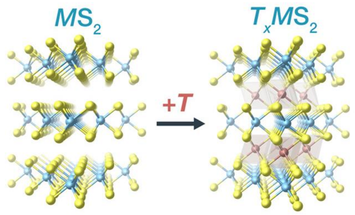
Exploring Topological Materials via Mechanical and Electro-Optical Methods

Ann Stettler, CAS '25
Department of Physics & Astronomy, University of Pennsylvania

Mechanical Exfoliation

Materials & Methods

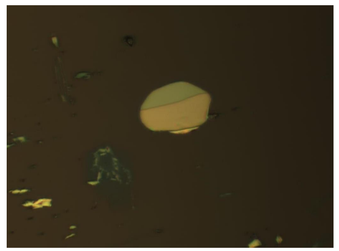
- 3 samples of manganese tantalum disulfide (Mn_XTaS_2) in ultra-thin crystal form: $Mn_{0.09}TaS_2$, $Mn_{0.19}TaS_2$, and $Mn_{0.28}TaS_2$.
- Exfoliated with Scotch tape → annealed and transferred to silicon wafers.



A similar intercalated atomic structure to Mn_XTaS_2. (1)

Results

- Ease of heat transfer corresponded to lesser Mn concentrations/fewer covalently intercalated Mn atoms.
- 5x, 20x, 50x magnification used to observe nanometer layers and identify those suitable for experiment in the THz setup.



$Mn_{0.28}TaS_2$ at 20x magnification. Note the darker area on the piece, which corresponds to a thinner layer.

Further Study

- These samples are able to be further analyzed in the THz setup for properties such as magneto-optic Kerr effect, inversion symmetry, and chirality handedness.

Introduction: What are Topological Materials?

- A kind of quantum matter with unique electromagnetic properties, like superconductivity.
- A promising area of study in condensed matter physics, with the potential to revolutionize and optimize technology.
- Able to be studied with a variety of techniques involving light, like terahertz (THz) spectroscopy.

The aim of this project is to explore some of the elementary methods through which topological materials can be studied in a time-domain THz setup, or another nonlinear optical setup.

Mechanical exfoliation and **balanced photodetection** are foundational steps to better understanding topological materials and their properties.

References and Acknowledgements

(1) Xie, et al. *Journal of the American Chemical Society*, 2022.

I would like to give special thanks to Dr. Liang Wu, as well as graduate students Benjamin Mead and Qi Tian, for their inspiring support and guidance this summer.

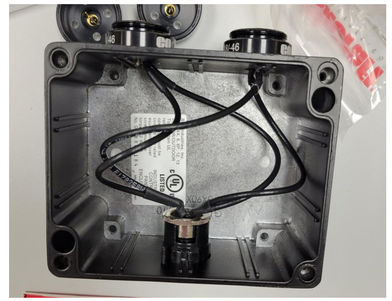
Balanced Photodetection

Materials & Methods

- 2 simplified balanced detectors were designed and constructed with the following:
  - Silicon photodiodes (Hamamatsu)
  - Aluminum enclosures (Bud Industries)
  - Detector mounts (Edmund Optics)
  - BNC cables and solder connectors

Results

- "Simplified" → will be connected to lock-in amplifiers in the Wu Lab.
- An itemized list of materials and a summary of theory was created for future student reference.



Bird's eye view of detector design.

Further Study

- These detectors can be integrated into a THz setup to determine the intensity difference between two beams of light → detect the THz pulse.
- Such electro-optical sampling is important for studying topological materials like Mn_XTaS_2.