# $MoS_2$ and $MoSe_2$ thin films fabrication

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## Abstract

Two dimensional (2D) materials have gained great interest in recent years due to their unique electronic, mechanical, and optical properties. Especially transition metal dichalcogenides (TMDs) with the formula $MX_2$, where M is a transition metal (Mo, W, and so on) and X is a chalcogen (S, Se, or Te), have attracted much attention due to their layer structure and semiconducting properties [1]. Their structure consists of a plane of metal atoms sandwiched between two planes of chalcogen atoms by covalent interaction and different layers are held together by van der Waals interactions [2]. These layered materials exhibit many distinctive characteristics such as outstanding flexibility, moderate carrier mobility and layer dependent electronic and optical properties. This makes TMD materials suitable for various applications such as transparent and flexible field effect transistors (FETs), photodetectors, photovoltaic cells, light-emitting diodes and catalysts [1].

Among metal dichalcogenides, molybdenum sulfide ($MoS_2$) materials have been extensively investigated for its interesting properties including enhanced optical absorption, thermoresponsive photogeneration, efficient hydrogen evolution reaction capability, valley polarization and high on/off ratio with low subthreshold swing, which can lead to ultrathin and highly efficient photovoltaics, photo-thermoelectrics, catalysis for sustainability [3]. Moreover, by quasi-continuous electrostatic carrier doping achieved by the combination of $HfO_2$ and ionic liquid, a superconducting state was achieved in $MoS_2$ [4]. Recently, monolayer $MoSe_2$ has started to gain attention because it has many interesting electronic and optical properties similar to those of monolayer $MoS_2$, such as a direct band gap, strong photoluminescence (PL), and a large exciton binding energy. It is known that sulfur defects in the $MoS_2$ monolayer greatly affect the electronic transport and optical properties [1]. Therefore, it would be meaningful to carefully compare the properties of monolayer $MoS_2$ and $MoSe_2$.

A large effort has been made to develop methods for growing high quality ultrathin films. Still, mechanical exfoliation is the most widely used way to prepare $MoS_2$ and $MoSe_2$ monolayers. On the other hand, the method is inherently not suitable for up-scaling. As an alternative, a chemical vapor deposition (CVD) is capable of producing large area $MoS_2$ and $MoSe_2$ films. Recently, physical vapor deposition, especially pulsed laser deposition (PLD) has successfully been used for the fabrication of $MoS_2$ thin films [5].

Molybdenum disulfide and molybdenum diselenide thin films were prepared by a two-step method on different substrates. First, molybdenum thin films were magnetron sputtered on different substrates (Si, sapphire). Second, the thin films were sulfurized / selenized in vapors of sulfur or selenium at high temperatures in a furnace. As-prepared films were characterized by XRD analysis, Raman spectroscopy, Rutherford backscattering and SEM techniques. Afterwards, the films were patterned to different types of structures using photolithography and ion beam etching. Electrical conductivity of the patterned structures were investigated. Finally, we discuss the structural and electrical properties of $MoS_2$ and $MoSe_2$ thin films and structures made of them.

## References

[1] Y.-H. Chang, W. Zhang, Y. Zhu, Y. Han, J. Pu, J.-K. Chang, W.-T. Hsu, J.-K. Huang, C.-L. Hsu, M.-H. Chiu, T. Takenobu, H. Li, C.-I. Wu, W.-H. Chang, A. T. S. Wee, L.-J. Li, ACS Nano, **8** (2014) 8582.

[2] X. Huang, Z. Zeng, H. Zhang, Chem. Soc. Rev., **42** (2013) 1934.

[3] G. W. Shim, K. Yoo, S.-B. Seo, J. Shin, D. Y. Jung, I.-S. Kang, C. W. Ahn, B. J. Cho, S.-Y. Choi, ACS Nano, **8** (2014) 6655.

[4] Ye, J. T. et al., Science, **338** (2012) 1193.

[5] Š. Chromik, M. Sojková, V. Vretenár, A. Rosová, E. Dobročka, M. Hulman, Appl. Surf. Sci, doi:10.1016/j.apsusc.2016.06.038.

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