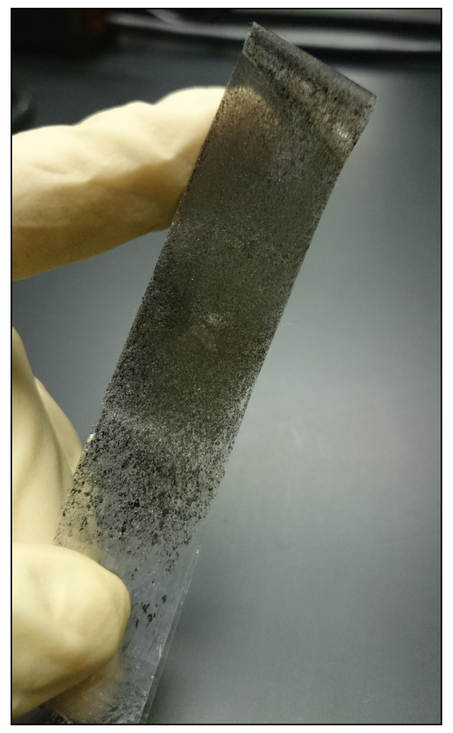
Synthesis and Fabrication of Nanoscale 2-D Semiconductor Heterostructures from Graphene, h-BN, and Few-Layered Transition Metal Dichalcogenides

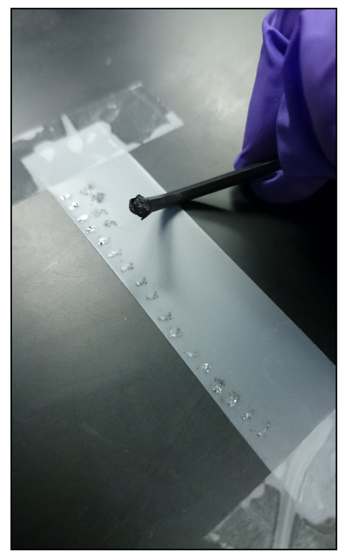
Joshua M. Woods[1,2], Dennis Pleskot[1,2], Nathaniel Gabor[2,3]

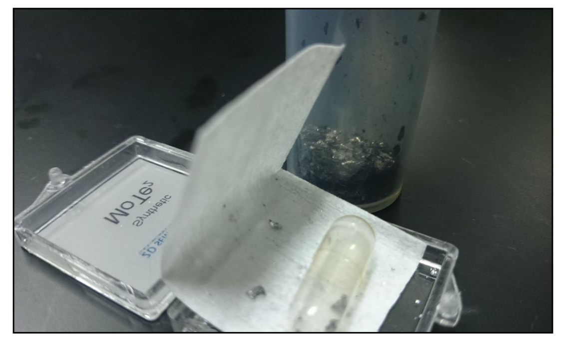
University of California, Riverside

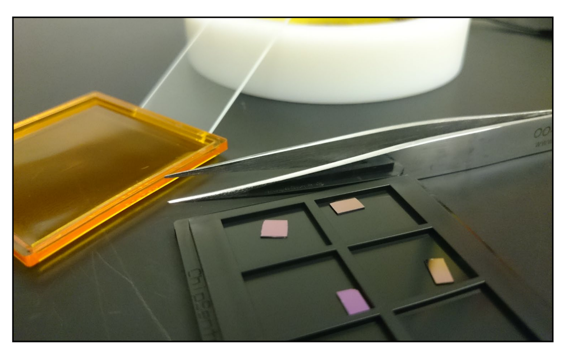
[1]Department of Materials Science and Engineering,
[2]Quantum Materials Optoelectronics Lab,
[3]Department of Physics and Astronomy

