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Supporting Information

Single nanoflake based $PtSe_2$ p-n junction (in-plane) formed by optical excitation of point defects in BN for ultrafast switching photodiodes

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Growth of graphene and $PtSe_2$/BN/graphene heterostructure:

For graphene growth, a popular chemical vapor deposition (CVD) method was implemented. A copper foil with a thickness of 25 μm was positioned into a CVD furnace (Alfa Aesar with 99.8% purity). The furnace temperature was retained at 1010 °C (~10^{-4} Torr) with the flow of hydrogen gas (~10^{-2} Torr). To synthesize graphene, hydrogen (H_2, 5 cc/min) and Methane (CH_4, 20 cc/min) were brought together into a furnace for 8 min, after stabilization of temperature (i.e., 1010 °C). Once the growth process of graphene was done the sample was cold down to a temperature of ~25 °C (room temperature). Wet transfer technique was used to transfer graphene film from the copper foil on a SiO_2/Si substrate. [1, 2] A monolayer graphene hall bar is achieved on Si/SiO_2 wafer by using the O_2 plasma etching technique. Ultra-thin nanoflakes of $PtSe_2$ and BN were obtained through a standard mechanical exfoliation method using an adhesive tape. Stacked $PtSe_2$/BN/graphene heterostructures were fabricated using a dry transfer method in such a way that $PtSe_2$ flake was partially placed on a heterostructure of BN/graphene while the remaining on BN.

