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Application of Nanostructures in Solar Optics

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Abstract

Nanomaterials refer to materials that are within 1000 nanometers in size in at least one dimension. This research concerns 2D materials — materials that are nanoscale only in thickness. Single layered materials or multilayered sections of a material have unique properties different from that of the source material in bulk. This research seeks to examine layers of the semiconductor material MoS_2 (Molybdenum Disulfide) and its optoelectronic properties — capabilities in absorbing solar energy for eventual current generation. Specifically, research will consider how changing the crystallinity of MoS_2 can affect this area of performance in the interest of finding a configuration that performs better than conventional silicon based solar cells. To create the necessary MoS_2 samples for analysis, a process known as Chemical Vapor Deposition will be used. Variances in MoS_2 structure can be generated with different wafer engravings on which MoS_2 is produced. The resulting structural features can be examined using a process involving microscopic analysis and thereafter its optoelectronic properties can be tested. The ideal outcome of the research is the finding of a configuration of MoS_2 that has significantly improved solar properties over properties of conventional silicon — the material currently used for solar energy generation. In the context of increasing energy demands and environmental concerns, this research can have significant implications regarding improvement of future solar technology and thus assist with a transition to from non-renewable to clean renewable energy.

Background

Current silicon technology is used due to already established infrastructure for its manufacturing and material abundance. However, there are a number of reasons for which 2D materials are considered for solar applications. Namely:

- Absorbance Spectrum
- Electron Mobility
- Lowered costs

Investigating how one might leverage the unique properties of 2D materials for solar applications prove to be a worthwhile endeavor given the listed reasons.

Current studies have already established one dimensional MoS_2 to be a promising material for usage in conjunction with Silicon for high efficiency, ultrathin solar devices. Previous research have shown that MoS_2 is specifically 1 – 3 orders of magnitude more efficient than existing ultrathin cells as of 2013, and show great promise for commercial viability. As of 2018, there have been cells of efficiency 15% produced.

This project is largely centered on finding a process able to precisely control the material configuration, using the process to produce optimized photovoltaic devices which can be analyzed for its properties.

My role largely consisted of understanding the project and helping produce usable preliminary samples. This includes repetition of the fabrication process occasionally with slightly different parameters or different setups proposed by other lab members.

Objectives

- Consistently produce high quality samples of 2D MoS_2 using Chemical Vapor Deposition (CVD)
- Understanding effect of MoS_2 on solar energy harvesting
- Characterize fabricated MoS_2 to understand its optoelectronic properties

Theory

Semiconductor and P-N Junctions

- Band gaps represent energy needed for electricity flow
- Doping semiconductors give materials excess of or lack of electrons

Properties of Sunlight

- Most energy in visible light (400 – 700nm), with a portion in UV (10 – 400nm)
- Current cells are skewed towards capturing visible light

Solar Cell Operation

- Typically an interface of two semiconducting materials – one of P type and N type
- Absorption represents generation of electrons due to sunlight (Photocurrent)
- Recombination is ideally minimized

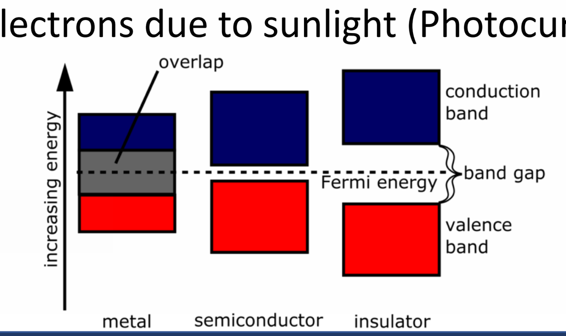

Figure 1: band gap configuration

Methods

Chemical Vapor Deposition (CVD) for device fabrication is a relatively new, standard way to produce nanometer thick materials and involves the following processes

- Vacuum tube
- Inert gas flow
- Application of Heat

10mg of MoO_3 and 150mg of Sulfur were used for production.
The process used the most involved reducing pressure to ~200mTorr, then flowing inert gas from the direction of the sulfur to MoO_3. This is done while the furnace heats to 800 °C.

The process aims to have the vaporized sulfur and MoO_3 meet on the silicon wafer at the same time for the formation of MoS_2 materials.

a)

b)

