Modelling Ion Production Inside An Electron Impact Ionizer For High-Vacuum Gas Analysis

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Abstract

Residual Gas Analyzers (RGA) are often used to measure background gases and contaminations in vacuum systems. An ionizer is used to ionize gas molecules and these ions are accelerated and focused by an electrical field from the ion source to form an ion beam. The ions can be discriminated based on mass/charge ratio by a magnetic field, and the selected ions are captured by a detector. The ion charge flux at this detector is measured as a current.
TNO is developing a new kind of contamination analyzer for high-vacuum systems for real time detection of contaminants. We rely on commercial available electron impact ion sources to generate the ions. To study the resulting ion beam as a function of partial gas pressure, gas composition, emission current, and source dimensions we developed a 3D COMSOL 5.5 model using the Electrostatics (es) and Charged Particle Tracing (cpt) modules. The source consists of an thermionic electron emitting filament, an open wired anode cage, a grounded outer cage, and an ion extraction hole in a grounded bottom plate. The electrons can ionize molecules inside the anode cage. A logarithmic function to mimic the electron kinetic energy distribution around an average of 0.2 eV is used. With the anode at 110 V, the filament at 40 V and the extraction hole grounded, the electrons obtain 70 eV and the ions close to 110 eV kinetic energy.
The electrons can freely oscillate around the center axis of the anode cage until they are absorbed by an anode wire or collide with a gas molecule. Based on the open fraction of the mesh the average number of passes per electron is around 2.5. The mean free path of the electrons through the gas is calculated using the molecule ionization cross section, which is in the kilometer range. Since the diameter of the anode cage is in the centimeter range, the chance of an electron ionizing a gas molecule is neglectable and therefore electron scattering and electron kinetic energy loss due to collisions is neglected.
The ionization sites are estimated based on the electron space charge density. Since the positive ions compensate for the electron space charge, the remaining space charge is neglected. The ion energy distribution is derived using the histogram function over the electron space charge and the electrical potential field.
We observed that coulomb forces diverging the ion beam are negligible when the gas pressure was under 1e-6 mbar, but at higher pressures the ion density in the ion beam increases and repelling coulomb forces become significant. Although it is possible to implicitly solve repelling ion trajectories it is impractical for 3D due to calculation time, and a series of iterations with explicitly coupled electrical potential and ion space charge are used instead.
Using the model we will be able to select and improve commercial ion sources for our contamination analyzer. We will show results from the simulations on the present ion source and comparison with measurements to verify the reliability of the simulation model.

Figures used in the abstract

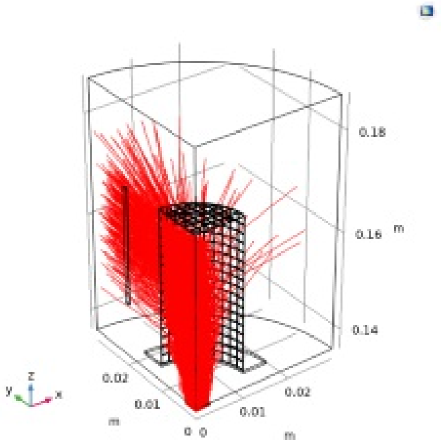

Figure 1 : Ion trajectories after ionization. Anode is the wired ‘hat’, filament is the vertical bar, and extraction hole is at the bottom. Symmetry planes at x=0 and y=0.

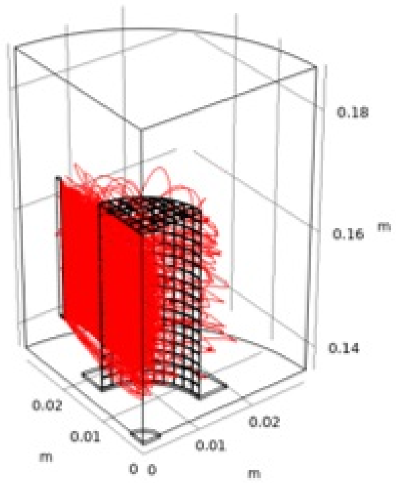

Figure 2 : Electron trajectories from filament into anode cage.

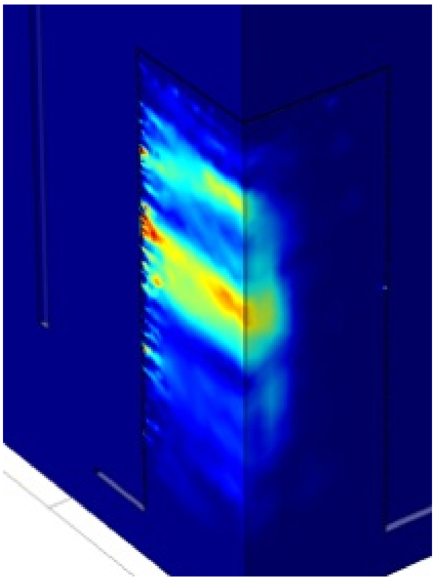

Figure 3 : Electron space charge density inside anode cage indicating ionization sites.

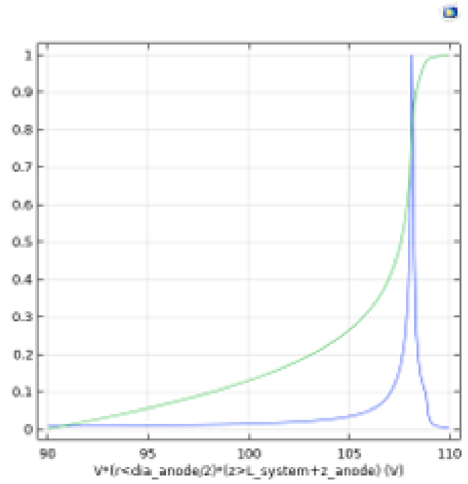

Figure 4 : Ion energy distribution (blue line) and its cumulative (green line).