Site-Specific Synthesis of Molybdenum Disulfide Using Chemical Vapor Deposition

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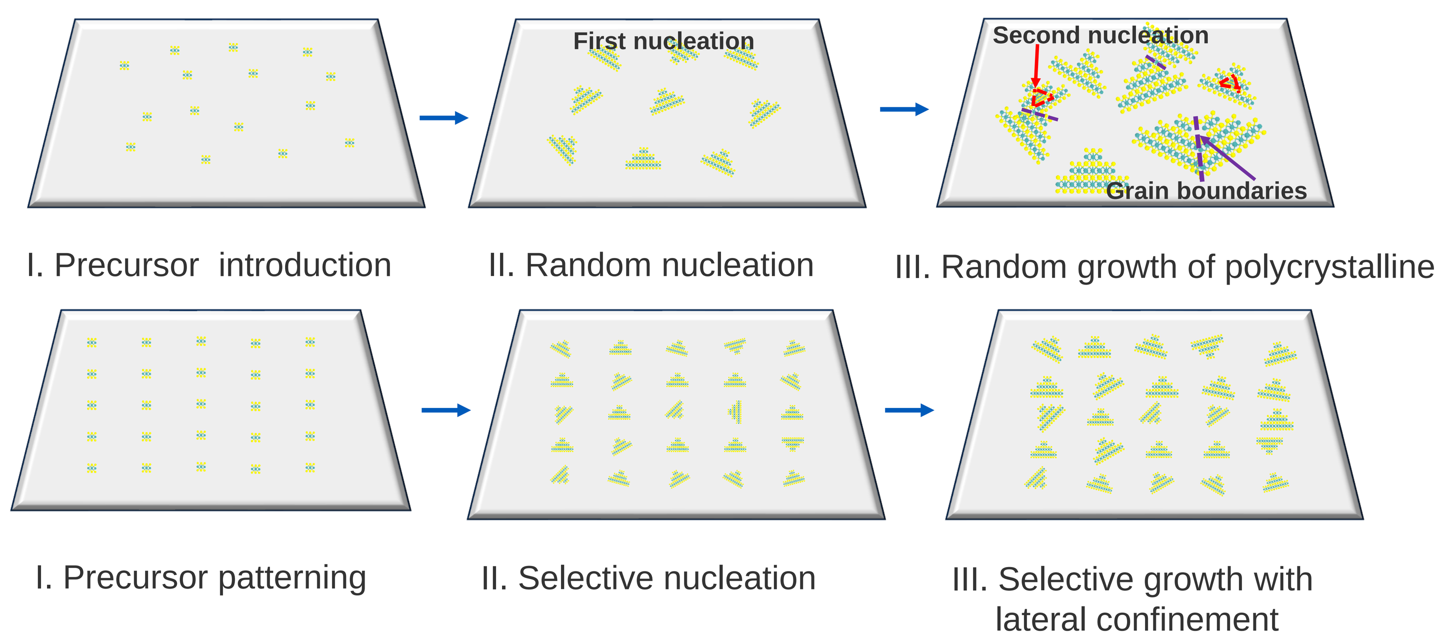
Abstract

