Influence of Nanoparticles and Carbon Nanotubes on Electrical Characteristics of Natural and Organic Dye-based Cell

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Abstract

Organic dye-based electrical research is vital today due to its role in creating low-cost, flexible, and eco-friendly technologies. Dyes used in solar cells, sensors, and electronic devices enable sustainable energy solutions and support green electronics. Their tunable properties, ease of production, and potential use in flexible or wearable tech make them ideal for next-generation applications in energy, healthcare, and environmental monitoring. This research explores the enhancement of charge transport and electrical conductivity in organic dye-based semiconducting devices through the incorporation of nanostructured materials such as titanium dioxide (TiO_2), zinc oxide (ZnO) nanoparticles, and multi-walled carbon nanotubes (MWCNTs). Organic dyes like Brilliant Blue (BB), Sunset Yellow (SY), and Carmoisine offer advantages such as flexibility, sustainability, and low cost. However, their performance is limited by inherent structural and energetic disorders, including disordered molecular packing, high trap densities, and localised states, which hinder efficient charge carrier mobility. Chapter 1 focuses on identifying the key mechanisms behind poor conductivity in these materials, laying the foundation for understanding how nanomaterials can improve electronic performance. Chapter 2 provides a comprehensive theoretical analysis of the electrical behaviour of organic dye-based cells, highlighting the critical role played by nanoparticles and carbon nanotubes in modulating trap-assisted conduction, energy level alignment, and hopping mechanisms. Chapter 3 examines the impact of TiO_2 nanoparticles on BB dye-based metal–semiconductor (MS) contact cells. The incorporation of TiO_2 reduces barrier inhomogeneity and enhances interfacial uniformity, as evidenced by temperature-dependent I–V measurements and Gaussian distribution analysis of the barrier height. Capacitance-voltage (C–V) and frequency-dependent measurements further confirm the improvement in charge injection efficiency and dielectric behaviour. Chapter 4 investigates ZnO-doped SY devices, demonstrating that ZnO nanoparticles significantly reduce activation energy from 0.683 eV to 0.532 eV at low temperatures and improve charge mobility. The charge transport follows the Correlated Barrier Hopping (CBH) model, with a notable decrease in hopping length, indicating reduced spatial disorder and enhanced conduction. Chapter 5 explores MWCNT incorporation into Carmoisine-based devices. MWCNTs form percolation networks that serve as efficient conductive pathways and introduce shallow traps that facilitate thermally activated hopping. These effects lead to lower activation energy, shorter hopping distances, and enhanced carrier mobility, contributing to improved electrical behavior.

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