Electronic Supplementary Information (ESI)

Synthesis of Cesium-doped ZnO Nanoparticle as Electron Extraction Layer for Efficient PbS Colloidal Quantum Dot Solar Cells

Fan Yang,† Yalong Xu,† Mengfan Gu, Sijie Zhou, Yongjie Wang, Kunyuan Lu, Zeke Liu, Xufeng Ling, Zhijie Zhu, Junmei Chen, Zhiyi Wu, Yannan Zhang, Ye Xue, Fangchao Li, Jianyu Yuan* and Wanli Ma*

Jiangsu Key Laboratory for Carbon-Based Functional Materials & Devices, Institute of Functional Nano & Soft Materials (FUNSOM), Soochow University, Suzhou 215123, China.

*Email: jyyuan@suda.edu.cn (J. Yuan); wlma@suda.edu.cn (W. Ma);

†The two authors contribute equally to this paper.

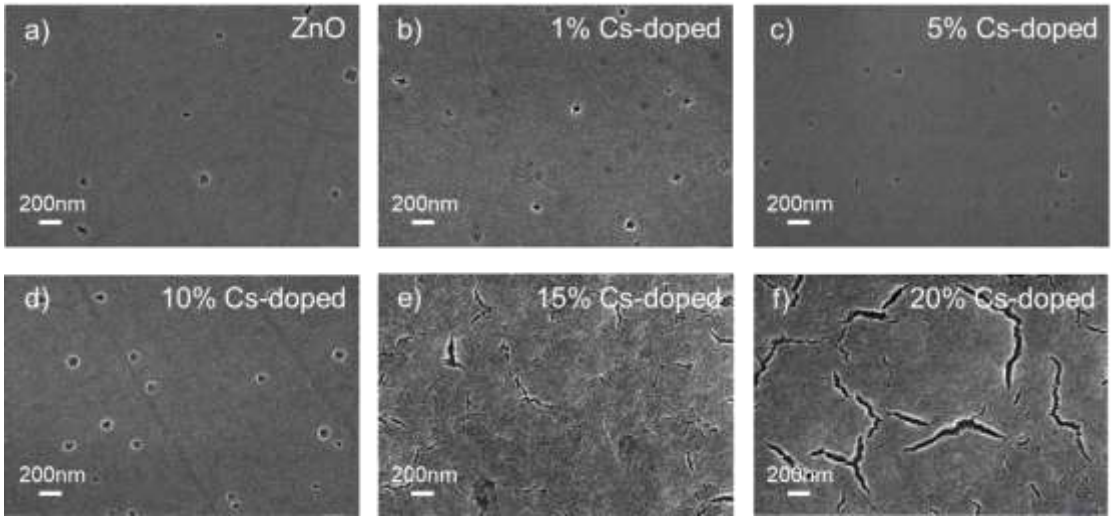

Figure S1. Top-view SEM images of a) ZnO, b) 1% Cs-doped ZnO, c) 5% Cs-doped ZnO, d) 10% Cs-doped ZnO, e) 15% Cs-doped ZnO and f) 20% Cs-doped ZnO films. The scale bars are 200 nm.

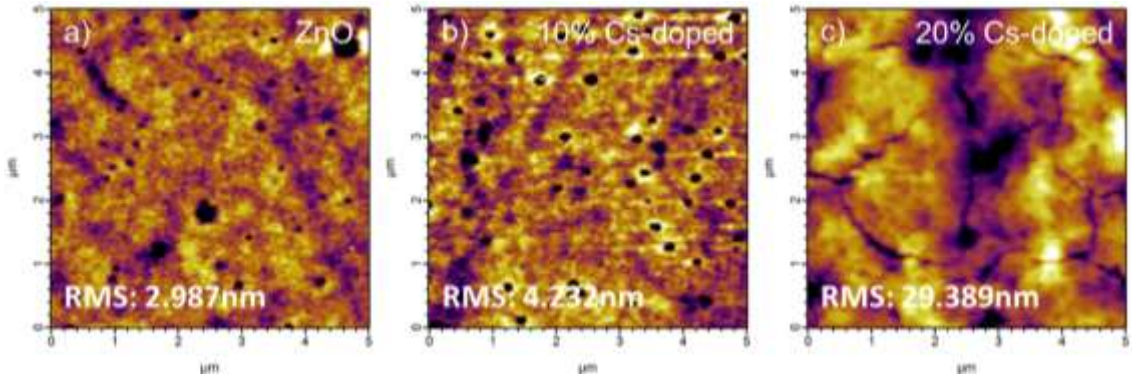

Figure S2. AFM height images of a) ZnO, b) 10% Cs-doped ZnO and c) 20% Cs-doped ZnO films.

