Electronic Supplementary Material (ESI) for Nanoscale.

Supplementary information

Sandwich-like Electron Transport Layer to Assist Highly Efficient Planar Perovskite Solar Cells

Zhichao Lin*,† Jingjing Yan,† Qingbin Cai, Xiaoning Wen, Hongye Dong and Cheng Mu*

Department of Chemistry Renmin University of China, Beijing, 100872, P. R. China.

†These authors contributed equally.

***All correspondence should be addressed to:**

Cheng Mu

E-mail addresses: cmu@ruc.edu.cn (Cheng Mu).

Zhichao Lin

E-mail addresses: linzc@stu.shzu.edu.cn (Zhichao Lin).

Table S1. Band gaps (E_g), secondary-electron cut-off ($E_{cut\text{-}off}$), Fermi level (E_F), valence band (E_{VB}) and conduction band (E_{CB}) for single SnO_2 and MgO/SnO_2/EA films.

Samples	E_g (eV)	$E_{cut\text{-}off}$ (eV)	E_F (eV)	E_{VB} (eV)	E_{CB} (eV)
SnO_2	3.62	16.35	4.87	7.85	4.23
MgO/SnO_2/EA	3.69	16.56	4.66	7.81	4.12

In order to get the Fermi level (E_F), we use $E_F = E_{cut\text{-}off} - 21.22$ eV, where $E_{cut\text{-}off}$ is cut-off binding energy, and 21.22 eV is emission energy from the He I irradiation. The $E_{cut\text{-}off}$ of single SnO_2 and MgO/SnO_2/EA films are 16.35 eV and 16.56 eV, respectively. The E_F of single SnO_2 and MgO/SnO_2/EA films are calculated as −4.87 eV and −4.66 eV, respectively. The E_{VB} of single SnO_2 and MgO/SnO_2/EA films are −7.85 and −7.81 eV, calculated using $E_{VB} = E_F - E_{F,\,edge}$ (Fermi edge). According to the absorption spectrum and Tauc plot, the band gap (E_g) of single SnO_2 (3.62 eV) and the MgO/SnO_2/EA (3.69 eV) are obtained. The E_{CB} obtained from E_g and E_{VB} is −4.23 eV and −4.12 eV, respectively.

Table S2. τ_1 and τ_2 from PL decay spectra with different samples.

Samples	τ_1 (ns)	τ_2 (ns)
SnO_2	26.52	83.05
$MgO/SnO_2/EA$	6.36	54.20

The PL decay fitting curve is based on a bi-exponential rate law:

$$f(t) = A_1\exp(-t/\tau_1) + A_2\exp(-t/\tau_2) + y_0$$

Here, τ_1 represents trap-assisted recombination, and τ_2 demonstrates free carrier recombination, A_1 and A_2 represent the decay amplitude, and y_0 is a constant for baseline offset.

Table S3. The fitted parameters for EIS measurements acquired under dark based on different samples.

Samples	R_s (Ω cm^2)	R_{rec} (Ω cm^2)
SnO_2	2.60	1.16×10^4
$MgO/SnO_2/EA$	1.98	3.33×10^4

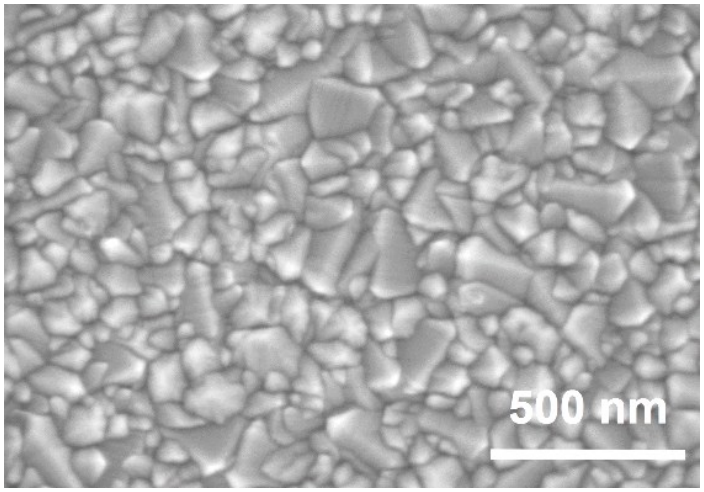

Figure S1. SEM image of FTO glass.

