Electronic Supplementary Material (ESI) for Nanoscale.

Electronic Supplementary Information (ESI)

Colloidal annealing of ZnO nanoparticles to passivate traps and improve charge extraction in colloidal quantum dots solar cells

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Table S1. O 1s peak information of ZnO nanoparticles thin films subjected to different annealing treatments

	Oxygen in lattice (at.%)	Oxygen vacancies (at.%)	Absorbed oxygen (at.%)
w/o annealing	57.9	20.6	21.5
film-annealing	72.6	13.0	14.2
Colloidal-annealing	71.2	12.0	16.8

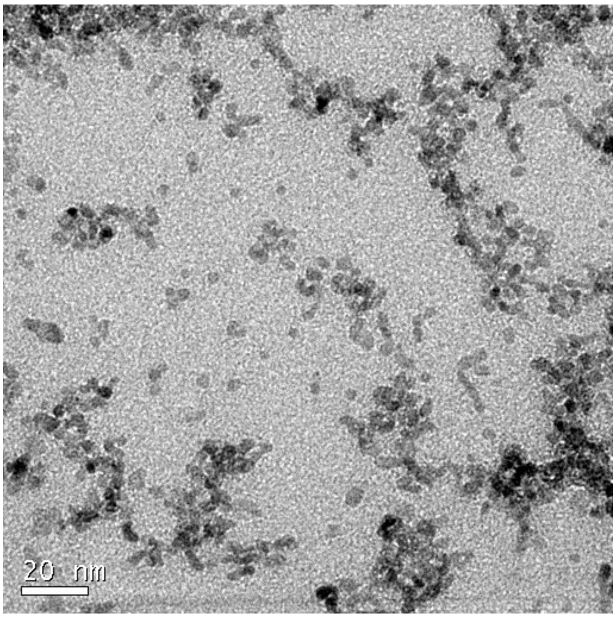

Fig. S1 Transmission electron microscopy image of as synthesized ZnO nanoparticles

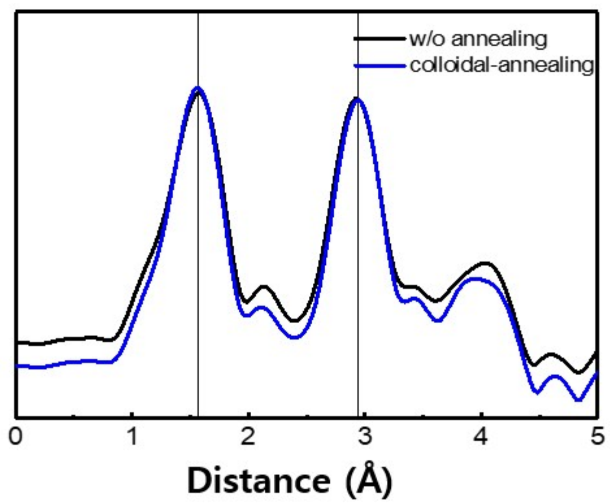

Fig. S2 Extended X-ray absorption fine structure spectra of ZnO nanoparticle powders without and with colloidal annealing.