The optical band gaps were obtained from the following equation:

$$\alpha = \mathrm{A} \cdot \frac{(h\nu - E)^{1/2}}{h\nu}$$

where α is the absorption coefficient, A is a constant, hν is the photon energy and E is the band gap. Bandgaps are derived by extrapolating the linear region of the plot of $(\alpha h\nu)^2$ versus hν to the energy axis.

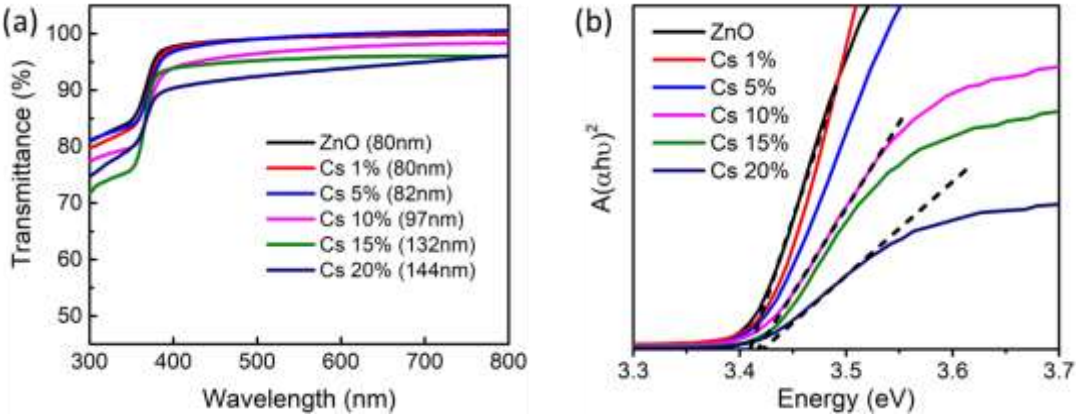

Figure S3. (a) Transmittance spectra of ZnO and Cs-doped ZnO films spin coated with the same concentration. (b) Extrapolated optical bandgaps of ZnO and Cs-doped ZnO films, showing slight shift after Cs doping.

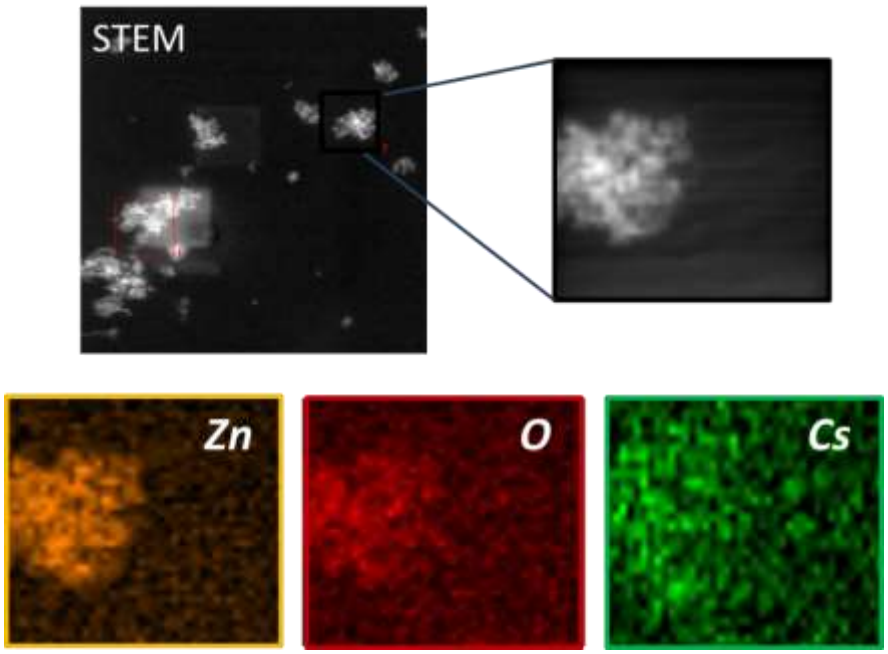

Figure S4. Drift corrected HAADF-STEM images and elemental mappings of Zn, O, and Cs for 20% Cs-doped ZnO NP performed on the selected area in STEM image.