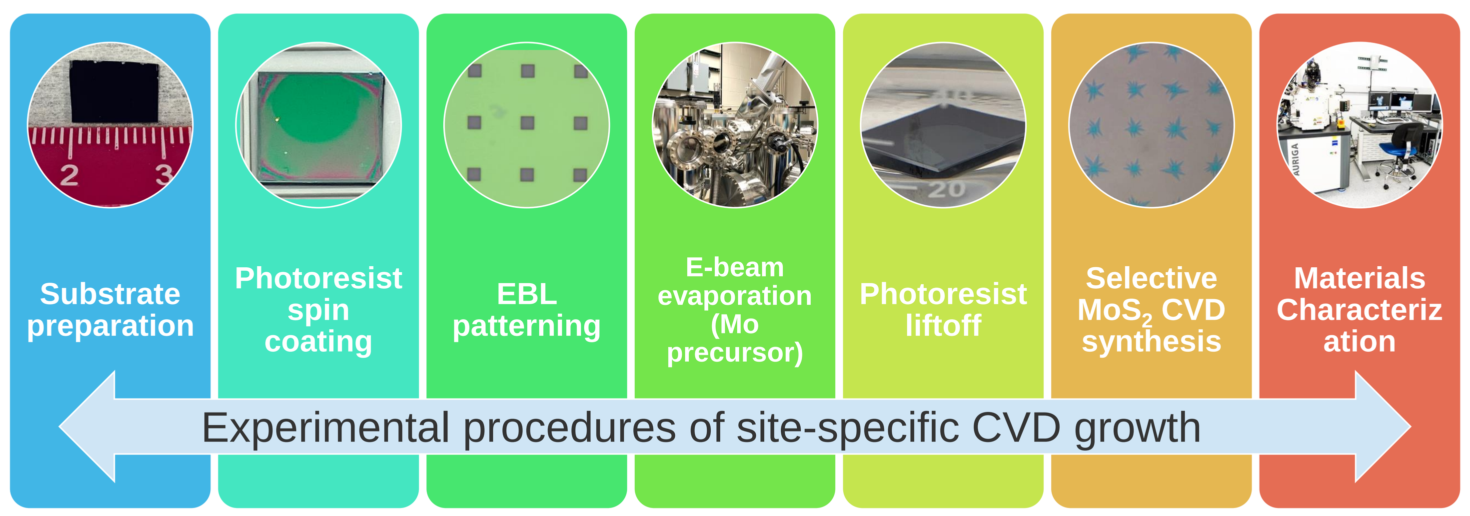
Two-dimensional (2D) semiconducting transition metal dichalcogenides (TMDs) have been considered as promising channel materials for electronic devices. In this study, a novel method for selective-area synthesis of molybdenum disulfide (MoS_2) on silicon substrates using chemical vapor deposition (CVD) is investigated. The approach involves molybdenum seed layer patterning using E-beam lithography (EBL), enabling site-specific nucleation and growth. The impact of growth temperature on MoS_2 formation is identified. Microscopic/spectroscopic characterizations confirm the successful growth of MoS_2 flakes at desired locations. This approach has broader applicability for synthesizing a variety of TMD materials, advancing the future adoption of 2D materials for next-generation nanoelectronics.

Introduction

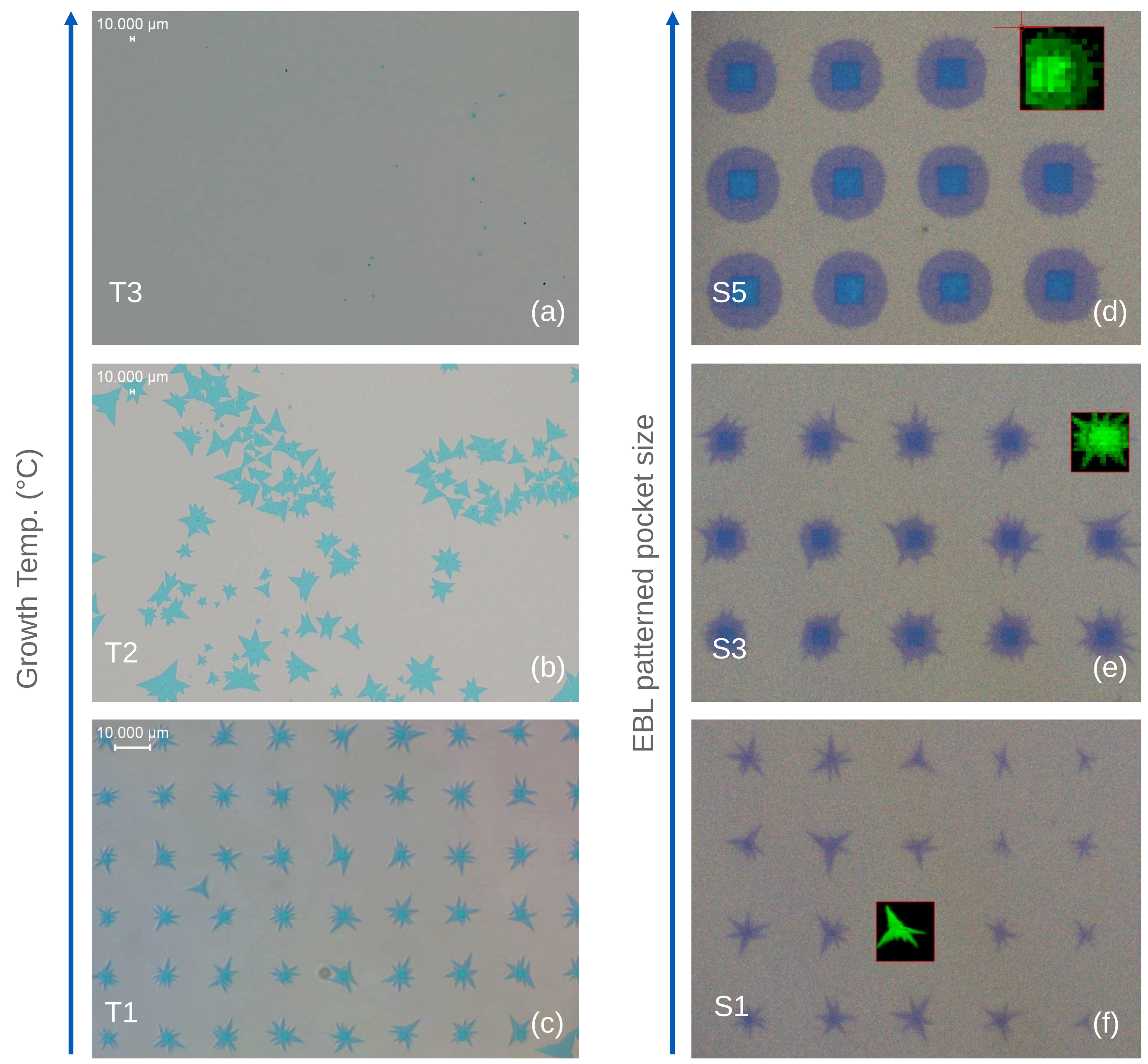
2D semiconducting MoS_2 has been extensively explored as a channel material for electronic devices owing to its ultrathin thickness along with outstanding mechanical and electrical properties [1]. Extensive research efforts have been dedicated to synthesizing large-area single-crystalline (SC) MoS_2 films (~ a few inches in size), which is difficult to achieve due to the formation of grain boundaries when merging adjacent flakes with different orientations (top panel) [1,2]. Despite the early success in proof-of-concept device demonstrations, large-area growth of SC MoS_2 films on suitable substrates remains a significant roadblock to the development of commercially viable 2D-based consumer electronics. To mitigate this problem, there is a critical need to precisely grow high-quality MoS_2 layers at desired locations in the device architecture with consistent layer characteristics (bottom panel).



