Multi-physics Simulation of Plasmonic Photoconductive Devices and Antennas

Hakan Bağcı
Computer, Electrical and Mathematical Science and Engineering Division (CEMSE)
King Abdullah University of Science and Technology (KAUST)
Thuwal 23955-6900, Saudi Arabia

Terahertz (THz) frequency electromagnetic fields have numerous applications ranging from wireless communications to imaging systems and nondestructive testing, to material characterization. One of the main obstacles in the way of widespread industrial use of THz technologies is the difficulty of implementing compact and frequency-stable THz sources that can operate at room temperatures. Among a variety of possible options, photoconductive devices (PCDs) satisfy these conditions. Indeed, they have become one of the most promising candidates for THz source generation since recent advances in fabrication techniques, such as metasurface integration and nanostructured surface inclusions have significantly increased their optical-to-THz conversion efficiency and made them polarization insensitive.

While experimental research on plasmonic PCDs has made rather significant progress, there is still room for improvement in rigorous numerical modeling of electromagnetic/electronic interactions on this type of devices. Existing numerical methods developed to simulate PCDs suffer from several drawbacks. Often, electromagnetic field interactions and semiconductor carrier dynamics are accounted for individually by different solvers and only the coupling from electromagnetic fields to charge carriers is modeled. Consequently, results obtained by these simulation tools do not match experimental findings, especially for high levels of optical pump power where the saturation/screening effects dominate the output of PCDs. Another drawback is the calculation of generation rate using electromagnetic fields. This is often done using the Poynting vector, but for time domain simulations, this approach over-estimates the charge generation and leads to divergent results. Finally, the last drawback stems from the fact that space and time characteristic scales involved electromagnetic field interactions and carrier dynamics differ by orders of magnitude. Existing methods do not account for this difference efficiently, and they often over-discretize one or more physical interactions involved in the PCD operation, which unnecessarily increases their computational requirements.

In this presentation, I will talk about my research group's recent efforts in addressing the drawbacks associated with the simulation of PCDs as listed above. More specifically, I will provide the details of a framework we have developed for rigorously-coupled simulation of electromagnetic interactions and carrier dynamics. This framework uses the Maxwell and the drift-diffusion equations to describe the behavior of electromagnetic fields and charge carriers, respectively. The photocurrent induced by carriers' movements is coupled with electromagnetic fields through the current term in Maxwell equations. Electromagnetic fields are coupled to carriers through the drift term and the charge generation in the drift-diffusion equations. To efficiently account for the multiple space and time characteristic scales involved in this multi-physics and multi-equation model, discontinuous Galerkin (DG) schemes are used for its discretization. At my talk, I will present real-life examples, which demonstrate the accuracy and the efficiency of this DG-based framework. These examples will also show that our numerical results match those of experiments even for high levels of optical pump power.

Hakan Bağcı received the B.S. degree in Electrical and Electronics Engineering from the Bilkent University, Ankara, Turkey, in 2001; and the M.S. and Ph.D. degrees in Electrical and Computer Engineering from the University of Illinois at Urbana- Champaign (UIUC), Urbana, IL, USA, in 2003 and 2007, respectively. From June 1999 to July 2001, he worked as an Undergraduate Researcher with the Computational Electromagnetics Group, Bilkent University. From August 2001 to December 2006, he was a Research Assistant with the Center for Computational Electromagnetics and Electromagnetics Laboratory, UIUC, Urbana, IL, USA. From January 2007 to August 2009, he was a Research Fellow with the Radiation Laboratory, University of Michigan, Ann Arbor, MI, USA. Since August 2009, he has been with the King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia, where he is currently an Associate Professor of Electrical and Computer Engineering. His research interests include various aspects of theoretical and applied computational electromagnetics with emphasis on well-conditioned frequency and time domain integral equation formulations and their discretization, hybrid time domain integral and differential equation solvers, accurate, stable, and efficient marching schemes for time domain solvers, stochastic characterization of electromagnetic field and wave interactions on complex geometries, and solution of two and three dimensional electromagnetic inverse scattering problem using signal processing techniques. He authored or co-authored around 110 journal papers and 240 contributions in conference proceedings.

Dr. Bağcı was the recipient of the 2008 International Union of Radio Scientists (URSI) Young Scientist Award presented at the XXIXth URSI General Assembly and the 2004-2005 Interdisciplinary Graduate Fellowship from the Computational Science and Engineering Department, UIUC, Urbana, IL, USA. His paper titled “Fast and Rigorous Analysis of EMC/EMI Phenomena on Electrically Large and Complex Structures Loaded With Coaxial Cables” was one of the three finalists (with honorable mention) for the 2008 Richard B. Schulz Best Transactions Paper Award given by the IEEE Electromagnetic Compatibility Society. He authored (as student) or co-authored (as student and advisor) 18 finalist/honorable mention papers in the student paper competitions at the 2005, 2008, 2010, 2014, 2015, 2016, 2017, 2018, and 2020 IEEE Antennas and Propagation Society International Symposiums and 2013, 2014, 2016, 2017, 2018, and 2019 Applied Computational Electromagnetics Society Conferences. In 2019, he received the Division of Computer, Electrical and Mathematical Science and Engineering (CEMSE) Distinguished Teaching Award at KAUST, Thuwal, Saudi Arabia. In 2020, he was one of the recipients of the Gauss Center for Supercomputing (GSC) Award for the paper titled “Solving Acoustic Boundary Integral Equations Using High Performance Tile Low-Rank LU Factorization” and presented at the International Supercomputing Conference (ISC) High Performance.

Dr. Bağcı is currently an Associate Editor for the IEEE Transactions on Antennas and Propagation, IEEE Journal on Multiscale and Multiphysics Computational Techniques, and IEEE Antennas and Propagation Magazine. He has organized and chaired many sessions at IEEE Antennas and Propagation Society International Symposiums and Applied Computational Electromagnetics Society Conferences. More recently, he served as a vice chair (responsible for computational electromagnetics track) of the technical program committee for the IEEE Antennas and Propagation Society International Symposium that was held in Atlanta, GA, USA, in July 2019. Dr. Bağcı is a senior member of the IEEE and the URSI Commission B and a member of the Applied Computational Electromagnetics Society.