MORPHOLOGICAL ANALYSIS OF IMPURITY ATOM CLUSTERS IN SEMICONDUCTORS TO ENHANCE ENERGY EFFICIENCY

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Abstract. *This article examines the relationship between impurity atom clustering in semiconductors and the enhancement of energy efficiency in electronic materials. The study focuses on the morphological characterization of nickel impurity clusters in monocrystalline silicon obtained through diffusion doping at controlled temperatures. Various analytical methods, including scanning electron microscopy (SEM) and Hall effect measurements, were employed to determine the structural and electrophysical changes occurring in the doped material. The findings reveal that the diffusion temperature and time significantly influence cluster formation, morphology, and the resulting electrical conductivity. The research highlights that controlled clustering of impurity atoms can lead to improved carrier mobility and reduced energy dissipation, thereby enhancing the overall efficiency of semiconductor devices used in renewable energy systems.*

Keywords: *Semiconductors, nickel doping, impurity clusters, morphology, energy efficiency, silicon.*

Introduction. Modern semiconductor technologies are increasingly focused on achieving higher energy efficiency through microstructural and morphological optimization of materials. Silicon, as the most widely used semiconductor, remains at the forefront of this pursuit. Doping silicon with transition metals such as nickel introduces unique electrical and thermal properties by forming impurity clusters that can alter carrier dynamics. Understanding how these clusters form, interact, and influence electrical behavior is essential for developing energy-efficient semiconductor devices.

Methodology. High-purity silicon wafers were doped with nickel through high-temperature diffusion. Experimental conditions varied between 1100 K and 1300 K, with diffusion times from 30 to 120 minutes. The microstructural morphology was characterized using SEM and energy-dispersive X-ray spectroscopy (EDX), while electrical properties were measured through Hall effect analysis. These methods allowed correlation between the size, shape, and distribution of nickel clusters and the material's electrical performance.

Results and Discussion. The study revealed that lower diffusion temperatures (1100–1150 K) led to the formation of small, uniform clusters (0.2–0.5 μm), while higher temperatures produced larger and irregular aggregates exceeding 1 μm. The optimized cluster morphology improved charge carrier mobility by up to 18% and reduced resistive losses by approximately 12%. These morphological improvements were also linked to enhanced thermal stability and decreased recombination centers, making nickel-doped silicon suitable for photovoltaic and thermoelectric device applications.

Conclusion. Controlled nickel doping of silicon enables precise tuning of morphological and electrical characteristics, contributing to energy-efficient semiconductor materials. The study underscores the importance of morphological control in impurity cluster formation to optimize performance in renewable energy applications. Future research should focus on integrating nanoscale cluster modeling with experimental analysis to further refine the energy conversion efficiency of such materials.

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