Supporting Information for

Multilayered $PtSe_2$/pyramid-Si heterostructures array with light confinement effect for high-performance photodetection, image sensing and light trajectory tracking applications

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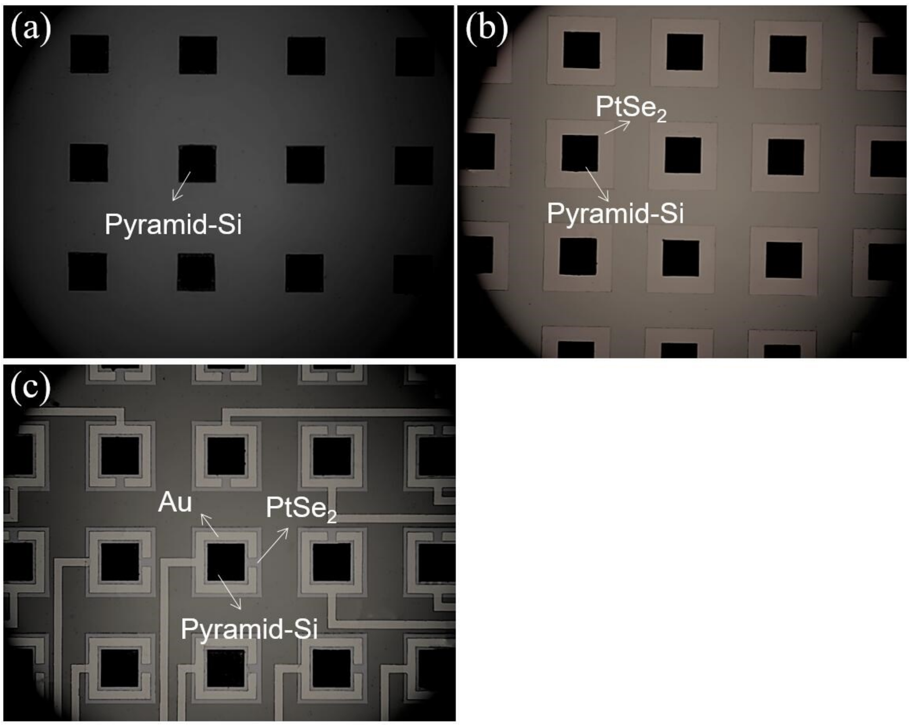

Figure S1. Optical images of (a) the pyramid-Si microstructures array, (b) the pyramid-Si microstructures array covered with $PtSe_2$ films, and (c) the heterostructrure-based photodetectors array.

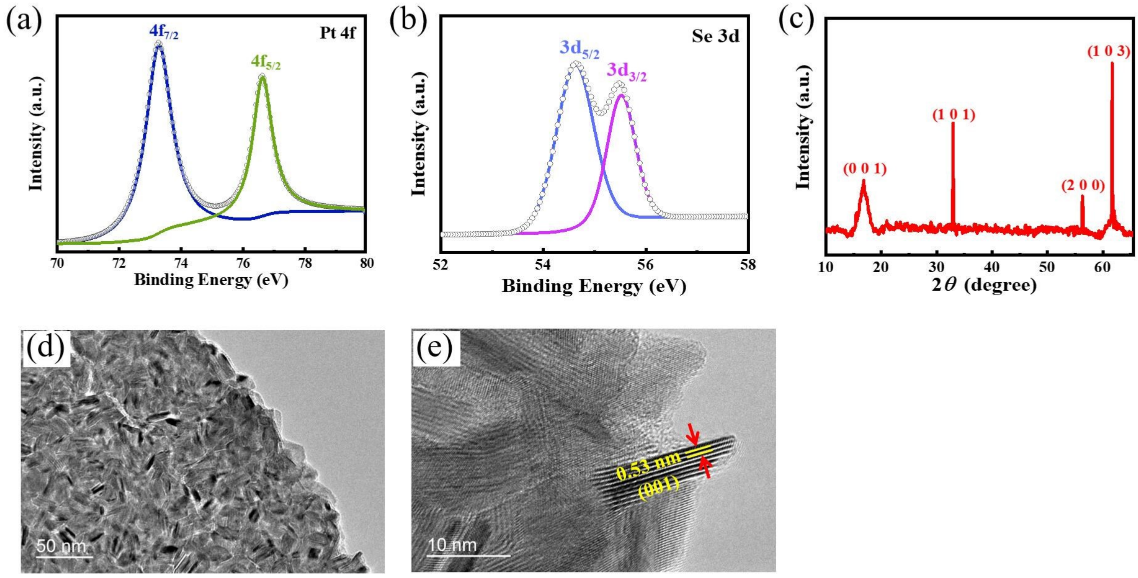

Figure S2. (a) High-resolution XPS spectra of (a) Pt 4f and (b) Se 3d of the $PtSe_2$ sample. (c) XRD pattern of the $PtSe_2$ sample. (d) TEM and (e) HRTEM images of the $PtSe_2$ sample.

