Supporting Information

Multifunctional organic ammonium salt modified SnO_2 nanoparticles toward efficient and stable planar perovskite solar cells

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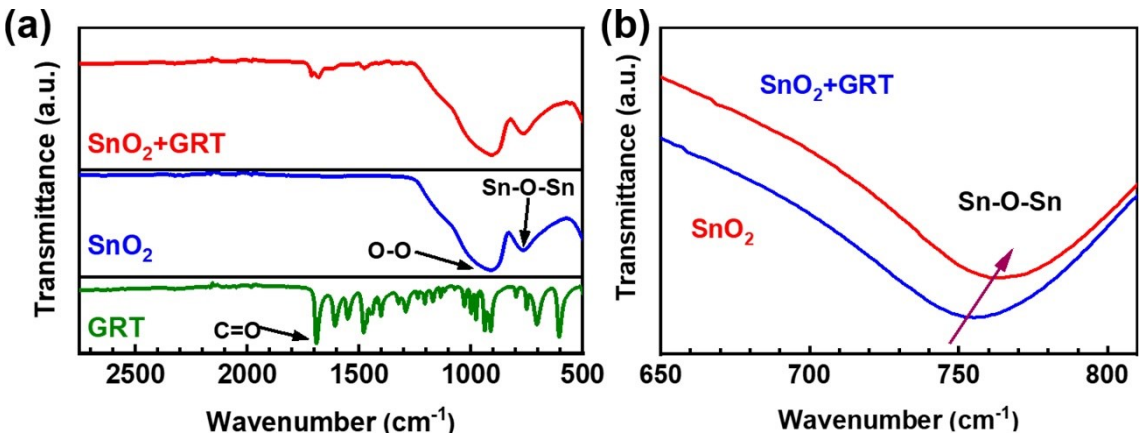

Fig. S1 FTIR spectra of GRT, SnO_2 and GRT-modified SnO_2 (SnO_2+GRT) films deposited on glass substrates.

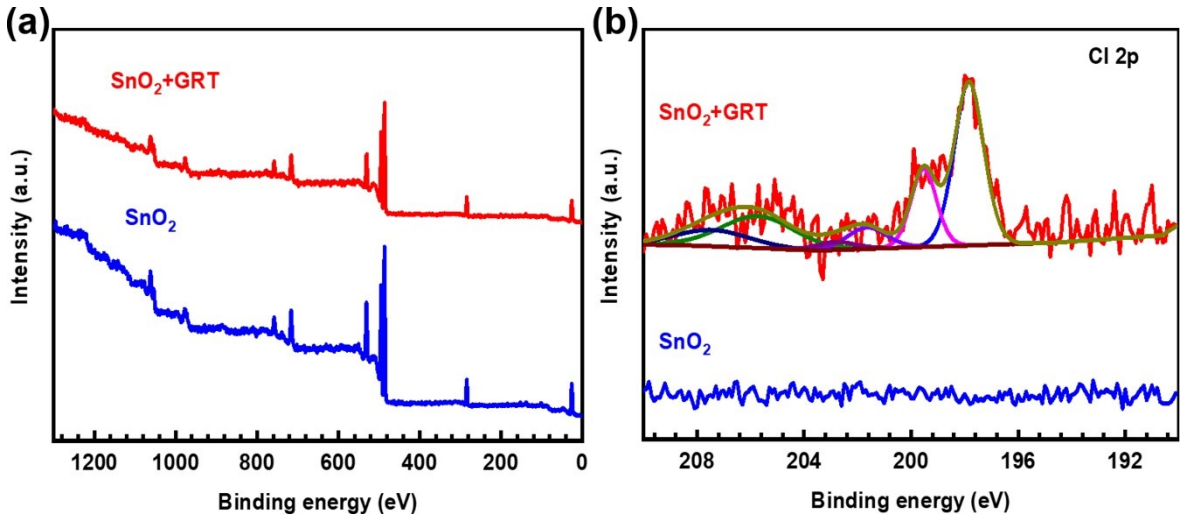

Fig. S2 (a) XPS full spectra and (b) Cl 2p spectra of SnO_2 and GRT modified SnO_2 films.

