Supporting Information

Improved Efficient Perovskite Solar Cells Based on Ta-doped TiO_2 Nanorod Arrays

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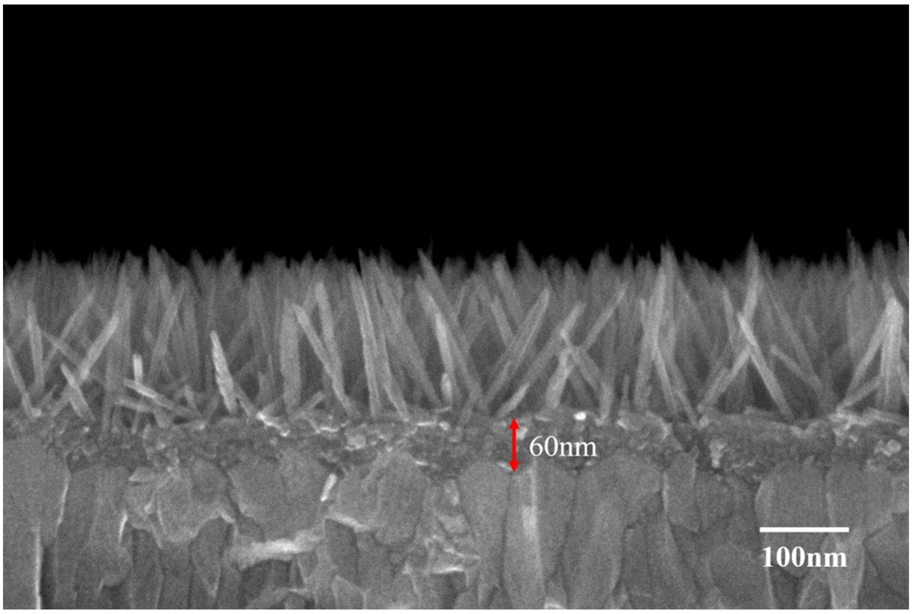

Figure S1. Cross section view of a typical undoped TiO_2 NR array film.

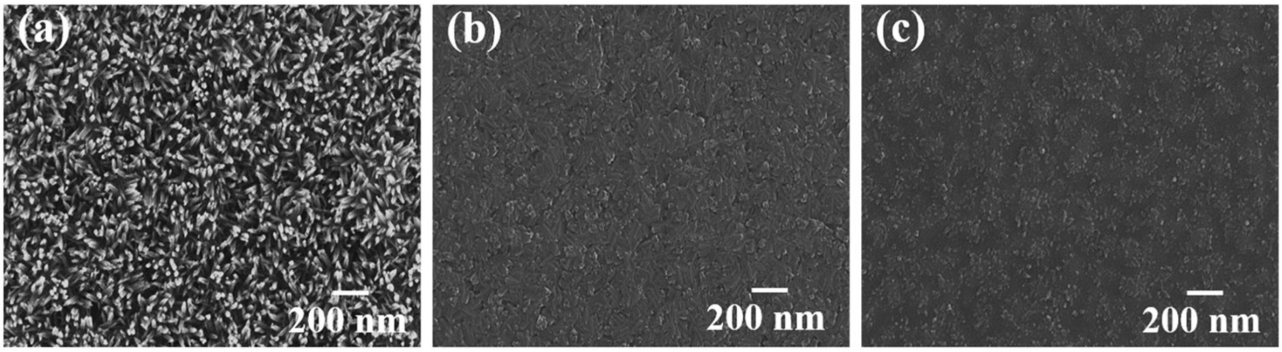

Figure S2. Surface view of (a) 0.1 mol%, (b) 0.5 mol%, (c) 1 mol% Ta-doped TiO_2 NR arrays.

