## Cooperative catalytic behavior of SnO<sub>2</sub> and NiWO<sub>4</sub> over BiVO<sub>4</sub> photoanodes for enhanced photoelectrochemical water splitting performance

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Fig. S1 FE-SEM micrographs of the BiVO<sub>4</sub> photoanodes fabricated using electrodeposition process.



Fig. S2 FESEM images of cross-section of the NiWO4 nanoparticles over  $BiVO_4/SnO_2$  photoanodes



**Fig. S2** SEM images and its corresponding EDX spectra with elemental composition of various stage of fabricated photoanodes a) SnO<sub>2</sub> b) BiVO<sub>4</sub>/SnO<sub>2</sub> c) NiWO<sub>4</sub>/BiVO<sub>4</sub>/SnO<sub>2</sub> electrodeposited on FTO substrate.

The charge separation efficiency  $\eta_{sep}$  is the yield of the photo-generated holes that reach the electrode/electrolyte interface or, in other words, the fraction of photo-generated holes that does not recombine with electrons in the bulk. While, the charge catalytic efficiency  $\eta_{CT}$  is the yield of those holes that have reached the electrode/electrolyte interface and that are injected into the electrolyte to oxidize the water, or in other words, do not recombine with electrons at surface traps. When the photocurrent measured with hole scavenger (HS) like Na<sub>2</sub>SO<sub>3</sub> or H<sub>2</sub>O<sub>2</sub> in the electrolyte ( $J_{HS}$ ) is a product of  $\eta_{abs}$  and  $\eta_{sep}$  only because, the  $\eta_{CT}$  yield becomes 100% ( $\eta_{CT} = 1$ ) in the presence of the hole scavenger in the electrolyte:

The  $\eta_{CT}$  yield into water is achieved by dividing  $J_{H2O}$  photocurrent by  $J_{HS}$  photocurrent.

$$\eta_{CT} = \frac{J_{H2O}}{J_{HS}} \qquad (2)$$

The  $\eta_{abs}$  will be calculated from the optical measurements by:

$$\eta_{abs} = \frac{e}{hc} \int I_{\lambda} (1 - 10^{-A}) d\lambda \dots (3)$$

with  $I_{\lambda}$  being the light intensity at a certain wavelength  $\lambda$  and A being the absorption coefficient.



**Fig. S4.** XRD patterns of SnO<sub>2</sub>/BiVO<sub>4</sub>/NiWO<sub>4</sub> photoanode before (black) and after (red) 3 h of J-t measurement in 0.1 M PBS (pH 7.5).



Fig. S5. XPS spectra of SnO<sub>2</sub>/BiVO<sub>4</sub>/NiWO<sub>4</sub> photoanode before and after 3 h of J-t measurement in 0.1 M PBS (pH 7.5).