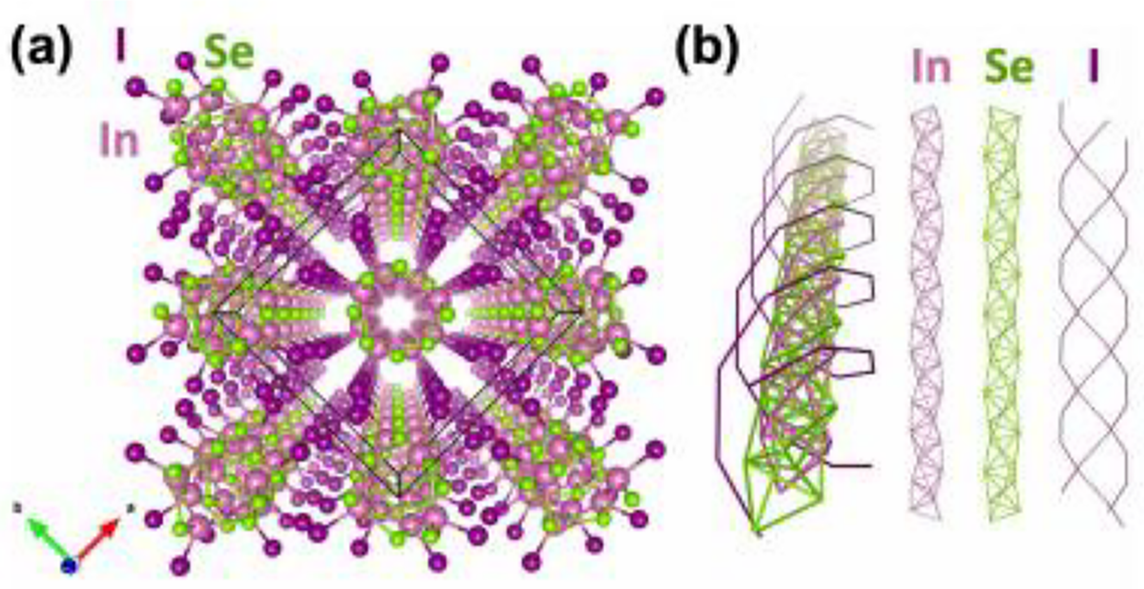
Understanding Chiral Material Systems by Synthesizing and Characterizing Vibrational Properties of Single-Crystal InSeI

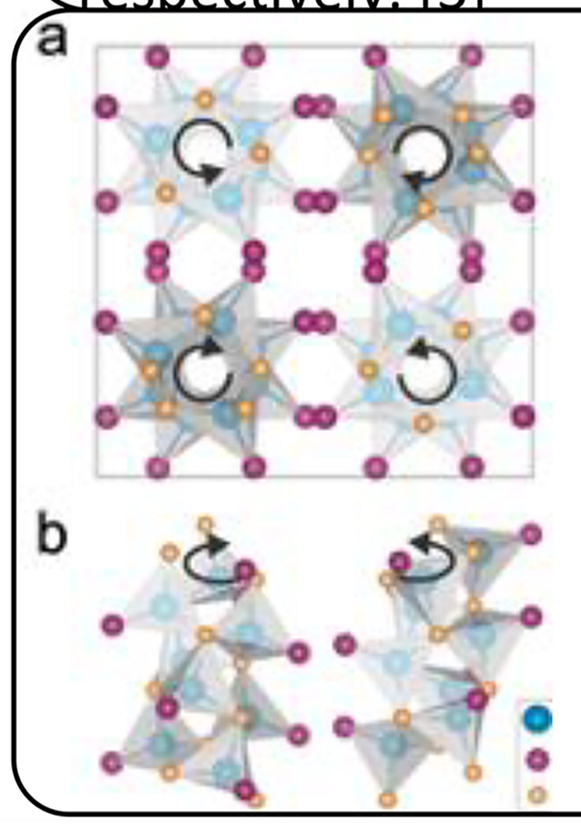
Lucas Hardesty, Materials Science and Engineering
Mentor: Sefaattin Tongay, Dr.
School for Engineering of Matter, Transport, & Energy

Background

InSeI was discovered in 2020 with promising results showing that InSeI might have “promising wide-bandgap capabilities” [1]. Looking more closely at the structure of InSeI, we can see that it naturally forms in a chiral-like structure, which allows for a property called “chiral-induced spin selectivity” (CISS) to emerge. CISS allows for a material with a chiral structure to act as a spin filter for electron transport, allowing possible implementation for future semiconductors. Furthermore, the promising wide-bandgap capabilities along with the properties of chiral-induced spin selectivity could possibly benefit the semiconductor industry as InSeI could emerge as an option for material selection.