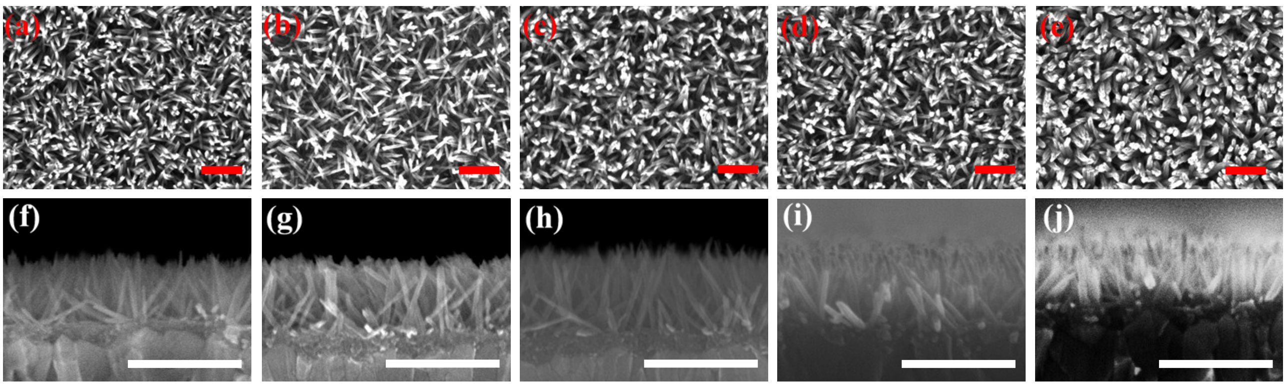

Figure S3. SEM images of the top and cross-section views of different TiO_2 NR arrays. (a) undoped, (b) 0.05-Ta, (c) 0.1-Ta, (d) 0.15-Ta, and (e) 0.2-Ta TiO_2 NR arrays. The scale bar is 200 nm.

Table S1. The void-space-fractions (VSFs) of the undoped and doped TiO_2 NR array films.

Sample	**0%-Ta**	**0.05%-Ta**	**0.1%-Ta**	**0.15%-Ta**	**0.2%-Ta**
VSF	0.682	0.683	0.683	0.684	0.686

Table S2. Lattice parameters of the undoped and doped TiO_2 nanorod arrays.

Sample	**0-Ta**	**0.05-Ta**	**0.1-Ta**	**0.15-Ta**	**0.2-Ta**
A (nm)	0.4566	0.4566	0.4568	0.4573	0.4575
C (nm)	0.2948	0.2953	0.2954	0.2955	0.2954

