Supplementary Information (SI) for Energy & Environmental Science.

Supplemental Information

Buried interface engineering enables efficient and refurbished $CsPbI_3$ perovskite quantum dot solar cells

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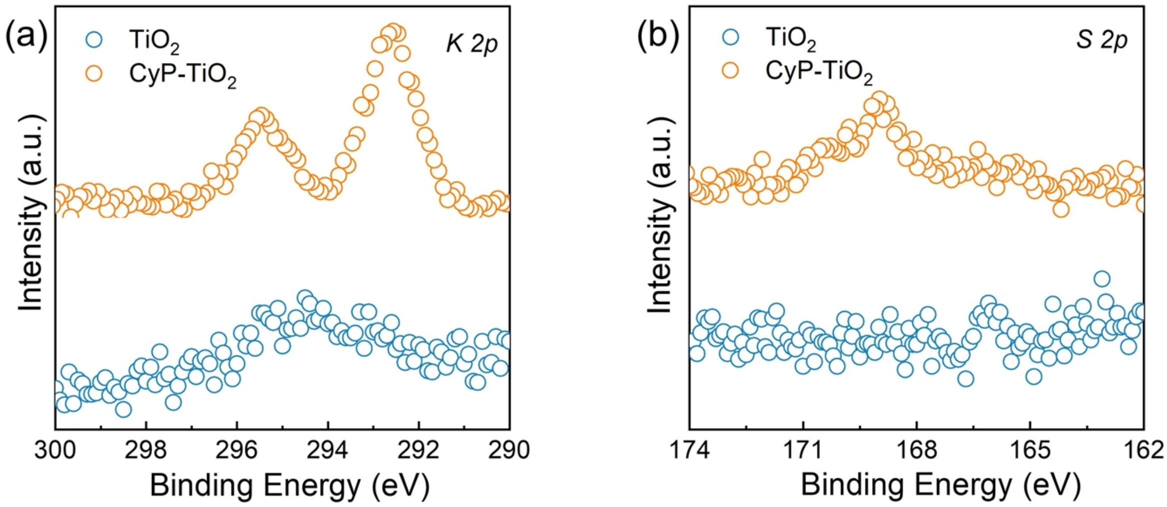

Fig. S1 (a-b) K 2*p*, and S 2*p* XPS spectra of TiO_2 and CyP-coated TiO_2 films.

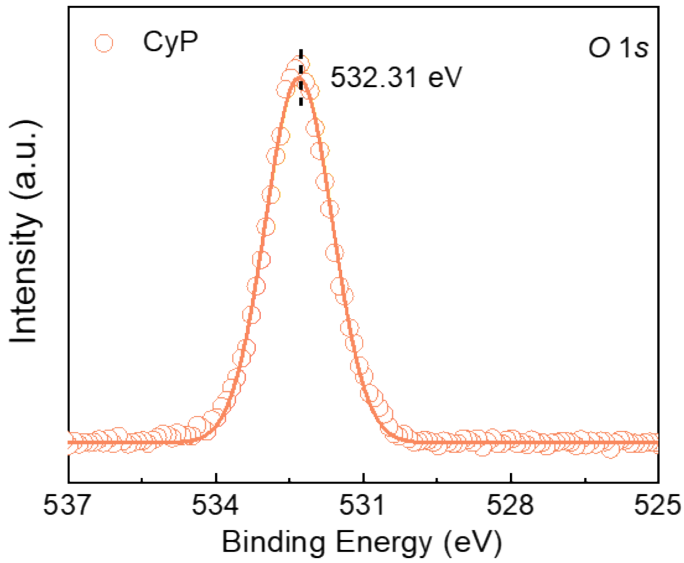

Fig. S2 O 1*s* XPS spectra of CyP molecule.

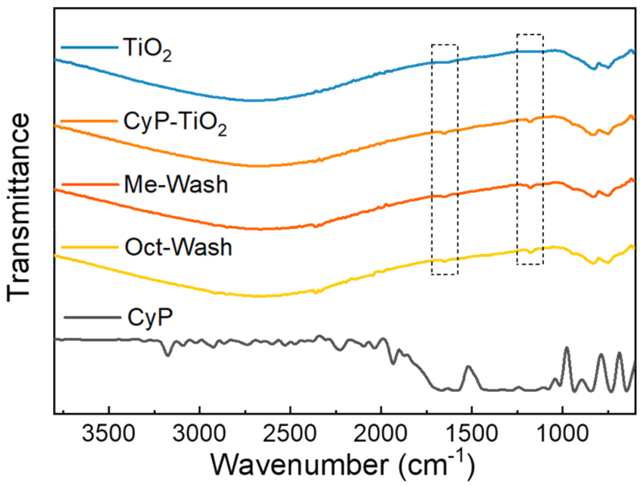

Fig. S3 The full FTIR spectra of TiO_2, CyP-TiO_2, Methyl acetate washed TiO_2, Octane washed TiO_2, and CyP samples.

