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Observation of chemical phenomena caused by molecular adsorption on MoS_2-FET

Abstract

Among the transition metal dichalcogenides (TMD), the only naturally occurring molybdenum disulfide (MoS_2) is also used in field effect transistors (MoS_2-Field Effect Transistor, MoS_2-FET). As already reported [1], since it has a very high on/off ratio, its application as a material capable of highly sensitive detection of molecular adsorbed on MoS_2 surface is expected. In addition, when carrier doping was applied to MoS_2, optical response depending on the electronic structure change of MoS_2 was observed [2]. In this study, we aimed to reproduce carrier doping by charge transfer between adsorbed molecules and MoS_2, and to detect the change in the electronic structure of MoS_2 as a change in electrical characteristics. As molecules to be adsorbed on MoS_2, tetracyanoquinodimethane ($(NC)_2CC_6H_4C(CN)_2$, TCNQ) and 2,3,5,6-tetrafluorotetracyanoquinodimethane ($(NC)_2CC_6F_4C(CN)_2$, F4-TCNQ) expected as electron acceptors was selected.

MoS_2 flake (Fig. 1) was transferred to $SiO_2/p^{++}Si$ substrate using mechanical exfoliation method [3], and Ti/Au electrodes were formed on both ends of MoS2 flake. A schematic diagram of the fabricated MoS_2-FET is shown in Fig. 2. After TCNQ (electron acceptor) was adsorbed on the MoS_2 channel surface, I_D-V_G curve was obtained by electrical measurement (Keithley 2634B®, Keithley Instruments). At this time, the drain voltage (V_D) was fixed at +50 mV, and the gate voltage (V_G) was swept in a range of –60 V to +70 V. In addition, the amount of deposited TCNQ was controlled using a film thickness meter (XTM/2 thin film deposition monitor®, INFICON).

Fig. 3 shows the I_D-V_G curve of the MoS_2-FET as a function the amount of the deposited TCNQ. It is considered that the positive shift of V_{th} and the decrease of the electrical conductivity occur due to the electron transfer from MoS_2 to TCNQ. Furthermore, the change of this I_D-V_G curve was also considered quantitatively. Fig. 4 shows the up take curve of threshold voltage (left) and electron mobility (right). It can be seen that F4-TCNQ (blue) has a larger V_{th} shift in the positive direction than TCNQ (red). V_{th} is closely related to electrical conductivity. Especially, we focused on μ (mobility). The MoS_2 surface is positively charged, which may be caused by coulomb scattering caused by the electrons flowing through the MoS_2 being attracted to it. The large decrease in mobility of F4-TCNQ compared to TCNQ is consistent with the fact that the magnitude of electron affinity for MoS_2 is larger than that of TCNQ.

From the above, it is considered that charge transfer is caused by adsorption of TCNQ and F4-TCNQ molecules on the surface of MoS_2-FET. Even for a very small amount of coverage, changes in the I_D-V_G curve, threshold voltage, and mobility could be observed clearly. Therefore, MoS_2-FET will be a very powerful tool for elucidating the chemical reactions that occur with molecules adsorbed on its surface.

In the future, the development to the control of the electronic structure of MoS_2 and the optical response control are also expected. Furthermore, we hope to observe the other phenomena expected to be generated by TCNQ or F4-TCNQ molecules adsorbed on MoS_2 devices (i.g. superconducting).

References

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Figures

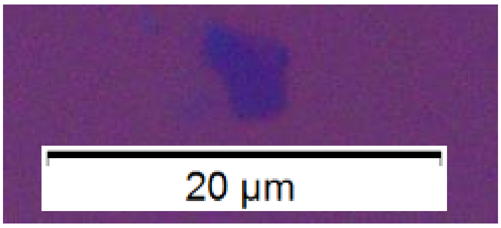

Fig. 1. MoS_2 flake. We can estimated this flake is 3 layers by using optical microscopy method [4].

