Chapter 14

Chalcogenide-Based Nanocomposites for CO2 Transformation Into Valuable Chemicals and Clean Energy Generation

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ABSTRACT

Optimizing the interaction between the nanocomposites and CO2, researchers aim to develop sustainable methods for producing essential chemicals while simultaneously addressing environmental concerns related to carbon emissions. This innovative strategy not only contributes to resource recovery but also supports the transition towards a more sustainable energy. Therefore, in this chapter, we explore the concept of chalcogenide nanocomposites for CO2 transformation into valuable chemicals and clean energy generation. In addition, by addressing a significant gap in renewable energy research, this chapter offers comprehensive guidance for researchers working on the development of chalcogenide-based materials specifically designed for CO2 transformation into valuable chemicals and clean energy generation.

DOI: 10.4018/979-8-3373-3962-7.ch014

INTRODUCTION

Chalcogenide-based nanocomposites represent a new class of advanced materials that integrate the unique properties of chalcogenides with nanoscale architectures, thereby enhancing their performance across a wide range of applications. Metal chalcogenide nanoparticles are employed in diverse devices, including fuel cells, solar cells, light-emitting diodes (LEDs), ion batteries, supercapacitors, thermoelectric systems, semiconductor diode lasers, photovoltaic cells, optoelectronic devices, sensors, and bioelectronic components, owing to their remarkable physical and chemical characteristics (Adabala and Dutta, 2022; Kannan & Tari, 2024). In addition, chalcogenides play a vital role in photocatalysis (Varadharajan et al., 2024; Kannan et al., 2021), particularly in hydrogen generation via water splitting (Kannan et al., 2023), battery technologies (Gurushankar et al., 2025), carbon dioxide conversion into fuels (Sliem et al., 2025; Kannan et al., 2020; Sadasivuni et al., 2022; Kumar et al., 2022) and selective oxidation processes (Bajpai et al., 2015). Structurally, chalcogenides are compounds composed of one or more chalcogen elements, primarily sulfur (S), selenium (Se), or tellurium (Te), in combination with more electropositive elements such as metals or metalloids.

At the nanoscale, these materials show different properties regarding electricity, light, heat, and strength because of quantum effects, a large surface area compared to their volume, and the ability to control interfaces at the atomic level, (Wani et al., 2025; Tari et al., 2025).

When these nanostructures are mixed with a composite material such as a polymer, metal, or ceramic, the resulting nanocomposites often have improved or entirely new properties compared to their bulk forms or traditional counterparts, (Tari et al. 2022).

Key Characteristics of Chalcogenide-Based Nanocomposites

1. High Tunability: The physical and chemical properties of chalcogenides can be changed by altering their composition, structure, and size.
2. Phase-Change Behavior: Many chalcogenides, especially those used in phase-change memory (like the Ge-Sb-Te system), can switch between amorphous and crystalline states, making them useful for data storage.
3. Optoelectronic Properties: Chalcogenide glasses have a high refractive index, infrared transparency, and photoconductivity, which make them valuable in photonics and infrared sensing.
4. Thermoelectric Potential: Chalcogenide nanocomposites can perform better in thermoelectric applications because they have lower thermal conductivity and maintain or even improve their electrical conductivity.

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