PhD Dissertation Defense Announcement
Mechanical and Aerospace Engineering Department
University of Texas at Arlington

Mathematical Modeling of Heat and Mass Transfer in Multilayer Systems

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Abstract

Multilayer systems are commonly found in a number of engineering devices like Li-ion cells and vertically integrated semiconductor devices. Li-ion cells are widely used for various engineering applications, but they come with a drawback in the form of thermal runaway, and thermal abuse is one of the scenarios that leads to thermal runaway. On the other hand, heterogenous integration in chip and package level architectures is being implemented in order to keep up with Moore's law. Modeling of heat and mass transfer in these systems is a topic of interest to improve performance and reliability.

The first segment of this dissertation defense will focus on fundamental problems, and as a part of this, a solution will be presented to understand thermal spreading in a cylindrical body with spatially varying convective heat transfer coefficient on the sidewalls. Next, theoretical analysis of a diffusion-reaction problem in a two-dimensional multilayer body will be presented. Theoretical novelty of this work stems from the possible existence of imaginary eigenvalues in such problems, which govern the stability of the multilayer body. Additionally, an analytical model to study transient diffusion in two-dimensional multilayer body with general convective boundary conditions along the surfaces normal to the layered direction will be looked at. This model represents a significant generalization of past works that were limited only to adiabatic or isothermal conditions, as a result of mathematical difficulties arising due to the general convective boundary conditions. Furthermore, to predict the stability of a system, a Laplace Transform based stability analysis of a two-dimensional multilayered diffusion-reaction problem will be discussed.

In the second segment of this dissertation defense, application-oriented heat and mass transfer models will be discussed. Firstly, a mathematical model that is capable of rapidly determining thermal performance of a realistic pouch cell-based battery pack will be demonstrated. The representation of thermal conductivity and heat generation distributions across layers with unified functions accurately captures the various components of the battery system. Following this, a Laplace transforms-based analysis of transient thermal conduction in a vertically integrated semiconductor device with spatially varying thermal contact resistance between layers and dynamic thermal loads will be presented, which will be followed by a model to analyze thermal performance of vertically integrated semiconductor devices with unequal layer widths. Subsequent to this, a one-dimensional mathematical model to study phase change in a two-PCM (Phase Change Material) stack being heated from one end will be presented. The theoretical results from this model can be used to understand the impact of placement and sizes of the PCMs on total melting time. Additionally, an eigenfunction expansion-based solution for one-dimensional phase change problems with time-dependent temperature and heat flux boundary conditions will be discussed. This mathematical model may be used to analyze thermal management of Li-ion cells using phase change materials. Finally, a theoretical model for solution phase limited ionic diffusion in a separator-electrode with concentration-dependent pore wall flux will be examined. This model is expected to contribute towards understanding and optimizing the performance of Li-ion cells.

The mathematical models developed here are expected to contribute towards the design and performance improvement of multilayer systems involving semiconductor devices and Li-ion cells.