


Chapter 4


Transition Metal Chalcogenides, Bimetallic Chalcogenides, Perovskites, and Nanocomposites: Advanced Materials for Optoelectronic and Thermoelectric Applications

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ABSTRACT

The accelerating advancement of modern technologies underscores an urgent need for the design and development of next-generation materials that exhibit multifunctionality, property tunability, and superior performance across a spectrum of applications. This chapter investigates into the state-of-the-art progress in four essential material systems such as transition metal chalcogenides (TMCs), bimetallic chalcogenides (BMCs), perovskites, and nanocomposites, which have emerged as frontrunners in the realms of optoelectronics and thermoelectrics. Transition metal chalcogenides, offer a versatile platform for applications ranging from photodetection and photovoltaics to thermoelectric energy conversion. The integration of bimetallic species within chalcogenide matrices introduces synergistic enhancements. The incorporation of these materials into nanocomposite architectures further enables tailored interfacial engineering

INTRODUCTION

The search for multipurpose and energy-efficient materials has accelerated in recent decades due to the rapid advancement of modern electronic, optoelectronic, and thermoelectric technology (Bal & Rani, 2025; Nallusamy et al., 2025; Sun et al., 2025; Kannan K. & Tari V. 2025). Extensive research efforts have been sparked by this increasing demand to design and engineer improved functional materials that can seamlessly integrate energy generation, conversion, and storage. Because of their remarkable physical, chemical, electrical, and thermal properties, Transition Metal Chalcogenides (TMCs), Bimetallic Chalcogenides (BMCs), Perovskites, and Nanocomposites have become especially interesting candidates among the many material systems being investigated (Choubey & Yadav, 2024; Jana et al., 2025; Njema & Kibet, 2025).

The typical formula for transition metal chalcogenides is MX_2 , where M stands for a transition metal and X for a chalcogen, such as tellurium, sulfur, or selenium. These compounds are distinguished by their high carrier mobilities, tunable bandgaps, strong light–matter interactions, and adaptable layered architectures (Panigrahy et al., 2024). They are perfect for next-generation thermoelectric and optoelectronic applications because of these features. In comparison to their monometallic counterparts, bimetallic chalcogenides, which combine two different metal species, produce higher electrical conductivity, catalytic activity, and structural robustness, further improving functional performance through synergistic effects (Giuffredi et al., 2021). Perovskite materials have transformed the fields of photovoltaics and photodetectors, especially halide perovskites with the general formula ABX_3 . Due

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