

# From $\text{Bi}_2\text{O}_2\text{Se}$ to $\text{Bi}_2\text{Se}_{(3-x)}\text{Te}_x$ : Utilizing CVD for Phase Transitions and Chalcogen Tuning

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## Objective and Research Question

This project seeks to investigate the feasibility of a controlled transition from the  $\text{Bi}_2\text{O}_2\text{Se}$  family to the  $\text{Bi}_2\text{Se}_{(3-x)}\text{Te}_x$  family via chemical vapor deposition (CVD). The conversion would establish synthesis routes with the goal of enabling chalcogen alloying and bandgap tuning for future studies.

## Background

Traditional transistor manufacturing processes heavily rely on Silicon-based materials but have found physical limitations in scaling down devices due to the electron tunneling effect [1].

Research and development teams have looked to 2D materials, or atomically thin films, capable of reproducing Silicon's high carrier mobility while maintaining structural integrity when scaled down [2].

Bismuth oxyselenide ( $\text{Bi}_2\text{O}_2\text{Se}$ ) ( $E_g \sim 0.8$  eV) stands out as a promising candidate for its low leakage current and exceptionally high electron mobility [3].

Furthermore, the broader family  $\text{Bi}_2\text{O}_2\text{X}$  and (where  $X = \text{S}, \text{Se}, \text{Te}$ ) allows for tunable bandgaps and carrier mobilities via chalcogen substitution, making this material very attractive for next-generation semiconductor applications [4].

## Methods

The starting  $\text{Bi}_2\text{O}_2\text{Se}$  film will be deposited via pulsed laser deposition (PLD) and introduced to thermal selenization and tellurization processes via CVD. The following parameters will be systematically adjusted to kinetically favor the  $\text{Bi}_2\text{Se}_{(3-x)}\text{Te}_x$  phase:

- Substrate temperature during the transition
- Temperatures and spatial placement of Se and Te sources
- Carrier and reactive gas composition (e.g., Ar,  $\text{H}_2$  or mixed) and flow rates
- Ramp-up and cooling rates

The film will then be assessed for phase transformation through X-ray Diffraction (XRD), Raman spectroscopy, scanning electron microscopy (SEM), and optical microscopy. The recipe will then be adjusted based on the resulting film and the process will be repeated until  $\text{Bi}_2\text{Se}_{(3-x)}\text{Te}_x$  presence is confirmed.