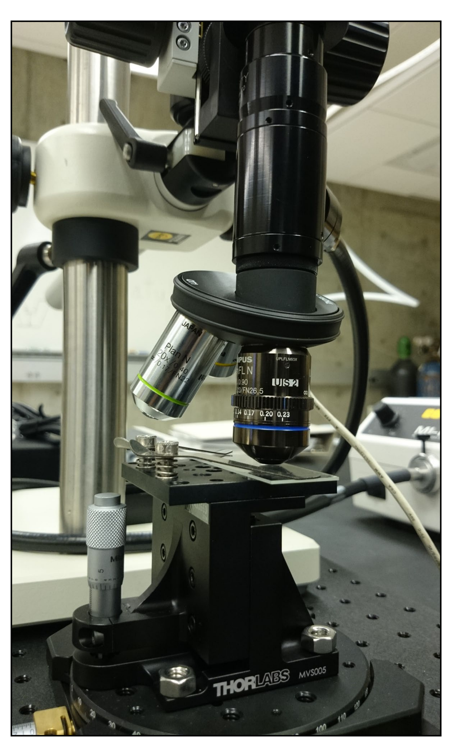
Fabrication Basics

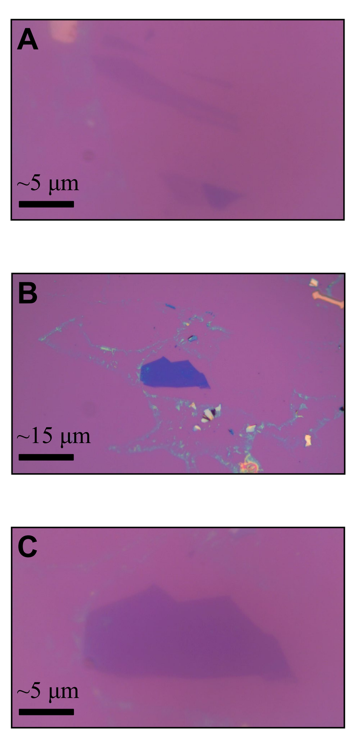








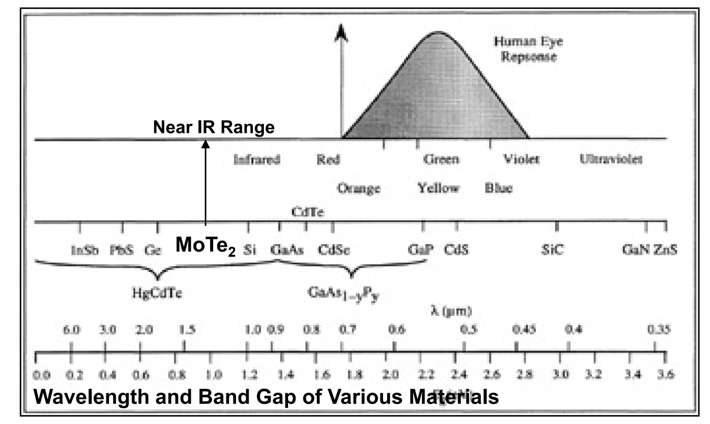


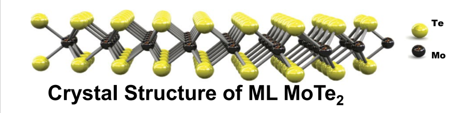


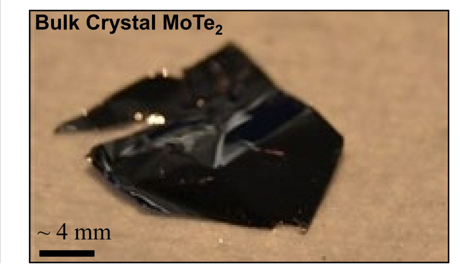
Optical Images:
[A] Graphene 60x
[B] Graphene 20x
[C] Graphene 60x

Graphene is the easiest semi-conducting material to exfoliate. Various methods of mechanical exfoliation are employed to accommodate various crystal lattice structures. Graphene is cheaper and more abundant than synthetic TMD semi-conductors in the bulk crystal form. Substrates are always placed into clean chip carriers to prevent cross-contamination. Pictures of ideal flake specimens are shown.

