**Supporting Information** 

## Microwave-Synthesized Tin Oxide Nanoparticles for Low-Temperature Solution-Processed Planar Junction Halide Perovskite Solar Cells

**Materials:** all materials were used without purification. Anhydrous dimethylsulphoxide (DMSO),  $\gamma$ -butyrolactone (GBL), ethanol, diethyl ether, methylamine, 57 wt% hydroiodic acid in water, 4tert-butylpyridine (TBP), anhydrous acetonitrile, anhydrous chlorobenzene, and lithium bis(trifluoromethane)sulfonylimide (Li-TFSI) were purchased from Sigma Aldrich, whereas 99.999% lead Iodide (PbI<sub>2</sub>) was purchased from Alfa Aesar. Tris(2-(1H-pyrazol-1-yl)-4-tertbutylpyridine)cobalt(III) bis(trifluoromethylsulphomyl)imide (FK 102 Co(III) TFSI Salt) were purchased from Dyesol. 2,2',7,7'-tetrakis(N,N-di-p-methoxyphenylamine)-9,9'-spirobifluorene (Spiro-MeOTAD) 98% was purchased from Borun ChemIcals, Methylammonium iodide was purchased from Dyesol. CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub> was prepared by reacting the synthesized CH<sub>3</sub>NH<sub>3</sub>I and PbI<sub>2</sub> at 1:1 molar ratio in 1 ml GBL/DMSO (3:2 Vol/Vol ratio) at 60 °C for 12 h.

**Device fabrication and characterization:** glass substrates with tin-doped indium oxide (ITO, 15  $\Omega$ .cm<sup>-2</sup>) pattern were first scrubbed with dilute Extran 300 detergent solution to remove organic residues before immersing in an ultrasonic bath of dilute Extran 300 for 20 min. Samples were rinsed in flowing deionized water for 5 min before being sonicated (Branson 5510) for 10 min each in successive baths of acetone and isopropanol. Next, the samples were dried with nitrogen before being exposed to UV–ozone plasma for 10 min. SnO<sub>2</sub> NPs ink solution was prepared by dissolving of 6-9 mg SnO<sub>2</sub> NPs powder into 1 ml ethanol. CH<sub>3</sub>NH<sub>3</sub>I + PbI<sub>2</sub> solution was deposited onto SnO<sub>2</sub>/ITO substrates by a consecutive two-step spin-coating process at 1000 rpm and 4500 rpm for 10 s and 40 s, respectively. During the second spin-coating step, the films were treated with 100 µl of chlorobenzene to promote crystallization then the samples were annealed at 100°C for 15 min. The HTM solution was coated on CH<sub>3</sub>NH<sub>3</sub>Pbl<sub>3</sub>/SnO<sub>2</sub>/ITO at 2200 rpm for 30 s. Finally, the samples were placed in a thermal evaporator for evaporation of 100 nm of gold electrodes at rate of 2 Å·s<sup>-1</sup> and pressure less than 1x10<sup>-7</sup> Torr.

The HTM solution was prepared by dissolving 80 mg of spiro-MeOTAD in 1 ml of chlorobenzene alongside 28.8  $\mu$ L TBP, 17.6  $\mu$ L Li-TFSi stock solution (520 mg Li-TFSI in 1 ml acetonitrile) and

29  $\mu$ L FK 102 Co(III) TFSI Salt stock solution (300 mg FK 102 Co(III) TFSI Salt in 1 ml acetonitrile).

**Films characterization:** scanning electron microscopy (SEM) images were taken at 5 V accelerating voltage and beam aperture 30  $\mu$ m, using a Zeiss Auriga microscope equipped with inlens detector. Atomic force microscopy (AFM) scan was measured with Dimension Icon from Veeco on 1 x 1  $\mu$ m surface areas. The structure of the films was investigated by X-ray diffraction (XRD) Bruker D8 Discovery with Cu K $\alpha$  radiation source ( $\lambda = 1.5418$  Å) UV-Vis-IR absorption measurements were taken using a Cary 6000i from Varian equipped with a diffuse reflectance accessory (integrating sphere). The Samples were positioned at the center of the sphere and tilted of 200 with respect to the incident light beam. This configuration allows most of the specular and diffused reflected and transmitted light to be integrated in the sphere and measured by the detector with minimal losses.



Figure S1: UPS spectra of a SnO<sub>2</sub>-NCs film deposited on ITO.

