High Accuracy Electron Beam Model Development in MICHELLE: eBEAM*

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Abstract:

We present a new software tool (eBEAM) for high accuracy simulations of electron beams with stochastic space charge effects, as a module of the MICHELLE particle simulation code. In modeling low current electron beam systems such as electron beam lithography, nanolithography and electron microscopy, it is necessary to simulate ensembles of individual electrons to account correctly for the statistical effects of inter-particle interactions. The MICHELLE–eBEAM simulation is accomplished via a CPU/GPU hybrid code that runs on multiple platforms.

Keywords: Coulomb interactions, lithography, GPU, stochastic space charge.

Introduction

Electron and ion beam simulations such as those applicable to charged particle beam lithography and nanolithography present challenges to particle-in-cell, mesh-based simulation codes due to the requirement to achieve high accuracy. For instance, blur simulations in lithography columns require nanometer spatial accuracy while the applicable device size is on the order of a meter. These disparate scales put unrealistic constraints on the mesh size in cell-based simulations.

The MICHELLE [1], [2] two-dimensional (2D) and three-dimensional (3D) steady-state and time-domain particle-in-cell (PIC) code has been employed successfully by industry, national laboratories, and academia and has been used to design and analyze a wide variety of devices, including multistage depressed collectors, gridded guns, multibeam guns, annular-beam guns, sheet-beam guns, beam-transport sections, and ion thrusters. However, to achieve higher accuracy over large distances, a different approach is necessary to represent both externally imposed static fields as well as the self fields resulting from global and stochastic space charge effects.

Approach

The approach taken in MICHELLE's eBEAM module to meet the externally applied field accuracy requirement is to employ an analytical expansion of electrostatic and magnetostatic fields calculated using finite element methods. The field at each point in space is represented by a sum over a finite number of Hermite basis functions [3]. The desired accuracy of the field representation can be achieved by increasing the order of the series expansion. Axially symmetric field components can be easily modeled this way.

High accuracy time integration of particle trajectories using the relativistic equations of motion is accomplished by using explicit integrators such as Prince-Dormand and Bulirsch-Stoer with adaptive time step size control.

To accurately model stochastic space charge, Coulomb interactions must be efficiently evaluated for a large number of particles. Current densities in lithography applications are sufficiently low that each simulated particle may represent a single electron or a single ion, for example. Direct calculation of these particle-particle interactions has $O(n^2)$ computational complexity, and therefore requires either substantial computing power or use of a tree algorithm that reduces the complexity to $O(n \log n)$. In our present approach the former is accomplished by using high performance GPU hardware which acts as a co-processor to the host CPU-based program.

We report on our progress on MICHELLE–eBEAM development and present illustrative examples of applications in charged particle optics for modeling lithographic beamlines.

References

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