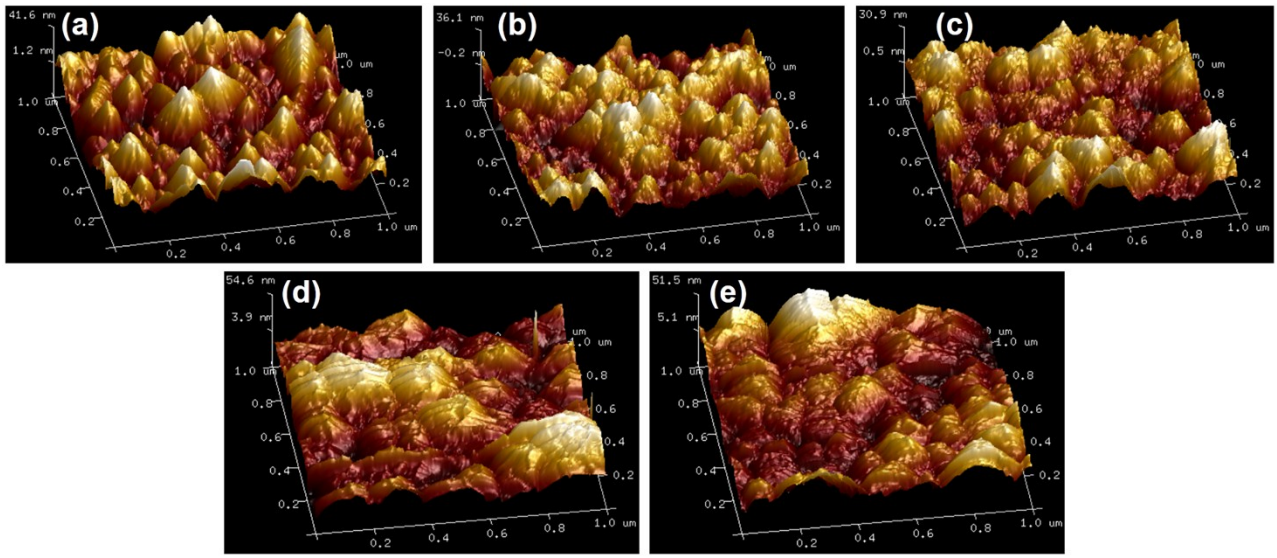

Figure S2. AFM images of a) FTO glass, b) FTO/SnO_2 film, c) FTO/MgO/SnO_2/EA film, perovskite film deposited on d) single SnO_2 and e) MgO/SnO_2/EA surface.

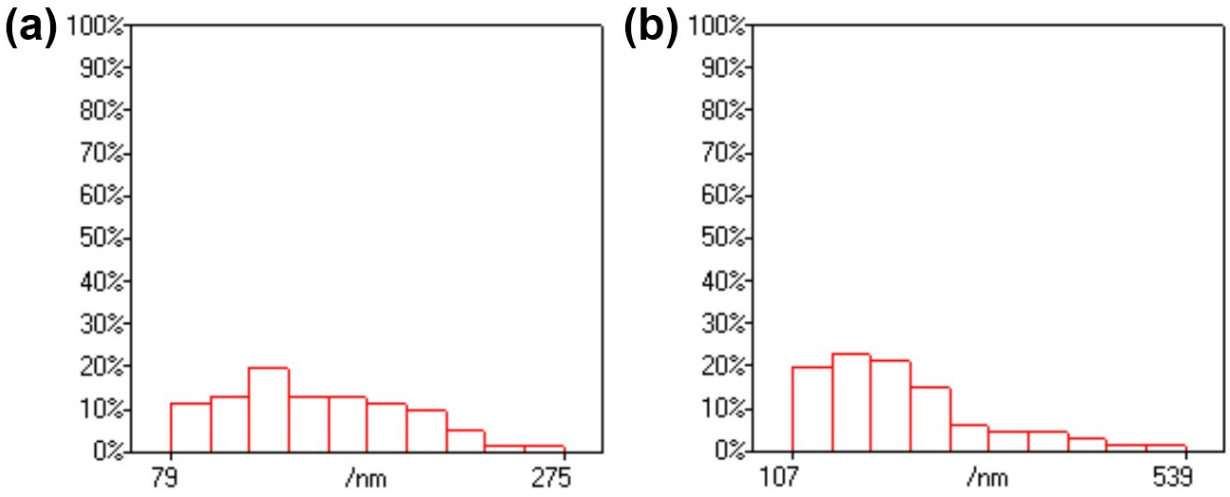

Figure S3. Grain-size distribution of perovskite films deposited on a) a single SnO_2 ETL, b) a MgO/SnO_2/EA ETL.

