Supporting Information

Enhanced photocatalytic performances of n-TiO_2 nanotubes by uniform creation of p-n heterojunctions with p-Bi_2O_3 quantum dots

Ming-Zheng Ge,[‡a] Chun-Yan Cao,[‡a] Shu-Hui Li,[a] Song-Nan Zhang,[a] Shu Deng,[a] Jian-Ying Huang,[a] Qing-Song Li,[a] Ke-Qin Zhang,*[a,b] Salem S. Al-Deyab[c] and Yue-Kun Lai*[a,b]*

[a] *National Engineering Laboratory for Modern Silk, College of Textile and Clothing Engineering, Soochow University, Suzhou 215123, China.*

[b] *Research Center of Cooperative Innovation for Functional Organic/Polymer Material Micro/Nanofabrication, Soochow University, Suzhou, Jiangsu 215123, China.*

[c] *Petrochemical Research Chair, Department of Chemistry, College of Science, King Saud University, Riyadh 11451, Saudi Arabia.*

Corresponding author email: jyhuang81@suda.edu.cn; kqzhang@suda.edu.cn; yklai@suda.edu.cn

Supporting figure captions:

Figure S1. The size of Bi_2O_3 quantum dots and EDS spectra of Bi_2O_3@TiO_2 NTAs with multiple SILAR processes for 1 (a,b), 4 (c,d), 7 (e,f) cycles, respectively.

Figure S2. TEM image of pristine TiO_2 NTAs.

Figure S3. The time-resolved photoluminescence (TRPL) spectrum of TiO_2 NTAs and Bi_2O_3@TiO_2 NTAs with ultrasonication-assisted SILAR deposition for 1, 4 and 7 cycles.

Figure S4. Bode phase plots of TiO_2 NTAs at 450°C and Bi_2O_3@TiO_2 NTAs with repeated SILAR processes for 4 cycles at the low open-circuit condition under solar light illumination, respectively.