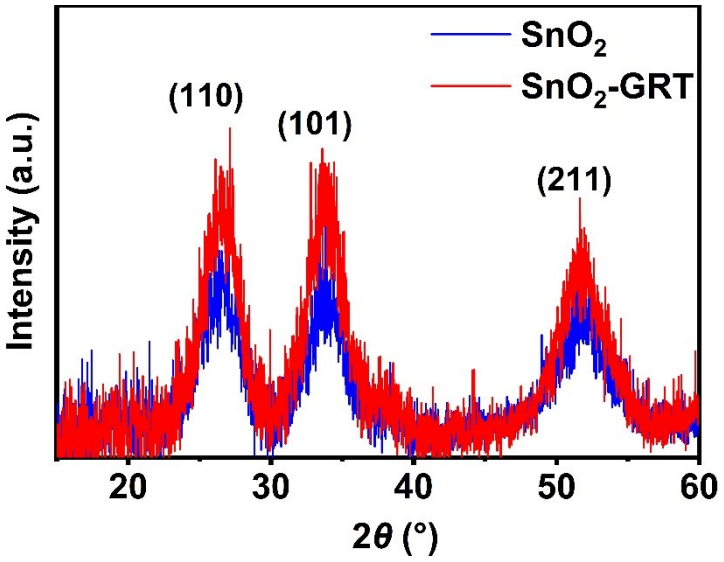

Fig. S3 XRD patterns of SnO_2 and SnO_2+GRT films spin-coated on glass substrates.

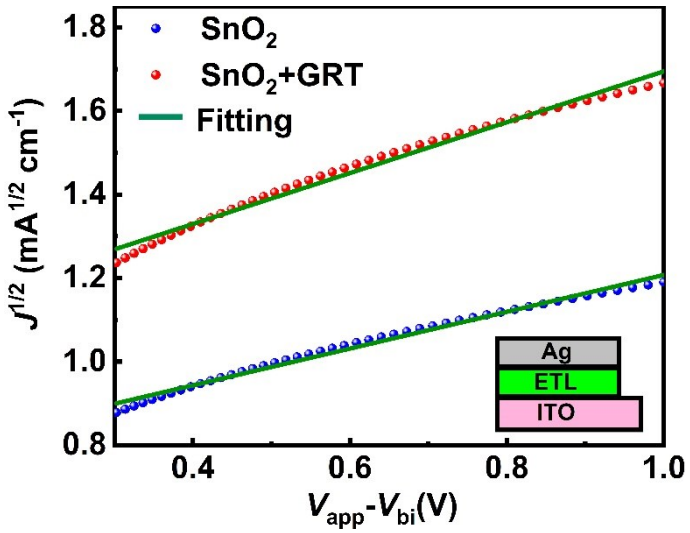

Fig. S4 *J-V* curves of the devices with the structure of ITO/ETL without or with GRT/Ag, which were measured in the dark and at room temperature.

