Fabrication & Characterization of High Entropy Chalcogenide: A Potential Spin Hall Material

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NSF Research Experience for Undergraduates

High Entropy Alloys (HEA) have gained significant attention over the last decade because they exhibit advantageous properties that their elements individually may not demonstrate. HEAs consist of five or more metals in equal proportions[1]; for example, Germanium Tin Lead Sulfur Selenium Telluride (GeSnPbSSeTe) is a high entropy chalcogenide (HEC). This HEC contains heavy elements and is proposed to present a stronger spin orbit coupling, which could induce a strong spin Hall angle. A flat thin film is required for maximal contact, essential for most devices, while a crystalline structure is preferred to maximize the spin Hall effect as it is a cumulative effect dependent upon local structural orientation. Using pulsed laser deposition, we deposited several HEC films at various substrate temperatures and chamber pressures. We then characterized the roughness of the films using atomic force microscopy and the structure using x-ray diffraction. We observed that, as the growth temperature was increased, the roughness of the film increased in an exponential fashion. Concurrently, the film exhibited a crystalline structure only at higher temperatures and was more pronounced at lower pressures. These observations are essential for the next step of fabricating devices to test the material's spin Hall angle.

Introduction

Spin Hall Effect

The spin Hall effect is a phenomenon that occurs in certain materials particularly ones with a higher atomic mass. A current is applied to the material and a perpendicular spin current is induced. A spin current can be thought of as a spin gradient with up spins accumulating on one end and down spins on the opposite (see figure 1) or in other words a spin voltage is formed [2].

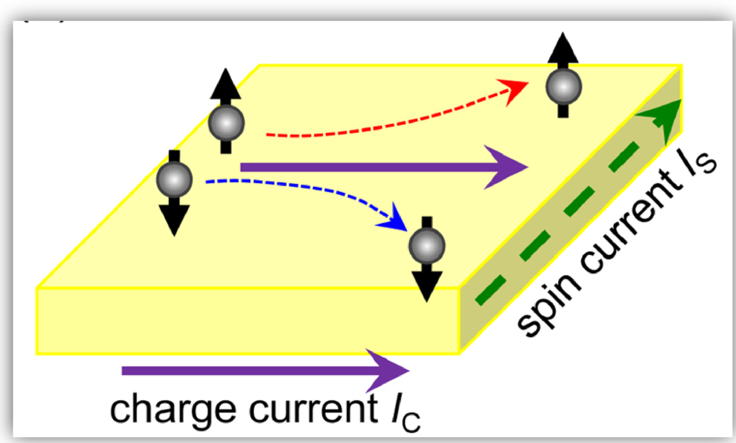


Figure 1: Spin Hall effect diagram [3]

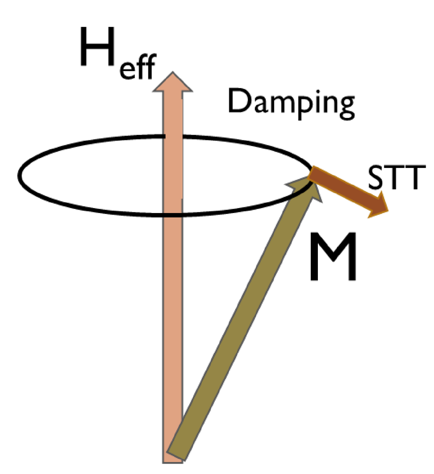


Figure 2: Spin transfer torque vector diagram

Potential Applications

By guiding the spin current into a ferromagnetic material, we can induce a spin transfer torque that could switch the magnetization of the ferromagnet (see figure 2). Currently, the magnetization of M-RAM (magnetic memory) is switched by passing a solenoid over each segment; however, the current through the solenoid requires a great amount of strength (energy) to switch the magnetization. This new approach has the potential to reduce the energy needed by 50 times [4]. While other forms of memory are being used, M-RAM is non-volatile and durable, qualities much desired in memory applications.

Material Fabrication

Pulsed Laser Deposition (PLD)

Parameters varied:
→ Substrate Temperature
→ Chamber Pressure

Target: GeSnPbSSeTe (Germanium Tin Lead Sulfur Selenium Telluride)

Substrate: $Ga_5Gd_3O_{12}$ (GGG)

