Metal Layer Architectures for 2D TMD Heterostructures

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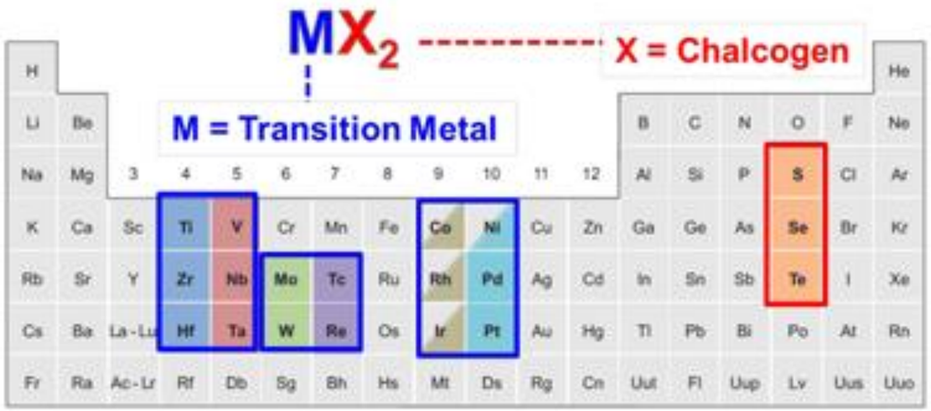
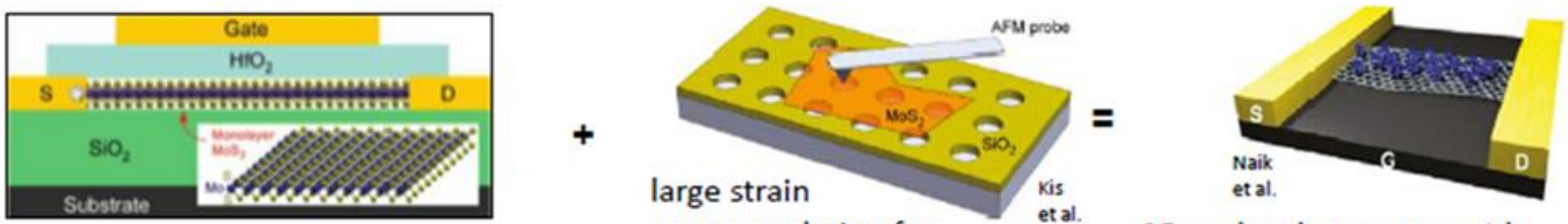
Overview of 2D Transition Metal Dichalcogenides

Two dimensional transition metal dichalcogenides (2D TMDs) exhibit useful electronic and mechanical properties for sensing applications:

- Flexible (> 10% Strain)
- Large Surface to Volume Ratio
- Large Band Gap (1.0-3.4 eV)
  - Low Subthreshold Swing → Strong Response to Surface Adsorption Events
    - MoS_2: 60 mV per decade of current
    - Graphene: >1000 mV per decade of current





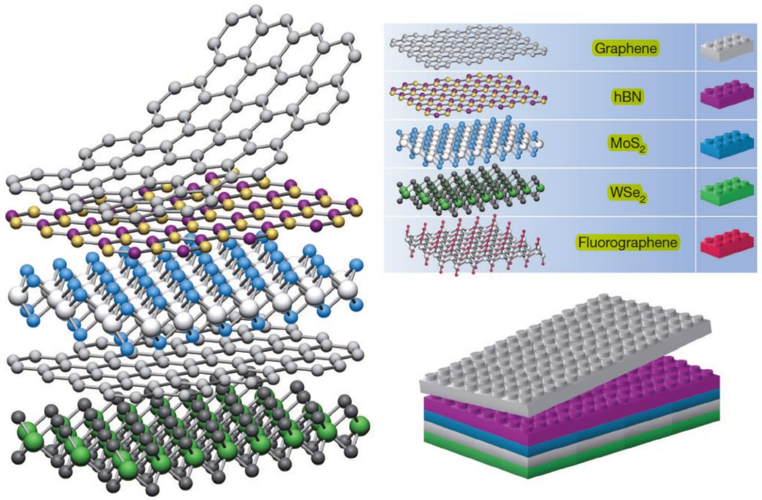
robust transistors Yoon et al.

large strain accommodation for flexible electronics Kis et al.

2D molecular sensors with enhanced sensitivity/selectivity

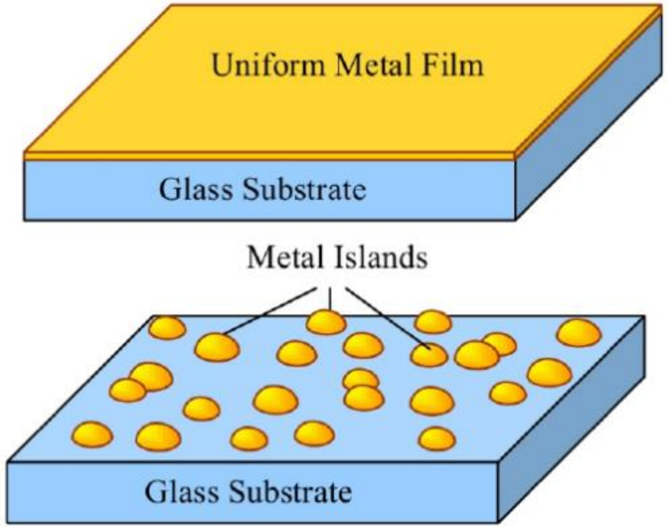
Purpose of Research

- Designing synthetic materials from ultra thin building blocks (1 atom or 1 molecule thick) allows design of materials at the ultimate scaling limit
- Materials held together with van der Waals bonds (like TMDs) allow assembly with no constraints on lattice parameter
- Ability to synthesize multilayer architectures currently limited by kinetics of film growth
- Short term objective: Create large 2D TMD materials
- Ultimate Goal: synthesis of >10 layer TMD heterostructures
  - Allows for the tailorability of material properties, such as band gap, absorption, etc.

