CVD Growth of MoS_2-hBN Heterostructures

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Abstract

Transition metal dichalcogenide (TMD) monolayers have been the subject of much interest due to their fascinating electronic and optical properties. However, the sensitivity of TMDs makes them susceptible to contamination and degradation. Dielectric encapsulation of TMDs with hexagonal boron nitride (hBN) has therefore been suggested as a way of protecting TMDs and improving device performance. However, the multiple transfers of hBN and TMDs onto different substrates required for encapsulation may result in unwanted contaminants or dopants.

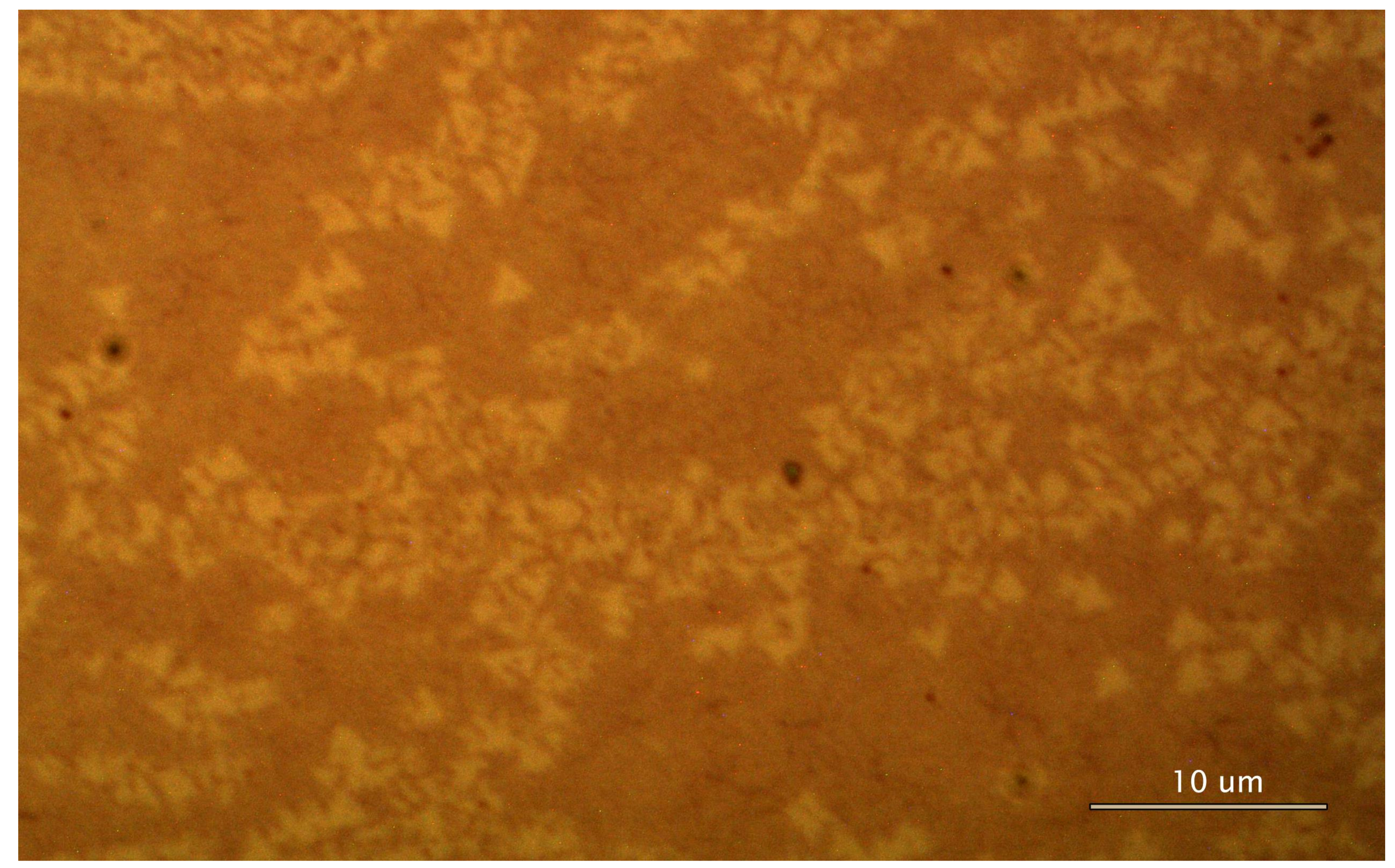
We herein investigate the possible ways of preparing an MoS_2-hBN heterostructure through chemical vapor deposition. It was found that, using a precursor solution of ammonium molybdate tetrahydrate and sodium chloride, multilayer MoS_2 was able to grow on top of a monolayer hBN surface with the hBN still intact. This demonstrates the promise of large-scale synthesis of MoS_2-hBN heterostructures, which would be highly advantageous in future device applications.