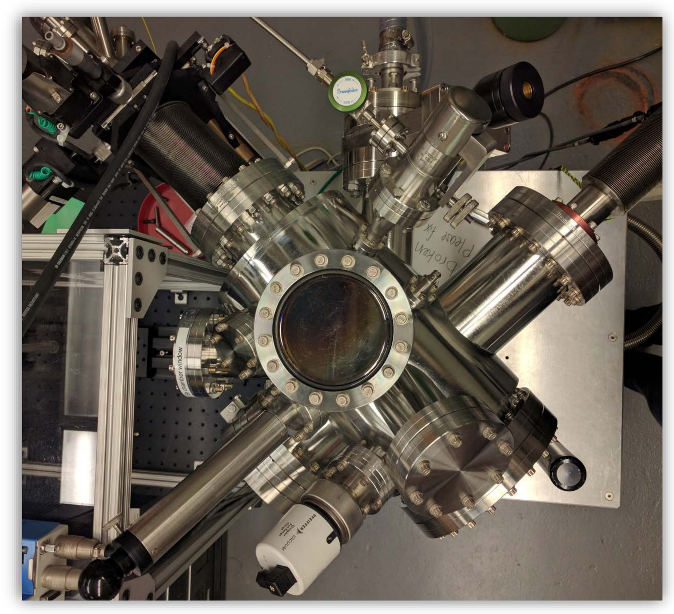


Figure 3: Photograph of PLD Chamber

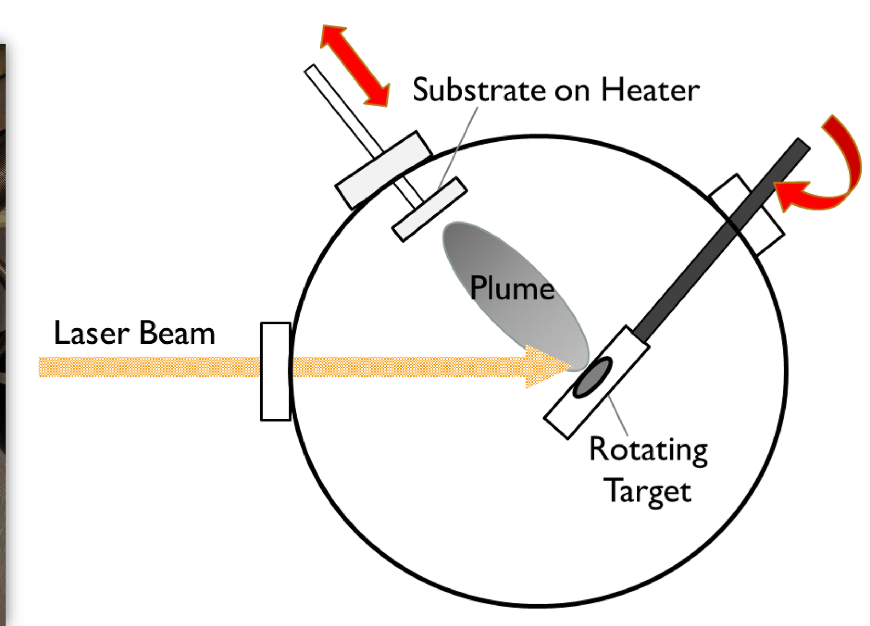


Figure 4: Diagram of PLD Chamber

High entropy alloys exhibit unusual and advantageous properties that their individual elements alone might not. For these reasons, it is worthwhile to fabricate HEAs using elements with properties predicted to induce the desired behavior. For example, heavier elements have stronger spin-orbit coupling, a element trait essential for a strong spin Hall angle; thus we included heavier elements in our HEC composition. HEAs also have favored single phase formations [5] – a property that could strengthen the spin Hall effect. We hypothesized that our HEC would have a rocksalt (face centered cubic) structure and chose our substrate, GGG, based off this prediction due to its structure and lattice constant.

Characterization Techniques

We used atomic force microscopy to map the topography of the thin film. Since a good contact surface is required by most technology applications, we must confirm that the material can produce a flat surface using PLD and secondly, find the growth parameters that provide a flat surface.

The spin Hall effect is maximized when the structural orientation of the atoms within the material are aligned; in other words, a crystalline structure will produce the greatest effect. We utilized x-ray diffraction techniques to measure if the thin film was crystalline; if the material was crystalline, we could extract the lattice constant and measure the thickness of the thin film.