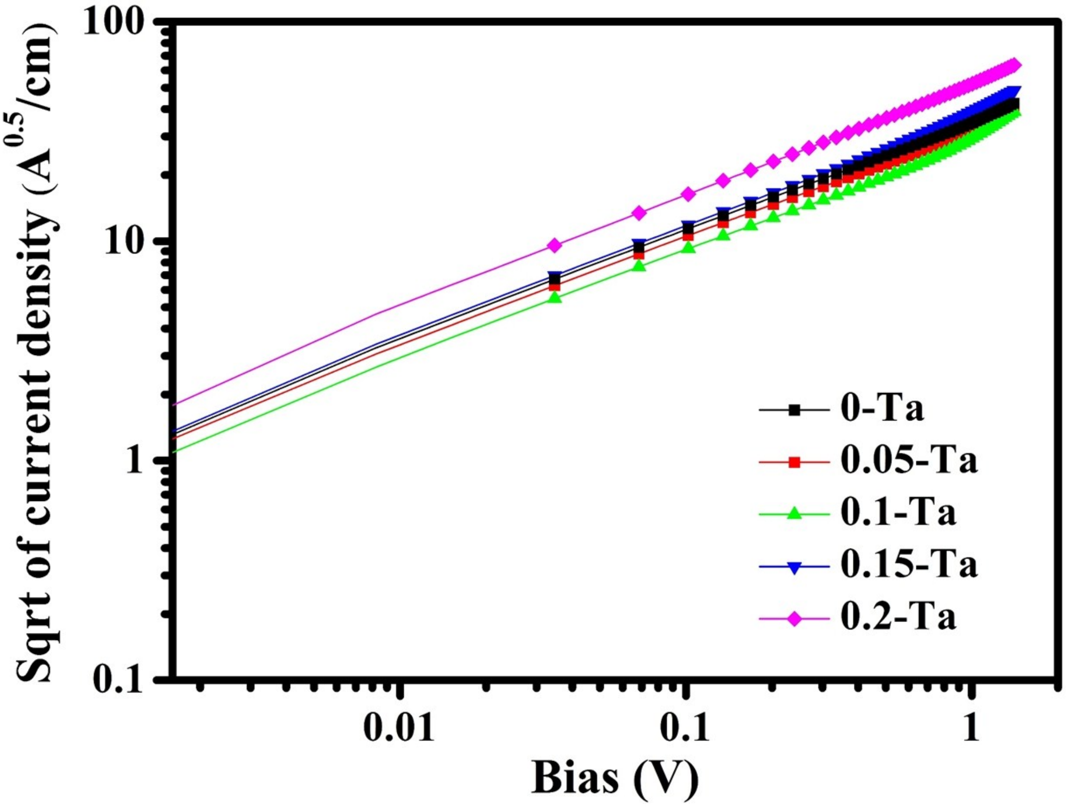

Figure S4. Electron mobility of different TiO_2 nanorods measured by space charge limited current (SCLC) method. [1, 2] The effective electron mobilities can be calculated as 1.9×10^{-5}, 2.11×10^{-5}, 2.34×10^{-5}, 3.00×10^{-5}, and 4.33×10^{-5} $cm^2\ V^{-1}s^{-1}$ based on the undoped and doped (0.05-Ta, 0.1-Ta, 0.15-Ta, 0.2-Ta) TiO_2 NR arrays.

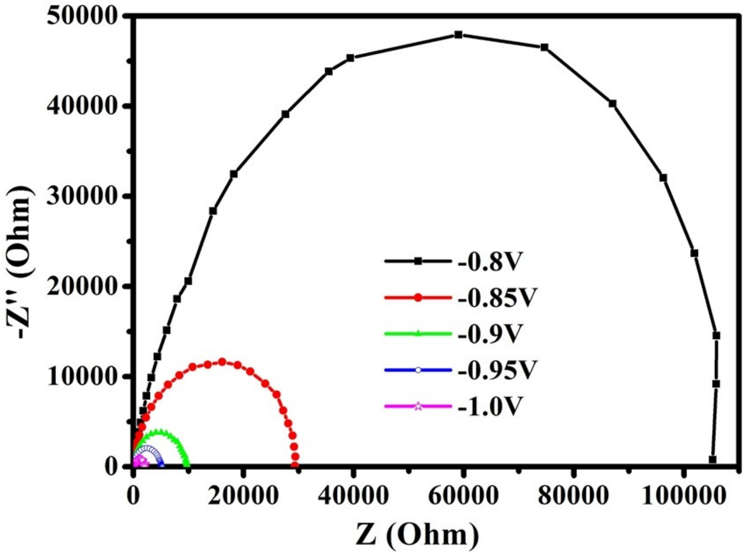

Figure S5. Example Nyquist plots of the devices based on 0.1-Ta TiO_2 NR arrays at the bias from -0.8 V to -1.0 V in the dark.

Table S3. The serial resistances of the devices based on the undoped and doped TiO_2 NR arrays. The data show the average values based on six devices. The active cell area is 0.16 cm^2.

Sample	**-0.8 V (Ω)**	**-0.85 V (Ω)**	**-0.9 V (Ω)**	**-0.95 V (Ω)**	**-1.0 V (Ω)**
0-Ta	18±0.3	18±0.4	17.7±0.2	17.5±0.1	17.3±0.7
0.05-Ta	18±0.3	18.4±0.5	18.5±0.4	17.7±0.4	17.5±0.2
0.1-Ta	17±0.6	18.1±0.2	18.3±0.3	17.7±0.3	17.3±0.2
0.15-Ta	16.8±0.4	17.3±0.4	17.2±0.3	17.1±0.3	17.5±0.4
0.2-Ta	21±0.9	21.8±1.1	21.4±0.7	21.2±0.5	21±0.3