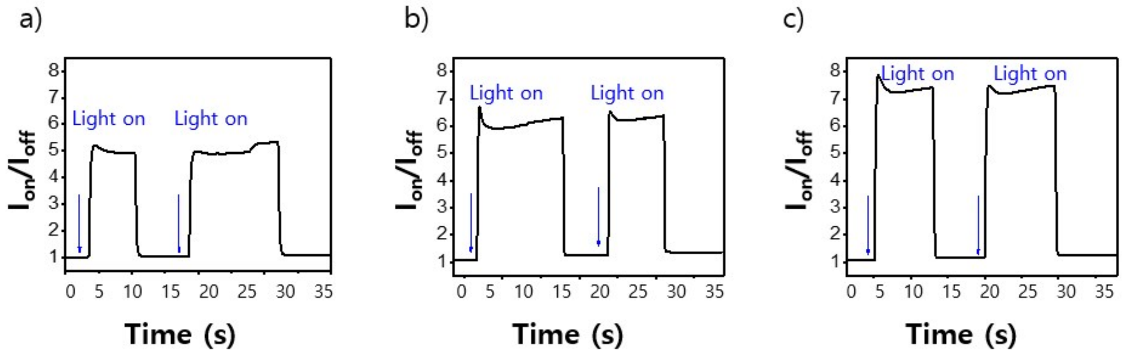

Fig. S3 Current on and off ratio (I_{on}/I_{off}) versus time graph of ZnO NP thin films (a) without annealing, (b) with film-annealing, and (c) with colloidal-annealing under light with wavelength of 254 nm

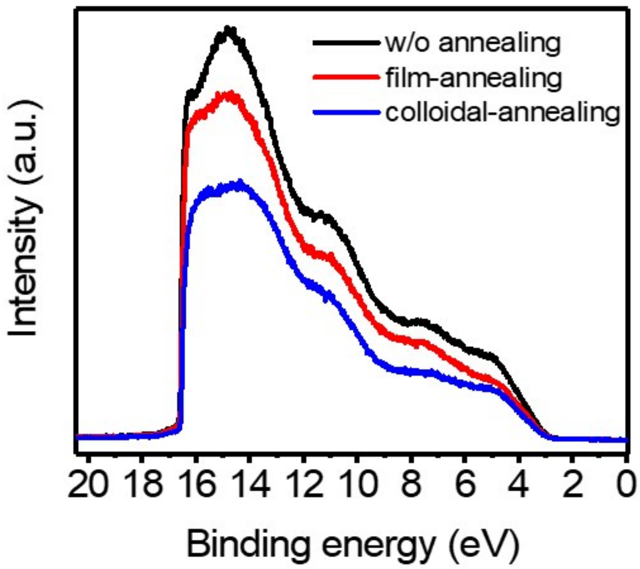

Fig. S4 Entire ultraviolet photo-emission spectra of ZnO NP thin films obtained using different annealing treatments deposited on Au electrodes.

