Supporting information

Static and Dynamic Piezopotential Modulation in Piezo-Electret Gated MoS_2 Field Effect Transistor

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(1) Transfer property of MoS_2 FET without P(VDF-TrFE)

The typical transfer characteristics of the device without P(VDF-TrFE) was shown in **Figure S1.** Due to the high dielectric constant of the Al_2O_3, the on/off ratio can be higher than 10^5 with the gate voltage sweeping from -3 V to 3 V. According to the equation: $\mu = \frac{L}{WC}\frac{\partial I_D}{\partial V_G}\frac{1}{V_D}$, the mobility was calculated to be ~ 30 $cm^2 \cdot V^{-1} \cdot s^{-1}$ with the channel length and width at ~ 20 μm and ~ 5 μm, respectively.

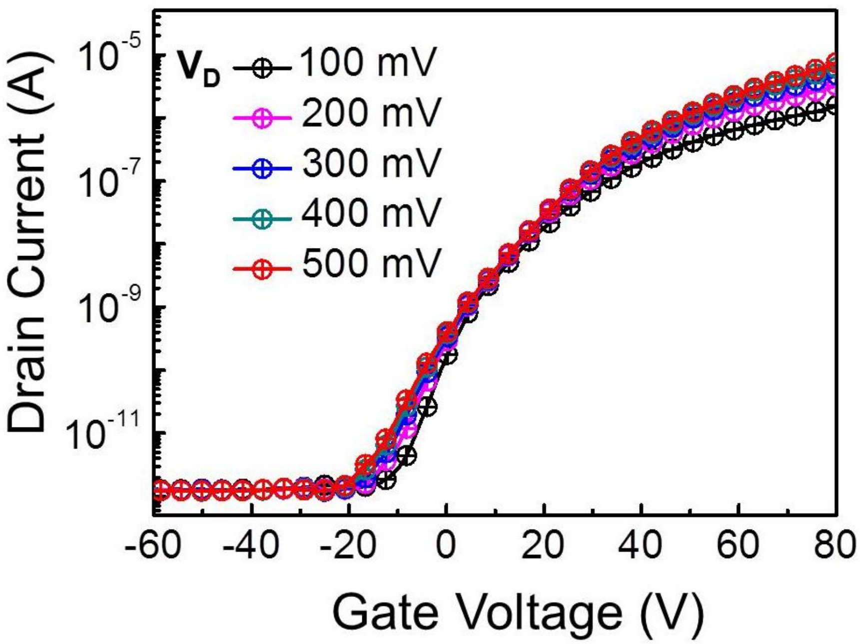

Figure S1. The transfer properties of MoS_2 FET without P(VDF-TrFE). The channel length and width are 20 μm and 5 μm, respectively.

(2) The schematic diagram of the device back-gated by the P(VDF-TrFE)

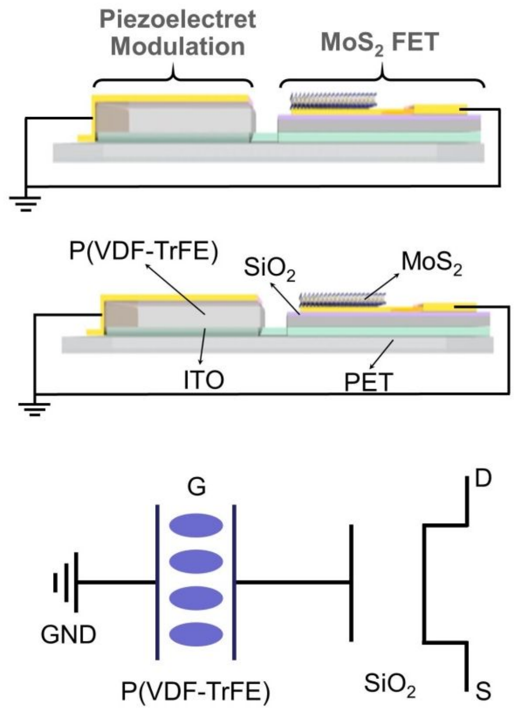

Figure S2. The schematic diagram of the MoS_2 FET gated by SiO_2 through sharing the ITO gate with the P(VDF-TrFE) device and equivalent circuit diagram.