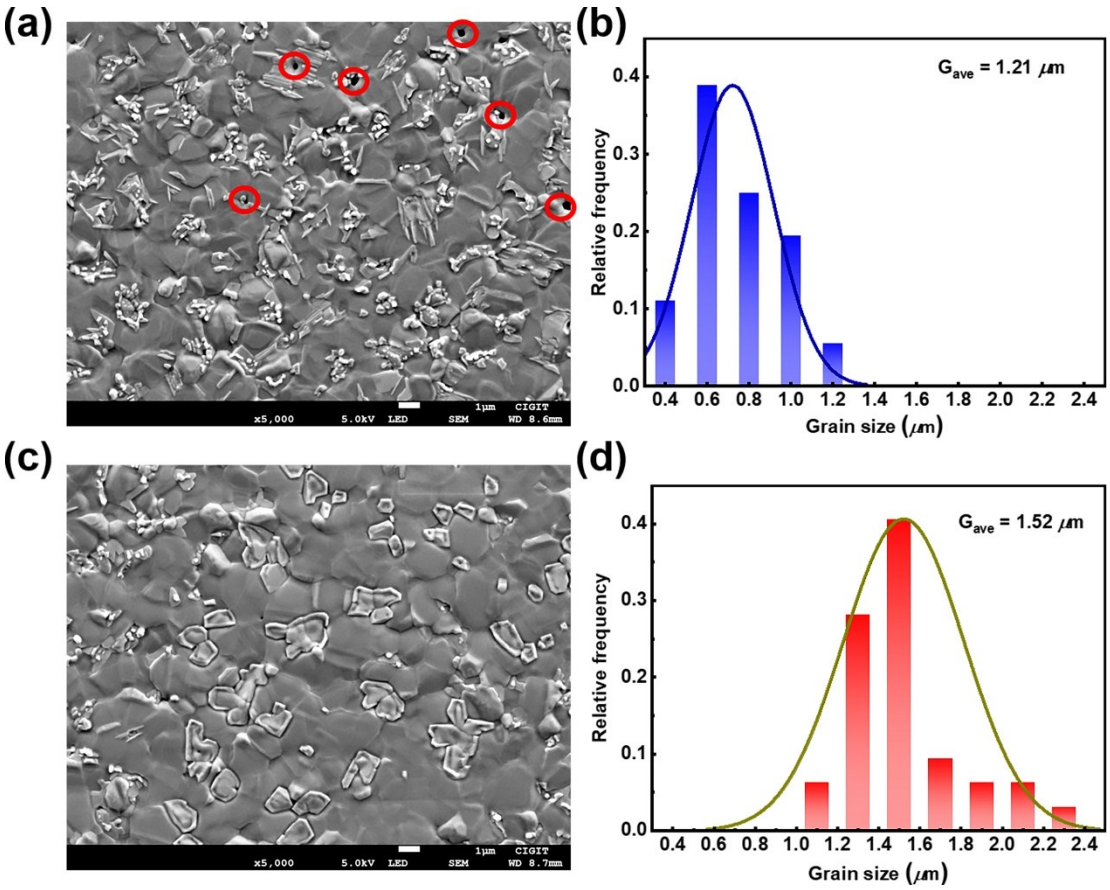

Fig. S5 Top-view SEM images of the perovskite films prepared on (a) SnO_2 and (c) SnO_2 modified by GRT films. The corresponding grain sizes statistics from (a) and (c) are shown in (b) and (d), respectively.

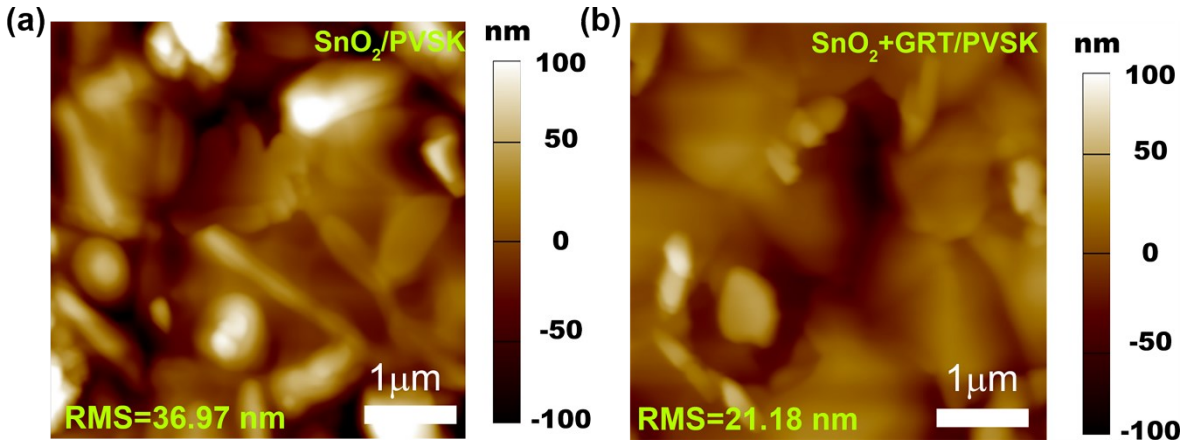

Fig. S6 AFM images of the perovskite films spin-coated on (a) SnO_2 and (b) SnO_2 with GRT. PVSK stands for perovskite.

