Ion Source Modeling at PRIME Lab

George S. Jackson, David Elmore, Marc Caffee, Kenneth A. Mueller, Bob De Bonte, Paul Muzikar, and Brad Alexander
Department of Physics, Purdue University, West Lafayette, IN 47907

Introduction

A high intensity cesium ion source, as well as a new sample changer are being developed and designed at PRIME Lab; the ion source is based on the CAMS at Lawrence Livermore National Laboratory design and the sample changer is based on one developed at the Chalk River Nuclear Laboratories in Canada [1]. Various aspects of the ion source performance are being modeled using Simion 7.0, which iteratively solves Laplaces' equation. Simion 7.0 does not require cylindrical symmetry so the effects of non-symmetric components, in particular the sample insertion rod and immersion lens (aperture above the surface held at cathode potential), can be explored.

Two types of simulations were examined. In the first the trajectories of Cs+ ions emitted from the surface of the spherical ionizer were examined. Ions were emitted with a random energy distribution centered around 0.15 eV that could vary by +/- 50%. The ions were emitted at randomized angles to the surface of the ionizer. The emission of the secondary ions (*m/z* of 100) was limited to the diameter of the cathode hole and the ions were emitted with a random energy distribution centered around 15 eV. Simion has several choices for charge repulsion. Ion beam repulsion was not used since the program requires that all of the ions start in the same plane (clearly not tenable in the case of the cesium ions). Thus, ion cloud repulsion was used. In this model each ion represents a cloud of ions. Since Simion is not Child's Law restrained and the manual states it does not model space charge in ion source regions well, care was taken to make sure that the results from simulation mimicked experiment and other ion source simulations. When the trajectories of the secondary ions were examined, over 90% of the charge was ascribed to a clould of cesium ions that the secondary ions had to fly through.The version of the Livermore source that Tom Brown uses as his starting point in his ion source modeling paper [2] was used as our comparison throughout the simulations.

