Student Paper

Performance Enhancement of MoS_2 Field Effect Transistors with Silver Contacts

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The success of graphene has led to an explosion of new research into two-dimensional (2D) electronic materials [1]. Compared with bulk semiconductors, 2D materials have better electrostatic control and are expected to improve short-channel effects during aggressive CMOS scaling. Recently, transition-metal dichalcogenides (TMDs), such as MoS_2 and WSe_2, have attracted much attention. Generally, these 2D materials have a layered structure coupled by van der Waals interactions and can be exfoliated from bulk crystals [2]. MoS_2 thin films have desirable bandgaps (Eg) ranging from 1.2eV to 1.8eV depending on the number of layers [3]. MoS_2 monolayers have a direct bandgap of 1.8eV and are, therefore, attractive for optoelectronic applications. After the demonstration of single-layer MoS_2 transistors with a high ON/OFF ratio and acceptable subthreshold slope [4], optoelectronic applications such as photoluminescence [5], electric luminescence [6] and photo detecting [7], have been reported. To achieve better device performance, high-quality metal contacts on MoS_2 are required. However, the study of metal contact effects is difficult because the relationship of the bulk metal work function to that of MoS_2 simply fails to explain the abnormal I-V behavior in MoS_2 transistors. [8]

This work presents the results of our recent attempts to enhance MoS_2 FET performance by selecting proper contact materials and insights into the contact mechanism obtained from scanning electron microscopy (SEM) and Raman spectroscopy. Devices were fabricated from exfoliated single and few layer MoS_2. Metal contacts to the MoS_2 were patterned by e-beam lithography, metal evaporation, and lift off techniques. The channel length of all devices is 1 μm (Fig. 1a). Either 30 nm Ag or 30nm Ti were deposited for this comparison, capped with 30 nm Au to ensure good electrical contact. I_D-V_D characterization reveals that by replacing commonly used Ti contacts with Ag as the contact to single layer MoS_2 back-gated FETs a sharper switching between ON and OFF states is obtained and the ON-state current is enhanced by more than 60 times (Fig. 1b - 1d).

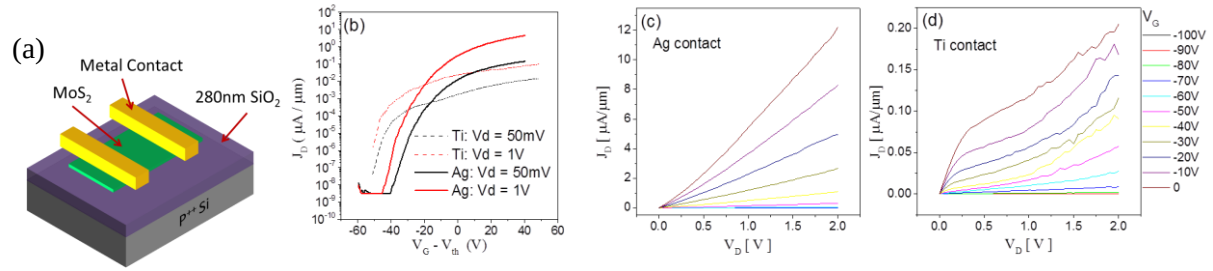

Fig. 1: (a) MoS_2 FET schematic. (b) Drain current normalized to unit channel width versus V_G-V_{th} with different drain voltage in single layer MoS_2 devices with Ag or Ti contact. (c,d) Drain current normalized to unit channel width versus drain voltage in single layer MoS_2 devices with (c) Ag or (d) Ti contact. Note the current amplitudes in (c) and (d).

To study the mechanism of current enhancement, we deposited thin metals, either 5 nm Ag or 5 nm Ti covered by 5 nm Au on exfoliated MoS_2. SEM was then carried out to show the morphology of these deposited thin films. SEM shows that relatively smooth Au/Ag films form on top of MoS_2 (Fig. 3(a)) despite the varied morphology of metal clusters that form when these metals are directly deposited on the SiO_2/Si substrate. These smooth Ag films are in contrast to Au/Ti films that are equally rough on both the MoS_2 films and the SiO_2/Si substrate (Fig. 3(b)). This difference indicates that the interaction

between Ag and MoS_2 is different from the interaction between Ti and MoS_2. A more efficient carrier transport is expected from the smoother Ag contact.

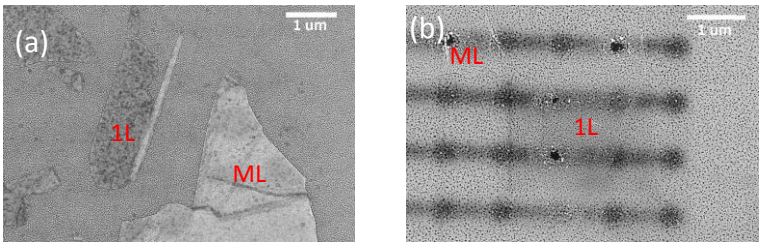

Fig. 2: SEM image after (a) Au/Ag deposition or (b) Au/Ti deposition

Raman spectroscopy performed before and after metal deposition in ambient conditions with a 514.5 nm excitation laser reveals changes. Preliminary analysis reveals different peak shifting and broadening for the two metals (Fig. 2). Similar Raman behavior was also seen in few-layer MoS_2. Further analysis is underway to fully understand these changes.

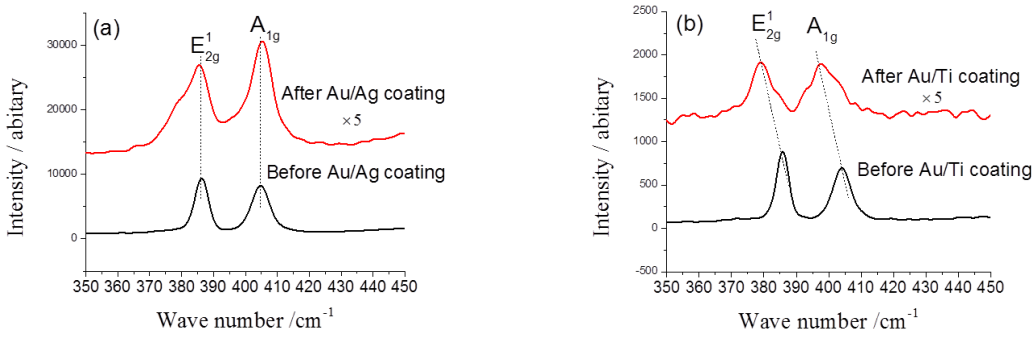

Fig. 3: Comparison of Raman spectroscopy before and after (a) Au/Ag deposition or (b) Au/Ti deposition

In conclusion, a smooth Ag film formed on top of MoS_2 results in more efficient carrier injection from Ag contacts compared to Ti which has a rough surface when deposited on MoS_2. As a result, current enhancement and better electrostatics are realized with Ag contacts.

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