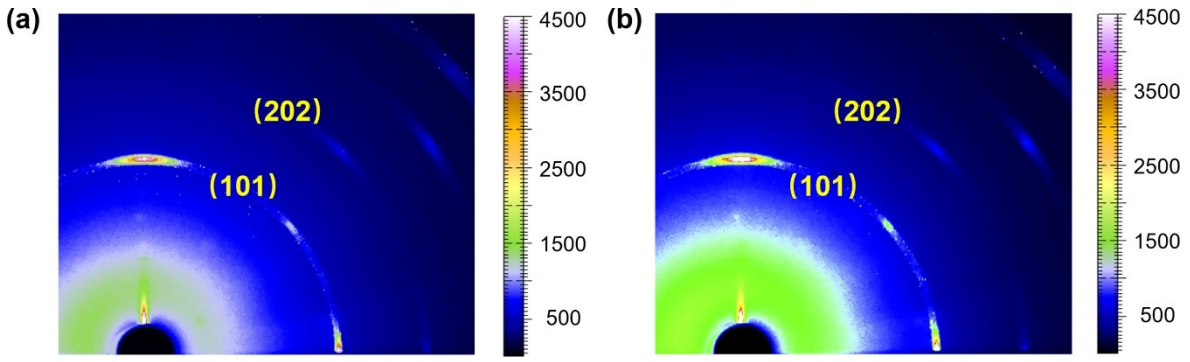

Fig. S7 GIWAXS patterns of the perovskite layers deposited on SnO_2 and SnO_2+GRT films.

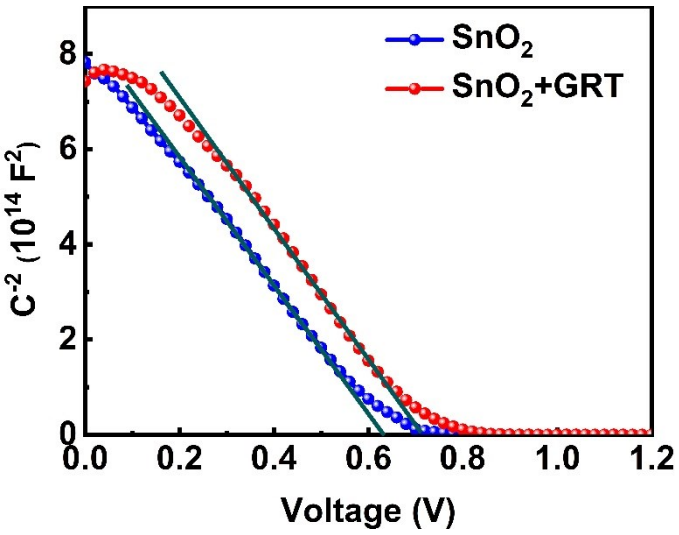

Fig. S8 Mott–Schottky analysis at 1000 Hz of the devices based on SnO_2 and SnO_2+GRT ETL, respectively.

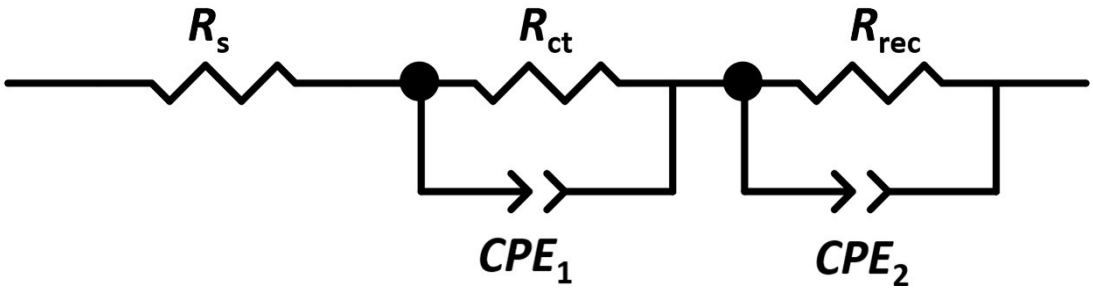

Fig. S9 The equivalent circuit for electrical impedance spectroscopy (EIS) composed of series resistance (R_s), transport resistance (R_{ct}) and recombination resistance (R_{rec}), and constant phase element (*CPE*).