## CVD System for Conversion

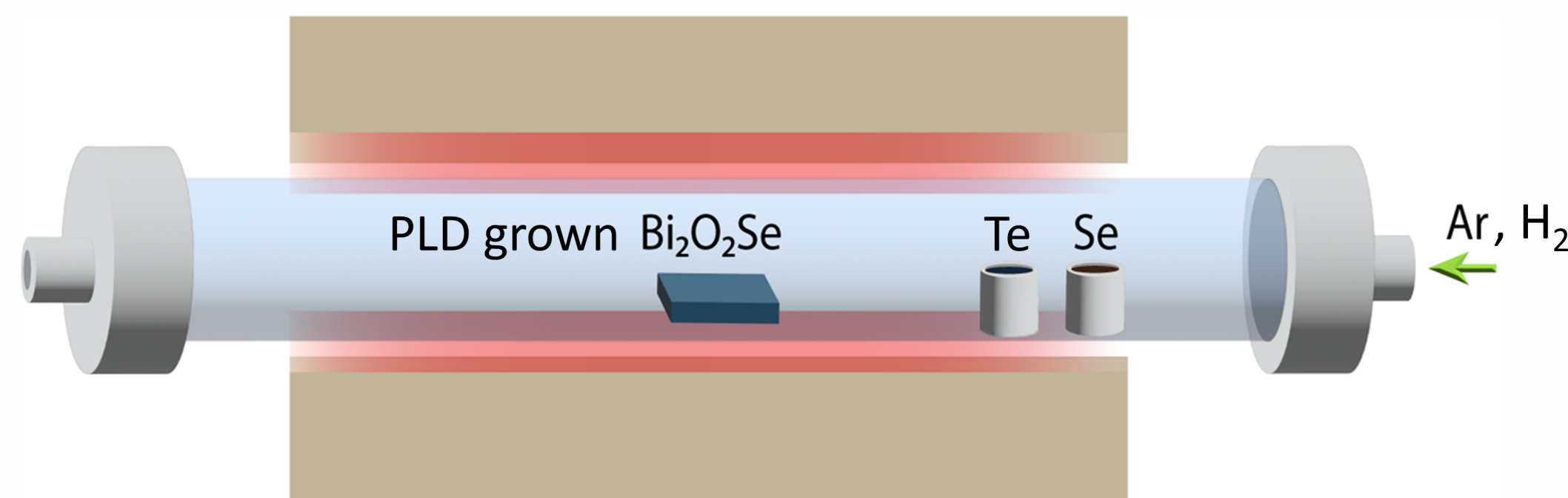
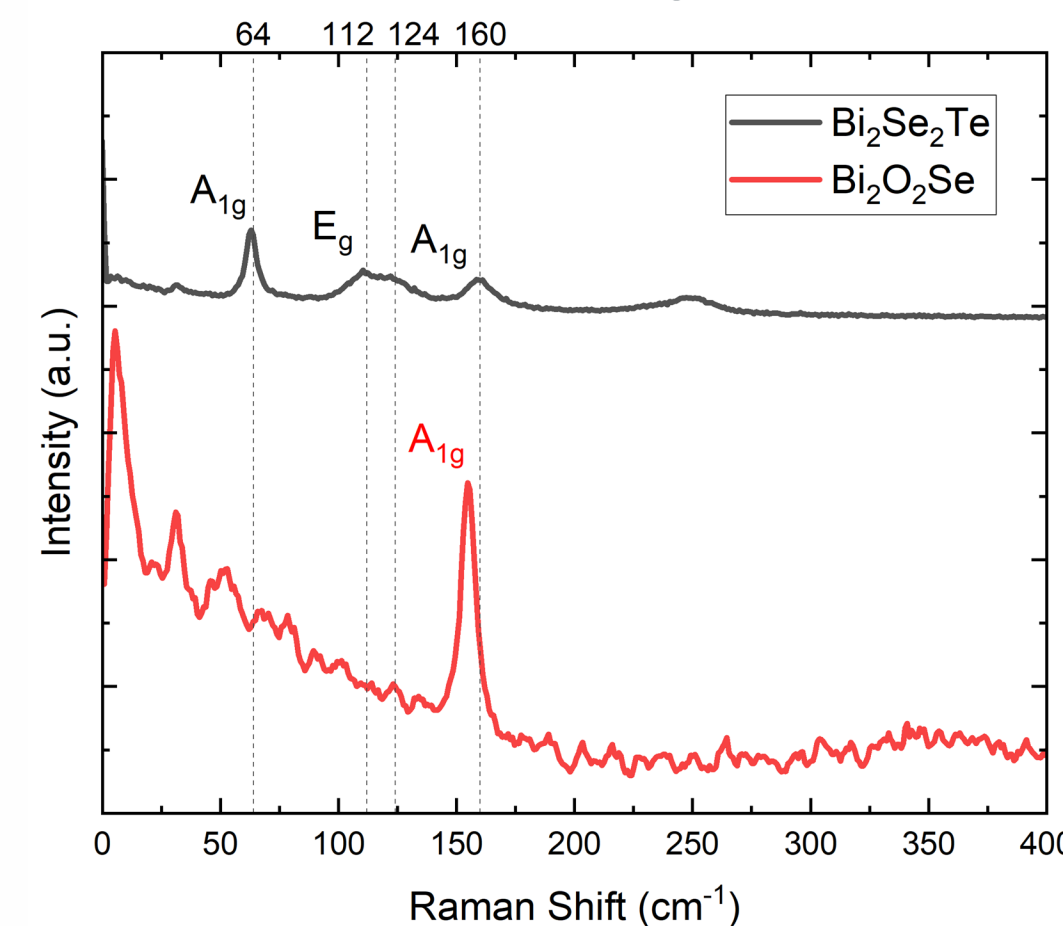


Figure 1: CVD set up for introducing a Selenium and Tellurium vapor-rich environment

## Results

Successfully achieved a full phase transformation from  $\text{Bi}_2\text{O}_2\text{Se}$  to  $\text{Bi}_2\text{Se}_2\text{Te}$ , as confirmed with Raman and XRD. SEM reveals crystalline formation, providing insight on the reaction pathways necessary for conversion.