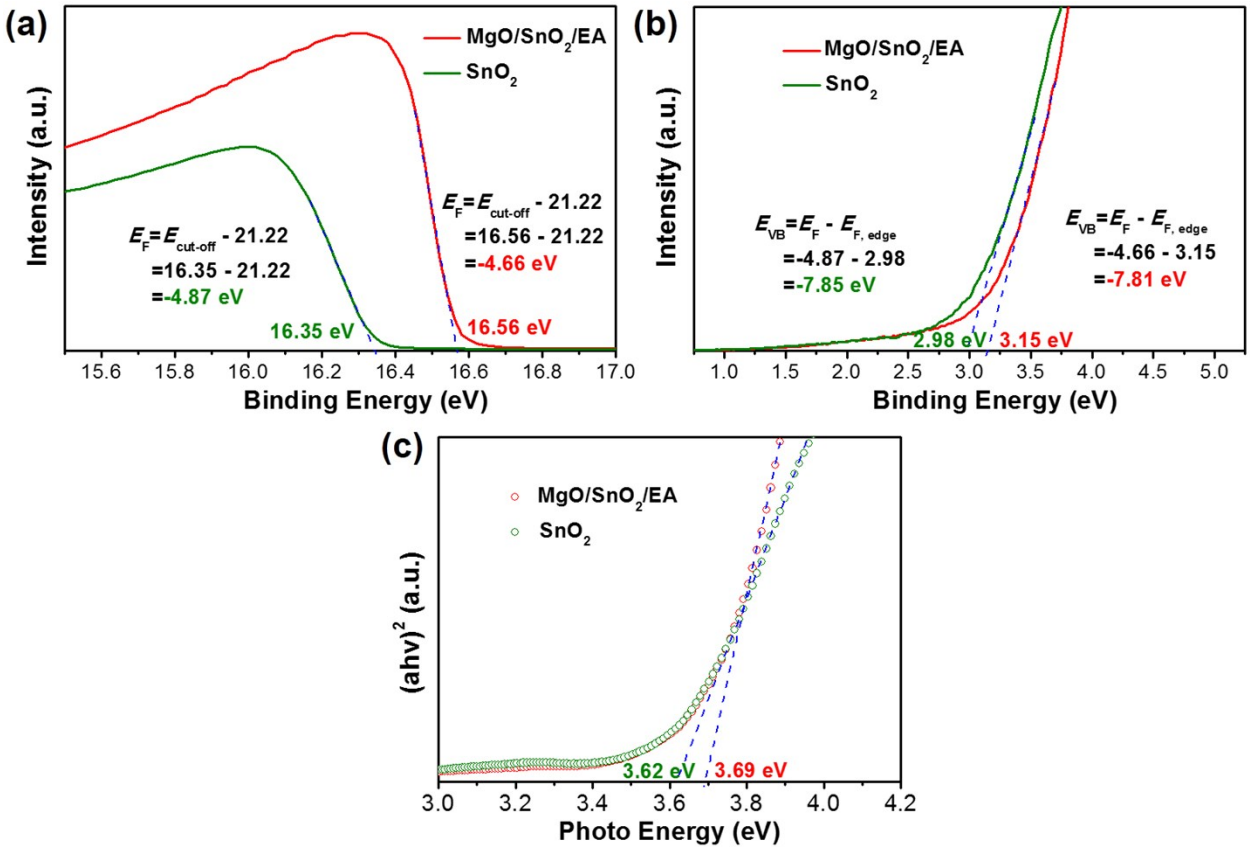

Figure S4. a, b) UPS and c) UV-Vis spectra of the $MgO/SnO_2/EA$ and single SnO_2 films.