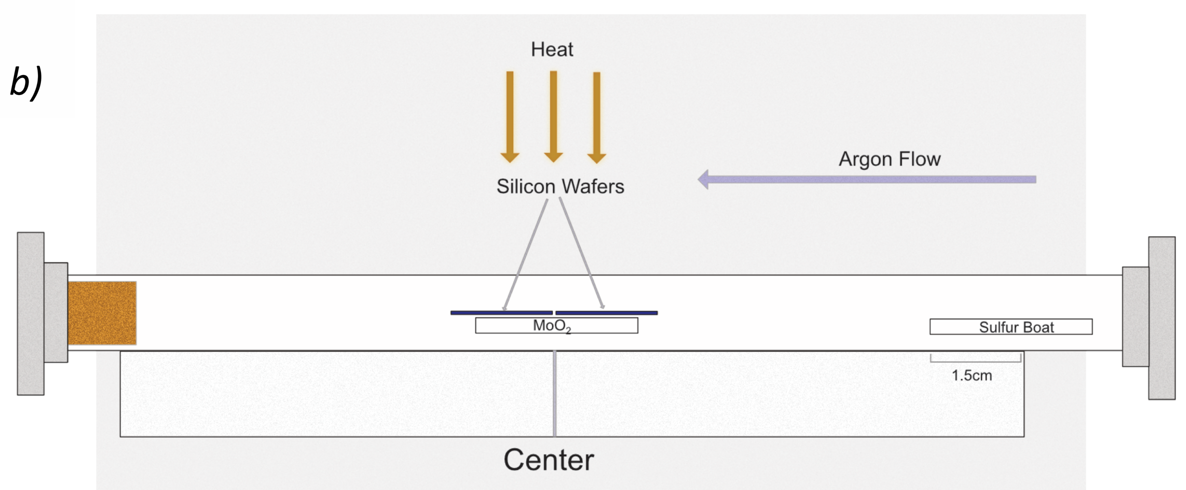

Figure 1 : four of ~16 samples produced

Results

Success was variable upon repetition of the experiment after ~20 samples were created.

- "Islands" of MoS_2 material are less viable as potential devices
- Blue bands represent a large area that can be used for testing
- Yellow indicates excess sulfur.

Examples of resulting samples are shown in Figure 2. Occasional successful samples were created, yet there remains room for repeating trials to consistently produce higher quality samples that can be used for testing.

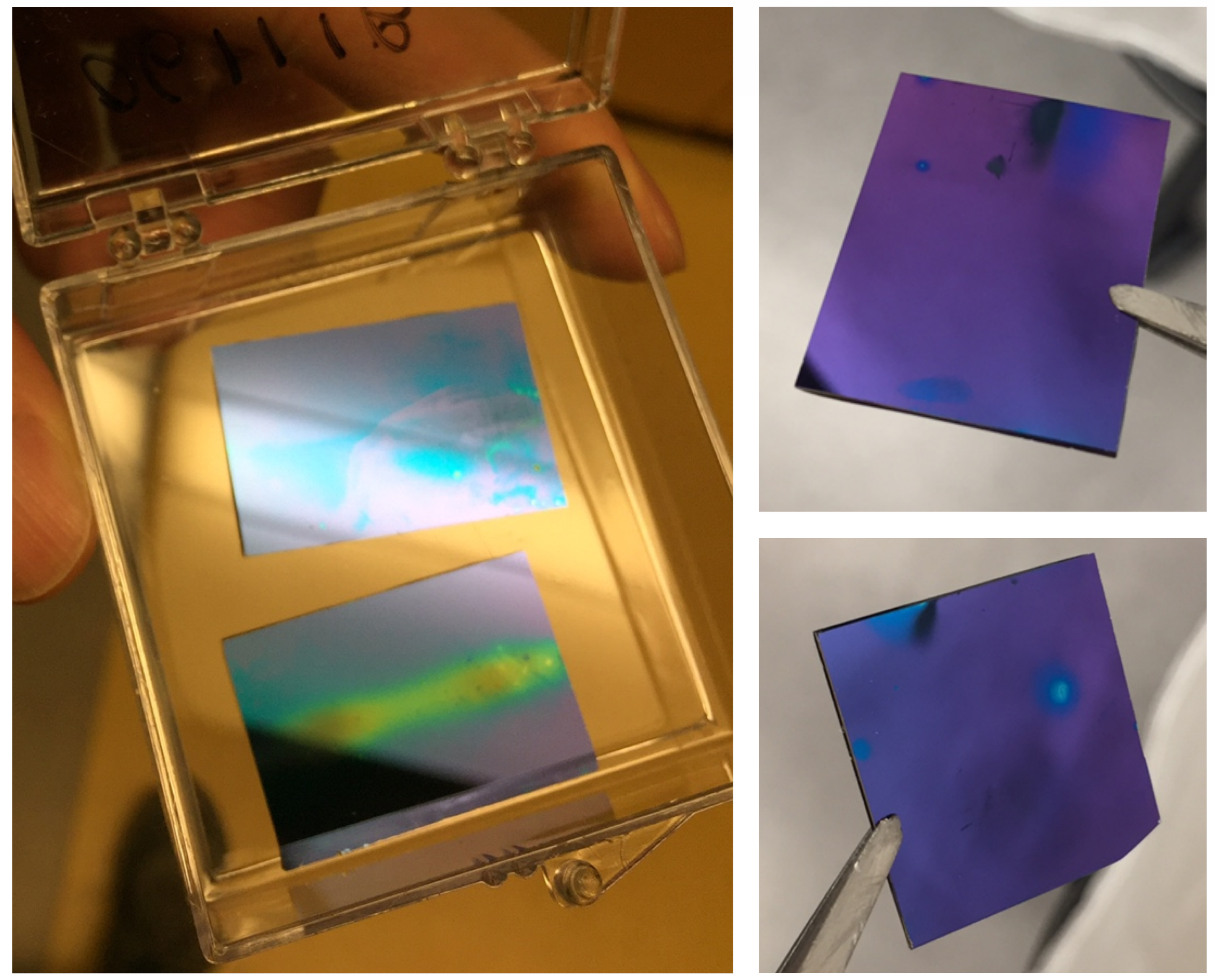

Figure 2 : four of ~16 samples produced

Next Steps

Steps to take after acquiring sufficient samples and finding a consistent method of production are to verify the two dimensionality of the material and use samples to test produce PV devices. Methods to do this would include spectroscopy. Metal electrodes will be added to allow for gathering of data relating to the cell's efficiency and electrical properties. Specifically, I-V properties that allow for characterization of the solar cell fill factor.

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