Tuning Electronic Properties in Strained and Suspended 2-D MoS_2

Tan Dao | Shawna Hollen

Department of Physics, University of New Hampshire, Durham, NH 03824

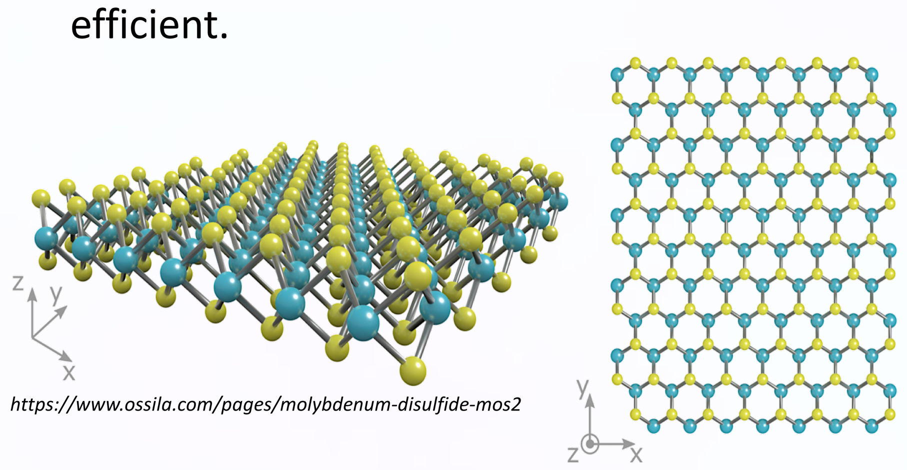
2-D materials are as thin as physically possible that can be an insulator, conductor, or semiconductor. Electronic properties in 2-D materials can be tuned with strain and suspension to optimize the performance of next-generation electronics.

Introduction

What is 2-D Molybdenum Disulfide?

MoS_2 is a 3-D semiconducting crystal made up of 2-D layers. MoS_2 will exhibit unique physical and electronic properties as the number of layers approaches the single layer, such as:

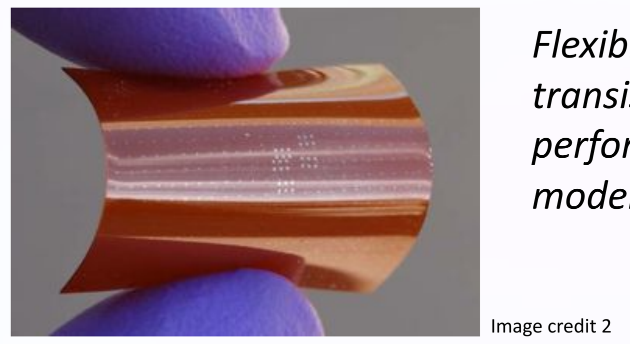
- Flexibility - Single layer MoS_2 can sustain very high elastic strain before rupturing[1].
- Direct bandgap - Conserves momentum in the lattice when electrons go from the valance band to the conduction band. This allows MoS_2 to be a light-sensitive semiconductor.
- High conductivity - Conductivity measures how well the material conduct electricity, or heat (thermal conductivity). Higher conductivity is more energy efficient.



Atomic structure of MoS_2. Without out-of-plane bonding, MoS_2 can bend, twist, and stretch to a significant amount before rupturing.

Practical Applications

- Transistors
- Optoelectronics
- Photovoltaic cells
- Flexible electronics
- Low power electronics

