Worcester Polytechnic Institute
Mathematical Sciences Department

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M.S. Thesis Presentation

Computational Characterization of Thermal Processes in an AlN:Mo Susceptor in a Millimeter Wave Heat Exchanger

Abstract

Electromagnetic (EM) heating is applied in a wide range of areas such as food engineering, chemistry, and materials science. Recent developments suggest using this technology in EM heat exchangers for solar energy collectors, microwave thermal thrusters, and ground-to-ground millimeter-wave (MMW) power beaming. Interaction between the MMW field and an absorbing ceramic element (susceptor) of a heat exchanger needs to be well understood to develop a device in which the material is controllably heated and the heat is efficiently transferred to a fluid.

In this work, we develop a computational model to simulate EM and EM-induced thermal processes in a simplified MMW heat exchanger and examine different ceramic materials to find the one that maximizes the device's efficiency. EM-thermal coupled problem is solved by the finite-difference time-domain (FDTD) technique (implemented in *QuickWave*) for a block of AlN:Mo composite backed by a thin metal plate and irradiated by a plane wave. Computation is based on experimental data on temperature-dependent dielectric constant, loss factor, specific heat, and thermal conductivity of the composite. The case of full thermal insulation of the ceramic block (Neumann scenario) is considered along with the case of a Dirichlet boundary condition on the interface between the metal and the ceramic block; the latter imitates a practical regime in which the metal plate is maintained at a constant temperature to prevent the ceramic block from overheating.

The FDTD model is verified by solving the underlying EM problem by the finite-element simulator, *COMSOL Multiphysics*. It is shown that in the scenario with the Dirichlet boundary condition, accuracy of the iterative solution of the coupled problem depends on the heating time step: higher concentrations of Mo trigger higher levels of temperature non-uniformity and require a smaller time step to achieve sufficient adequacy. With the power of the plane wave of 100 W, at 95 GHz, $10\times10\times10$ mm blocks with Mo = 0.25-4% can be heated up to 1,000^{o}C highly uniformly for 50-110 s, depending on the percentage of Mo. The composite producing the highest level of total dissipated power in both the Neumann and Dirichlet scenarios is found to have Mo concentration around 3%; this material is recommended for use in the first physical prototype of a MMW heat exchanger.

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3:00 pm
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