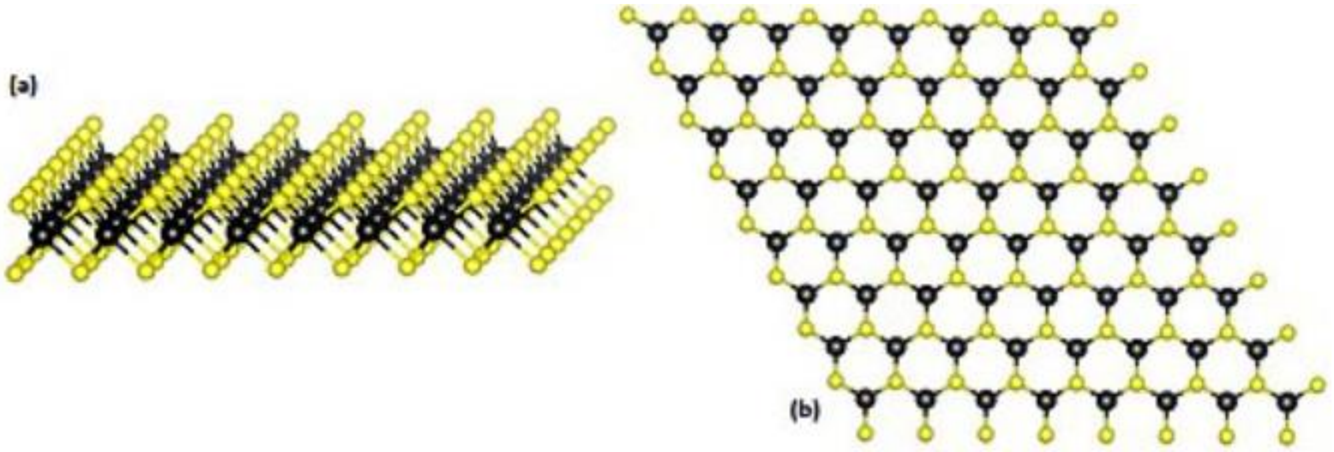


Process: Create Uniform TMDs

- Control morphology of monolithic metal layers
  - Grow transition metal films using a vapor phase process with control over:
    - Flux (atoms/cm^2·s)
    - Kinetic energy of incident species
    - Temperature
- Observe morphology of metals
  - AFM/SEM
  - electronic probe station
- Expose metals to sulfur/selenium vapor at high temperature
  - With collaborators at Rice University/AFRL
- Observe structure and properties of TMDs
  - AFM
  - Raman Spectroscopy
  - photoluminescence

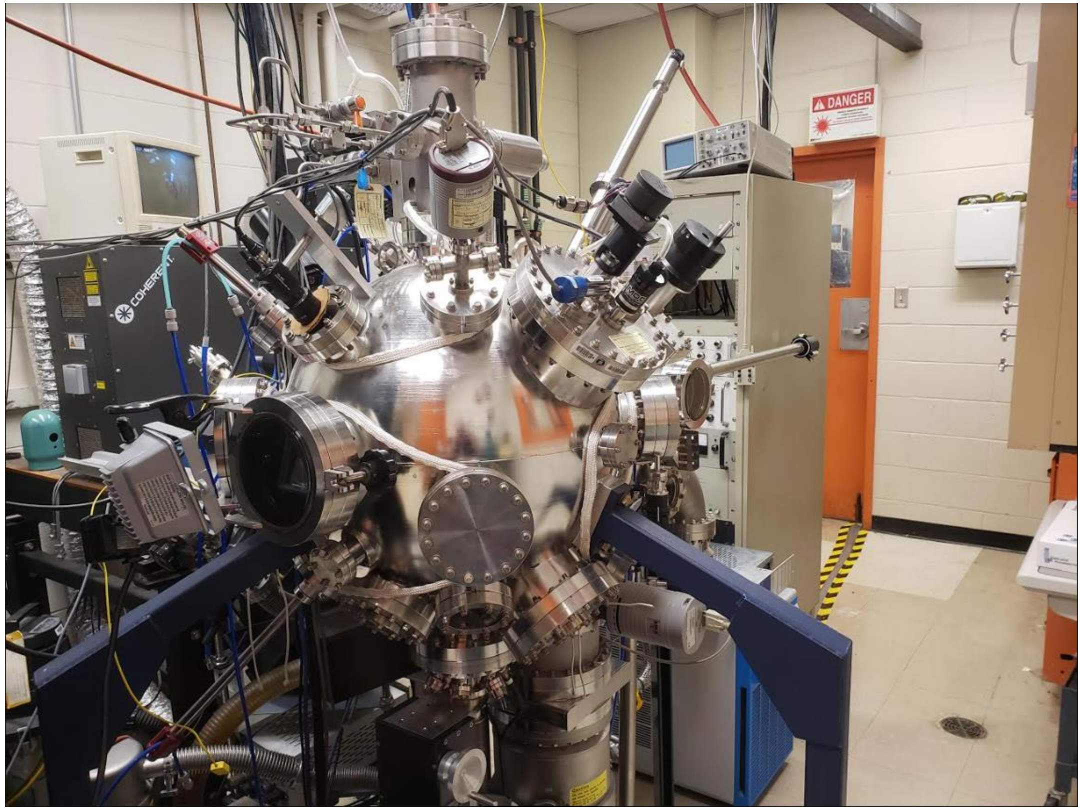


Expose metal film to chalcogen vapor to transform it into large area uniform transition metal dichalcogenide film