UPS measurements were performed with an Omicron SPHERA hemispherical analyzer under He-I excitation (21.22 eV) of an attenuated discharge lamp (Omicron/Focus HIS 13, 1/12 attenuation). The base pressure of the analysis chamber was  $8 \cdot 10^{-10}$  mbar. As substrates, ITO covered glass was used. The samples were prepared in glovebox according to the device procedures and transferred to the UPS analysis chamber via ambient conditions, estimating the total air exposure time to less than 2 min. The film work function (*Wf*) are determined from the spectra high binding energy cutoffs through the equation:

$$Wf = 21.22 \text{ eV} - E_{cutoff},$$

where  $E_{\text{cutoff}}=16.51 \text{ eV}$  is the respective cut-off energy. The film ionization energy (*IE*) was obtained by adding the photoemission onset of the valence edge  $E_{\text{VB}}$  relative to the Fermi level  $E_{\text{F}}$ :

$$IE = Wf + E_{VB}.$$

The multi-channeltron detector and analyzer were calibrated to the Fermi edge of a sputter-cleaned Au foil, yielding an energy resolution of 100 meV at room temperature.

XPS measurements were performed with the same equipment yet using an Al X-ray source providing 1486.6 eV excitation.



**Figure S2:** Comparison of Tauc plot of  $SnO_2$  and  $TiO_2$  nanoparticles dispersions in ethanol obtained with the MWNASG route.



Figure S3: SEM image of the SnO<sub>2</sub>-NCs coated on ITO glass.



**Figure S4:** From the left, AFM images of ITO glass substrate, SnO<sub>2</sub>-NCs thin film and MAPbI<sub>3</sub> film.

**Solar cells Characterization:** J-V measurements of solar cells were performed in the glovebox with a Keithley 2400 source meter and an ABET Technology Sun 3000 class AAA solar simulator calibrated to 1 sun, AM1.5 G, with a NREL calibrated reference silicon cell (ABET Technology). The external quantum efficiency (EQE) measurements were performed at zero bias by illuminating the device with monochromatic light supplied from a Xenon arc lamp in combination with a dual-

grating monochromator. The number of incident photons on the sample was measured for each wavelength by using a NIST calibrated silicon photodiode. The size of each device is of 0.1 cm<sup>2</sup>. Measurements were performed with and without the use of a shade mask without exhibiting any significant differences.

Hole mobility values were extracted using the modified Mott-Gurney equation:

$$J_{SCLC} = \frac{9}{8} \varepsilon_0 \varepsilon_r \mu \frac{V_{in}^2}{L^3} \exp\left(\frac{0.98\beta}{\sqrt{L}} \sqrt{V_{in}}\right)$$

where  $J_{SCLC}$  is the measured current density,  $\varepsilon_0$  and  $\varepsilon_r$  are the vacuum permittivity and material dielectric constant respectively, *L* is the film thickness,  $\mu$  the hole mobility,  $\beta$  is the field activation parameter and  $V_{in}$  is the applied voltage.



Figure S5: SCLS curve acquired on 120 nm thick SnO<sub>2</sub>-NCs film in the Au/SnO<sub>2</sub>/ITO configuration.

Thickness (nm)	Mobility (cm <sup>2</sup> V <sup>-1</sup> ·s <sup>-1</sup> )
30	2.24.10-5
60	3.37 <sup>.</sup> 10 <sup>-5</sup>
120	$1.57 \cdot 10^{-5}$

Table 1: Measured values of electronic mobility for three SnO<sub>2</sub>-NCs film thicknesses.



Figure S6: Statistic distribution of the efficiency on 40 devices.



Figure S7: J-V curve of the best-performing Au/spiro-MeOTAD/CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub>/TiO<sub>2</sub>/ITO device.



Figure S8: SEM image of the MAPbI<sub>3</sub> stacked with SnO<sub>2</sub>-NCs film and ITO glass.



**Figure S9:** J-V curves of the best performing Au/spiro-MeOTAD/MAPbI<sub>3</sub>/SnO<sub>2</sub>-NCs/ITO solar cell acquired in forward to reverse and reverse to forward bias to evidence the hysteresis of the device.



**Figure S10:** Stability test under illumination of the Au/spiro-MeOTAD/MAPbI<sub>3</sub>/SnO<sub>2</sub>-NCs/ITO device measured as current density versus time.