

# Investigation of Molybdenum Disulfide Transistors with Aluminum Oxide Passivation

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## Abstract:

Two methods were investigated as a means of achieving conformal nucleation of aluminum oxide ( $\text{Al}_2\text{O}_3$ ) on molybdenum disulfide ( $\text{MoS}_2$ ). The first method consisted of depositing a thin metal layer on  $\text{MoS}_2$ , and the second method was treating the  $\text{MoS}_2$  with oxygen ( $\text{O}_2$ ) plasma. Next, four types of  $\text{MoS}_2$  back gate transistors were fabricated and treated with a different metal layer or  $\text{O}_2$  plasma. Electrical measurements were then compared.

## Introduction:

To further Moore's law, two dimensional (2D) materials are being investigated as a possible replacement for silicon in transistors, because of their ability to achieve a thickness smaller than 1 nm. The 2D material graphene, which has been extensively investigated, does not intrinsically possess a bandgap, preventing it from being used in logic transistors; on the other hand, the 2D material  $\text{MoS}_2$  does possess a bandgap. Although logic transistors have been fabricated using  $\text{MoS}_2$  [1], there has been difficulty in obtaining a uniform deposition

of the dielectric  $\text{Al}_2\text{O}_3$  on  $\text{MoS}_2$ , as shown in Figure 1. The difficulty has been attributed to the lack of dangling bonds on  $\text{MoS}_2$ . Several treatments have been suggested to improve nucleation by intentionally producing nucleation sites on  $\text{MoS}_2$  [2, 3]. We examine two of these methods. First is the deposition of a thin layer of metal, referred to as a seed layer. And second is an oxygen plasma treatment.

The purpose of our investigation was to find a method that would enable the production of a high quality top gate dielectric that would not degrade the performance of the device. In this investigation, we fabricated back gate transistors. Once a suitable method is determined, fabrication of top gate  $\text{MoS}_2$  transistors with  $\text{Al}_2\text{O}_3$  passivation will be pursued.

## Experiment:

The  $\text{MoS}_2$  flakes were obtained using micromechanical exfoliation and transferred to an Si wafer with 280 nm of  $\text{SiO}_2$ . The wafer was then split into four pieces. Three of the samples each had a different seed layer of aluminum (Al), chromium (Cr), or titanium (Ti); all were deposited by electron beam physical vapor deposition (EBPVD), with an average thickness of 1 nm. For the oxygen plasma treatment, a wafer with  $\text{MoS}_2$  was placed in a reactive ion etcher (RIE) for 30 s, at room temperature, with a power of 55 W and a flow rate of 19 sccm. Using atomic layer deposition (ALD), 25 nm of  $\text{Al}_2\text{O}_3$  was deposited on all four samples at 200°C. Inspection was done using an atomic force microscope (AFM). As shown in the AFM image in Figure 2, all four treatments did achieve conformal nucleation of  $\text{Al}_2\text{O}_3$  on the  $\text{MoS}_2$  flakes.



Figure 1:  $\text{Al}_2\text{O}_3$  deposition on  $\text{MoS}_2$  flakes with no treatment. The black regions are devoid of  $\text{Al}_2\text{O}_3$ .

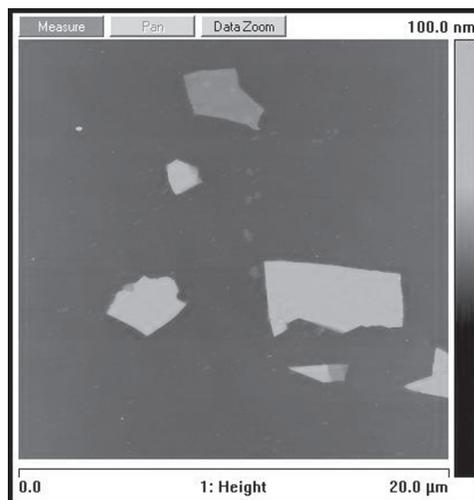


Figure 2: Uniform deposition of  $\text{Al}_2\text{O}_3$  on  $\text{MoS}_2$  flakes with Al seed layer. All treated samples produced similar results.

