Li Shisheng
International Center for Young Scientists (ICYS), National Institute for Materials Science (NIMS), Namiki 1-1, Tsukuba 305-0044, Japan

LI.Shisheng@nims.go.jp

Chemical Vapor Deposition of 2D Transition Metal Dichalcogenides – Just Add Salts

Chemical vapor deposition (CVD) of 2D transition-metal dichalcogenides (TMDCs) usually involves the conversion of vapor precursors into solid products via a vapor-solid-solid (VSS) mode (WO_3 + S/Se + H_2 → WS_2/WSe_2). It always requires an extremely high temperature and low pressure to sublimate the transition metal oxides. In 2015, we published a pioneering work on halide-assisted atmospheric-pressure CVD of WSe_2 and WS_2 monolayers at lower temperature due to the formation of low-melting-point volatile tungsten oxychlorides (WO_3 + NaCl → WO_xCl_y, WO_xCl_y + S/Se + H_2 → WS_2/WSe_2, Figure.1a).[1,2] This method has been widely used for growing ~ 50 types of 2D TMDCs in the last five years.[3]

Vapor transportation as the core process in CVD of 2D TMDCs, one inevitable problem is the spatial inhomogeneity of the vapors. The non-stoichiometric supply of transition-metal precursors and chalcogen leads to poor control in products' location, morphology, crystallinity, uniformity and batch to batch reproducibility. In 2018, we revealed the important vapor-liquid-solid (VLS) growth of TMDCs which is triggered by the alkali metals in salt-assisted CVD (MoO_3 + NaCl → $Na_2Mo_xO_y$, $Na_2Mo_xO_y$ + S → MoS_2). The in-situ generated non-volatile Na-Mo-O droplets mediate the growth of 1D MoS_2 nanoribbons on NaCl crystal and 2D MoS_2 film (Figure 1b).[4] The VLS growth involves non-volatile molten precursors (e.g., Na_2MoO_4, Na_2WO_4) shows great advantages in wafer-scale growth of 2D TMDC film and patterned (site-controlled) growth of 2D TMDC monolayers (Figure 1c).[5] Taking advantage of the VLS growth, we recently achieved two important achievements: (i) 2-inch-wafer-scale growth of continuous MoS_2 film with a grain size exceeding 100 μm on sapphire substrates, and (ii) pattern (site-controlled) growth of MoS_2 flakes. We clarified that the VLS growth thus pave the new way for the high-efficient, scalable synthesis of two-dimensional TMDC monolayers. It opens a new research direction for the 2D community.

References

[1] S. Li, S. Wang, D.-M. Tang, W. Zhao, H. Xu, L. Chu, Y. Bando, D. Golberg, G. Eda,* Appl. Mater. Today 1 (2015), 60-66
[2] D. Bradley, Mater. Today 18 (2015), 533
[3] J. Zhou, J. Lin,* X. Huang, Y. Zhou, Y. Chen, J. Xia, H. Wang, Y. Xie, H. Yu, J. Lei, D. Wu, F. Liu, Q. Fu, Q. Zeng, C.-H. Hsu, C. Yang, L. Lu, T. Yu, Z. Shen, H. Lin, B. I. Yakobson, Q. Liu, K. Suenaga, G. Liu,* Z. Liu,* Nature 556 (2018), 355-359
[4] S. Li,* Y.-C. Lin, W. Zhao, J. Wu, Z. Wang, Z. Hu, Y. Shen, D.-M. Tang, J. Wang, Q. Zhang, H. Zhu, L. Chu, W. Zhao, C. Liu, Z. Sun, T. Taniguchi, M. Osada, W. Chen, Q. Xu, A. T. S. Wee, K. Suenaga, F. Ding, G. Eda,* Nat. Mater. 17 (2018), 535-542
[5] S. Li,* Y.-C. Lin, X.-Y. Liu, Z. Hu, J. Wu, H. Nakajima, S. Liu, T. Okazaki, W. Chen, T. Minari, Y. Sakuma, K. Tsukagoshi, K. Suenaga, T. Taniguchi, M. Osada, * submitted (2019)

Figures

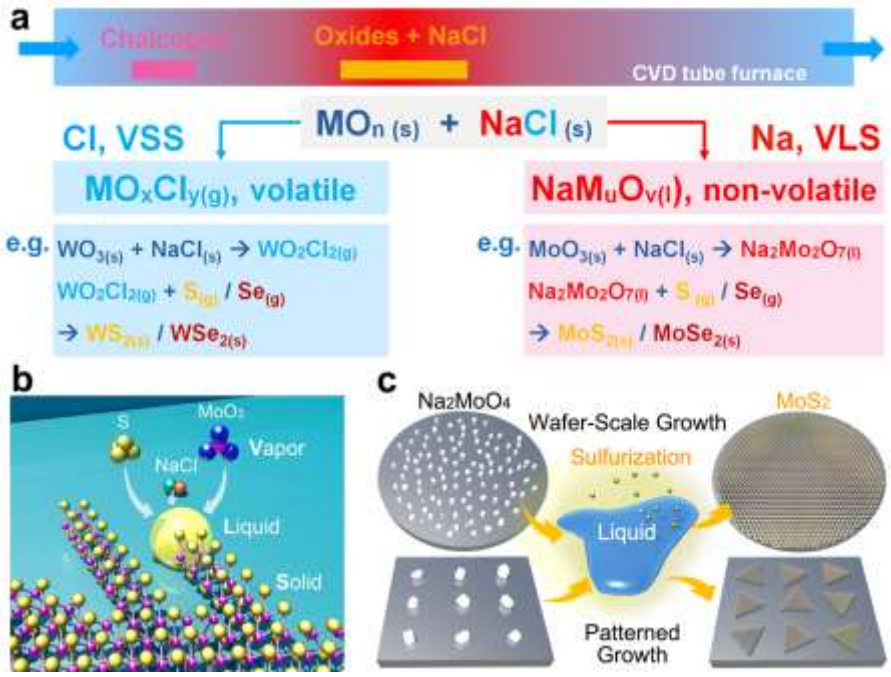

Figure 1: (a) Schematic of the VSS and VLS growths of 2D TMDCs in salt-assisted CVD. (b) Schematic of VLS growth of 1D MoS_2 nanoribbons. (c) Schematic of wafer-scale and patterned VLS growth of 2D MoS_2 monolayers by sulfurization of non-volatile Na_2MoO_4 liquid.