Characterizations of a Hexagonal BN-encapsulated Multilayer MoS_2 Photodetector

Tomoki Ayano, Akihisa Saito, Shintaro Nomura

[1] Division of Physics, University of Tsukuba
E-mail: s1720236@s.tsukuba.ac.jp

1. Introduction

Atomically thin layered semiconductor transition metal dichalcogenides have attracted considerable attention for applications such as field-effect transistors (FETs) and photodectors [1]. High photoresponsivity has been demonstrated in molybdenum disulfide (MoS_2) FETs, but the photoresponsivity was suffered by the scatterings of the carriers by, for example, the oxide fixed charges and the trapping states induced by adsorbates on the MoS_2 channel.

In this presentation, we report on characterizations of a photodetector with hexagonal boron nitride (h-BN) /MoS_2/h-BN heterostructure as a channel to reduce the extrinsic scatterings. Multilayer MoS_2 thin film is used as a channel because higher photo-responsivity is expected for multilayer MoS_2 with indirect band gap than for monolayer MoS_2 with direct band gap due to the longer photo-generated carrier lifetime.

2. Experimental

Figure 1 shows a cross-sectional view of the schematic structure of the h-BN/MoS_2/h-BN heterostructure back-gated device. A polydimethly siloxane/polypropylene carbonate dry transfer method was employed to prepare the h-BN/MoS_2/h-BN heterostructures. The thickness of the MoS_2 channel layer was characterized by an AFM to be 4.3 nm. The thicknesses of the upper and the lower layer h-BN were 13.0 and 18.3 nm, respectively. Cr/Au contacts were prepared for the source and drain contacts and for the back gate. Laser light at the wavelength of 532 nm was incident on the sample with the spot size of 12 μm at the incident power (P) less than 2 μW. All the measurements were performed at room temperature.

3. Results and Discussions

The fabricated h-BN/MoS_2/h-BN heterostructure back-gated device was normally-on and operated as a depletion-mode n-channel FET, in stark contrast to the previously reported photodetectors with MoS_2 channel prepared directly on SiO_2, operated as an enhancement-mode [2-4]. The device had a subthreshold swing of 208 mV/dec and a current on-off ratio of more than 10^5 at the drain voltage V_{DS} = 0.1 V. The field-effect mobility was 25 cm^2/Vs. The hysteresis in the drain current (I_{DS})-back-gate voltage (V_G) curve was small probably because of the h-BN capsulate that reduces the effect of adsorbed water molecules.

We measured photocurrent I_{ph} as defined by $I_{ph} = I_{DS}^{illum} - I_{DS}^{dark}$, where I_{DS}^{illum} and I_{DS}^{dark} are the drain current under illumination and in dark, respectively. The I_{DS}-V_{DS} characteristics in dark were linear in the low V_{DS} region. The nonlinear and the saturation regions were observed in the high V_{DS} region in dark. Under illumination, the linear region shifts to the higher V_{DS}. We observed large photocurrent at V_{DS} which was in the nonlinear or the saturation regions in dark. This indicates that the photocurrent in the high V_{DS} region is associated with the nonlinear screening in the electron gas near the drain contact. Photo-responsivity I_{ph}/P exceeding 900 A/W was observed at 0.82 mW/cm^2 at V_G = 20 V.

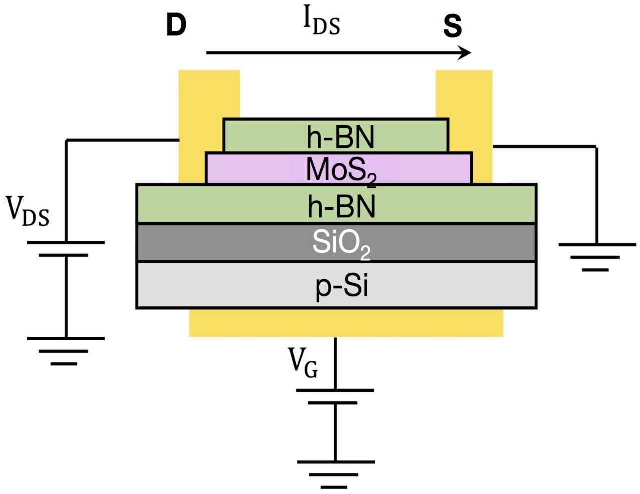

Figure 1. Cross-sectional view of the schematic structure of the h-BN/MoS_2/h-BN heterostructure back-gated device.

4. Conclusions

We have investigated photo-response of an FET with h-BN/MoS_2/h-BN heterostructures as a channel. The hysteresis in the I_{DS}-V_G curve has been remarkably reduced and the drain current and the photoreponsivity have been significantly increased as compared with MoS_2 FETs on SiO_2.

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