

## Supporting Information

### **Enhanced Electrical Conductivity of TiO<sub>2</sub> Micro-Rods Through Surface Modification by Antimony-doped Tin Oxide**

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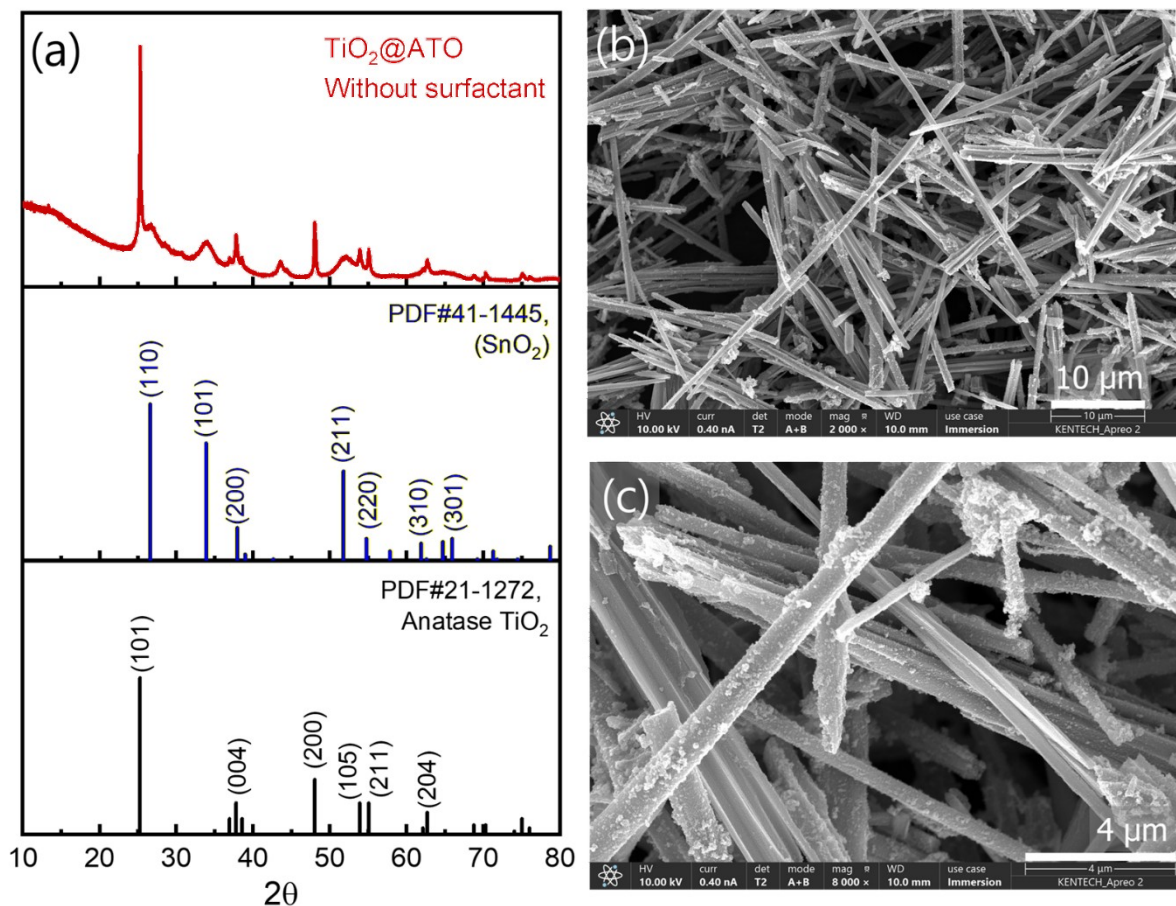


Figure S1. (a) XRD spectra of prepared  $\text{TiO}_2@$ ATO micro-rods without surfactant with JCPDS data of  $\text{SnO}_2$  and Anatase  $\text{TiO}_2$ . SEM images of prepared  $\text{TiO}_2@$ ATO without surfactant with lower (b) and higher (c) magnification.

Figure S1 presents the XRD patterns of the synthesized  $\text{TiO}_2@$ ATOMIC microrods prepared in the absence of any surfactant. As observed, the characteristic diffraction peaks corresponding to ATO exhibit very low intensity compared to those of  $\text{TiO}_2$ , indicating that the formation or deposition of the ATO phase is limited under these conditions. This weak signal suggests that ATO is either poorly crystallized or unevenly distributed on the  $\text{TiO}_2$  surface, resulting in insufficient surface coverage. The absence of a surfactant likely leads to uncontrolled nucleation and growth of ATO particles, causing aggregation in localized regions rather than uniform coating across the microrods.

