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SYNERGETIC DESIGN OF Si@B-C/rGO CORE-SHELL NANOSTRUCTURES FOR HIGH-STABILITY LITHIUM-ION BATTERY ANODES

Azaizia A. (ITMO University)

Scientific supervisor – Associate professor, PhD Dorogov M.V. (ITMO University)

Lithium-ion batteries (LIBs) are essential for modern energy storage, powering devices from smartphones and laptops to electric vehicles and renewable energy systems. Conventional graphite anodes, with a capacity of approximately 372 mAh/g, fall short of the energy demands of emerging technologies. Silicon (Si) and silicon dioxide (SiO₂), with theoretical capacities of ~4200 mAh/g and ~1965 mAh/g respectively, present highly promising alternatives. However, their practical application is limited by significant volume expansion (up to 300%) and poor cycling stability during charge-discharge cycles. Both domestic and international studies have explored alternative materials such as transition metal oxides and tin-based compounds [1,2], yet these too suffer from structural degradation. This report proposes the development of advanced composite anodes by integrating Si or SiO₂ cores with a boron-doped carbon (B-C) shell and a reduced graphene oxide (rGO) network to overcome these inherent challenges through a multi-layered protective architecture [3,4].

The proposed solution is implemented using a multi-stage chemical synthesis. At the first stage, a graphene oxide (GO) is synthesized via a modified Hummer's method, where natural graphite is oxidized using concentrated sulfuric acid and specific oxidizing agents, followed by purification through dialysis and sonication [3]. Simultaneously, the active cores (Si and SiO₂) are synthesized or modified using a sol-gel method. For SiO₂-based composites, tetraethyl orthosilicate is hydrolyzed to ensure uniform particle size. To enhance electronic conductivity and Li-ion diffusion kinetics, the particles are coated with a boron-doped carbon layer through the carbonization of a polymer precursor (e.g., glucose) mixed with a boron source (boric acid). Boron atoms act as p-type dopants, creating vacancies in the carbon lattice that facilitate faster ion transport. Finally, the B-C coated nanoparticles are anchored onto the GO framework via a hydrothermal process, followed by thermal reduction to form the Si@B-C/rGO and SiO₂@B-C/rGO composites. Advanced characterization techniques, including SEM, TEM, and XRD, are utilized to verify the "pomegranate-like" morphology, where the B-C shell acts as a primary buffer and the rGO network provides long-range electrical connectivity [3].

This study demonstrates that the integration of silicon-based cores with a dual-layer protection of boron-doped carbon and rGO effectively mitigates the drawbacks of traditional silicon anodes. While Si@B-C/rGO offers higher initial capacity, the SiO₂@B-C/rGO composite is expected to show superior cycling stability due to the lower absolute volume change of the oxide matrix and the robust buffering effect of the B-C/rGO layers. The proposed synthesis approach, combining sol-gel and modified Hummer's methods, is cost-effective and scalable. The practical implications are significant: the synergetic effect of heteroatom doping (Boron) and the conductive graphene network addresses the critical need for high-performance, long-lasting LIBs. Future work will focus on optimizing the boron doping concentration and evaluating the full-cell performance against commercial cathodes to ensure industrial viability.

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