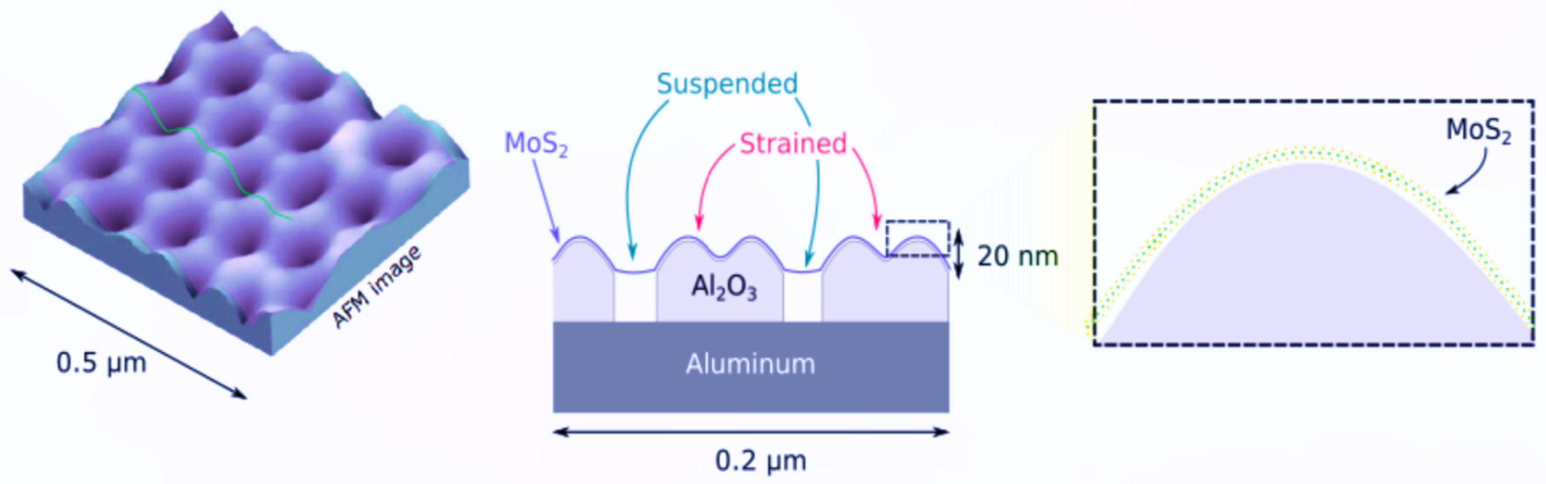


Flexible MoS_2 transistor that out performed existing model.

We can optimize the performance of these applications for commercial use by tuning the electronic properties. Ways to tune the electronic properties are making strained and suspended MoS_2 regions.

How does strain and suspension affect the conductivity?

- Strain is the stretching or compression between atoms in a crystal lattice. This changes the atomic structure, therefore affecting the flow of electrons.
- A suspended region is where the sheet of MoS_2 does not touch the substrate. This eliminates the impact of substrate on the conductivity in MoS_2.

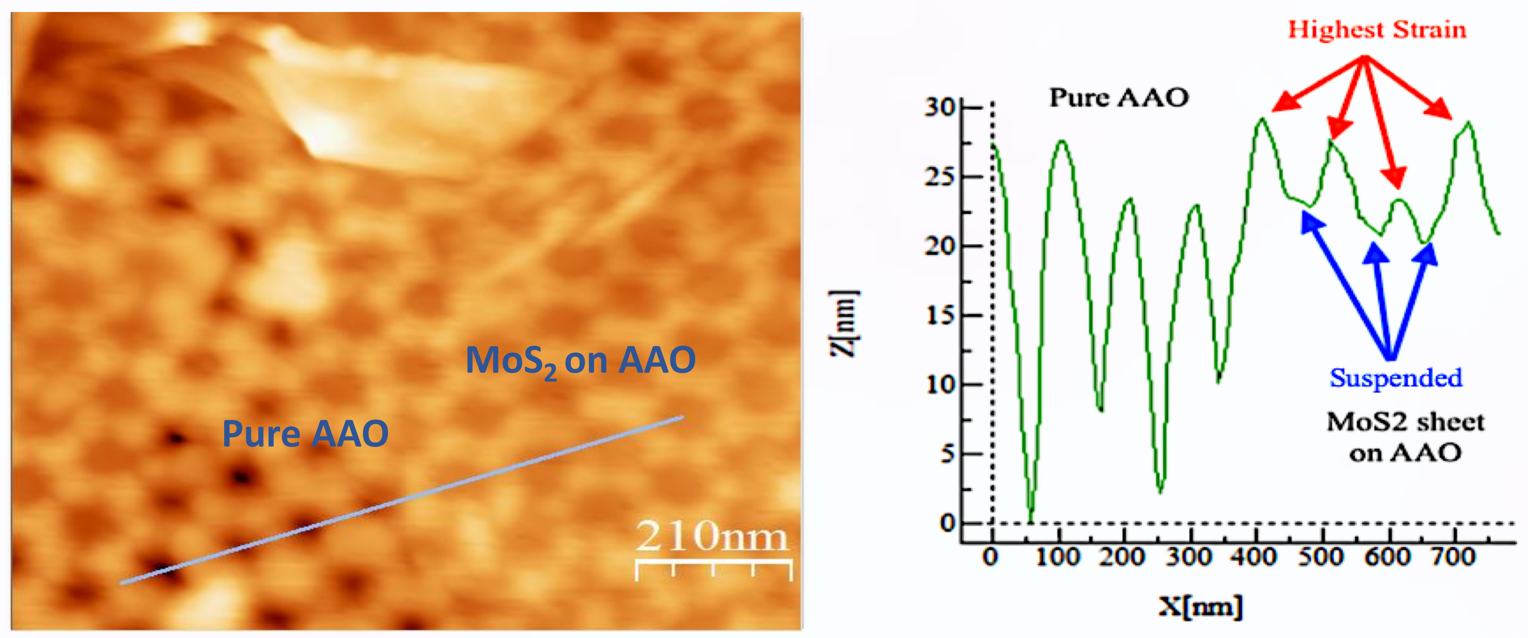


MoS_2 sheets are transferred to anodized aluminum oxide (AAO) – a nanopatterned substrate. The sheets conform on the surface of the AAO with regions with highest strain at the hill tops and suspended region at the valleys.