TMD Spotlight: $MoTe_2$







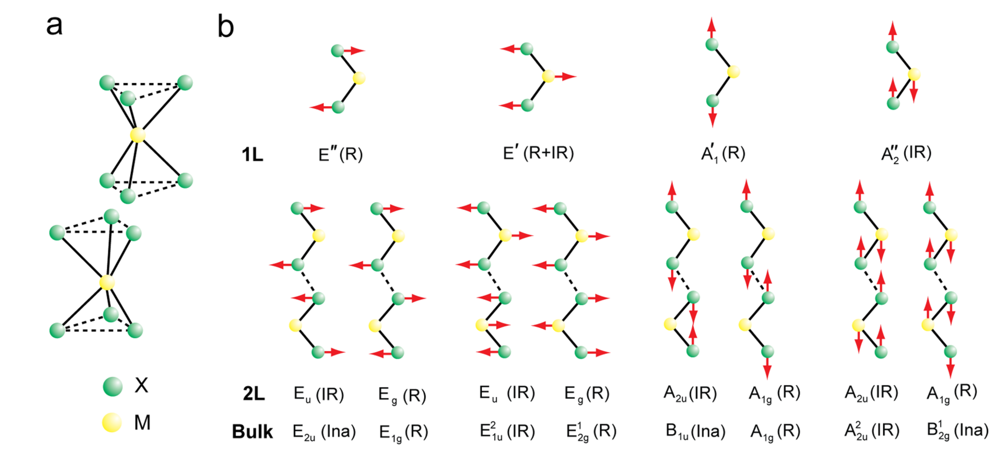
Ideal TMD flakes exhibit uniform surface area. As TMD layers near the monolayer limit, they begin to develop a tunable, direct band gap for use in optoelectronics.

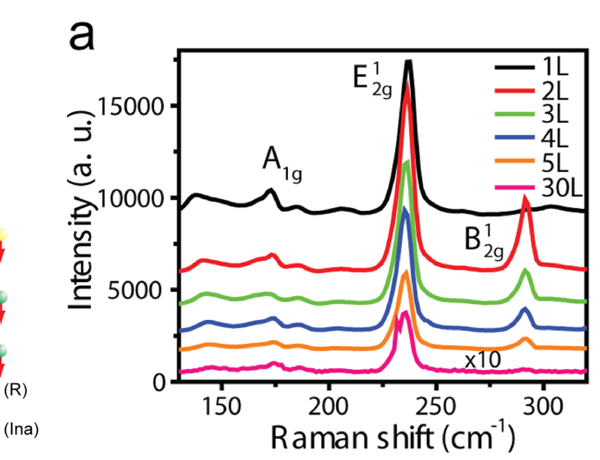
- Singh, J. *Smart electronic materials*. Cambridge University Press. (2005)
- Schwierz, F. *Nature Nanotech* 6(3), p.135-136. (2011)
- (2dsemiconductors.com, 2015)

Discussion

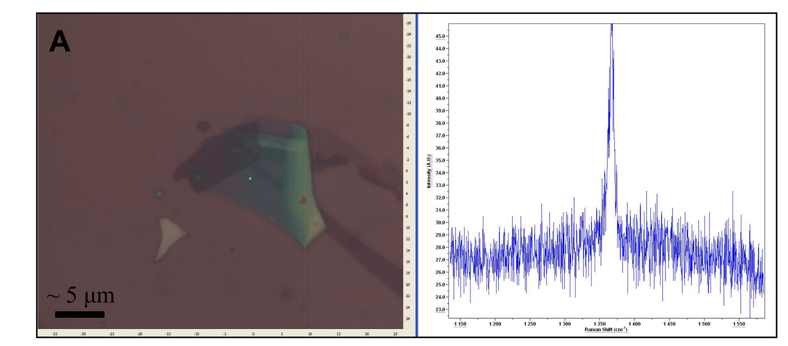
Atomically thin semiconductors such as few-layered molybdenum ditelluride ($MoTe_2$) inspire new fields of research in condensed matter physics as well as materials science. Both fields share common interest in procuring atomically thin semiconductors with a tunable, finite band gap. Single layer $MoTe_2$ exhibits a band gap in the near infrared range, allowing for further research into electron-hole pairs in a 2D setting. Like other transition metal dichalcogenides (TMD), $MoTe_2$ exhibits a transition from an indirect band gap to a direct band gap as the material reaches the monolayer limit. In this work, we have successfully manufactured two and three layered $MoTe_2$ heterostructures by micro-mechanical exfoliation and semi-dry contact alignment transfer. With selected flakes, semi-dry transfer contact is done by the stacking of selected flake specimens using a custom transfer microscope to create heterojunctions. Hexagonal boron nitride is used in heterostructure synthesis to serve as a tunneling promoter to graphene. After heterostructure assembly, resultant structures are analyzed by measuring optical and optoelectronic response.