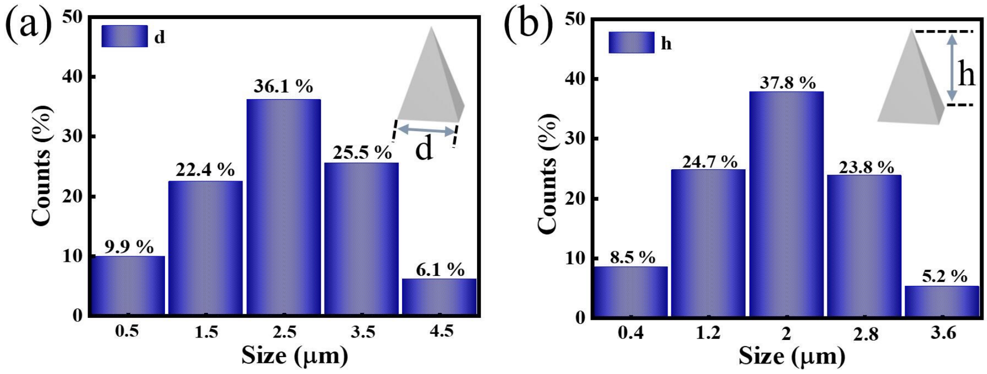

Figure S3. (a) The dimeter and (b) height distribution of the pyramid-Si microstructures.

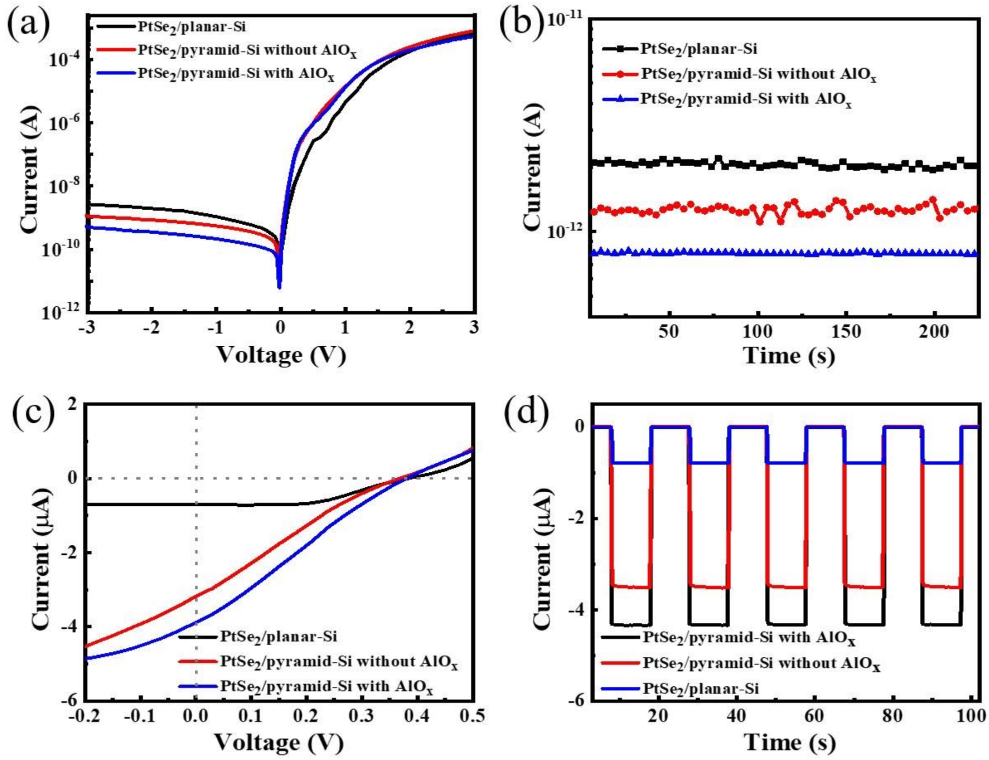

Figure S4. (a) *I-V* curves in dark, (b) dark current at zero bias, (c) *I-V* curves under 810 NIR illumination, and (d) time-dependent photoresponse under 810 NIR illumination of $PtSe_2$/planar-Si heterostructure, $PtSe_2$/pyramid-Si heterostructures with and without AlO_x passivation layer.