Methods

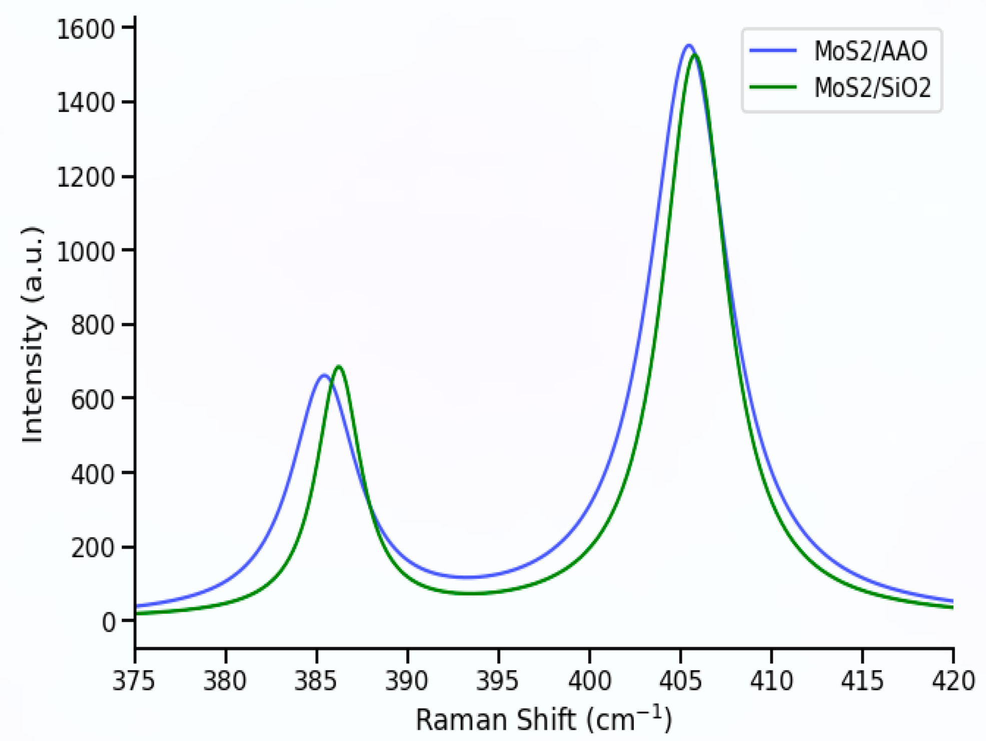
Inducing Strain and Characterizing Strain

MoS_2 is transferred onto the AAO substrate to deform its lattice. Atomic Force Microscopy (AFM) scans the sample surface and records the surface topography.

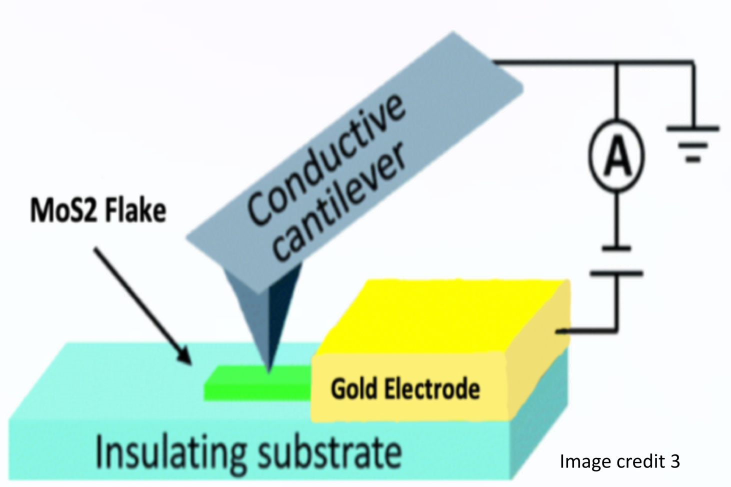


Raman spectroscopy works by detecting the energy lost to vibrations in the crystals.

