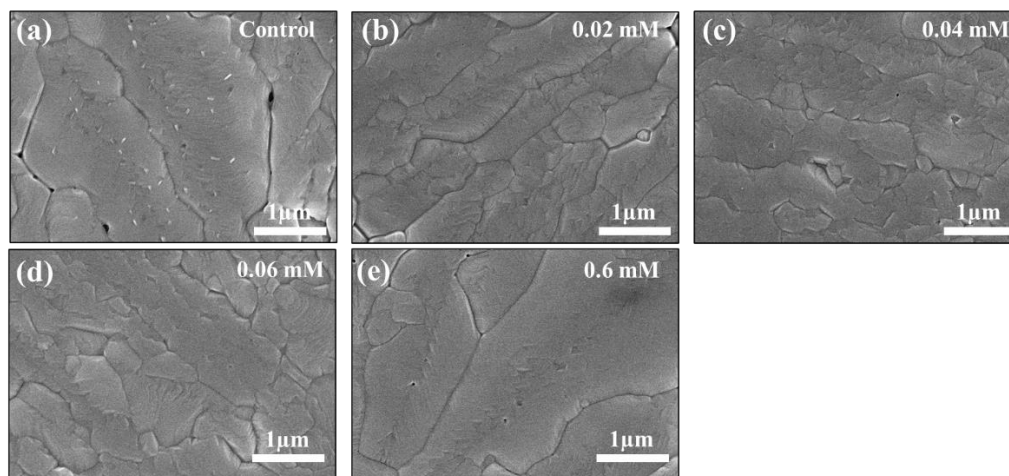
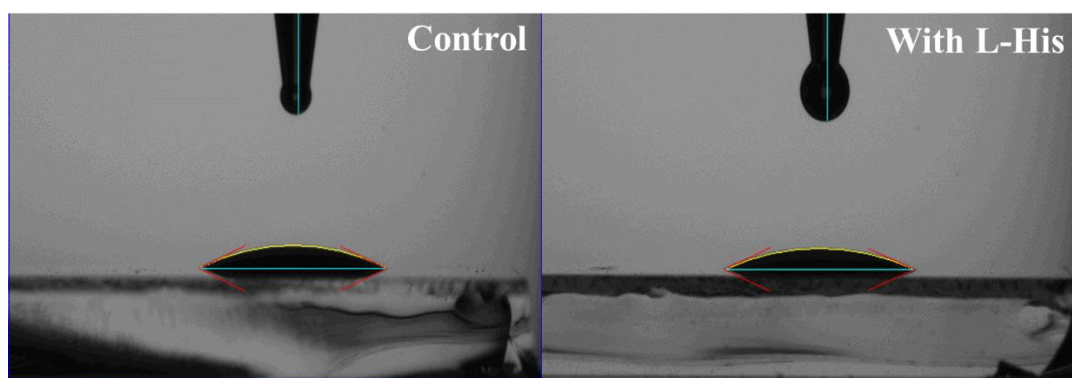


## **Supplementary information**

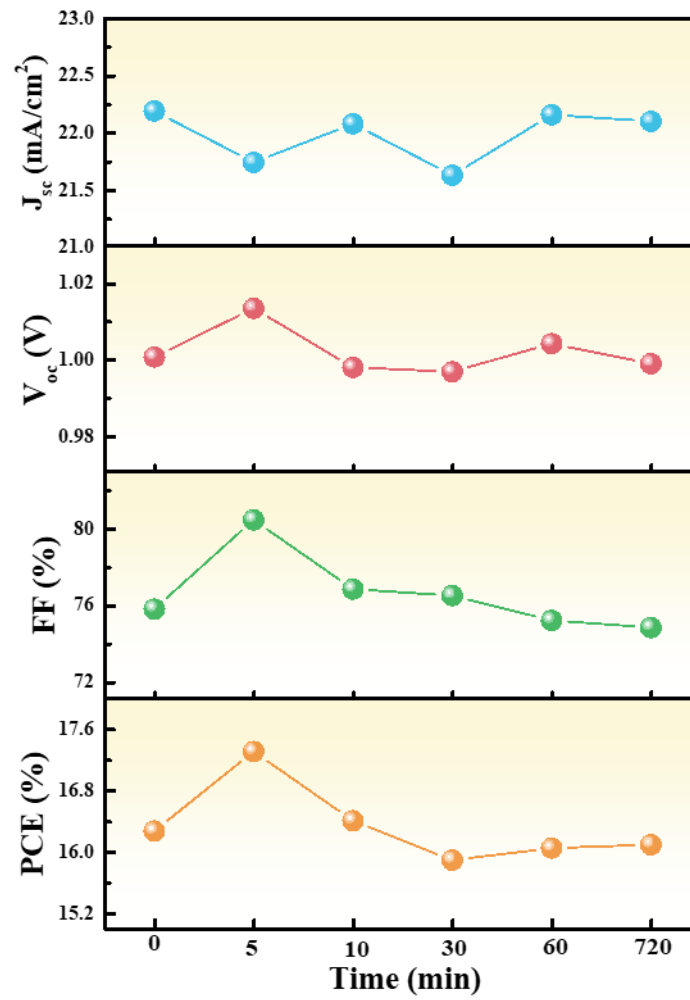
**Large-area Perovskite Solar Module Produced by Introducing Self-Assembled L-Histidine Monolayer between TiO<sub>2</sub> and Perovskite Interface**