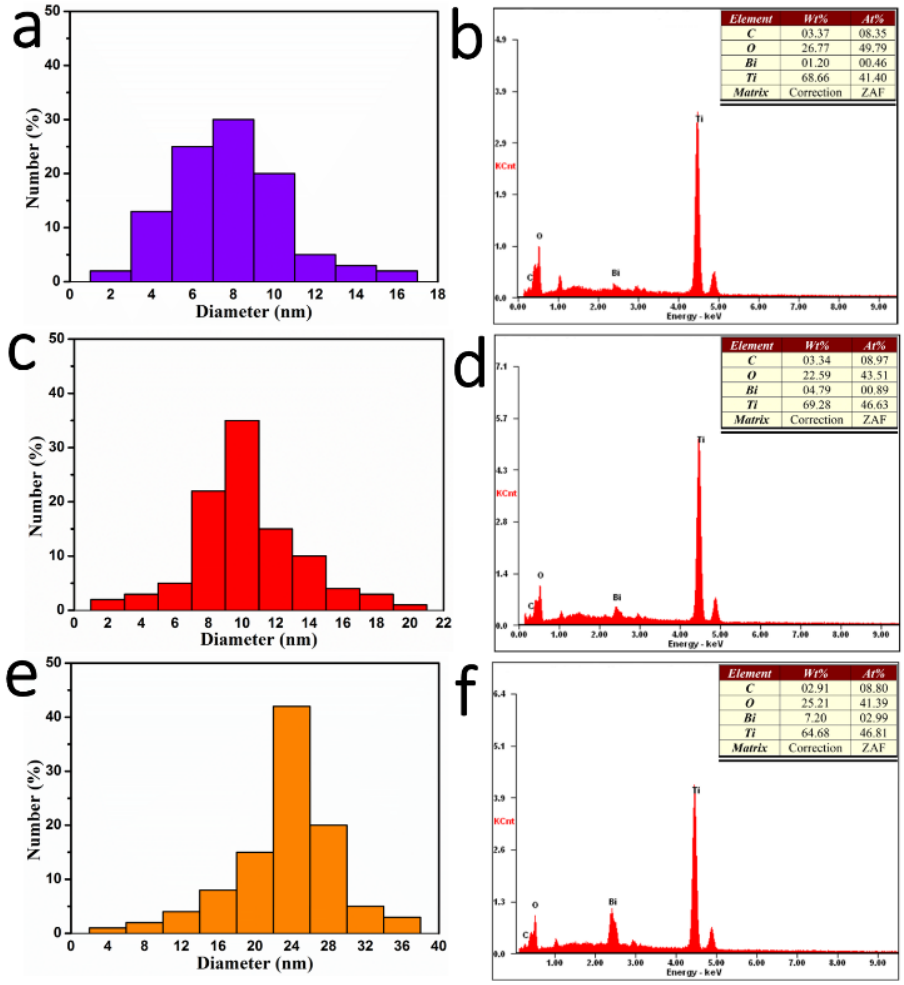

Figure S1. The size of Bi_2O_3 quantum dots and EDS spectra of Bi_2O_3@TiO_2 NTAs with multiple SILAR processes for 1 (a,b), 4 (c,d), 7 (e,f) cycles, respectively.

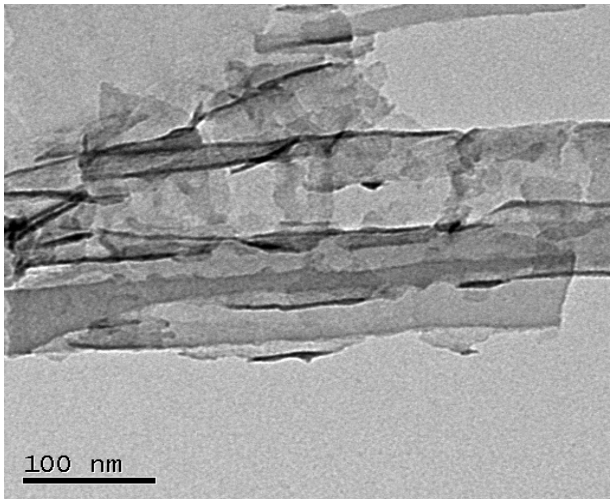

Figure S2. TEM image of pristine TiO_2 NTAs.

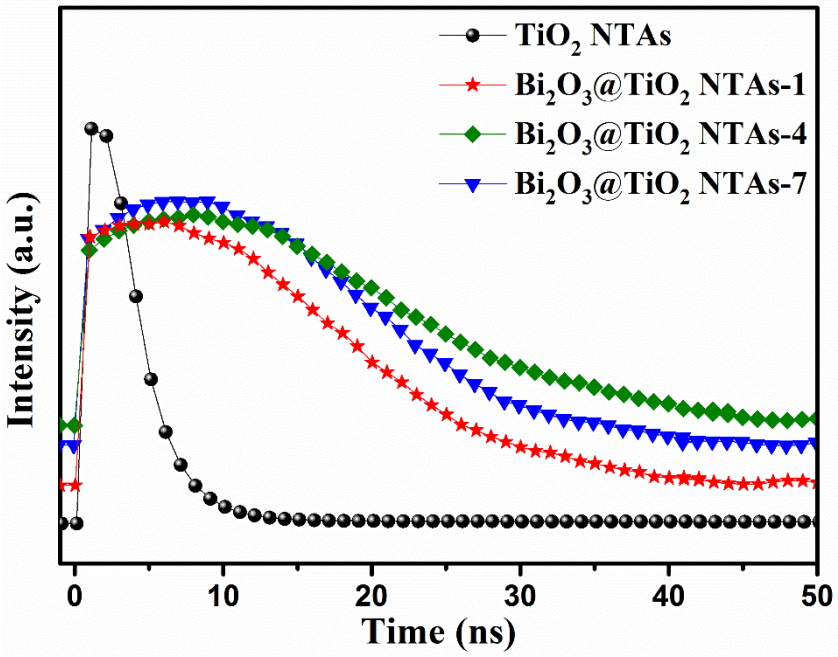

Figure S3. The time-resolved photoluminescence (TRPL) spectrum of TiO_2 NTAs and Bi_2O_3@TiO_2 NTAs with ultrasonication-assisted SILAR deposition for 1, 4 and 7 cycles.

