Substrate Effects and Transfer Optimization of Janus WSSe Monolayers

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Problem Statement

Due to the intrinsic strain of the material caused by the broken out of plane symmetry, monolayer Janus WSSe scrolls very easily when decoupled from the substrate. This makes transferring it to new substrates for different measurements very difficult and even harder to use for semiconductor applications. Thus, a new transfer method had to be developed to transfer Janus WSSe monolayers without damaging the crystal lattice or inducing defects during the transfer process.

Method

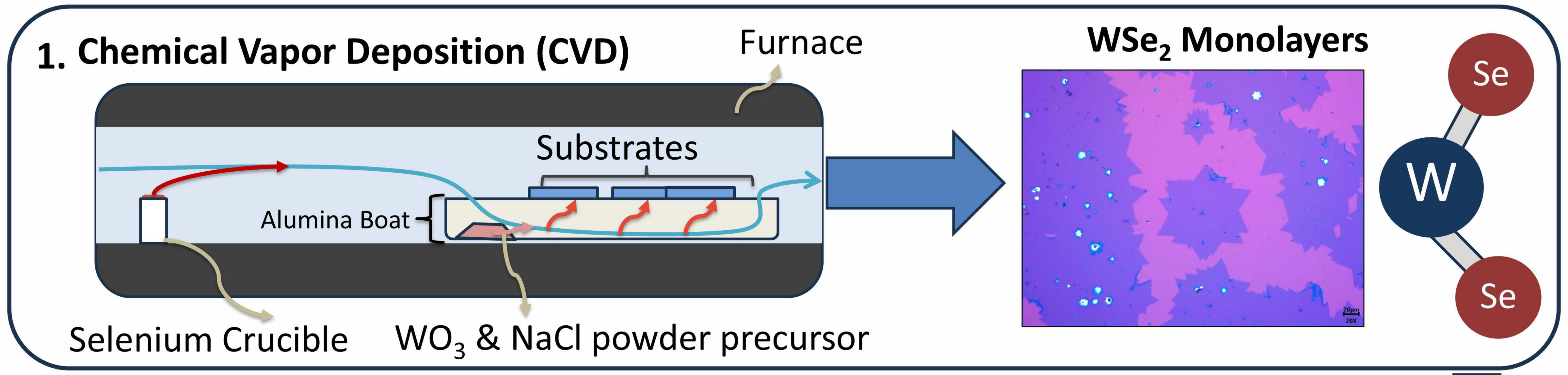

Figure 1: Furnace schematic showing chemical vapor deposition in which WO_3 & NaCl powder precursors react with selenium carried by a hydrogen and argon gas mixture. Then they react to form WSe_2 on the SiO_2 substrates.