(3) Energy band bend and charge distribution in P(VDF-TrFE) with different polarization conditions

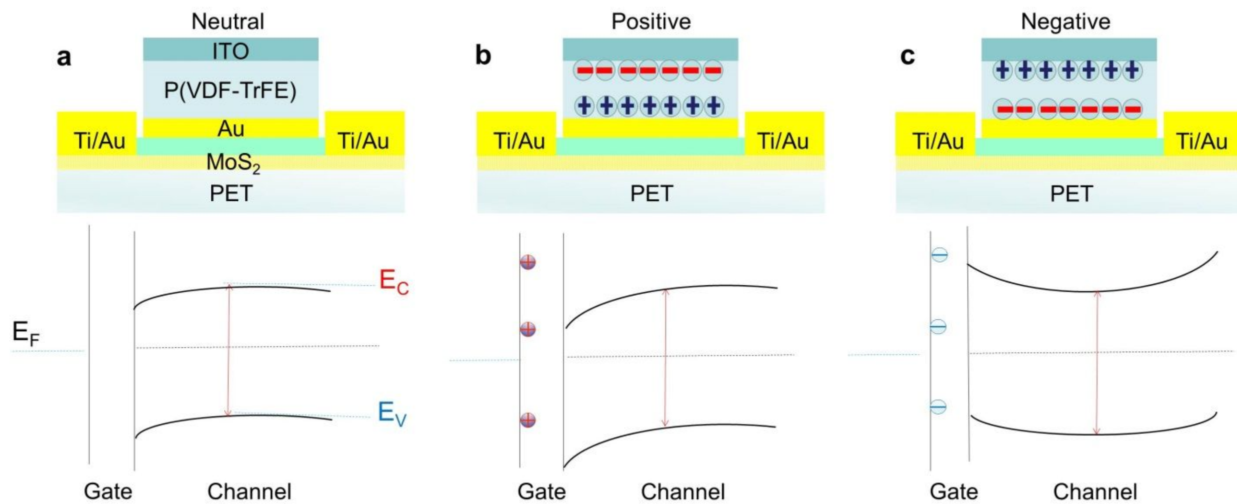

Figure S3. The cross-section structures of MoS_2 FET with P(VDF-TrFE) and equilibrium energy band diagrams of three different polarization states (V_D = 0 V). E_F, E_C, E_V are the Fermi level energy, minimum conduction band energy and maximum valence band energy, respectively. (a) MoS_2 FET without pre-polarized P(VDF-TrFE). (b) (c) The charge distribution on the surface of P(VDF-TrFE) and the energy band shift of MoS_2 FET with positive and negative polarization, respectively.

(4) Raman shift and PL spectrum for the pristine MoS_2 film on SiO_2 substrate by CVD growth

For the pristine monolayer MoS_2 grown by oxygen assistant CVD method on SiO_2/Si substrate, the Raman shift has two typical peaks: E_{2g} ~384 cm^{-1} and A_{1g} ~404 cm^{-1}, which reflects the in-plane vibration and out-of-plane phonon coupling mode of MoS_2, respectively.[1] The difference between the two peaks is ~20 cm^{-1}, confirming the monolayer property of the film. The PL peak of MoS_2 is observed at ~ 663 nm (A_1 exciton) and ~ 613 nm (B_1 exciton), corresponding to the direct optical transitions at the Brillouin zone K-point and the spin-orbital splitting of the valence band, respectively.[2] The A_1 peak has a red shift compared with the suspended MoS_2 film, which is attributing to the doping effect from H_2O/O_2 adsorption on the surface and the impurity scattering from the substrate.