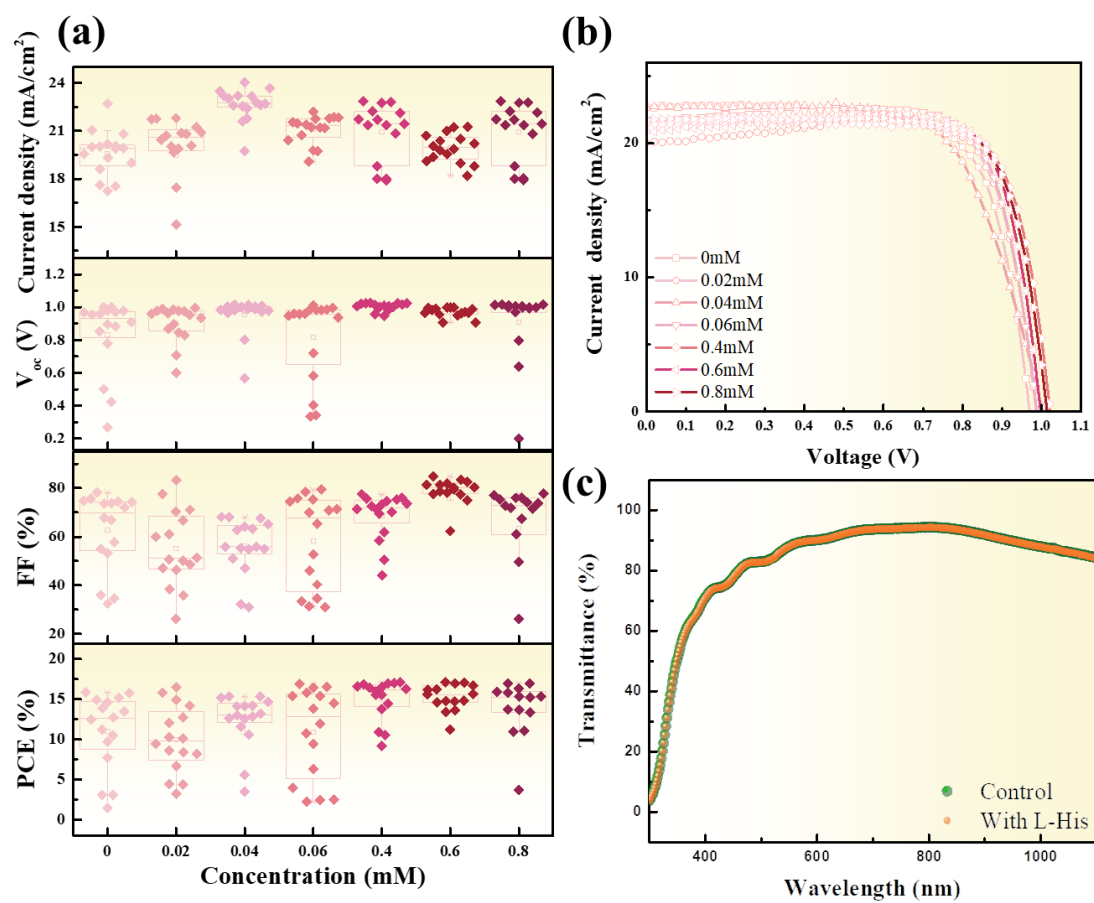
**Figure S1.** SEM images of perovskite films deposited on L-His with different concentration: (a) control, (b) 0.02mM, (c) 0.04mM, (d) 0.06mM, (e) 0.6mM.