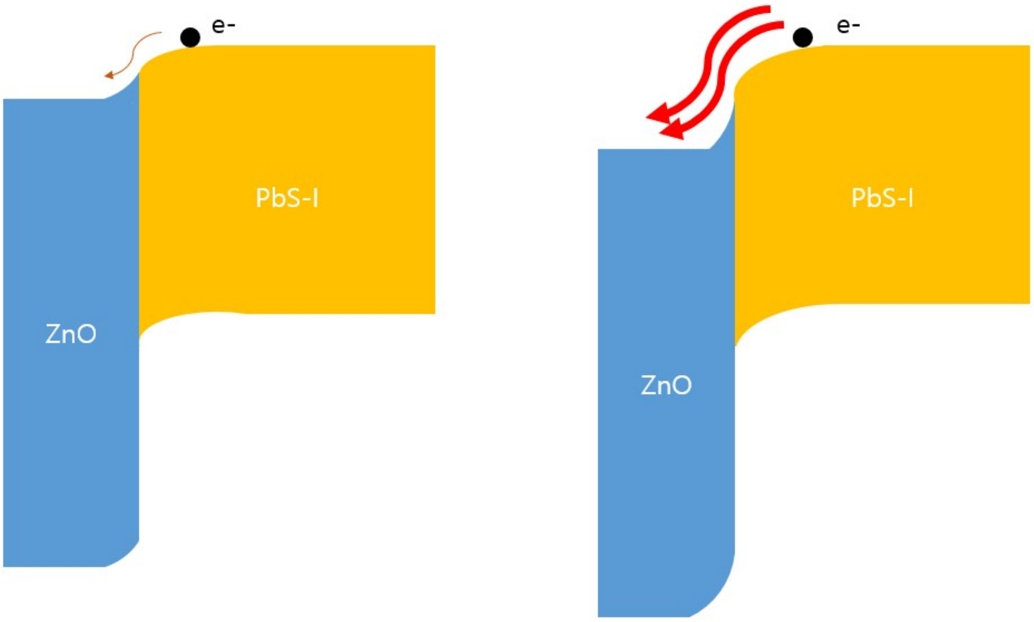

Fig. S5 Schematic of band structure of a) bare and b) annealed ZnO NPs

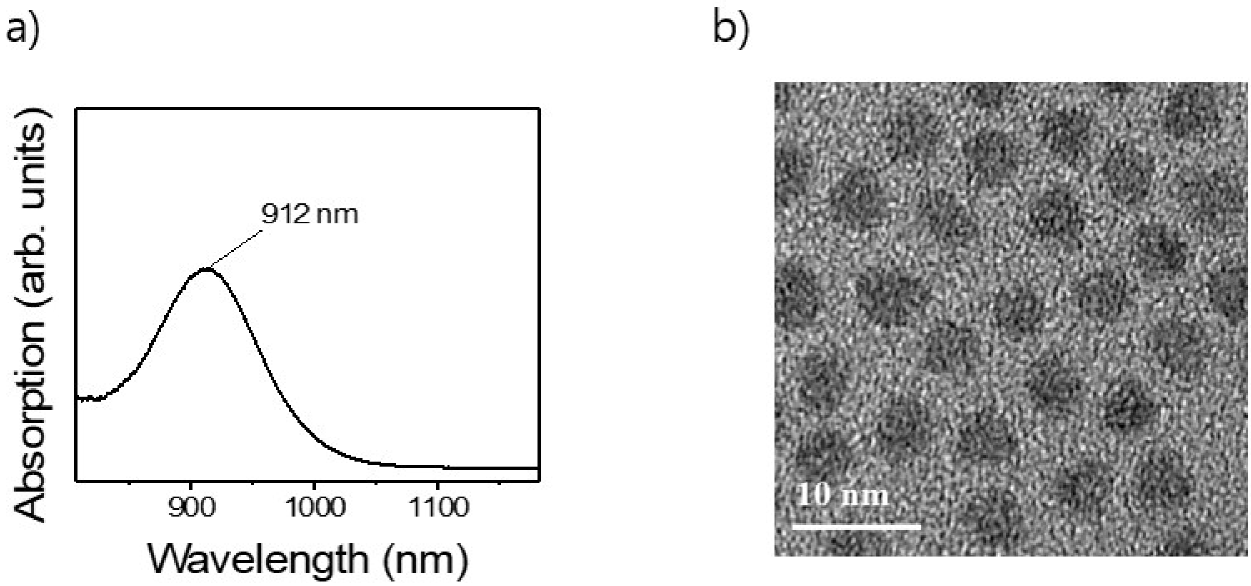

Fig. S6 a) Ultraviolet–visible spectra and b) transmission electron microscopy image of as-synthesized PbS colloidal quantum dots