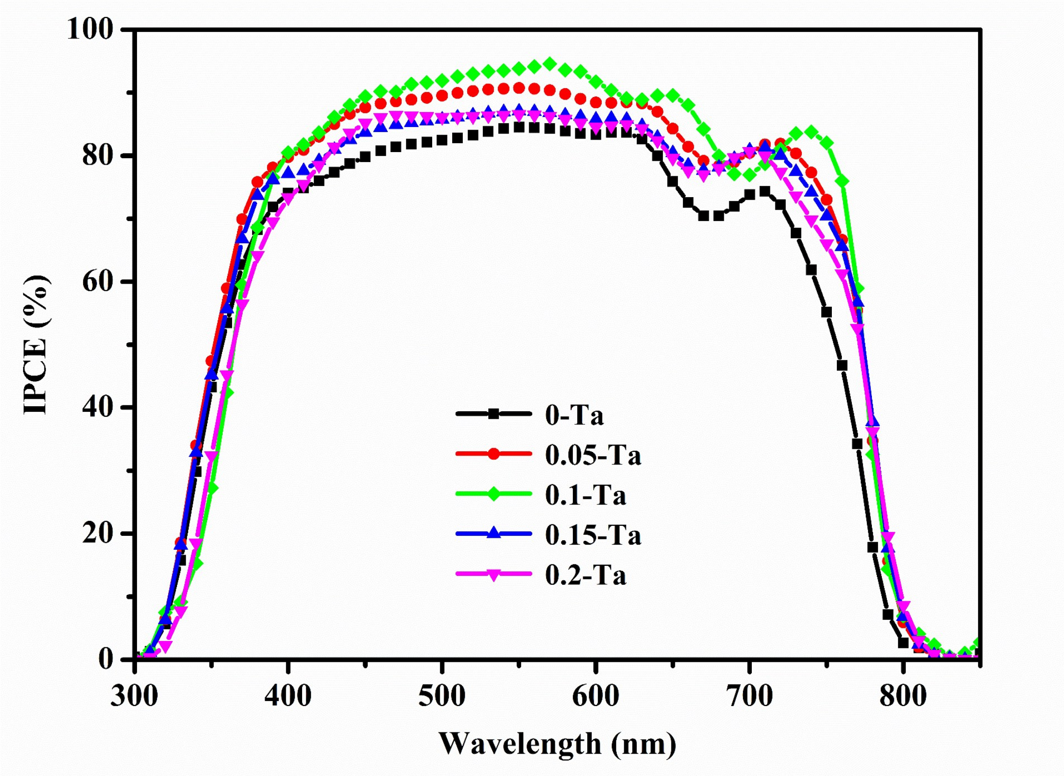

Figure S6. The incident photon-to-current efficiency (IPCE) spectra of perovskite solar cells based on undoped and Ta-doped TiO_2 NR arrays.

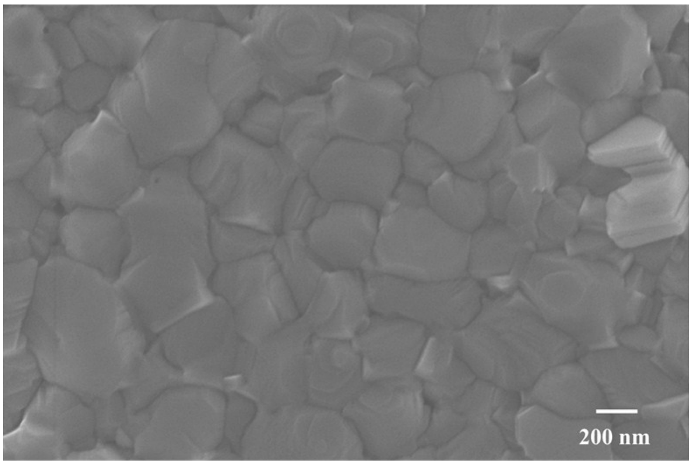

Figure S7. SEM image of the top view of the perovskite deposited on the 0.1-Ta TiO_2 NR array.

