Supplementary information

MXene–TMD Heterostructure Photodetector: Engineering Ti_3C_2/SnS_2 Interface for High-Speed Visible Light Detection

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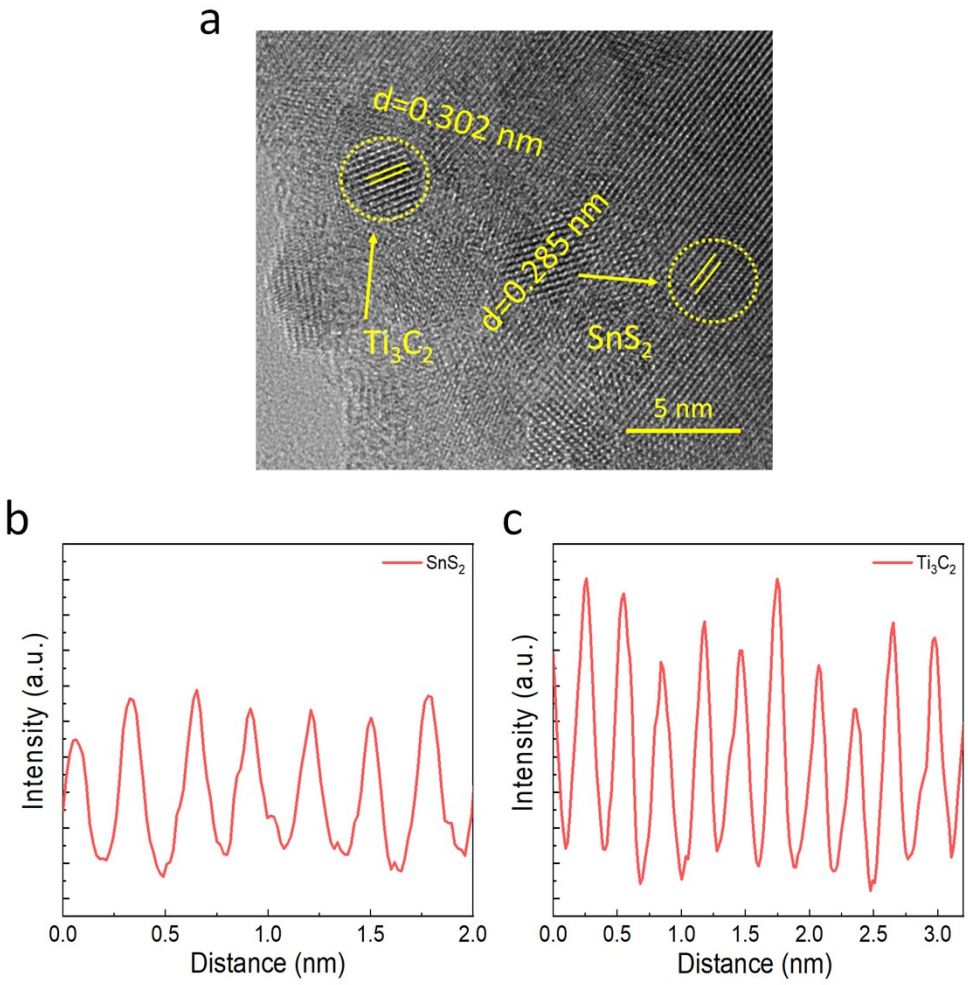

Figure S1: (a) HRTEM image of Ti_3C_2/SnS_2 heterostructure with distance profile scans at specific regions of (b) SnS_2 and (c) Ti_3C_2.

The HRTEM image of Ti_3C_2/SnS_2 heterostructure is shown in **Figure S1 a**. The distance profile scan of SnS_2 is shown in **Figure S1 b,** and the average interplanar distance was found to be 0.285 nm. The distance profile scan of Ti_3C_2 is shown in **Figure S1 c,** and the average interplanar distance was found to be 0.302 nm.

