The Mechanics of Lithium-ion Batteries

T. Wierzbicki, E. Sahraei and J Zhu
Impact and Crashworthiness Lab,
Massachusetts Institute of Technology, Cambridge, MA, USA

Lithium-ion batteries are increasingly used in transportation on roads, air, and sea. By the end of the present decade, Electric Vehicle manufacturing will be a five billion dollar industry. The objective of the battery research program at MIT is to develop a scalable computational models that will provide the industry with tools needed for optimal design of a battery pack based on the physics at the component and individual cell-level, resulting in weight reduction for the vehicle battery packs, as well as improved performance and abuse-tolerance. The program consists of four components:

- *Cell model development*
- *Component characterization*
- *Assembly of cells into modules and battery packs*

Modeling of Lithium-ion batteries for mechanical loading, poses a lot of challenges in Solid, Experimental, and Computational Mechanics. Independent from the so-called form factor (Cylindrical, Pouch, and Prismatic), all batteries are made of alternating layers of copper coated anode, aluminum coated cathode, and polymeric separators. Thickness of individual components, are in the order of 10 to 150 microns. The size of battery cells are measured in centimeters, and battery modules and packs are in the range of meters. Thus, the problem expands six orders of magnitude in length scale, see Figure 1. Additional complexities come from the asymmetric behavior of graphite and Li metal oxide coatings in tension and compression and very pronounced anisotropy at the separator level.

The talk will describe various steps to characterize mechanical properties and develop a computational model for three types of cells subjected to different loading conditions. A comprehensive experimental program was completed at the scale of individual components of the jellyroll and the results were used to construct a representative volume element. The predictions of the RVE were then compared with homogenized model of the battery cell constructed from global tests on full battery cells. Special attention was paid to the prediction of the electric short circuit caused by fracture of a separator and direct contact between anode and cathode. Such contacts can trigger electrochemical reactions that produce smoke, fire, and may lead to battery explosion. The battery pack simulation was also conducted using the homogenized model which could be used to optimize individual modules and the battery-vehicle interface. There are still a lot of open unresolved questions related to the computational aspect as well as full 3D modeling at various length scales. This project was supported over the past six years by a consortium of car companies and battery manufacturers.

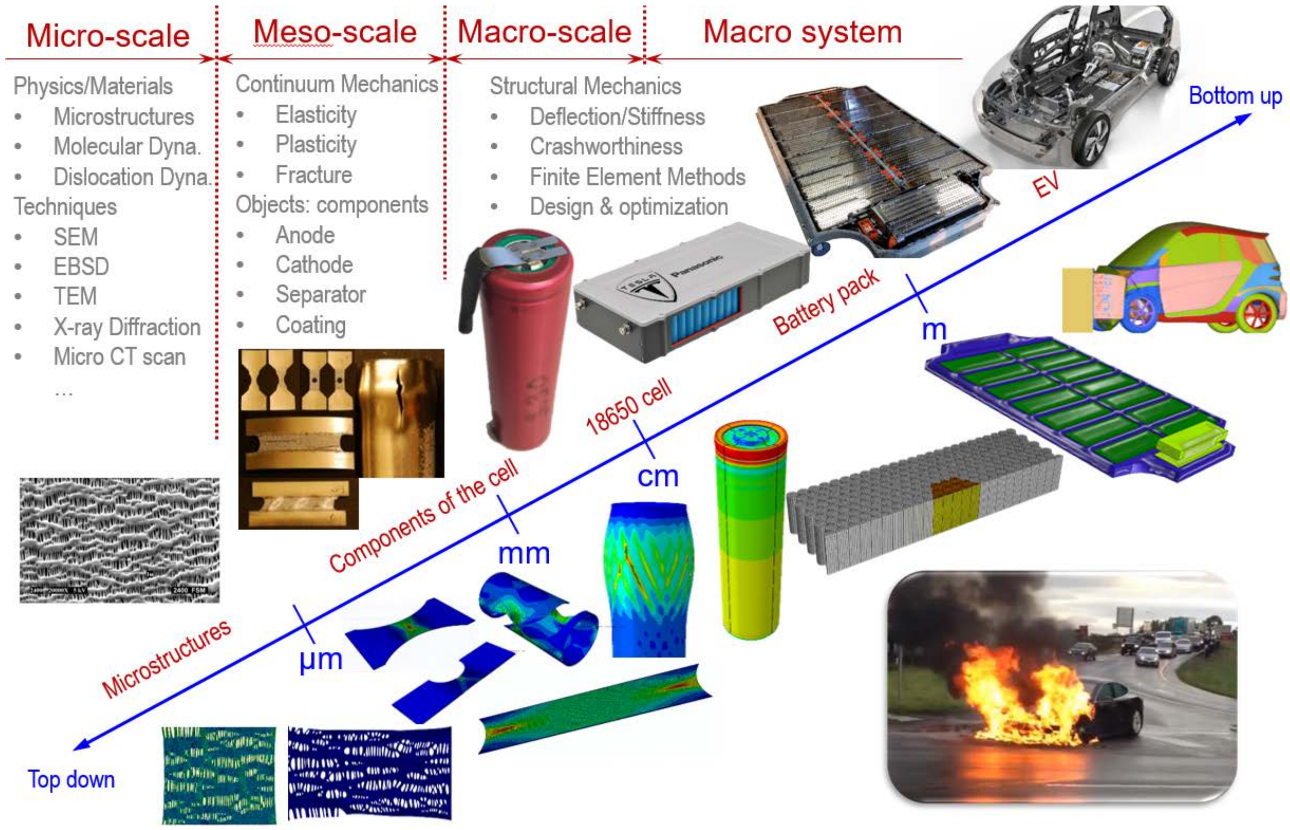

Figure 1: Lenght Scales of the EV Battery Modeling

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