This interpretation is further supported by the SEM images shown in Figure S1b and S1c. The micrographs clearly reveal that the surface of the TiO<sub>2</sub> microrods lacks a consistent and homogeneous ATO layer. Instead, irregular and scattered deposits can be observed, confirming that ATO nanoparticles are not uniformly anchored onto the TiO<sub>2</sub> framework. Such non-uniform coating may adversely affect interfacial contact and limit the enhancement of electrical or functional properties expected from the TiO<sub>2</sub>@ATO composite system.

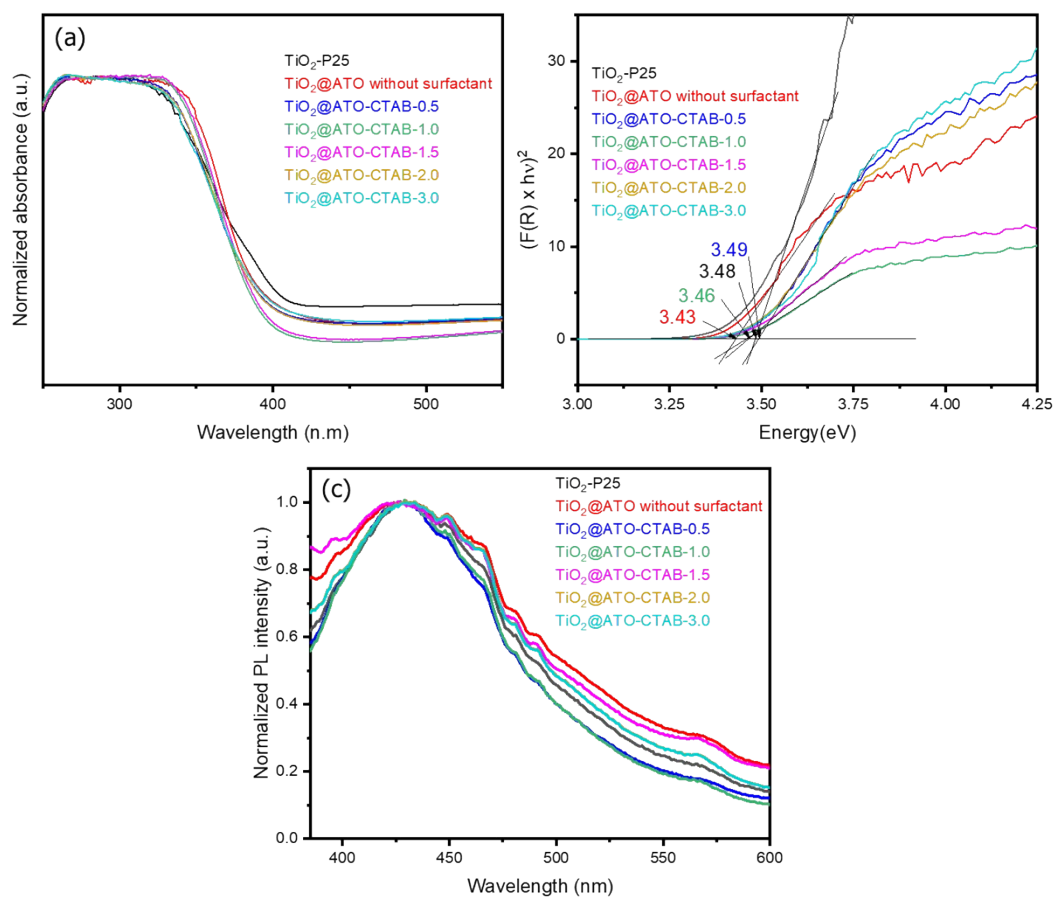


Figure S2. (a) UV-absorbance, (b) Tauc plot and (c) Photoluminescence spectra of pristine TiO<sub>2</sub>, TiO<sub>2</sub>@ATO without surfactant and TiO<sub>2</sub>@ATO with the variation of CTAB surfactant.

The UV–vis absorption spectra (Figure S2a) of pristine TiO<sub>2</sub>-P25 and TiO<sub>2</sub>@ATO composites with varying CTAB concentrations (0–3.0 wt%) were analyzed to evaluate their optical properties. All samples exhibit strong absorption in the UV region ( $\approx$ 250–400 nm), corresponding to the intrinsic band-to-band transitions of TiO<sub>2</sub> from the valence band to the conduction band.<sup>1,2</sup> The presence of a well-defined absorption edge in all cases confirms that the fundamental semiconductor characteristics of TiO<sub>2</sub> are retained after ATO incorporation with CTAB assisted synthesis.