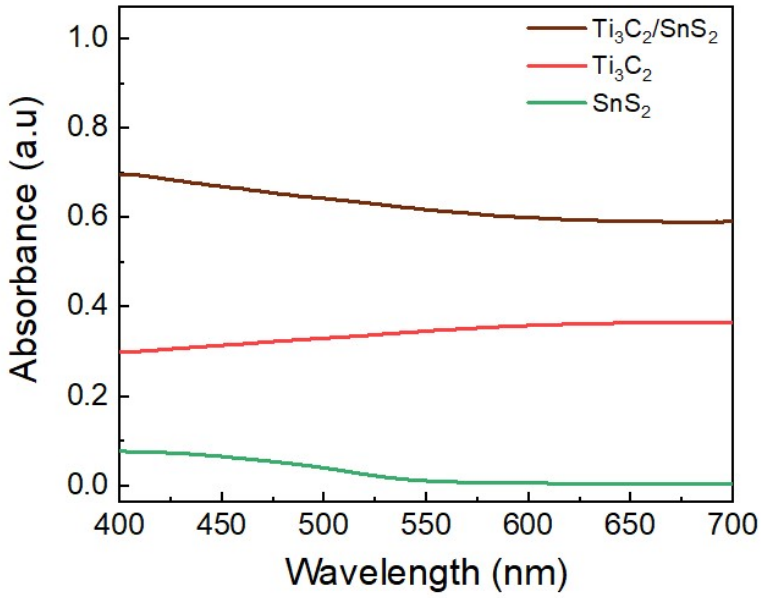

Figure S2: Representation of absorbance of SnS_2, Ti_3C_2, and Ti_3C_2/SnS_2 with respect to wavelength.

The absorbance of SnS_2, Ti_3C_2, and Ti_3C_2/SnS_2 with respect to wavelength is shown in **Figure S2a.** It shows an improved absorption of Ti_3C_2/SnS_2 compared to both individual components. For our sample (solid sample) we used diffused reflectance in the integrating sphere embedded in the system and used the Kubelka-Munk transformation function to calculate the absorbance.

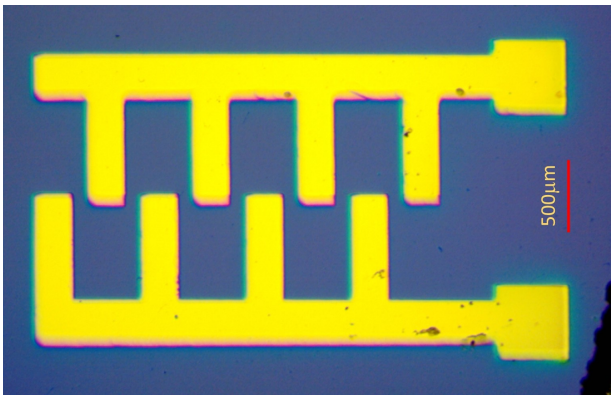

Figure S3: Image of one individual device (cell) with scale bar of 500 µm.

The device image is shown in **Figure S3**. The image of one individual device (cell) is shown in **Figure S3a.**