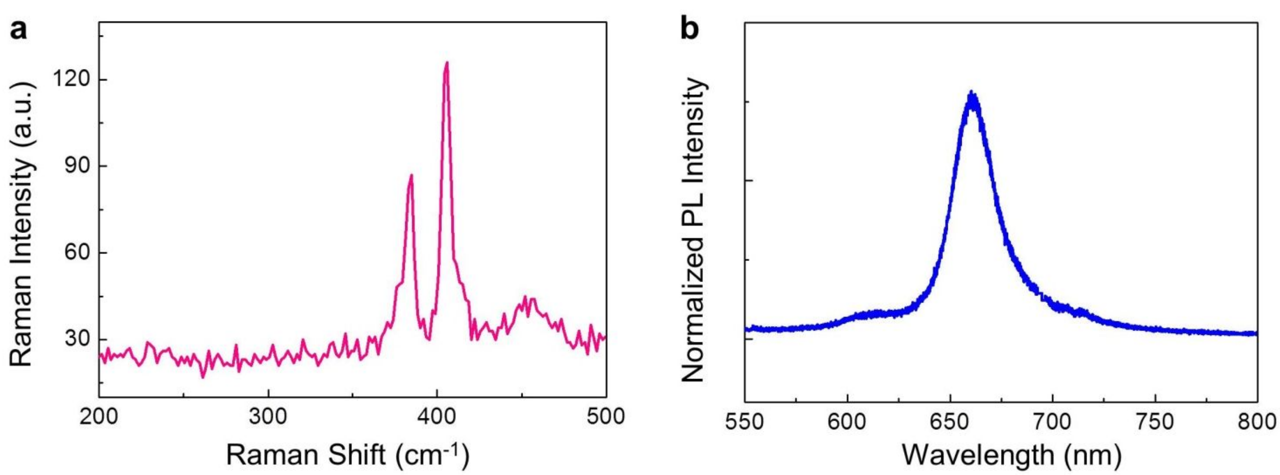

Figure S4. The Raman shift (a) and PL spectrum (b) for the pristine MoS_2 film on SiO_2

substrate by CVD growth.

(5) Raman shift and PL spectrum for monolayer MoS_2 FET with P(VDF-TrFE) as gate material under different strains

The optical property of the MoS_2 FET with the P(VDF-TrFE) film as gate material is shown in Figure S5. In **Figure S5a**, there is nearly no obvious change of the Raman shift (both for A_{1g} and E_{2g} peak) with strain changing, which means that the piezo-potential induced by P(VDF-TrFE) has no influence on in-plane vibration and out-of-plane phonon coupling mode of MoS_2. However, for the PL peak with P(VDF-TrFE) under different strain, the A_1 exciton peak shows a blue shift with strain increasing step by step while the B_1 exciton keeps stable. The shift of the A_1 peak under different strains is uniform and repeatable, due to the piezo-potential-reduced passivation of MoS_2 surface states caused by trapped charges from the MoS_2/SiO_2 interfaces.[3]

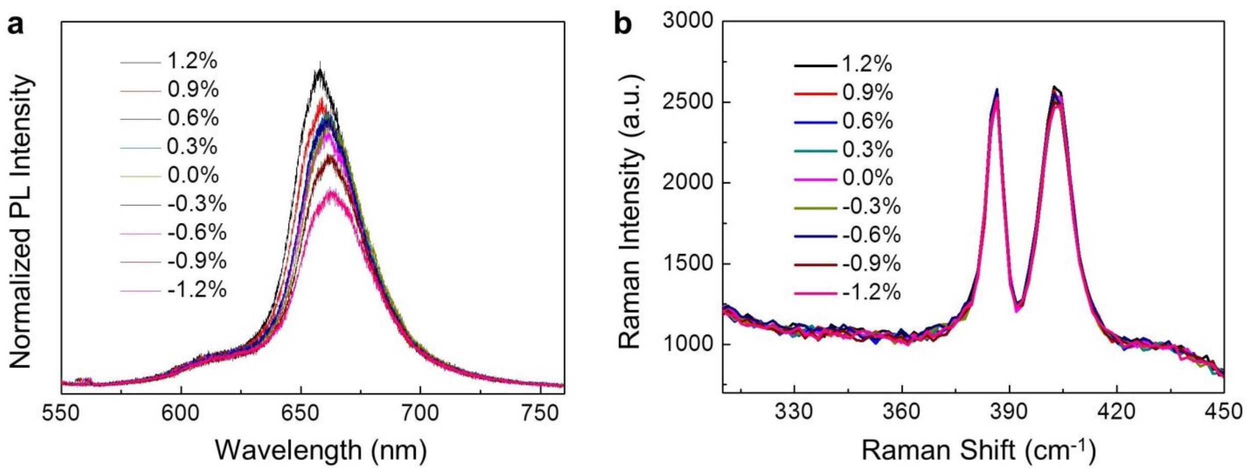

Figure S5. (a) Raman shift has no obvious change under different strains. (b) The A_1 exciton peak has a blue shift ~ 14 meV with the strain varying from -1.2% to 1.2%.

