Takamasa Kawanago

FIRST, Tokyo Insititute of Technology, 2-12-1-S9-12, Ookayama, Meguro-ku, Tokyo, 152-8550, Japan

kawanago.t.ab@m.titech.ac.jp

Two-Dimensional Inorganic/Organic Hetero Interface for Field-Effect Transistor Applications

Two-dimensional (2D) materials, such as layered transition metal dichalcogenides (TMDC) semiconductors, are emerging research areas that involve multiple fields ranging from fundamental scientific interests to practical device applications [1]. Primary concerns of 2D materials to device applications is that conventional semiconductor process (e. g. high temperature anneal, ion implantation and thermal diffusion) is not applicable since these fabrication steps disrupt and spoil the 2D crystal structure, resulting in the degradation of characteristics or failure of devices [2]. In this context, molecular chemistry approaches to 2D TMDC have considerable attention because of their low temperature, low energy process [2]. In addition, amazingly rich chemistry and structure of organic molecules enables not only the tailoring of the properties of TMDC but also the fabricating of the functional devices [2].

This study describes our experimental results regarding the hybrid systems based on TMDC and organic self-assembled monolayer (SAM) for functional device applications [3]. The SAM is 2D organic molecular monolayer that spontaneously organizes at specific surface [4]. The SAM can tailor surface and interfacial properties including adhesive, hydrophilic, and hydrophobic properties [5]. A recent study has also demonstrated that a SAM can be utilized as ultrathin gate dielectric for field-effect transistors (FET) [6]. A phosphonic acid-based SAM can provide a low gate leakage current owing to its close-packed structure even when the physical thickness is 2.1 nm [6]. In this study, SAM-based gate dielectric with n-octadecylphosphonic acid (ODPA) is applied to the fabrication of molybdenum disulfide (MoS_2) FET [3]. Of particular interest in this study is how the MoS_2/SAM structure affects the interfacial properties and electrical characteristics. The interfacial properties of semiconductor/dielectric structure fundamentally determines the device characteristics of FET. Since the terminal functional group of ODPA consists of a methyl group ($–CH_3$), an inert surface that has electrical and chemical stability is accomplished. Consequently, superior interfacial properties can be anticipated for the MoS_2/SAM structure.

The fabrication process and device structure are summarized in Fig. 1. An Al gate electrode and Au source/drain contacts were prepared on a SiO_2/Si substrate by mask contact photolithography. The substrate was exposed to oxygen plasma to form AlO_x and a hydroxyl groups on the surface of Al. Then, the substrate was immersed in 2-propanol containing 5 mM ODPA for 1 h at room temperature. Mechanically exfoliated MoS_2 flakes were deterministically transferred to the substrate using a poly(dimethylsiloxane) (PDMS) elastomer and micromanipulator. Subthreshold slope (SS) of 69 mV/dec and no hysteresis were obtained from the I_d-V_g characteristics, indicating a low defect density at the MoS_2/SAM interface (Fig. 2). TEM image highlights the flat and abrupt interface of the MoS_2/SAM structure (Fig. 2). The fabricated FET device has a peak mobility of 13 cm^2/Vs from I_d-V_g and C-V characteristics (Fig. 3). This studies open up interesting directions for research on the functional devices based on 2D materials.

