Modeling of Space-Charge Effects in 3D Thermionic Devices

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Abstract

Photon-enhanced thermionic emission (PETE)[1] appears as a promising technology for electric power generation from renewable resources. Its combination of photovoltaic and thermionic effects leads to devices which can operate at high temperature through thermionic emission still exploiting efficient electrons promotion through a semiconductor band gap when it is chosen as a cathode. However, the efficiency of the process is hindered by several factors such as weak radiation absorption, recombination at the interface of the cathode and space-charge effects in the vacuum region between electrodes.

This latter issue in particular has been often neglected in theoretical models [2] by considering very small anode-cathode gaps (few microns) to minimize the problem. However, from the fabrication point of view, achieving stability of very thin gap layers at high temperatures is not trivial, and may result in increased costs. In other studies the treatment has been restricted to the 1D case of flat cathode and anode structures [3], thus limiting the engineering possibilities.

Here we show how the problem of space charge cloud in photon enhanced thermionic emitters can be studied in 3D by means of COMSOL Multiphysics. The full 3D approach enables to investigate more complex gap geometries, involving large anode-cathode distances, structured cathode emission surfaces and the possible insertion of accelerating gates placed in the gap middle to help reducing the space charge problem.

We show in particular how the presence of a micro and nanostructured cathode can affect the net current flux between anode and cathode. An array of sharp microcones constituting the cathode enables to enhance the saturation current thanks to the field emission from the tip apex. The latest functionalities introduced in the Particle Tracing Module of COMSOL Multiphysics, enable an easy modeling of the space-dependent field-enhanced electrons emission. The electron velocities can also be made random both in their absolute values (Maxwell Boltzmann distribution) and direction of emission. Thus a realistic model of thermionic emission can be set up in COMSOL.

The solution of the stationary space charge limited current problem is then achieved by means of an iterative procedure. In a first step, electrons are emitted from the cathode and their trajectories are calculated as if they were non-interacting particles. The space charge produced by this

freely propagating electron cloud is then calculated and introduced in an electrostatic solution step. At iteration number 2, electrons are emitted and interact with the calculated self-potential. The iteration continues until convergence is reached.
We present preliminary results of the studies of the considered cones emission array, showing criticalities and limits of the model.

Reference

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Figures used in the abstract

Figure 1: Simulation of the space charge cloud produced by a 3D structured cathode emitter.

Figure 2

Figure 3

Figure 4