Vibrations are sensitive to strain, therefore an average tensile strain of 0.23% is detected by observing the frequencies shift.



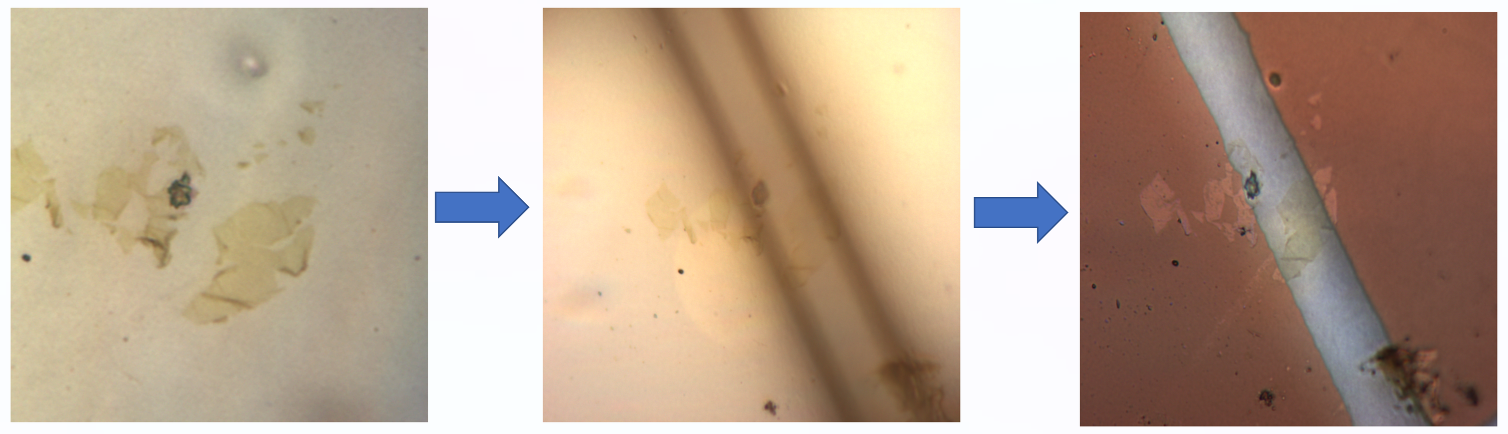
Characterizing the Conductivity



Conductive AFM scans the sample surface to obtain the topography and conductivity simultaneously. This allows electrical characterization at the nanoscale.

In order to use the conductive AFM, we need to make electrical contacts to the MoS_2 sample.

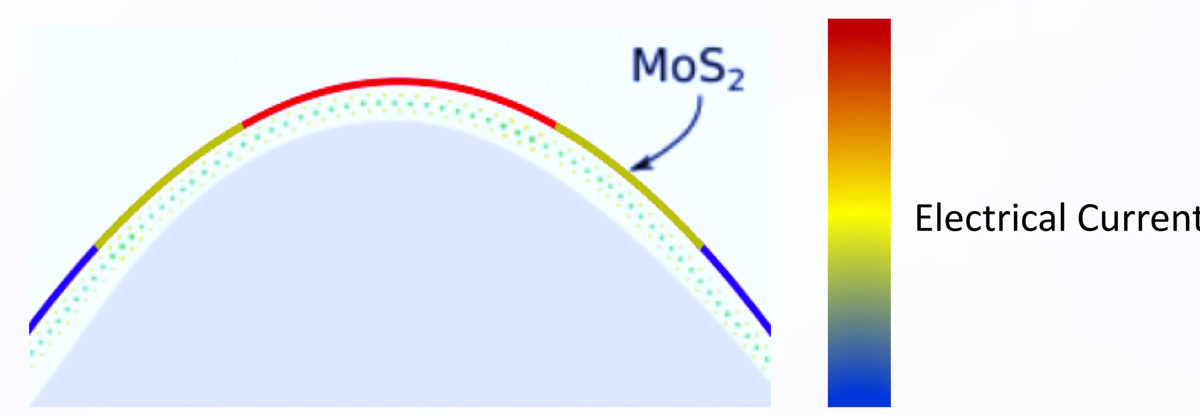
Making Gold Electrodes



Optical image of MoS_2 on AAO | *TEM grid is aligned on top of the MoS_2 flakes* | *20 nanometers of gold is evaporated onto the sample*