Results

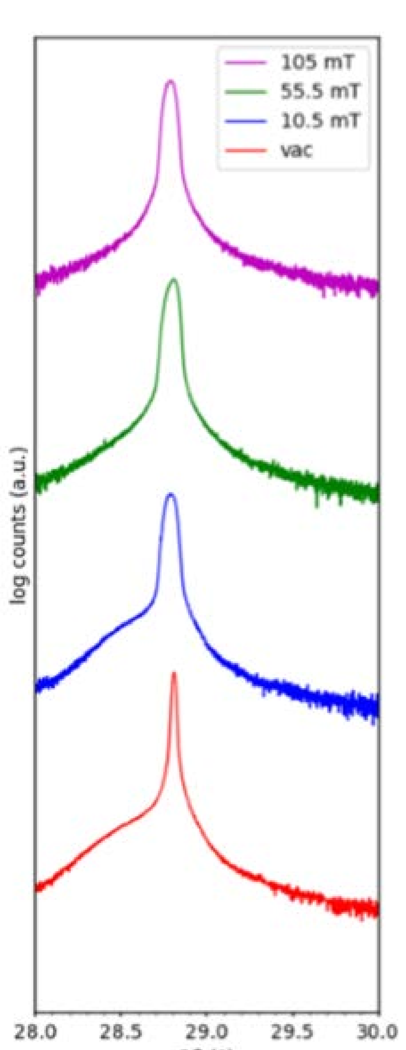
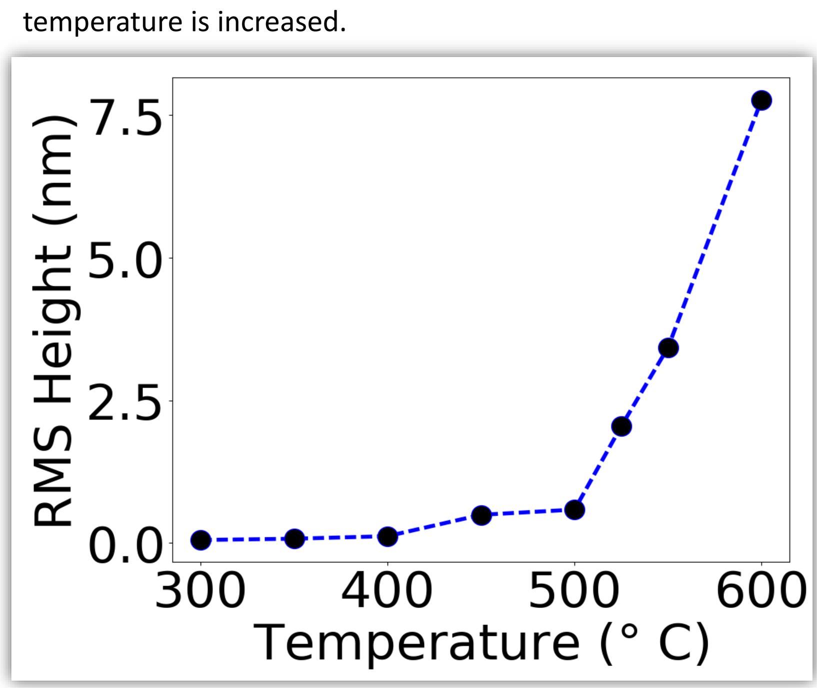


Figure 3: X-ray diffraction patterns taken of samples with substrate temperature 550° C and varying chamber pressures. Notice that the thin film peak is only detected at lower pressures.

Figure 4: AFM results for samples grown at vacuum with varying substrate temperatures. The roughness of the thin film increases in an exponential fashion as the substrate temperature is increased.



Discussion

Finding the growth parameters that produced a thin film with a smooth surface and crystalline structure completed the first stage of this project. Fabricating a thin film at a substrate temperature of 550° C at a chamber pressure of 10.5 millitorr would result in a thin film with a smooth surface and a crystalline structure, properties needed for the next stage of the project.

Future Work

Finding the growth parameters that produced a thin film with a smooth surface and crystalline structure completed the first stage of this project. Next, we need to test the spin Hall angle of the material. This is a measure of the strength of the induced spin current in relation to the applied current. We planned to utilize the Hall effect to extract the spin Hall angle experimentally (see figure 5). The Hall effect occurs when a current is pushed through a material and a transverse voltage is created. If an external magnetic field is applied while an alternating current is pushed through a ferromagnetic material (for experimental purposes shaped into a Hall bar), we can computationally extract the SHA of the HEC from the resulting Hall voltage [6]. Constructing the device pictured in figure 5 and measuring the material's SHA is the next step in the project.

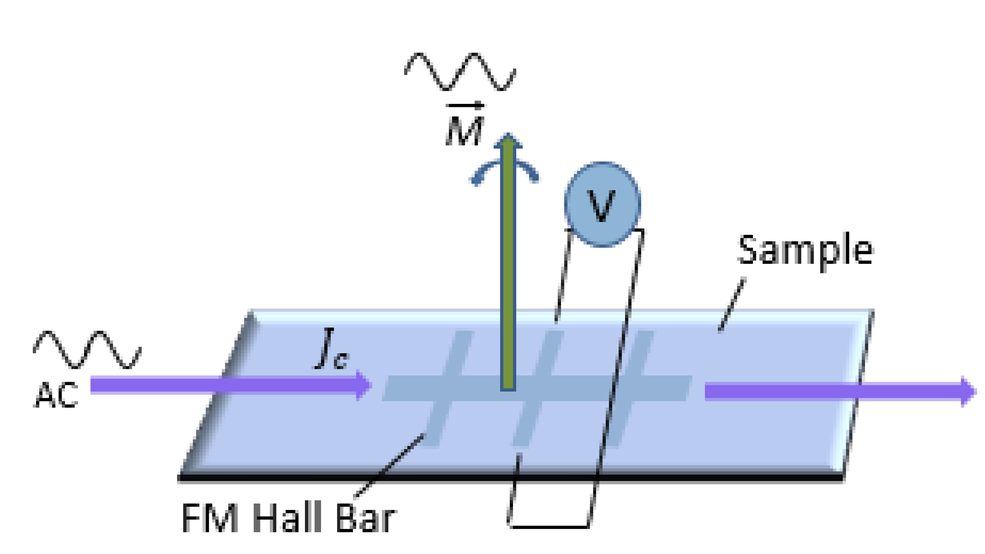


Figure 5: Proposed device to test the material's spin Hall angle.

Hall Effect → Magnetization Precesses → Measure Hall Voltage → Compute θ_{SH}

References

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