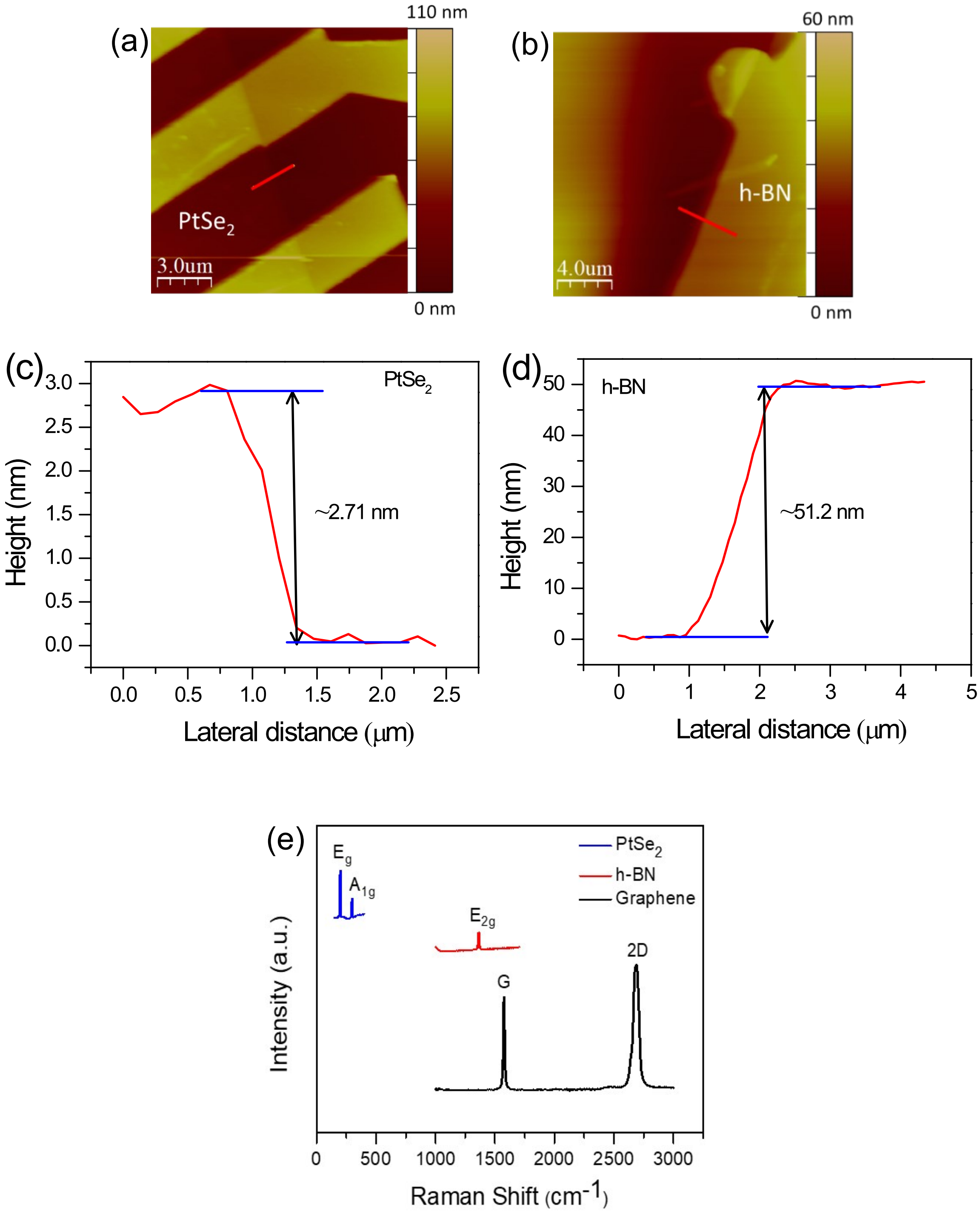

Figure S1. (a) AFM image of $PtSe_2$ showing on the BN substrate. (b) AFM image of BN showing on Si substrate. (c) The $PtSe_2$ flake has a thickness of ~2.71 nm. (d) The BN nanoflake has a thickness of ~51.2 nm. (e) The Raman spectra of $PtSe_2$, BN, and graphene.

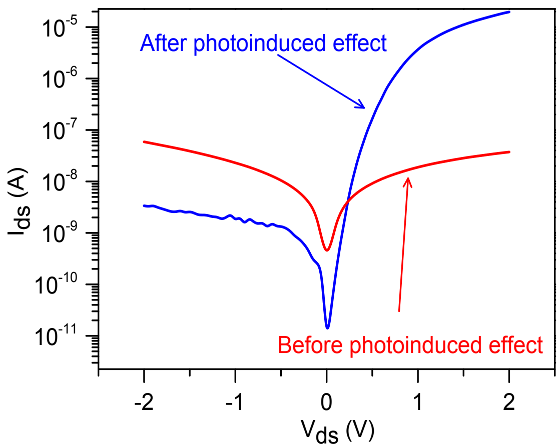

Figure S2. I_{ds}-V_{ds} characteristics of our p-n diode at zero back-gate voltage, which shows the stability which showing the effect of doping on rectifying behavior.

