Supporting Information for

Trap engineering using oxygen-doped graphitic carbon nitride for high-performance perovskite solar cells

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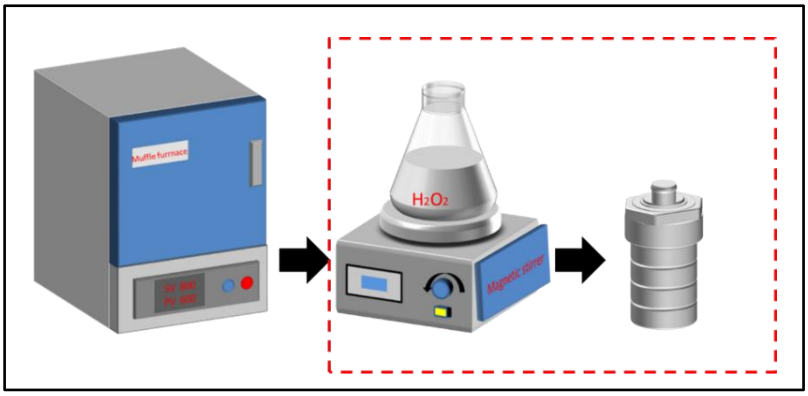

Fig. S1 The preparation process of g-C_3N_4 and g-C_3N_4-O.

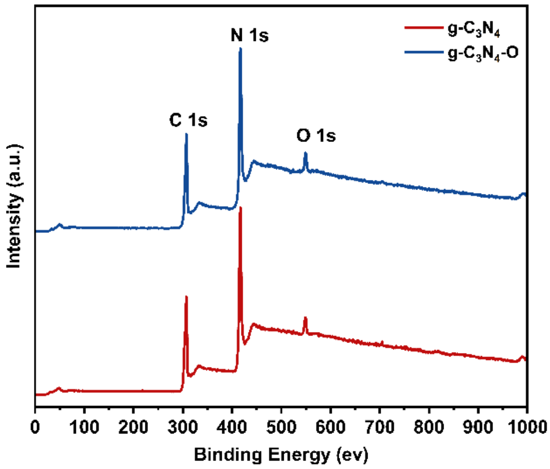

Fig. S2 The whole survey scan XPS spectra of g-C_3N_4 and g-C_3N_4-O.

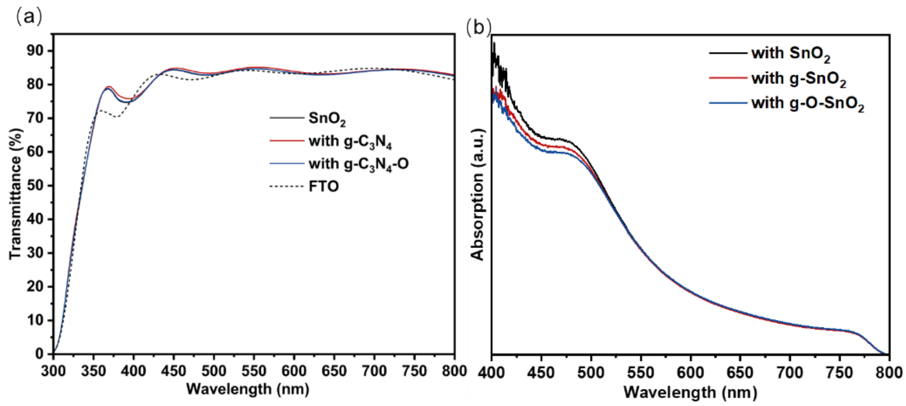

Fig. S3 (a) UV-vis transmittance spectra of different ETLs; (b) UV-vis absorption spectra of perovskite film deposited on different ETLs.

