Plasma-Assisted Doping for Fabricating MoS_2 Diodes and Ambipolar Transistors

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Molybdenum disulfide (MoS_2) and other two-dimensional (2D) layered transition metal dichalcogenides (LTMDs) recently received a great deal of interest due to their excellent electronic, optoelectronic and mechanical properties, versatile chemistry, as well as large abundance of relevant bulk materials.[1]-[4] Especially as a 2D semiconductor, MoS_2 can be used for making phototransistors,[5] highly sensitive sensors,[6] high-performance thin-film transistors (TFTs) that are immune to short-channel effects,[7] and ultra-thin flexible photovoltaic (PV) cells and other relevant optoelectronic devices.[8] However, people now lack proper doping methods for creating permanently stable p-n junctions and rectifying diode structures in MoS_2 and other relevant 2D semiconductors, which seriously limits their practical applications, especially the long-term electronic and optoelectronic applications of such 2D materials at ambient conditions. [9][10]

To address this challenge, we developed a new plasma-assisted doping method for modulating the electronic properties of MoS_2 and other relevant 2D semiconductors. Using blank plasma doping processes, we have demonstrated p-type MoS_2 transistors that can be complementary to undoped n-type MoS_2 transistors, potentially enabling MoS_2-based CMOS circuits. Using selected-area plasma doping processes, we have created permanently stable *p-n* junctions in MoS_2 layers and 2D diodes with a high rectification degree (*i.e.*, forward/reverse current ratios ~ 10^4).[11] These plasma-doped devices are anticipated to play an important role in the development of new nanoelectronic devices based on emerging 2D semiconductors.

Fig. 1 shows the SEM image of an exemplary MoS_2 rectifying diode fabricated by doping a selected MoS_2 channel area with a CF_4-based plasma recipe. Such plasma-doped diodes exhibit a high rectification degree (*i.e.*, forward/reverse current ratios ~ 10^4 within a range of $V_{DS} = \pm1$ to ±2V) and a superior long-term stability at room temperature, as shown in Fig. 2. Fig. 3 shows that the presented plasma-assisted doping process can also be used for making MoS_2-based ambipolar and *p*-type transistors. The final presentation will also include our in-depth X-ray photoelectron spectroscopic (XPS) characterizations of MoS_2 layers treated with different plasma species, aiming to undertand the mechanisms of plasma-induced doping at atomic scales.

This work could serve as an important foundation for exploration of new physical and/or chemical mechanisms for tailoring the band structures of emerging 2D semiconductor micro-/nanostructures to achieve desirable characteristics for device applications in the fields of renewable energy, nanoelectronics, and optoelectronics.

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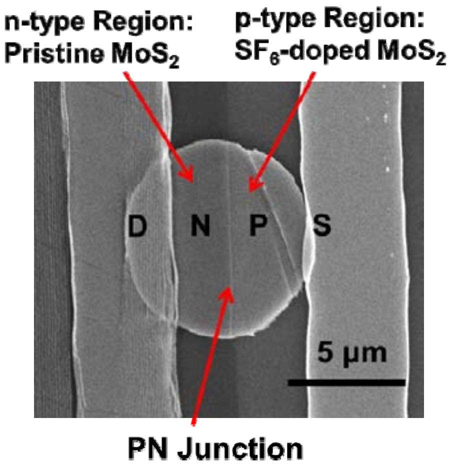

Fig. 1 SEM image of a fabricated MoS_2 rectifying diode with selected area treated by CF_4 plasma.

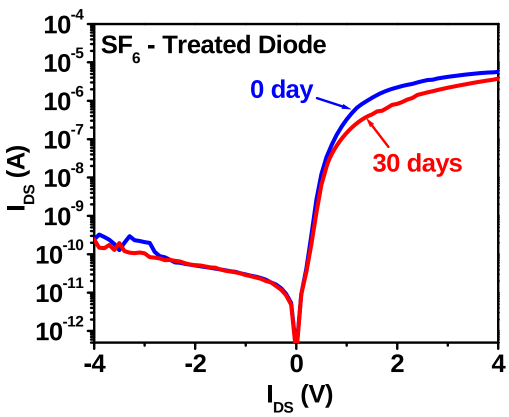

Fig. 2 Semi-logarithmic plots of I_{DS}-V_{DS} characteristic curves of a SF_6-treated diode, which were measured 0 (dashed line) and 30 (solid line) days after the device fabrication.

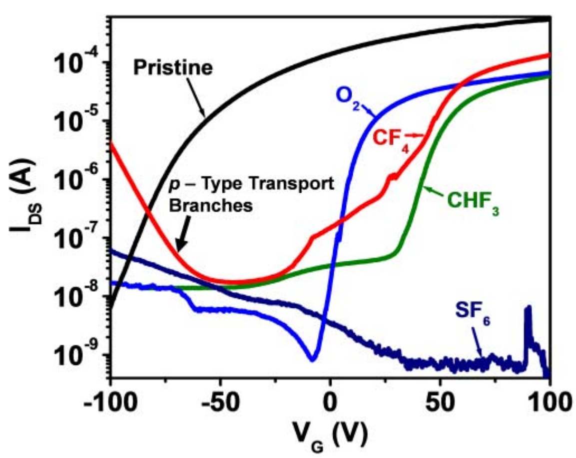

Fig. 3 I_{DS}-V_G characteristics of back-gated MoS_2 FETs treated with different plasma recipes as well as an untreated pristine FET (for all curves, V_{DS} = 5 V).

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