Growing Transition Metal Films

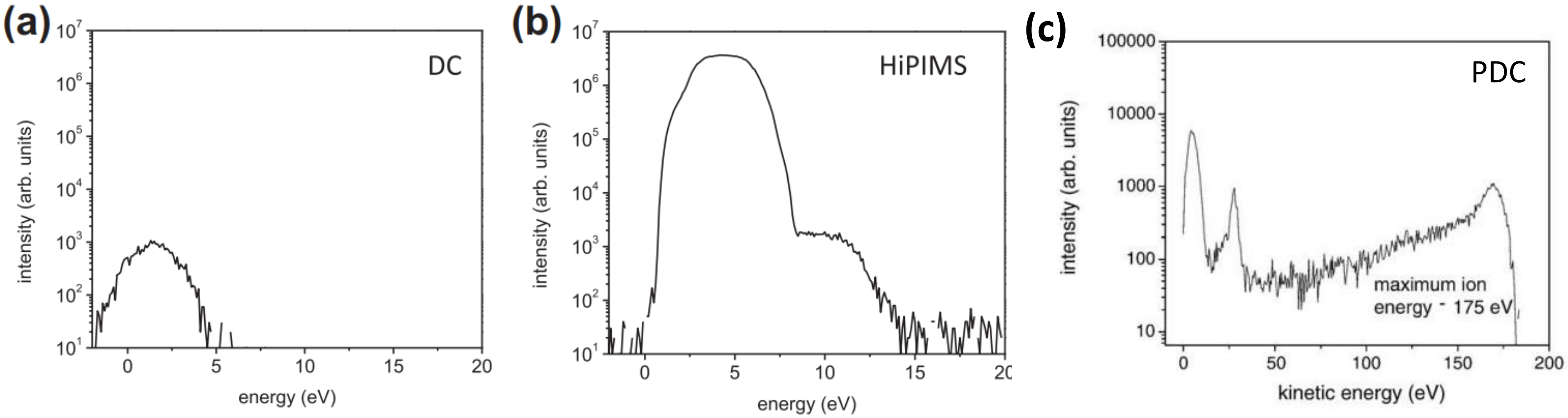
- Transition metal films grown in a sputtering chamber
  - Varied metal deposition conditions
    - Deposition time
    - Temperature
      - Room temperature (25 °C)
      - 500 °C
    - Power modulation
      - Direct current (DC)
        - Lowest energy of deposited atoms
      - Pulsed direct current (PDC)
        - Medium energy range
      - High-Power
        - High energy range



Power Modulation Importance

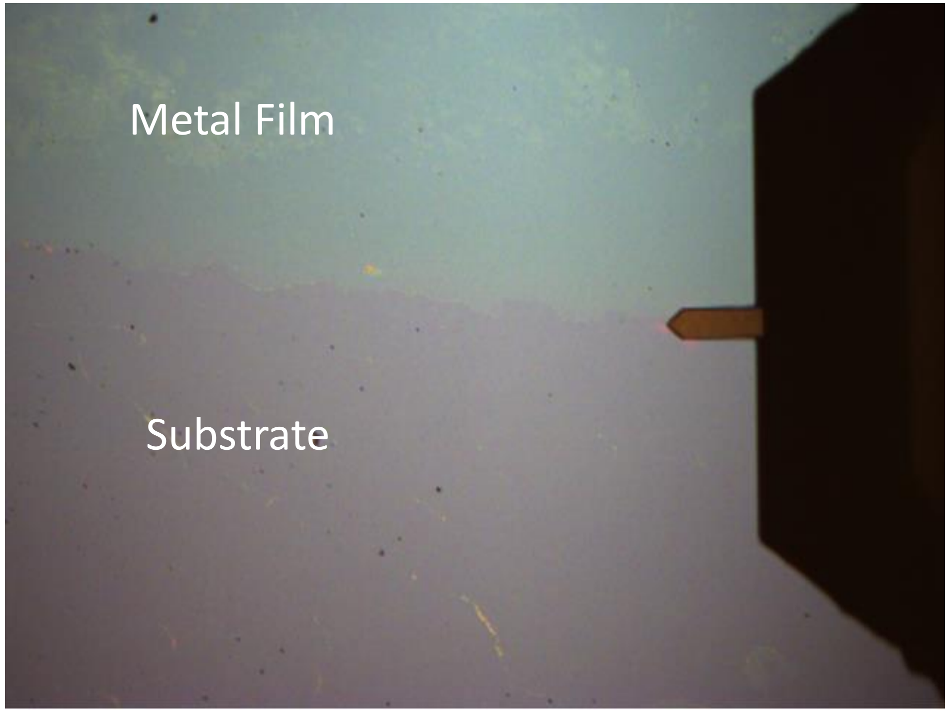
- Surface Energy of Metals
  - Metals have higher surface energy than substrate
  - Favors the formation of islands
- Power Modulation Changes the Surface Energy of the Substrate

