A Hybrid Finite Element–Discontinuous Galerkin Solver for Analyzing Electromagnetics-Plasma Interaction in Four Dimensions

Su Yan* and Jian-Ming Jin
Center for Computational Electromagnetics
Department of Electrical and Computer Engineering
University of Illinois at Urbana-Champaign
Urbana, IL 61801-2991, USA
E-mail: suyan@illinois.edu; j-jin1@illinois.edu

High-power microwave (HPM) devices and systems have very important civilian and military applications. However, as the power density goes higher and higher, the HPM devices and systems are more and more vulnerable to the HPM breakdown, which becomes a critical limiting factor for the generation and transmission of the HPM radiation and the operation of HPM devices and systems. During HPM breakdown, the particle density and velocity in a HPM device can be modeled by plasma fluid equations with various ionization parameters, which would become highly nonlinear when the electromagnetic (EM) field intensity is sufficiently high (J. A. Bittencourt, *Fundamentals of Plasma Physics*. New York: Springer-Verlag, 2004).

To describe the HPM breakdown, the propagation of the EM waves is modeled by Maxwell's equations, which provides energy for the neutral particles in air to be ionized. The ionized particles are then moved by the high-frequency high-power EM waves, and diffuse from the higher density regions to the lower density regions, which can be described using a plasma fluid model. These motions of plasmas produce conduction currents which serve as the secondary source for the EM waves, and are coupled back into Maxwell's equations.

In this presentation, we propose a hybrid nonlinear finite element–discontinuous Galerkin solver to analyze the interaction between the EM wave and the plasma fluid. In this method, Maxwell's equations are solved using the finite-element time-domain method with an unconditionally stable time marching scheme (J.-M. Jin, *The Finite Element Method in Electromagnetics, Third Edition*. Hoboken, NJ: Wiley, 2014) to allow a large time step; and the plasma fluid equation is solved using the discontinuous Galerkin time-domain method with higher order basis functions (Y. Xu and C.-W. Shu, "Local Discontinuous Galerkin Methods for High-Order Time-Dependent Partial Differential Equations," *Commun. Comput. Phys.*, vol. 7, no. 1, pp. 1–46, Jan. 2010) to resolve the Debye length in a relatively coarse mesh grid. A Newton-Raphson scheme is developed to handle the nonlinearity introduced by the plasma current, and a positivity-preserving method is applied to maintain the positivity of the solution for the particle density. The performance of the proposed solver is demonstrated with a specific example.