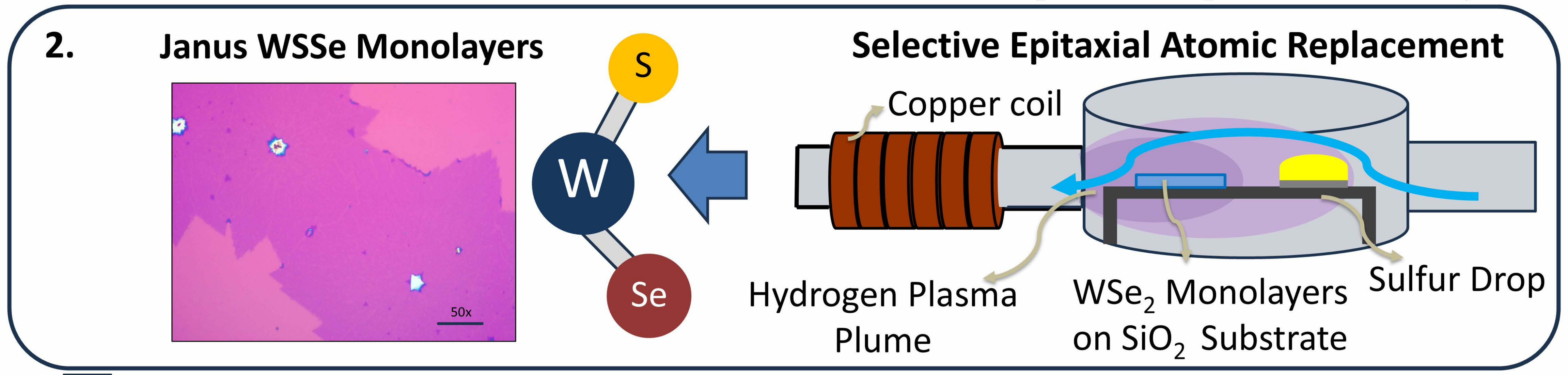

Figure 2: Representation of Selective epitaxial atomic replacement in which the top layer of selenium atoms in the WSe_2 structure are stripped off by the hydrogen plasma and are being replaced by sulfur atoms, forming Janus WSSe monolayers.

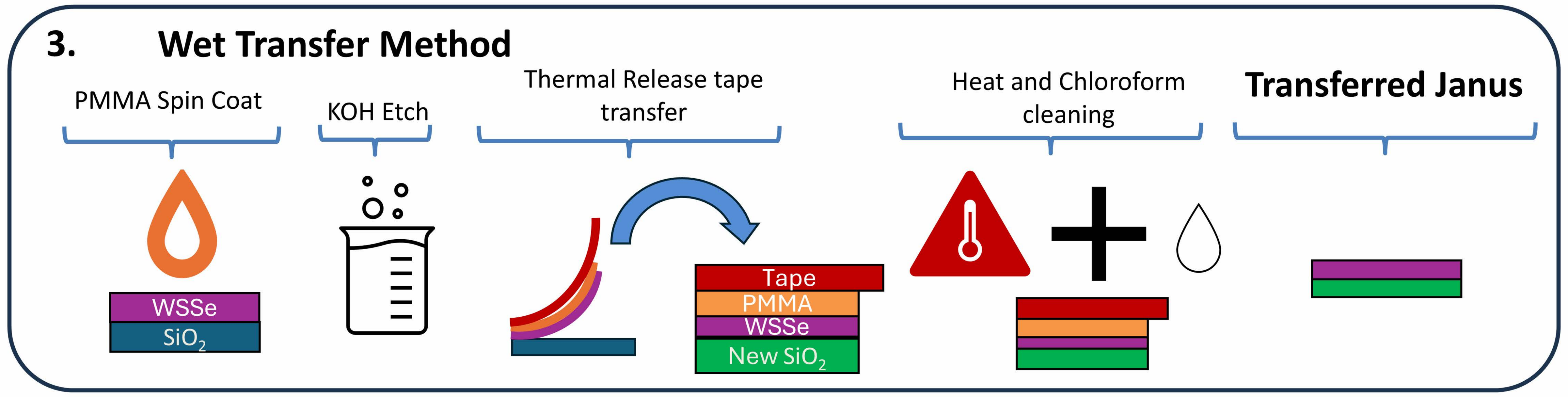

Figure 3: Representation of the Wet Transfer method which first utilizes a spin coated PMMA polymer back bone for the Janus sample. Then the sample is dipped in KOH to etch the substrate and help isolate the growth. Then using a heat release tape, the Janus is transferred from one substrate to another where heat and chloroform are used to dissolve the tape residue and PMMA, leaving the Janus intact.

Results

4.

