Development of ALD gate dielectrics for TMD nanosheet FETs

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Abstract

Superior electrostatics control of monolayer (1L) TMDs holds great potential in advancing the scaling of nanosheet (NS) transistors in advanced technology nodes [1]. One critical aspect is to achieve a conformal dielectric layer on TMD NS channel using atomic layer deposition (ALD) [2]. The main challenge in achieving high-quality gate dielectrics is forming a good nucleation layer on the dangling bond-free TMD interface. This study successfully used the ALD technique to form a uniform AlO_x thin film on 1L-MoS_2 without damaging the material. Furthermore, good performance of MoS_2 NS nFET is also successfully demonstrated.

Experiment

To improve surface nucleation in the AlO_x layer on TMD, a low ALD temperature and high dosage (HD) of TMA precursor are required. During ALD, the TMA pulse time is extended with the pump valve off to increase surface dosage. After preparing the 1L-MoS_2 channel on SiN_x/Si, a top-gated FET was fabricated using HD ALD-AlO_x at 90 °C (30 cycles) and standard ALD-HfO_x at 200 °C (50 cycles). The gate metal and source/drain contacts were made of Au.

Result and discussion

The AFM images in Fig. 1(a) shows that the HD process in ALD improves the coverage of the AlO_x film on 1L-MoS_2 to 89% with a lower RMS (0.32 nm). Therefore, conformal AlO_x interfacial layer of 2.8 nm is revealed in MoS_2 top-gated nFET, as TEM image shown in Fig. 1(b). Moreover, the HD-AlO_x ALD process is applied to the 1L-MoS_2 sheet structure (see TEM images in Fig. 2). Good conformality of the AlO_x interlayer and HfO_x film, wrapping around 1L-MoS_2 sheet, is achieved without any pinholes. Good transfer characteristics is displayed in Fig. 3. This demonstrates that high-dose ALD AlO_x can be used as the dielectric interlayer in 1L-MoS_2 NS devices. A large scaling window in HD AlO_x and HfO_x thickness allows for further enhancement of device performance.

Conclusion

We successfully explored the ALD approach of forming a conformal gate dielectric bilayer on monolayer MoS_2 and demonstrated good NS nFET characteristics. A uniform ALD-AlO_x thin film was achieved through enhanced physical adsorption at a lower temperature (90 °C) and higher TMA precursor concertation. This facilitated subsequent HfO_x deposition at a higher temperature (200 °C) without damaging the MoS_2. The proposed method provides a practical pathway to integrate ALD gate dielectric into TMD nanosheet devices.

Reference

[1] S.-K. Su *et al*., Small Structures, 2.5, 2000103 (2021).

[2] Yun-Yan Chung *et al*., IEDM 34.5.1 (2022).

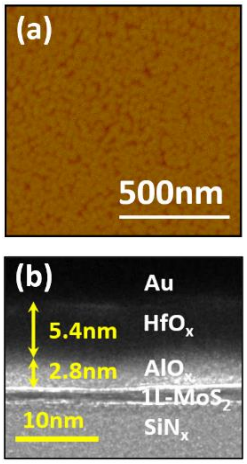

Fig. 1. (a) AFM of high-dose ALD AlO_x/ 1L-MoS_2/ sapphire. (b) TEM images of Au/ HfO_x/ high-dose AlO_x/ 1L-MoS_2 on SiN_x/Si substrates.

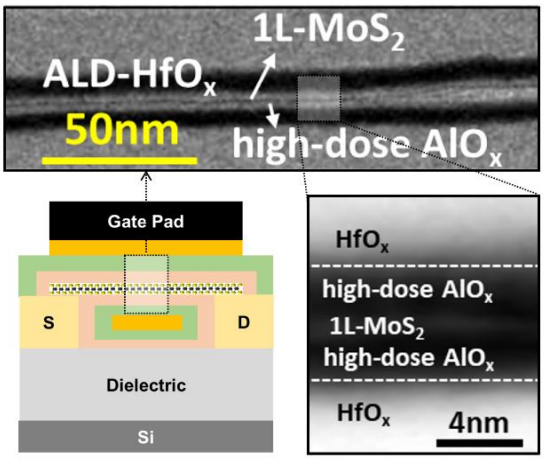

Fig. 2. Schematic diagram and TEM cross-section images of 1L-MoS_2 NS nFET with high-dose AlO_x interlayer (2.8 nm) and HfO_x (5.4 nm) as ALD gate stack.

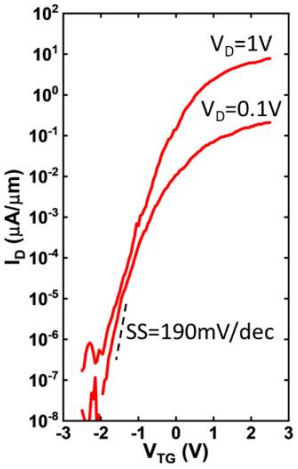

Fig. 3. I_D-V_G curves of 1L-MoS_2 NS nFET with high-dose AlO_x and HfO_x gate dielectrics.