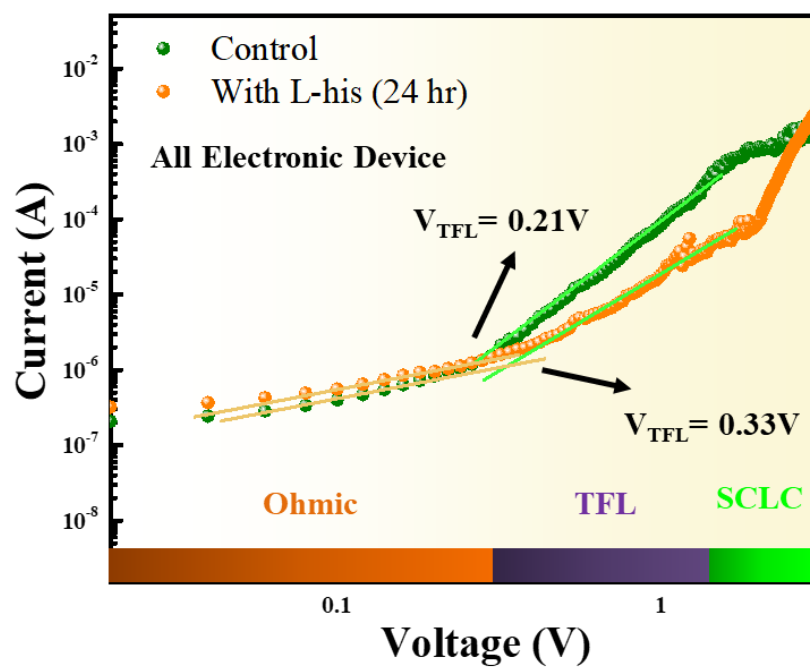
**Figure S2.** The contact angel of perovskite precursor (a) without (control) and (b) with L-His.



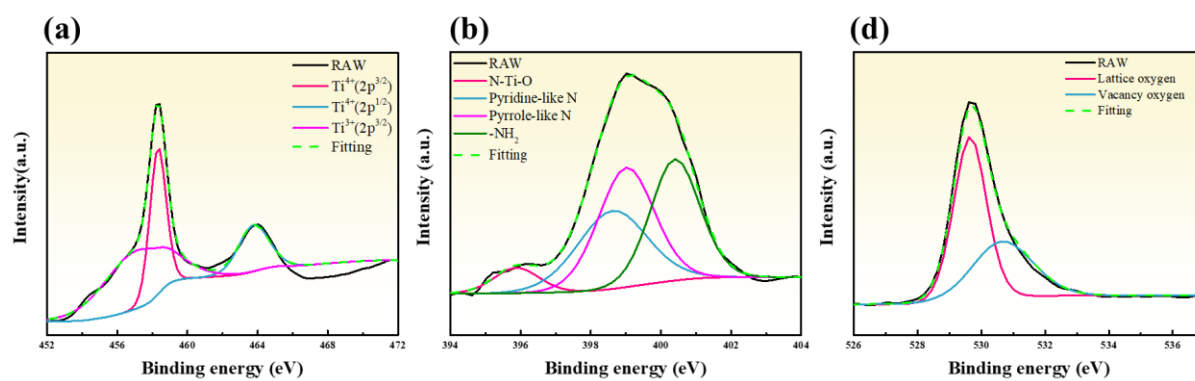
**Figure S3.** Photovoltaic performance of perovskite solar cells with different L-His deposition times.



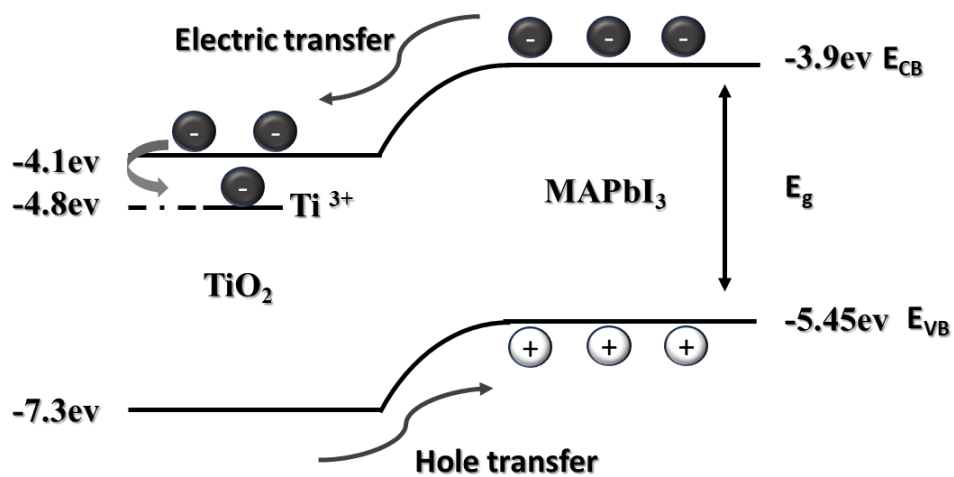
**Figure S4.** (a) I-V characteristics of the perovskite solar cell at different concentration of L-His. (b) I-V curve of perovskite solar cell. (c) Transmittance of TiO<sub>2</sub> layer with and without L-His (control).



