Second-Life Assessment of EV Cells Through Acoustic Diagnostics

Electric vehicle (EV) adoption has seen tremendous growth in recent years and this trend will likely continue into the future. The lithium-ion batteries that power these vehicles have noticeable capacity fade over time; in order to ensure safety and reliability of the car during operation, car manufacturers thus dictate that these batteries be replaced once cell capacity has reached 80% of its original value. However, these used cells could potentially be placed into another energy storage operation after their EV life, hence a “second life” for these batteries.

Potential second-life applications for repurposed batteries include grid-level energy storage.[1] Grid-level energy storage requires much less power per individual cell than automotive applications and, as there are little to no volumetric constraints when building a storage system for the grid, capacity loss can be adjusted for by simply adding more batteries to the system. In addition, second-life grid applications for EVs can assist in decreasing carbon emissions from the transportation as well as power generation sectors. By finding another use for these batteries, the steep initial cost of an EV can be offset, allowing for wider adoption of EVs over internal combustion engines vehicles to take place. With a significant energy storage portion of the grid, intermittent renewable energy sources such as solar and wind can also be more widely adopted by allowing energy produced by these resources to be used at all times of the day.

However, a few issues currently prevent second-life EV batteries from being incorporated into our grid network. These issues mainly revolve around reliability and safety of these batteries post-EV cycling. For instance, car manufacturers typically place a warranty on their vehicle components and, in the instance where a second-life battery malfunctions, who is liable for the faulty batteries? Policy issues aside, it is difficult to characterize state of charge (SOC) and state of health (SOH) of a battery cell. As a result of this, two batteries that underwent different EV cycling protocols could have vastly different SOHs and thus different cell lifetimes, even though their capacity level suggests similar outcomes. This hysteresis effect has made battery characterization challenging, and to date very few researchers have explored this issue. Dubarry et al. have proposed binning electrochemical behavior into one of three different degradation mechanism, namely (1) loss of active material, (2) loss of lithium inventory, and (3) change in reaction kinetics.[2] Using this methodology, Dubarry et al. have begun to notice differences in cell performance when factoring in how the cell was previously cycled.[3]

These methods bin the electrochemical behavior by quantifying SOC and SOH through electrochemical measurements. The SOC of the cell is tracked via Open Circuit Voltage (OCV) measurements, and SOH is tracked via analysis of the “incremental capacity” (dQ/dV) of the cell. While these methods couple SOC/SOH to experimental data fairly well, issues of accurately measuring this data (particularly the dQ/dV analysis) make it difficult to reliably track SOC/SOH in a battery. Recently, acoustic methods have been proposed as an in operando tool for determining mechanical changes in batteries, including SOC and SOH characterizations.[4] Through these methods, one can accurately capture shifts in the distribution of density that occur during the cycling of a cell via changes in the time of flight (TOF) response to an acoustic pulse. The focus of my doctoral work will be the electrochemical- acoustic TOF technique to determine battery properties based on the acoustic fingerprint of a cell during normal degradation as well as several failure modes of the cell. This work will then be used to assess the feasibility of second-life applications for battery cells that have undergone EV cycling.

Physical transitions in a battery occur as materials within the battery shift between electrode layers through an electrolytic medium. In Li-Ion batteries, for example, Li+ ions are shuttled from the cathode (typically lithium cobalt oxide (LCO) or lithium nickel-manganese-cobalt (NMC)) through the electrolyte and into an anode (typically graphite or silicon). This intercalation process causes the anode to swell, and thus produces a shift in the local density of the battery. The speed of sound through a medium has an inverse-square root dependence on density; hence, the speed of sound through the battery will change as the battery is cycled. This relationship can be exploited by measuring the acoustic signal of a battery and noting shifts in the TOF response of the signal.

We began this characterization by demonstrating such a shift in acoustic TOF data from an alkaline battery.[5] An illustrative example of this TOF shift is shown in Figure 1. Using a longitudinal transducer operating in transmission pulsing mode, a shift in TOF was found as the battery was discharged. By using energy-dispersive X-ray diffraction (EDXRD) data and scanning electron microscope (SEM) images, this shift was correlated to dehydration of the Zn gel anode and formation of ZnO in the system. In addition, this study noted that differences in acoustic profiles can differentiate various brands of alkaline batteries. Therefore, we have demonstrated that physical transitions and differences in a battery have been correlated to shifts in acoustic waveform from time of flight experiments. With the correlation demonstrated, this technique can be used to probe potential second-life battery cells.

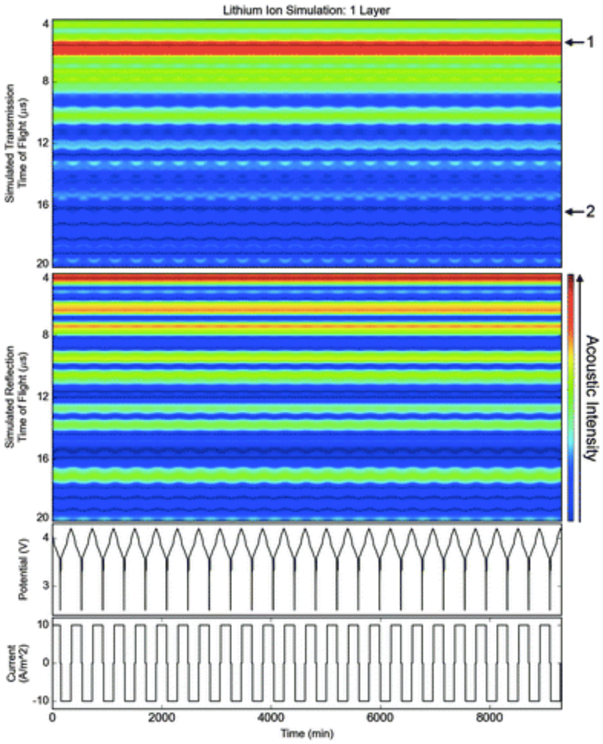

Figure 1: Acoustic TOF Data for Li-Ion Simulation

For my dissertation, an experiment will be developed to test the hypothesis that minute differences in manufactured cells can result in vastly differing cell performances. The acoustic measurements will qualitatively detail these small differences by showing slightly different acoustic signals / TOF shifts. Snapshots of the acoustic data will be taken for a set of otherwise identical cells, and then the cells will be subjected to the same cycling protocols until failure. Continual acoustic snapshots will be taken throughout the test, noting any changes that occur over the lifetime of the cell. With this data in hand, cell with different charging protocols will subsequently be tested. A simulation model of the acoustic data will be developed concurrently to understand the propagation of the acoustic wave through the battery medium. We hope to reach a point where one could test cells post-EV cycling in order to note and discard any potentially problematic cells, thereby leaving a set of reliable battery cells for use in grid-level energy storage operations.

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[1] C. Curry. BNEF New Life for Used EV Batteries as Stationary Storage, (2016)
[2] M. Dubarry et al., *J. Energy Power Sources*, 2014
[3] M. Dubarry, EVTC Report HI-11-16, (2016) 1-15
[4] A. Hsieh et al., *Energy Environ. Sci.*, 2015
[5] S. Bhadra et al., *J. Electrochem. Soc.*, 2016