Tunable Spin Splitting in the Two-Dimensional Transition Metal Chalcogenides

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Introduction

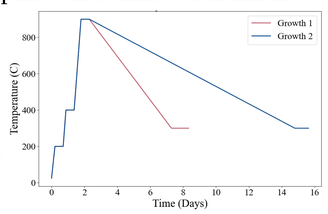
Spintronics is a field of electronics where electron spin is manipulated to enhance modern computer performance. These devices require materials with ideal electrical and magnetic properties. Specifically, materials must exhibit strong spin-orbit coupling (SOC) as well as persistent spin texture (PST).

Computational research indicates that stable two-dimensional germanium monochalcogenides (GeMC) should exhibit natural PST. Moreover, the material exhibits a large SOC parameter where the PST sustains [1]. Experimentally exploring 2D GeMC will help optimize current spintronic devices.

Methods

Metallic Flux

Two experiments with self-flux were performed with the following temperature profiles. Samples were removed from the furnace at 300°C and centrifuged at 3000 rpm for 3 minutes



Chemical Vapor Transport (CVT)

Four experiments were performed with various temperature profiles inside a three-zone tube furnace. The temperature profiles for the reactions were as follows:

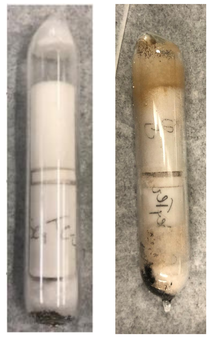
1. T_{cold} = 300°C; T_{hot} = 350°C; t = 7 days
2. T_{cold} = 300°C; T_{hot} = 350°C; t = 14 days
3. T_{cold} = 350°C; T_{hot} = 400°C; t = 7 days
4. T_{cold} = 350°C; T_{hot} = 400°C; t = 14 days

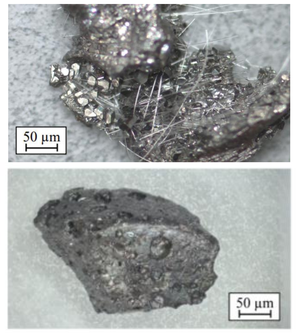
All solid materials from the reactions were sonicated with ethanol and acetone to remove any surface contaminants.

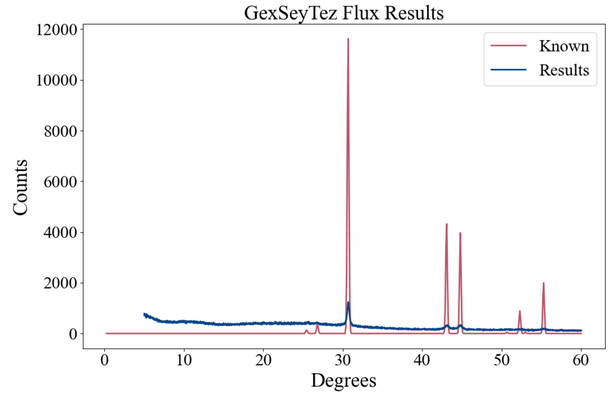
Results

Flux Growths

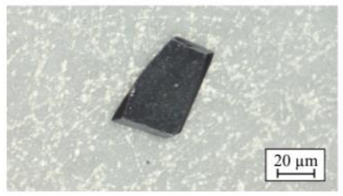
Although X-Ray Diffraction (XRD) analysis showed ideal chemical composition for target ternary phases, quality single crystals were not obtained. However, there were clear signs of crystal nucleation, particularly for the reaction cooled at 5°C/hr. Abnormal growths on the sides of the quartz tube were found, indicating sublimation during the reaction.

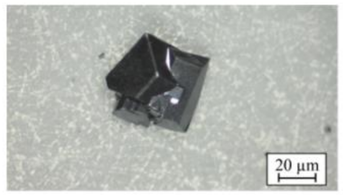


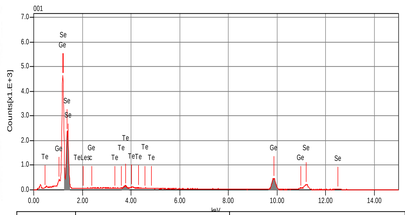




CVT: Binary Single Crystals





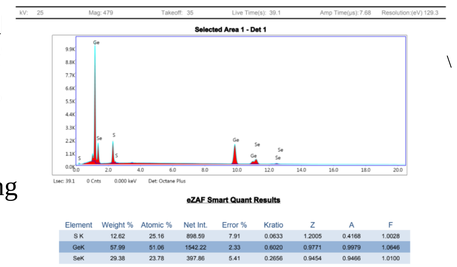


	Mass Percent	Atomic Percent
Ge	48.53	50.77
Se	48.27	46.97
Te*	3.76	2.26

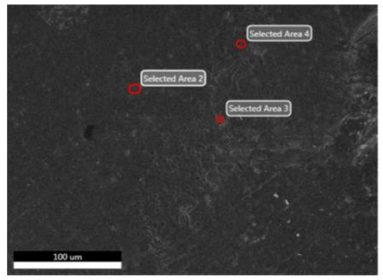
XRD results for the crystals showed successful single crystal synthesis of pure binary phases. However, Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS) measurements were used to identify surface defects composed of iodine and tellurium, indicating the formation of TeI_4. These results indicate that tellurium doping may be present in some binary phases.

CVT: Ternary Single Crystals

SEM/EDS analysis also identified a potential ternary composition of Ge2SSe. Without further analysis, the crystal composition cannot be confirmed. However, this preliminary analysis is encouraging that ternary crystal synthesis is possible through CVT methods.



Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	A	F
S K	12.62	25.16	898.59	7.91	0.0633	1.2005	0.4168	1.0028
GeK	57.99	51.06	1542.22	2.33	0.6020	0.9771	0.9979	1.0646
SeK	29.38	23.78	397.86	5.41	0.2656	0.9454	0.9466	1.0100

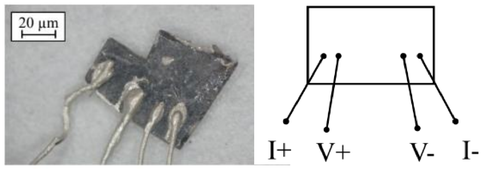


Conclusions

- Future flux growths may benefit from a lower reaction temperature for a longer time as evidenced by sublimation
- another chemical transport should be considered over iodine to reduce transport reactions

Future Work

- Analysis on the electrical and magnetic properties should be explored using a Physical Property Measurement System (PPMS).



- Further analysis should be conducted to definitively identify the potential ternary Ge2SSe crystal.

Acknowledgments

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[1] M. A. Ulil Absor, Y. Faishal, M. Anshory, I. Santoso,and F. Ishii, Highly persistent spin textures with gianttunable spin splitting in the two-dimensional germaniummonochalcogenides, Journal of Physics: Condensed Mat-ter33, 305501 (2021).