(a) The bulk crystal with right-handed chirality. (b) The 1D nanochain with the decomposed chains for In, Se, and I, respectively. [3]



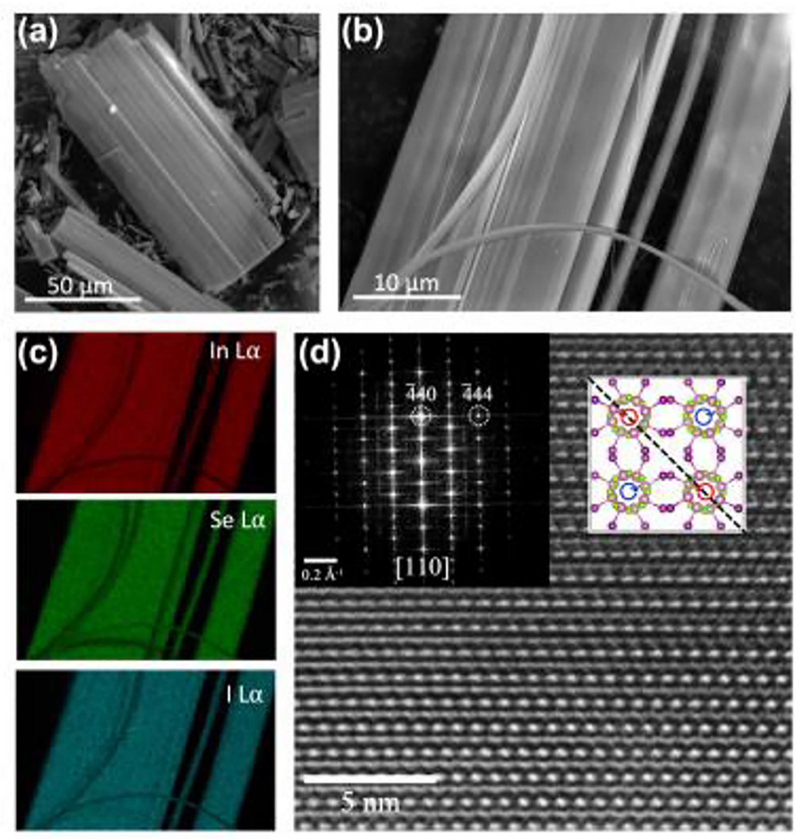
a) The crystal structure of bulk InSeI contains two types (left-handed and right-handed) of chiral chains.
(b) Crystal structures of left- and right-handed 1D InSeI. Blue, yellow, and purple balls represent In, Se, and I atoms [4].

Research Question

InSeI holds some interesting properties upon further inspection of preliminary research, and requires further research to truly understand InSeI and other chiral material systems. The question posed was “To what extent does InSeI posses the properties of chiral-induced spin selectivity, and how can it be grown efficiently?”. Furthermore, this research question challenges whether or not we can synthesize chiral materials with only left or right handed geometries, which was the secondary question to this project.