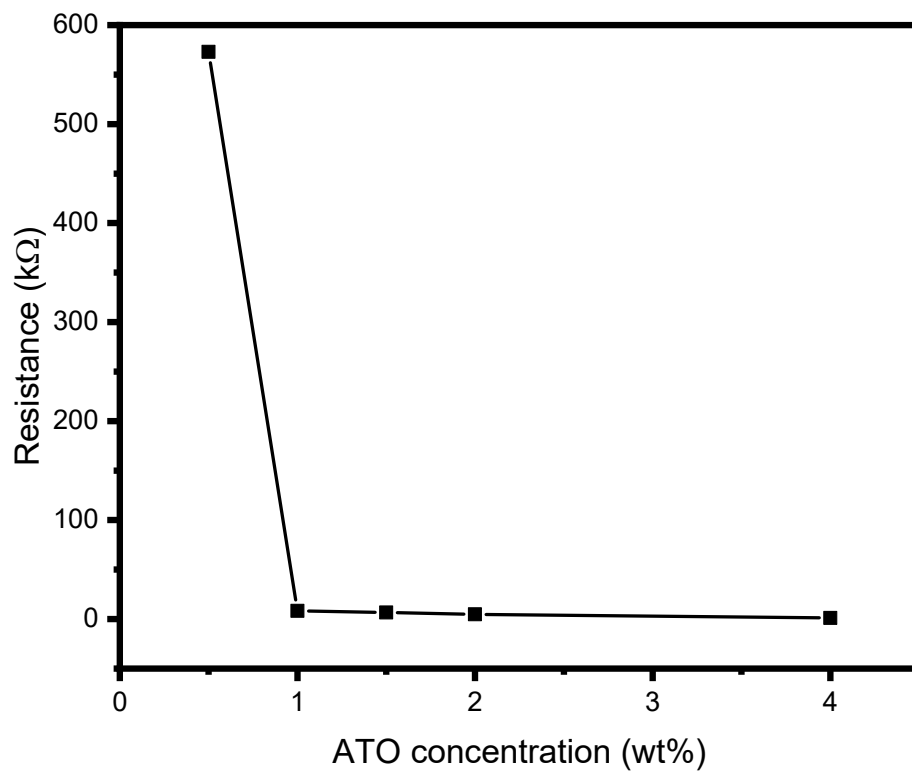
The optical band gaps were estimated using Tauc plots (Figure S2b). Pristine TiO<sub>2</sub> shows a band gap of approximately 3.48 eV. Upon incorporation of ATO without the use of surfactant, the band gap slightly decreases to 3.43 eV, which can be attributed to morphological variations, such as the formation of relatively larger TiO<sub>2</sub> nanorods compared to P25 nanoparticles. In the presence of CTAB, the band gap values remain nearly unchanged, with a value of 3.46 eV observed at 1.0 wt% CTAB and only negligible variation at higher concentrations. A slight increase to 3.49 eV is observed at 0.5 wt% CTAB. These results indicate that neither ATO incorporation nor CTAB-assisted synthesis significantly alters the intrinsic electronic structure of TiO<sub>2</sub>.

The absence of any notable red shift or visible-light absorption suggests that ATO does not act as a sensitizer but rather serves as a conductive phase. Additionally, CTAB primarily facilitates improved dispersion and uniform coating of ATO on the TiO<sub>2</sub> surface, particularly at an optimal concentration of 1.0 wt%. Therefore, the observed modifications are predominantly interfacial rather than electronic in nature. Overall, the UV–vis analysis demonstrates that the enhanced functional performance of TiO<sub>2</sub>@ATO composites is unlikely to originate from changes in optical absorption, but rather from improved charge separation and transport enabled by the conductive ATO network and optimized interfacial contact.