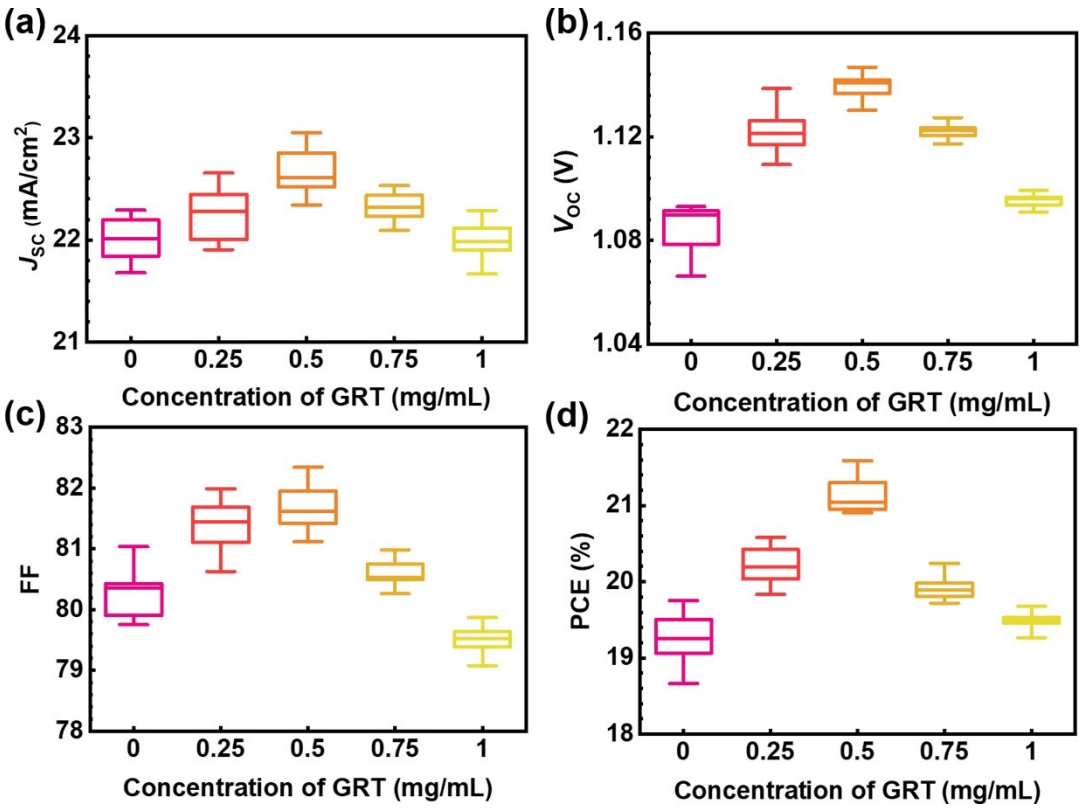

Fig. S10 Statistics of (a) J_{SC}, (b) V_{OC}, (c) FF, and (d) PCE of PSCs based on SnO_2 modified by different concentrations of GRT.