Introduction

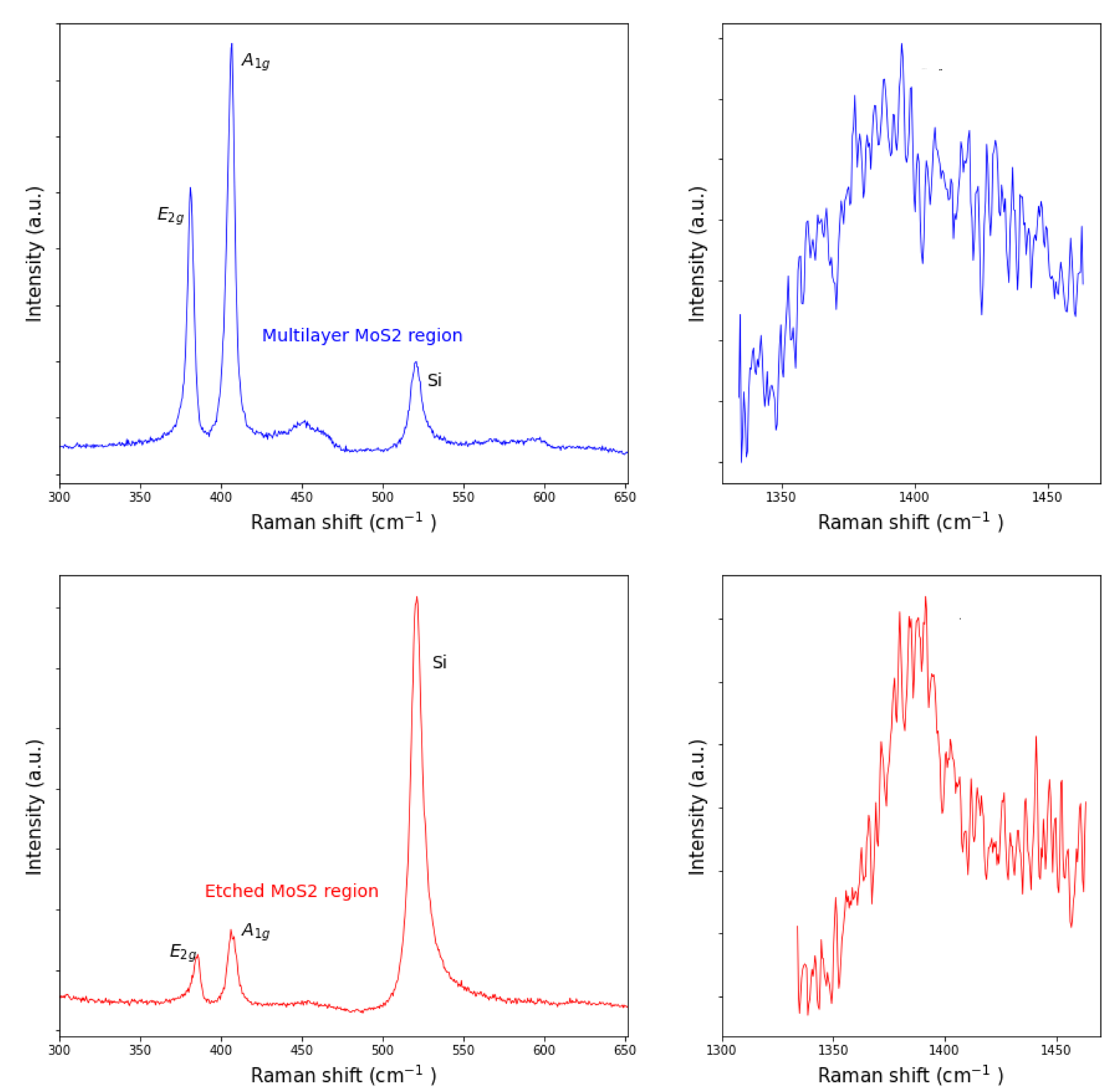
- TMDs are made of one transition metal atom sandwiched between two chalcogen atoms.
- Monolayer TMDs are semiconductors with a direct bandgap.
- hBN is composed of alternating boron and nitrogen atoms arranged in a hexagonal honeycomb lattice.
- hBN is an excellent insulator due to its wide bandgap, large breakdown voltage, and lack of dangling bonds or charge traps.
- TMDs can be stacked with other 2D materials to form van der Waals heterostructures.
- The dielectric encapsulation of TMDs can enhance its electrical properties by screening charge impurities and increasing carrier mobility.
- Chemical vapor deposition is a synthesis method that uses precursors and carrier gases, which react and diffuse onto a heated substrate surface, to produce a thin film of the desired material.

