In situ Studies of Lithium Ion Batteries using Stray Field Imaging

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Introduction

Examining the physical properties of solid materials as they are being utilized would provide highly useful information to improve and further develop their functions. *In situ* studies are often difficult to execute since in many cases the technique is destructive or the sample is chemically/physically altered. Magnetic resonance methods, such as imaging or spectroscopy, are often utilized since they are non-invasive allowing for a true representation of the mechanisms occurring during the *in situ* study. One material that has garnered much attention within the past few decades is lithium based materials for secondary batteries. The charge-discharge mechanism of Li-rechargeable batteries is important to understand so that their energy capacitance, efficiency and cycle lifetime can be improved. Most often, however, the fine details required to examine the surface layers of the battery electrodes are not easily attainable with conventional magnetic resonance imaging (MRI) methods since extremely strong gradients are not producible with typical setups. An alternative approach to MRI is stray field imaging (STRAFI) where the strong magnetic field gradients (> 50 T/m) in the fringe field of a superconducting magnet are exploited. In this work we use a high-resolution STRAFI probe with charge-discharge capabilities to study Li-ion batteries *in situ*.

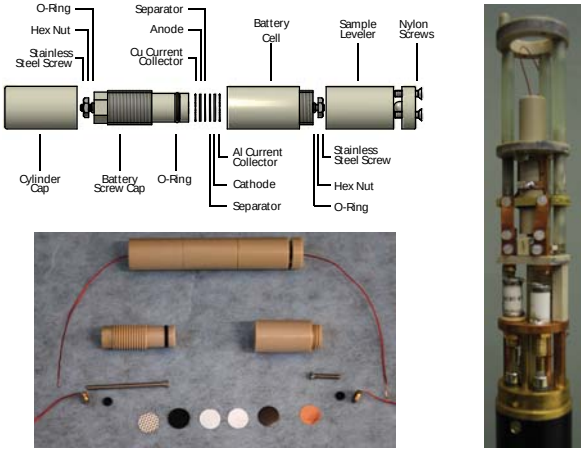

Fig. 1: *in situ* battery cell (left) used for charge/discharge STRAFI studies. The cell attached to the STRAFI probe (right)

Experimental

A 19.6 T magnet with a Bruker DRX console, using a custom single channel broad band probe with electrical leads (Fig. 1) [1] were utilized for ^{7}Li STRAFI studies. The sample translated through the uniform XY field gradient and at each step the signal intensity was measured and plotted with respect to position generating the 1D image profile. Battery electrodes were purchased from MTI Corporation and thoroughly dried prior to cell assembly. The battery consisted of a $LiFePO_4$ electrode and Li foil separated by a Celgard membrane and $LiPF_6$ electrolyte.

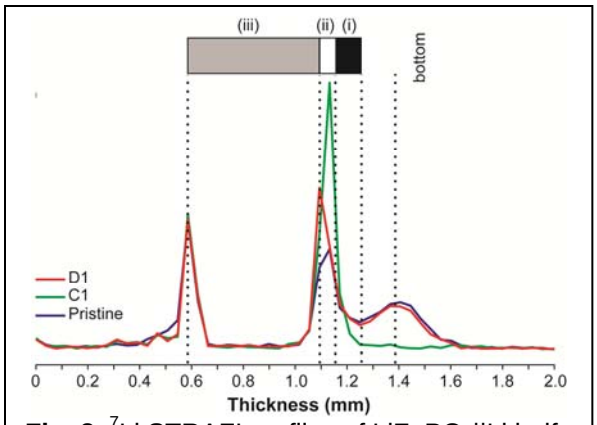

Fig. 2: ^{7}Li STRAFI profiles of $LiFePO_4$||Li half-cell battery after a charge (C1, green) and discharge (D1, red) cycle. (i) $LiFePO_4$ electrode, (ii) separator layers consisting of two Celgard 3501 membranes, and (iii) Li foil.

Results and Discussion

Fig. 2 shows the 1D profile of the LiFePO4||Li half-cell battery after charge/discharged states. The two sharp peaks in the left side are attributed to skin effects on the metal's surface. As the battery is charged, the Li content of the cathode depletes as the anode surface increases. Similarly as the battery is discharged, the flow reverses and the original states are almost regained [2].

Conclusions

STRAFI is an alternative method to provide high resolution images for in situ studies of battery cells.

Acknowledgements

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References

[1] Tang J.A., *et al*., Journal of Magnetic Resonance, **225**, 93-101 (2012).
[2] Tang J.A., *et al.,* Scientific Reports, **3**, 2596 (2013).