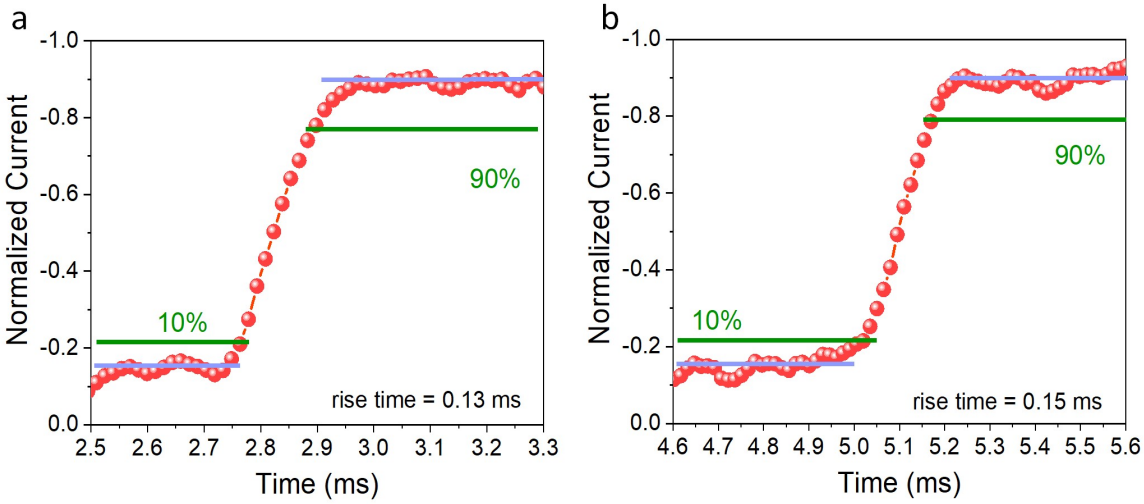

Figure S4: Rise time calculation of Ti_3C_2/SnS_2-based device (a) set 1, (b) set 2, with bias voltage of -5V and under light of 455 nm wavelength and intensity of 100 µW/cm^2.

The time necessary to change the photocurrent from 10% to 90% was used to compute the response time. We repeated the experiment of determining the Ti_3C_2/SnS_2-based device. It exhibited a rise

time of 0.13 (**Figure S4 a) and** 0.15 ms (**Figure S4 b).** And the rise time shown in **(Figure 8 d)** is 0.17 ms. The average rise time (0.13 + 0.15 + 0.17) ms/3 = 0.15 ms.

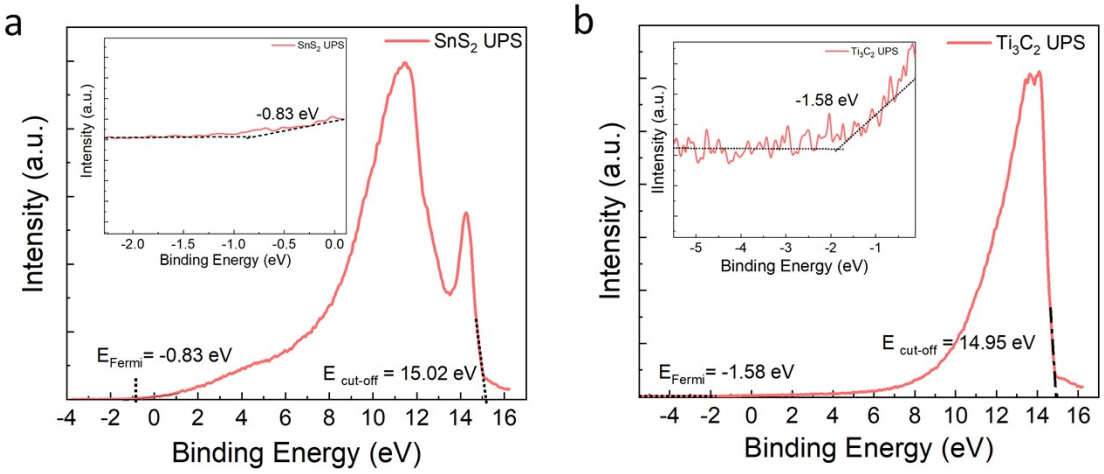

Figure S5: Ultraviolet photoelectron spectroscopy (UPS) spectrum plot of (a) SnS_2 and (b) Ti_3C_2 with respect to energy.

The ultraviolet photoelectron spectroscopy (UPS) measurement was performed using a He-Iα light source with an energy of 21.22 eV. The UPS plot of SnS_2 is shown in **Figure S5 a.** The work function (WF) was calculated using the formula WF = 21.22-$E_{cut\text{-}off}$ - E_{Fermi} = 5.37 eV. The WF of Ti_3C_2 was also calculated to be 4.70 eV from the UPS plot of **Figure S5 b.**

We fabricated four Ti_3C_2/SnS_2 devices, i.e., D1, D2, D3, and D4, excluding our studied device, on which pristine SnS_2 also showed interconnectedness across the channel, in a single wafer. Their photo and dark current levels, and photo to dark current ratio were added in Table S1.