VS

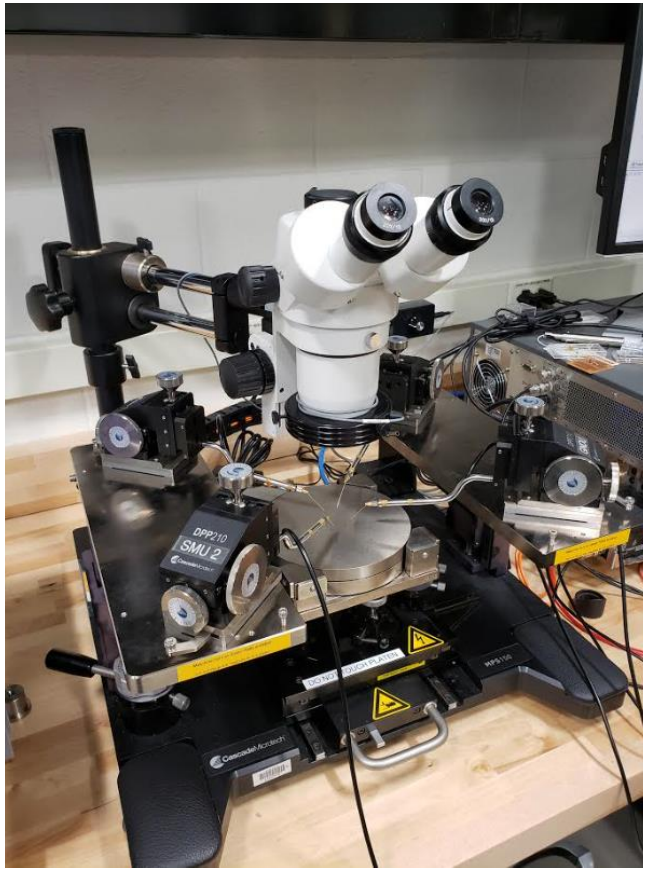


Characterization of Transition Metal Films

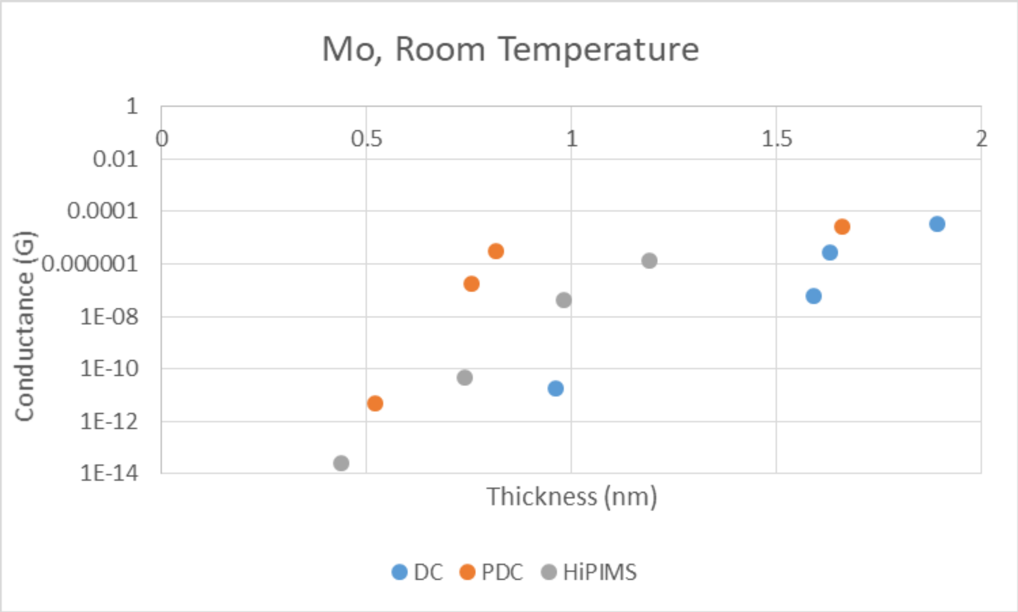
- Surface Characteristics
  - Atomic Force Microscope (AFM)
    - Thickness of material
    - Morphology (cluster size)
  - Scanning Electron Microscope (SEM)
    - Surface characteristics

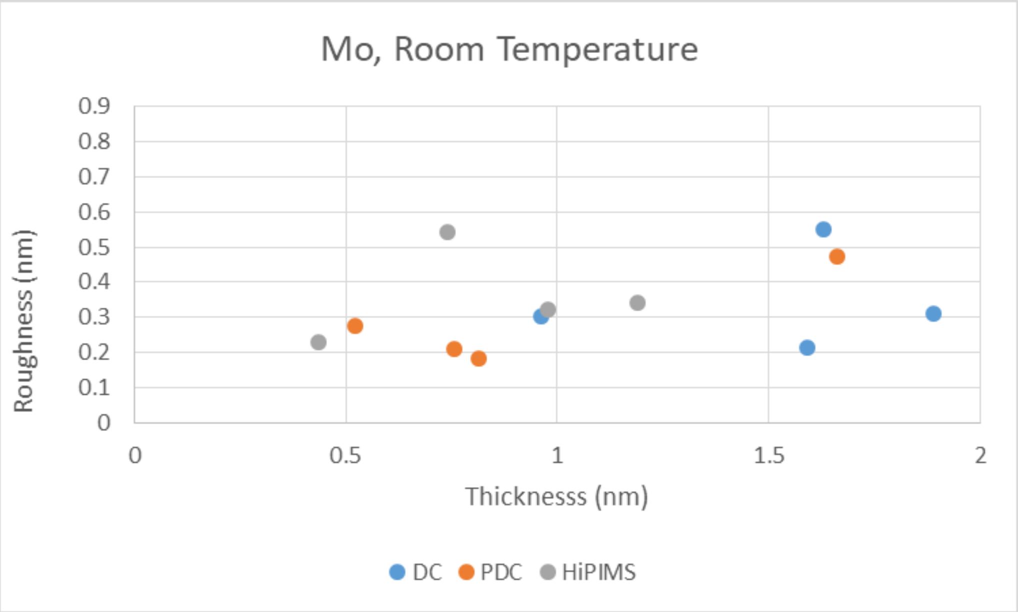


- Conductivity
  - Traditional Probing Station
    - Direct indicator of film continuity



