# Supporting information for:

# Photoresponse of atomically thin MoS<sub>2</sub> layers and their planar heterojunctions

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#### S1. Raman spectroscopy for identification of number of layers in MoS<sub>2</sub> film

To support observations by optical contrast, well known Raman spectroscopy technique is used to identify monolayer and bilayer  $MoS_2$  films, by finding the separation between  $E^{1}_{2g}$  and  $A_{1g}$  peaks. The separation for monolayer and bilayer are found to be 18.67 cm<sup>-1</sup> and 21.53 cm<sup>-1</sup>, respectively. Larger separation is expected for thicker layers.



Figure S1. Raman signal of monolayer and bilayer MoS<sub>2</sub>, measured after the formation of the device.

S2. Photoluminescence characterization of MoS<sub>2</sub> samples with varying number of layers



Figure S2. Thickness dependent photoluminescence signal of  $MoS_2$ , with a 532 nm excitation. The A peak at the K point shows clear dependence of the PL intensity with thickness.

#### S3. Band diagram in MoS<sub>2</sub> monolayers and heterojunctions

The band diagrams are calculated by solving Poisson equation: 
$$\frac{d^2\phi(x)}{dx^2} = \frac{q[n(x) - p(x) + N_a - N_d]}{\epsilon_0 \epsilon_r}$$

 $\epsilon_r$  is assumed to be 5. We assumed two band model with 2D density of states:  $D(E) = \frac{m^*}{\pi \hbar^2}$  with degenerate spin up and spin down states. The electron density n(x) is obtained from:

$$n(x) = \int_{E_c}^{\infty} dE f(x,E)D(E) \quad \text{with} \quad f(x,E) = \frac{1}{1 + e^{[E - F(x)]/k_B T}} \text{ where } F(x) \text{ is the local quasi-Fermi level. The}$$

hole densities are also found similarly. In the absence of any intentional doping or external gate voltage, the relatively large electrical band gap of the monolayer results in small net charge, and hence weak band bending, as shown in Fig. S3. We have used four different doping conditions, and  $V_{ds}$ =0. The bandgap in this example has been assumed to be 1.9 eV, although it is important to keep in mind that the electrical bandgap can be higher than this value, depending on the strength of the exciton binding energy. We have also assumed a Fermi level pinning of the metal contacts at 0.25 eV below the conduction band. The predicted quasi-linear bands in Fig. S3 are arising due to the presence of low carrier density which does not allow strong band bending.

In the case of heterojunctions, the calculation remains similar, with the band offsets are added appropriately. There are varying reports on the exact magnitude and direction of the band offsets between monolayer and multi-layer [1,2]. In this work, we have taken the values from [2], but we report the energy scale in arbitrary unit in the absence of a consensus on these values.



Figure S3: Band diagram of monolayer  $MoS_2$ , with  $V_{ds}$ =0, and four different n-type doping conditions. The Fermi-level is at zero energy. Metal Fermi-level is assumed to have been pinned at 0.25 eV below the conduction band minimum.

### S4. Scanning photoluminescence characterization of MoS<sub>2</sub> heterojunctions



Figure S4: Scanning photoluminescence intensity across 1L/2L and 1L/FL/ML MoS<sub>2</sub> heterojunction.

## S5. AFM thickness characterization of MoS<sub>2</sub> heterojunctions



Figure S5: Measured thickness of 1L/2L and 1L/FL/ML  $MoS_2$  heterojunctions using AFM.

S6. Scanning photocurrent measurement for few-layer/multi-layer heterojunction device and uniform multi-layer device



Figure S6: Scanning photocurrent in (a) few-layer/multi-layer (FL/ML) heterojunction with L=8.2  $\mu$ m and W=4.5  $\mu$ m, and (b) multi-layer (ML) homojunction, with L=6.7  $\mu$ m and W=1.9  $\mu$ m. The scans have been performed at different V<sub>ds</sub>, in steps of 0.1 V. The laser power used is 2.6  $\mu$ W.

S7. Transient response of a monolayer MoS<sub>2</sub> photodetector



Figure S7. Transient response of a monolayer  $MoS_2$  photodetector, with larger fall time (90% to 10%), in excess of 100 s, due to strong hole trapping.

SI No	Material/Device	Fall time	Ref.
1	CVD grown MoS <sub>2</sub>	80 s	[3]
2	Exfoliated MoS <sub>2</sub>	50 ms	[4]
3	HfO <sub>2</sub> encapsulated MoS <sub>2</sub>	120 ms	[5]
4	CVD WS <sub>2</sub>	190 ms	[6]
5	exfoliated MoS <sub>2</sub>	9 s	[7]
6	Graphene MoS <sub>2</sub>	Few minutes	[8]
7	Few layer exfoliated MoSe <sub>2</sub>	30 ms	[9]
8	Few layer MoS <sub>2</sub>	400 ms	[10]
9	Few layer WSe <sub>2</sub>	40 µs	[11]
10	Monolayer/few-layer/bulk MoS <sub>2</sub> heterojunction	26 ms	This work

**S8.** Reported rise/fall time of TMD based photodetector with oxide substrate support:

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