Raman Spectroscopy

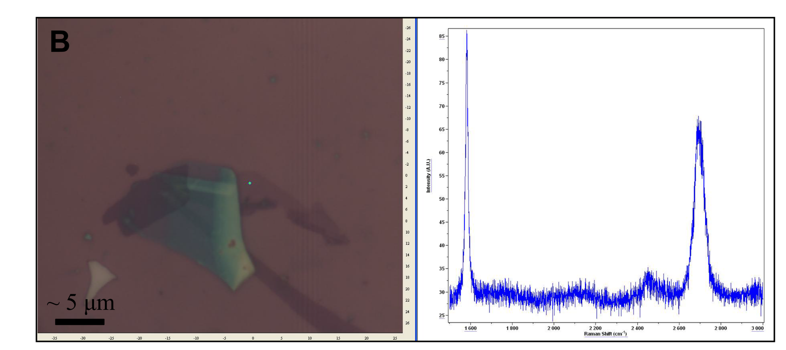


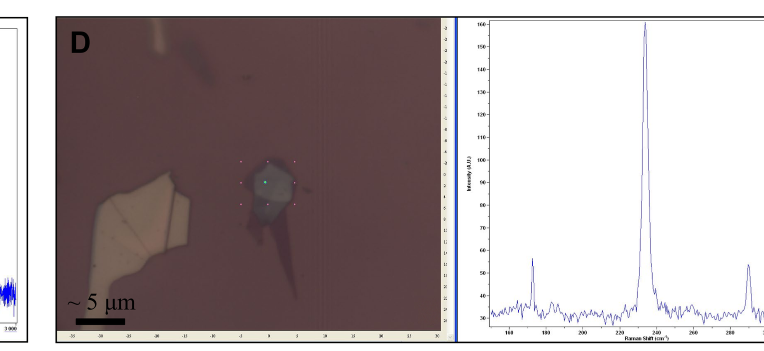


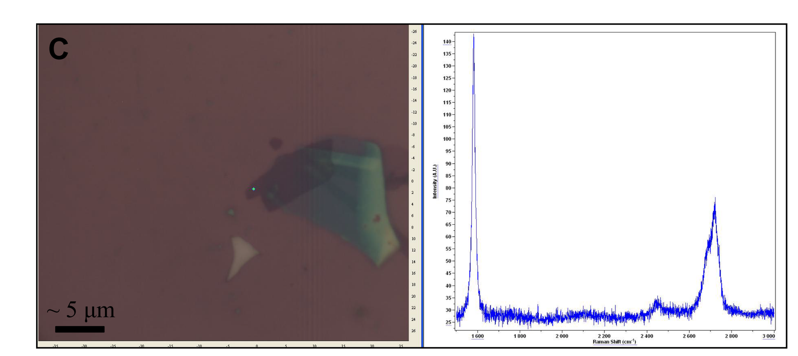
Top Left: Vibrational Modes for ML, 2ML, and Bulk $MoTe_2$ samples
Top Right: Characteristic height profile for varying $MoTe_2$ layer thicknesses

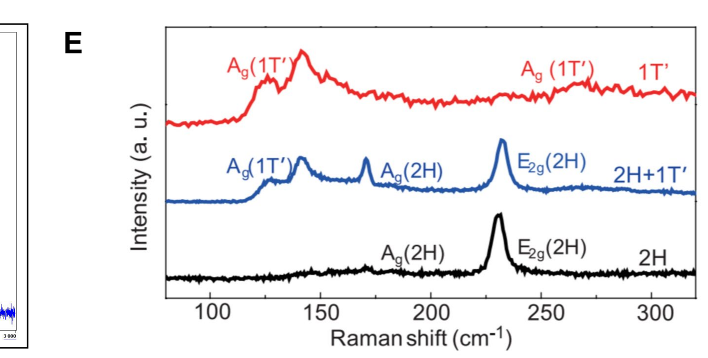


Left and Below:
[A] h-BN Raman Signature
[B] Graphene Raman Signature
[C] Graphite Raman Signature
[D] $MoTe_2$ Raman Signature
[E] $MoTe_2$ Laser Irradiated 2H and 1T' Progressive Raman Signature