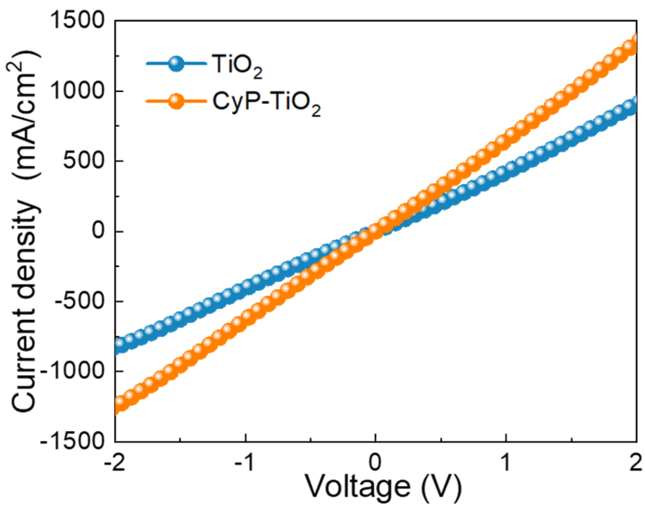

Fig. S4 *J*–*V* curves of devices structured as FTO/ETLs/Ag.

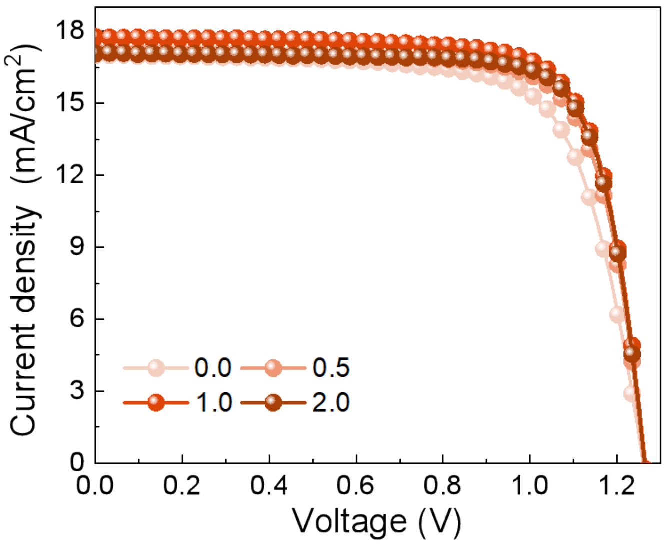

Fig. S5 *J–V* curves of CyP-engineered $CsPbI_3$ QD solar cells with different concentrations of CyP.

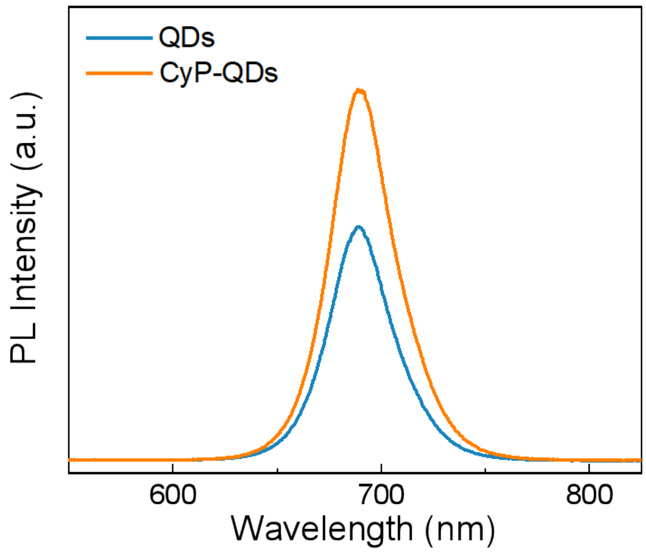

Fig. S6 Steady PL spectra of QD films deposited on quartz substrates with and without CyP modification layer.

