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Experimental Investigation of the Contact Resistance of Graphene/MoS_2 Interface Treated with O_2 Plasma

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Abstract

In this study, we investigate the contact resistances of different layered graphene film with MoS_2 film with Ti/Au electrodes under different O_2 plasma treatment time using the circular transmission line model (CTLM). Annealing process followed O_2 plasma process to reduce the oxygen element introduced. Raman and X-ray photoelectric spectroscopy were used to analyze the quality of the materials. Finally, the current and voltage curve indicates good linear characteristics. Under the optimized condition of the O_2 plasma treatment, a relatively low contact resistance (~35.7 Ω•mm) without back gate voltage in single-layer graphene/MoS_2 structure at room temperature was achieved compared with the existing reports. This method of introducing graphene as electrodes for MoS_2 film demonstrates a remarkable ability to improve the contact resistance, without additional channel doping for two-dimensional materials based devices, which paves the way for MoS_2 to be a more promising channel material in optoelectronic and electronic integration.

1. Introduction

The representative of transition metal dichalcogenides (TMDs), molybdenum disulfide (MoS_2) has been widely investigated for electronic and photonic devices. However, MoS_2 usually suffers from the high contact resistance between an electrode metal and MoS_2. Several studies have been reported to improve the contact resistance at the metal-MoS_2 interface and among these, graphene with semi-metallic characteristics can be used as electrodes for MoS_2 and O_2 plasma treatment is the most common used method to remove graphene in the channel, but further research about the influences of this technical process on the device has rarely been reported in the literature.

In this letter, we used a large area of graphene and MoS_2 films to investigate three different interfaces: single-layer graphene /MoS_2 (SLG/MoS_2), bi-layer graphene /MoS_2 (BLG/MoS_2), and tri-layer graphene /MoS_2 (TLG/MoS_2). These structures were fabricated using the circular transmission line model (CTLM) with Ti/Au electrodes. Then O_2 plasma treatment was utilized to etch graphene on channel and annealing process followed. Through optimizing the O_2 plasma time and annealing process, we achieved the lowest contact resistance at room temperature.

2. Device Fabrication

Fig.1 shows device structure of graphene/MoS_2. The MoS_2 film was grown on a highly resistive silicon substrate with 285 nm thick silicon oxide. Then different layered graphene film grown on copper by chemical vapor deposition were transferred onto the MoS_2/SiO_2/Si substrate by wet transfer using PMMA. The CTLM test structures were fabricated on the graphene/MoS_2 structures with 20 nm/60 nm Ti/Au by electron-beam evaporation. Finally, low power O_2 plasma was used to etch graphene from the channel. In the CTLM, the gap of the width varies from 3 μm to 30 μm and the inner radius L of the conducting circular is 50 μm.

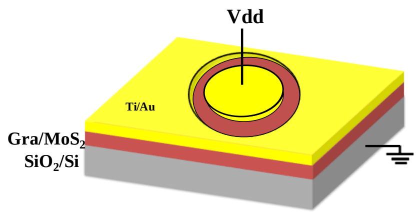

Fig.1. Device structure of graphene/MoS_2.

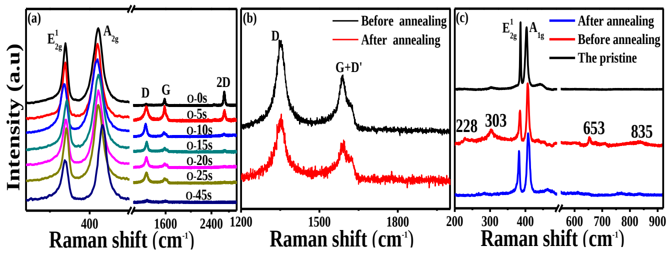

Fig.2. (a) Raman spectra of the SLG/MoS_2 sample subjected to different O_2 plasma time. (b) Raman spectra collected of graphene with 20 s O_2 plasma treatment before (red line) and after (blue line) 250℃annealing at Ar atmosphere. (c) Raman spectra collected of MoS_2 with 20s O_2 plasma treatment before (red line) and after (blue line) 250℃annealing at Ar atmosphere.

3. Results and Discussion

Fig. 2 shows Raman spectra of the SLG/MoS_2 sample subjected to different O_2 plasma time at room temperature. Compared with the pristine, with the increasing of O_2 plas-ma time, the G peak broadens, an additional D' appears peak at ~1619.7 cm^{-1} and the intensity of the 2D peak decreases sharply. For MoS_2, the extra peaks located at 228, 303, 653 and 835 cm^{-1} are recorded in Fig.2 (c), which indicates the appearance of MoO_3 and MoO_2 and the surface of a small area of the MoS_2 film have been converted into MoO_3 and MoO_2. Then, after annealing process, these peaks including G, D, D', E^1_{2g} and A_{1g} decrease obviously due to the reduction of oxygen atoms.

X-ray photoelectric spectroscopy of the pristine MoS_2 film and the SLG/MoS_2 films exposed at O_2 plasma for 20s are shown in Fig.3. Before O_2 plasma process, the compo-nent of molybdenum is just MoS_2 at 229.1 eV. As shown in the spectra, after O_2 plasma treatment, there are two com-ponents of molybdenum: first Mo^{6+}, second Mo^{4+}. According to the previous reports, the standard value of S/Mo is 2 [1]. The S/Mo ratio from our experiments at 20s O_2 plasma is 0.62 and the calculated relative content of MoS_2 is 31%. After 250℃ annealing at Ar atmosphere, the values are 1.1 and 54.9%, which reveals that oxygen element introduced during oxidation process can be reduced by annealing. Fig.3 (d) indicates the S 2p spectrum.