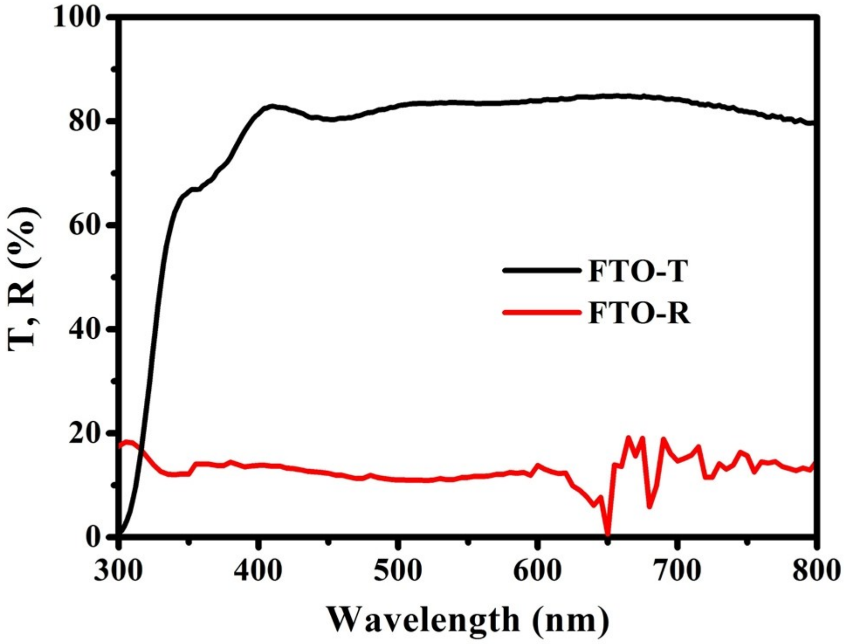

Figure S8. Transmission, T, and reflection, R, versus wavelength of the FTO substrate

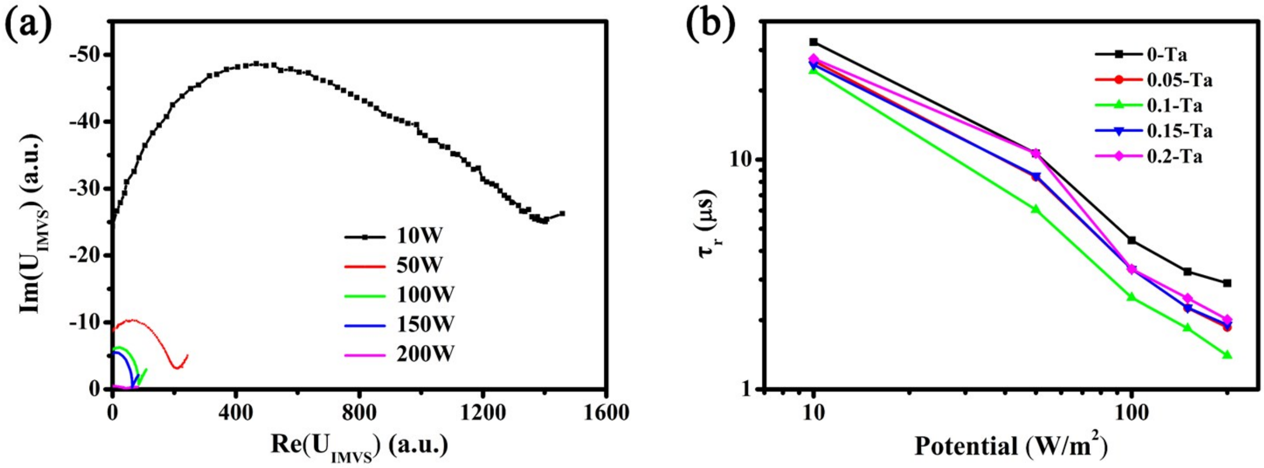

Figure S9. (a) Example IMVS plots for the 0.1-Ta device under different bias light intensities; (b) Intensity dependence of the lifetimes measured by IMVS for the devices based on undoped and doped TiO_2 NR arrays.

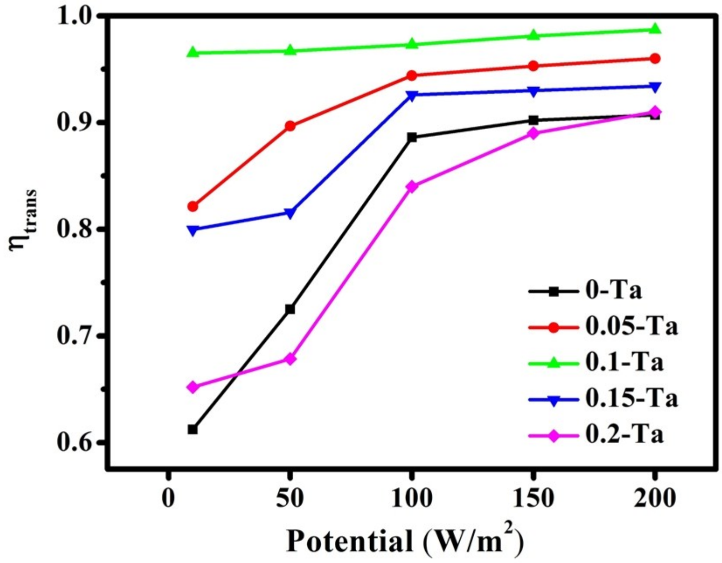

Figure S10. Intensity dependence of the collection efficiency measured by IMPS for the devices based on undoped and doped TiO_2 NR arrays.