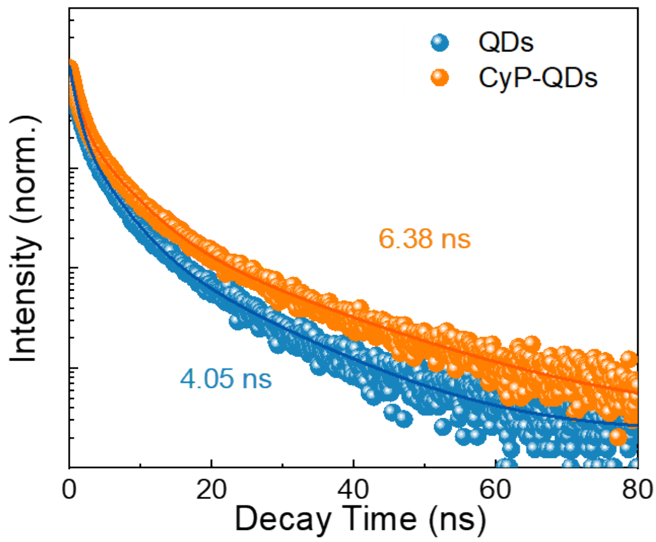

Fig. S7 TRPL spectra of QD films deposited on quartz substrates with and without CyP modification layer.

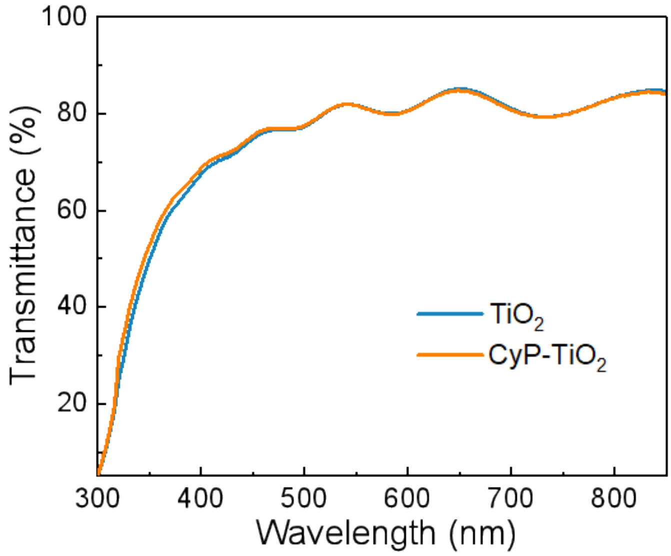

Fig. S8 Optical transmittance spectra of TiO_2/FTO and CyP-TiO_2/FTO films.

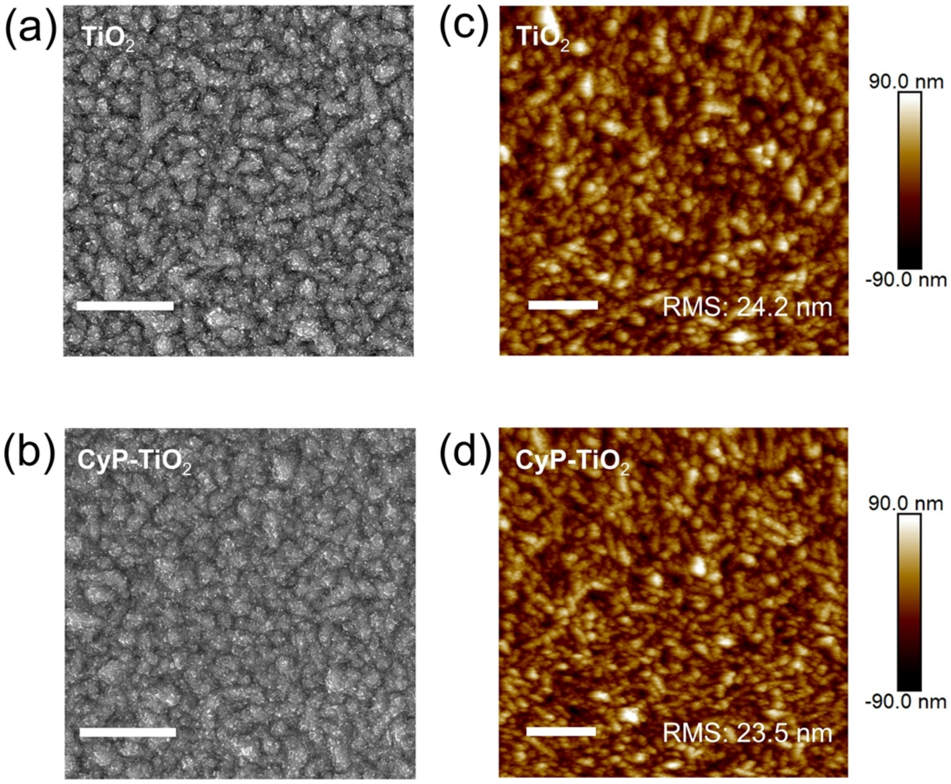

Fig. S9 (a-b) Top-view SEM images (scale bar is 1μm), (c-d) AFM images (scale bar is 1 μm) of TiO_2 and CyP-TiO_2 films, respectively.