CVD growth schematic of MoS_2 on hBN

Results



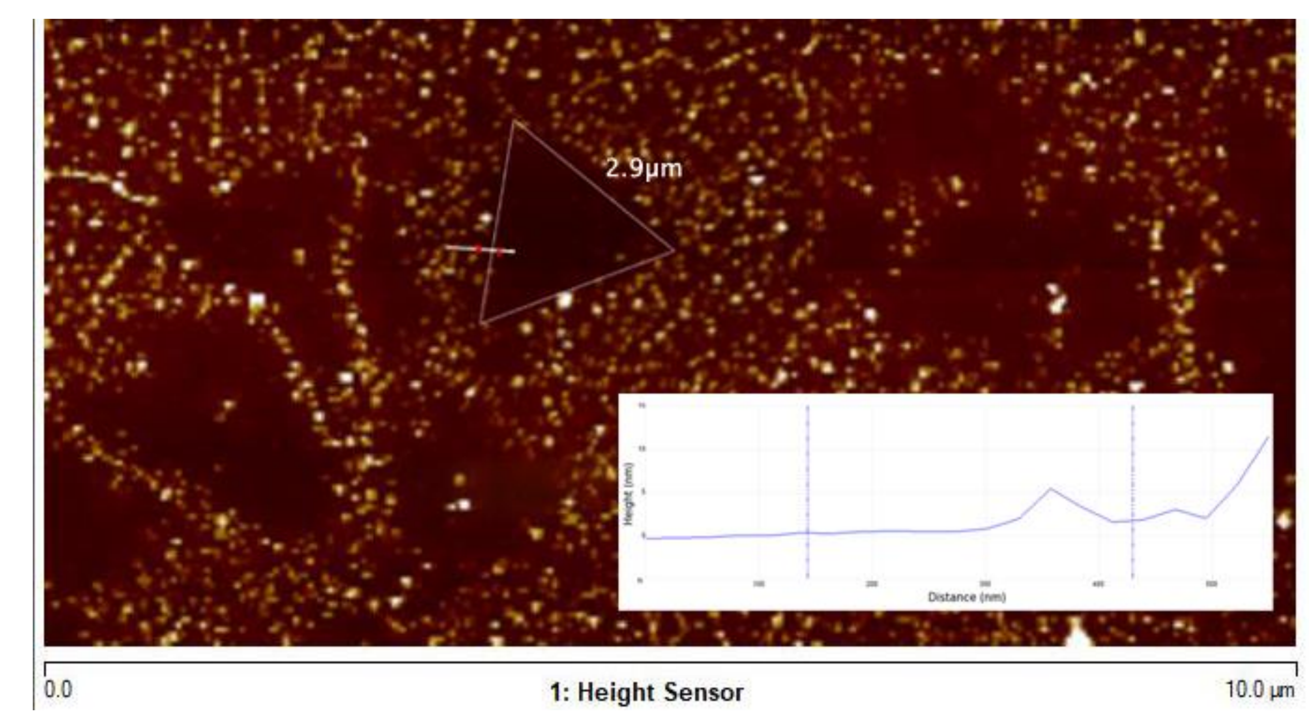
Optical image of MoS_2 on hBN. Triangular etched pits of MoS2 visible.



Raman spectroscopy of multilayer MoS_2-hBN region (blue) and etched MoS_2-hBN triangles (red). Both regions show the characteristic hBN peak (~1370cm^{-1}), as well as E_{2g} and A_{1g} peaks, indicative of MoS_2.

Methods

- hBN was grown on a 2 cm x 7 cm sheet of Cu foil.
- Cu foil was annealed at 1050°C for 20 min with 400 sccm Ar and 50 sccm H_2.
- hBN was grown with ammonia borane for 30 minutes at 1050°C.
- Monolayer hBN was transferred onto SiO_2 substrate using $FeCl_3$.
- Transferred hBN was placed in a one-inch quartz tube downstream from Mo precursor (30% 0.5M NaCl, 70% saturated ammonium molybdate tetrahydrate) and S source.
- CVD growth of MoS_2 on hBN was carried out under 500 sccm Ar and 15 sccm H_2 for 9 minutes at 800°C.



Atomic force microscopy image of MoS_2-hBN.

Conclusions

It is demonstrated that direct growth of multilayer MoS_2 on an hBN-SiO2 substrate is possible through CVD. Raman spectroscopy showed strong signals of hBN, proving that the hBN was still intact. Under optical and AFM images, there are evidently triangular pits in the MoS_2, which are presumably etched areas of MoS_2 that decomposed into MoO_3. Future investigation into the growth mechanism of MoS_2-hBN heterostructures, as well as fine-tuning of growth parameters to achieve monolayer MoS_2 growth on hBN, will be valuable in furthering the electronic applications of hBN-encapsulated MoS_2.

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