Carrier transport properties of MoS_2 field-effect transistors produced by multi-step chemical vapor deposition method

National Institute for Materials Science[1], **Kyushu University**[2]

○[(DC)]**Sinae Heo**[1,2], **Ryoma Hayakawa**[1], **Yutaka Wakayama**[1, 2]

E-mail: HEO.Sinae@nims.go.jp

A main purpose of this study is to explore carrier transport properties of field-effect transistors (FET), which are formed by an original multi-step CVD method. This process is consisted of four steps: MoO_3 thermal evaporation, annealing, sulfurization and post-annealing. This method enables us to grow patterned MoS_2 thin films simply by using shadow masks in MoO_3 thermal evaporation step. Here, we observed a wide range of electronic properties (ambipolar and n-type) by changing post-annealing temperature (T_{PA}). Importantly, high T_{PA} of 1000 ºC yielded a high electron mobility of 13.1 $cm^2/V{\cdot}s$.

Figure 1(a) indicates the drain current-gate voltage (I_d-V_g) transfer characteristics at a fixed drain voltage (V_d) of 5 V. The FET, formed at T_{PA} = 600 ºC, has a top contact-top gate configuration. The inset shows an optical microscope image of the FET. In general, the MoS_2 transistors have an n-type property. However, the transistor exhibited ambipolar operation; both electron and hole transports were observed in response to the gate bias voltages. This ambipolar operation was observed in transistors below T_{PA} = 1000 ºC. Meanwhile, the transistor operation transited from ambipolar to n-type transport at a T_{PA} of 1000 ºC as shown in Figure 1(b). The inset in Fig. 1(b) presents the corresponding well-modulated drain current by gate voltage. To get insight into the detailed mechanism, we examined the compositions of thin films using X-ray photoelectron spectroscopy (XPS). The S/Mo ratios depending on T_{PA} are plotted in Figure 1(c). There were large amounts of excess sulfur (ca. 20 %) up to 800 ºC. Although the T_{PA} at 900 °C caused a large decrease in the S/Mo ratio, a T_{PA} of 1000 ºC was needed to produce stoichiometric MoS_2 film. These results demonstrate that excess sulfurs are responsible for the ambipolar operation by acting as acceptors that generate holes. Moreover, high T_{PA} of 1000 ºC had another distinct effect, i.e., it improved the crystallinity of the MoS_2 films. The electron mobility consequently reached 13.1 $cm^2/V{\cdot}s$.

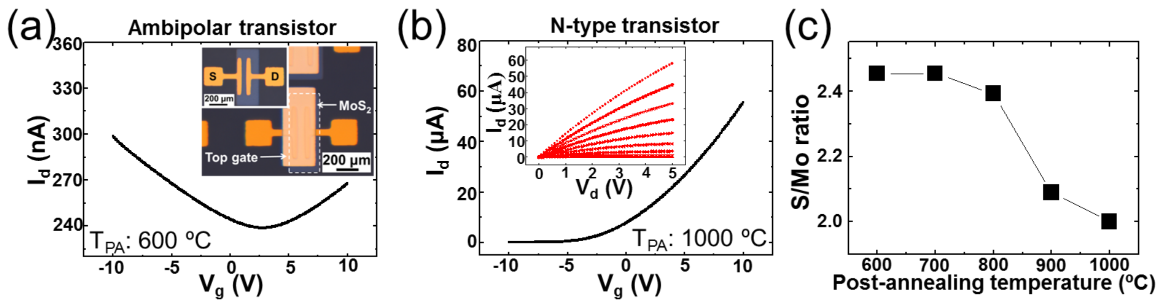

Figure 1. Transfer characteristics of the MoS_2 FET produced at T_{PA} of (a) 600 ºC and (b) 1000 ºC. The inset in (a) shows optical microscope image (top view) of the transistor. The inset in (b) indicates the output characteristics. (c) Compositional ratios (S/Mo) depending on the T_{PA}.