The time-resolved photoluminescence (TRPL) measurements were carried out at room temperature by using fluorescence spectroscopy (made by HOKIBA, FL3-TCSPC) with a Xenon lamp as excitation source (λ_{ex} = 370 nm, 300 nm laser). The time-resolved photoluminescence (TRPL) decay profiles were fitted using the biexponential decay function expressed as follows,

$$I(t)=A_1 \exp(-t/\tau_1) + A_2 \exp(-t/\tau_2)$$

Where A_1 and A_2 are the amplitudes (or weighing factors), and τ_1 and τ_2 are the corresponding lifetimes. As calculated, the average decay lifetime of TiO_2 NTAs and Bi_2O_3@TiO_2 NTAs with ultrasonication-assisted SILAR deposition for 1, 4 and 7 cycles are 6.6 ns, 3.4 ns, 1.8 ns and 4.2 ns, respectively. Compared to the pristine TiO_2 NTAs, Bi_2O_3@TiO_2 NTAs showed more decay lifetime. Shorter decay lifetime clearly indicates lower recombination and higer separation efficiency of electron-hole pairs. What's more, lower recombination of electron-hole pairs will lead to weaker photoluminescence and higher photocatalytic activity, which is

consistent with the PL spectra. Bi_2O_3@TiO_2 NTAs with ultrasonication-assisted SILAR deposition for 4 cycles owns the longest decay lifetime and the highest photocatalytic activity.

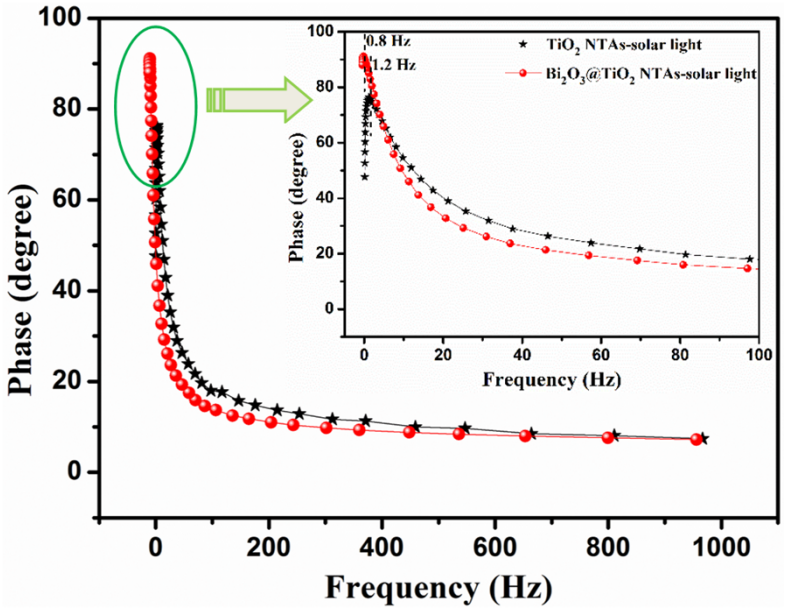

Figure S4. Bode phase plots of TiO_2 NTAs at 450°C and Bi_2O_3@TiO_2 NTAs with repeated SILAR processes for 4 cycles at the low open-circuit condition under solar light illumination, respectively.

The electron lifetime (τ_n) in photonode is correlated with the characteristic frequency peaks (f_{max}) in Bode phase plots,

$$\tau_1 = \frac{1}{2\Pi f max}$$

As shown in Figure S4, the f_{max} value for TiO_2 NTAs and Bi_2O_3@TiO_2 NTAs with repeated SILAR processes for 4 cycles was 1.2 Hz and 0.8 Hz at the open-circuit condition under simulated solar light illumination. Therefore, the electron lifetimes are calculated to be 0.132 ms and 0.199 ms for TiO_2 NTAs and Bi_2O_3@TiO_2 NTAs with repeated SILAR processes for 4 cycles. The longer electron lifetimes revealed longer electron migration distance with fewer trappings and lower combination of electron-hole pairs. These results suggest the presence of Bi_2O_3 quantum dots can prolong the electron lifetimes and facilitate the charge transport.