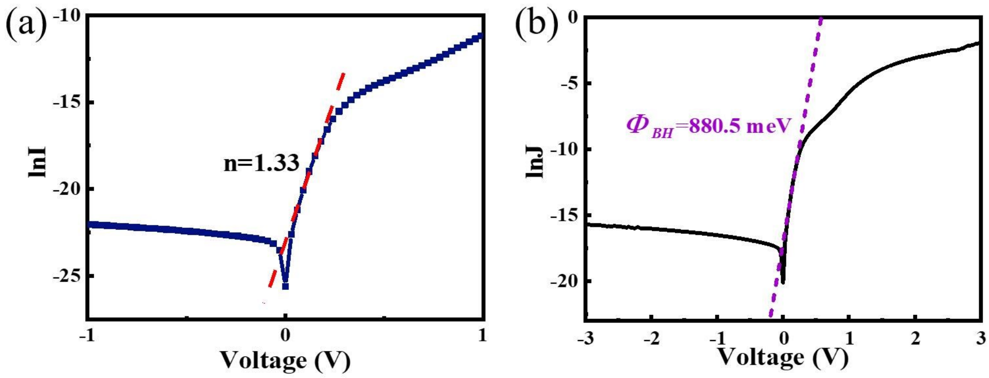

Figure S5. (a) The plot of ln*I*-*V* curve for estimating the diode ideality factor (n). (b) The plot of ln*J*-*V* curve for calculating the barrier height of the heterostructure.

Calculation of the barrier height (ϕ_{BH}) of the heterostructure: The diode properties of the heterostructure is described by thermionic emission theory of majority charge carriers over a potential zero bias barrier Φ_{BH}, from the pyramid-Si to the $PtSe_2$:[S1]

$$J(T,V) = J_S(T)[\exp\left(\frac{eV}{nk_BT}\right) - 1] \quad (1)$$

Where $J(T, V)$ is the current density across the $PtSe_2$/pyramid-Si interface, V is the applied voltage, e is the elementary charge, k_B is the Boltzmann constant, T is the temperature, and n is the ideality factor. The saturation current density $J_S(T)$ is defined by

$$J_S(T) = A^* T^2 exp(-\frac{e\Phi_{BH}}{k_BT}) \quad (2)$$

Where A^* is the effective Richardson constant, which is 252 A/(cm^{2}K^2) for n-type Si.[S2] $J_S(T)$= 3.88 10^{-5} mAcm^{-2} is deduced from the ln$J$-V curve in Fig. S5(b). Therefore, based on eqn (2), the barrier height Φ_{BH} is estimated to be 880.5 meV,

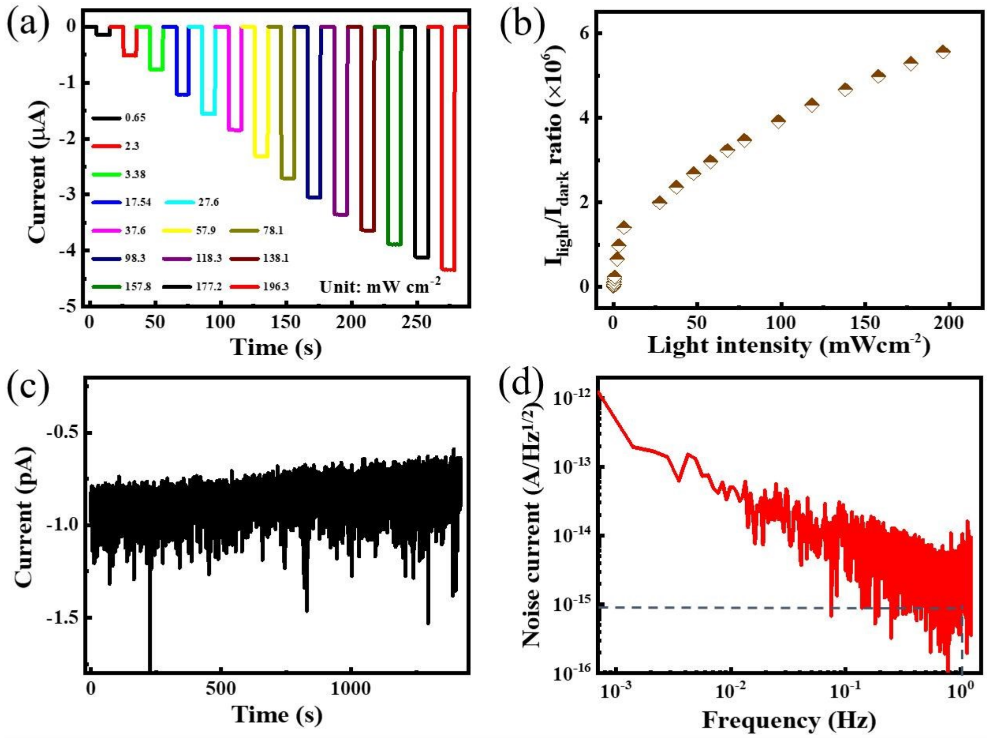

Figure S6. (a) Time-dependent photoresponse of the heterostructure under NIR illumination with different intensities. (b) I_{light}/I_{dark} ratio of the heterostructure as a function of incident light intensity. (c) Dark current at zero bias as a function of time. (d) Analysis of the noise spectral density of the heterostructure.