Table S1: Obtained photo and dark current levels, and photo to dark current ratio of another four Ti_3C_2/SnS_2 based devices with a bias voltage of -5V, and wavelength of 455 nm along with an intensity of 7.5 mW/cm^2.

Device	I_{ph} (A)	I_{dark} (A)	I_{ph}/I_{dark}
D1	1.31×10^{-5}	1.44×10^{-7}	153
D2	4.32×10^{-6}	1.09×10^{-7}	39
D3	4.83×10^{-6}	1.08×10^{-7}	33

D4	3.21×10^{-6}	1.16×10^{-7}	28

The current levels of Ti_3C_2/SnS_2 device in presence and absence of light are denoted as I_{ph} and I_{dark} with a wavelength 405 nm of and an intensity of 7.50 mW/cm^2. The max photo-to-dark current ratio I_{ph}/I_{dark} for all these devices are calculated. As their ratio is less than our reported device, we did not proceed with the other characterizations, considering it a low-performance device.

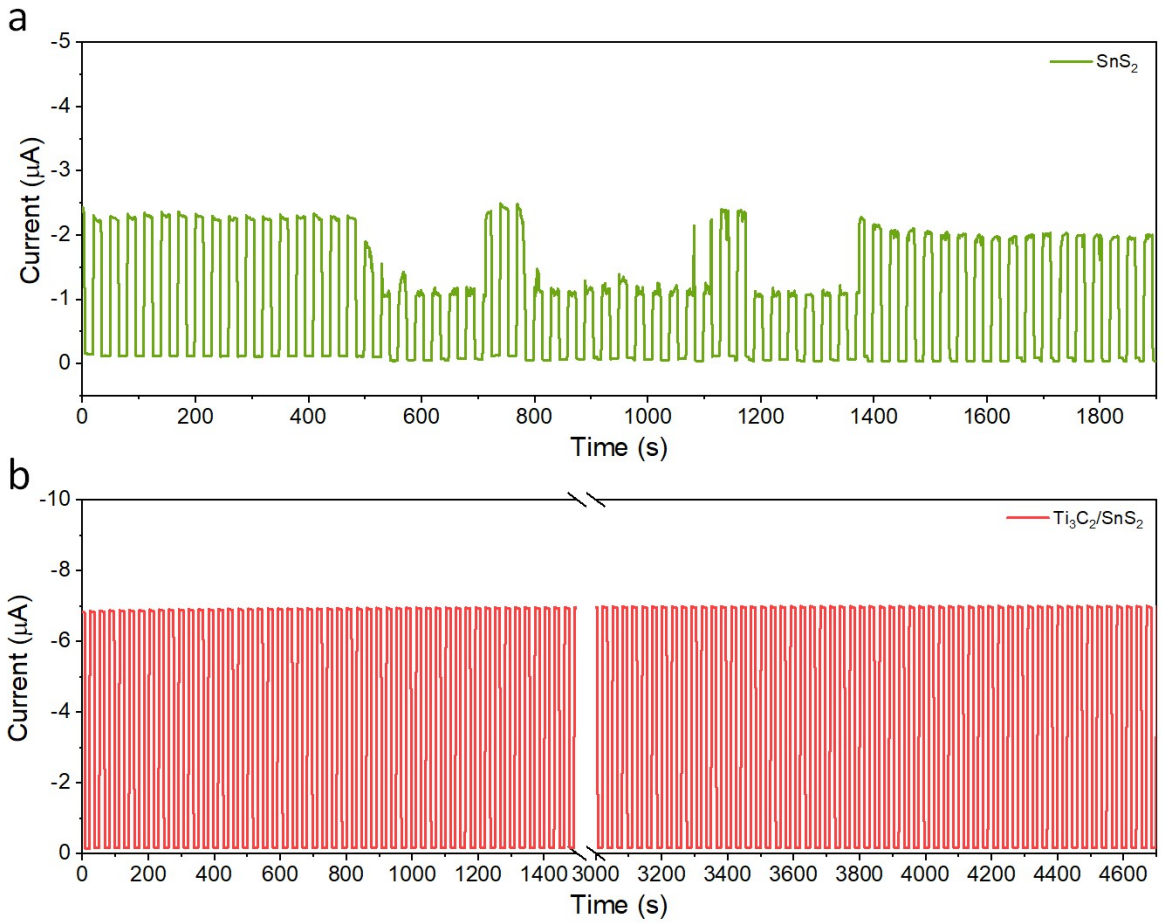

Figure S6: (a) Cycling performance of pristine SnS_2-based device for 1900 s under continuous illumination (455 nm, 100 μW cm^{-2}, pulse width 15 s).

(b) Cycling performance of Ti_3C_2/SnS_2-based device after one-month ambient storage for 4700 s under the same conditions.