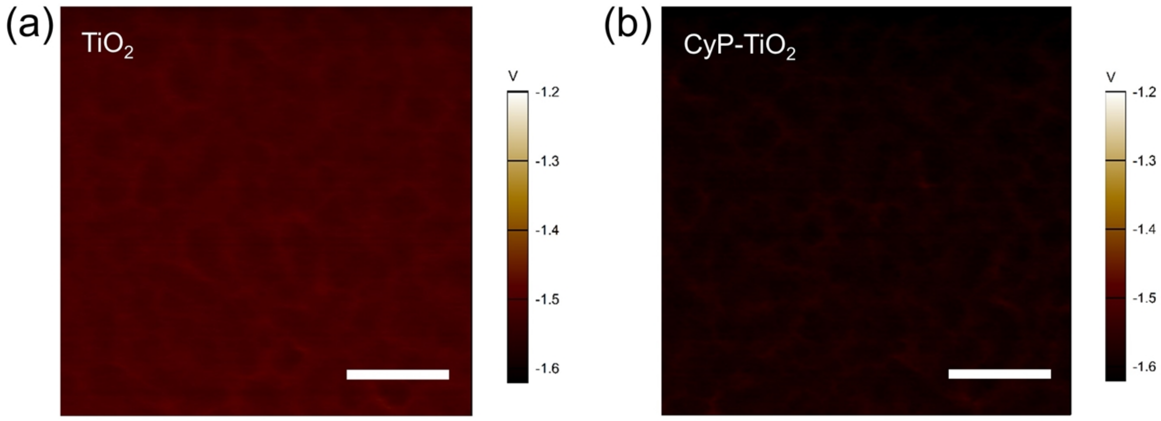

Fig. S10 (a-b) KPFM images of TiO_2 and CyP-TiO_2 films. (scale bar is 500 nm).

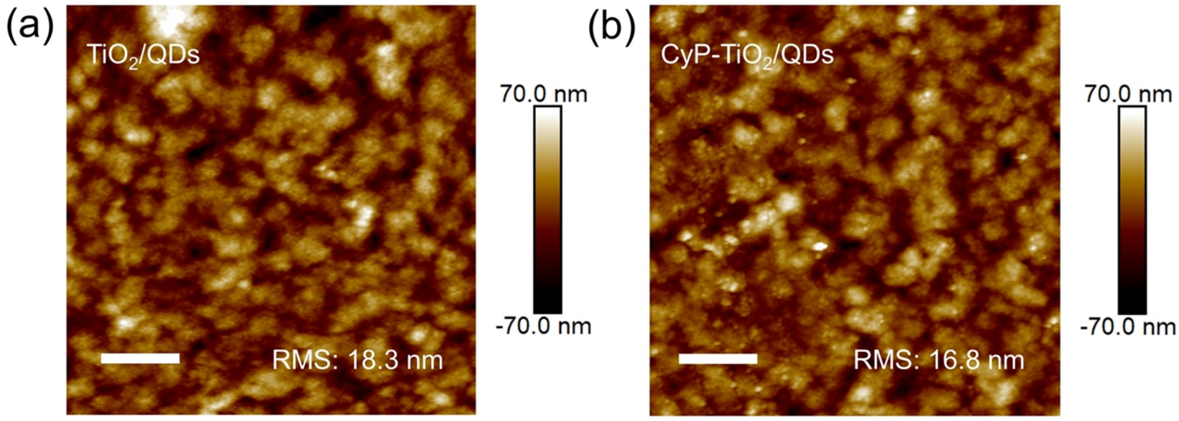

Fig. S11 (a-b) The AFM images (scale bar is 1 μm) of QD films deposited on the TiO_2 and CyP-TiO_2 films.

