Supplementary Information
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Largely Enhanced V_{OC} and Stability in Perovskite Solar Cells with Modified Energy Match by Couple 2D Interlayers

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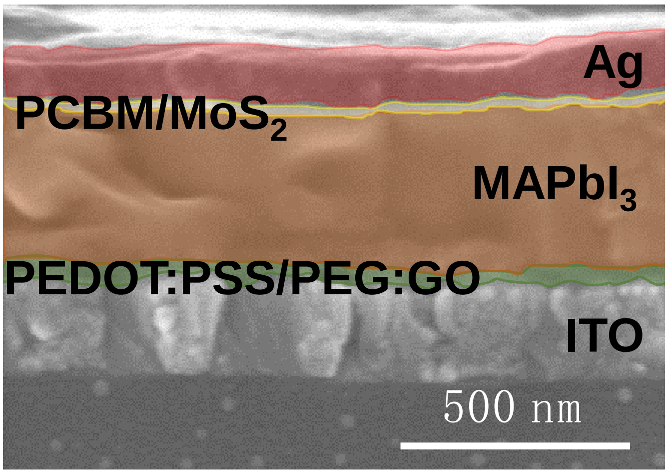

Fig. S1. Cross section SEM image of devices with both of MoS_2 and PEG:GO interfaces.

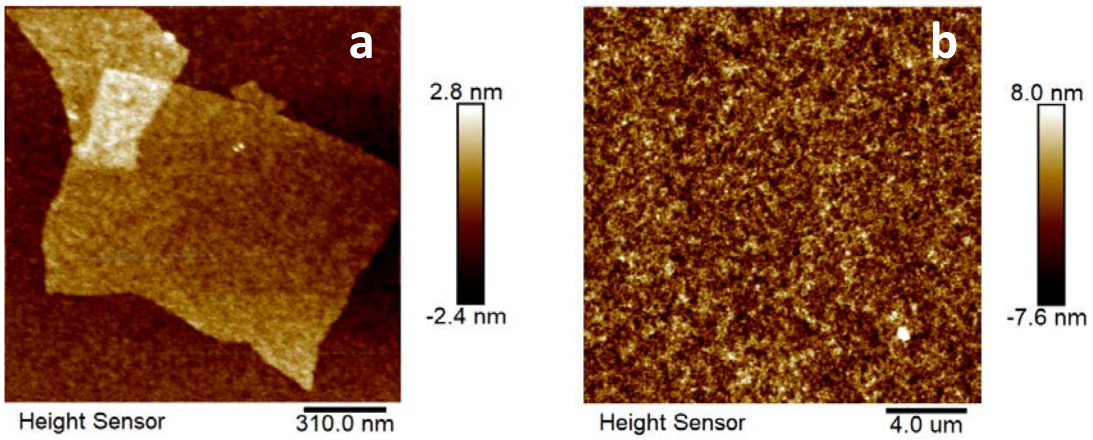

Fig. S2. The AFM images of PEG:GO/PEDOT:PSS (a) and 3 nm MoS_2 (b) films deposited on the underlayers.

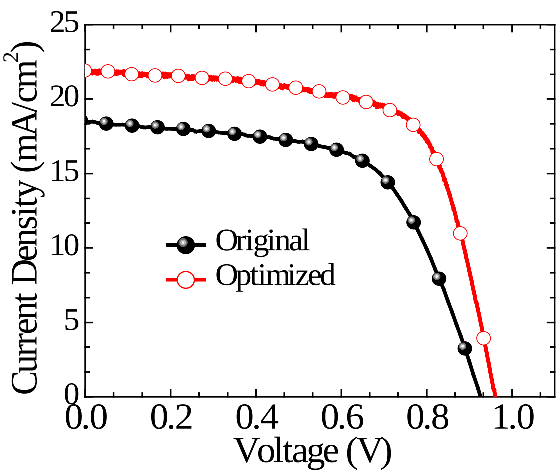

Fig. S3. J-V curves of devices based on films prepared via the original process in our earlier work and the optimized process in this work.