## Raman Spectroscopy



## XRD

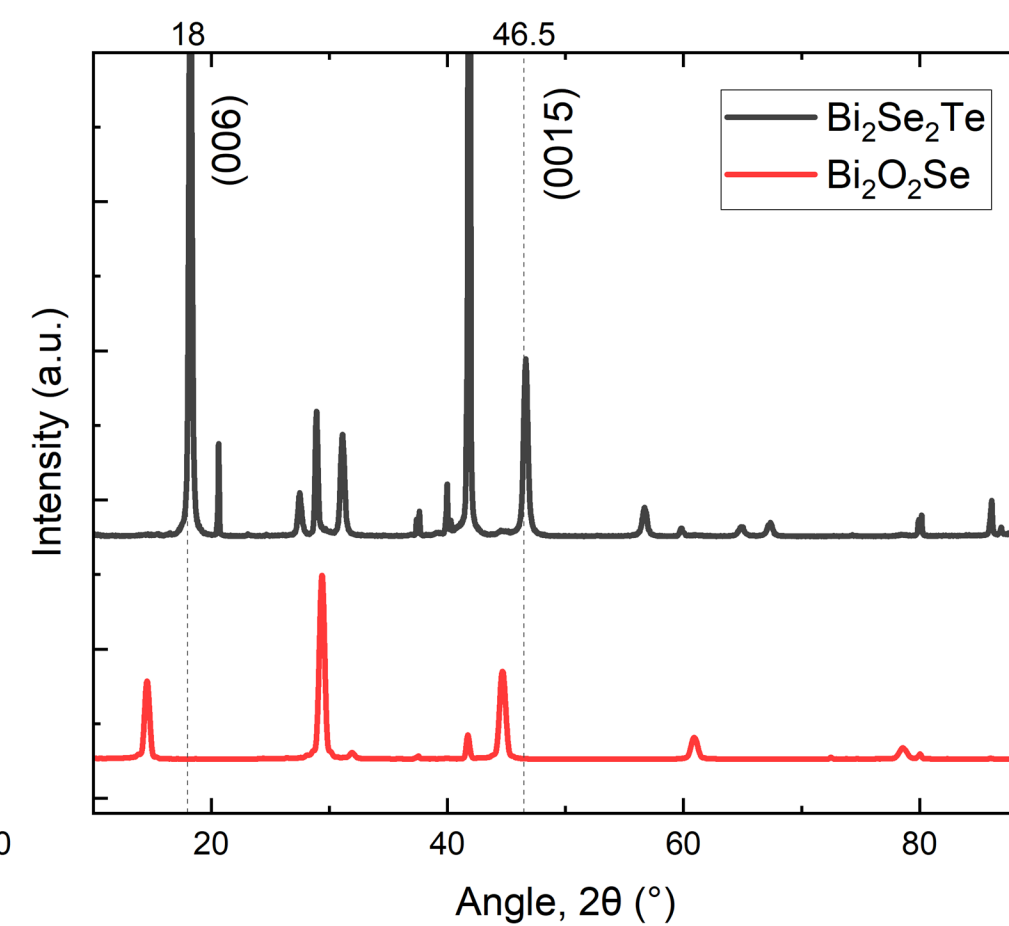
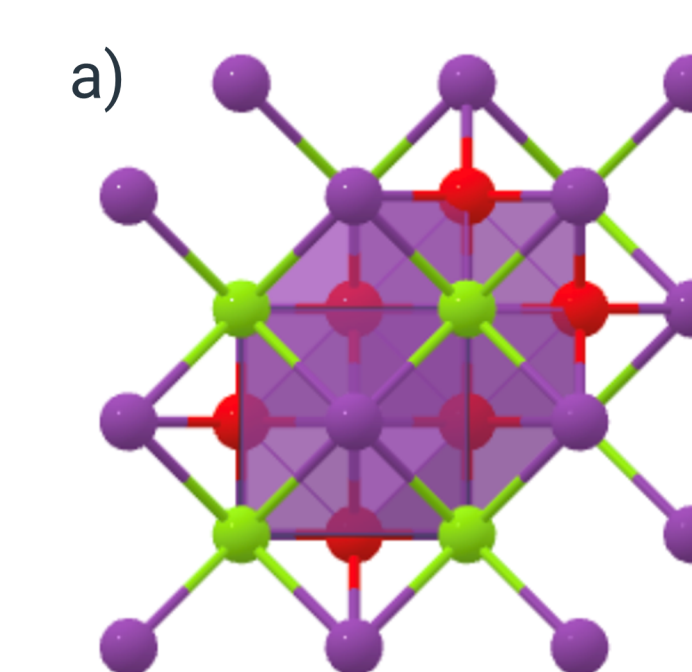


