From Waste to Energy Storage: Spent Catalyst–Derived Carbon Nanotubes for Fast-Charging Lithium-Ion Battery Anodes

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Abstract

Repurposing spent catalysts as energy storage materials provides a sustainable pathway to address environmental challenges, reduce energy consumption, and deliver economic benefits. Spent catalysts derived from methane decomposition are often discarded as waste and typically require energy-intensive treatments—such as high-temperature oxidation or chemical leaching—to recover valuable metals. In this work, we present an alternative strategy that employs acid digestion to purify spent catalysts and extract multi-walled carbon nanotubes (MWCNTs), which are subsequently used as high-performance anodes for lithium-ion batteries. Comprehensive structural and compositional analyses confirm that extended acid digestion effectively removes residual metallic impurities while preserving the integrity of the CNT framework. The purified MWCNT anode delivers an impressive specific capacity of 648 mAh g^{-1} at 0.1 C and exhibits excellent cycling stability over 1,000 cycles at 1 C. These superior electrochemical properties are attributed to the porous architecture and high electrical conductivity of the CNT network, which together facilitate rapid lithium-ion transport and efficient charge transfer. Moreover, the material exhibits elevated lithium-ion diffusion coefficients (10^{-13}–10^{-11} cm^2 s^{-1}) and multiple interconnected conductive pathways, facilitating fast Li-ion insertion and extraction. This combination of structural and transport advantages makes the purified CNTs particularly well-suited for fast-charging lithium-ion battery technologies. Overall, this study establishes a viable upcycling strategy for transforming industrial spent catalysts into high-value materials for next-generation lithium-ion energy storage applications.

References

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Figures

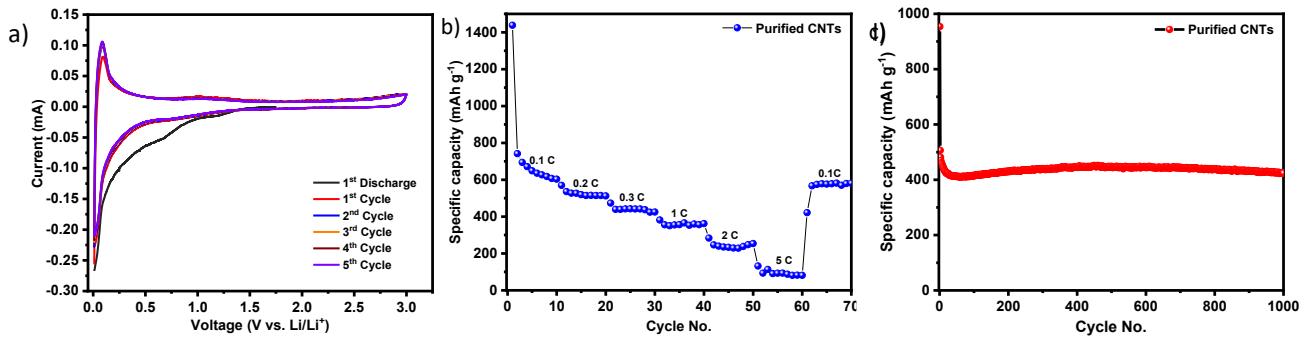

Figure 1: a) CV at 0.1 mV s−1, b) rate capabilities (0.1–5 C rate), and c) cycling stability at 1C