**Figure S5.** Dark current of perovskite devices soaking L-his 24 hours and without L-his (control).



**Figure S6.** (a) XPS spectra of Ti 2p (b) N 1s O 1s transport layer/perovskite interface fitting curves with soaking L-his 24 hours.



**Figure S7.** Schematic representation of the defect energy levels in the  $\text{TiO}_2$  transport layer.



**Table S1.** Summary of different SAM Materials

SAM material	Solar cell	chemical properties	PSC performance	Reference
3-(Triethoxysilyl) propylamine (TSPA)	p-i-n (inverted)	The TSPA passivate hydroxyl group on the surface of the NiOx and improve defect passivation	20.21% (0.0464 cm <sup>2</sup> )	[7]
Bifunctional 4-picolinic acid	n-i-p	The COOH group is chemically grafted with mp-TiO <sub>2</sub>	18.9% (0.09 cm <sup>2</sup> )	[8]
glycine	n-i-p	Reducing the inevitable defects formed during crystallization of perovskite	12.02%	[9]
dopamine (DA)	n-i-p	Regulating growth and passivating surface trap states via N-H/I hydrogen-bonding interactions. The hydroxyl group reacts with SnO <sub>2</sub> to stabilize the perovskite structure.	16.87%	[23]
amino acid (AA)	p-i-n	The introduce of AAs into MAPbI <sub>3</sub> -based PSCs resulting in reductions in oxygen-induced photodegradation	20.1%	[24]
glycine	n-i-p	The carboxylic acid group of glycine reacts with surface hydroxyl groups of SnO <sub>2</sub>	20.68%	[18]
L-Histidine	n-i-p	The -NH <sub>2</sub> group can form hydrogen bonds with MA ions, while the carboxyl group can fill oxygen vacancies in the TiO <sub>2</sub> .	16.54% (25 cm <sup>2</sup> )	This work

**Table S2.** Trap-Filling Limited Voltage ( $V_{\text{TFL}}$ ) and trap density ( $N_t$ ) calculation of different electron transport layer from SCLC measurement.

Structure	$V_{\text{TFL}}$ (V)	$N_t$ (cm <sup>-3</sup> )
Control	0.21	$4.66 \times 10^{15}$
With L-His	0.17	$3.96 \times 10^{15}$

**Table S3.** Fitting parameters of TRPL spectra for perovskite with and without L-His

Structure	$\tau_{avg}$ (ns)	$\tau_1$ (ns)	$\tau_2$ (ns)
Control	56.42	68.58	12.26
With L-His	24.40	35.08	9.19

**Table S4.** XPS fitting data of Ti 2p with and without L-His

Structure	Ti <sup>4+</sup> (2p <sup>3/2</sup> )	Ti <sup>4+</sup> (2p <sup>1/2</sup> )	Ti <sup>3+</sup> (2p <sup>3/2</sup> )
Control	31.52% (459.30eV)	19.72% (464.79eV)	48.76% (457.95eV)
With L-His	37.87% (458.34eV)	19.70% (463.84eV)	42.43% (457.1eV)
With L-His (24 hours)	31.65% (458.31eV)	18.64% (463.77eV)	49.71% (457.12eV)

**Table S5.** XPS fitting data of N 1s with and without L-His

Structure	N-Ti-O	Pyridine like-N	Pyrrole like-N	-NH <sub>2</sub>
With L-His	3.3% (395.61V)	37.28% (399.13eV)	52.21% (399.42eV)	7.17% (400.53eV)
With L-His (24 hours)	5.96% (395.88V)	28.20% (398.62eV)	34.78% (399.01eV)	31.07% (400.40eV)

**Table S6.** XPS fitting data of O 1s with and without L-His

Structure	Lattice oxygen	Oxygen vacancy
Control	61.75% (530.60eV)	38.25% (531.34eV)
With L-His	71.99% (529.65eV)	28.01% (530.62eV)
With L-His (24 hours)	61.29% (529.64eV)	38.71% (530.65eV)