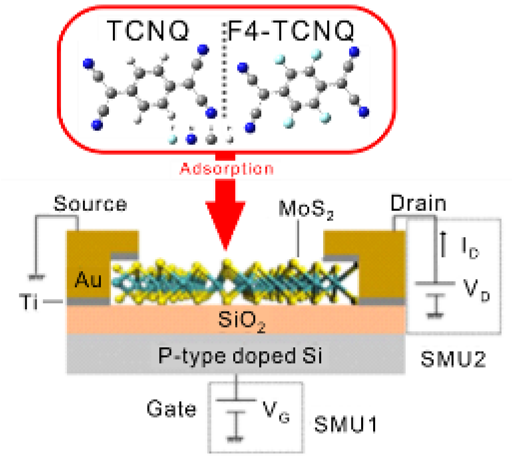

Fig. 2. MoS_2-FET and TCNQ adsorption on MoS_2 surface.

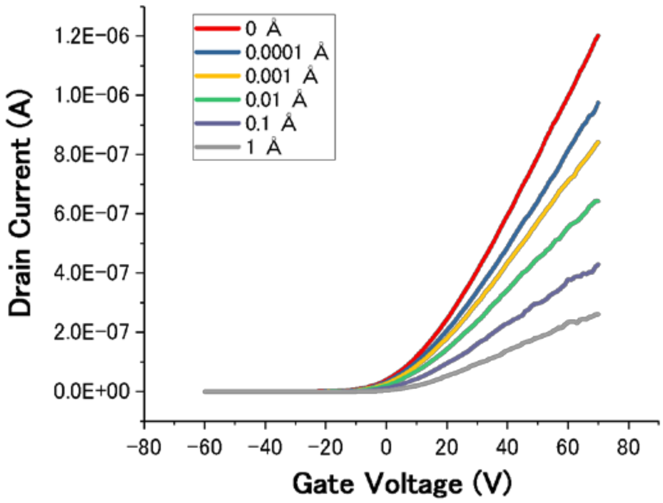

Fig. 3. I_D-V_G curve of TCNQ deposition.

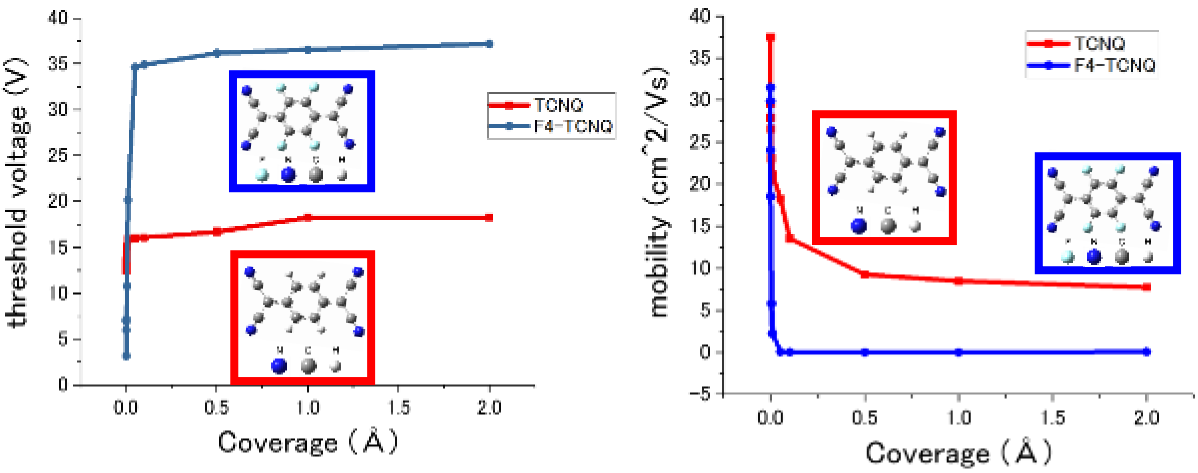

Fig. 4. the up take curve of threshold voltage (V_{th}, left) and mobility (μ, right). Red and blue plots are the data of TCNQ and F4-TCNQ respectively.