An Advanced Laser Desorption Ionization Ion Source with Controlled Superposition of Electric and Pneumatic Fields

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Introdction

Typically, the designs of LDI ion sources are based upon SIMION calculations where gas pressure is a global constant. To achieve an improved understanding of ion dynamics in gas flow fields, an advanced multi-physics simulation system called GEMIOS [1]-[5] was created. Various novel configurations of a LDI ion source based on non-trivial electro-pneumatic element (EPE) configurations were numerically investigated. Such designs belong to a of new class of electro-pneumatic ion optical devices in which elements act as electrodes as well as nozzles or wings and in which collision frequencies and momentum transfer vary spatially in a controlled fashion. However, the ion dynamics resulting from the superposition of non-trivial electric and pneumatic fields is no longer easily imagined or calculated and simulations are required for realistic 3D electro-pneumatic configurations (Fig. 1).

Results

Exclusively based on predictions from such extensive GEMIOS simulations, an experimental workbench was created to support the development of LDI-EPI source technology compatible with commercial orthogonal time-of-flight instruments (Fig. 2). The vacuum and pneumatic systems were equipped with a magnetically levitated high power turbomolecular pump (Shimadzu TM2003) as well as needle and throttling gate valves to vary gas load and pumping speed. Fundamentally, the functionality of the LDI-EPI source depends on a number of coaxial electro-pneumatic elements which create a highly non-equilibrium supersonic gas flow field configuration as well as accelerating and guiding electric fields.

A nitrogen laser (Spectra Physics 337VL) was operated at a pulse frequency of 30 Hz, and the incident laser fluence was 140 to 210 J/m^2 per pulse. Due to the use of mirrors on one of the EPEs the laser beam impinges nearly orthogonal onto the sample spot. In addition, a digital HDTV video zoom microscope enables observation of the sample spot with about 20µm spatial resolution.

Ion cooling efficiency was studied by analyzing labile species such as ACTH 18-39, phosphopeptide Epithelial Growth Factor (EGF) receptor 661-681, Phosphorylated protein Kinase C, and P14R. All samples were analyzed using either normal phase arrays (Ciphergen) and alpha-cyano-4-hydroxy cinnamic acid matrix, or Surface Enhanced Neat Desorption (SEND) arrays.

Due to the complex non-equilibrium supersonic gas flow field in which the ions are introduced, we report here only the gas pressure p_r established as measured proximal to the source elements. Source pressures were varied between p_r=25Pa and p_r=400Pa, which corresponded to a maximum gas throughput of q_{pV}=5000Pa·l/s (Nitrogen). Independent of ion stability, altering pressure as noted created as large as a 50 fold difference in parent ion signal intensity. At lower pressures, the signal intensity fell off rapidly since the electro-pneumatic superposition was considerably sub-optimal for effective ion collection. Further, substantial unimolecular decay was observed since ion-gas collision frequencies were significantly reduced, prolonging the period of unstable ion vibrational modes. Specifically for a 1pmol EGF sample at p_r=100Pa, the parent ion count was about 5300 but only 100 at p_r=25Pa (Fig. 3). At this reduced pressure the relative intensity of the fragmented ions could be up to 80% of the parent ion vs. 5% at p_r=200Pa. Using a 1pmol ACTH 18-39 sample, the relative intensity of fragmented ions could be reduced to < 3% at p_r=150Pa. Optimal pressure was found to be on the order of p_r=100Pa to p_r=200Pa. It can be computed that under these instrumental conditions, effective ion cooling and collection is achieved within the electrostatic–pneumatic source region, well before the ions enter the instruments RF ion guide. Further increase in gas pressure caused a slow decline of the parent ion count and ion-matrix clustering became dominant. De-clustering could be crated by increasing electrostatic field strength. Under optimal electro-pneumatic conditions, 1fmol of EGF was detected at 25 counts above a noise floor of approximately 5 counts, when using normal phase surfaces. Using a SEND array, parent ion count increased to 50 above a reduced noise floor of about 3 counts.

[1] A. Hieke: “GEMIOS – a 64-Bit multi-physics Gas and Electromagnetic Ion Optical Simulator”, 51st ASMS Conf. Montreal, 2003

[2] A. Hieke: "Development of an Advanced Simulation System for the Analysis of Particle Dynamics in LASER based Protein Ion Sources", 2004 NSTI Nanotechnology Conference and Trade Show, Boston, MA, March 2004

[3] A. Hieke: "3D electro-pneumatic Monte-Carlo simulations of ion trajectories and temperatures during RF quadrupole injection in the presence of gas flow fields", 52nd ASMS Conf. Nashville, TN, May 2004

[4] A. Hieke: "Simulations of ion population dynamics dominated by discrete collisions events in rarified gases in the presence of electromagnetic fields", International Conf. on Transport Phenomena in Micro and Nanodevices, Kona Coast, Hawaii, Oct. 2004

