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Morphology and electrical studies on MoS_2 field-effect transistor irradiated with N_2 plasma

Transition metal dichalcogenide (TMDC) is one of promising candidates of future electronic materials for applications of ultra-low power devices, optoelectronic devices, and various sensing devices. To obtain the best performance of these devices, modulation of electronic properties of materials is essential. Defects in the layered materials take an important role to modify their intrinsic properties. Recently, Azcatl et al. have been reported the use of N_2 plasma treatment for doping processes of Molybdenum-disulfide (MoS_2) [1]. In this work, we fabricated the back-gate MoS_2 FETs, and investigated the effect of N_2 plasma irradiation on morphology and electrical characteristics.

Figure 1(a) shows our fabrication process flow of the back-gate MoS_2 FETs. An experimental procedure for N_2 plasma irradiation and characterization of morphology and electrical properties is shown in Fig. 1(b). Micro-mechanically exfoliated natural MoS_2 sheets on a 285 nm thick SiO_2 substrate with underlying highly doped silicon [2] were used for FET channels. Ni/Au (10/50 nm) metal electrodes formed by e-beam evaporation and lift-off technique [3] were used for source/drain electrodes. The device channel lengths were 2000-4000 nm. Figure 2 shows an optical microscope image of a fabricated FET after N_2 plasma irradiation of three times for 5 min each. N_2 plasma treatment was performed with a resist strip system (Diener electronics, Nano). Surface morphology and thickness of the MoS_2 channel were evaluated by atomic force microscope (Digital Instruments, Nanoscope IIIa) measurements. Electrical characterization of MoS_2 FETs was performed with a semiconductor parameter analyzer (Keithley 4200-SCS) in room temperature and under dark ambient conditions.

Figure 3(a) shows an AFM image of MoS_2 surface after N_2 plasma irradiation of two times for 5 min each. Many pits are observed and their depth are 1-2 single-layer of MoS_2 as shown in Fig. 3(b). These results indicate that MoS_2 channel surface was etched by N_2 plasma of our condition and many defects were induced to the channel. Figure 4 shows drain-gate (Id-Vg) characteristics of pristine MoS_2 FET, MoS_2 FET irradiated with O_2 plasma for 2 min, MoS_2 FET additionally irradiated with N_2 plasma for 5 min and MoS_2 FET more additionally irradiated with N_2 plasma for 5 min (Total 10 min). Figure 5 shows drain-source (Id-Vd) characteristics at various gate voltages for Fig. 5(a) pristine MoS_2 FET, Fig. 5(b) MoS_2 FET irradiated with O_2 plasma for 2 min, Fig. 5(c) MoS_2 FET additionally irradiated with N_2 plasma for 5 min and Fig. 5(d) MoS_2 FET more additionally irradiated with N_2 plasma for 5 min (Total 10 min). After 10 min N_2 plasma irradiation, drain currents increased to about 2 times as shown in Fig. 5 (Vd=0.1 V, Vg=20 V). On the other hand, the threshold voltage was not changed by our N_2 plasma irradiation experiments as shown in Fig. 4. The detailed results will be discussed at the presentation.

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References

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[3] N. Ninomiya, T. Mori, N. Uchida, E. Watanabe, D. Tsuya, S. Moriyama, M. Tanaka and A. Ando, Jpn. J. Appl. Phys., 54 (2015) 046502.

Figures

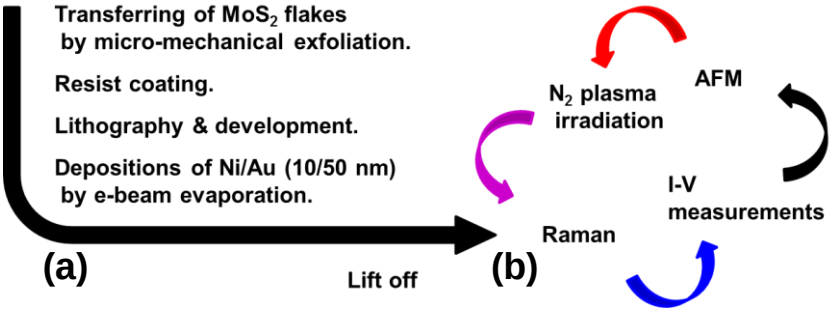

Figure 1: (a) Fabrication process flow for back-gate MoS_2 FETs. (b) Experimental procedure for N_2 plasma irradiation and characterization.

