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p-Type Multilayer MoS_2 Enabled by Plasma Doping for Ultraviolet Photodetectors Application

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Abstract : Two-dimensional (2D) transition metal dichalcogenides (TMDCs), such as MoS_2, have attracted considerable attention owing to the unique optical and electronic properties related to its 2D ultrathin atomic layer structure. MoS_2 is becoming prevalent in post-silicon digital electronics and in highly efficient optoelectronics due to its extremely low thickness and its tunable band gap (Eg = 1-2 eV). For low-power, high-performance complementary logic applications, both p- and n-type MoS_2 FETs (NFETs and PFETs) must be developed. NFETs with an electron accumulation channel can be obtained using unintentionally doped n-type MoS_2. However, the fabrication of MoS_2 FETs with complementary p-type characteristics is challenging due to the significant difficulty of injecting holes into its inversion channel. Plasma treatments with different species (including CF_4, SF_6, O_2, and CHF_3) have also been found to achieve the desired property modifications of MoS_2. In this work, we demonstrated a p-type multilayer MoS_2 enabled by selective-area doping using CHF_3 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 is 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_2 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_2 at 1.8 Torr. The grown MoS_2 films are subjected to out-of-plane doping by CHF_3 plasma treatment using a Dry-etching system (ULVAC original NLD-570). 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. Back-gated MoS_2 PFETs were presented with an on/off current ratio in the order of 10^3 and a field-effect mobility of 65.2 $cm^2V^{-1}s^{-1}$. The MoS_2 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_2 in UV photodetectors for environmental monitoring, human health monitoring, and biological analysis.

Keywords : photodetection, p-type doping, multilayers, MoS_2
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