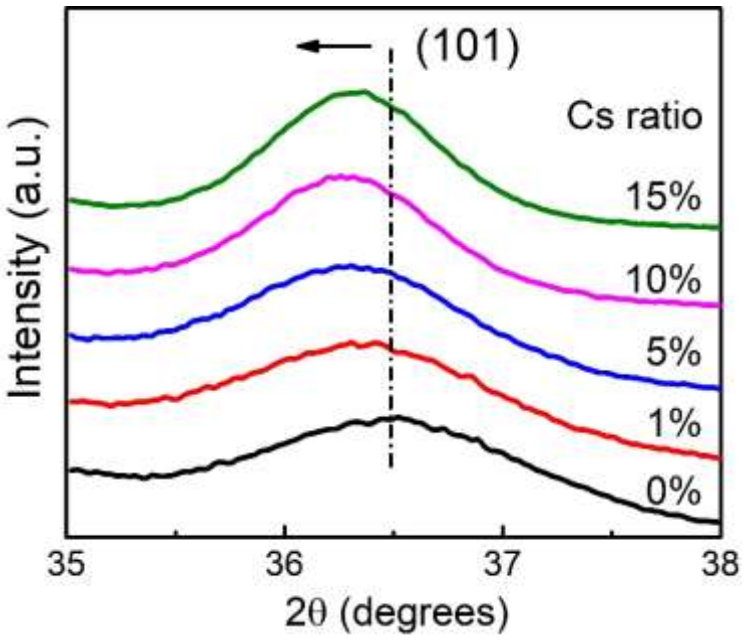

Figure S5. Enlarged view of (101) plane from XRD spectra of ZnO and Cs-doped ZnO NPs.

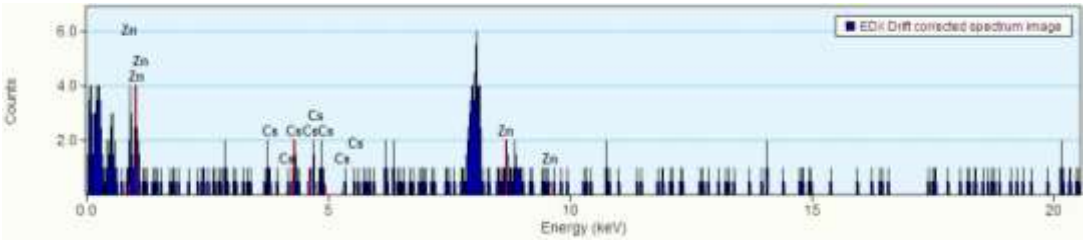

Figure S6. The EDX spectrum of 5% Cs-doped ZnO nanoparticles.

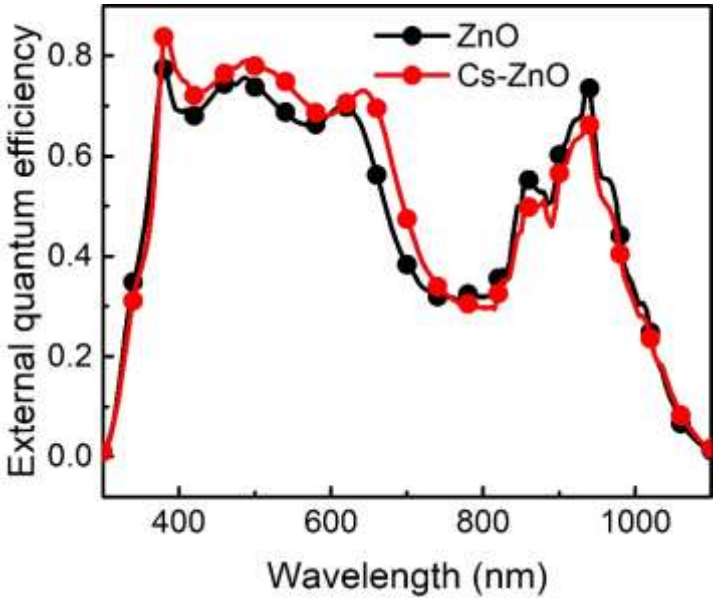

Figure S7. EQE of the optimized CQD photovoltaic device with ZnO and 5% Cs-doped ZnO ETLs.