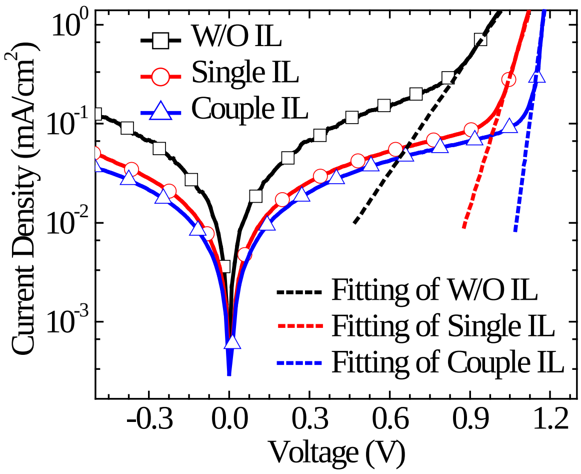

Fig. S4. J-V curves of devices with different ILs in the dark.

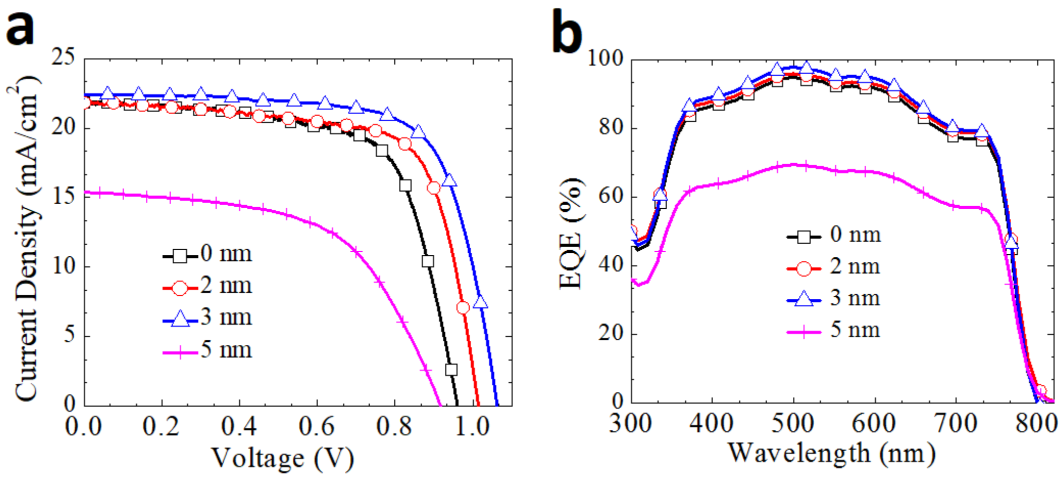

Fig. S5. MoS_2 thickness-dependent device performances. Current density–voltage (J–V) (a) and EQE (b) characteristics of devices modified by MoS_2 with different thickness of 0, 2, 3 and 5 nm.

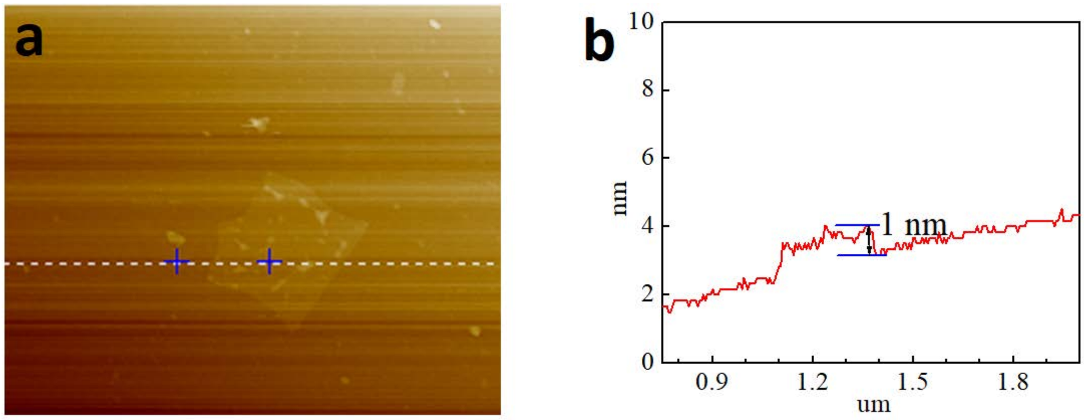

Fig. S6. AFM image (a) and section profiles (b) of PEG:GO films deposited on PEDOT:PSS.

