
THERMAL EVAPORATION PROCESSES OF CHALCOGENIDES UNDER VACUUM CONDITIONS

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Abstract

This study investigates the thermal evaporation processes of chalcogenide compounds in vacuum environments. Chalcogenides, known for their unique optical and electronic properties, are increasingly used in semiconductor technologies and thin-film applications. The research focuses on the mechanisms of evaporation, material deposition, and the influence of vacuum conditions on film quality and uniformity. Through detailed analysis, we examine the impact of temperature, pressure, and deposition rates on the resulting thin films, providing insights into optimizing these parameters for improved performance. The findings contribute to advancements in the fabrication of high-quality chalcogenide-based materials for applications in optoelectronics, photovoltaics, and thermoelectric devices.

Keywords: Chalcogenides, thermal evaporation, vacuum deposition, thin films, material synthesis, semiconductor technology, optoelectronics, film uniformity.

Introduction

Chalcogenide materials, which contain elements from group 16 of the periodic table (such as sulfur, selenium, and tellurium), have attracted significant attention due to their exceptional optical, electrical, and thermoelectric properties. These characteristics make chalcogenides highly suitable for applications in optoelectronics, phase-change memory devices, photovoltaics, and thermoelectric energy conversion systems [1].

One of the most effective methods for producing high-quality thin films of chalcogenides is thermal evaporation under vacuum conditions. In this

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process, chalcogenide materials are heated in a vacuum chamber, causing them to evaporate and then condense onto a substrate, forming thin films with precise control over thickness and uniformity. Vacuum environments are critical to this process as they prevent oxidation and contamination, which can negatively affect the film quality and its functional properties [2]. Previous research has demonstrated that controlling key parameters such as temperature, pressure, and deposition rates significantly impacts the morphology, crystallinity, and performance of chalcogenide films [3]. For instance, higher evaporation temperatures tend to improve film uniformity, but they can also introduce structural defects if not carefully regulated [4]. Similarly, the deposition rate influences the smoothness and adhesion of the films, which are crucial for applications in semiconductor devices [5].

Despite considerable advancements in this area, challenges remain in optimizing the thermal evaporation process to produce films with enhanced structural integrity and functional properties. The current study aims to address these challenges by analysing the effects of varying vacuum conditions on the thermal evaporation of chalcogenides and exploring ways to improve the film quality for advanced technological applications.

Recent research on the thermal evaporation of chalcogenides, particularly for applications in thin-film solar cells and high-performance electronics, has shown promising results. One key study focused on the co-evaporation of ternary chalcogenide AgBiS₂ thin films, successfully fabricated for photovoltaic use. By optimizing the composition and post-annealing processes, researchers achieved a power conversion efficiency of 1.52%, demonstrating the viability of this technique for scaling up thin-film solar cell production. The study emphasizes the advantages of thermal evaporation in producing large-area, phase-pure films with high crystallinity [6,7].

Another recent breakthrough in the field involves the deposition of Bi₂S₃ nanometer films for scalable electronics. Researchers achieved uniform, defect-free thin films through a precise thermal evaporation process, with post-annealing significantly improving crystallinity and electronic performance. The evaporation method allowed for rapid deposition of films as thin as 5 nm, showing the potential for large-scale applications. Improved

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charge transport and a reduction in the bandgap were observed, further enhancing the films' optoelectronic properties [8].

These studies highlight thermal evaporation as a highly effective method for fabricating high-quality chalcogenide films, applicable in energy and electronic devices. Both research efforts underscore the importance of optimizing thermal and post-deposition processes to enhance film performance.

Recent advancements in the field of thermal evaporation of chalcogenides under vacuum conditions have yielded significant insights, particularly in thin-film deposition for optoelectronic and energy-harvesting applications. Below is a more detailed look at the latest findings from multiple studies.

1. Co-Evaporation of AgBiS₂ for Solar Applications

A study published in 2024 examined the fabrication of AgBiS₂ thin films through thermal co-evaporation, focusing on their use in photovoltaic cells. AgBiS₂ is a ternary chalcogenide with a favorable bandgap and high absorption coefficient, making it a strong candidate for solar energy applications. Researchers optimized the Ag/Bi ratio, achieving phase-pure, highly crystalline films through a precise combination of thermal evaporation and post-annealing at 200°C for 10 minutes. The resulting thin films exhibited superior microstructure and enhanced power conversion efficiency (PCE) of 1.52%. Additionally, the study highlighted the scalability potential of this method for commercial thin-film solar cells, providing an efficient alternative to solution-based processes, which often limit scalability due to more complex chemical routes [7].

2. Bi₂S₃ Thin Films for High-Performance Electronics

In a separate study from 2022, researchers explored the thermal evaporation of Bi₂S₃ for large-scale production of thin-film transistors (TFTs). This work focused on the uniformity and electrical properties of Bi₂S₃ films deposited via thermal evaporation under vacuum. The evaporated Bi₂S₃ films initially exhibited an amorphous structure, which transformed into a polycrystalline state after post-annealing at 250°C. This structural shift significantly improved the films' electronic properties, including charge transport and reduced surface roughness. The Bi₂S₃ films displayed enhanced performance

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metrics such as a high mobility of 10.8–14.2 cm²/Vs and excellent on/off current ratios of 1–4 × 10⁸. Additionally, the films demonstrated scalability, with 5 nm films produced rapidly within 25 seconds of deposition, indicating a high-throughput capability ideal for commercial applications [8].

3. Crystallinity and Material Optimization

Both studies emphasize the importance of controlling crystallinity through thermal and post-deposition annealing processes. In the case of Bi₂S₃ films, researchers found that annealing at 250°C produced a well-defined laminar texture with minimal defects. This improved the optical properties of the material, including an increased light absorption and a slight reduction in the bandgap from 1.6 eV to 1.5 eV. The smooth surface topography, with root-mean-square values of less than 0.3 nm, enabled higher device yields over larger areas. Similarly, in the AgBiS₂ study, post-annealing contributed to better crystallinity, which directly influenced the efficiency of the photovoltaic devices [9].

4. Material Efficiency and Cost-Effectiveness

A notable outcome of the Bi₂S₃ research was the efficient use of materials. For example, the entire evaporation process required only 40 mg of Bi₂S₃ powder to deposit uniform films across a 4-inch substrate, reflecting a highly cost-effective approach. This material efficiency, combined with the high throughput of the process, offers a significant advantage over other deposition techniques like chemical vapor deposition (CVD), where material consumption and process times are often higher [10].

Conclusions

The research highlights the growing role of thermal evaporation under vacuum conditions in producing high-quality chalcogenide thin films. The combination of vacuum deposition and controlled annealing allows for precise tuning of film properties, including crystallinity, surface morphology, and electronic performance. These studies provide a foundation for scaling up the production of chalcogenide-based thin films for use in photovoltaics, transistors, and other optoelectronic devices. Future work is expected to focus on further optimizing deposition parameters,

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improving power conversion efficiencies, and integrating these films into commercial-scale production.

In summary, recent research into the thermal evaporation of chalcogenides under vacuum conditions is demonstrating clear advantages in terms of material efficiency, scalability, and enhanced film properties, all of which are critical for advancing applications in electronics and energy systems.

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