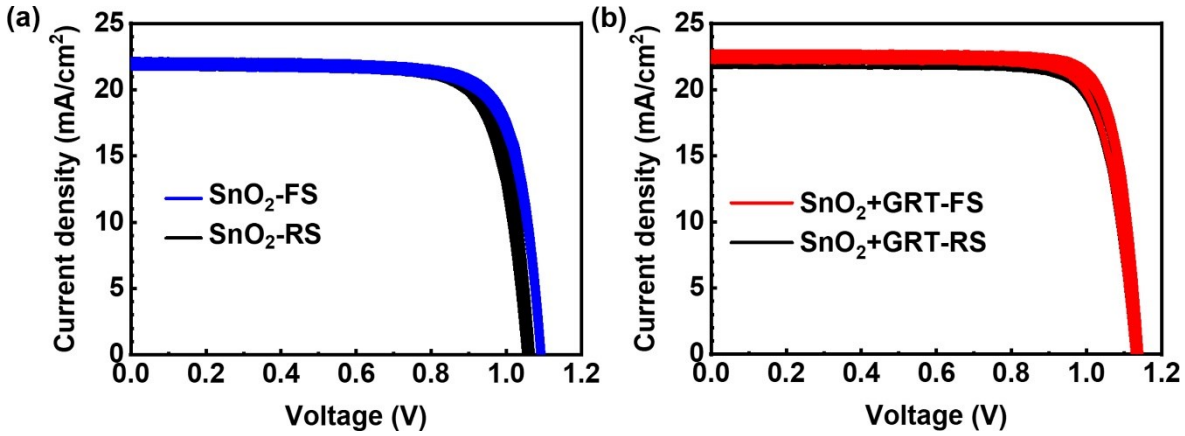

Fig. S11 *J-V* curves of the PSCs based on SnO_2 and SnO_2+GRT (0.5 mg/mL).

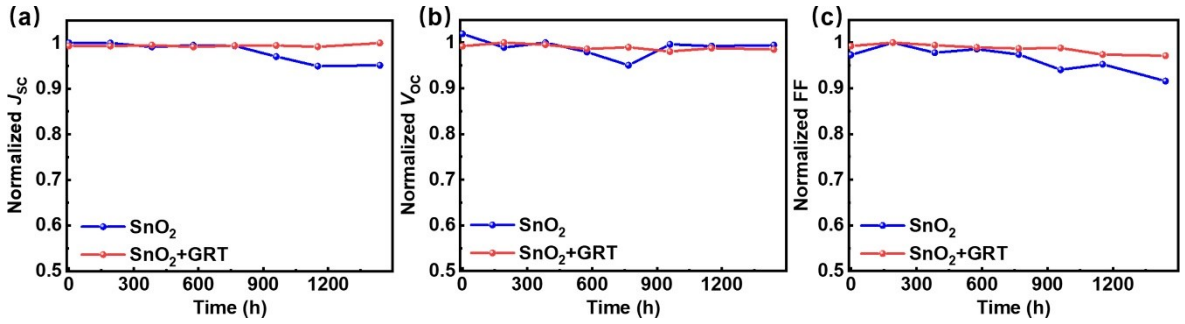

Fig. S12 (a) Normalized J_{SC}, (b) Normalized V_{OC}, and (c) Normalized FF as a function of time for the unencapsulated devices based on SnO_2 without and with GRT modification exposed to the humidity of 5-10 RH% at room temperature in the dark.

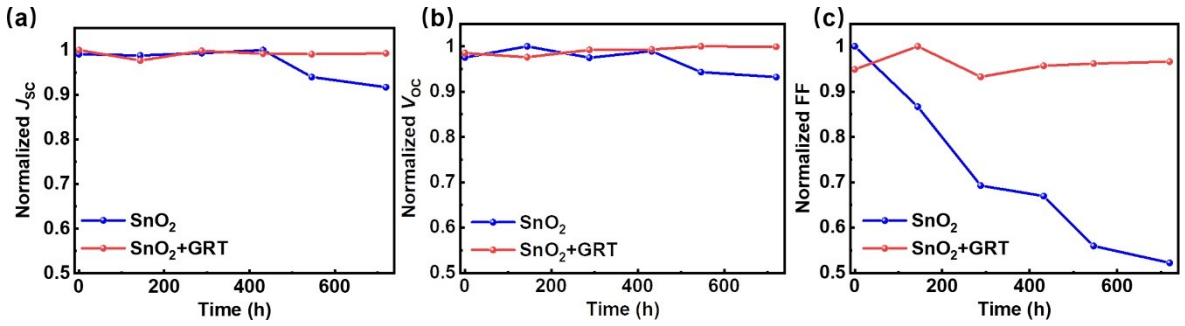

Fig. S13 (a) Normalized J_{SC}, (b) Normalized V_{OC}, and (c) Normalized FF as a function of time for the unencapsulated devices based on SnO_2 without and with GRT modification aged at 60 °C in the dark where the unencapsulated devices were located in the glovebox filled with nitrogen.

