MoS_2 transistors with ohmic or Schottky contacts

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Abstract

We discuss several features of MoS_2 back-gate transistors with ohmic or Schottky contacts. We investigate important phenomena such as hysteresis, persistent conductivity and field emission of mono or bilayer MoS_2.

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1. Introduction

The molybdenum disulfide (MoS_2) has recently become one of the most promising layered materials for next generation of electronic devices and sensors as alternative or complement to graphene.

Few-layer MoS_2 can be easily produced by exfoliation or chemical vapor deposition (CVD) and offers remarkable properties, such as intrinsic n-type conduction, good mechanical strength and layer-dependent bandgap. Monolayer and bilayer MoS_2, in particular, possesses direct bandgap of 1.6-1.8 eV, which enables field-effect transistor with high On/Off current ratio and strong photoresponse.

A drawback of MoS_2 is the low carrier mobility, in the order of few tens $cm^2V^{-1}s^{-1}$ on substrate, and the sensitivity to oxygen, water or other adsorbates, which make unprotected MoS_2 devices rather unstable.

The achievement of ohmic contacts with low resistance is a key issue that has gathered a lot of research effort. Metals with low work function are selected to achieve low contact resistance. However, defects at the interface usually result in the formation of uncontrollable Schottky barriers.

2. Experimental

The fabrication of back-gate field effect transistors started with the mechanical exfoliation or the chemical vapour deposition of MoS_2 flakes on heavily doped Si substrates, covered by ~300 nm thermal oxide (Figure 1(a) and (b)). Mono and bilayer MoS_2 were selected by micro-Raman spectroscopy (Figure 1(c)). Ti/Au (or Ni/Au) contact leads were patterned by electron beam lithography and standard lift-off. Electrical measurements were performed in dark and under illumantion, at given temperatures and pressures.

3. Results and Discussion

We discuss the current-voltage (I-V) characteristics at high drain bias of transistors with Schottky contacts [1]. We show that oxidized Ti contacts, due to a long air exposure, form rectifying junctions on MoS_2 and cause asymmetric output characteristics (Figure 2). We propose a model based on two slightly asymmetric back-to-back Schottky barriers (with ~0.3 to 0.5 eV height). We show that, in the source-drain rectified I-V curves, the highest current arises from image force barrier lowering at the electrically forced junction, while the reverse current is due to Schottky-barrier limited injection at the grounded junction. The device achieves a photo responsivity greater than 2.5 AW^{-1} under 5 $mWcm^{-2}$ white-LED light.

We demonstrate that features commonly observed in MoS_2 transistors, such as persistent photoconductivity and hysteresis, are peculiarities of the MoS_2 channel rather than effects of the contacts. We use transistors with ohmic contacts (Figure 3(a) and (b)), at low drain bias, to deeply investigate such features. We find that the n-type transistors exhibit threshold voltage depending on the illumination, which we explain by photoconductive and photogating effect [2]. We point out that the photoconductivity can persist (Figure 4 (a)) with a decay time longer than 10^4 s, due to photo-charge trapping at the MoS_2/SiO_2 interface and in MoS_2 defects. We further show that the hysteresis (Figure 4 (b)) [3] is strongly enhanced by increasing the gate voltage, the pressure, the temperature or the light intensity. We conclude that intrinsic defects in MoS_2, such as S vacancies, which result in effective positive charge trapping, play an important role, besides H_2O and O_2 adsorbates on the unpassivated device surface. We pointed out that charge transfer from/to trapping centers is facilitated by the polarization of water molecules. Finally, we show that an electric field of ~200 V/μm is able to extract current from the flat part of MoS_2 flakes, an effect that can be conveniently exploited for field emission applications [4].

4. Conclusion

We show several features of MoS_2 back gate transistors and we discuss the underlying physical mechanisms.

References

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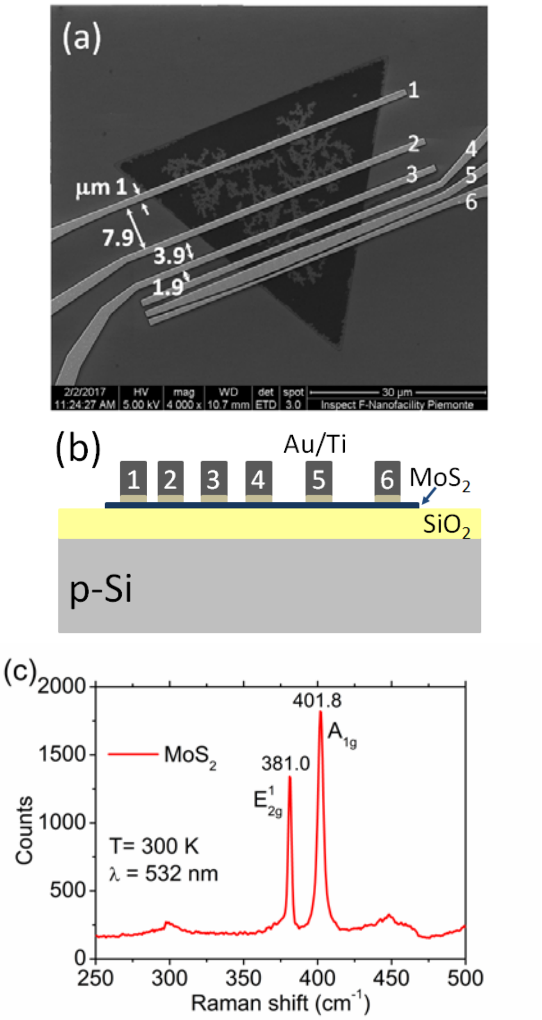

Fig.1: SEM top view of a CVD-synthesized bilayer MoS_2 with Ti/Au contacts. The brighter patterns are unreacted WO_3 precursors. (b) Schematic of a back-gate MoS_2 transistors. (c) Raman spectrum of a bilayer MoS_2.