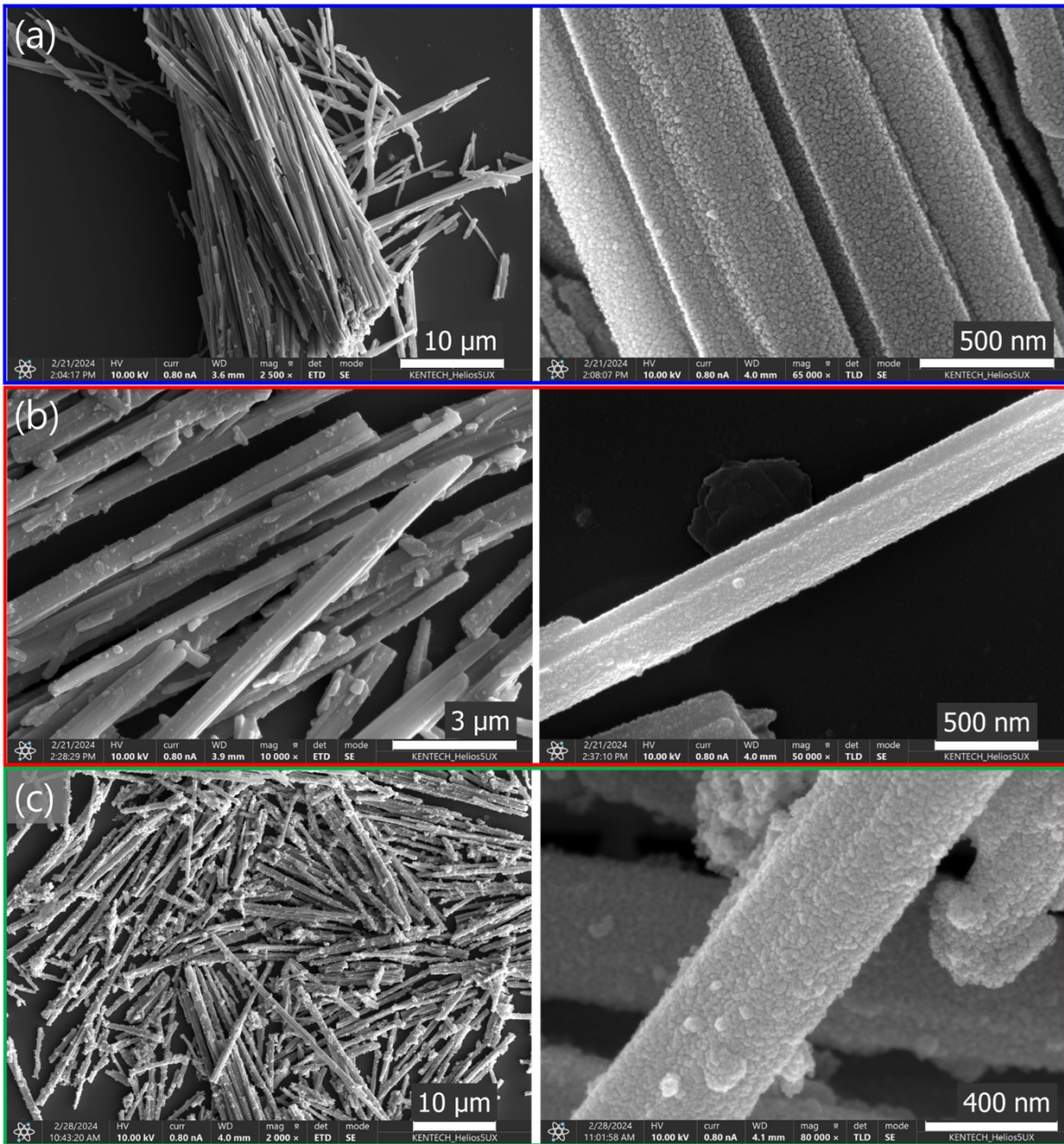
Figure S2c presents the normalized photoluminescence (PL) emission spectra of pristine TiO<sub>2</sub>-P25 and TiO<sub>2</sub>@ATO composites, recorded under an excitation wavelength of 350 nm. All samples exhibit a dominant emission band centered at approximately 430 nm, which is characteristic of near-band-edge recombination in TiO<sub>2</sub>, along with contributions from shallow trap states such as oxygen vacancies and surface defects.<sup>3</sup> The PL intensity reflects the rate of radiative recombination of photogenerated electron–hole pairs. Compared to pristine TiO<sub>2</sub>, the TiO<sub>2</sub>@ATO composites exhibit reduced PL intensity, indicating suppressed charge carrier recombination due to improved interfacial charge transfer. Notably, the sample prepared with 1.0 wt% CTAB shows the lowest PL intensity among all compositions, suggesting the most efficient separation of photogenerated charge carriers. This improvement can be attributed to the role of CTAB as a structure-directing agent, which enhances the ATO uniform and intimate interfacial contact with TiO<sub>2</sub>, thereby facilitating electron transfer.

However, further increasing the CTAB concentration beyond 1.0 wt% (1.5–3.0 wt%) results in a gradual increase in PL intensity, indicating a decline in charge separation efficiency. This behavior suggests that excessive surfactant may disrupt the optimal interfacial interaction between TiO<sub>2</sub> and ATO, due to forming isolated islands rather than a uniform layer which hinder effective electron transport.

