Chapter 3
Emerging Materials for Energy Storage and Environmental Applications

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ABSTRACT

The advent of new materials offers promising solutions for enhancing energy storage systems, improving energy efficiency, and mitigating environmental impacts. These advanced materials are characterized by their unique properties, which enable them to address the limitations of conventional materials and contribute to innovative technologies in various fields. In the realm of renewable energy, emerging materials are transforming photovoltaic technology. Traditional silicon-based solar cells are being complemented by new materials such as perovskite solar cells, organic photovoltaics, and quantum dots. Perovskite materials, known for their exceptional light absorption and charge transport properties, have demonstrated the potential for high-efficiency, low-cost solar cells with ease of fabrication. Organic photovoltaics, which use organic compounds to convert sunlight into electricity, offer flexibility and lightweight characteristics, making them suitable for a range of applications from wearable electronics to building-integrated photovoltaics.

DOI: 10.4018/979-8-3693-7974-5.ch003

INTRODUCTION TO EMERGING MATERIALS FOR ENERGY STORAGE AND ENVIRONMENTAL APPLICATIONS

The advent of new materials offers promising solutions for enhancing energy storage systems, improving energy efficiency, and mitigating environmental impacts. These advanced materials are characterized by their unique properties, which enable them to address the limitations of conventional materials and contribute to innovative technologies in various fields. In the realm of renewable energy, emerging materials are transforming photovoltaic technology. Traditional silicon-based solar cells are being complemented by new materials such as perovskite solar cells, organic photovoltaics, and quantum dots. Perovskite materials, known for their exceptional light absorption and charge transport properties, have demonstrated the potential for high-efficiency, low-cost solar cells with ease of fabrication. Organic photovoltaics, which use organic compounds to convert sunlight into electricity, offer flexibility and lightweight characteristics, making them suitable for a range of applications from wearable electronics to building-integrated photovoltaics. Quantum dots, with their tunable bandgaps, enable the development of highly efficient solar cells that can capture a broader spectrum of sunlight. The pursuit of sustainable energy solutions has also spurred innovation in energy harvesting materials. These materials are designed to capture and convert ambient energy sources—such as solar, wind, thermal, and mechanical energy—into usable electrical power. Emerging materials for energy harvesting include thermoelectric materials, piezoelectric materials, and triboelectric nanogenerators. Thermoelectric materials, which convert temperature differences into electrical voltage, are being improved with materials like skutterudites and half-Heusler alloys to enhance efficiency. Piezoelectric materials, such as certain ceramics and polymers, generate electricity from mechanical stress and are used in applications ranging from self-powered sensors to energy-harvesting devices. Triboelectric nanogenerators exploit the contact electrification effect to convert mechanical energy into electrical energy, with applications in wearable devices and low-power electronics.

Environmental Remediation Materials: In addressing environmental challenges, emerging materials play a crucial role in pollution control and environmental remediation. Nanomaterials, including nanocapsules, nanofibers, and nanoparticles, are being utilized for their high surface area-to-volume ratio and reactivity to target and remove contaminants from air, water, and soil. For instance, magnetic nanoparticles are employed in water treatment processes to remove heavy metals and organic pollutants through magnetic separation (Kumar, R., et al., 2024). Photocatalytic materials, such as titanium dioxide and graphitic carbon nitride, can degrade organic pollutants under light irradiation, offering an effective method for water purification and air purification. Additionally, advanced sorbents, including biochar and engineered activated carbon, are used to capture and immobilize pollutants, enhancing the efficiency of soil and water remediation efforts.

Smart Materials for Environmental Monitoring: Emerging smart materials with sensing and responsive capabilities are enhancing environmental monitoring and management. These materials include responsive polymers, nanosensors, and smart coatings that can detect and react to environmental changes such as pollution levels, temperature variations, and humidity. Responsive polymers change their properties in response to environmental stimuli, providing real-time feedback on pollution levels or hazardous conditions. Nanosensors offer high sensitivity and specificity for detecting trace contaminants and environmental pollutants. Smart coatings, which can change color or exhibit other visual indicators in response to environmental changes, are being used for monitoring infrastructure health and environmental conditions.

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