Results and Discussion

CAMS Ion Source

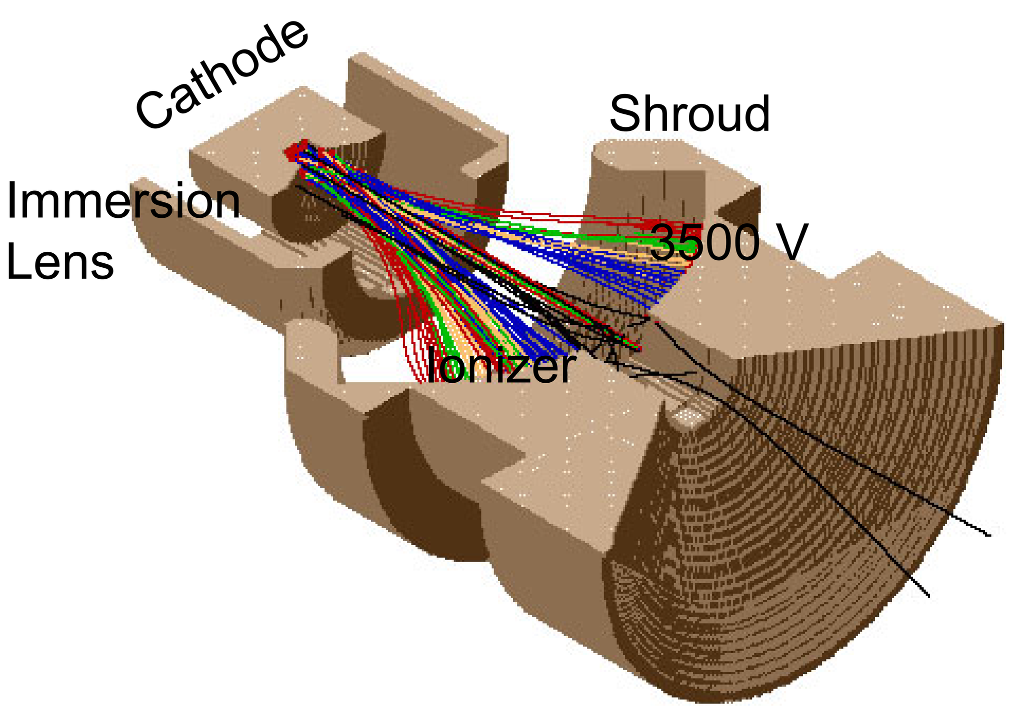

Figure 1

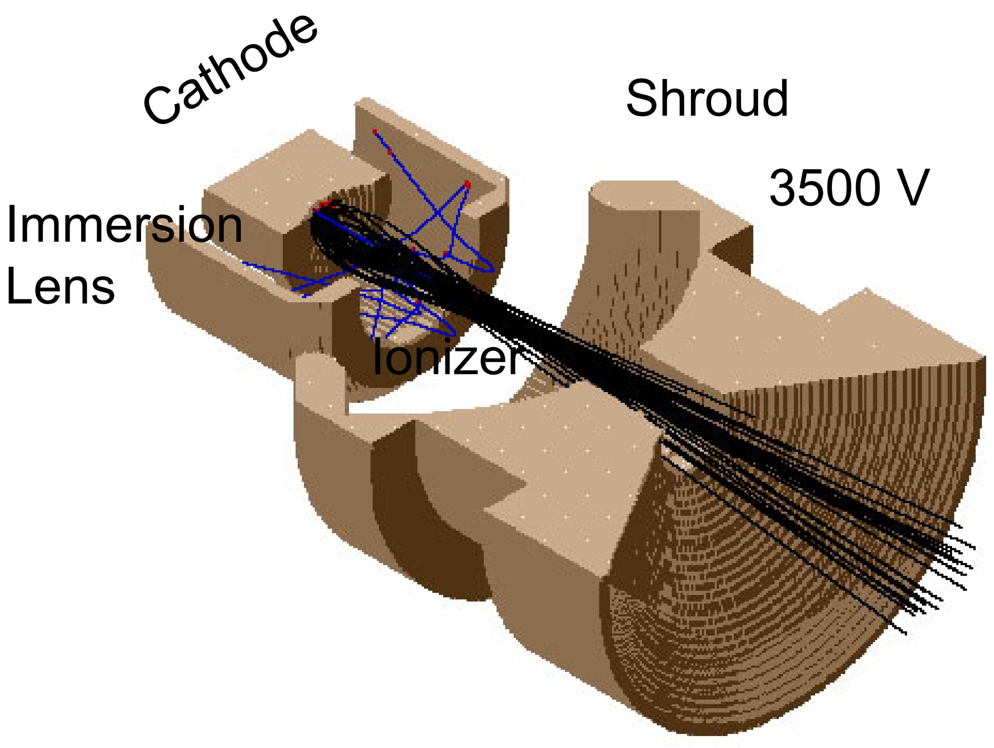

Figure 2

Figure 1 shows cesium ions being focused onto the cathode by the version of the CAMS ion source that we used as our figure of merit. This view was generated by cutting into one plane of the ion source. Different colors denote different starting positiions on the ionizer surface. The cesium ions near the ionizer hole tend to be over-focused and cross-over the central axis. This is cosistent with the simulations carried out by Brown *et al*. Figure 2 shows secondary ions being emitted from the cathode and transported out of the source through the central hole of the ionizer. This view was generated by cutting into one plane of the ion source. The blue traces are positively charged ions used to simulate the high cesium charge density near the cathode surface. A waist is formed about halfway between the cathode and ionizer. This is consistent with the simulations carried out by Brown *et al*.

