RuO_2 as Cathode Material of Thin Film Lithium Ion Batteries (LIB)

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Technologies for the Internet of Things (IoT) are being developed for a vast number of networking applications. Thin film batteries are important for IoT systems as they are better integrated within an integrated circuit (IC) and can store energy that is harvested by green generators (e.g. solar cells) and provide it to sensors. RuO_2 had been found to have a larger specific capacity compared to other cathode materials of lithium ion batteries (LIB), and thus is a good candidate as a cathode material of thin film LIB. We are currently studying the reaction mechanism of RuO_2 and lithium in parallel with the fabrication of full battery devices.

To analyze the mechanism of lithium storage in thin film RuO_2, we performed cyclic voltammetry (CV) tests with varying lower limits, as shown in Figure 1. Surprisingly, the lithiation process consists of 3 peaks while the delithiation process consists of 4 peaks. Moreover, the 3rd delithiation peak does not appear in a sequential order relative to the other delithiation peaks. To reveal the correspondence between the peaks and specific reactions, ex-situ cross sectional TEM, electron diffraction, Raman spectroscopy and XPS are currently being used.

In addition to characterizing the lithiation of RuO_2, we have also built full battery devices that include a lithiated Si anode, a lithium phosphorous oxynitride (LiPON) electrolyte, and RuO_2 cathode. Figure 2 shows the cycle performance of the microbattery at a rate of C/10. It could deliver a highly reversible capacity of approximately 150 μAh cm^{-2} $μm^{-1}$ after 100 cycles, which is still 2.5 times higher than commercial CYMBET microbatteries. On-going work is focused on improving the cyclability of the RuO_2 and silicon anodes through stress engineering, as well as improving the volumetric capacity through process improvements. These initial results suggest a promising route towards IC integratable batteries for on-chip power delivery.

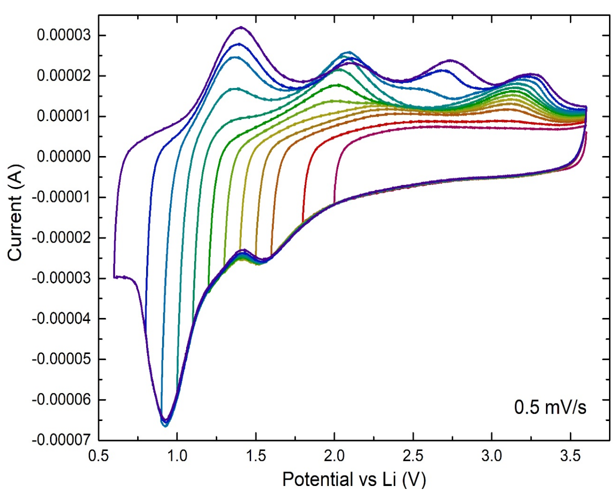

Figure 1: CV scans with varying lower limit of RuO_2 thin film. Counter electrode was Li metal, and electrolyte was 1M $LiPF_6$ in 1:1(v:v) EC/DMC.

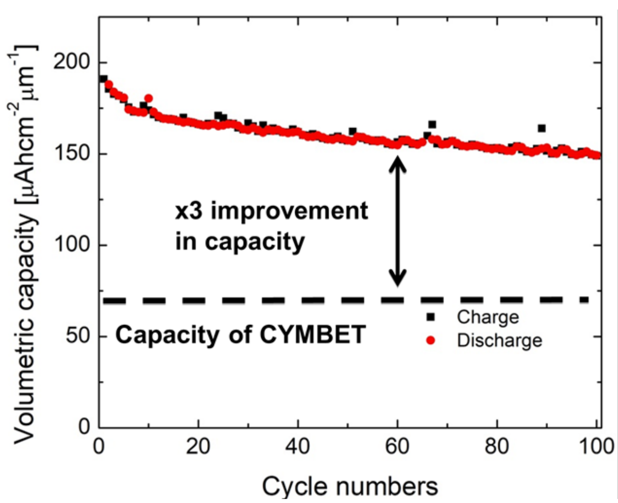

Figure 2: Cycle data of thin film RuO_2/LiPON/Li-Si full batteries.

Further Reading

- A. Al-Obeidi, D.K. Kramer, S. T. Boles, R. Mönig, and C. V. Thompson, "*Mechanical Measurements on Lithium Phosphorous Oxynitride Coated Silicon Thin Film Electrodes for Lithium-ion Batteries during Lithiation and Delithiation,*" *Appl. Phys. Letts.* **109**, 071902 (2016)
- Balaya, P., Li, H., Kienle, L., & Maier, J. (2003). "*Fully reversible homogeneous and heterogeneous Li storage in RuO_2 with high capacity*". *Advanced Functional Materials*, 13(8), 621–625.