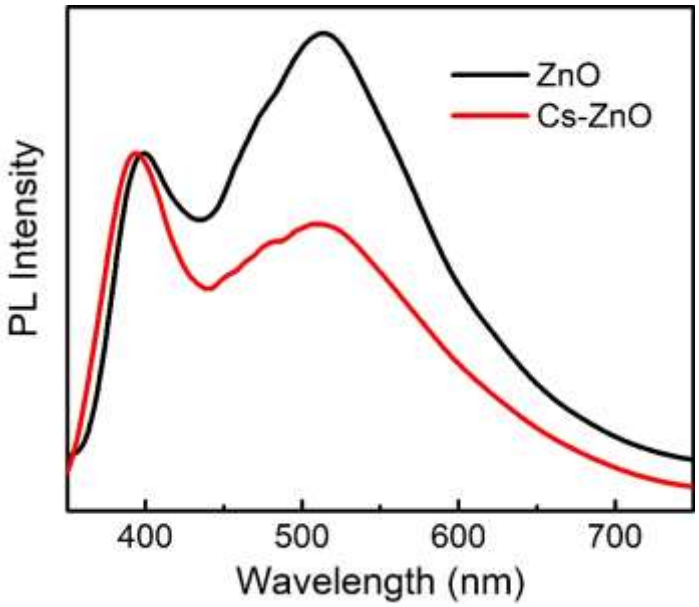

Figure S8. PL spectra of pristine ZnO layer and 5% Cs-doped ZnO layer.

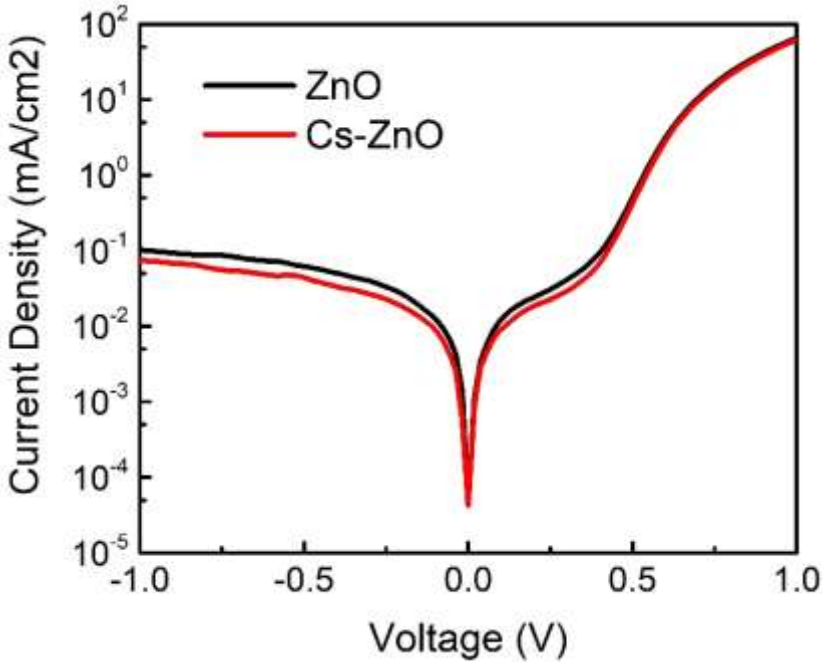

Figure S9. Dark J–V curve of the CQD photovoltaic devices with ZnO and 5% Cs-doped ZnO ETLs.