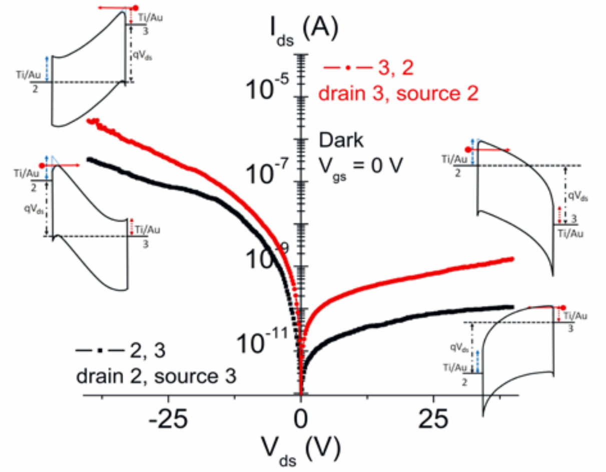

Fig.2: *Band diagram based on two back-to-back Schottky barriers. The forward current observed for negative V_{ds} is due to the image-force barrier lowering at the forced junction, while the lower (reverse) current at $V_{ds}>0$ V is limited by the low electric field at the grounded junction. The red arrow represents the direction of the electron flow.*

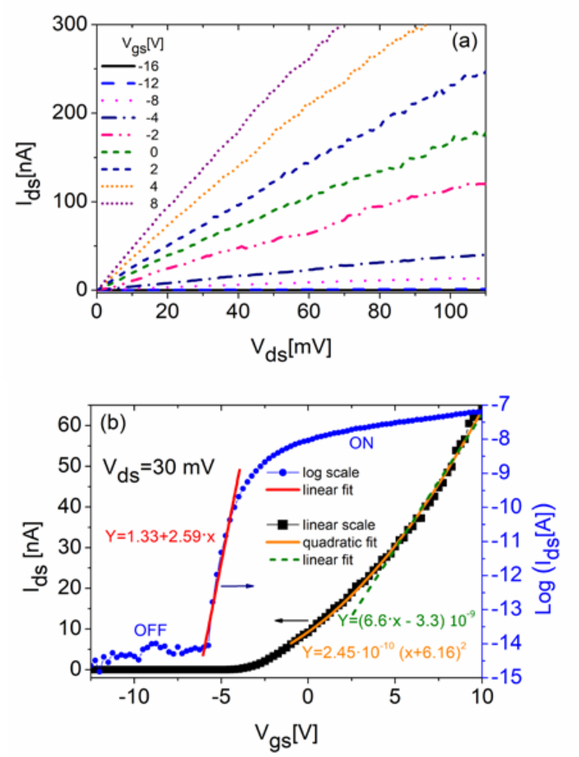

Fig.3: (a) I_{ds}–V_{ds} output characteristics of a MoS_2 back-gate field effect transistor with ohmic contacts. (b) I_{ds}–V_{gs} transfer characteristic at V_{ds}=30 mV with current in logarithmic and linear scale, and linear and parabolic fitting curves.

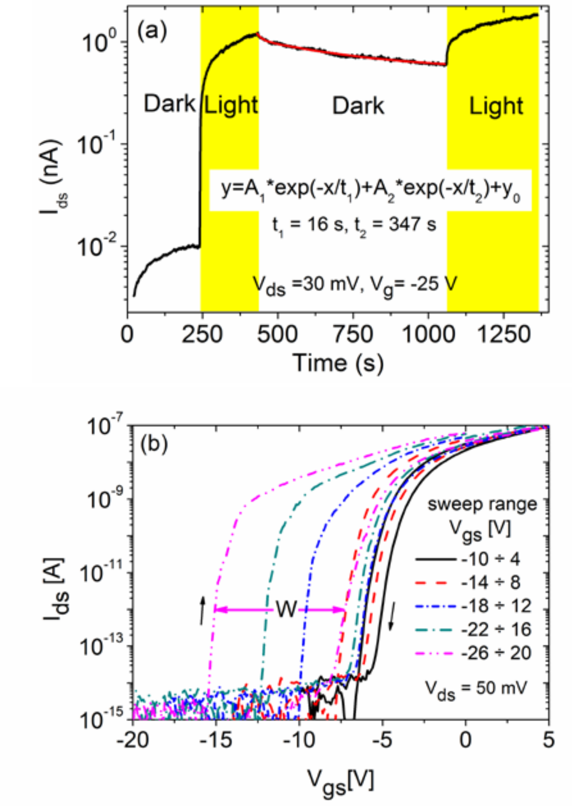

Fig.4: (a) Transistor current versus time under dark and illumination showing persistent photocurrent. (b) Transfer characteristics showing hysteresis (W) in back-gate voltage loops of different amplitudes.