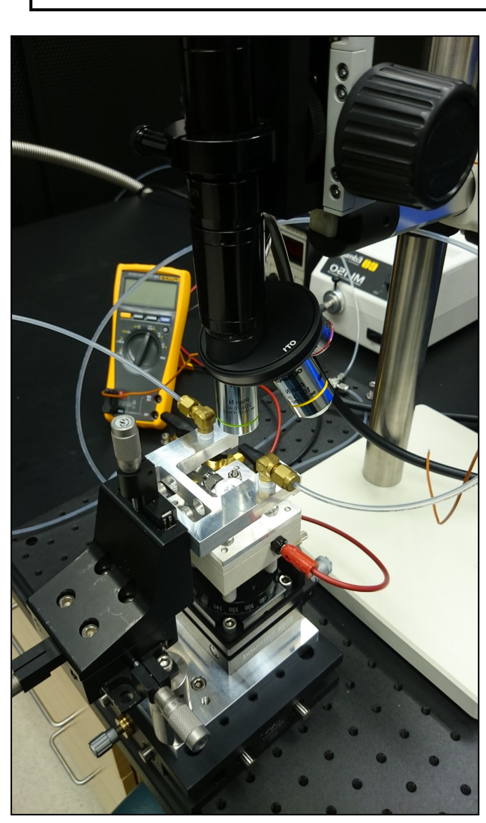




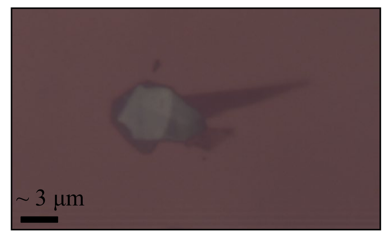


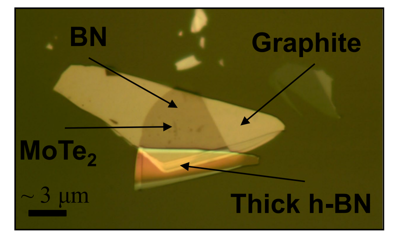
- Suyeon, C. *Science*, 349(6248), p. 625-648. (2015)
- Yamamoto, M. *ACS Nano,* 8(4), p. 3895-903. (2014)