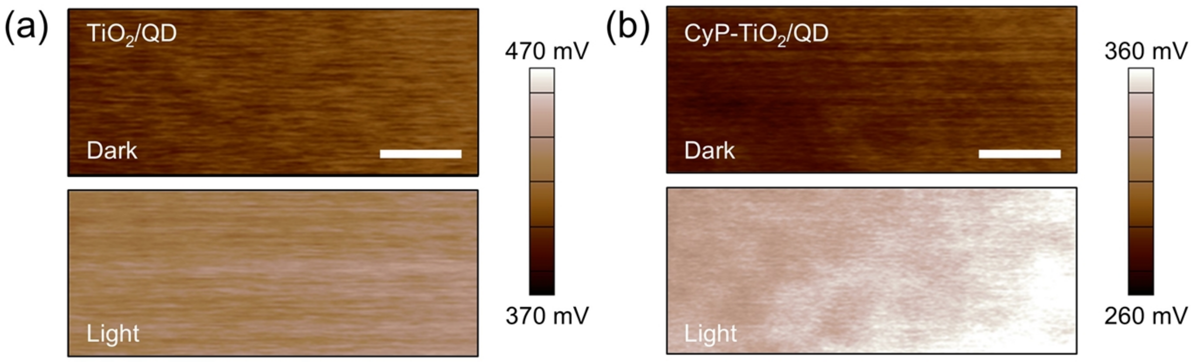

Fig. S12 (a) Surface potential mapping measured in the dark (average surface potential: 401.30 mV) and light (average surface potential: 434.24 mV) for QD film deposition on TiO_2, respectively. (b) Surface potential mapping measured in the dark (average surface potential: 288.27 mV) and light (average surface potential: 348.58 mV) for QD film deposition on CyP-TiO_2, respectively, the scale bar is 1 μm.

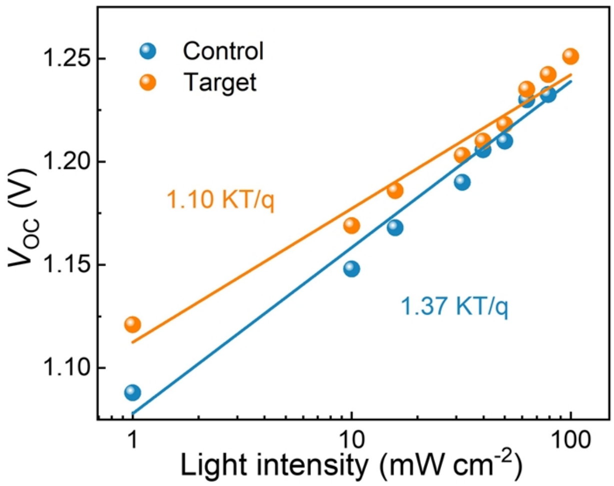

Fig. S13 The double-logarithmic I dependent V_{OC} curves of control and target cells.

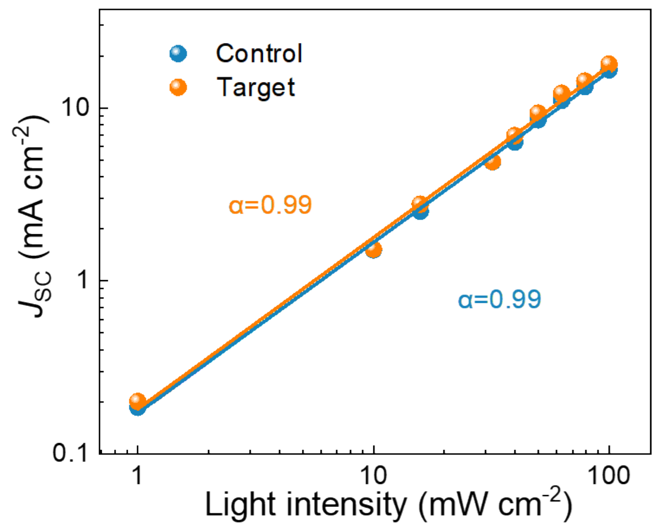

Fig. S14 The double-logarithmic I dependent J_{SC} curves of control and target cells.

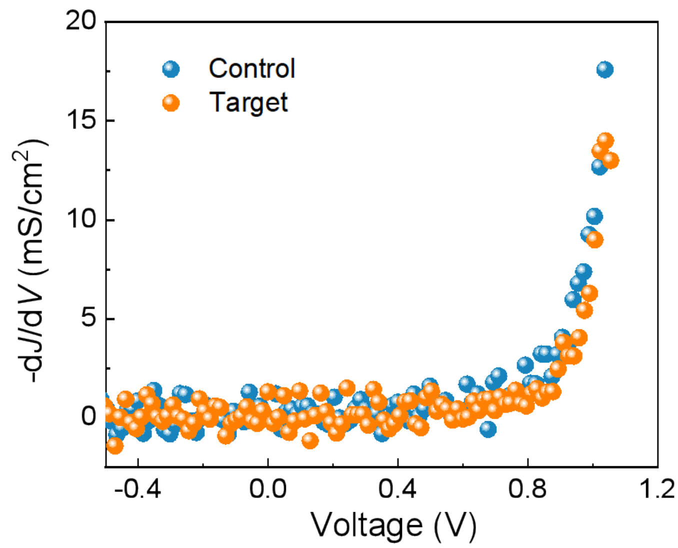

Fig. S15 The relationship of $-\mathrm{d}J/\mathrm{d}V$ with respect to voltage, which was derived from Fig. 2b.