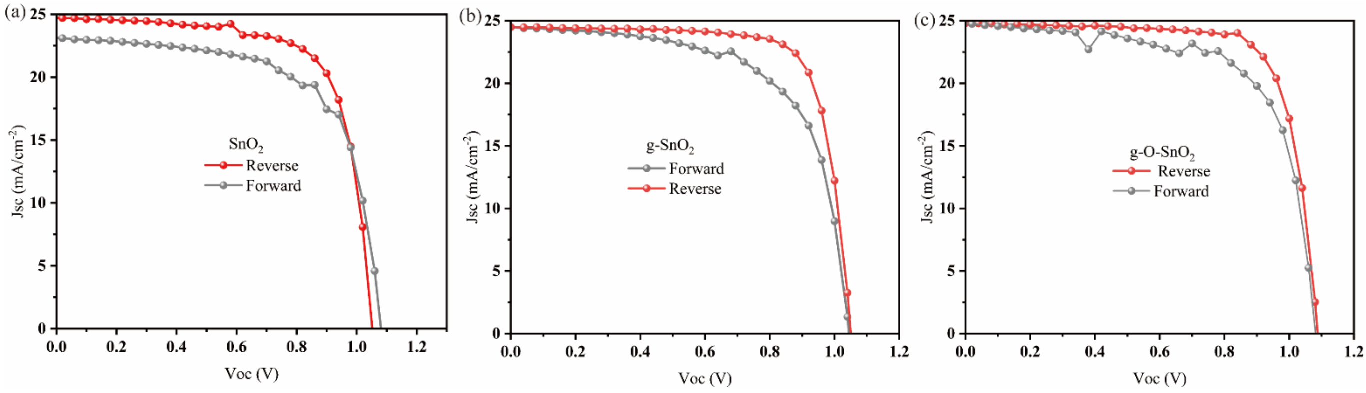

Fig. S4 *J-V* curves of $MA_{0.7}FA_{0.3}PbI_3$ perovskite solar cells with different ETLs(SnO_2 (a),g-SnO_2 (b) and g-O-SnO_2 (c)) under reverse and forward scans.