The same cycle test was performed with only the SnS_2-based device after one month by applying sequential pulses with a pulse width of 15s. The device's response clearly shows its degradation in the ambient. The test lasted for 1900 s (**Figure S6a),** indicating poor stability under ambient conditions. One of the possible reasons is electrochemical reactions in the presence of light, oxygen, and humidity [17]. It affects the photoinduced electrons/holes at the interface of materials by redox reaction. In presence of oxygen, NO_2 and, toxic gases the materials create different kind of oxide nitride and salts which permanent damage in device performance [18]. But on the other hand, the Ti_3C_2/SnS_2-based device showed its excellent stability after one month in ambient (**Figure S6b**), which shows its potential against absorbents like moisture, oxygen, etc.

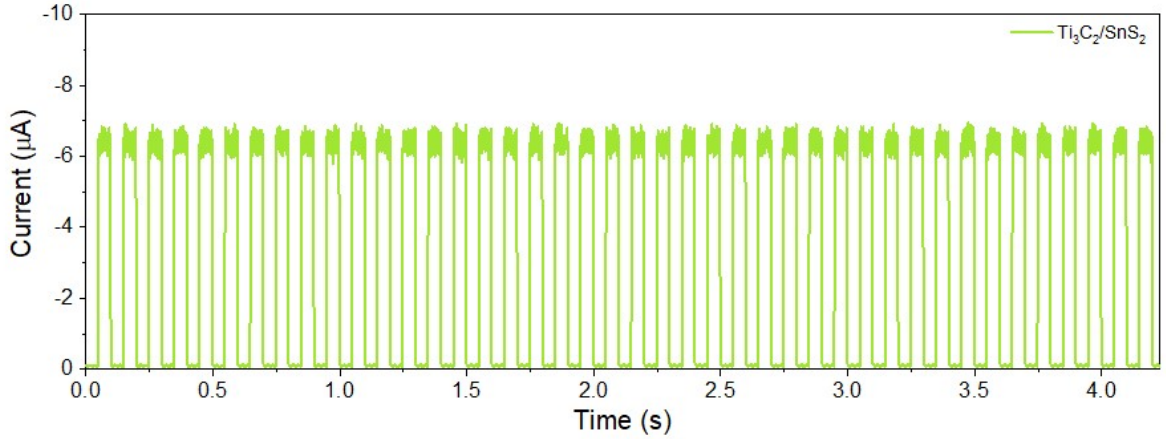

Figure S7: Cycle test of the Ti_3C_2/SnS_2 photodetector performed after five months in ambient conditions using 100 ms light pulses at 455 nm and 100 μW cm^{-2}, with a sampling interval of 0.56 ms per point.

The Ti_3C_2/SnS_2 device shows clear and reproducible on/off transitions within the 4.5 s test duration, corresponding to ~45 cycles. The extracted rise and decay times (~0.15 ms and ~0.17 ms) are consistent with Figure 8, confirming that the device remains fully functional under rapid optical modulation and validating its high-speed photoresponse capability.