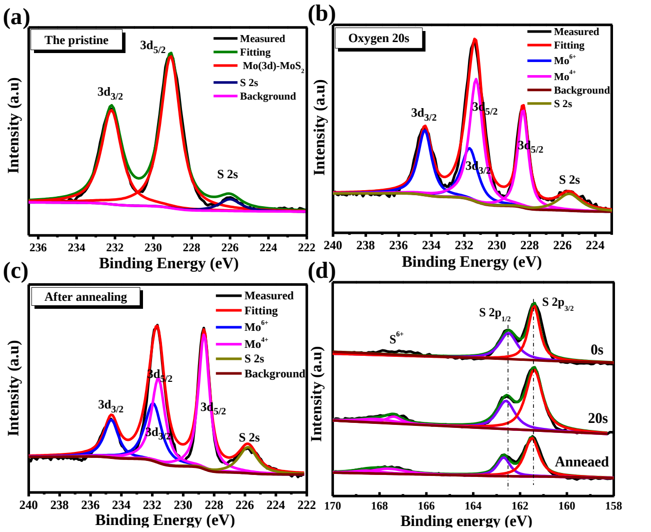

Fig.3. (a) XPS measurements on MoS_2 at the pristine state. (b) The chemical binding states of the etched MoS_2 films subjected to 20s etching with O_2 plasma. (c) The chemical binding states of MoS_2 film after 20 s etching and 250℃ annealing. (d) Scan spectrum of the S 2p doublet peaks.

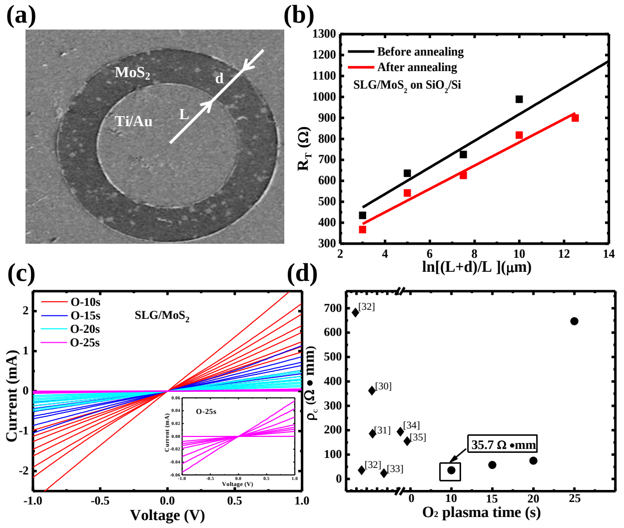

Fig.4. (a) SEM of the device followed by O_2 plasma treatment. The gap of width varies are 3μm, 5μm, 7.5μm, 10μm, 12.5μm, 15μm, 20μm and 30μm. (b) The relationship between the total resistance and the gap of width varies, (c) Output curve of SLG/MoS_2 under different O_2 plasma time. Inset is the magnification of the I-V characteristics at 25s O_2 plasma time. (d) The contact resistance of SLG/MoS_2 from references (rhombus) and this study (circular).

Fig. 4 illustrates the SEM and the standard I-V characteristics of the SLG/MoS_2 layer. Subsequently, through cal culating we got the contact resistance after an-nealing and found the value reduces from 141.5 Ω to 113.7 Ω. We further calculated the specific contact resistance to be ~35.7 Ω• mm, which is much lower than the conventional contact resistance of MoS_2 film without inserting graphene [2-3]. Before and after O_2 plasma treatment, the device both shows linear output curves and the ohmic behavior is observed.

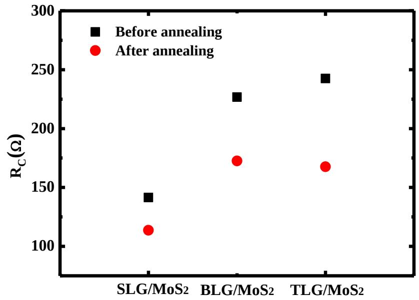

Fig.5. Contact resistances of these different devices before and after annealing, SLG/MoS_2, BLG/MoS_2 and TLG/MoS_2.

However, the contact resistivity increases along with the O_2 plasma time, which is shown in Fig. 4 (d). Consider-ing the large size of our graphics, a low contact resis-tivity about 35.7 Ω• mm at 10s O_2 plasma is comparable with the references according to the reported devices [2-8]. Besides, we summarized the contact resistance of three different devices before and after annealing, shown in Fig.5. In contrast to the multilayer graphene, we found the lowest resistance in the monolayer graphene/MoS_2 structure.

4. Conclusions

In summary, the CTLM test structure was utilized to compare their contact resistance behavior of three devices based on graphene/MoS_2 interface under O_2 plasma treatment. O_2 plasma treatment was introduced to remove graphene exposed outside the ring. In the end, it is found that monolayer graphene/MoS_2 structure has the lowest contact resistance compared to the multilayer. Moreover, a low contact resistance ~35.7 Ω• mm was achieved at 10s O_2 plasma treatment without back gate voltage in single-layer graphene/MoS_2 structure at room temperature.

References

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