New PRIME Lab Ion Source

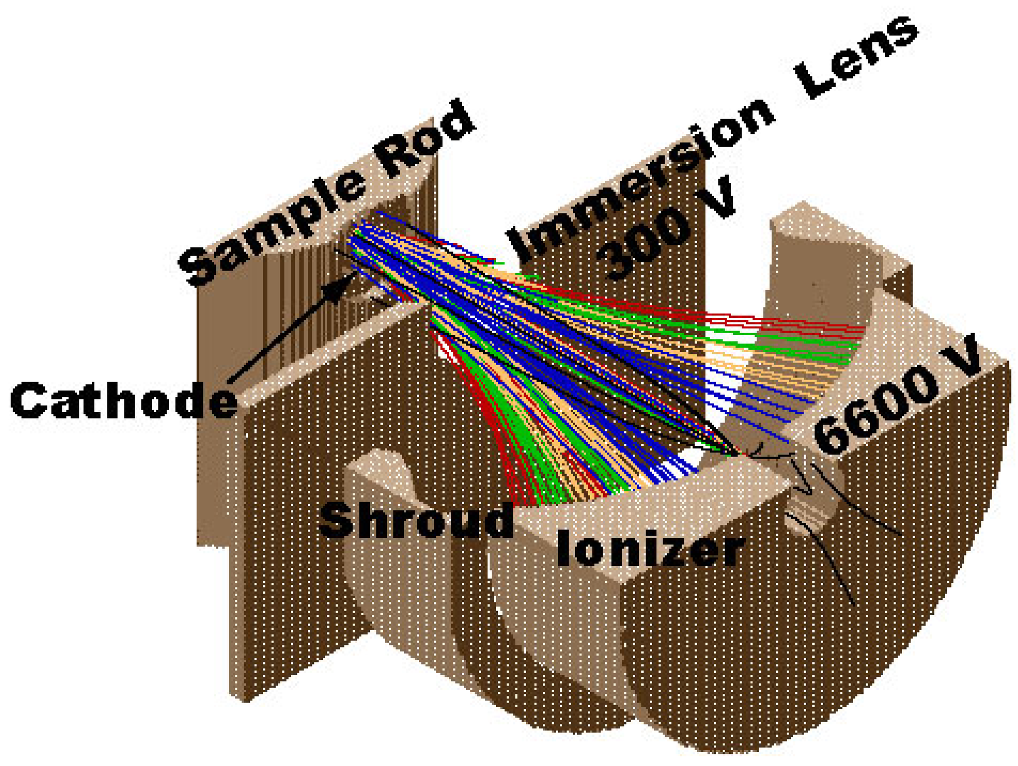

Figure 3

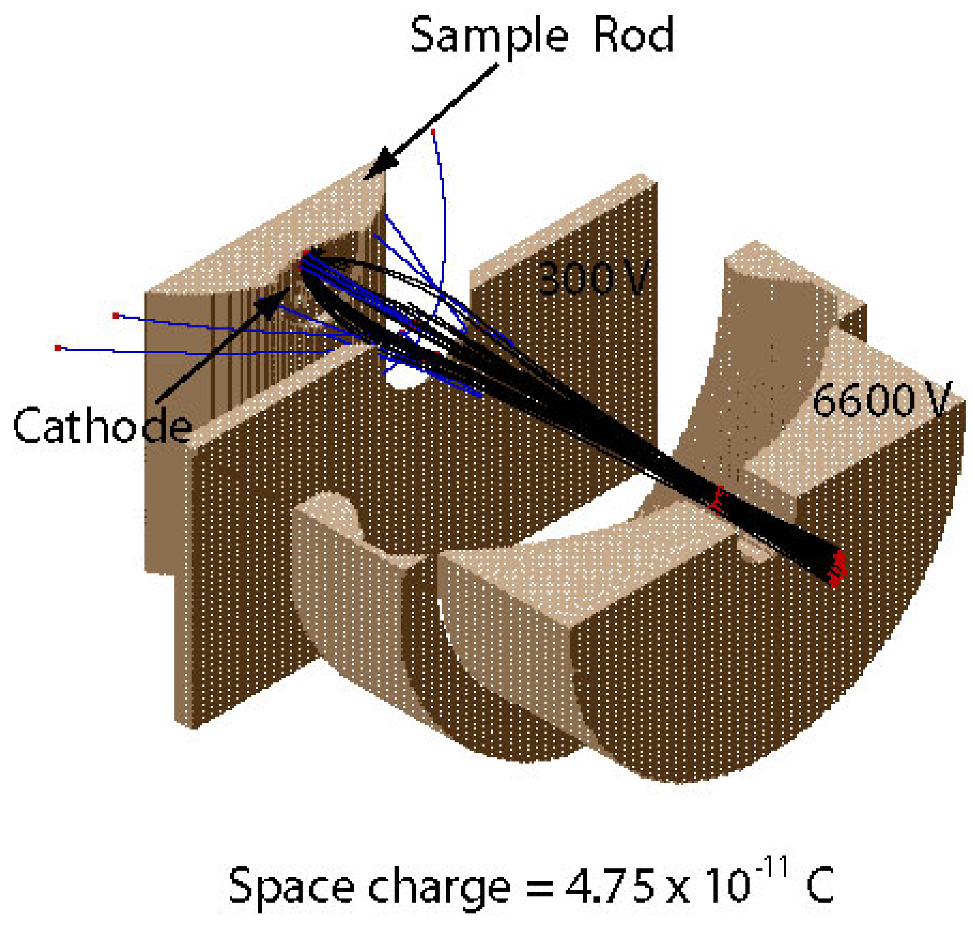

Figure 4

Figure 3 shows cesium ions being focused onto the cathode in the proposed PRIME Lab ion source. This view was generated by cutting into one plane of the ion source. Different colors denote different starting positiions on the ionizer surface. Figure 4 shows secondary ions being emitted from the cathode and transported out of the source through the central hole of the ionizer. This view was generated by cutting into one plane of the ion source. The blue traces are positively charged ions used to simulate the high cesium charge density near the cathode surface.

One of the obvious differences between the PRIME Lab source and existing cesium sputter ion sources is the size of the ionizer. Since the Chalk River rabbit source design is being used the ion source housing is contained in the sample rod and the cathode must be recessed with the result that one side of the immersion lens is very close to the sample rod. To increase this distance (and conductance of the ion source) we increased the size of the ionizer. The new spherical ionizer will have a radius of 0.945" as opposed to 0.687" on sources made by HVEE. After this alteration was decided upon, the space charge and voltage were scaled up so that approximately the same current density would be represented in the two sources. The distance from the cathode to immersion lens and from the ionizer to cathode was varied in both sources. The cesium focus and the divergence and spatial spread of the secondary ions were evaluated in many different geometries. It was found that the distance between the front of the sample and the ionizer should be 1.4" and the distance between the back of immersion lens and front of the sample should be 0.24". The sample insertion rod will be able to move 0.25" in the z direction. The cesium focus and approximate emittance of the secondary ion beam agreed to within a few percent of each other in the optimal geometry for the two sources. The divergence and spatial spread of the secondary ion beam is much more dependent on geometry in the CAMS source than the proposed PRIME Lab source. In Figure 5, we see two potential energy surfaces from the midplane of each source. The potential energy surface of the proposed PRIME Lab source has less curvature due to the larger diameter of the ionizer. This accounts for the lack of dependence the secondary ion beam has on geometry in the proposed PRIME Lab source.