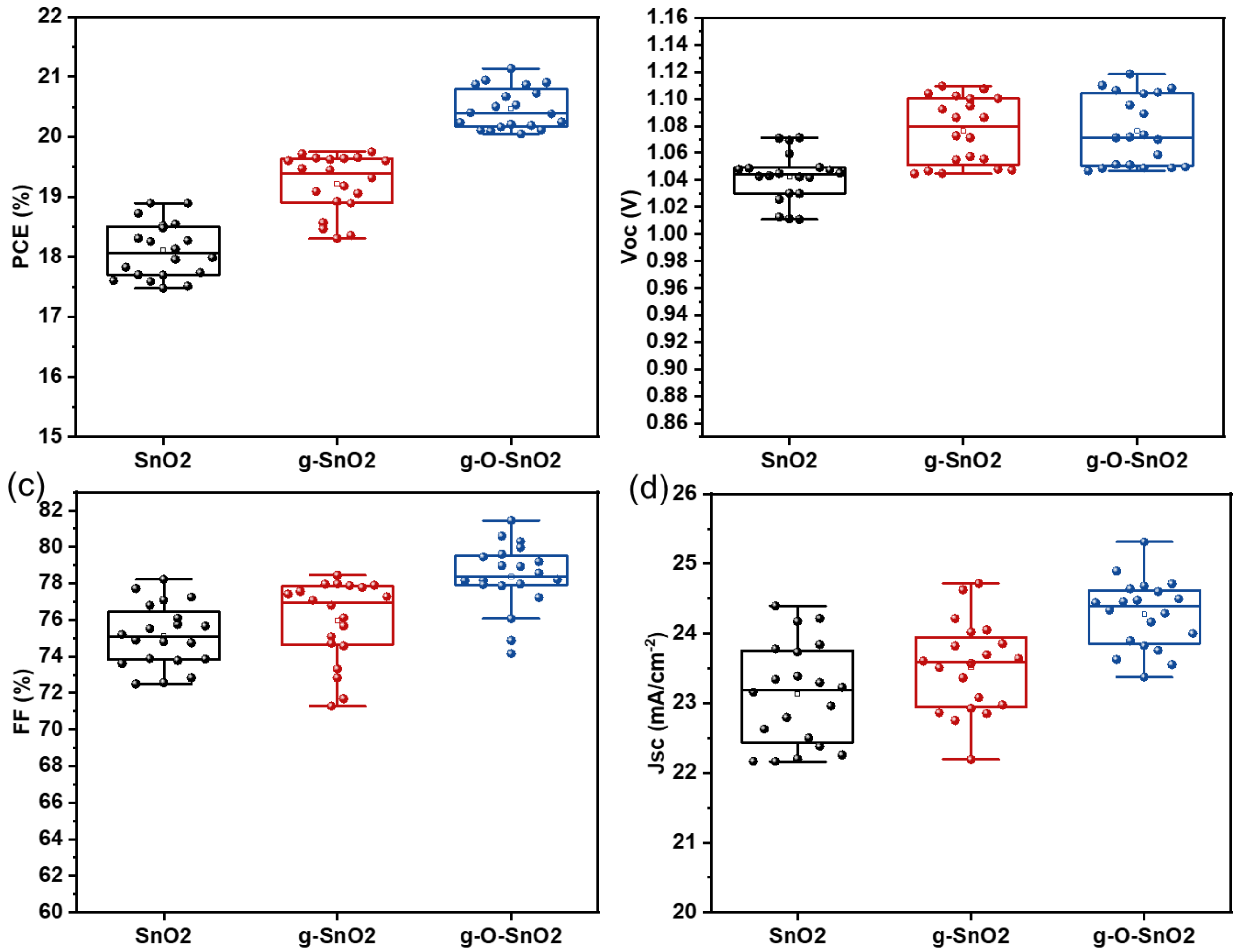

Fig. S5 Statistic of thePCE(a), Jsc(b), Voc(c) and FF(d) values of PVSCs with different ETLs (SnO_2,g-SnO_2 and g-O-SnO_2).

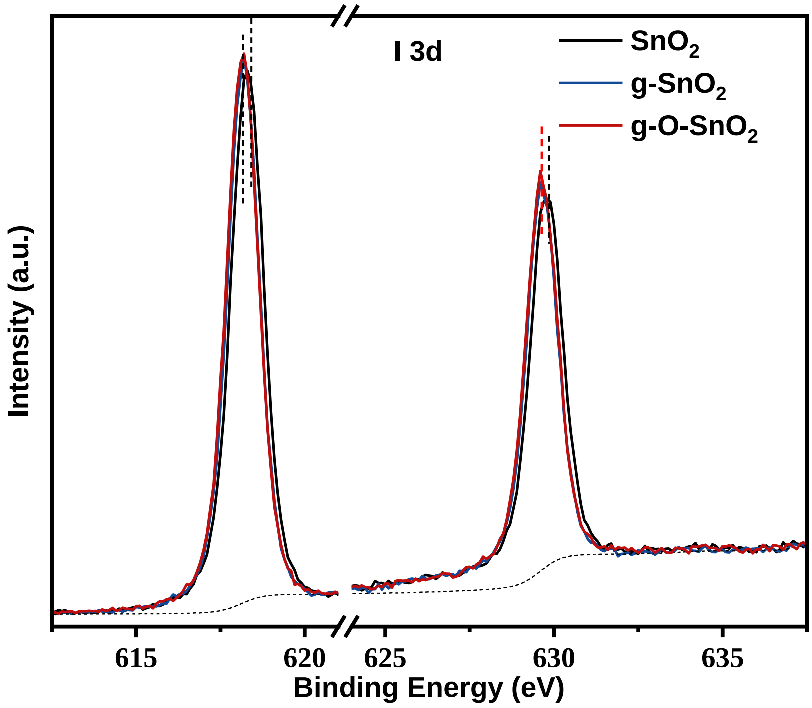

Fig. S6 I 3d XPS spectra for perovskite films doposited on different ETLs.