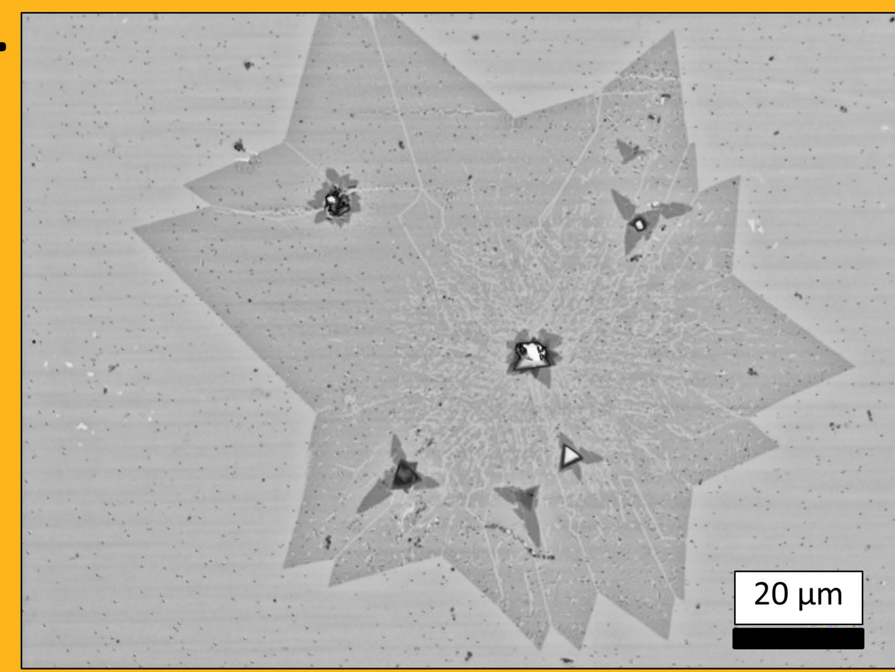

Figure 4: Confocal microscope image of a successful Janus WSSe monolayer transfer featuring a large visible domain with cracks due to intrinsic material strain and damage introduced in the transfer process.

5.

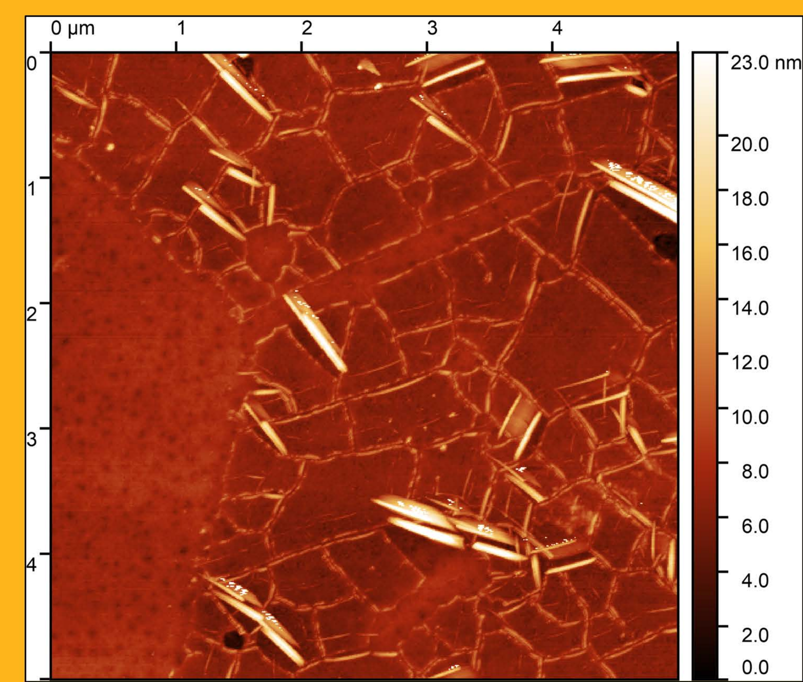

Figure 5: AFM scan revealing smaller grains with minimal scrolling and a reasonably uniform transferred film over a 5x5 µm scan.

6.