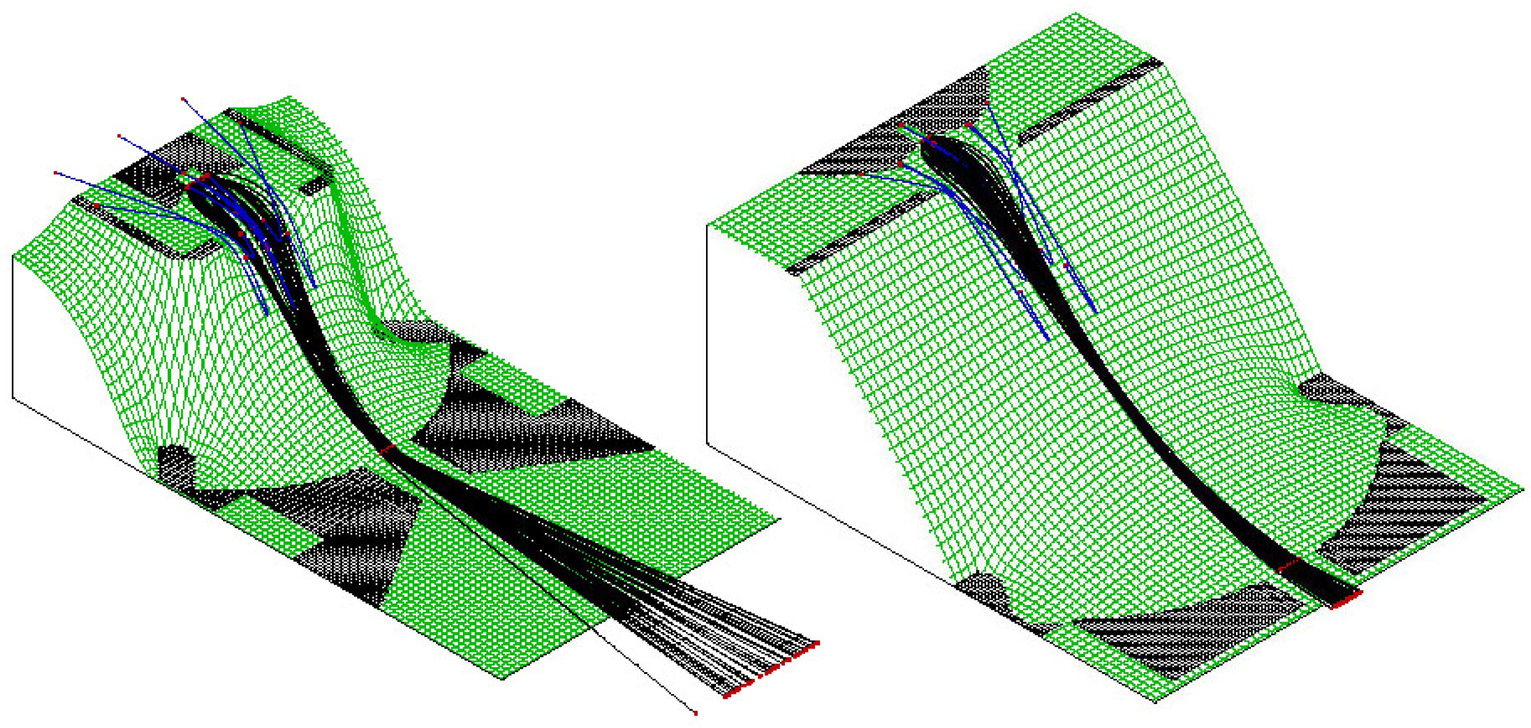

Figure 5. On the left is the potential energy surface in the midplane for the modeled CAMS source. The black lines represent secondary ion traces. On the right is the potential energy surface in the midplane of the PRIME Lab source.