Results: Conductivity



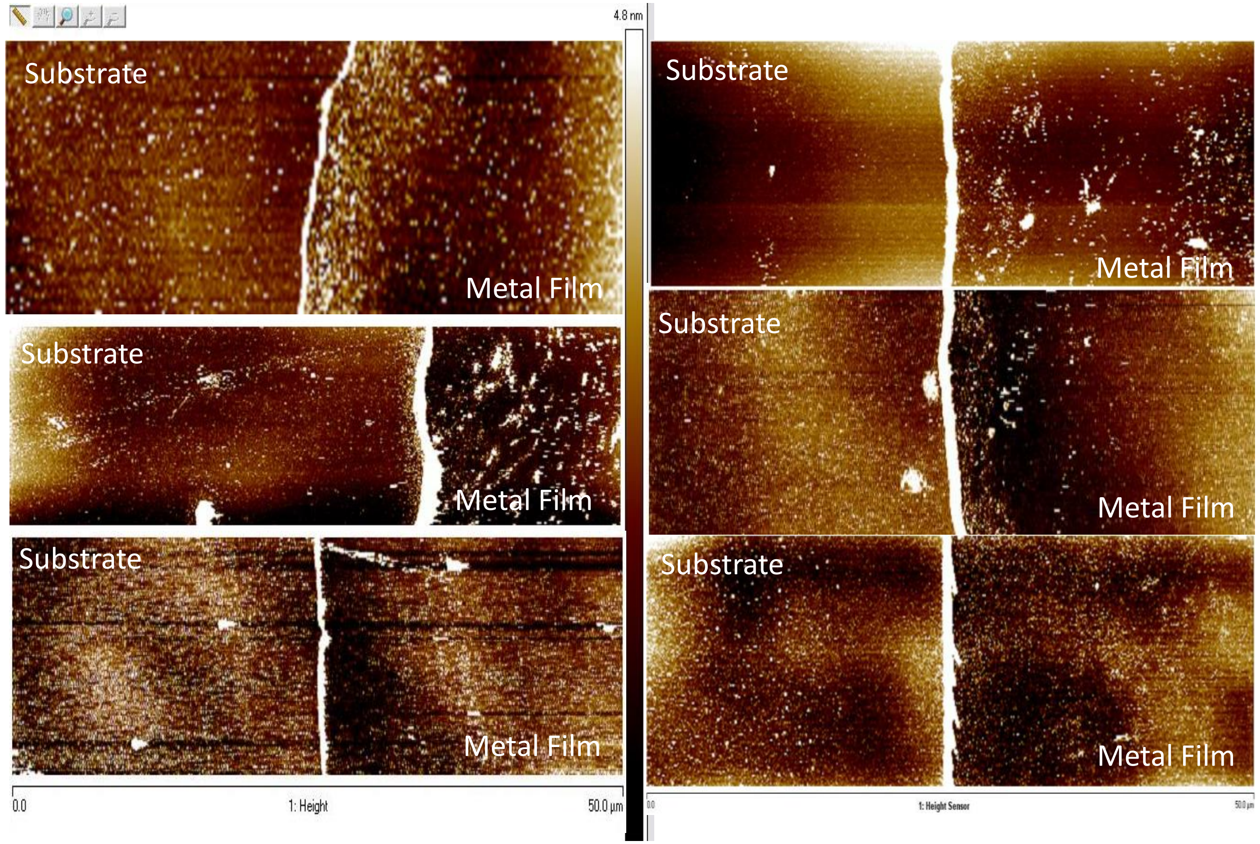


Results: AFM Thickness

DC, 2s
Thickness: 0.961 nm
Roughness: 0.303 nm

PDC, 2s
Thickness: 0.521 nm
Roughness: 0.274 nm

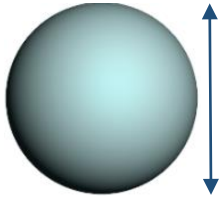
HiPIMS, 5s
Thickness: 0.437 nm
Roughness:0.231 nm



DC, 8s
Thickness: 1.89 nm
Roughness: 0.390 nm

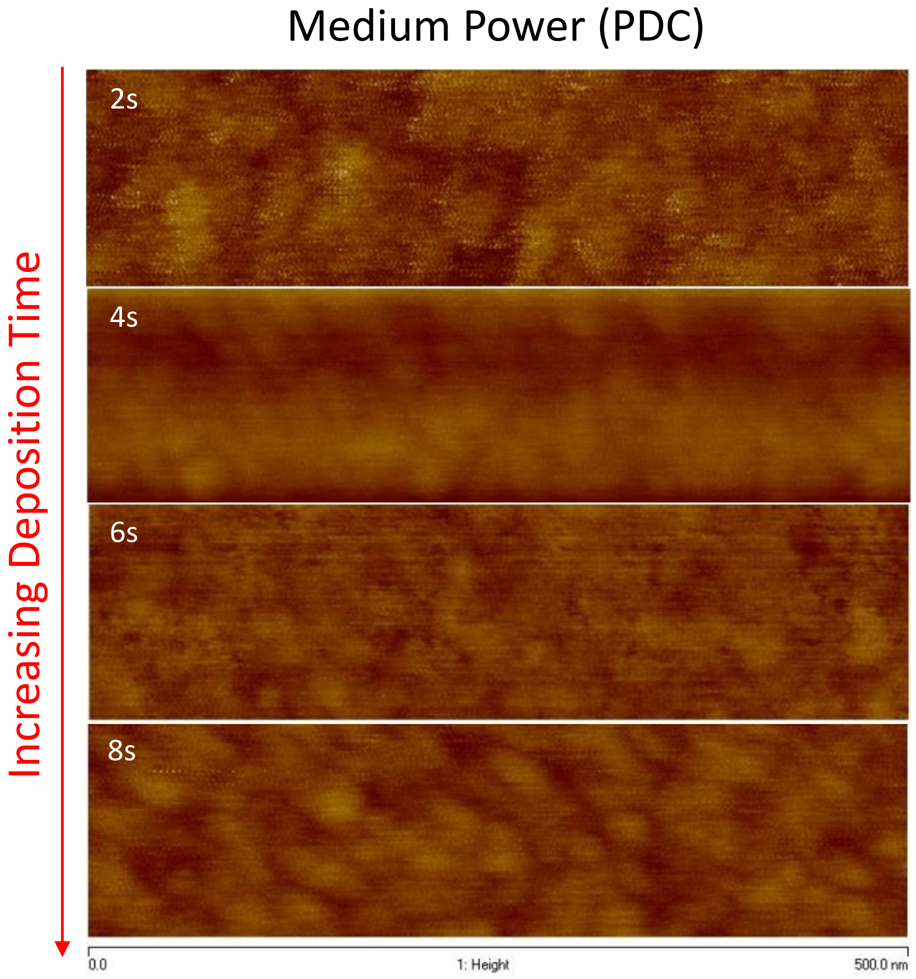
PDC, 8s
Thickness: 1.66 nm
Roughness: 0.473 nm