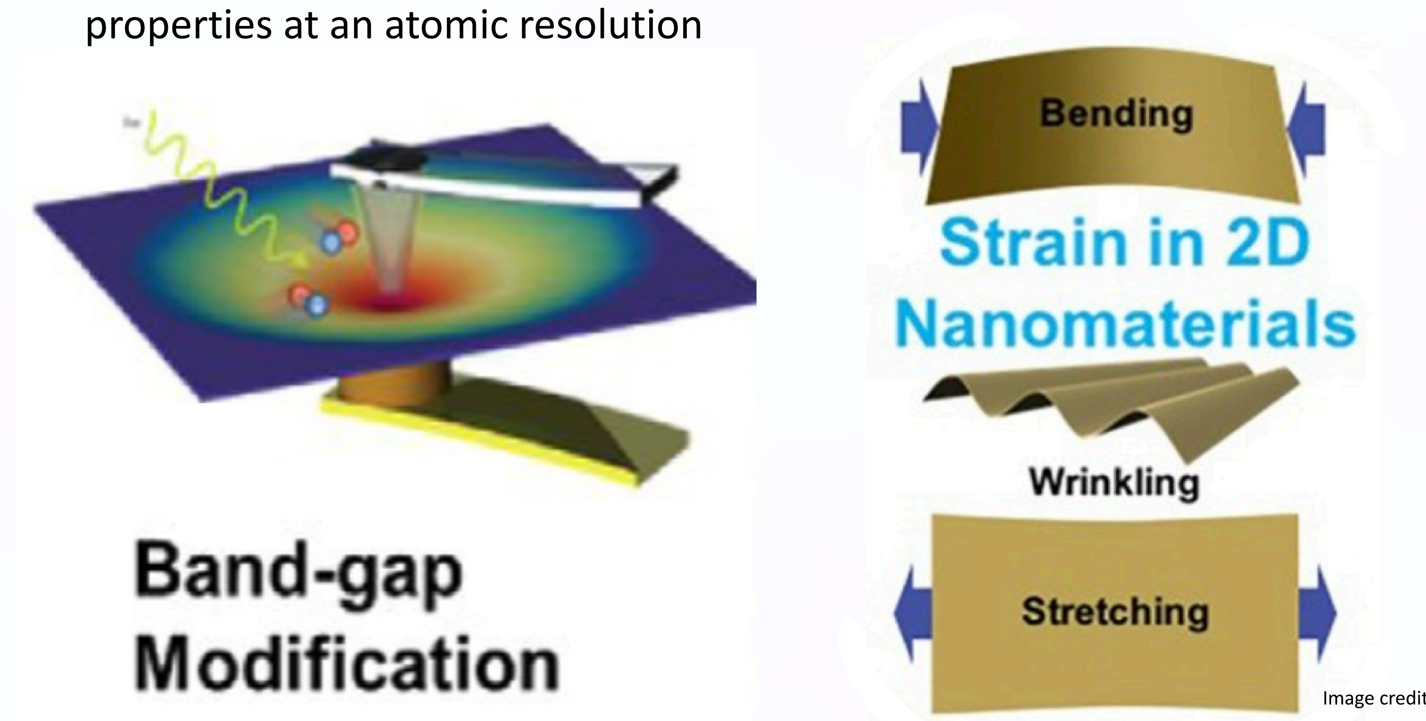
Expected Results

- The most strained MoS_2 regions are expected to have the highest conductivity because strain reduces the bandgap.
- Suspended MoS_2 is expected to have a change in conductivity because there is no interactions between sample and substrate.



Future Work

- Use tip-enhanced Raman spectroscopy to obtain the strain at the nanoscale
- Use scanning tunneling microscopy to obtain the electronic properties at an atomic resolution



This project will demonstrate the tunability of electronic properties for future electronics by using strain and suspension at the nanoscale.

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References

1. *Li, H., Contryman, A. W., Qian, X., Ardakani, S. M., Gong, Y., Wang, X., ... & Li, J. (2015). Optoelectronic crystal of artificial atoms in strain-textured molybdenum disulphide. Nature communications, 6, 7381.*
2. *Cheng, R., Jiang, S., Chen, Y., Liu, Y., Weiss, N., Cheng, H. C., ... & Duan, X. (2014). Few-layer molybdenum disulfide transistors and circuits for high-speed flexible electronics. Nature communications, 5, 5143.*
3. J. M. Mativetsky, Y.-L. Loo, and P. Samor`ı, "Elucidating the nanoscale origins of organic electronic function by conductive atomic force microscopy," *Journal of Materials Chemistry C*, vol. 2, no. 17, 2014.
4. Deng, S., Sumant, A. V., & Berry, V. (2018). Strain engineering in two-dimensional nanomaterials beyond graphene. *Nano Today*.