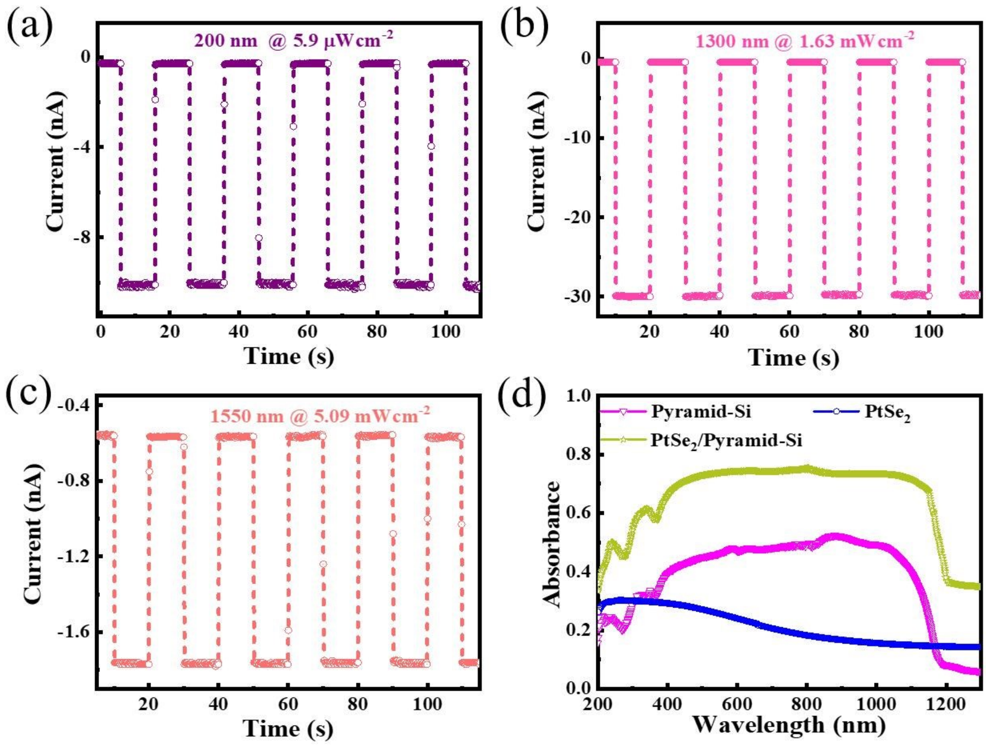

Figure S7. (a) Time-dependent photoresponse of the heterostructure under light illuminations with wavelength of (a) 200 nm, (b) 1300 nm and (c) 1550 nm. (d) Absorbance spectra of $PtSe_2$ layer, pyramid-Si and $PtSe_2$/pyramid-Si heterostructure.

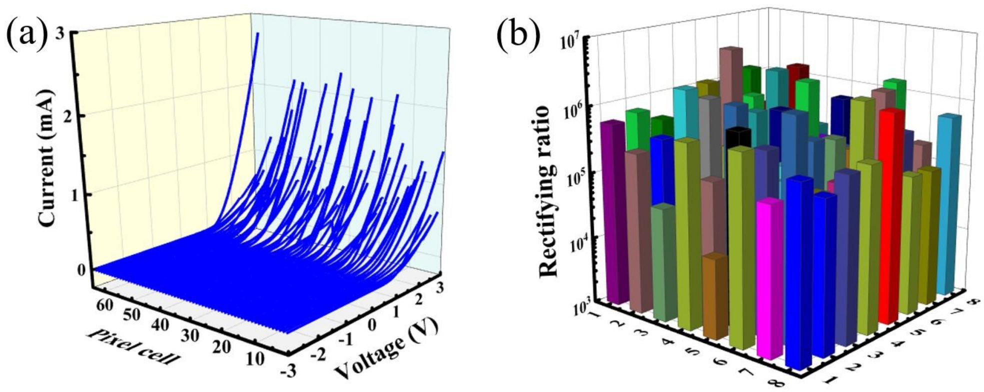

Figure S8. (a) *I-V* curves of all 64 device units in darkness. (b) 3D diagram of the rectification ratio for each device unit.

Supporting Information References:

S1. C. Xie, B. Nie, L. Zeng, F.-X. Liang, M.-Z. Wang, L. Luo, M. Feng, Y. Yu, C.-Y. Wu, Y. Wu and S.-H. Yu, *ACS Nano*, 2014, **8**, 4015–4022.

S2. S. M. Sze and K. K. Ng, *Physics of Semiconductor Devices*, John Wiley & Sons: Hoboken, NJ, 2007..