(6) Piezoelectrical property of the P(VDF-TrFE) device

The piezoelectrical property of the pre-polarized P(VDF-TrFE) device is shown in **Figure S6**. (a) The output voltages of the device varied with strains, indicating linear relationships between voltage and tensile/compressive strain, respectively. (b) With the strain increased step by step from 0% to 0.4%, the corresponding voltage increased. (c) The output voltage of the device under strain ~ 0.15% kept stable for over 10 mins, indicating that the good stability of the device under strain.

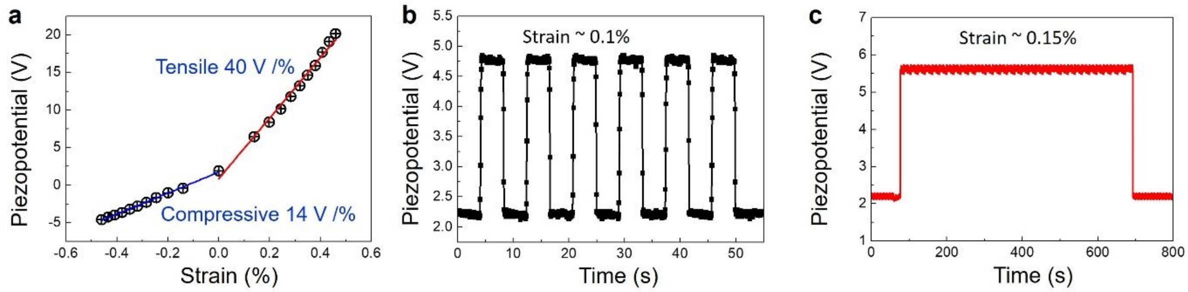

Figure S6. The piezoelectrical property of the P(VDF-TrFE) film. (a) The linear relationship between piezo-potential and strain. (b) The piezo-potential varied with the strain pulse (~ 0.1%). (c) The stability of the piezo-potential voltage under the strain ~ 0.15%.

(7) The output property of MoS_2 FET changed with the strain applied on the P(VDF-TrFE) film

When the strain applied on the P(VDF-TrFE) film varying from 0.2% to -0.4%, the *I*-*V* curves of the MoS_2 FET decreased accordingly. The current (V_D= 3 V) changed from 1.5×10^{-6} A to 7.6×10^{-11} A, leading to on/off ratio ~ 2×10^4, which can be compared to the device property regulated by the external gate voltage. This strain dependent electrical property is stable and repeatable caused by the piezoelectricity of the P(VDF-TrFE) film.

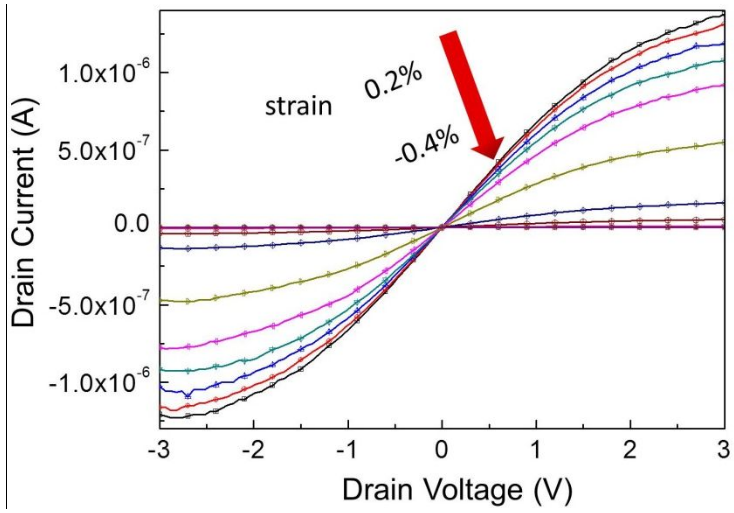

Figure S7. The *I*-*V* curve of the MoS_2 FET device changed with the strain applied on the P(VDF-TrFE) film.

(8) Gauge factor of the piezo-electret gate MoS_2 FET strain sensor

The gauge factor (GF, or sensitivity) of the device can be defined as the equation: $GF = \frac{\Delta R / R_0}{\varepsilon}$, where the $\Delta R / R$ and ε is the resistance change rate and strain, respectively. According to the **Figure S8**, the resistance decreased under strain and the GF can be calculated to be ~ 4800 with the compressive strain varying from -0.1% to 0% and 250 with tensile strain varying from 0% to 0.2%, respectively. For the exponential growth of the resistance with strain increasing, the sensitivity of the device was tunable by different strain range.