Experimental procedures

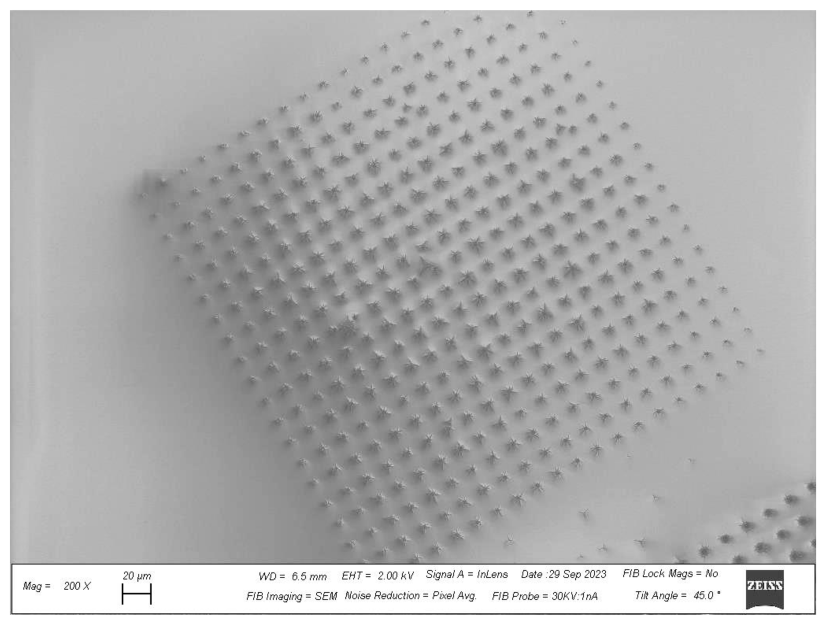


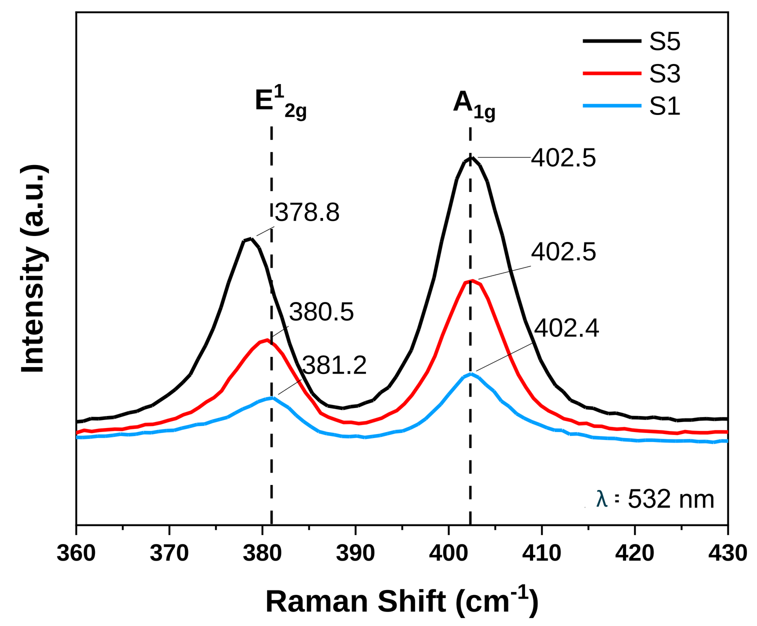
Results



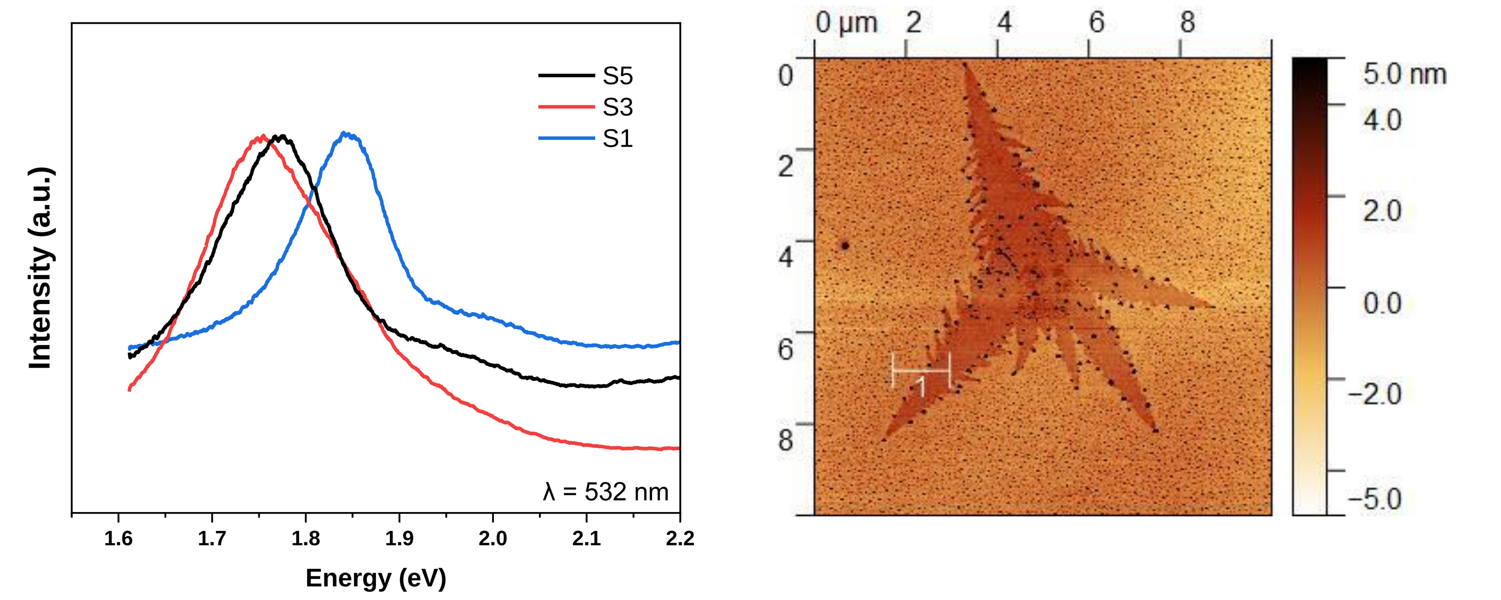
- Left: Site-specific growth can be achieved by optimizing the growth temperature.
- Right: Formation of dendritic flakes is observed and confirmed via Raman mapping at pre-patterned locations. As the patterned pocket size increases, the flake's contour tends to be rounded and extends beyond the pocket region.

