

Abstract

Sodium ion batteries (SIB's) have become a popular area of research in recent years due to their low cost and high sustainability compared to the current lithium-ion technology. The abundance of sodium on Earth makes sodium-based batteries a viable option for portable electronic devices, electric vehicles, and in grid sized energy storage applications. Although, SIB's are a good alternative to lithium ion batteries (LIB's) there are still improvements that need to be made before commercially produced (SIB's) can compete with the overall performance of (LIB's). The improvements needed include an increase in the capacity, in the cycle life, and in the voltage of the batteries. Improvements in these areas can be realized through the development of high-performance sodium-based cathode materials, specifically sodium transition metal oxide materials. The research presented here deals with cobalt-free $\text{Na}_{0.6}\text{Fe}_{0.5}\text{Mn}_{0.5}\text{O}_2$ (NFM) based cathode materials and a number of copper and vanadium doped variations. The focus of this research is on improving the electrochemical performance of sodium ion batteries through the stabilization of the transition metal oxide cathode structure. The main areas of improvement that are achieved in this research is minimizing the effects of Jahn-Teller distortion on the transition metal oxide layers and increasing the distance between the transition metal oxide layers by doping with copper and vanadium. Alleviating the Jahn-Teller distortion will improve the structural stability of the P2-type cathode material and promote higher cyclability in the battery. Multiple structural analysis tools and techniques were used to determine how the copper and vanadium doping effected the P2-type structure of the cathode material. The material characterization was performed using the Rigaku Ultima IV diffractometer with an ultra-high-speed detector over the range from 10° to 80° at a scan speed of $2^\circ/\text{min}$ with Cu K α radiation (power setting 40kV, 44mA). Rietveld refinements on the XRD patterns as well as a thorough analysis of the lattice parameters and d-spacing were performed to determine the effects of the Cu and V doping (1%, 2%, 3%, and 5%) with respect to the pristine NFM cathode material. The pristine NFM cathode material resulted in a P2-type crystal structure with lattice parameters of $a=b=2.9170\text{\AA}$ and $c=11.3032\text{\AA}$ which resulted in the d-spacings of $2.043\text{\AA}$ in the transition metal oxide layer and $3.607\text{\AA}$ in the sodium layer. The 1% doped cathode material resulted in an increase in the d-spacing of the transition metal oxide layer and a decrease in the d-spacing of the sodium layer. The 2% doped cathode material resulted in a decrease in the d-spacing of the transition metal oxide layer and an increase in the d-spacing of the sodium layer with respect to the 1% doped cathode material. This change in d-spacing could show a trend with respect to a higher percentage of doping with Cu and V. Morphological assessment of the pristine and doped NFM cathode materials were performed using scanning electron microscopy (SEM) with energy dispersive X-ray analysis (EDAX). All the synthesized samples had prismatic hexagonal shaped particles conforming to the space group P63/mmc and having an average size in the range of $1\text{-}5\mu\text{m}$. The elemental mapping results verified a homogeneous distribution of Cu and V throughout the cathode material. It was observed that all the elements were evenly dispersed throughout the surface, confirming uniform doping into the crystal structure.