New approaches for charged particle optics for ionic liquid ion sources

C. S. Perez-Martinez
London Centre for Nanotechnology, University College London, London WC1H 0AH, United Kingdom
carla.perezmartinez@ucl.ac.uk

Ionic liquid ion sources (ILIS) have been proposed as a source of alternative ion chemistries for surface etching, focused ion beams, and secondary ion mass spectrometry. Ionic liquids are mixtures of cations and anions that are liquid at room temperature without need for a solvent. The cations are usually large organic molecules, while the anions may be complex organic or simple inorganic ions. In ILIS, a micro-tip emitter is covered with ionic liquid and subjected to an electric field to trigger ion evaporation. This talk will review the fundamentals of ILIS and recent efforts towards creating charged particle optics for use with ILIS, including filtering experiments and the use of intelligent algorithms for lens design.

ILIS produce several solvated ion species with a distribution of energies. The ion ion beam should be filtered to obtain a monoenergetic beam with a single ion chemistry as required by manufacturing and analytical applications. A Wien filter has been designed, built, and tested using the liquid 1-ethyl-3-methylimidazolium tris(pentafluoroethyl)trifluorophosphate[1]. Time-of-flight mass spectrometry and retarding potential analysis confirmed the filter's effectiveness in isolating monomer ions from other solvated species in the beam.

Genetic algorithms (GA) and Particle Swarm Optimisation (PSO) have been used in conjunction with the Differential Algebra (DA) method for Einzel lens design[2]. The GA and PSO algorithms both start with initial populations of lenses with random geometrical configurations. These starting populations are then altered for a set number of iterations according to the performance of the existing designs. To evaluate the performance of each test lens geometry, the spot size is calculated from the aberration coefficients obtained using the DA method. The DA technique uses nonstandard analysis for ray tracing a particle as it is subjected to the field generated by an optics element. The crucial advantage of the DA method is that it provides higher-order aberration coefficients from a single ray trace, and thus reduces the computational cost of calculating the spot size over the many iterations required by the intelligent algorithms, when compared to other ways of calculating the spot size (aberration integrals, direct ray tracing). This approach has been demonstrated on both the design of an Einzel lens (see Figure 1) as well as in the design of a focusing column with two lenses and a Wien filter.

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[1] A. Storey *et al.*, J. Vac. Sci. Technol. B 42, 064201 (2024)
[2] A. Sabouri and C. S. Perez-Martinez, Ultramicroscopy, 266, 114024 (2024)

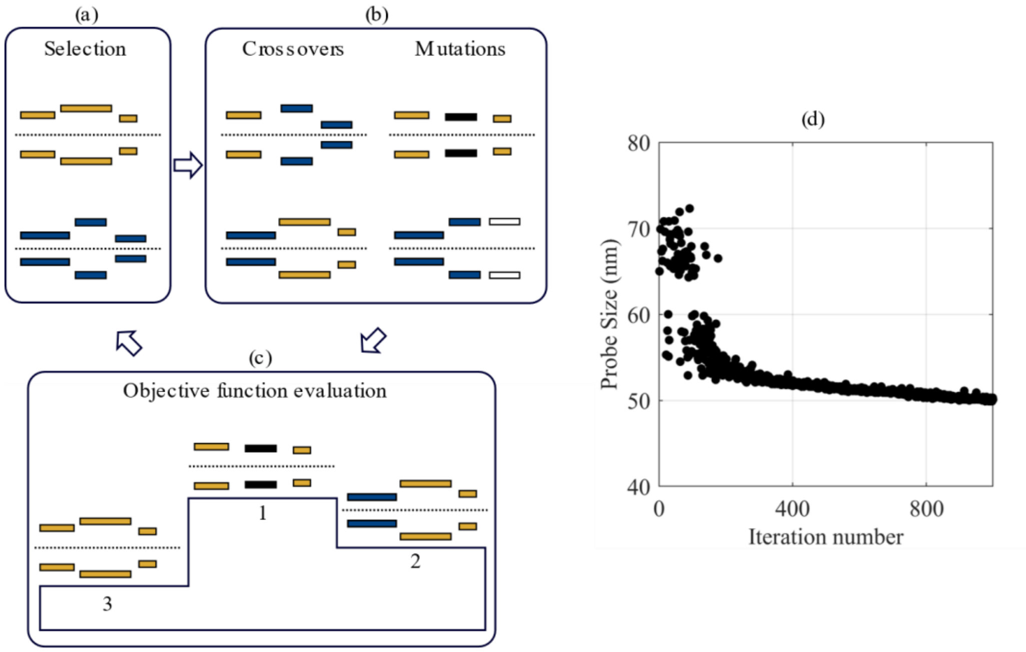

Figure 1: Fundamentals of Genetic Algorithms and Example of Einzel Lens Optimisation: The sketch in (a) shows the cross sections of two Einzel lenses, each formed of three electrodes, with different electrode radii and lengths. These two lenses are selected at random, and they serve as the starting population for the genetic algorithm. In (b), crossover and mutation are applied to the parent lenses to produce new configurations, for this example, four additional lens geometries. The next step, (c), consists of evaluating the objective function (spot size) for the six lenses, and raking the lenses based on their performance. Lenses with a smaller spot size are ranked with preference. The top two performers would be used as parents for the next generation. The process is repeated for a finite number of iterations. (d) Example of a GA optimisation for a three-electrode Einzel lens where the spot size gets progressively smaller as the algorithm searches the parameter space for better performers. Figure based on A. Sabouri and C. S. Perez-Martinez, Ultramicroscopy, 266, 114024 (2024)