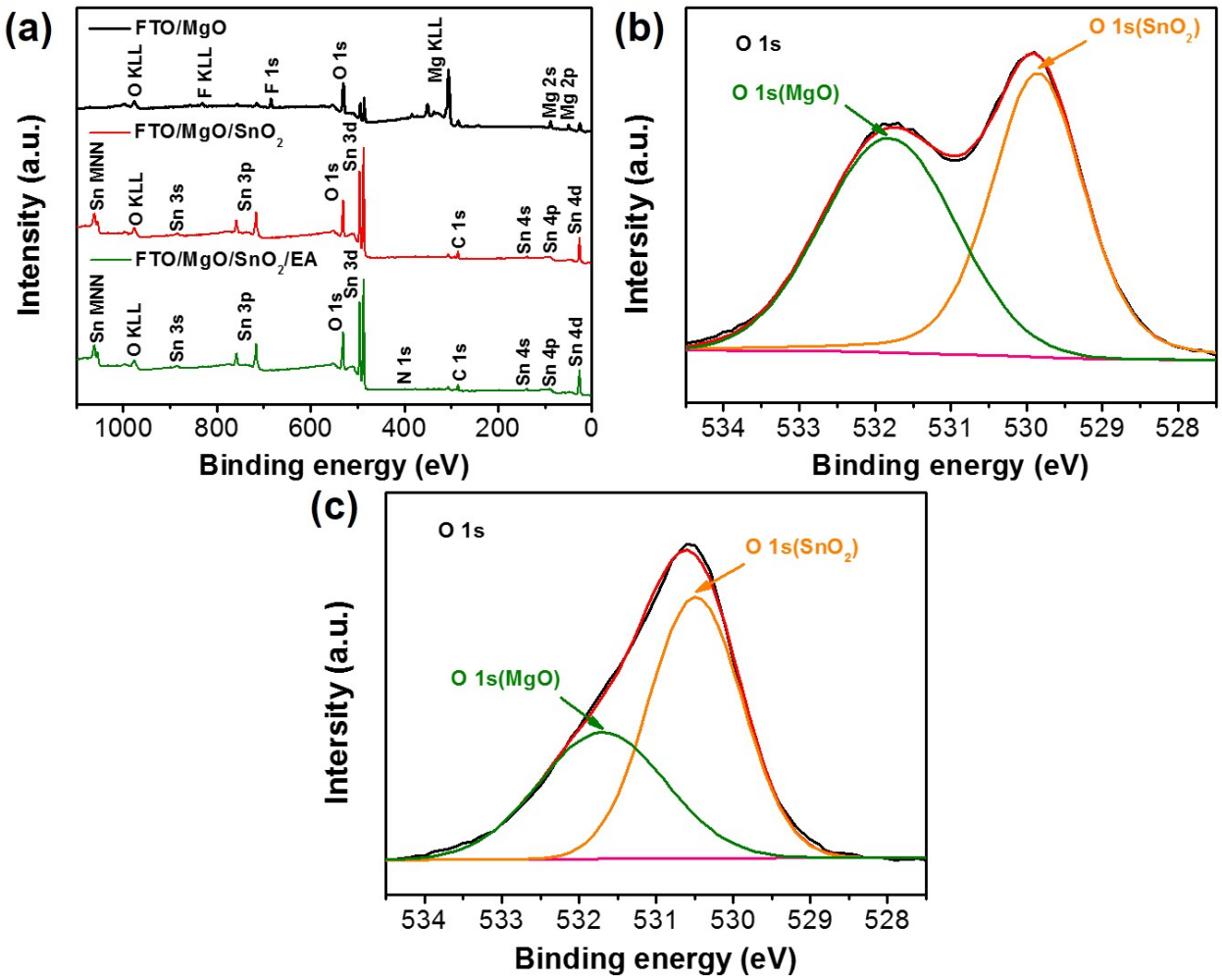

Figure S5. a) XPS survey spectra of the MgO, MgO/SnO_2, and MgO/SnO_2/EA films and high-resolution O 1s XPS spectrum of the b) FTO/MgO and c) FTO/MgO/SnO_2/EA films.

