Enhanced Field-Effect Mobility of MoS_2 Transistors Prepared by Chemical Vapor Deposition with Low-Power Oxygen Plasma Treatment

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Abstract

Two-dimensional (2-D) material, such as graphene, has emerged as a possible material for transistor applications in the < 10 nm technology node. However, due to the zero-bandgap nature, the low ON/OFF ratio of graphene transistors has limited its practical applications. In this case, other 2-D material with bandgaps such as MoS_2 has attracted attentions for transistor applications [1]. However, although high ON/OFF ratios are observed for MoS_2 transistors, its low field-effect mobility has become a major disadvantage of this device. In this report, we have demonstrated that by using low-power oxygen plasma treatment, enhanced field-effect mobility values can be observed for MoS_2 transistors prepared by transition metal deposition following by high-temperature sulfurization. The flow chart for the MoS_2 transistor fabrication procedure is shown in Fig. 1. The MoS_2 film is grown on a sapphire substrate by using 800 ^oC sulfurization of 1 nm Mo pre-deposited on the substrate by using a sputtering system. The cross-sectional HRTEM image of the MoS_2 film shown as an inset figure in Fig. 1 reveals that 5-layer MoS_2 is obtained. After growth, the MoS_2 film is transferred to a 300 nm SiO_2/p-Si substrate with pre-patterned 5 nm Ti/50 nm Au electrodes fabricated by using standard photo-lithography [2]. After channel definition by using a reactive ion etching system, back-gated MoS_2 transistors with channel length/width 5/150 μm are fabricated. The device's optical microscopy image is also shown as an inset figure in Fig. 1. After fabrication, the device is treated by low-power oxygen plasma (20 W) for 5 and 10 sec., respectively. During this procedure, a DC bias of 30 V is applied to the sample holder. The I_D-V_{GS} curves of the device with 0, 5 and 10 sec. plasma treatment time are shown in Fig. 2. As shown in the figure, the threshold voltages (V_{th}) of the device shift from -78, -116 to -176 V with increasing plasma treatment time, which suggest that increasing electron concentrations are obtained in the MoS_2 channel after low-power oxygen plasma treatment. The field-effect mobility values of the device derived from the I_D-V_{GS} curves also increase from 0.01, 2.5 to 9.6 $cm^2V^{-1}s^{-1}$ with increasing plasma treatment time. Also observed in the figure are the decreasing drain currents with increasing gate biases higher than -144 V for the device after 10 sec. plasma treatment. The phenomenon suggests that severe electron scattering is observed for the device after 10 sec. plasma treatment, which also indicates that electron concentrations increase very rapidly with increasing plasma treatment time. The results are very different with the photoluminescence quenching of MoS_2 films treated under relatively high oxygen plasma powers, which indicates that damages to the films are introduced during the plasma treatment process [3]. To explain the phenomenon of V_{th} shifting and mobility increasing of MoS_2 transistors after low-power oxygen plasma treatment, a model is established. The derived field-effect mobility value of the MoS_2 transistor in this report is far below that of the device fabricated on exfoliated MoS_2 flakes [1]. Therefore, the defect density of the grown MoS_2 film should be much higher than the exfoliated ones. Assuming the defects on the MoS_2 film act as electron traps for devices, since the low plasma power is not sufficient to etch or damage the film, O^{2-} ions in the plasma gas will be attracted by the defects and attach to the film. With increasing plasma treatment time, more defects will be de-activated with increasing O^{2-} ion attachment. In this case, increasing electron concentrations will induce decreasing threshold voltages. The lowered defect scatterings will result in increasing field-effect mobility values.

References

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Figures

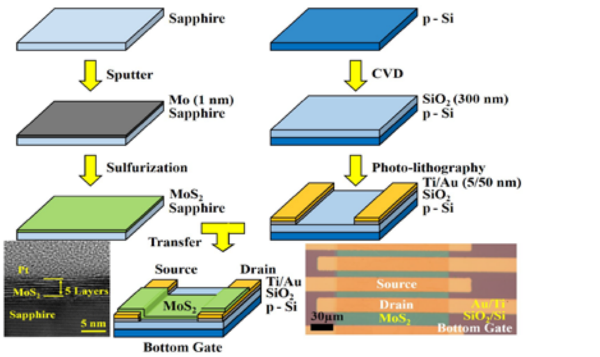

Fig. 1 The flow chart for the MoS2 transistor fabrication.

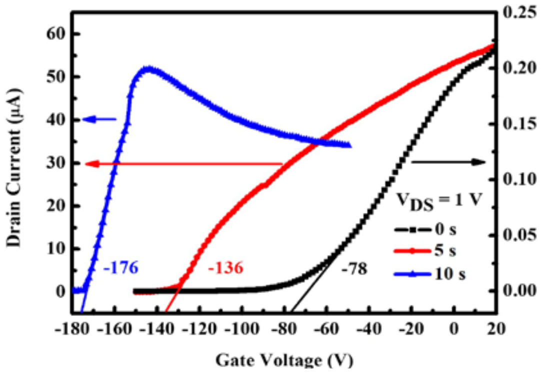

Fig. 2 The I_D-V_{GS} curves of the device with 0, 5 and 10 sec. plasma treatment time.