Analysis of Electro-Thermal Hot Spot Formation in Li-Ion-Battery-Cells

W. Beckert[1], C. Freytag[1], T. Frölich[1], G. Fauser[1]

[1]Fraunhofer IKTS, Dresden, Germany

Abstract

Thermal Management is a key-factor for use of Li-Ion-Batteries in high power applications, to stabilize cell temperature within an optimum range ensuring efficient and safe operation and low degradation. Thermal cell behavior is controlled by interaction of various mechanisms: internal (conduction) and external (free and forced convection, radiation) heat transport, internal electric conduction, electrochemistry and a complex geometrical structure (multilayer winding body, contact tabs, housing). Processes are bidirectionally coupled: reaction and Joule's heat acting as thermal sources and all processes and parameters showing an distinct temperature dependence. Experimental means to characterize the distribution of internal quantities (temperature, heat source and current density, state of charge) during operation in a noninvasive way are very limited, impeding an detailed analysis of important problems as, for instance, the formation of internal thermal hot spots. Purpose of this model is to provide a simulation tool that gives virtual, localized 3D-insight into the essential processes within a Li-Ion Battery Cell, accounting for coupled internal electrical and thermal processes and the geometrical design features on a practically relevant level of detail (figure 1). Due to its user specific, multiphysics capabilities, COMSOL Multiphysics® was used as platform. Heart of a battery is the cylindrical winding body with a large number of windings. A full structural resolution of the individual layers (consisting of several electrode, separator and current collector films) was avoided by applying an homogenized composite continuum approach. The model consists of two simultaneously solved thermal and electrical branches (figure 2). The thermal model of the winding body (with contact tabs) applies a thermal conduction mode with circular anisotropy in the original 3D-domain. The electrical model is based on the 2D domain of the unrolled battery film (with contact tabs) and distinguishes 2 DOF's for the electrical potential distribution along the anode and the cathode electrode film, solving a 2D PDE for electrical conduction within each electrode plane. Both PDE's are connected by specific charge carrier source terms, accounting for distributed charge transfer through the electrochemically active electrolyte layer. These terms reflect the electrochemical characteristics (electrolyte current density as function of anode-cathode voltage difference, temperature and state of charge) of the battery based on a simple empirical model approach (Shepherd's model). The characteristics are obtained from experimental characterization of example cells. To couple the 2D electrical and the 3D thermal branch, information on local temperature (3D->2D) and local heat production (2D->3D) had to be simultaneously mapped and transferred between the models during solution process, making use of proprietary COMSOL Multiphysics® procedures. The geometry of the winding body was completed by the housing and the rest of the contacting structure connected as assemblies,

extending the analysis to a full cell geometry (figure 3). The model results revealed strong field concentrations in the electrode layers around the embedded contact tabs causing strongly localized heat sources (figure 4). In a dynamic load case (current pulse) this induces a pattern of thermal temperature hot spots, disclosing the influence of the contacting structure on dangerous, localized overheating as potential source for thermal runaway.

Reference

C. M. Shepherd, Design of primary and secondary cells: II. An equation describing battery discharge , Journal of Electrochemical Society, 1965 (112), pp. 657-664

Figures used in the abstract

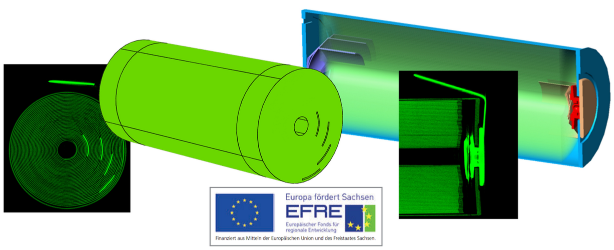

Figure 1: Example geometry of a Li-Ion-Cell: winding body with embedded contact tabs connected to housing and contacting structure

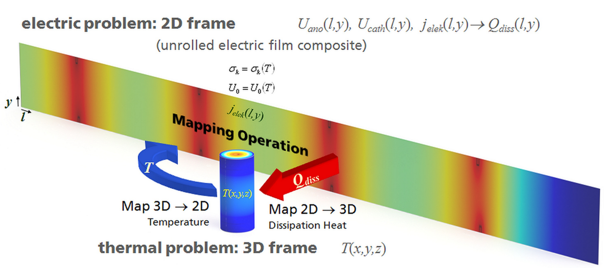

Figure 2: Hybrid 2D-3D-model approach with a 2D electric (unrolled winding body) and a 3D thermal branch (3D composite). Information is passed between the models during solution by a mapping process.

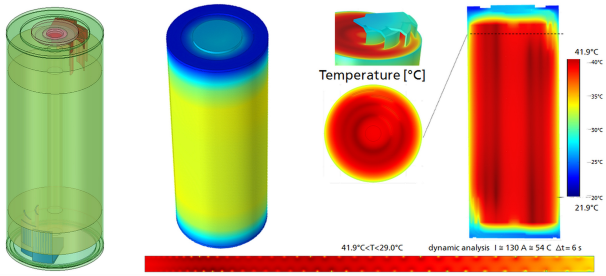

Figure 3: Results for the model of the complete cell with housing.

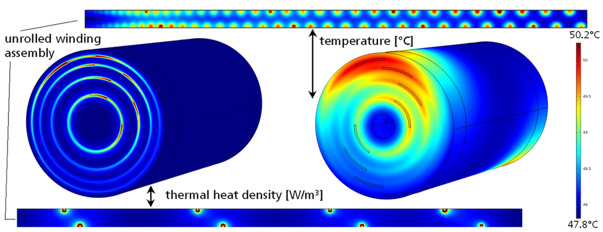

Figure 4: 2D and 3D Results (and its mappings) from the model for distribution of thermal heat density and temperature. Hot spots originate from the positions of the embedded contact tabs.