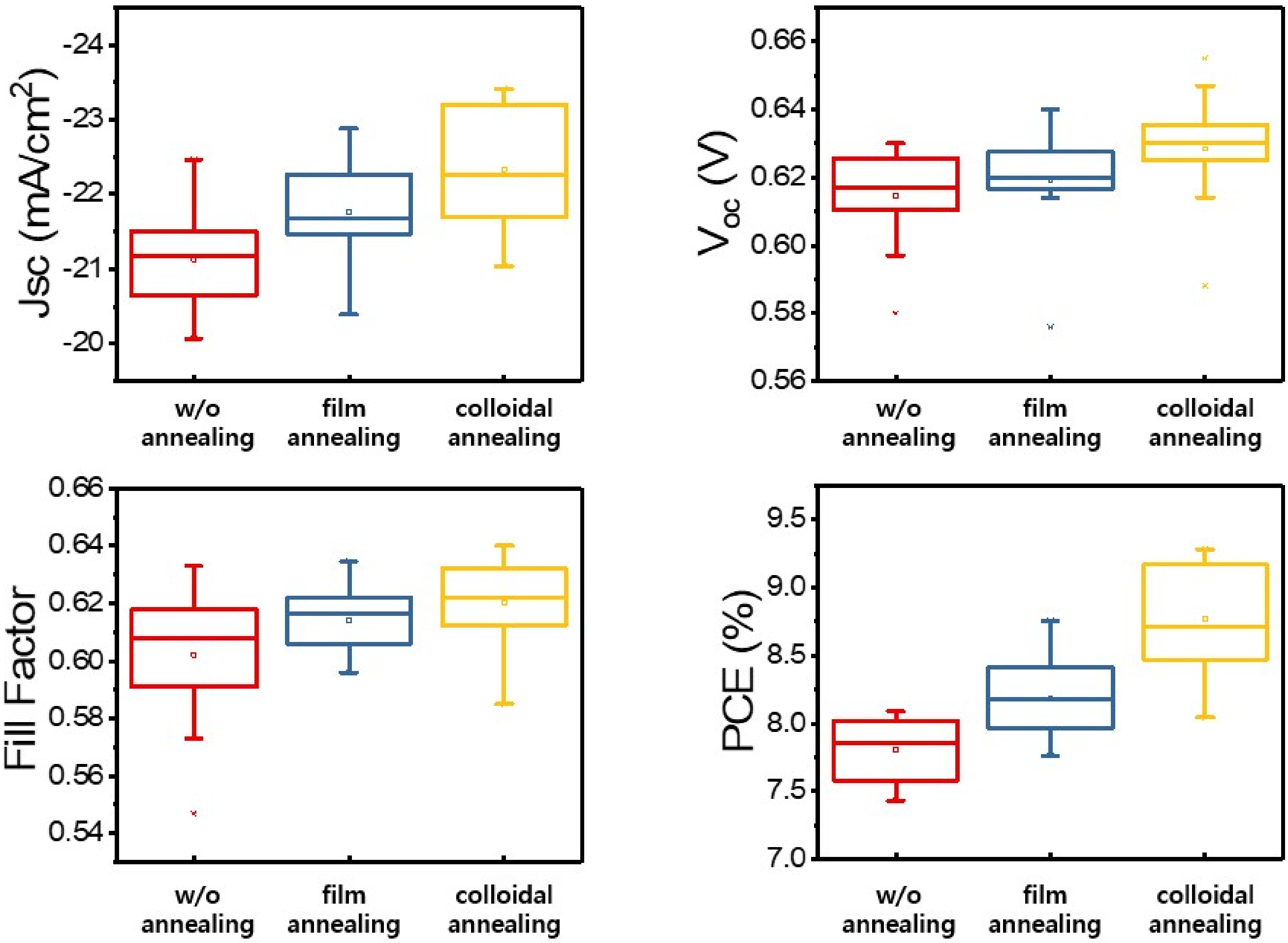

Fig. S7 Statistical analysis of 20 colloidal quantum dots solar cells using ZnO NP thin films subjected to different annealing conditions (J_{SC}, V_{OC}, FF, and PCE are the short-circuit current density, open circuit voltage, fill factor, and power conversion efficiency, respectively)