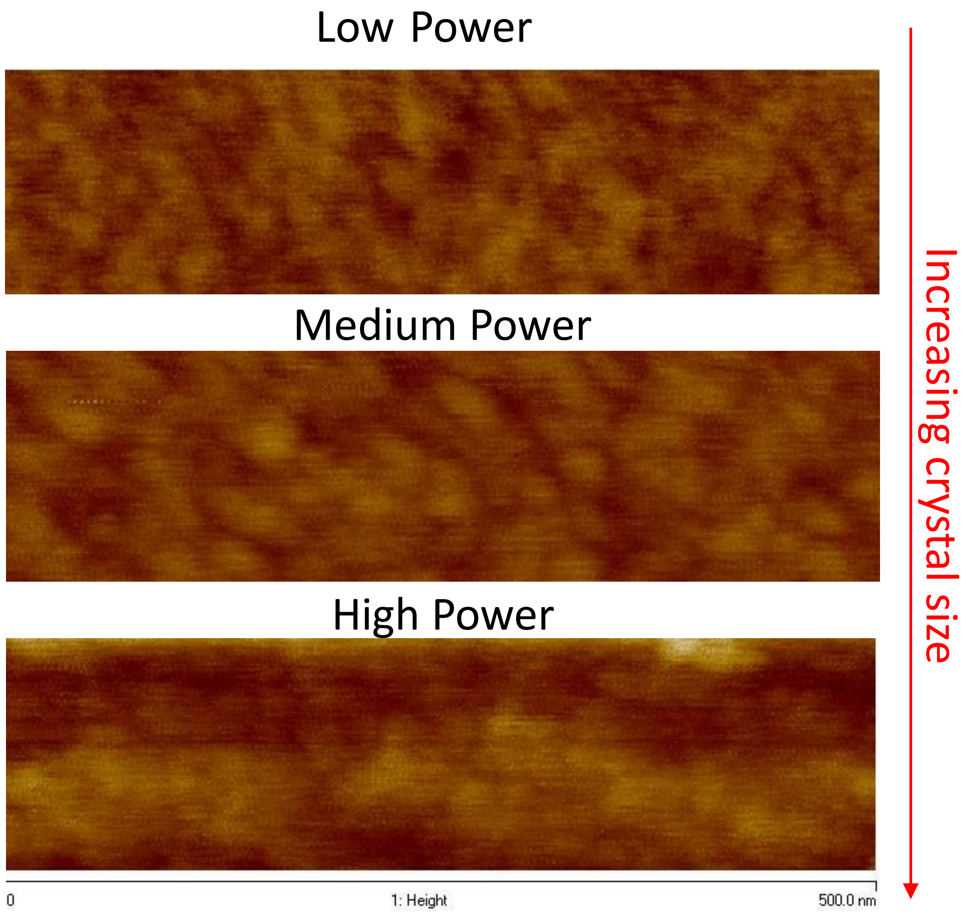
HiPIMS, 20s
Thickness: 1.19 nm
Roughness: 0.340 nm