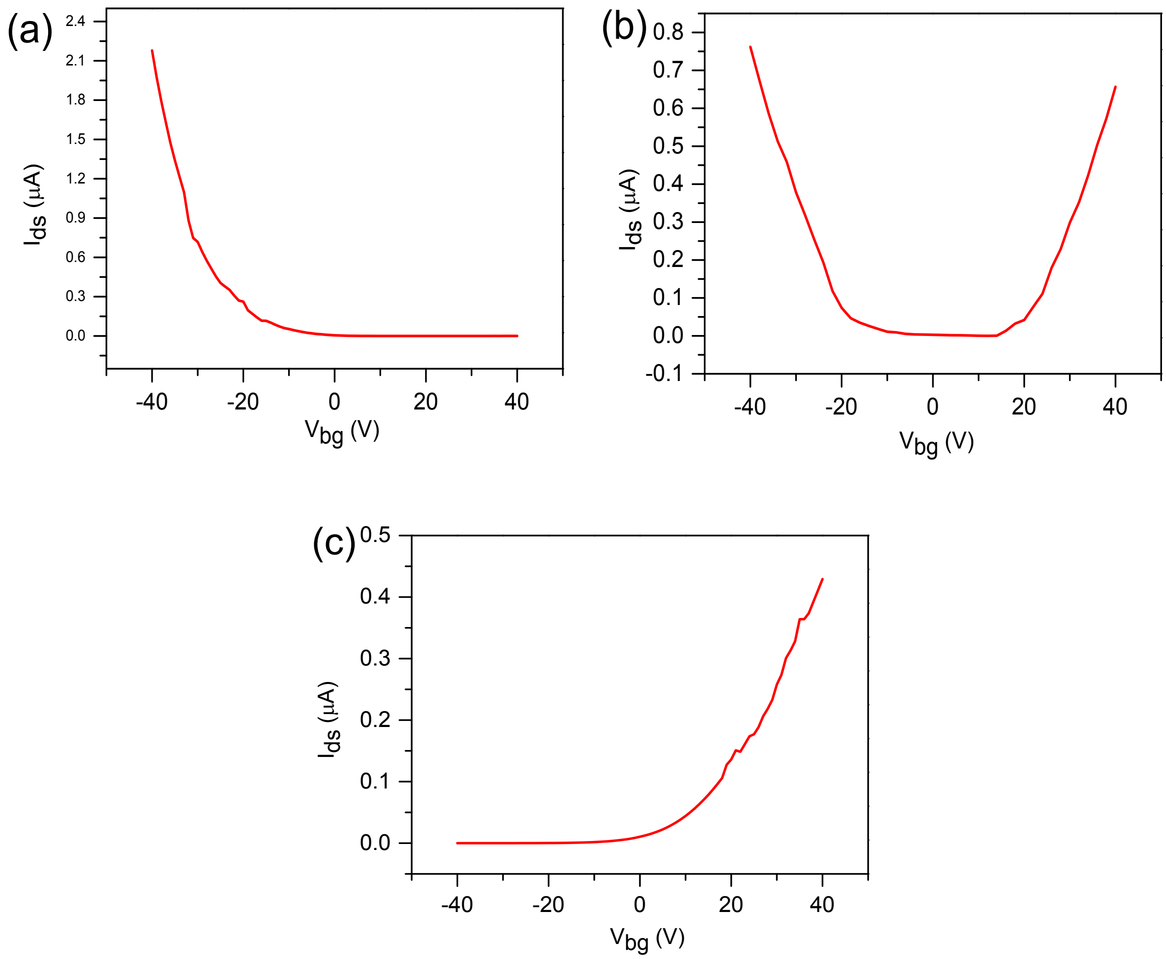

Figure S3. Transfer curves of p-$PtSe_2$ flakes showing the (a) p-type, (b) ambipolar type, and (c) n-type FETs doping at V_{ds}= 1V.

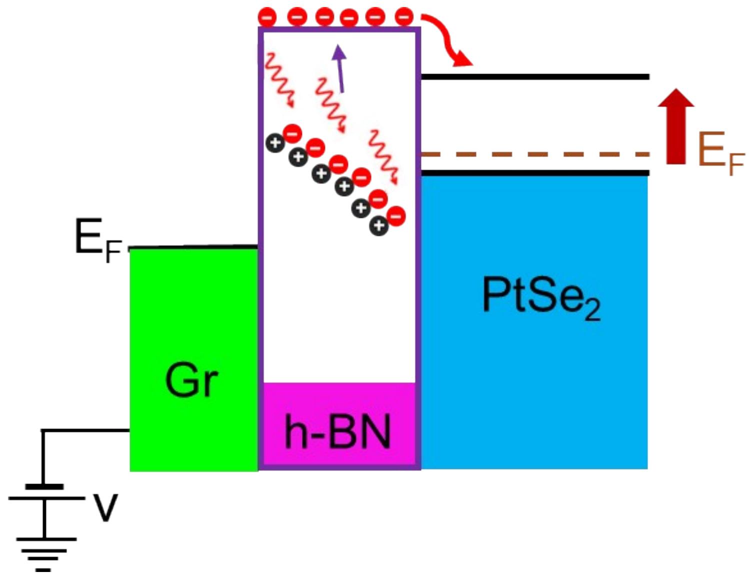

Figure S4. An illustration of photo-induced doping mechanism, where incident light excites electrons from mid-gap defect states in BN. The photons excited electrons are entered into the $PtSe_2$ flake under negative gate stress voltage which is applied to graphene during the process of doping.