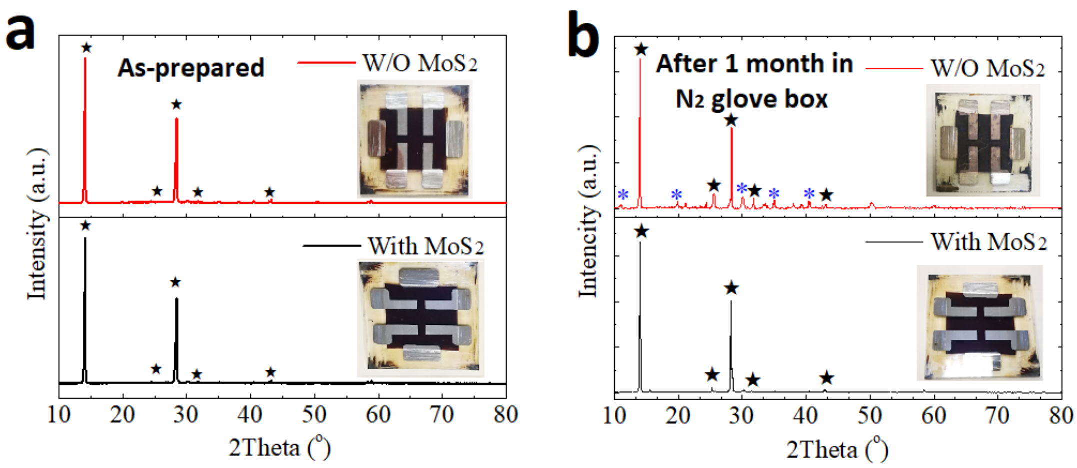

Fig. S7. The aging test for devices modified without or with MoS_2 films. (a) The XRD spectrum of perovskite films in as-prepared devices shown in inserted figures. (b) The XRD spectrum of perovskite films in devices that were stored for 1 month in glove box shown in inserted figures.

Tab. S1. Different performances of devices based on films prepared via the original process and optimized in later work.

Device	V_{OC} (V)	J_{SC} (mA/cm^2)	FF (%)	PCE (%)
Original	0.923	18.501	60.8	10.38
Optimized	0.962	21.743	67.6	14.15

Tab. S2. The parameters of ITO/PEDOT:PSS/$MAPbI_3$/PCBM/MoS_2/Ag devices with different thichness of the MoS_2 layer.

Thickness of MoS_2	V_{OC} (V)	J_{SC} (mA/cm^2)	FF (%)	PCE (%)
0 nm	0.962	21.743	67.6	14.15
2 nm	1.017	21.814	70.4	15.62
3 nm	1.062	22.423	71.0	16.89
5 nm	0.917	15.392	56.2	7.94

Tab. S3. EIS parameters for the electrode films shown in Figure 5 (a, b).

Electrode Film	R_S (Ω)	R_1 (Ω)
PEDOT:PSS film without GO:PEG	30	1660
PEDOT:PSS film with GO:PEG	20	2970
Ag film without MoS_2	17	790
Ag film with MoS_2	9	1390

Tab. S4. PL life times fitted by a bi-exponential decay model for the data in Figure 5 (c, d).

Electrode Film	τ_1 (ns)	τ_2 (ns)
ITO/ PEDOT:PSS/$MAPbI_3$	4.4	35.2
ITO/ PEDOT:PSS/GO:PEG/$MAPbI_3$	1.8	15.2
$MAPbI_3$/PCBM/MoS_2/Ag	3.9	30.4
$MAPbI_3$/PCBM/Ag	1.0	12.2

Tab. S5. A comparison of performances obtained using halide perovskites $MAPbI_3$ in inverted planar heterojunction perovskite solar cells with different cathode metals reported in our work and others.

Cathode Metal	Work Function of Cathode Metal	V_{OC} (V)	J_{SC} (mA·cm^{-2})	FF	PCE (%)	ETL	Perovskite	HTL	Reference
Ag	4.7	1.135	22.834	0.73	19.14	PCBM/MoS_2	$MAPbI_3$	PEDOT:PSS	Our Work
Al	4.3	1.132	22.850	0.73	18.88	PCBM/MoS_2	$MAPbI_3$	PEDOT:PSS	
Al	4.3	0.98	19.8	0.70	13.58	ICBA/C60/BCP	$MAPbI_3$	PTAA	[1]
Cu	4.6	1.03	19.8	0.73	14.88	ICBA/C60/BCP	$MAPbI_3$	PTAA	
Au	5.1	0.98	19.8	0.63	12.22	ICBA/C60/BCP	$MAPbI_3$	PTAA	

References

(1) Y. Deng, Q. Dong, C. Bi, Y. Yuan, J. Huang, Adv. Energy Mater. 6 (2016) 1600372.