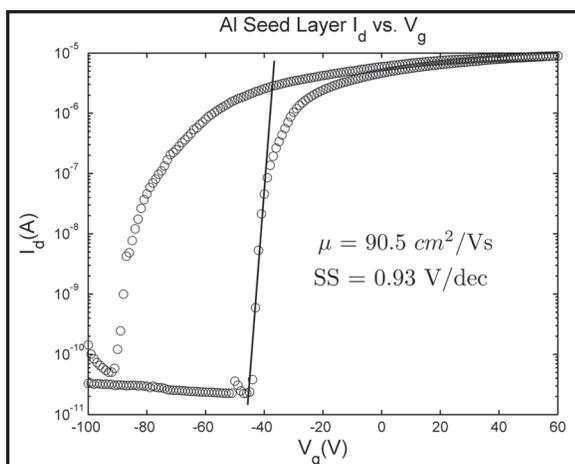


Figure 3:  $I_d$  vs.  $V_g$  hysteresis of Al seed layer transistor.

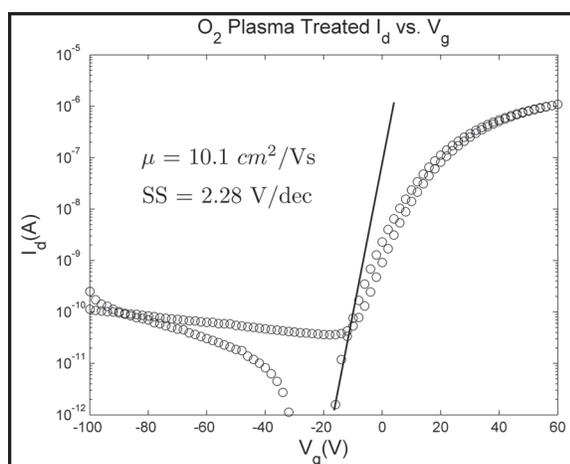


Figure 4:  $I_d$  vs.  $V_g$  hysteresis of  $O_2$  treated transistor.

For the fabrication of the back gate transistors, four wafer samples with  $MoS_2$  flakes had two layers of resist spin-coated onto the substrate, with MMA on the top and PMMA on the bottom. Next, the metal contacts were fabricated employing electron beam lithography for the pattern, followed by the deposition of 50 nm of gold using EBPVD, and finally lift-off. Then, each of the four samples received a different treatment, just as the four samples mentioned above. Three had a different seed layer; the thicknesses were 8 Å for Al and 6 Å for both Cr and Ti. The fourth sample was treated with  $O_2$  plasma. Lastly,  $Al_2O_3$  was deposited. The electrical measurements were collected using a two point probe, where the substrate served as the bottom gate.

### Results:

The electrical measurements that were collected from the transistors included mobility and the subthreshold slope. From the results, it appeared that, out of the four, the best performance came from the transistor with the Al seed layer, with a mobility of  $90.5 \text{ cm}^2/\text{Vs}$  and a subthreshold slope (SS) of  $0.93 \text{ V/dec}$ , as shown in Figure 3. The Cr seed layer transistor had a mobility of  $47.9 \text{ cm}^2/\text{Vs}$  and a SS of  $3.01 \text{ V/dec}$ . And the Ti seed layer transistor had a mobility of  $38.1 \text{ cm}^2/\text{Vs}$  and a SS of  $0.99 \text{ V/dec}$ . Finally, the oxygen plasma treated transistor had a mobility of  $10.1 \text{ cm}^2/\text{Vs}$  and a SS of  $2.28 \text{ V/dec}$ .

Although the  $O_2$  plasma treated transistor did not have impressive numbers, its  $I_d$  vs.  $V_g$  graph was intriguing, as seen in Figure 4. The threshold voltage shifted significantly to the right and the hysteresis curve was narrower than any of that produced by the seed layer transistors. Further analysis showed

that the poor measurement numbers were not entirely due to the  $O_2$  treatment and could be mostly attributed to the  $MoS_2$  flakes. This finding is promising for further investigations of the  $O_2$  treated transistors.

### Conclusions:

Two methods were investigated as a means of achieving conformal nucleation of  $Al_2O_3$  on  $MoS_2$ . The first treatment was the deposition of a seed layer, and the second was an  $O_2$  plasma treatment. From the electrical measurements, it appears that the Al seed layer transistor had the best improvement in mobility, and the  $O_2$  treated transistor showed promise for modifying the threshold voltage and the hysteresis effect. Future work includes an investigation to see if the current results are reproducible, and further analysis will be done to determine the cause of the observed effects.

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### References:

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