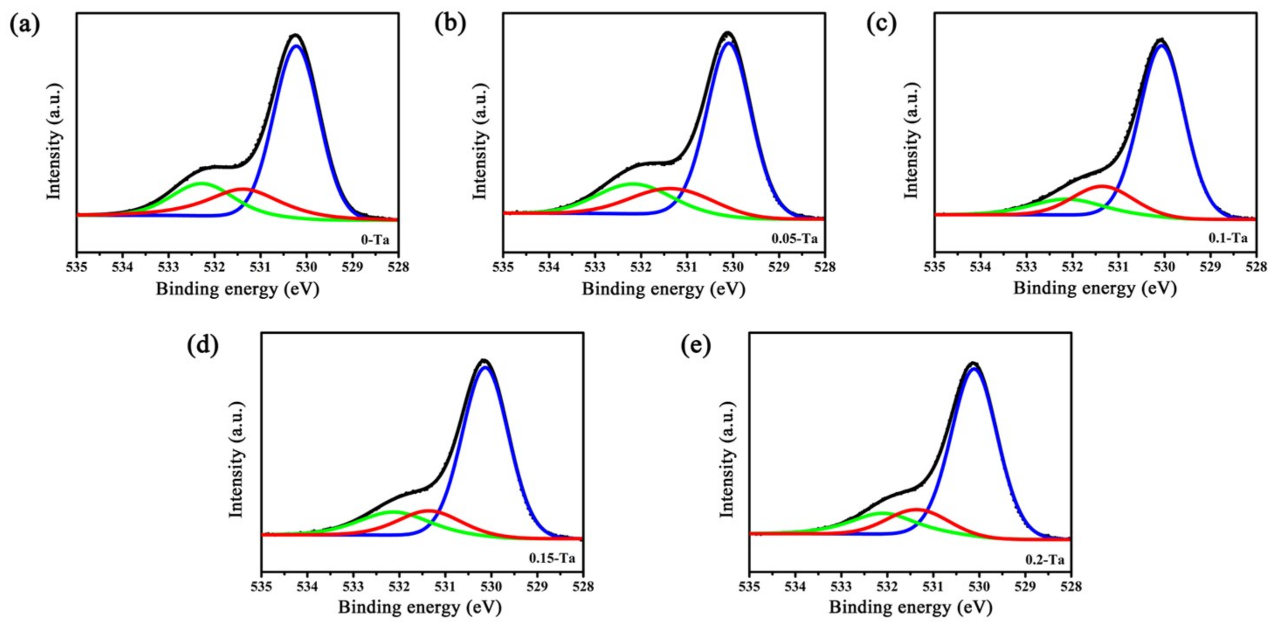

Figure S11. High-resolution XPS spectra of O 1s core levels of the TiO_2 nanorods: (a) undoped TiO_2 nanorods, (b) 0.05-Ta TiO_2 nanorods, (c) 0.1-Ta TiO_2 nanorods, (d) 0.15-Ta TiO_2 nanorods, (e) 0.2-Ta TiO_2 nanorods.