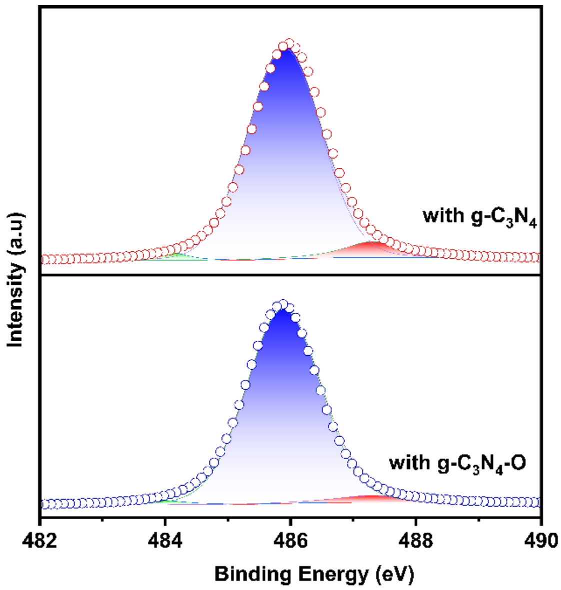

Fig. S7 XPS spectra of Sn atoms in different SnO_2.

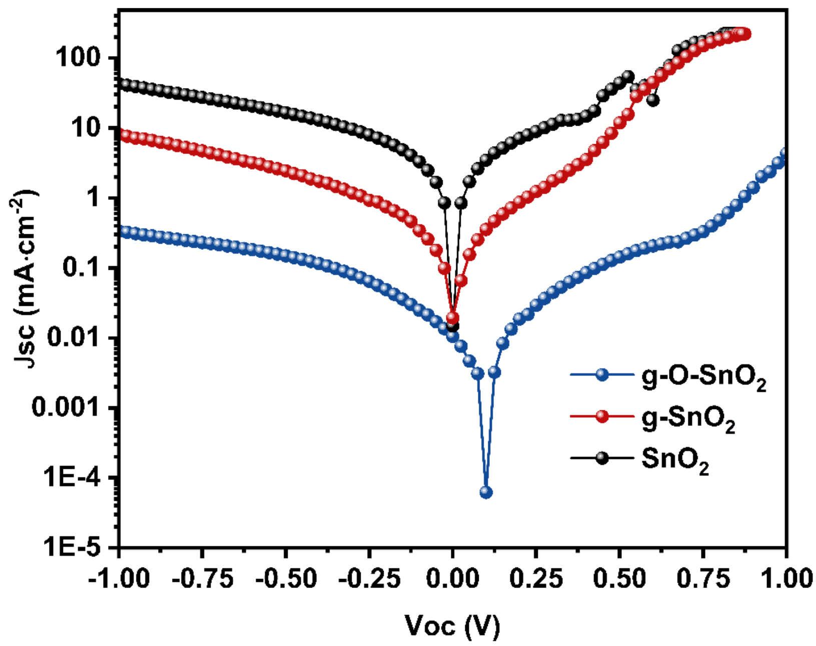

Fig. S8 The J-V under dark condition on a semi-log plot with different ETLs.