Custom Transfer Microscope

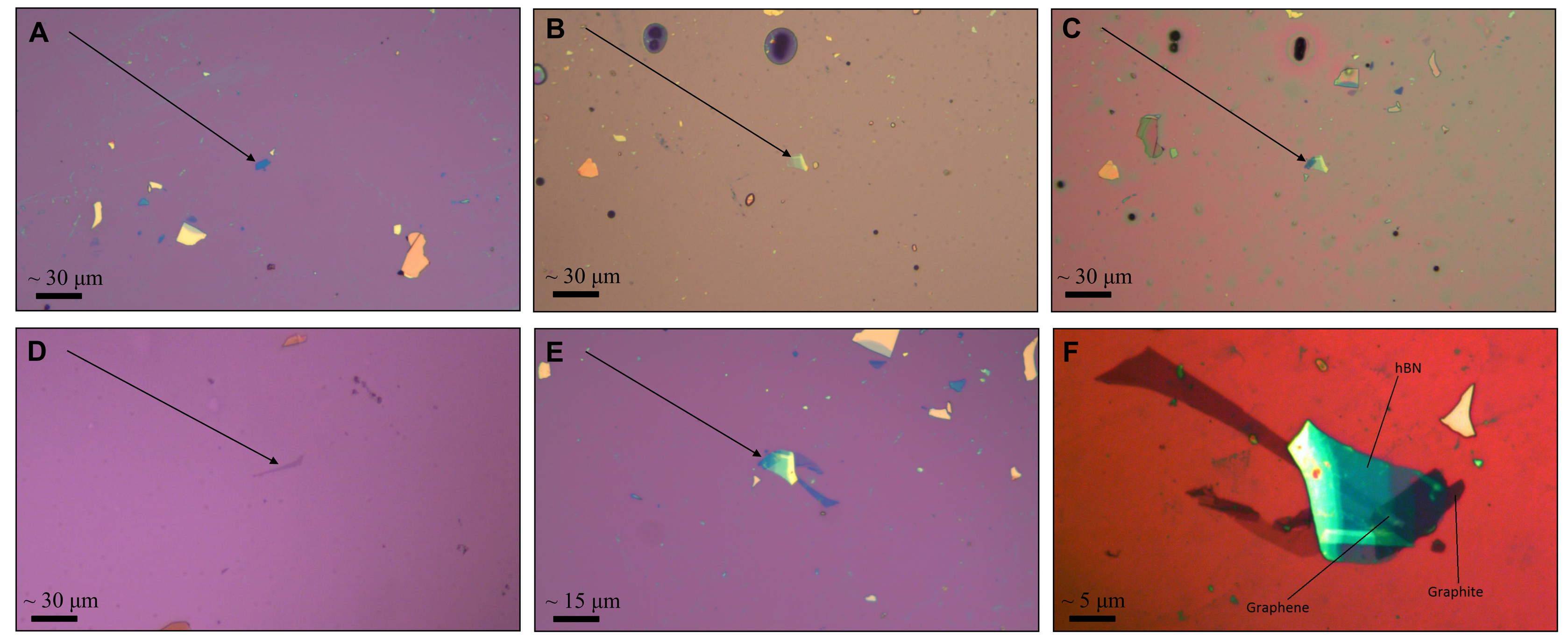


The transfer microscope takes two different layers of material and contacts them together via a multi-step polymer adhesion process. The Gabor group currently characterizes by atomic force microscopy, Raman spectroscopy, and photoluminescence spectroscopy. These characterization techniques will ultimately inform experiments that probe the novel optoelectronics properties of $MoTe_2$.



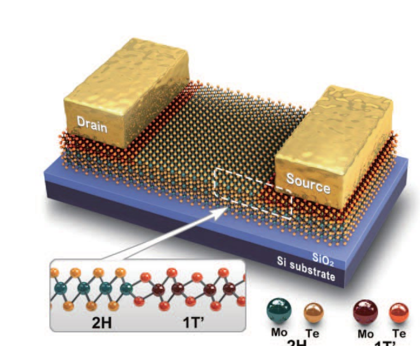


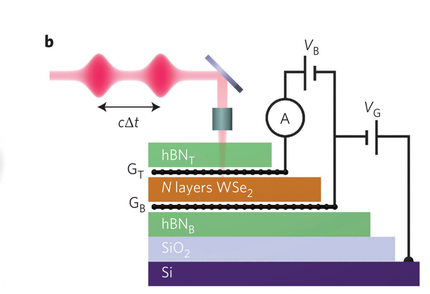
Heterostructure Fabrication

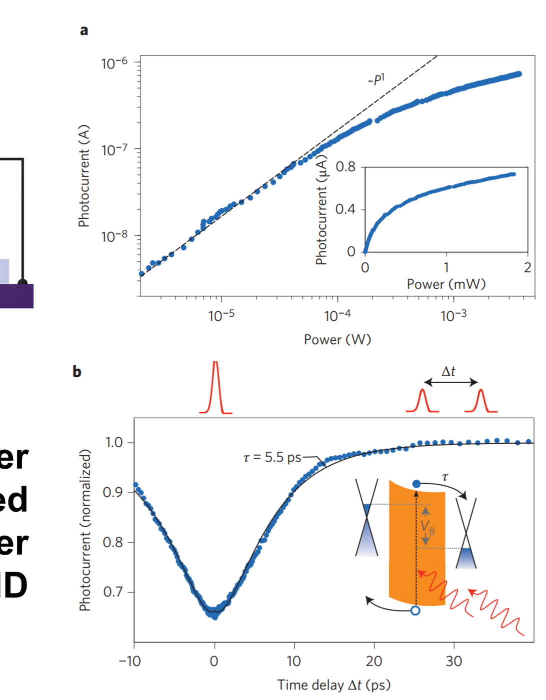


[A] Graphite 10x [B] h-BN on PPC 10x [C] h-BN on Graphite 10x
[D] Graphene 10x [E] Graphene/h-BN/Graphite 20x [F] Graphene/h-BN/Graphite 100x

Future Considerations







Alternative methods of producing few-layer TMD samples as well as producing wired devices capable of withstanding further optical characterization. Terraced TMD samples are especially of interest.

- Massicotte, M. *Nature Nanotechnology,* 11(1), p. 42-46. (2015)
- Suyeon, C. *Science*, 349(6248), p. 625-648. (2015)

Author Contact:
jwood020@ucr.edu