[5] A. Hieke: "Ion Sources for Biomolecules with controlled Superposition of Electric and Pneumatic Fields", 2005 NSTI Nanotechnology Conference and Trade Show, Anaheim, CA, May 2005

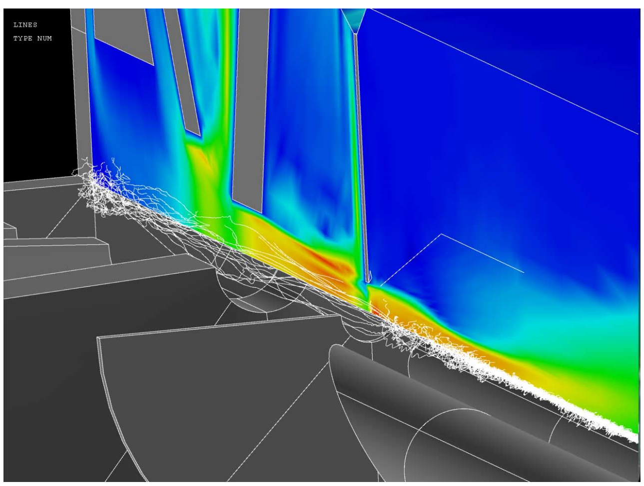

Fig.1: GEMIOS simulation of ion trajectories based on simultaneous consideration of electric DC and RF fields and gas flow fields

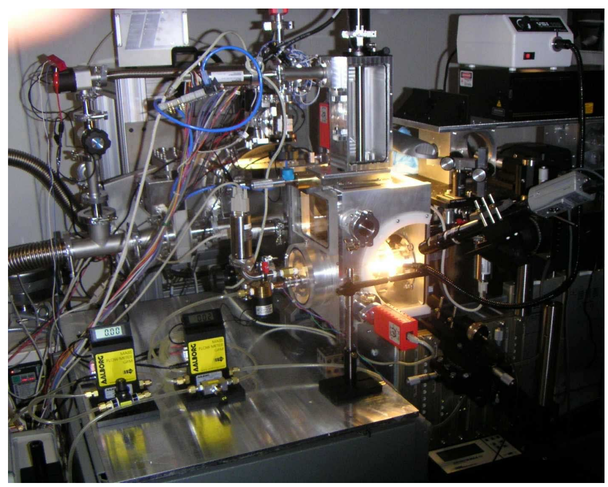

Fig. 2: First prototype of the advanced LDI-EPI source workbench fitted to the ABI Qstar

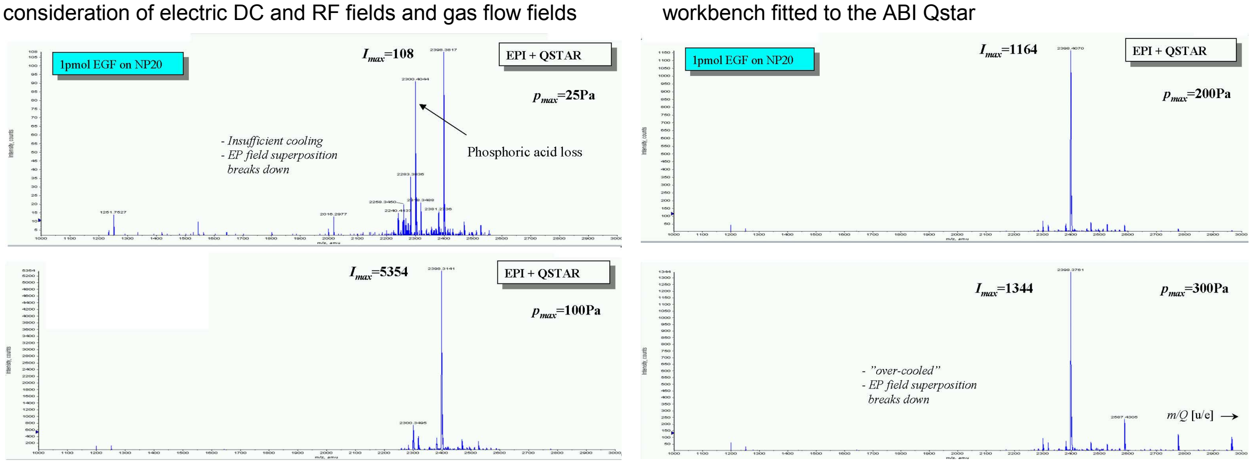

Fig.3: Comparison of LDI-EPI source performance at increasing gas reservoir pressure illustrating the buildup of electro-pneumatic superposition and excellent ion cooling performance; 1pmol EGF on Ciphergen NP20 arrays using CHCA as matrix