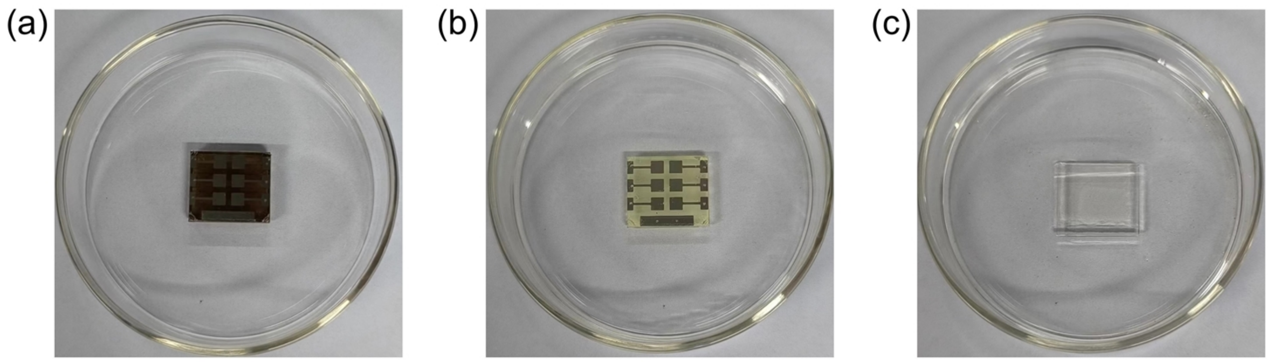

Fig. S16 Photographs of the process of recycling TiO_2/FTO. (a) Aged $CsPbI_3$ QD solar cells. (b) Aged solar cell after contacting with acetone solvent. (c) Clean TiO_2/FTO after ultrasound treatment.

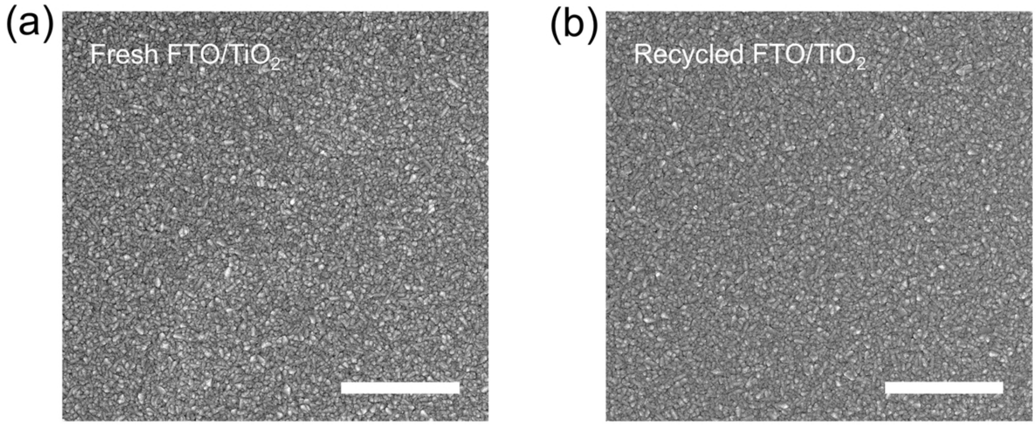

Fig. S17 (a-b) Top-view SEM images of fresh TiO_2/FTO and recycled TiO_2/FTO. (scale bar is 5 μm).

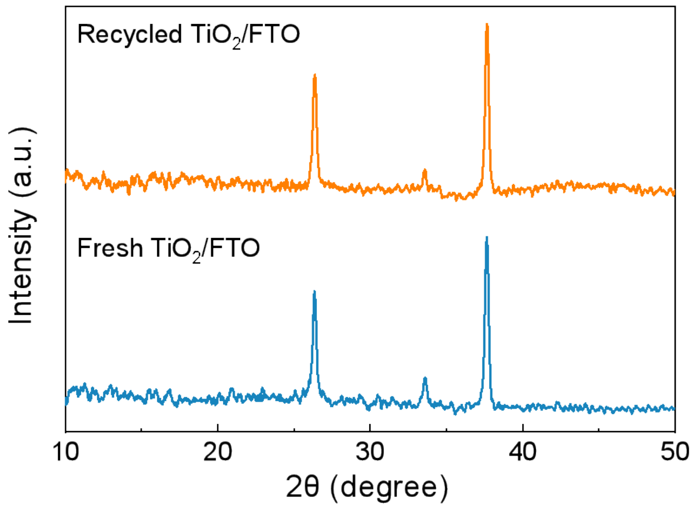

Fig. S18 XRD patterns of fresh TiO_2/FTO substrate and recycled TiO_2/FTO substrate.