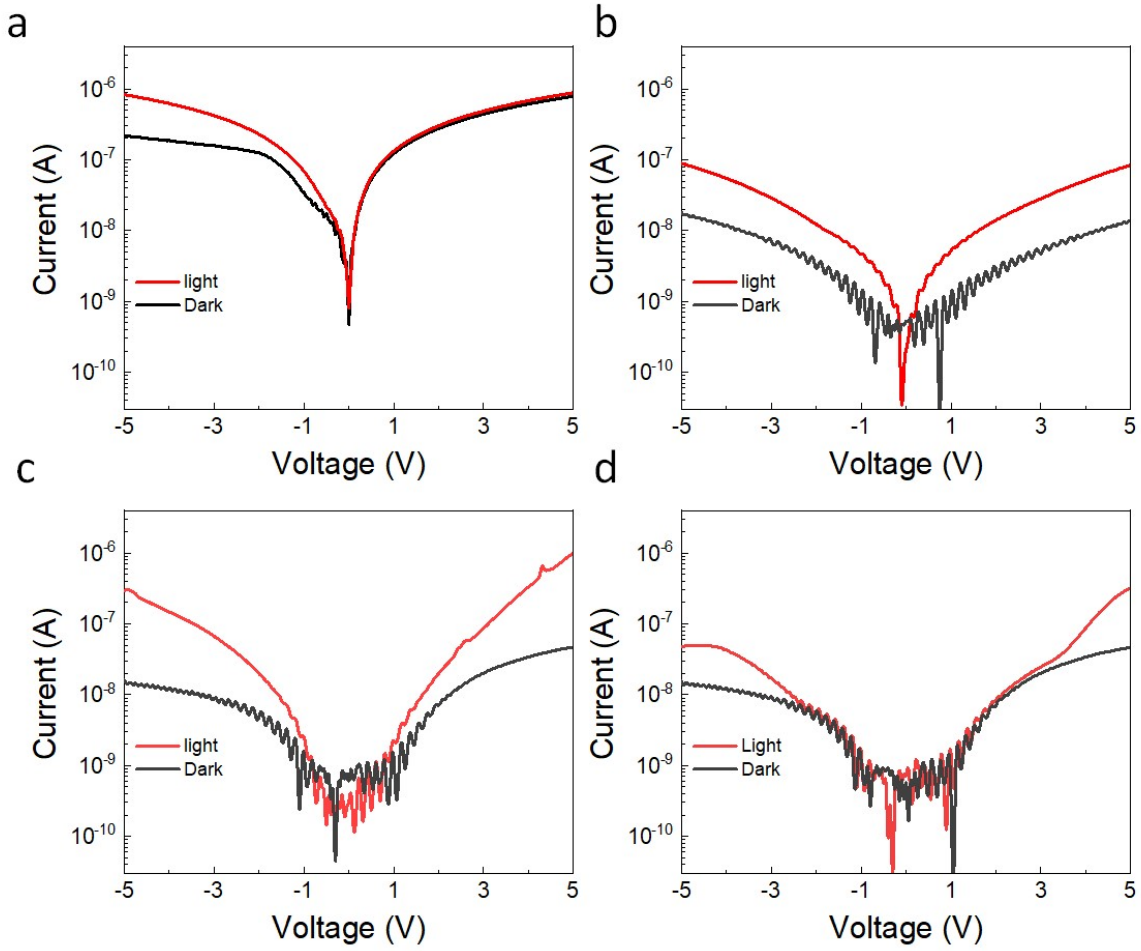

Figure S8: The I-V characteristic of Ti_3C_2-SnS_2-devices drop casted with different concentrations (a) 2 mg/L (b) 1 mg/L, (c) 0.5 mg/L, (d) 0.1 mg/L of Ti3C2 with a bias voltage of -5V, and wavelength of 455 nm along with an intensity of 7.5 mW/cm^2.

The photo-to-dark current ratios were found to be 3.8, 5.5, 15.2, and 3.2 for 2, 1, 0.5, and 0.1 mg L^{-1}, respectively. The optimized concentration of 0.5 mg L^{-1} provided the highest performance and was used in the reported device. These results demonstrate the influence of Ti_3C_2 loading on interfacial charge transport and overall photodetection efficiency.