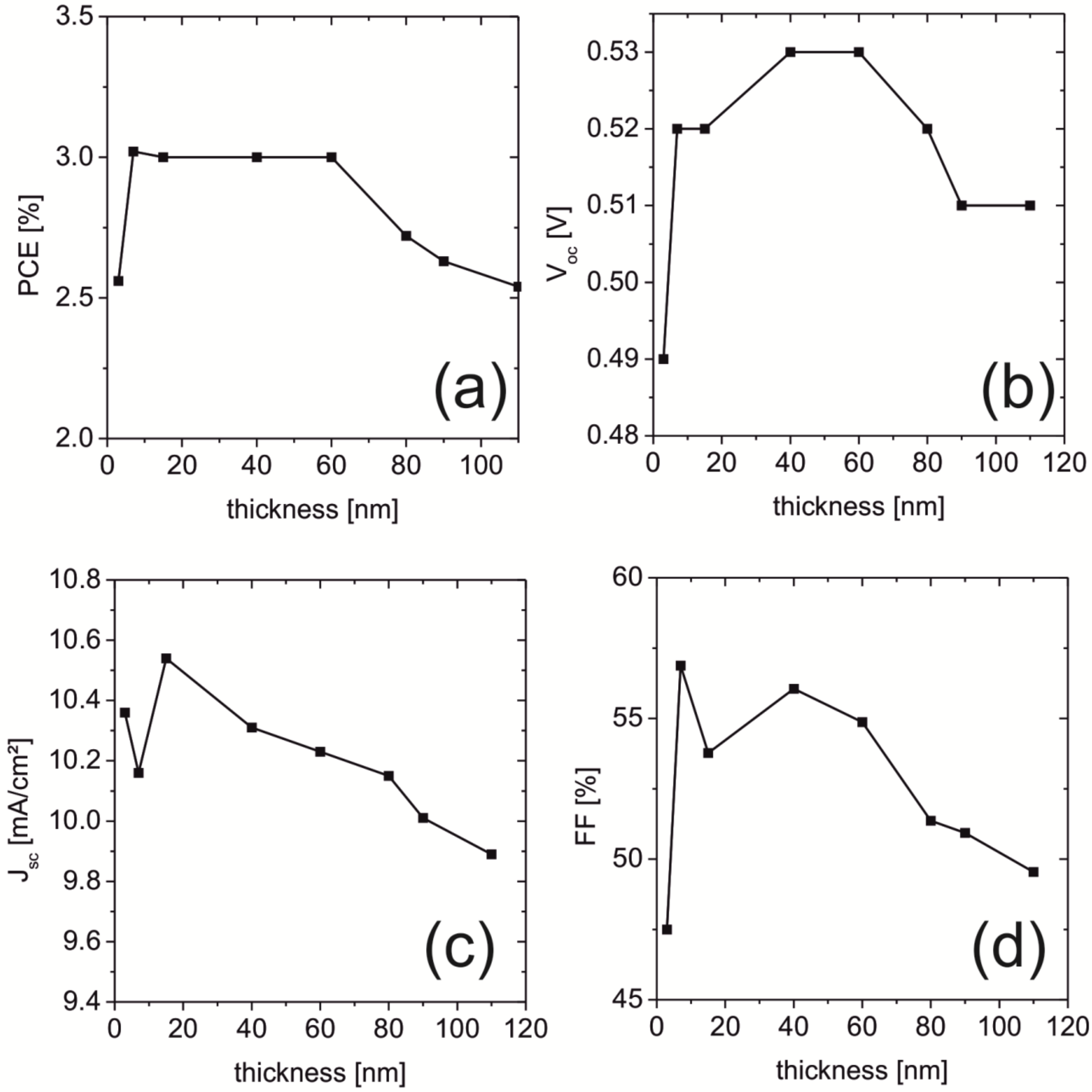

Figure S2. Characteristics of OSCs with a varied thickness of the pristine SnO_x layer. (a) PCE, (b) V_{oc}, (c) J_{sc} and (d) FF. Each data point is an average over all cells with the same SnO_x thickness on one substrate.