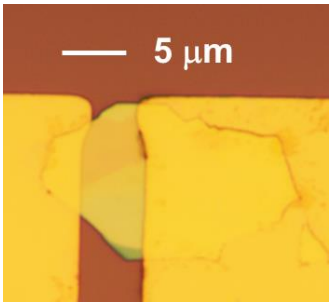

Figure 2: Optical microscope image of a MoS_2 FET after 5 min x 3 N_2 plasma irradiation.

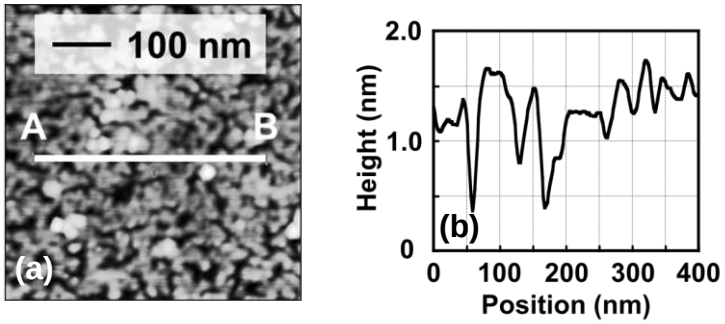

Figure 3: (a) AFM image of MoS_2 surface after 5 min x 2 N_2 plasma irradiation. (b) Cross-section profile between A and B in Fig. 3(a).

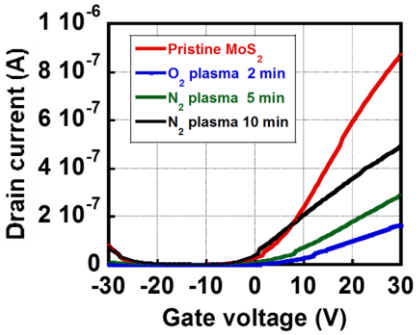

Figure 4: Drain-gate (Id-Vg) characteristics of pristine MoS_2 FET, MoS_2 FET irradiated with O_2 plasma for 2 min, MoS_2 FET additionally irradiated with N_2 plasma for 5 min and MoS_2 FET more additionally irradiated with N_2 plasma for 5 min (Total 10 min).

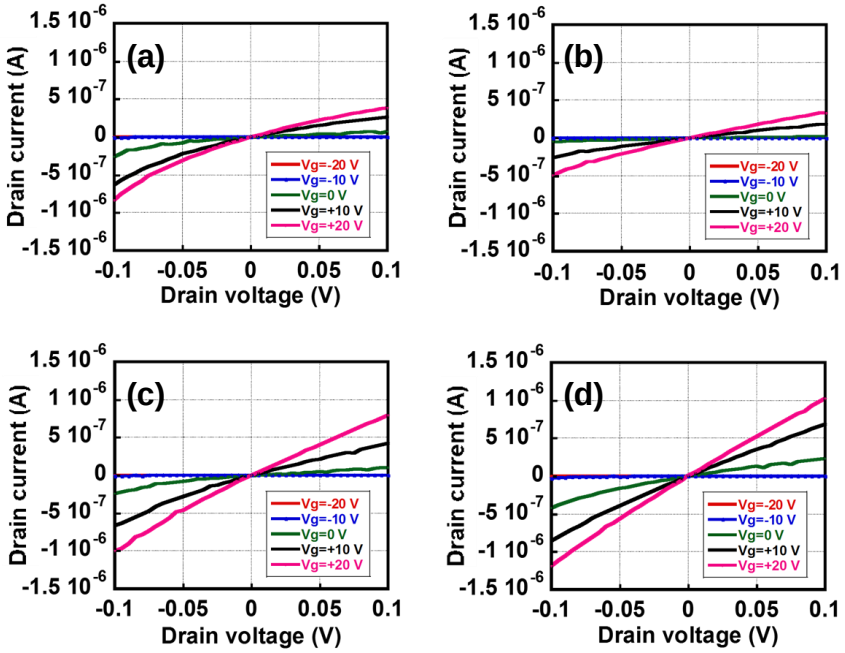

Figure 5: Drain-source (Id-Vd) characteristics at various gate voltages Vg (ranging from -20 to +20 V with steps of 10 V) for (a) pristine MoS_2 FET, (b) MoS_2 FET irradiated with O_2 plasma for 2 min, (c) MoS_2 FET additionally irradiated with N_2 plasma for 5 min and (d) MoS_2 FET more additionally irradiated with N_2 plasma for 5 min (Total 10 min).