Results/Current Findings/Methods

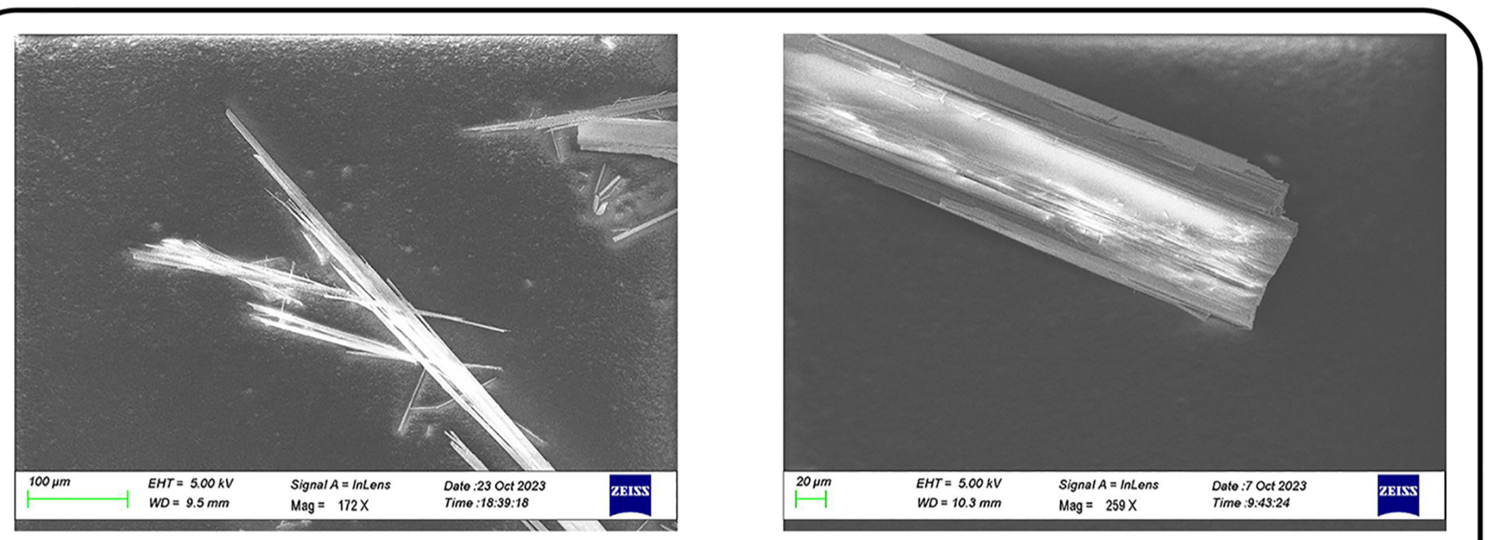
To characterize InSeI accurately, multiple growth techniques had to be used to create the 1:1:1 ratio and chiral structure desired. CVD growth was firstly used, with yielded results that were insignificant to the research question. Growth using the Bridgman technique showed centimeter-sized crystals produced, along with high crystallinity. Furthermore, electron microscopy revealed structural characteristics and established a bandgap of 2.08eV in highly crystallized regions. Raman spectroscopy was then used to determine vibrational properties in 5 regions relating to the composition. Results indicate that the bridgman technique is a reasonable method to grow high-quality InSeI crystals, which allows a path toward further research for chiral material systems. Furthermore, these results allow for more characterization of InSeI, and to lead towards research of its electrical properties and what InSeI could be used for within the semiconductor industry.



(a,b) SEM pictures of InSeI [3]
(c) EDS elemental mapping of Lα representing the relaxation from M (n = 3) to L (n = 2) electrons of In, Se, and I, respectively [3].
(d) TEM image for the (110) surface with the FFT pattern inserted on the top left; dashed line represents same chirality [3].

Future Uses/Implications

InSeI possess the bandgap similar to other semiconductor materials, with the benefit of having chiral-induced spin selectivity, as well as another phenomenon known as Spin Orbit Coupling [2]. Spin-orbit coupling in chiral materials is known to induce chirality-dependent spin splitting, which can enable the electrical manipulation of the spin polarization [4]. This harnessing of SOC and CISS can allow InSeI to become a possibly critical and useful material in the fields of data transfer, reducing power outages, and processing capabilities in computing machines [3].



Photos showing grown InSeI with high crystallinity grown using the bridgman technique within the Tongay Lab at ASU

References

[1] S. Jiang *et al.*, “Computational prediction of a novel 1D Insei nanochain with high stability and promising wide-bandgap properties,” *Physical Chemistry Chemical Physics*, vol. 22, no. 46, pp. 27441–27449, 2020. doi:10.1039/d0cp04922k

[2] S. Zhao, Z. Zhu, X. Yao, and W. Li, *Chirality-induced spin splitting in 1D InSeI*, Aug. 2023. doi:https://doi.org/10.48550/arXiv.2308.04350

[3] Y. Zhou, D. L. M. Cordova, G. M. Milligan, M. Q. Arguilla, and R. Wu, *Higher-dimensional spin selectivity in chiral crystals*, May 2023. doi:https://doi.org/10.48550/arXiv.2305.18637

[4] S. Jiang *et al.*, “Ferroelectricity in novel one-dimensional P42-INSEI nanowires,” *Results in Physics*, vol. 31, p. 104960, 2021. doi:10.1016/j.rinp.2021.104960