Material characterizations

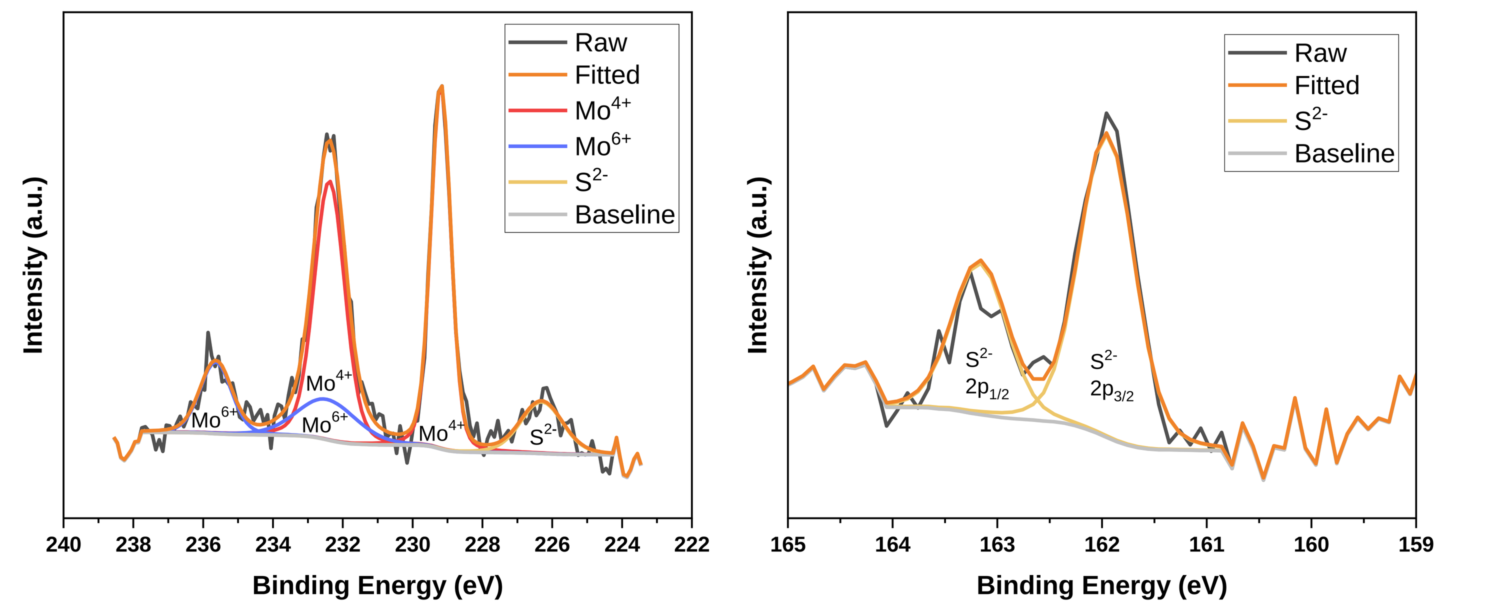




- Left: SEM image of the MoS_2 flake array formed at the pre-defined locations.
- Right: Raman spectra with the characterization peaks of MoS_2. The layer thickness increases as increasing the pocket size.

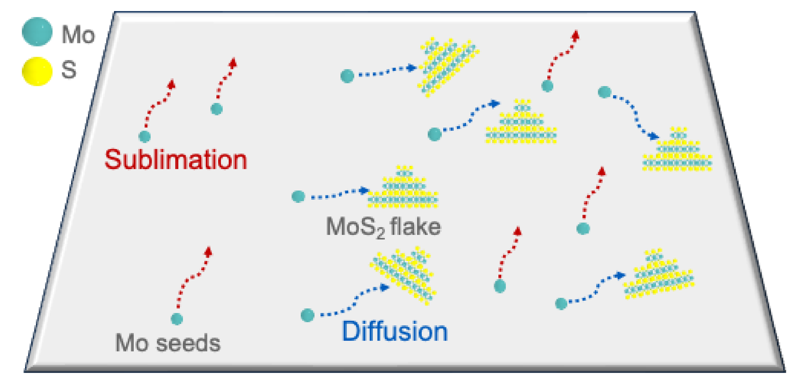


- Photoluminescence analysis confirm the existence of monolayer/bilayer MoS_2.
- AFM images confirm the existence of monolayer/bilayer MoS_2.



- XPS analysis shows that the sample contains Mo and S elements.
- The existence of Mo^{6+} peaks indicates the presence of undesired Mo-containing species.

Conclusion



- Site-specific MoS_2 growth has been successfully demonstrated using a patterned seed layer method.
- The sublimation of Mo seeds increases with the growth temperature, leading to the loss of Mo precursor. The balance between sublimation and diffusion rates is critical for site-specific growth.

Acknowledgment

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References

[1] Rare Metals, 41, 262 (2022) [2] Mater. Res. Express, 3, 075009 (2016)