Diameter of 1 Mo atom: 0.3 nm

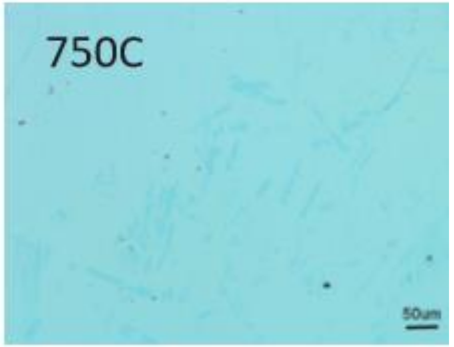
Results: AFM Morphology

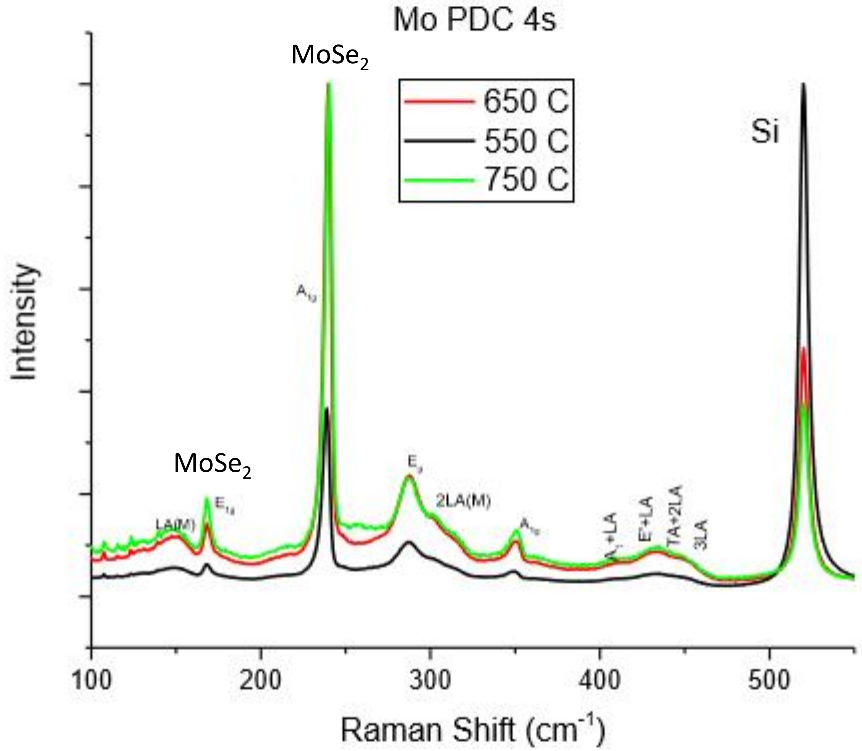


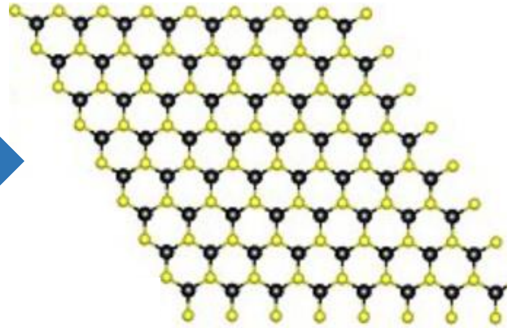


Selenation of Mo samples

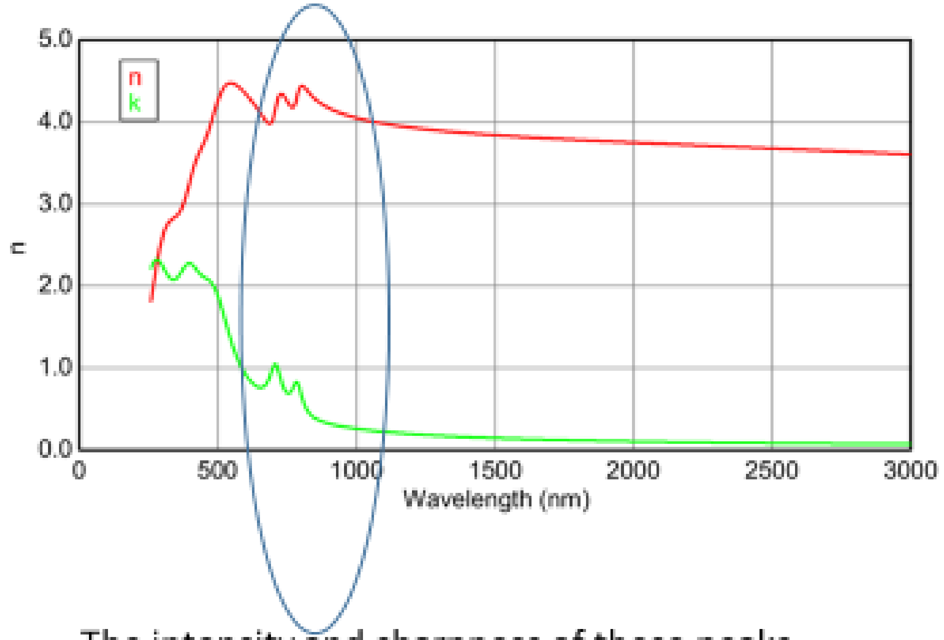
- Completed by collaborators at Rice University and AFRL
- Raman Spectroscopy
  - Shows bond formation
- Conversion from Mo to $MoSe_2$ was successful
- The conversion was not localized
  - Film is continuous





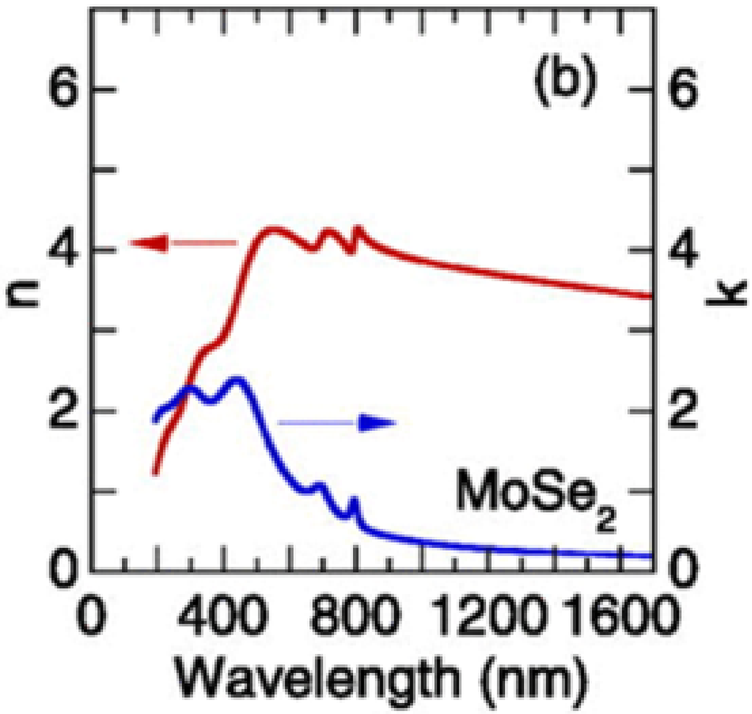


Refractive index and extinction coefficient of selenized Mo films for different wavelengths of light