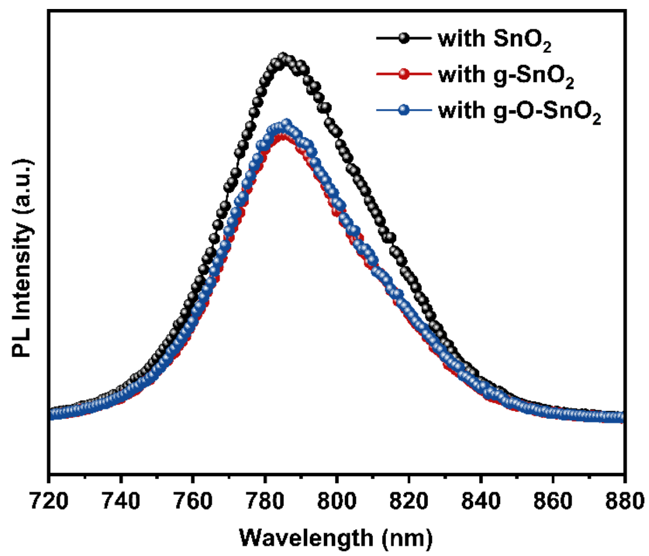

Fig. S9 Steady-state photoluminescence (PL) of perovskite films on different ETLs.

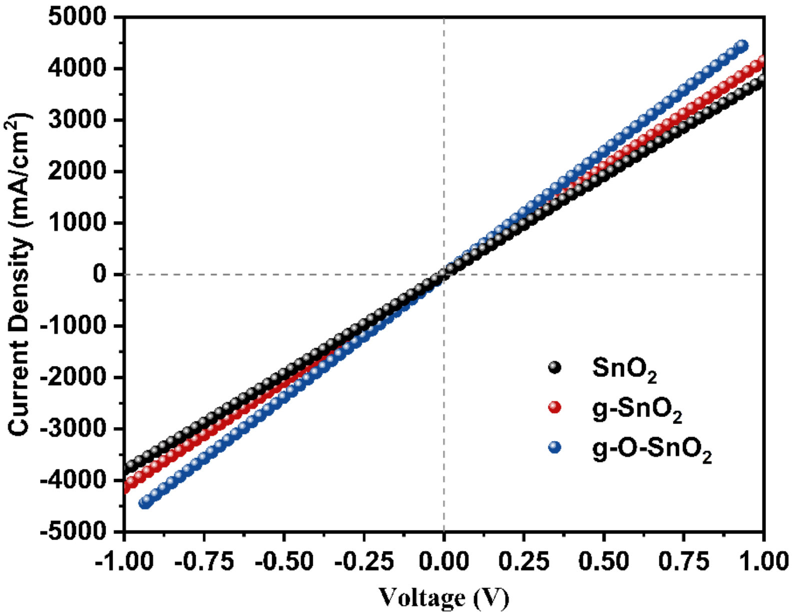

Fig. S10 I-V characteristics of SnO_2, g-SnO_2 and g-O-SnO_2 thin films

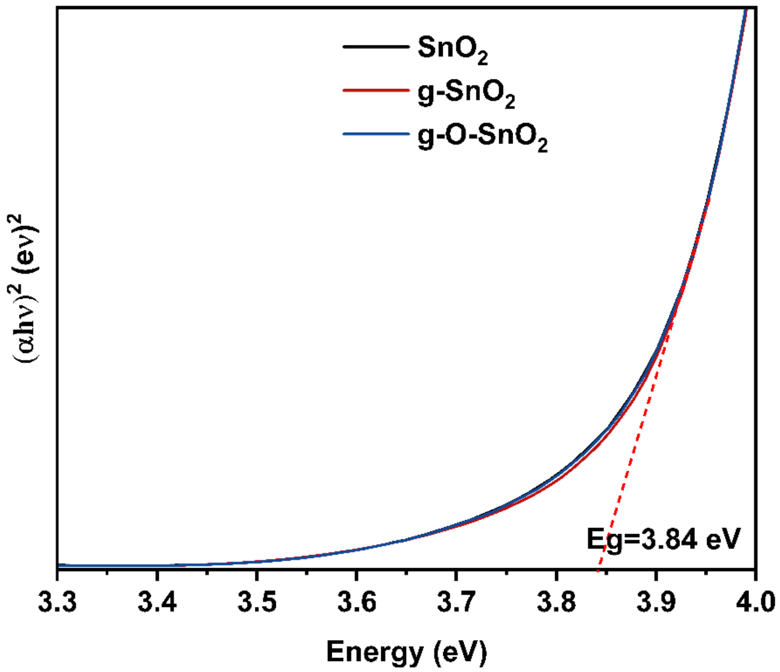

Fig. S11 The bandgap diagrams of different electron transport layers(SnO_2, g-SnO_2 and g-O-SnO_2).

