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## p-Type Multilayer MoS<sub>2</sub> Enabled by Plasma Doping for Ultraviolet Photodetectors Application

Two-dimensional (2D) transition metal dichalcogenides (TMDCs), such as MoS<sub>2</sub>, have attracted considerable attention owing to the unique optical and electronic properties related to its 2D ultrathin atomic layer structure <sup>[1]</sup>. MoS<sub>2</sub> is becoming prevalent in post-silicon digital electronics and in highly efficient optoelectronics due to its extremely low thickness and its tunable band gap (E<sub>g</sub> = 1–2 eV) <sup>[2]</sup>. For low-power, high-performance complementary logic applications, both p- and n-type MoS<sub>2</sub> FETs (NFETs and PFETs) must be developed. NFETs with an electron accumulation channel can be obtained using unintentionally doped n-type MoS<sub>2</sub>. However, the fabrication of MoS<sub>2</sub> FETs with complementary p-type characteristics is challenging due to the significant difficulty of injecting holes into its inversion channel <sup>[3]</sup>. Plasma treatments with different species (including CF<sub>4</sub>, SF<sub>6</sub>, O<sub>2</sub>, and CHF<sub>3</sub>) have also been found to achieve the desired property modifications of MoS<sub>2</sub> <sup>[4-5]</sup>.

In this work, we demonstrated a p-type multilayer  $MoS_2$  enabled by selective-area doping using CHF<sub>3</sub> plasma treatment. Compared with single layer  $MoS_2$ , multilayer  $MoS_2$  can carry a higher drive current due to its lower bandgap and multiple conduction channels. Moreover, it has three times the density of states at its minimum conduction band. Large-area growth of  $MoS_2$  films on 300 nm thick  $SiO_2/Si$  substrate are carried out by thermal decomposition of ammonium tetrathiomolybdate,  $(NH_4)_2MoS_4$ , in a tube furnace. a two-step annealing process is conducted to synthesize  $MoS_2$  films. For the first step, the temperature is set to 280 °C for 30 min in an N<sub>2</sub> rich environment at 1.8 Torr. This is done to transform  $(NH_4)_2MoS_4$  into  $MoS_3$ . To further reduce  $MoS_3$  into  $MoS_2$ , the second step of annealing is performed. For the second step, the temperature is set to 750 °C for 30 min in a reducing atmosphere consisting of 90% Ar and 10% H<sub>2</sub> at 1.8 Torr. The grown  $MoS_2$  films are subjected to out-of-plane doping by CHF<sub>3</sub> plasma treatment using a Dry-etching system (ULVAC original NLD-570) as shown in Fig.1a. The radiofrequency power of this dry-etching system is set to 100 W and the pressure is set to 7.5 mTorr. The final thickness of the treated samples is obtained by etching for 30 s. Fig. 1b shows the optical micrograph (OM) image of the selective-area  $MoS_2$  films with and without CHF<sub>3</sub> plasma treatment.

Back-gated MoS<sub>2</sub> PFETs were presented with an on/off current ratio in the order of  $10^3$  and a field-effect mobility of 65.2 cm<sup>2</sup>V<sup>-1</sup>s<sup>-1</sup>. The MoS<sub>2</sub> PFETs photodetector exhibited ultraviolet (UV) photodetection capability with a rapid response time of 37 ms and exhibited modulation of the generated photocurrent by back-gate voltage. This work suggests the potential application of the mild plasma-doped p-type multilayer MoS<sub>2</sub> in UV photodetectors for environmental monitoring, human health monitoring, and biological analysis.

## References

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## **Figures**



**Figure 1:** (a) Schematic diagram of out-of-plane doping by  $CHF_3$  plasma treatment. (b) OM image of the selective-area  $MoS_2$  films with and without  $CHF_3$  plasma treatment.