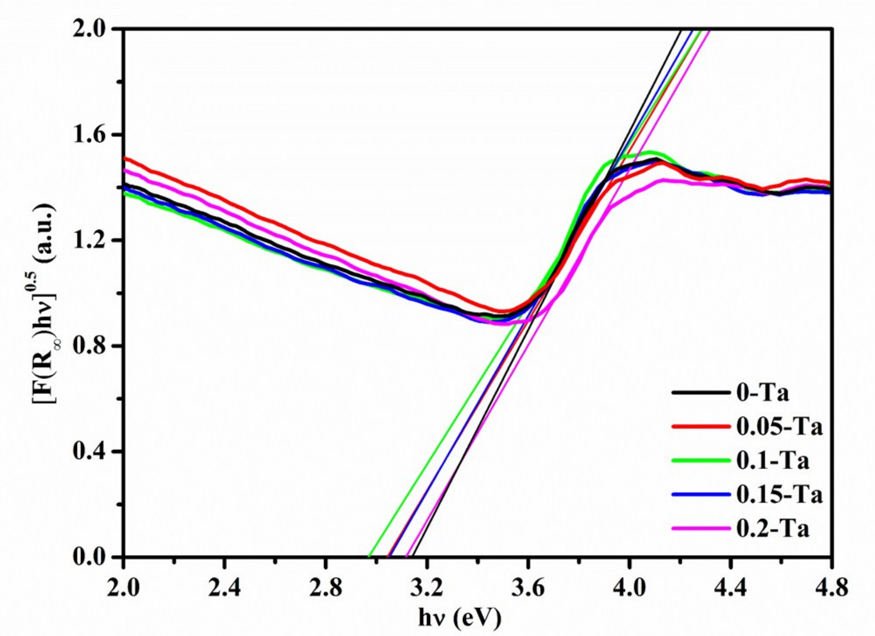

Figure S12. UV-vis absorption spectra for the undoped and doped TiO_2 nanorod array films.

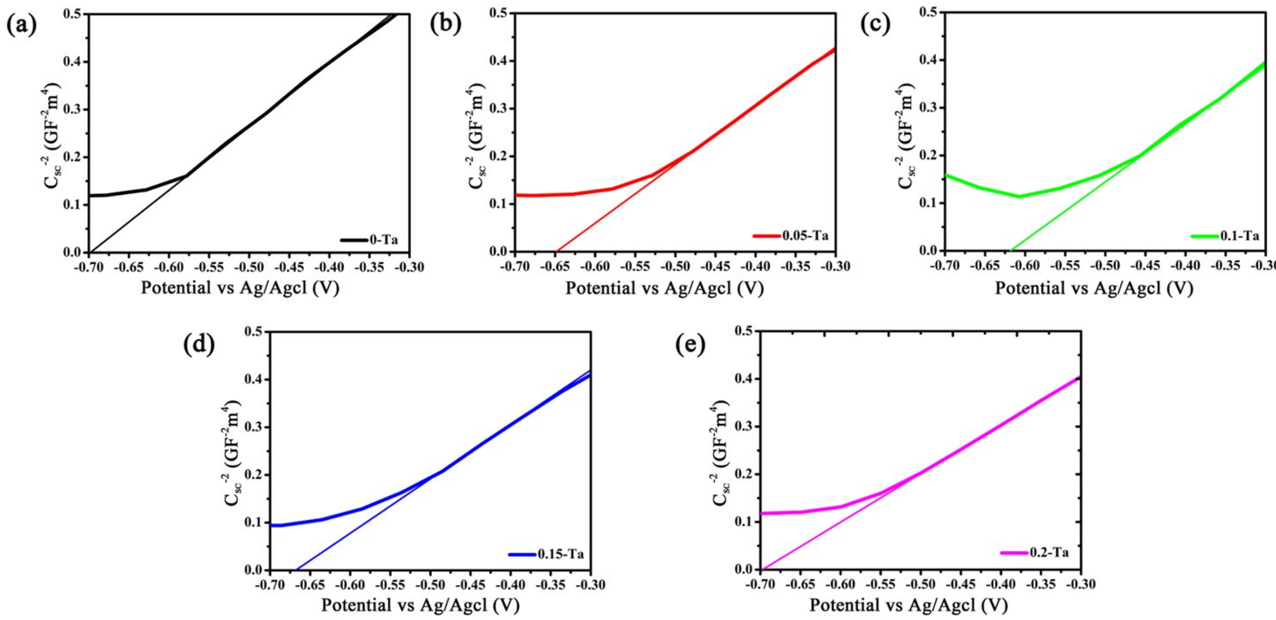

Figure S13. Mott-Schottky (M-S) spectra of the TiO_2 nanorods: (a) undoped TiO_2 nanorods, (b) 0.05-Ta TiO_2 nanorods, (c) 0.1-Ta TiO_2 nanorods, (d) 0.15-Ta TiO_2 nanorods, (e) 0.2-Ta TiO_2 nanorods

References

1. Y. Tu, J. Lin, W. Lin, C. Liu, J. Shyue and W. Su, *Cryst. Eng. Comm.*, 2012, **14**, 4772-4776.

2. A. Mohammadpour, S. Farsinezhad, B. Wiltshire, and K. Shankar, *physica status solidi (RRL)-Rapid Research Letters*, 2014, **8**, 512-516.