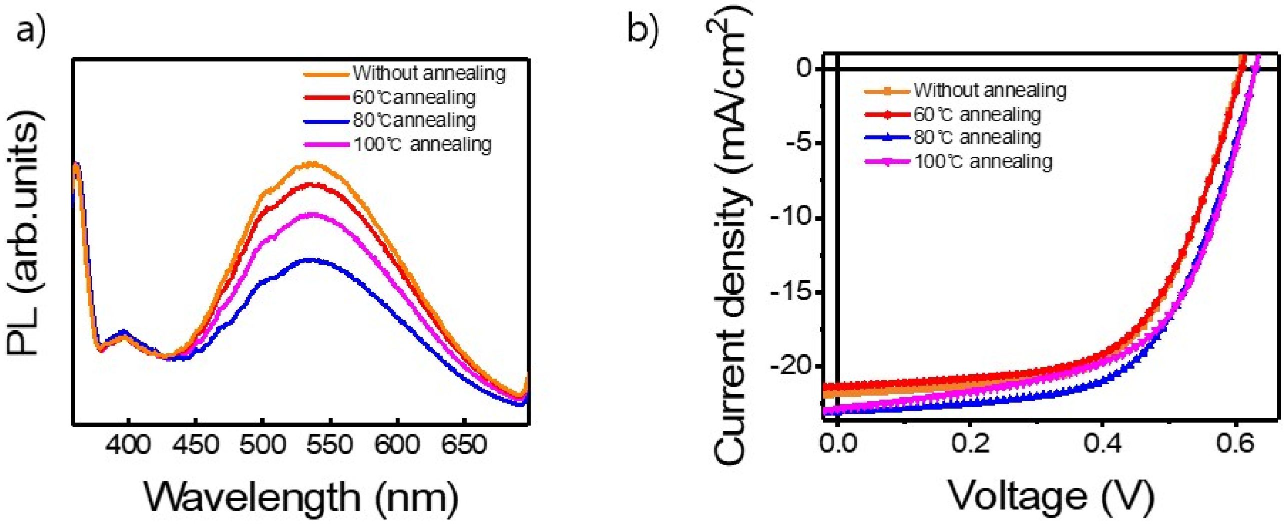

Fig. S8 Optimization of annealing temperature of ZnO nanoparticle (NP) thin films used for colloidal quantum dots (CQDs) solar cells. (a) Photoluminescence spectra of ZnO NP thin films and (b) Current density–voltage curves of CQD solar cells using ZnO NP thin films subjected to different colloidal annealing temperatures

Table S2. Summary of colloidal quantum dots solar cells parameters using subjected to different annealing treatments.

ETL	**J_{SC}**	**V_{OC}**	**FF**	**PCE**
Without annealing	21.86	0.608	60.7	8.05
60 °C annealing	22.33	0.610	60.2	8.20
80 °C annealing	23.08	0.629	60.8	8.78
100 °C annealing	22.87	0.628	58.8	8.46

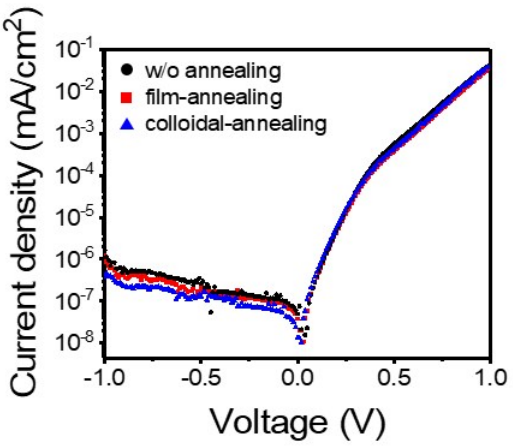

Fig. S9 Current density–voltage curves of colloidal quantum dots solar cells using ZnO NP thin films subjected to different annealing treatments in the dark

Calculation of depletion region width[1]

$$W_D(V) = \frac{1}{N_a}\sqrt{\frac{2 \in_r \in_o (V_{bi} - V)}{e(\frac{1}{N_a} + \frac{1}{N_b})}} \quad (1)$$

$$\frac{1}{C^2} = \frac{2(V_{bi} - V)}{A^2 e \in_r \in_o N_a} \quad (2)$$

The depletion region width was calculated using Eq. (1), where N_a is the doping density of PbS-PbI_2, N_b is the doping density of the ZnO nanoparticles, e is the elementary electric charge of the electron, V_{bi} is the built-in potential of the colloidal quantum dots (CQDs) solar cells, and ε_r is the PbS-CQDs dielectric constant. The V_{bi} and doping density values were obtained from the Mott–Schottky plot based on Eq. (2).

References

1. R. Azmi, S. Y. Nam, S. Sinaga, S. H. Oh, T. K. Ahn, S. C. Yoon, I. H. Jung and S. Y. Jang, *Nano Energy*, 2017, **39**, 355–362.