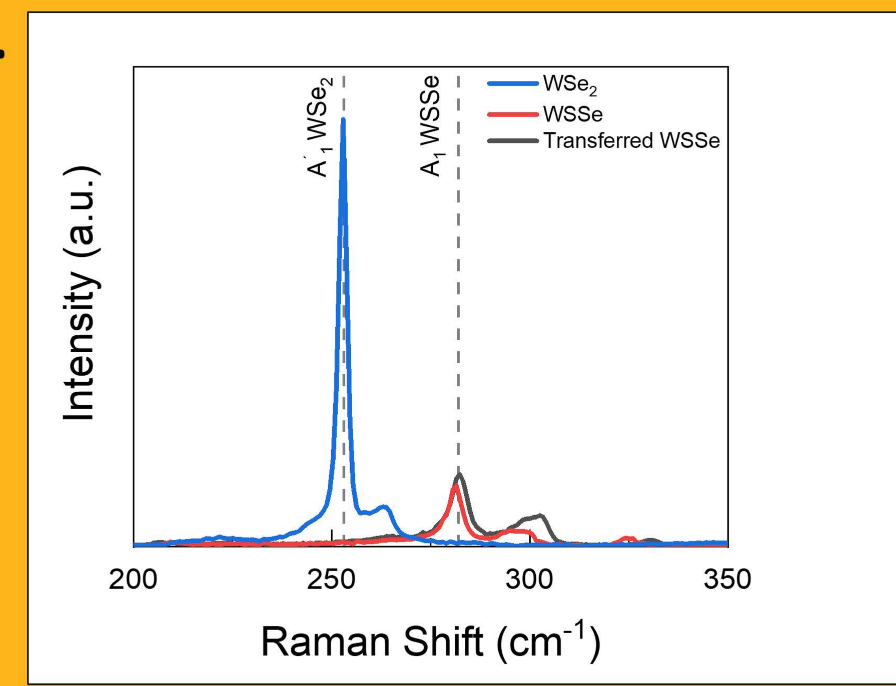

Figure 6: Raman spectra of the sample at every stage (WSe_2 → WSSe → Transferred WSSe) which confirms based on the peak positions that the correct material was grown, converted, and transferred.

7.

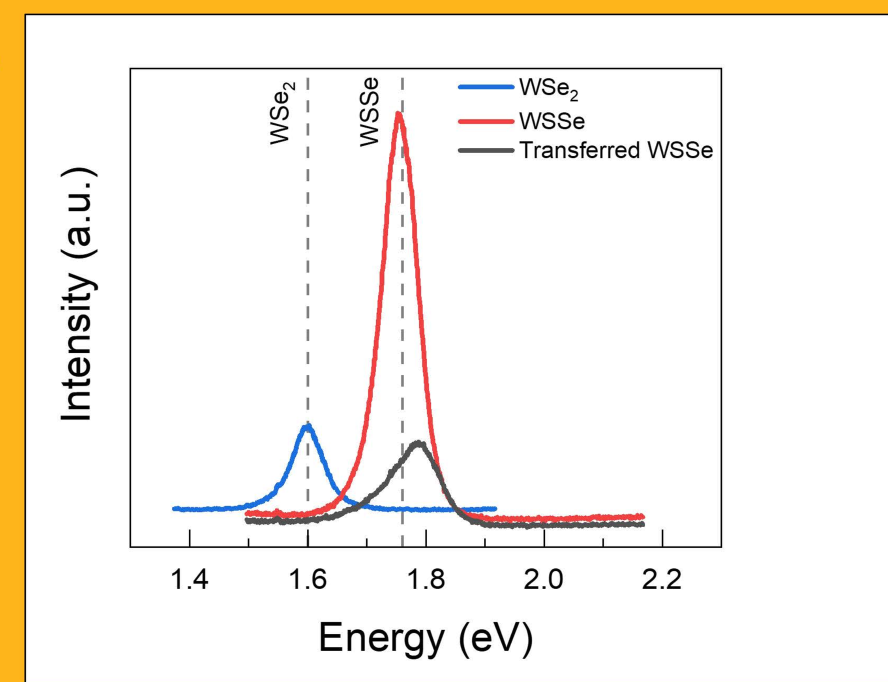

Figure 7: Photoluminescence measurements confirming the monolayer direct band gap of the initial WSe_2, and its conversion to Janus WSSe based on peak positioning. The existence of a PL peak after transfer indicates the existence of large area un-scrolled Janus.

Conclusions

- The Wet Transfer Method can be used to transfer large area CVD Janus WSSe to a new substrate with minimal scrolling to the monolayer, without damaging the crystal lattice or inducing defects in the process, maintaining its Raman and PL response.
- Future works may include studies on the effect of the polymer solvent, substrate type, as well as further refinement to the process to reduce polymer residue.

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References:
- Pham, Phuong V., et al. "Transfer of 2D Films: From Imperfection to Perfection." ACS Nano, vol. 18, 2024, pp. 14841–14876.
- Kaneda, Masahiko, et al. "Nanoscrolls of Janus Monolayer Transition Metal Dichalcogenides." ACS Nano, vol. 18, 2024, pp. 2772–2781.

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