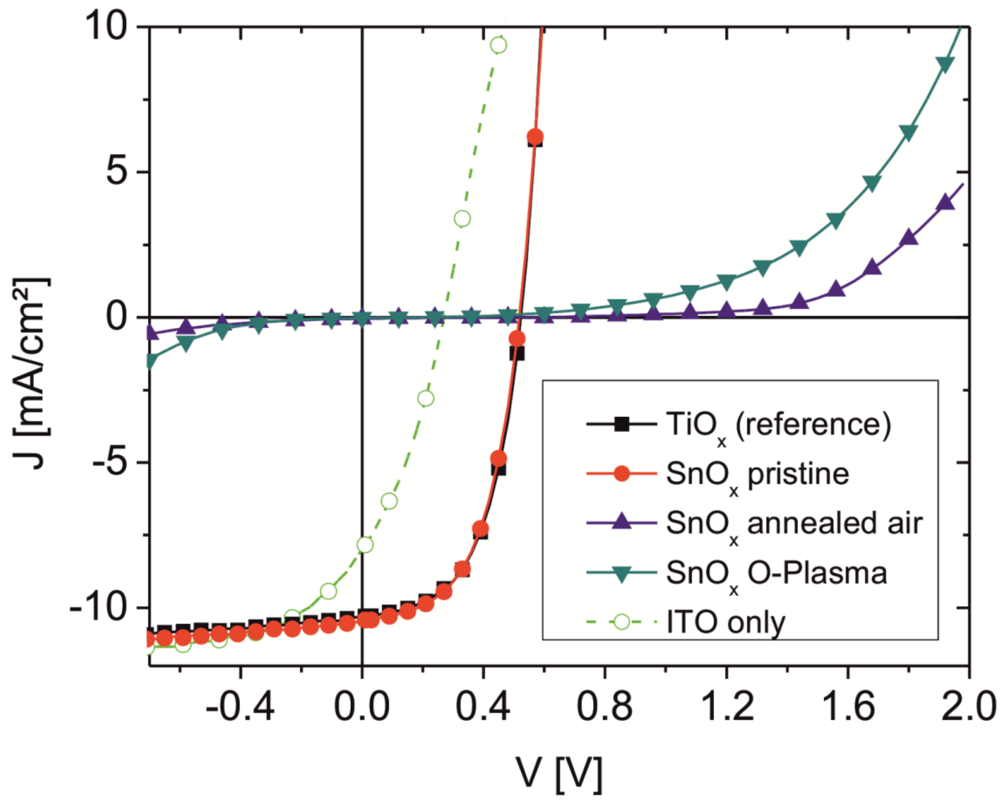

Figure S3: *I-V characteristics of OSCs based on SnO_x electron extraction layers under illumination (AM1.5G, 100 mW/cm^2). The SnO_x electron extraction layers are either pristine or have been treated by annealing in air or oxygen plasma prior to the deposition of the organic BHJ. The cells based on TiO_x or on ITO only are shown as reference.*

OSC devices with a SnO_x layer that has either been annealed in air or has been treated with an oxygen plasma show strongly S-shaped *I-V* characteristics. It is known that an injection barrier at the electrode does not cause S-shaped *I-V* characteristics in BHJ solar cells but rather leads to a reduction of V_{oc}.[1, 2] This can be seen for the *I-V* curve of a device without electron extraction interlayer (ITO only) which shows a low V_{oc} = 0.23 V and a low *FF* but no pronounced S-shape. Similarily, a low V_{oc} is also found for the device with the plasma treated SnO_x layer. Its high WF of 5.13 eV makes an injection barrier for electrons a likely explanation. In recent reports, severely S-shaped *I-V* characteristics have been unambiguously associated with a strongly limited extraction of charges.[1-3] This hints to a poor electron extraction if annealed or plasma treated SnO_x is used. The dramatically decreased conductivity of SnO_x layers annealed in air (~3-6×10^{-6} S/cm) compared to the pristine layers (~1-2×10^{-5} S/cm) also leads to deteriorated device characteristics. Specifically, a high series resistance of 100 Ωcm^2 is found for the devices with air annealed SnO_x compared to 1.8 Ωcm^2 for that based on the pristine SnO_x.

Table S1. Characteristics (open circuit voltage (V_{oc}), short-circuit current density (J_{sc}) and filling factor (FF)) of inverted OSCs with TiO_x layer. The cells are either pristine or have been treated in climate cabinet for 60 min. The devices are without encapsulation.

	PCE [%]	V_{oc} [V]	J_{sc} [mA cm^{-2}]	FF [%]	R_s [Ω cm^2]
TiO_x (pristine cell)	3.0	0.52	10.0	57	2.7
TiO_x (80°C/30%rh)	2.6	0.53	10.0	50	5.1
TiO_x (80°C/80%rh)	1.4	0.53	8.5	32	12.8

[1] A. Wagenpfahl, D. Rauh, M. Binder, C. Deibel, V. Dyakonov, Phys. Rev. B 2010, 82.
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[3] H. Schmidt, K. Zilberberg, S. Schmale, H. Flugge, T. Riedl, W. Kowalsky, Appl. Phys. Lett. 2010, 96, 243305.