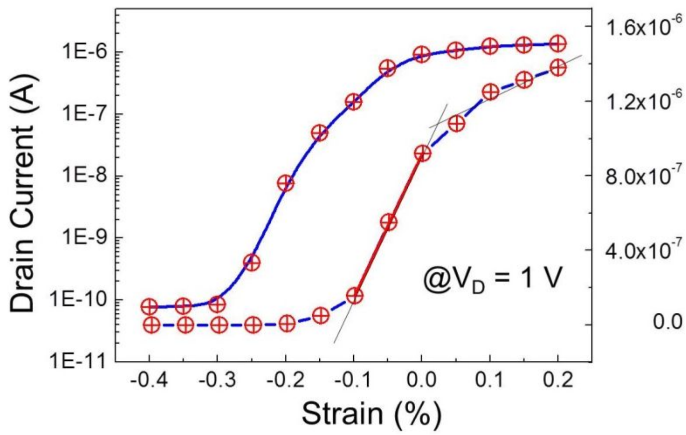

Figure S8. The sensitivity of MoS_2 FET extracted from the relationship between drain current and strain.

(9) Measurement of the thickness of P(VDF-TrFE) spin-coated on MoS_2 film

After spin-coating 5%wt P(VDF-TrFE) on the surface of the MoS_2 FET and baking for 4 hours to make it completely cured. The thickness of the P(VDF-TrFE) film was measured to be ~ 300 nm by the step profile.

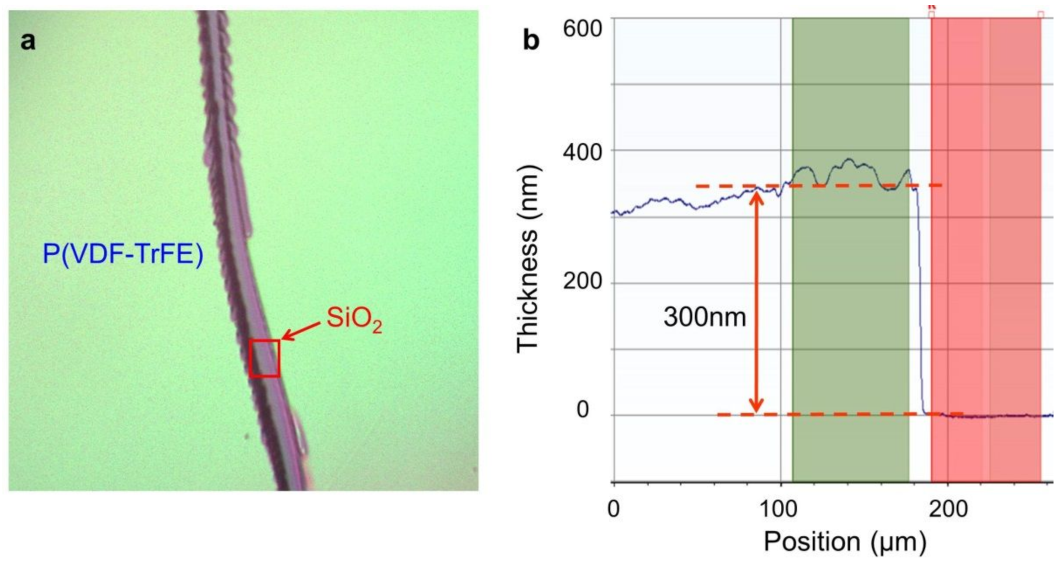

Figure S9. The thickness of the P(VDF-TrFE) film is ~ 300 nm measured by the step profile.