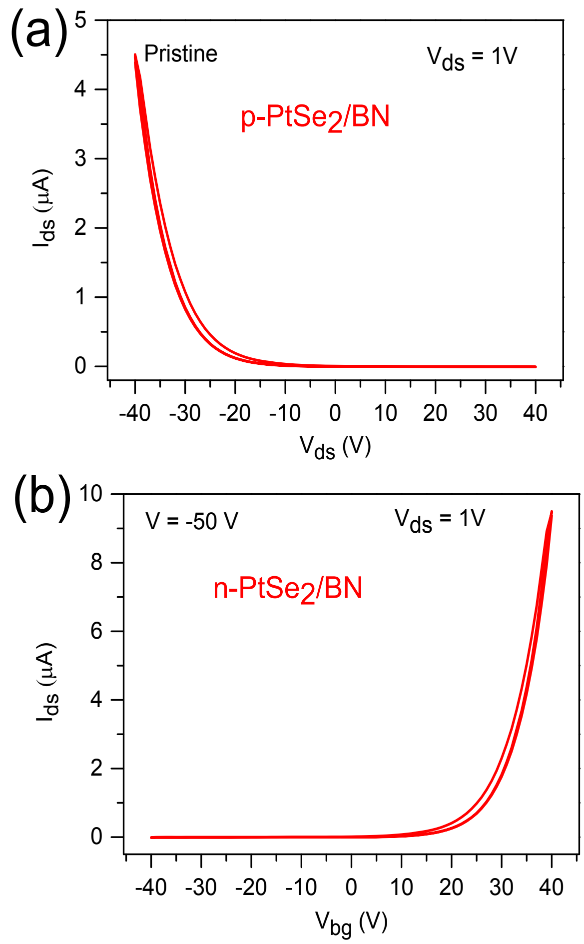

Figure S5. (a) Transfer curves of p-$PtSe_2$ flakes on h-BN substrates. (d) Transfer curves of n-$PtSe_2$ flakes on h-BN after doping.

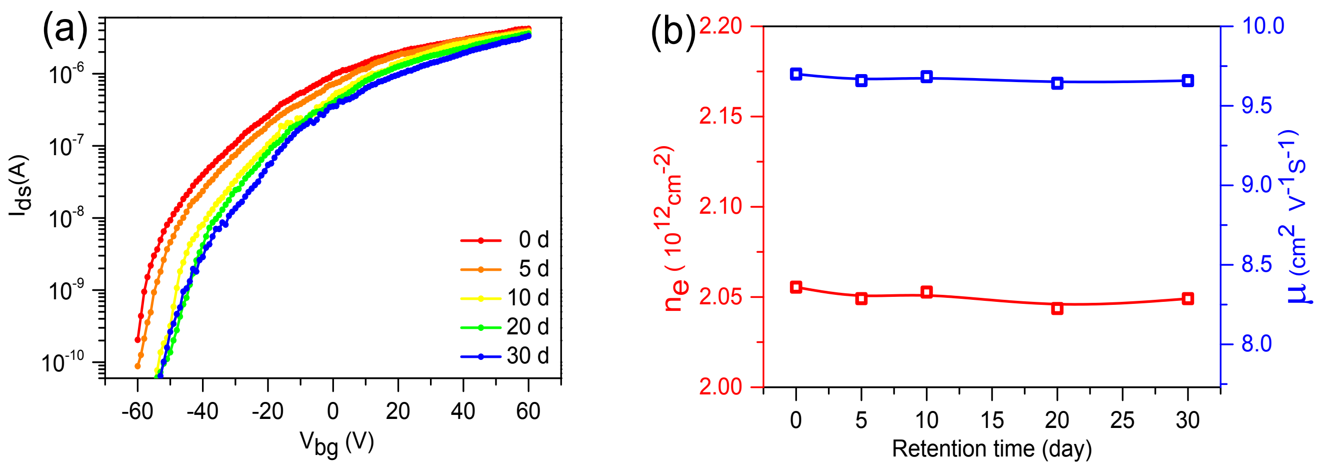

Figure S6. (a) Transfer characteristics of $n-PtSe_2$ after photo-induced doing, which shows the stability of the device in an ambient environment. (b) Carrier concentration and electron mobility as a function of retention time