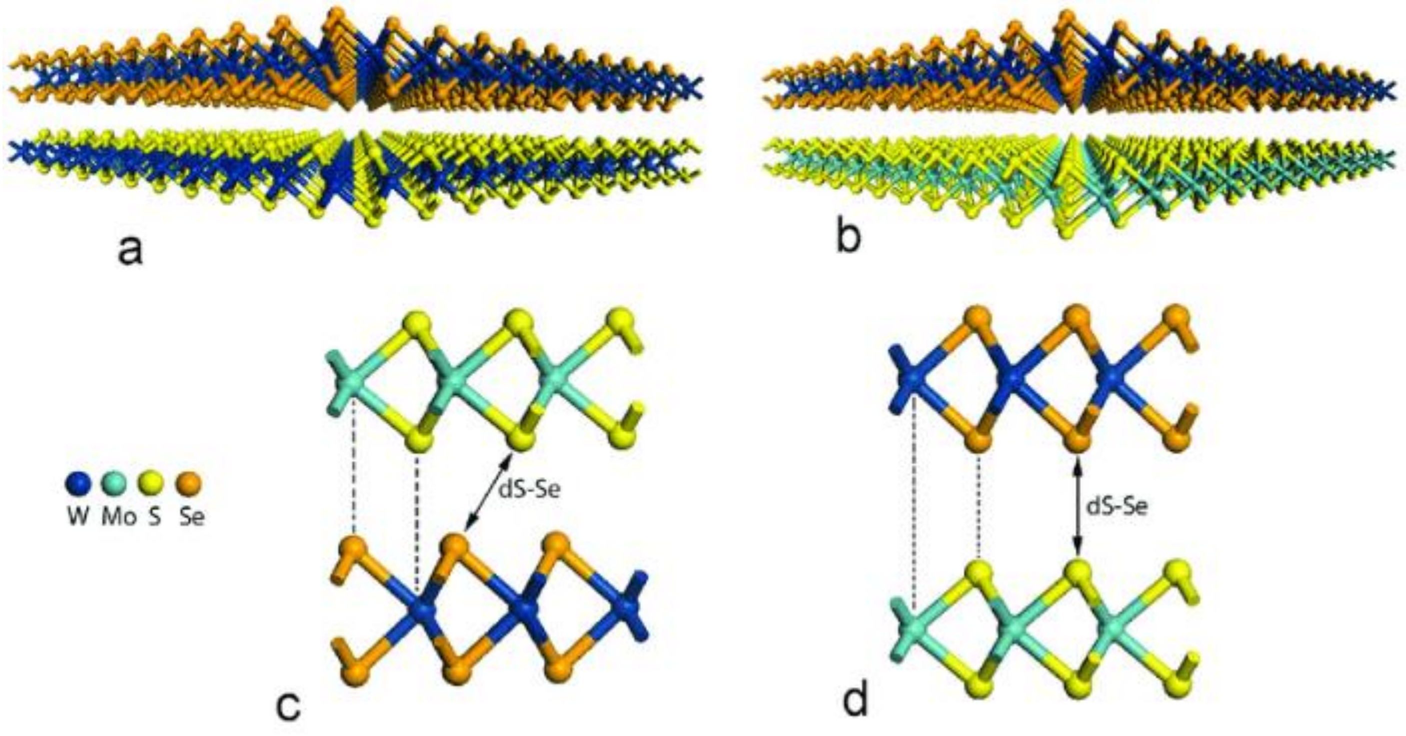
The intensity and sharpness of these peaks indicate crystal quality….the peaks are sharper for the selenized metal films than for CVD films ☺

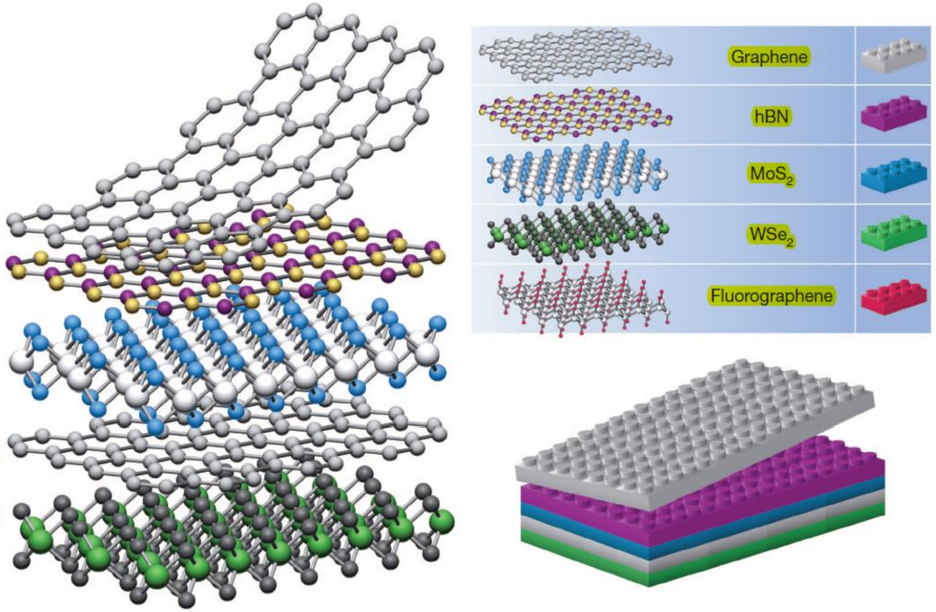
Refractive index and extinction coefficient of CVD $MoSe_2$ films



Future Work

- Stack Mo, W
- Convert the stacks to TMDs
- Tune the band gaps by changing the order of the TMD layers





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