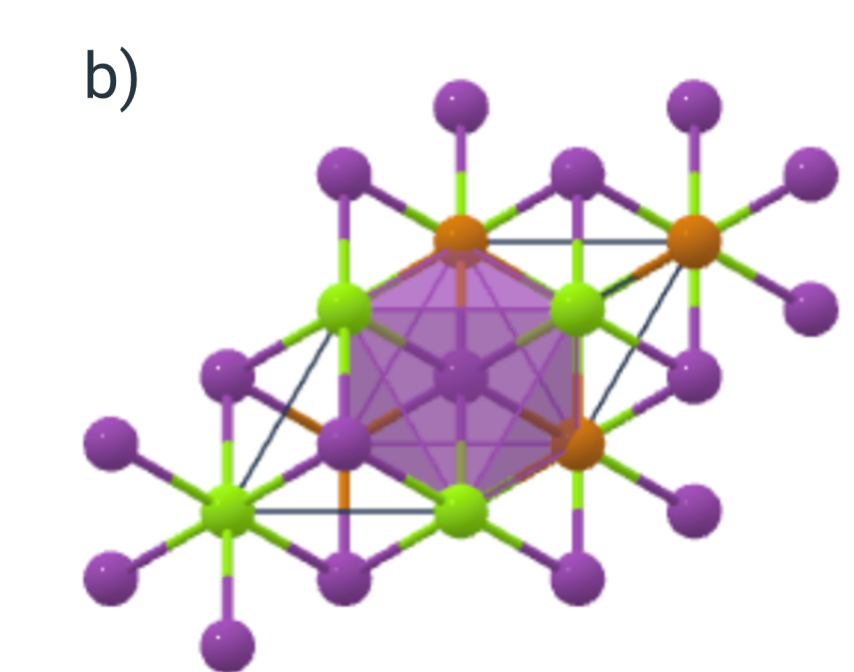
Figure 2: Raman spectroscopy comparing before and after conversion. Peaks for  $\text{Bi}_2\text{Se}_2\text{Te}$  are compared with literature [5].

Figure 3: XRD comparing before and after conversion. Peaks for  $\text{Bi}_2\text{Se}_2\text{Te}$  are compared with literature [6].