Table S1. Summary of the photovoltaic performance of devices based on different ETLs.

Sample	J_{SC} (mA/cm^2)	V_{OC}(V)	Fill Factor (%)	PCE (%)
SnO_2	23.22	1.05	77.71	18.95
g-SnO_2	23.08	1.10	77.79	19.75
g-O-SnO_2	24.44	1.11	77.94	21.14

Table S2. Statistics on the photoelectric conversion efficiency of binary perovskite solar cells.

Year	Perovskite(additive)	Device Configuration	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF (%)	PCE (%)	Ref
2017	$(FAPbI_3)_{0.85}(MAPbBr_3)_{0.15}$	FTO/TiO_2/TiO_2/ perovskite/ Spiro-OMeTAD/ Au	1.16	23.18	78	21.3	[1]
2017	$(FA_{0.85}MA_{0.15})_{1-x}Pb(I_{0.85}Br_{0.15})_3$ （KI）	FTO/TiO_2:LiMg/TiO_2:Li/ perovskite/Spiro-OMeTAD/ Au	1.167	22.99	76	20.32	[2]
2017	$(FAPbI_3)_{0.85}(MAPbBr_3)_{0.15}$	FTO/c-SnO_2/$(FAPbI_3)_{0.85}(MAPbBr_3)_{0.15}$/spiro-OMeTAD /Au	1.05	22.8	66.2	15.8	[3]
2017	$(FA_{0.85}MA_{0.15})_{0.95}Pb(I_{0.85}Br_{0.15})_3$（KI）	FTO/SnO_2(sol-gel)/ perovskite/Spiro-OMeTAD/ Au	1.132	22.95	79	20.56	[4]
2018	$FA_{0.85}MA_{0.15}PbBr_{0.45}I_{2.55}$ （KI）	FTO/TiO_2:LiMg/ TiO_2:Li/perovskite/Spiro-OMeTAD/Au	1.154	22.92	77.7	20.55	[5]
2018	$MAFAPbI_{3-x}Cl_x$	FTO/TiO_2/perovskite Spiro-OMeTAD/Au	1.04	22.7	75	17.7	[6]
2018	$(FAPbI_3)_{0.85}(MAPbBr_3)_{0.15}$	(FTO)/TiO_2/perovskite/ Spiro-OMeTAD/Au	1.07	23.76	80	20.31	[7]
2019	$FA_{0.93}MA_{0.07}PbI_3$	ITO/SnO_2/Perovskite/ PEAI/Spiro/Au	1.18	25.2	78.4	23.32	[8]
2019	$MAxFA_{1-x}PbI_{3-y}Br_y$	ITO/c-SnO_2/$MAxFA_{1-x}PbI_{3-y}Br_y$ + MWCNTc /C	1.04	23.5	66.5	16.3	[9]
2019	$FA_{0.83}MA_{0.17}Pb(I_{0.83}Br_{0.17})_3$（KI）	FTO/TiOx/perovskite/ Spiro-OMeTAD/Ag	1.15	23.5	75	20.4	[10]
2019	MA:FA:Pb:I:Cl=1:1:1:3:1	FTO/SnO_2/perovskite/ Spiro-OMeTAD /Ag	1.06	23.75	81	20.39	[11]
2020	$MAFAPbI_3Cl_{3-x}$	ITO/SnO_2:GQDs/$MAFAPbI_3Cl_{3-x}$/spiro-OMeTAD/Ag	1.11	24.4	0.78	21.1	[12]
2020	$MAFAPbI_3$(TD-NT)	FTO/TiO_2/perovskite/Spiro-OMeTAD/Au	1.14	23.85	68.32	19.14	[13]
2021	$(FAPbI_3)_{0.93}MAPbBr_3)_{0.07}$	FTO/TiO_2/perovskite/spiro-MeOTAD/Au	1.017	22.196	72.176	16.301	[14]
2021	FAPbI(47% MAI)	ITO/MeO-2PACz perovskite/C_{60}/BCP/Cu	1.05	25.70	75.91	20.4	[15]
2021	$(FAPbI_3)_{0.95}(MAPbBr_3)_{0.05}$ （5%HACL）	(FTO)/NiO/perovskite/Spiro-OMeTAD/Au	1.11	24.75	81.03	22.32	[16]
2022	$(MA_{0.5}FA_{0.5})PbI_3$ （TAA）	FTO/c-TiO_2/mp-TiO_2/perovskite/spiro-MeOTAD/Au	1.109	24.62	78	21.29	[17]
2022	$MAFAPbI_{3-x}Cl_x$	ITO/SnO_2/	1.05	20.94	74.08	16.26	[18]