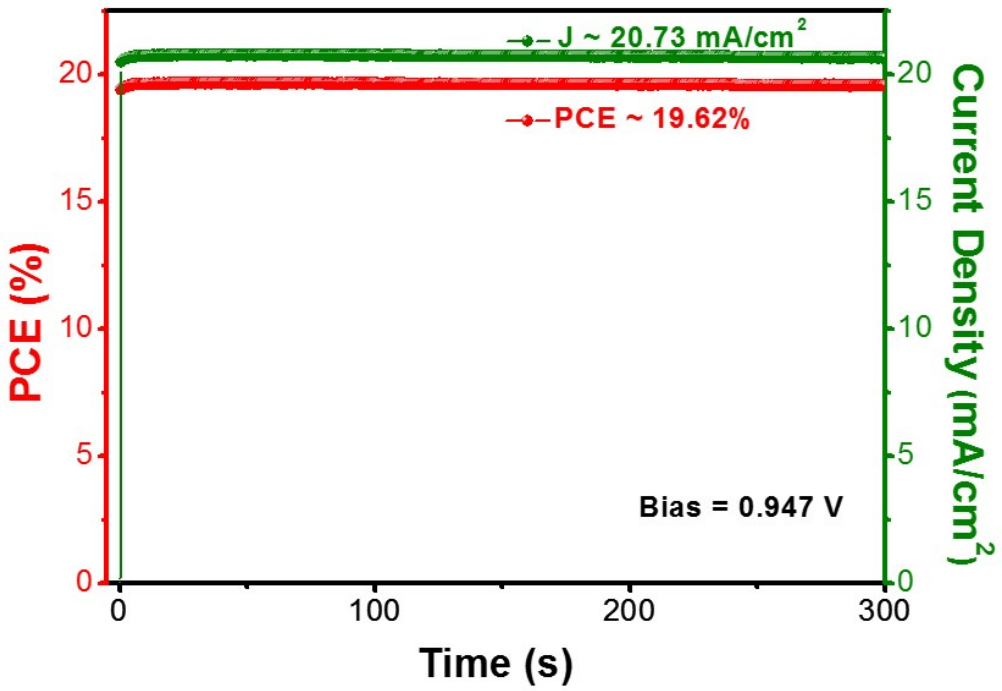

Figure S6. Steady state efficiency and photocurrent density output of PSC with MgO/SnO_2/EA as the ETL.

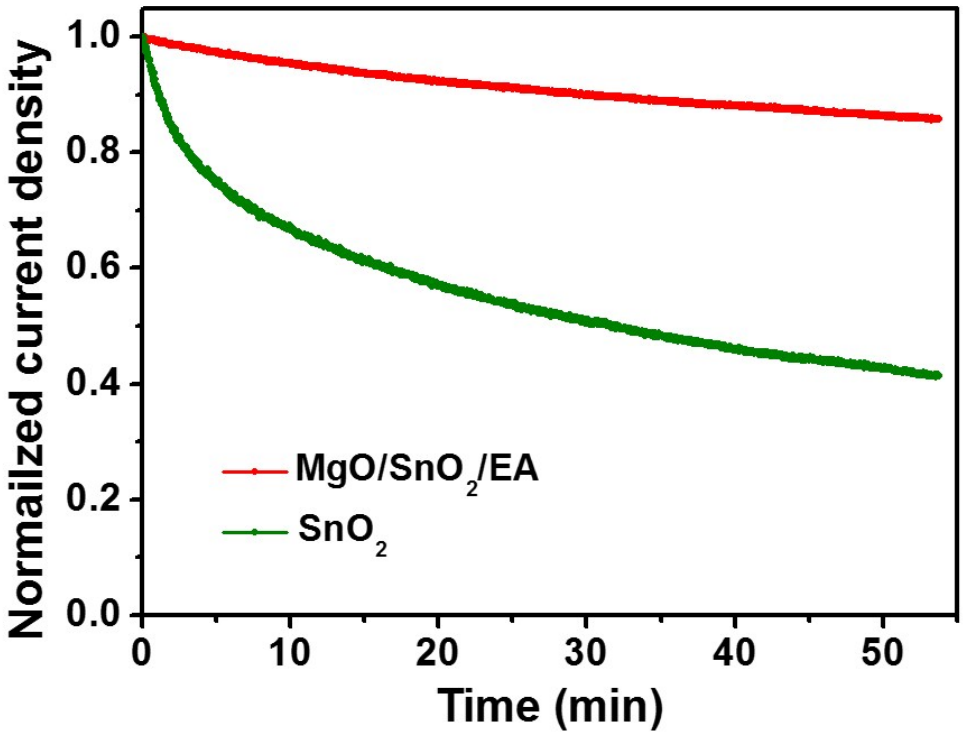

Figure S7. Photo and electric field stability test of the unencapsulated MgO/SnO_2/EA sandwich ETL and single SnO_2 ETL devices under continuous illuminated in ambient air (20 ± 5% relative humidity, 20 ± 5 ° C), at a bias voltage of 0.9 V.