## $\text{Bi}_2\text{O}_2\text{Se}$



## $\text{Bi}_2\text{Se}_2\text{Te}$



● Bismuth  
● Oxygen  
● Selenium  
● Tellurium

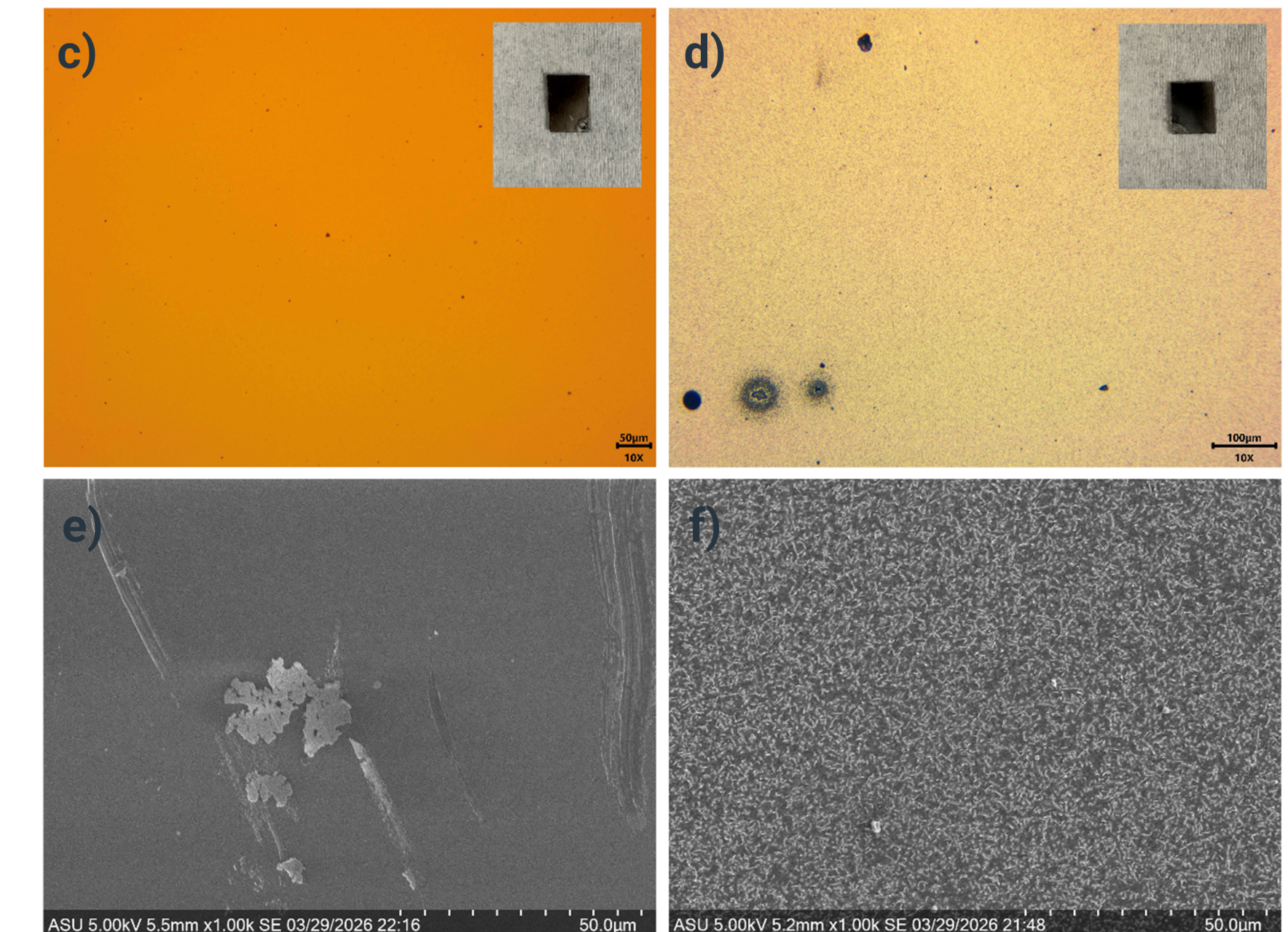


Figure 4: a)  $\text{Bi}_2\text{O}_2\text{Se}$  atomic crystal structure [7]. b)  $\text{Bi}_2\text{Se}_2\text{Te}$  atomic crystal structure [8]. c) Optical image and iPhone image of  $\text{Bi}_2\text{O}_2\text{Se}$  film. d) Optical image and iPhone image of  $\text{Bi}_2\text{Se}_2\text{Te}$  film. e) SEM image of  $\text{Bi}_2\text{O}_2\text{Se}$ . f) SEM image of  $\text{Bi}_2\text{Se}_2\text{Te}$ .

## Future Work

Optimize Selenium and Tellurium energies to achieve different ratios of  $\text{Bi}_2\text{Se}_{(3-x)}\text{Te}_x$ . Establish oxidation processes to achieve  $\text{Bi}_2\text{O}_2\text{Se}_{(1-x)}\text{Te}_x$  conversion, completing the chalcogen tuning process necessary for bandgap engineering.

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