High Accuracy Charged Beam Modeling in MICHELLE–eBEAM*

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Abstract:
We report on the latest development in the SAIC/NRL MICHELLE–eBEAM modeling framework designed for high accuracy simulations of electron and ion beams with stochastic space charge effects. Higher-order optical elements such as magnetic and electrostatic dipoles and quadrupoles have been added to the list of MICHELLE–eBEAM capabilities for Wien filter modeling. Higher-order aberration coefficients are calculated using differential algebra. A GPU-enabled tree algorithm has been incorporated into the framework to allow for efficient evaluation of the statistical effects of inter-particle interactions. We also report the latest progress in counter-streaming beam modeling, where two beams propagate in opposite directions while being co-located in space.

Keywords: eBEAM, MICHELLE, GPU, Coulomb, lithography, stochastic space charge, Wien filter.

Introduction

Electron and ion beam simulations such as those applicable to charged particle beam lithography present a substantial computational challenge due to the requirement to predict large numbers of particle trajectories to high accuracy over large distances. Often this requirement puts unrealistic constraints on particle-in-cell, mesh-based simulation codes due to disparate spatial scales present in lithographic column designs.

The MICHELLE [1], [2] two-dimensional (2D) and three-dimensional (3D) electrostatic 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. The eBEAM [3] module in MICHELLE has been introduced to meet the higher accuracy over large distances requirement present in lithography simulations. Moreover, a model such as used in eBEAM has many potential applications in simulations of high bunch charge ultra-relativistic beamlets in particle accelerators due to the absence of mesh-induced inhomogeneities. The MICHELLE–eBEAM simulation is accomplished via a CPU/GPU hybrid code that runs on multiple platforms.

Development

The approach taken in MICHELLE–eBEAM module is to employ an analytical expansion of electrostatic and magnetostatic fields, where the field at each point in space is represented by a sum over Hermite basis functions [4]. Optical components such as electrostatic and magnetostatic lenses as well as dipoles and quadrupoles can be modeled this way. Using a combination of such elements beams traversing Wien filters can be simulated. In addition, third– and fifth–order aberration coefficients are calculated using differential algebra (DA).

Coulomb interactions are a major contributor to the image blur in wide-field electron lithography column designs. These interactions must be efficiently evaluated for a large number of particles. As a result we employ a GPU-based tree code algorithm for efficient evaluation of particle-particle interactions with asymptotic scaling of $O(n \log n)$ where n is the number of particles. When modeling higher currents or counter-streaming beams, the particle count requirement may increase by an order of magnitude thus making the tree code implementation essential.

In addition to the improvements discussed above the development of pre– and post–processor components of eBEAM have been on-going. 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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