Nanostructure Synthesis and Fabrication
Room Auditorium - Session NS-WeM

2D Nanomaterials by ALD I

Moderators: Tae Joo Park, Hanyang University, Virginia Wheeler, U.S. Naval Research Laboratory

10:45am **NS-WeM-1 Exploring ALD 2D Chalcogenides Beyond MoS_2**, ***Miika Mattinen,*** University of Helsinki, Finland **INVITED**

Two-dimensional (2D) materials have rapidly emerged as promising materials for a range of applications from microelectronics to sensing as well as energy storage and production. Deposition of 2D materials as high-quality films of controlled thickness on large, temperature-sensitive, and complexly shaped substrates is one of the main challenges hindering industrial applications. ALD can fulfill these requirements, but unlocking the full potential of ALD of 2D materials requires careful examination of precursor chemistry, nucleation, substrates, film characteristics, and device performance.

Much of the ALD research on 2D transition metal dichalcogenides (TMDCs) has focused on semiconducting MoS_2. Lately, some of the efforts have shifted to other 2D semiconductors, which may offer improved charge carrier characteristics (e.g. WS_2 and WSe_2) and lower processing temperatures (SnS_2), for example. So far, little attention has been given to ALD of metallic TMDCs (e.g. NbS_2 and TaS_2), which may be used to complement 2D semiconductors in devices or by themselves in energy storage and production. Furthermore, ALD of selenide and telluride TMDCs is still in its infancy.

Deposition of these “new” 2D chalcogenides by ALD is no simple feat. This talk focuses on finding precursors for a range of 2D chalcogenides from MoS_2 to other semiconductors including HfS_2, SnS_2, WS_2, and ZrS_2 as well as my recent efforts towards metallic sulfide TMDCs. Precursor challenges related to reactivity, thermal stability, and etching reactions will be considered. I will cover some challenges and opportunities related to selenide and telluride TMDCs. I am also going to discuss the stability of the deposited films and deposition of protective layers.

The anisotropic, layered crystal structure of 2D materials affects their growth. The morphology of the grown films in turn affects their properties and performance in applications. The effect of the substrate on morphology, continuity, and crystallinity of 2D films will be discussed through the following three examples. First, the growth of crystalline TMDC films often leads to rough morphology. By depositing amorphous films that are crystallized after deposition, smooth crystalline SnS_2 and WS_2 films can be obtained. Second, deposition of thin and continuous TMDC films is challenging. It will be shown that thinner continuous SnS_2 films can be deposited on sapphire compared to silicon. Third, methods to improve the quality of the films deposited at low temperatures are desired. To this end, I will discuss van der Waals epitaxial growth of 2D chalcogenides.

11:30am **NS-WeM-4 Growth of Wafer-Scale Monolayer MoS_2 using Adsorbate-Controlled Atomic Layer Deposition**, *D Kim,* ***Jae Chan Park****, W Kim,* Hanyang University, Republic of Korea*; J Park, B Shong,* Hongik University, Republic of Korea*; J Ahn, T Park,* Hanyang University, Republic of Korea

Monolayer transition-metal dichalcogenide compounds with two-dimensional (2D) layered structures have attracted considerable attention because of their potential applicability as next-generation active materials for versatile electronic and optoelectronic devices. For industrial application of these materials, a reliable method for well-controlled large-area growth of high-quality material at the wafer scale should be developed. Atomic layer deposition (ALD) of 2D materials has been widely studied for realizing atomically flat monolayer films, but it has limitations regarding the implementation of a perfect monolayer owing to its deposition characteristics.

In this work, we propose a novel chemical route for the deposition of a monolayer MoS_2 film with large-area uniformity at wafer scale using ALD. First, by modulating the precursor injection step, the amount of adsorbed precursor in one cycle can be precisely controlled in a range exceeding the limitation imposed by “typical” ALD reaction. Utilizing such process, we successfully realized (for the first time) a uniform and complete monolayer MoS_2 film using ALD at the wafer scale. The monolayer MoS_2 film exhibited excellent uniformity at the wafer scale, and the luminescence quantum efficiency of a monolayer MoS_2 film deposited via the newly-proposed ALD method was approximately 9 times greater than that of the film formed via conventional ALD. These results indicate that our method can be employed for obtaining complete single layers of various materials or developing high-quality monolayer-scale 2D materials using ALD.

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