Electrochemical Performance of Deep Discharged $Li_4Ti_5O_{12}$ Anode Material for Lithium-Ion Batteries

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Lithium titanate ($Li_4Ti_5O_{12}$, LTO) is considered a promising anode material for next-generation lithium-ion batteries due to its excellent thermal stability, long cycle life, and intrinsic safety [1]. Its "zero-strain" property during Li^+ intercalation/deintercalation minimizes volume change and ensures outstanding structural stability [2]. The relatively high voltage plateau (~1.55 V vs. Li/Li^+) suppresses lithium dendrite formation, providing superior safety compared with graphite anodes [3]. The spinel structure of LTO offers abundant Li-ion sites, allowing a theoretical capacity of 293 mAh g^{-1} when Ti^{4+} is fully reduced to Ti^{3+} under deep-discharge conditions near 0 V [4]. However, most studies have examined the 1.0–3.0 V range, with limited attention to performance below 1.0 V [4]. To improve conductivity and Li^+ diffusivity, doping at Ti or Li sites and *in situ* or *ex situ* carbon coating are effective strategies that enhance electrochemical performance and rate capability [5].

In the present work, we investigate the electrochemical behavior of Na- and Yb-co-doped, carbon-coated LTO anodes under deep-discharge conditions at room temperature. Pristine $Li_4Ti_5O_{12}$ (LTO) and $Li_{3.98}Na_{0.02}Ti_{4.98}Yb_{0.02}O_{12}$ (LTO–Na–Yb), along with their carbon-coated derivatives (LTO@C and LTO–Na–Yb@C), were synthesized via a conventional solid-state reaction method. The carbon-coated variants were further prepared through an *ex situ* pyrolysis process using organic carbon precursors. Galvanostatic charge–discharge tests were conducted within the potential range of 3.0–0.01 V at current densities of 30, 300, and 500 mA g^{-1}, respectively. Structural, morphological, and electrochemical properties were comprehensively characterized using X-ray diffraction (XRD), field-emission scanning electron microscopy (FESEM), galvanostatic cycling, cyclic voltammetry (CV), and electrochemical impedance spectroscopy (EIS).

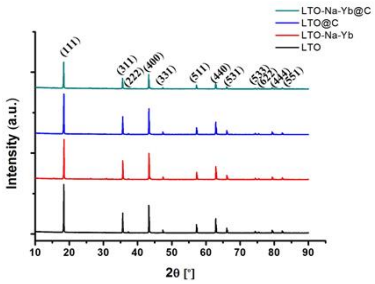

Fig.1. XRD patterns of the pristine LTO and LTO-Na-Yb, LTO@C, LTO-Na-Yb@C.

The phase purity was analyzed by XRD (PANalytical Empyrean, Cu–Kα, 2θ = 10–90°). As shown in Fig. 1, both LTO and doped-coated anodes exhibit diffraction peaks consistent with the cubic spinel structure (JCPDS No. 72-0426). All diffraction peaks correspond to pure cubic LTO, and the refined lattice parameter of pristine LTO and LTO–Na–Yb materials were determined as 8.357 Å and 8.359 Å, respectively.

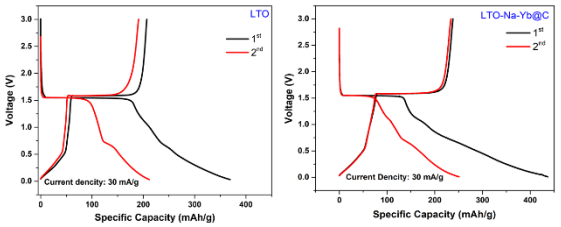

Fig 2. The charge-discharge profiles of LTO and LTO-Na-Yb@C anodes at 30 mA/g in the range of 0.02–3 V (vs. Li/Li^+)

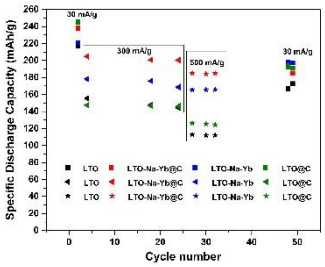

Fig. 3. Rate capabilities of LTO and LTO-Na-Yb, LTO@C, LTO-Na-Yb@C anode materials

As can be seen in Figs. 2 and 3, among all the as-prepared composite anodes, LTO–Na–Yb@C delivers the highest initial discharge capacity across various current densities. Furthermore, it exhibits superior rate capability compared with pristine LTO, LTO–Na–Yb, and LTO@C at 30, 300, and 500 mA /g.

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