# Chapter 6
# Tailored Chalcogenide Materials for Eco-Efficient Electronic and Energy Systems

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## ABSTRACT

*Abstract: Chalcogenide-based materials, which are primarily made up of sulfur, selenium, and tellurium, have become an essential category of compounds for advanced optoelectronic and energy applications due to their distinctive electronic, optical, and thermal characteristics. These materials hold particular importance in the fields of photodetectors, solar cells, thermo electrics, and non-volatile memory devices. Their adjustable band gap, elevated refractive index, and capacity to create glassy phases render them suitable for sustainable energy solutions. This chapter delves into the synthesis, characterization, and application of chalcogenides, emphasizing recent developments and their contribution to facilitating environmentally friendly technologies. Through comparative analysis and experimental findings, we*

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*demonstrate how advancements in material engineering improve performance in energy harvesting and storage. We conclude by underscoring future opportunities and challenges in scaling these materials for commercial use.*

## INTRODUCTION

Chalcogenide materials, composed primarily of elements from group 16 of the periodic table namely sulfur (S), selenium (Se), and tellurium (Te) constitute a significant class of semiconductors that exhibit a wide range of electrical, optical, and thermal properties. Their ability to form both crystalline and amorphous phases, combined with high polarizability and strong spin-orbit coupling especially for heavier chalcogens like Te, has positioned them as key candidates in emerging applications across optoelectronics, energy conversion, and sustainable material technologies, (Tari et al., 2022). Unlike conventional semiconductors such as silicon (Si) or gallium arsenide (GaAs), chalcogenides possess a tunable bandgap that can be modified by varying their composition, stoichiometry, and synthesis conditions. This tunability, along with their high refractive index and non-linear optical coefficients, makes them particularly valuable for infrared (IR) optics, photodetectors, phase-change memory devices, and photovoltaic absorbers. Concentrated Examination: SnS, $Sb_2Se_3$, and CZTS in Energy Frameworks - Chalcogenide substances like tin sulfide (SnS), antimony selenide ($Sb_2Se_3$), and copper zinc tin sulfide (CZTS) have received considerable focus for their use in environmentally friendly electronic and energy systems, mainly in photovoltaics and thermoelectrics. These materials present a hopeful combination of earth availability, eco-friendliness, adjustable electronic characteristics, and affordable production, positioning them as appealing substitutes for conventional hazardous or costly semiconductor substances, (Tari et al., 2025; Wani, Tari, V& Mansoor, 2025). Tin Sulfide (SnS): SnS is a p-type semiconductor featuring a direct bandgap around 1.3 eV, making it highly appropriate for photovoltaic absorber layers that exhibit robust intrinsic light absorption within the visible spectrum. It is also appreciated for its favorable environmental characteristics and affordable material cost.

## LITERATURE REVIEW

Numerous studies have shown SnS thin films created through chemical bath deposition and thermal evaporation. For instance, SnS solar cells at the laboratory scale have demonstrated power conversion efficiencies (PCE) between 4%, which, although modest in comparison to silicon cells, are significant given their afford-

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