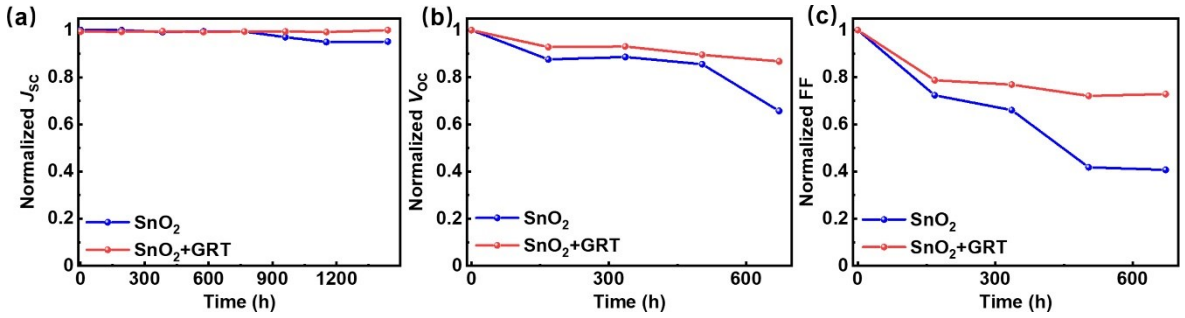

Fig. S14 (a) Normalized J_{SC}, (b) Normalized V_{OC}, and (c) Normalized FF as a function of time for the unencapsulated devices based on SnO_2 without and with GRT modification aged under one sun illumination at room temperature where the devices were located in the glovebox filled with nitrogen.

Table S1. Fitted results of TRPL curves of the perovskite films deposited on the different substrates without SnO_2, with SnO_2 or with SnO_2+GRT.

	Glass/PVSK	**Glass/SnO_2/PVSK**	**Glass/SnO_2+GRT/ PVSK**
τ_1 (ns)	963.16	498.06	402.71
%	26.78	37.17	36.67
τ_2 (ns)	2590.68	2002.78	1129.50
%	73.22	62.83	63.33
τ_{ave} (ns)	2399.99	1809.78	1002.20

Table S2. The fitted EIS parameters of the devices based on SnO_2 and SnO_2+GRT ETLs, respectively.

ETL	R_s (Ω)	R_{ct} (Ω)	R_{rec} (Ω)
SnO_2	5.43	2006	1356
SnO_2+GRT	4.42	1560	2526

Table S3. Photovoltaic parameters of the PSCs based on SnO_2 modified with different concentrations of GRT from 0 to 1 mg/mL.

GRT (mg/mL)		J_{SC} (mA/cm^2)	V_{OC} (V)	FF	PCE (%)
0	Champion	22.64	1.075	0.812	19.77
	Average	21.98±0.19	1.083±0.009	0.803±0.004	19.23±0.32
0.25	Champion	22.65	1.118	0.813	20.62
	Average	22.23±0.22	1.121±0.006	0.814±0.004	20.20±0.26
0.5	Champion	22.92	1.146	0.823	21.63
	Average	22.67±0.20	1.139±0.004	0.817±0.003	21.19±0.22
0.75	Champion	22.49	1.120	0.805	20.28
	Average	22.30±0.12	1.122±0.004	0.805±0.002	19.92±0.16
1	Champion	22.27	1.096	0.797	19.47
	Average	22.00±0.15	1.095±0.05	0.795±0.002	19.48±0.12