(10) The hysteresis of the device with PMMA as the isolation layer

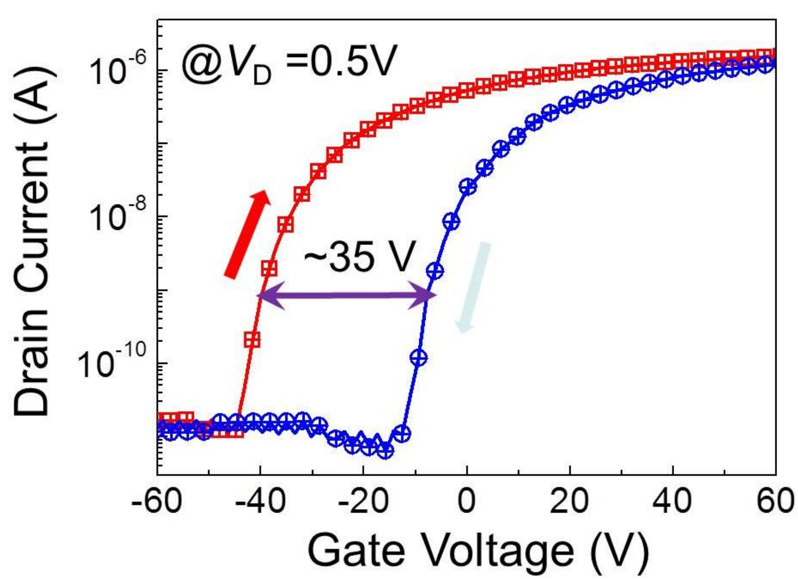

Figure 10. The nearly unchangeable large hysteresis of the device with PMMA as the isolation layer shows that the large hysteresis was not coming from the charge traps at the interface between the P(VDF-TrFE) and MoS_2 layer.

(11) Perspective of new research direction and applications with piezo- and pyro-electrets

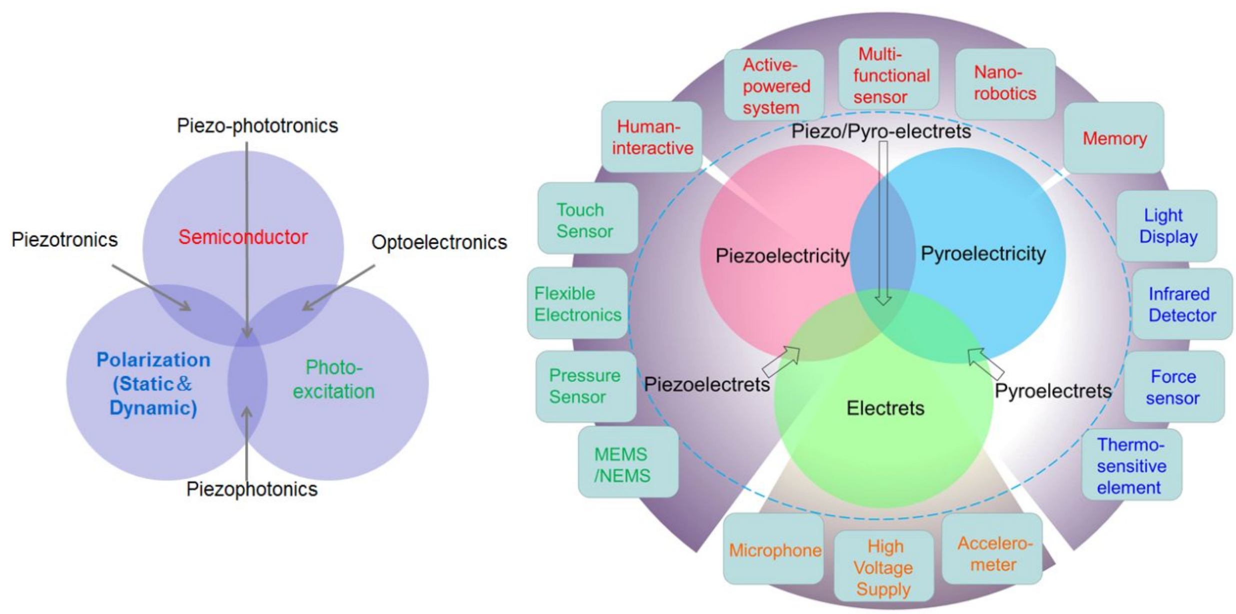

Figure S11. New research direction and applications of piezo- and pyro- electrets.

References

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2. Mak, K. F.; He, K. L.; Lee, C.; Lee, G. H.; Hone, J.; Heinz, T. F.; Shan, J., Tightly Bound Trions in Monolayer MoS_2. *Nat. Mater*. **2013**, *12*, 207-211.

3. Li, Z.; Chang, S.; Chen, C.; Cronin, S. B., Enhanced Photocurrent and Photoluminescence Spectra in MoS_2 Under Ionic Liquid Gating. *Nano Res.* **2014**, *7*, 973-980.