Observation of chemical phenomena caused by molecular adsorption on MoS₂-FET

Abstract
Among the transition metal dichalcogenides (TMD), the only naturally occurring molybdenum disulfide (MoS₂) is also used in field effect transistors (MoS₂-Field Effect Transistor, MoS₂-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 MoS₂ surface is expected. In addition, when carrier doping was applied to MoS₂, optical response depending on the electronic structure change of MoS₂ was observed [2]. In this study, we aimed to reproduce carrier doping by charge transfer between adsorbed molecules and MoS₂, and to detect the change in the electronic structure of MoS₂ as a change in electrical characteristics. As molecules to be adsorbed on MoS₂, tetracyanoquinodimethane ((NC)₂CC₆H₄C(CN)₂, TCNQ) and 2,3,5,6-tetrafluorotetracyanoquinodimethane ((NC)₂CC₆F₄C(CN)₂, F₄-TCNQ) expected as electron acceptors were selected.

MoS₂ flake (Fig. 1) was transferred to SiO₂/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 MoS₂-FET is shown in Fig. 2. After TCNQ (electron acceptor) was adsorbed on the MoS₂ channel surface, I₉-V₉ curve was obtained by electrical measurement (Keithley 2634B®, Keithley Instruments). At this time, the drain voltage (V₉) was fixed at +50 mV, and the gate voltage (V₉) 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 I₉-V₉ curve of the MoS₂-FET as a function of the amount of the deposited TCNQ. It is considered that the positive shift of V₉ and the decrease of the electrical conductivity occur due to the electron transfer from MoS₂ to TCNQ. Furthermore, the change of this I₉-V₉ 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 V₉ shift in the positive direction than TCNQ (red). V₉ is closely related to electrical conductivity. Especially, we focused on μ (mobility). The MoS₂ surface is positively charged, which may be caused by coulomb scattering caused by the electrons flowing through the MoS₂ 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 MoS₂ 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 MoS₂-FET. Even for a very small amount of coverage, changes in the I₉-V₉ curve, threshold voltage, and mobility could be observed clearly. Therefore, MoS₂-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 MoS₂ 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 MoS₂ devices (i.e. superconducting).

References
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 ($\mu$, right). Red and blue plots are the data of TCNQ and F4-TCNQ respectively.