(Invited) **Plasma-enhanced atomic layer deposition of transition metal dichalcogenides: from 2D monolayers to 3D vertical nanofins**

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2D materials have been the focus of intense research in the last decade due to their unique physical and chemical properties. This presentation will highlight our recent progress on the synthesis of two-dimensional transition metal dichalcogenides (2DTMDs) for nanoelectronics and catalysis applications using atomic layer deposition (ALD). ALD is a chemical process that is based on self-limiting surface reactions and results in ultrathin films, with sub-nm control over the thickness and wafer-scale uniformity at low temperatures. ALD-grown 2DTMD films typically exhibit a high density of out-of-plane 3D structures in addition to the desired 2D horizontal layers. While the out-of-plane 3D structures are ideal for catalysis applications, the presence of such 3D structures can hinder charge transport, which hampers device applications.

We investigated the growth mechanism of the 3D structures by extensive high resolution transmission electron microscopy analysis. We found that the fins typically originate at the grain boundaries in the 2D layers and that the grain orientation of adjacent 2D crystals play an important role in 3D structure formation. We demonstrate that both the shape and density of the 3D structures can be controlled during plasma-enhanced ALD. The shape of the 3D structures can be varied by modulating the plasma gas composition (H_2/H_2S ratio) in the ALD co-reactant step (figure 1). This has a direct influence on the number a catalytic edge sites in WS_2 films. The density of 3D structures can be suppressed by introducing a novel three step (ABC) ALD process, which involves the addition of an extra Ar and/or H_2 plasma step (step C) to the conventional AB-type ALD process. This reduces the 3D structure density and consequently reduces the resistivity of the TMD film by an order of magnitude.

Our work showcases the versatility of plasma-enhanced ALD for the controlled synthesis of transition metal dichalcogenide nanolayers, which can enable applications in both the nanoelectronics and catalysis field.

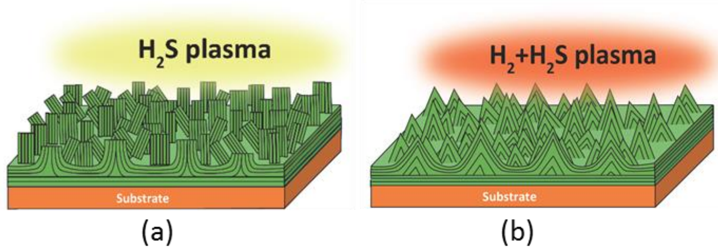

Figure 1: Schematic of the obtained shape control of 3D WS_2 nanostructures by changing the co-reactant in PEALD.