References

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Figures

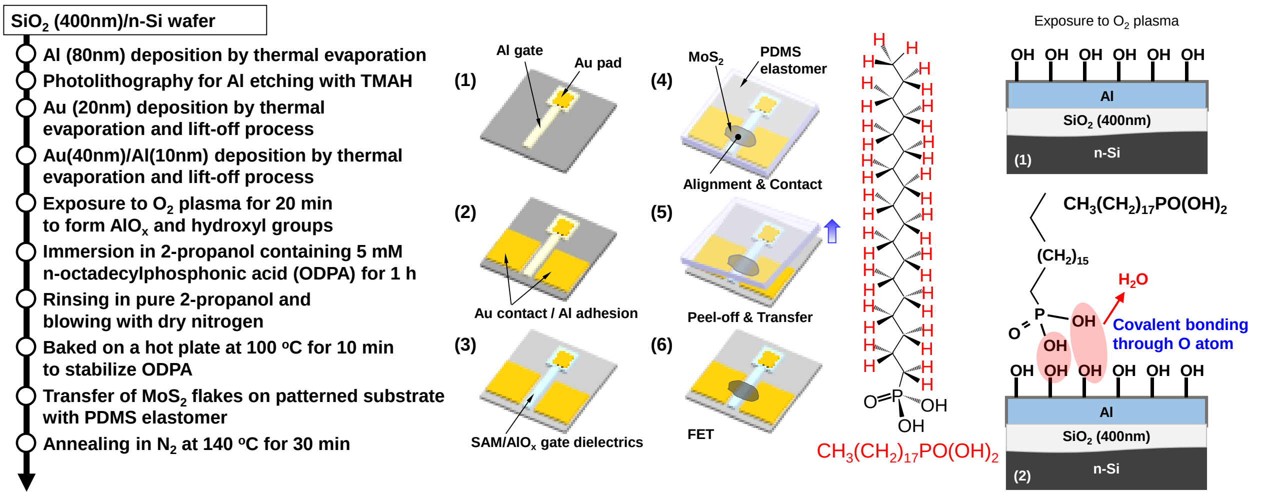

Figure 1: Fabrication process and device structure. Chemical structure of ODPA are also shown

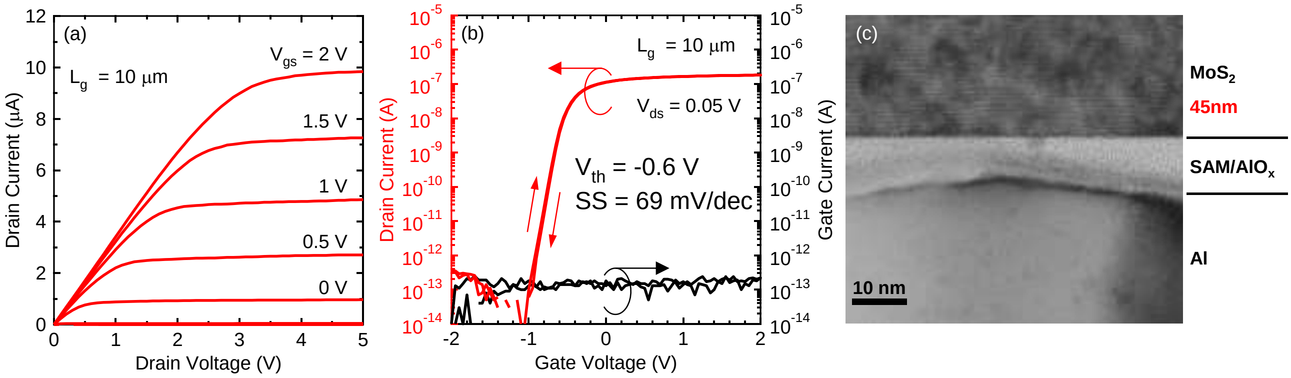

Figure 2: (a) I_d-V_d, (b) I_d-V_g characteristics and (c) TEM image of MoS$_2$ FET with SAM-based gate dielectric

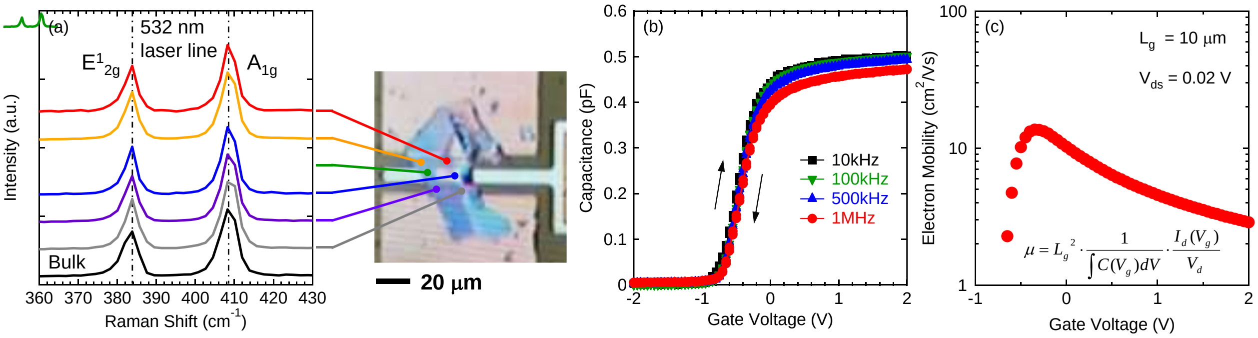

Figure 3: (a) Raman spectra, (b) C-V characteristics and (c) Mobility of MoS$_2$ FET with SAM-based gate dielectric