MINISTERUL EDUCAȚIEI ȘI CERCETĂRII

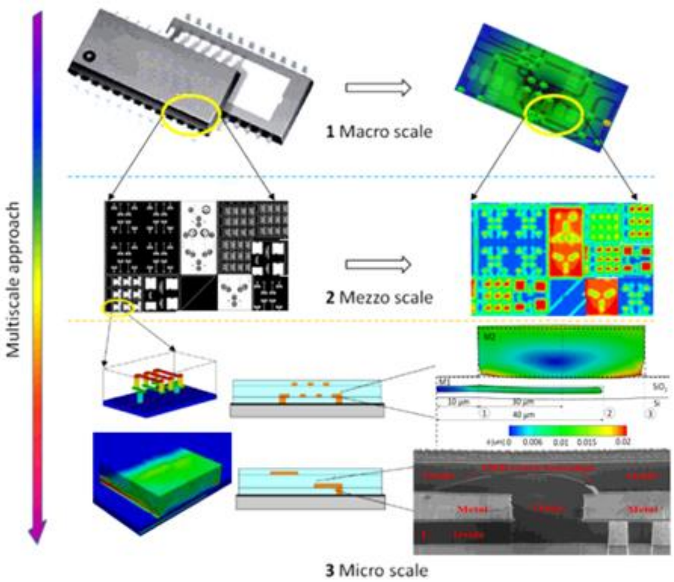
UNIVERSITATEA TEHNICĂ
DIN CLUJ-NAPOCA

Fundamental field: Engineering Sciences
Specialisation: Electrical Engineering

HABILITATION THESIS

– ABSTRACT –

NUMERICAL MODELING OF MULTIPHYSICAL PROCESSES



Assoc. Prof. PhD Eng. Ioan Marius Purcar
Faculty of Electrical Engineering
Technical University of Cluj-Napoca

– Cluj-Napoca –
2020

During the last two decades, a new approach has become widespread in computer-aided engineering. This approach is based on models and simulations that capture multiple physical processes. Each of these processes operates on a different scale of space or time, with the potential to influence other processes, while each process is represented by a sub-model. This approach is known as multilevel modeling or multilevel simulation. The term "modeling at multiple levels" (or scales) refers both to the modeling/ simulation of multiple physical processes, and to the simulation of these processes at different scales (micro, mezzo, macro).

Numerical modeling of multiphysical processes has been an on-going activity of the author's professional evolution, even before starting the doctoral studies. His research and teaching activity are both centred on this theme, especially after the PhD graduation in 2005.

The author has scientifically contributed, both as member[1] and as managing director[2] of research project teams, at developing and expanding Multiphysics modeling.

The author's scientific achievements have been validated via more than 90 scientific papers, 21 in ISI international journals (11 as first author) and an international patent. The author accumulated 133 citations without self-citations and h-index 7, according to ISI Web of Science.

On the didactic level, the author developed five new disciplines in the field of computer-aided design: CAD Tools, Modern CAD / CAE / CAM Design Techniques and Tools, Electromagnetic Field Numerical Modeling, Advanced CAD Techniques and Technologies and Advanced Programming Languages for Electrical and Electronic Engineering. Three published books out of six, range within the scope of the habilitation thesis.

This work frames within the research topics of the research group Basics of Electrotechnics of the Electrical Engineering and Measurements Department of the Electrical Engineering Faculty, namely, Optimal Modeling of Electromagnetic Field Problems. The thesis presents examples of technical problems and their Multiphysics modeling, solved with the simulation tools developed by the author and/or research teams he has been part of, or solved using open-source CAE software, e.g. Salome Meca / Code_Aster, or solved using commercial CAD/ CAE software, SolidWorks and Ansys Multiphysics, of Applied Electromagnetism Research Center and CAD laboratory.

The habilitation thesis is organized in 12 chapters. The first part of the work provides a short introduction (Chapter 2) and presents the scientific, professional, and academic achievements of the author that led to the contributions in the field of Multiphysics modeling (Chapter 3).

The Multiphysics models analysed in this work tackle electrochemical processes - Chapter 4, and thermal induced stress and deformations in metallization structures of power integrated circuits (ICs) - Chapter 5.

These processes are usually characterized by large set of Partial Differential Equations. The equations are quite complex, and they are subjected to several simplifications in order to be efficiently solved, either analytically or numerically. The (direct) analytical solutions of these equations are generally limited to simple and particular situations, hence, for the analysis of complex problems numerical technics are used instead. The governing equations,

---

[1] Tem member of 11 research projects (starting from 2000),see table 1 Chapter 3 and the annexes.

[2] Managing director of three research projects:

i. PN-III-P2-2.1-BG-2016-0388 „Electro-Thermo-Mechanical, Multiscale- Multigrid Simulator of Power Integrated Circuits - Set4CIP", http://set4cip.utcluj.ro/.
ii. PN-III-P1-1.2-PCCDI2017-0652 „Innovative Technologies for Advanced Materials Recovery from IT and Telecommunication Waste - Trade-IT", https://tradeit.utcluj.ro/.
iii. H2020-ECSEL-2017-1-IA-TWO STAGE, Nr. 122386, POC-A1-A1.1.3-H/ 2019 " Integrated Development 4.0 - iDev4.0", http://www.idev40.eu/.

their simplification and the methods of analysis are described for each application presented in this work.

Chapter 4 presents the Multiphysics analysis of electrochemical reduction and oxidation processes for metal recovery of printed circuit board waste by hydrometallurgical processes. The equation system is simplified in the first phase and then solved to determine the velocity field of the electrolyte, the ion concentrations at the electrodes and the thickness of the Cu layer deposited in the leaching solution regeneration reactor. The simulation of Multiphysics problems is performed both with the help of commercial software of CAD laboratory, Ansys Multiphysics and with the help of simulation programs developed by the author. The parameters determined by numerical simulation allowed defining the electrolyte mas flow rate and the geometric shape of the flow cells for a constant imposed current density. Based on this analysis, the technological scheme and 3D model of chemical dissolution installation for base metals of printed circuit boards have been designed. The dissolution installation is currently under construction.

Chapter 5 presents a methodology for multiphysics analysis applied to power integrated circuits, subjected to repeated thermal stress. The methodology is based on iterative simulations with progressively increased resolution at three scales (macro, meso and micro). The scheme integrates several methods of numerical analysis: Finite Element Method (FEM), Extended Finite Element Method (XFEM) and Level Set Method (LSM) for the analysis of thermo-mechanical elasto-plastic deformation processes at macro, meso and micro scales. In order to highlight the failure mechanisms caused by repeated thermal cycles, the author developed and integrated this methodology, in an open source software structure Salome-Meca and Code_Aster. The simulation methodology is demonstrated in the numerical analysis of a real power IC (currently in production/consturction), and the simulation results are compared with the measurements.

Chapter 6 presents the author's professional development plans, regarding both research and teaching activities, followed by Chapter 7, Final Conclusions.

Chapters 8, 9, 10, 11 and 12 are related to the references, the list of figures, the list of tables, annexes and the list of publications.

The career evolution and development plans presented in Chapter 6 add further dimensions to the development of the proposed theme by introducing new physical processes (electromagnetic interference) and analysis methods (isogeometric finite element method). The success potential of the forthcoming research directions is supported by the long-term construction of a strong teaching and research group in the fields of multi-physical process modeling and modern CAD / CAE / CAM design techniques and tools used in engineering.

Ioan Marius Purcar
Cluj-Napoca, September 2020