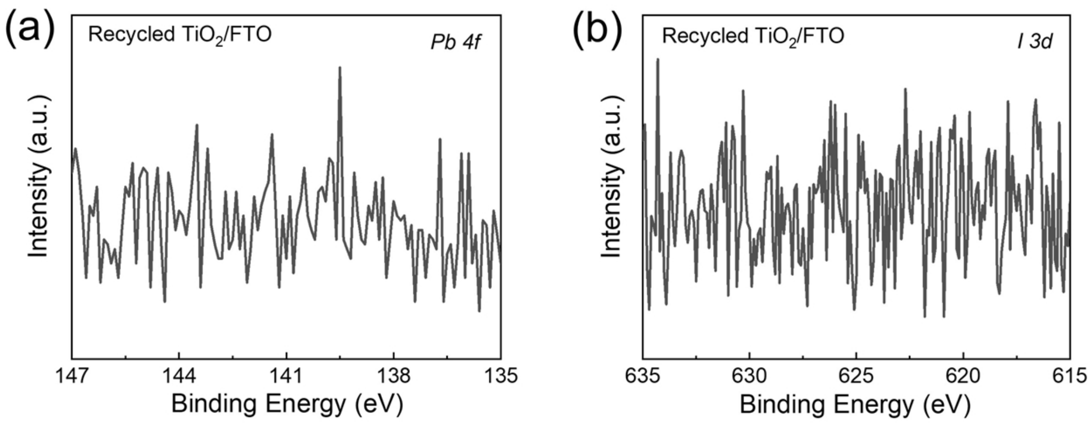

Fig. S19 Pb 4*f* (a) and I 3*d* (b) XPS spectra of recycled TiO_2/FTO electrode.

Table S1 The detailed *J*–*V* parameters of CyP-engineered $CsPbI_3$ QD solar cells with different concentrations of CyP.

Sample	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF	PCE (%)
0.0 mg/mL	1.251	16.99	0.724	15.39
0.5 mg/mL	1.251	17.19	0.762	16.39
1.0 mg/mL	1.251	17.75	0.771	17.13
2.0 mg/mL	1.251	17.08	0.784	16.75

Table S2 The detailed *J–V* parameters of performance for control and target devices.

Sample	Scan direction	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF	PCE (%)
Control	Forward	1.268	16.47	0.739	15.42
	Reverse	1.251	16.76	0.748	15.70
	Average[a]	1.245±0.015	16.30±0.47	0.743±0.018	15.19±0.35
Target	Forward	1.268	17.89	0.763	17.30
	Reverse	1.251	18.09	0.773	17.50
	Average	1.245±0.010	17.61±0.21	0.770±0.011	17.11±0.21

[a] The average data based on 20 cells.

Table S3 The corresponding statistical data in Fig. 2e of reported $CsPbI_3$ QD solar cells.

Publication Date	PCE (%)	Reference
May. 25, 2020	15.21	*Adv. Mater.* **2020**, *32*, 2001906[1]
Oct. 21, 2020	16.07	*Adv. Funct. Mater.* **2021**, *31*, 2005930[2]
Jan. 20, 2021	15.10	*Nat. Commun.* **2021**, *12*, 466[3]
Apr. 19, 2021	15.05	*Adv. Funct. Mater.* **2021**, *31*, 2101272[4]
Jul. 9, 202	16.21	*Energy Environ. Sci.* **2021**,*14*,4599-4609[5]
Oct. 25, 2021	15.29	*Adv. Mater.* **2022**, *34*, 2105977[6]
Oct. 27, 2021	15.21	*Adv. Funct. Mater.* **2022**, *32*,2108615[7]
Jun. 20, 2022	16.53	*Joule* **2022**, *6*, 1-22[8]
Jul. 30, 2022	16.25	*Adv. Mater.* **2022**, 2204259[9]
Aug. 16, 2022	16.64	*Energy Environ. Sci.,* **2022***, 15, 4201–4212*[10]
Jan. 17, 2023	16.14	*Adv. Funct. Mater.* **2023***, 2210728*[11]
Feb. 26 2023	15.38	*Adv. Mater.* **2023,** 2212160[12]