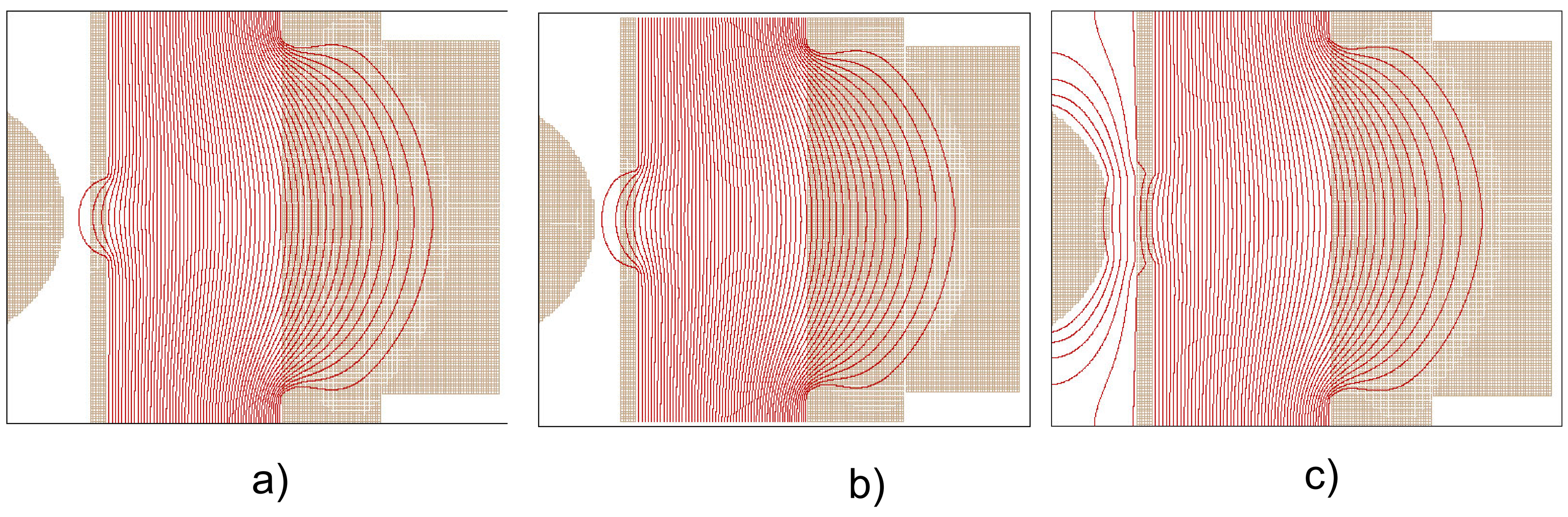

Figure 6. Midplane isopotential contours (6600 V applied to the ionizer in every case). a) The PRIME Lab ion source. b) The PRIME Lab ion source with the hole in the immersion lens 25% larger in diameter. c) The PRIME lab ion source with 600 V applied to the immersion lens.

Different immersion lens geometries were explored. One simple rule of thumb is that if the immersion lens is to be moved further from the cathode, then the immersion lens aperture should be made larger. Increasing the aperture size increases the electric field near the cathode. Thus, the immersion lens can be moved further away and provide essentially the same results. However, if the immersion lens aperture gets too large, then it has essentially no effect. For our geometry, that happens when the immersion lens aperture is approximately three times the cathode diameter. Applying voltage to the immersion seems to have great promise in increasing the cesium focus and decreasing the emittance of the secondary ion beam. Voltage on the immersion lens increases the electric field near the cathode enabling one to increase the distance between the cathode and immersion lens. Figure 6 shows isopotential contours for different immersion lens apertures and for voltage applied to the immersion lens.

Another aspect of the ion source that was modeled was small shifts in the position of the ionizer caused by heating. This results in a Cs beam that is not centered on the sample. This misalignment magnifies mass fractionation effects from small physical differences in the samples. Since the sample insertion rod transports the sample through vacuum seals it is not practical to have the cathode move in concert with the immersion lens. Simlulations demonstrate that if the immersion lens is off center by 0.33 mm relative to the ion source housing that there is no effect on the beam. Even if the immersion lens is off center by 0.66 mm, an amount unlikely given proper initial alignment of the ion source components, the beam is displaced by approximately 0.5 mm off center with no increase in its emittance- this effect could be corrected with appropriate steering.

References

[1] V.T. Koslowsky, N. Bray, Y.Imahori, H.R. Andrews, W.G. Davies, Nucl. Instr. and Meth. B 123 (1997) 203.

[2] T.A. Brown, M.L. Roberts, J.R. Southon, Nucl. Instr. and Meth. B 172 (2000) 344.