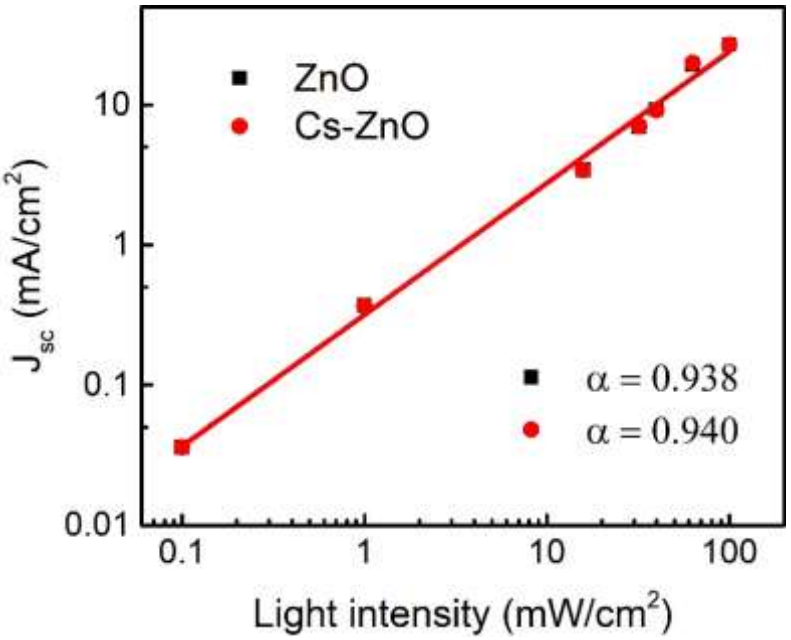

Figure S10. Light-intensity dependence of Jsc (solid lines: linear fits) of the CQD solar cells with pristine ZnO and 5% Cs-doped ZnO.

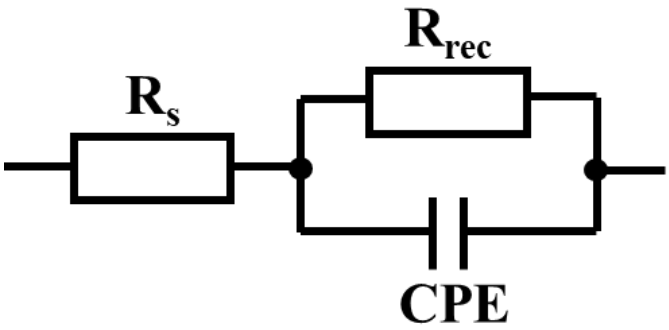

Figure S11. The equivalent circuit model employed to fit the Nyquist plots for CQD solar cells.

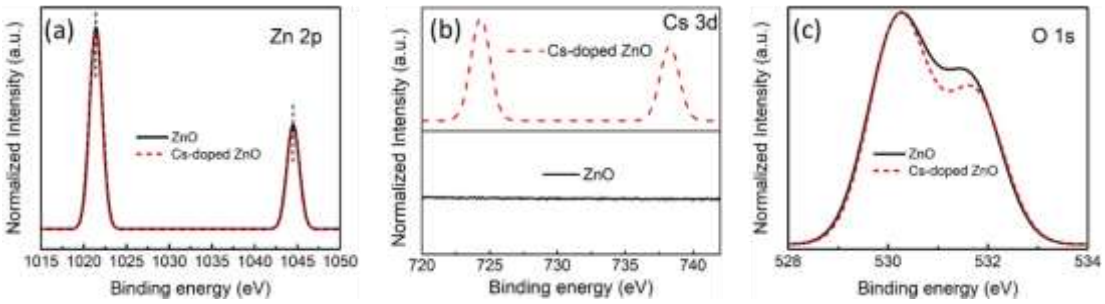

Figure S12. XPS spectra of (a) Zn 2p, (b) Cs 3d and (c) O 1s core level measured on ZnO and 5% Cs-doped ZnO.

Table S1. EIS parameters of the CQD photovoltaic devices based on ZnO or 5% Cs-doped ZnO as ETLs.

ETL	$\mathbf{R_s}$ [Ω]	$\mathbf{R_{rec}}$ [Ω]	**CPE**	**Freq Power**
ZnO	23.3	4687	3.18×10^{-8}	0.86
Cs-ZnO	13.9	18270	9.36×10^{-9}	0.98

Table S2. Valence-band level (VB), conduction-band level (CB) and Fermi level for pure ZnO and 5% Cs-doped ZnO films.

	CB [eV]	**VB** [eV]	**Fermi level** [eV]
ZnO	-4.33	-7.74	-4.40
Cs-ZnO	-4.27	-7.69	-4.29