Overall, the observed trend demonstrates that an optimal CTAB concentration is critical for achieving efficient interfacial engineering in TiO<sub>2</sub>@ATO composites. Moderate surfactant content (1.0 wt%) enhances charge separation, whereas excess CTAB adversely affects electron transfer, leading to increased recombination. These results highlight the importance of controlled surfactant-assisted synthesis in optimizing the photophysical properties of TiO<sub>2</sub>-based heterostructures.



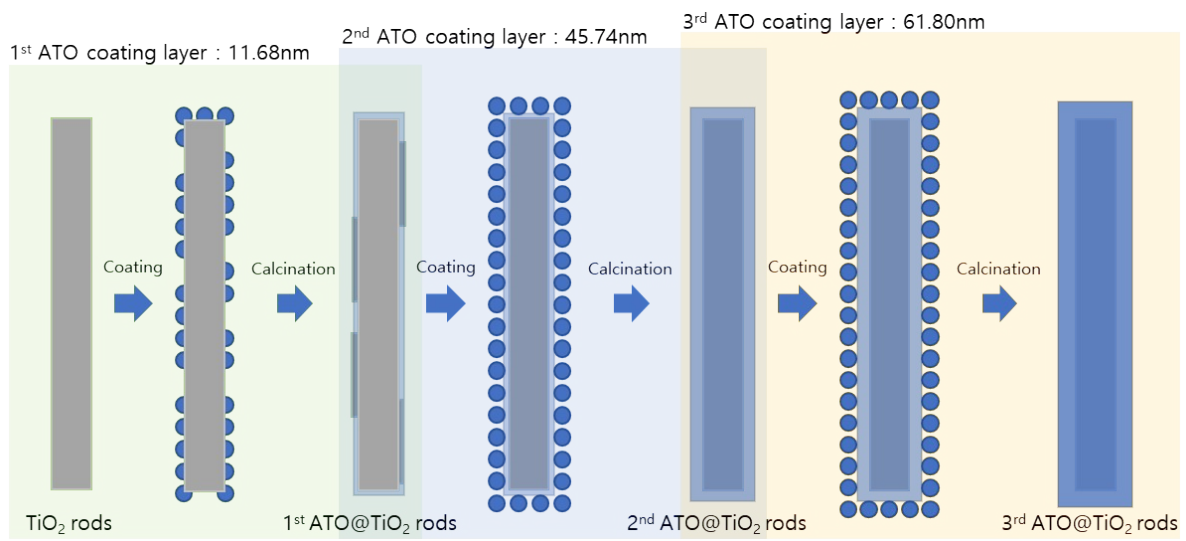
**Figure S3.** Resistance values of TiO<sub>2</sub> micro-rods prepared at different ATO concentrations.



**Figure S4.** SEM data of lower and higher magnification for 0.5 wt% ATO coating on the surface of TiO<sub>2</sub> micro-rods for the (a) first time, (b) second time and (c) third time.

**Table S1.** Resistance value of TiO<sub>2</sub> micro-rods with 0.5 wt% ATO coating at different times, with CTAB concentration held constant at 1wt%.

<b>ATO solution (wt%)</b>	ATO x 0.5wt%	ATO x 0.5wt%	ATO x 0.5wt%
<b>Coating</b>	1 <sup>st</sup> time	2 <sup>nd</sup> time	3 <sup>rd</sup> time
<b>Resistance(KΩ)</b>	573	6.71	0.696



**Figure S5.** Schematic representation of 0.5 wt% ATO coating on the surface of TiO<sub>2</sub> micro-rods in three different times when CTAB kept constant as 0.5wt%.

**Table S2.** The careful resistance of ATO coated TiO<sub>2</sub> micro-rods measured by sophisticated four probe techniques for five different samples prepared with same experimental condition

CTAB(wt%)	ATO(wt%)	Sheet Resistance ( $\Omega$ /sq)					Average
		1	2	3	4	5	
1.0	0.5	6474	6814	6770	7026	7167	6850
	1.0(0.5/0.5)	344	344	342	346	344	344
	1.5(0.5/0.5/0.5)	69	71	67	67	67	68.2

and check the results reproducibility.

## References

1. A. Fujishima, X. Zhang, D. A. Tryk, *Surface Science Reports*, 2008, **63**, 515-582.
2. U. Diebold, *Surface Science Reports*, 2003, **48**, 53-229.
3. A. Saha, A. Moya, A. Kahnt, D. Iglesias, S. Marchesan, R. Wannemacher, M. Prato, J. J. Vilatela, D. M. Guldi, *Nanoscale*, 2017, **9**, 7911-7921.