Jun. 4, 2023	15.40	*Adv. Sci.* **2023**, *10*, 2301793[13]
Jun. 29, 2023	15.72	*Nano-Micro Lett.* **2023** *15:163*[14]
Sep. 20, 2023	15.88	*Adv. Mater.* **2024**, *36, 2306854*[15]
May. 18, 2024	16.44	*Adv. Mater.* **2024**, 2404495[16]
Jul. 19, 2024	16.10	*ACS Energy Lett.* **2024**, *9, 3970−3981*[17]
Aug. 13, 2024	16.06	*Nat. Energy* **2024**. https://doi.org/10.1038/s41560-024-01608-5[18]
2024	**17.50**	**This work**

Table S4 The detailed *J–V* parameters of devices with CyP-TiO_2 and LiP-TiO_2.

Sample	V_{OC} **(V)**	J_{SC} **(mA cm^{-2})**	**FF**	**PCE (%)**
CyP-TiO_2	1.251	17.89	0.778	17.40
LiP-TiO_2	1.251	17.32	0.741	16.07

Table S5 Fitted TRPL parameters of the QD films deposited on the TiO_2/FTO substrates.

Sample	A_1	τ_1 **(ns)**	A_2	τ_2 **(ns)**	A_3	τ_3 **(ns)**	τ_{ave} **(ns)**
TiO_2	0.82	0.615	0.16	2.207	0.02	7.429	2.06
CyP-TiO_2	0.87	0.524	0.12	1.841	0.01	5.693	1.31

Table S6 Fitted TRPL parameters of the QD films deposited on the quartz substrates.

Sample	A_1	τ_1 **(ns)**	A_2	τ_2 **(ns)**	A_3	τ_3 **(ns)**	τ_{ave} **(ns)**
QDs	0.73	1.038	0.25	4.750	0.02	19.535	6.38
CyP-QDs	0.77	0.918	0.21	3.742	0.02	13.354	4.05

Table S7 The detailed *J–V* parameters of $CsPbI_3$ QD solar cells with different recycled TiO_2 substrates (the average data based on 10 cells).

Substrate	**Recycled times**		V_{OC} **(V)**	J_{SC} **(mA cm^{-2})**	**FF**	**PCE (%)**	**Percentage Remaining**
TiO_2	**Fresh**	Champion	1.251	16.69	0.738	15.42	100%
		Average[b]	1.244 ±0.015	16.28 ±0.48	0.723 ±0.020	15.11 ±0.38	
	R1	Champion	1.251	15.87	0.716	14.18	92.0%
		Average	1.241 ±0.018	15.19 ±0.55	0.701 ±0.025	13.79 ±0.66	
	R2	Champion	1.251	15.38	0.695	13.37	86.7%
		Average	1.238 ±0.022	14.84 ±0.69	0.683 ±0.033	12.74 ±0.78	
	R3	Champion	1.251	15.59	0.660	12.87	83.5%
		Average	1.230	14.65	0.646	12.74	

			±0.028	±0.73	±0.038	±0.99	
	R4	Champion	1.186	15.09	0.630	11.28	73.2%
		Average	1.109 ±0.035	14.14 ±0.89	0.605 ±0.046	10.67 ±1.12	
CyP-TiO_2	**Fresh**	Champion	1.251	17.94	0.762	17.12	100%
		Average	1.245 ±0.010	17.52 ±0.22	0.758 ±0.011	16.94 ±0.22	
	R1	Champion	1.251	17.43	0.769	16.77	98.0%
		Average	1.242 ±0.010	17.12 ±0.26	0.755± 0.012	16.60 ±0.31	
	R2	Champion	1.251	17.07	0.775	16.56	96.7%
		Average	1.241 ±0.013	16.84 ±0.31	0.768± 0.016	16.24 ±0.50	
	R3	Champion	1.251	16.86	0.762	16.08	93.9%
		Average	1.237 ±0.016	16.32 ±0.36	0.757± 0.020	15.66 ±0.67	
	R4	Champion	1.235	16.76	0.753	15.60	91.1%
		Average	1.223 ±0.021	16.12 ±0.48	0.743± 0.029	15.14 ±0.84	

Supplementary Note 1:

Methods of exposing buried interfaces

Glass slices coated with a UV curable glue was used to encapsulate the QD film, after curing with UV light, followed by glass separation from FTO substrates with a nipping plier.

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