Year	Perovskite(additive)	Device Configuration	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF (%)	PCE (%)	Ref
2022	$MAxFA1\text{-}xPbI_3$	perovskite/P3HT/Au $FTO/TiO_2/ZnO$/perovskite/ Spiro-OMeTAD /MoO_3/Ag	0.99	21.2	0.67	14.1	[19]
2022	$MA_{0.7}FA_{0.3}PbI_3$	FTO/SnO_2/perovskite/ Spiro-OMeTAD/Ag	1.11	24.44	77.94	21.14	our work

Table S3. The specific numerical value of the Sn atom in SnO_2 XPS spectrum.

		Position	**Area**	**Ration**	**Sn^{4+}/sn^{2+}**
$G\text{-}SnO_2$	Sn	484.08	14264	0.022088	13.69
	Sn^{4+}	485.88	588515	0.911334	
	Sn^{2+}	487.28	42994	0.066578	
$G\text{-}O\text{-}SnO_2$	Sn	483.88	16452	0.022681	22.79
	Sn^{4+}	485.88	679125	0.936237	
	Sn^{2+}	487.28	29799	0.041082	

Table S4. TRPL decay-time fitting for perovskite films deposited on different electron transport layers.

Sample	τ_1 (ns)	A1 (%)	τ_2 (ns)	A2 (%)	$\tau_{average}$ (ns)
$PVK+SnO_2$	46.8165	42.90	194.3809	57.10	171.77
$PVK+g\text{-}SnO_2$	42.5370	52.34	96.3990	47.66	78.82
$PVK+g\text{-}O\text{-}SnO_2$	35.3823	37.26	127.4703	62.74	114.44

Table S5. The energy data of SnO_2, $g\text{-}SnO_2$ and $g\text{-}O\text{-}SnO_2$ from UPS measurements

Sample	**E_{cutoff} (eV)**	**W_F (eV)**	**E_F (eV)**	**E_{VBM} (eV)**	**E_{CBM} (eV)**
SnO_2	17.19	4.01	-4.01	-7.73	-3.89
$g\text{-}SnO_2$	17.25	3.95	-3.95	-7.71	-3.87
$g\text{-}O\text{-}SnO_2$	17.51	3.69	-3.69	-7.49	-3.65

Work function (W_F) is evaluated by the formula: $W_F = h\upsilon - E_{cutoff}$

Fermi level energy (E_F) is evaluated by the formula: $E_F = - W_F$

$h\upsilon$ is the photon energy of irradiation light. (21.2 eV)

Valence band energy level (E_{VBM}) is evaluated by the formula: $E_{VBM} = E_F\text{-}E_g$

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