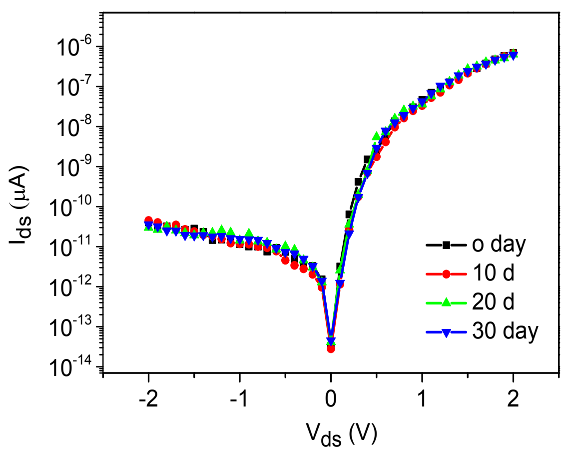

Figure S7. I_{ds}-V_{ds} characteristics of our p-n diode at zero back-gate voltage, which shows the stability of the device in an ambient environment.

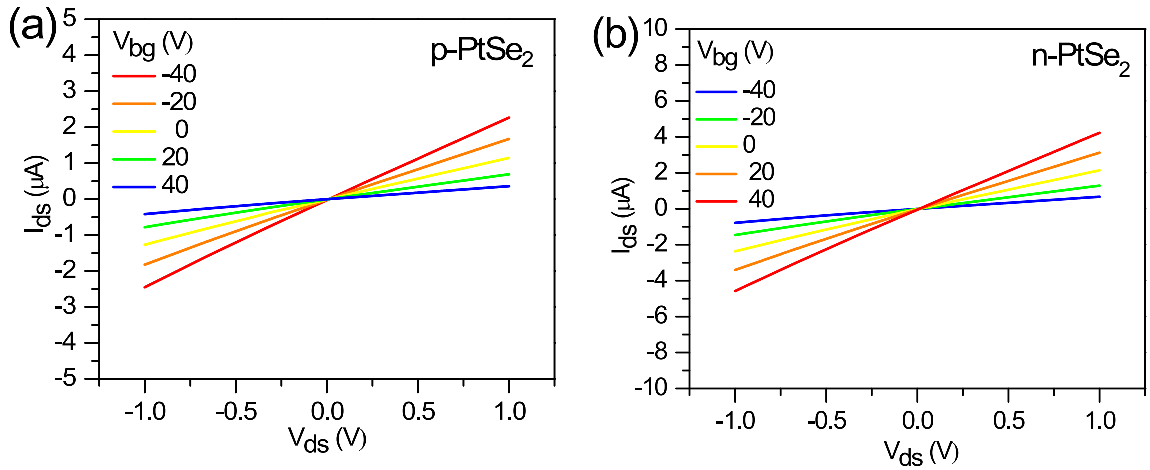

Figure S8. (a) The $I_{ds} - V_{ds}$ characteristics of $p - PtSe_2$ at various V_{bg}. Good ohmic contact behavior is observed with Ni/Au metal contacts. (b) The $I_{ds} - V_{ds}$ characteristics of $n - PtSe_2$ at various V_{bg}. Good ohmic contact behavior is observed with Ni/Au metal contacts.

REFERENCES

1. K. S. Kim, Y. Zhao, H. Jang, S. Y. Lee, J. M. Kim, K. S. Kim, J.-H. Ahn, P. Kim, J.-Y. Choi and B. H. Hong, *nature*, 2009, **457**, 706.
2. Y. Xue, B. Wu, Y. Guo, L. Huang, L. Jiang, J. Chen, D. Geng, Y. Liu, W. Hu and G. Yu, *Nano Research*, 2011, **4**, 1208-1214.