Ion-Imaging Plasma Diagnostics

by **E. V. Barnat and P. A. Miller**

Motivation—Sandia is developing the 3-D unstructured-mesh plasma code "Aleph". The code will provide unprecedented capabilities for modeling plasma and charged-particle flows inside neutron tubes, a nuclear weapons component. This will greatly improve Sandia's computational capabilities for design and manufacturing of neutron tubes. In parallel with this code work, we are developing novel plasma diagnostic techniques and conducting experimental tests for code validation. The diagnostics and tests do not simulate details of neutron tubes but are designed to isolate key pieces of plasma physics that the code must be able to treat accurately for eventual success.

Accomplishment—A plasma "sheath" is a region in which plasma properties change abruptly with spatial position. Plasma sheaths have been studied for decades, and their properties under different plasma conditions continue to be scientifically interesting and computationally challenging. The initial focus of our experimental studies is the extraction of an ion beam from quasi-neutral plasma. This effort tests the ability of the code to treat flowing, field-free plasma, its interaction with surfaces, and the transition in a sheath from plasma to a high-electric-field region in which an ion beam forms.

Figure 1 shows schematically the geometry of our experiment and the plasma and ion-beam behavior. We generated flowing plasma using a pulsed vacuum arc. That plasma expanded in a field-free region and was incident normally on a flat metal surface containing a 1-mm-wide rectangular slit (~12 mm long). Figure 1 shows a schematic view across the 1-mm slit. An acceleration electrode was located 5 mm away from the slit. The application of negative high voltage to the acceleration electrode caused extraction of an ion beam from the flowing plasma.

We used two different diagnostic techniques to characterize the ion beam. One diagnostic technique consisted of a linear array of Langmuir probes embedded in the acceleration electrode and oriented perpendicular to the slit. The probes were biased to collect ions and thus measured the ion current density distribution across the slit as a function of time. Figure 2 shows a photograph of the acceleration electrode with the embedded probes and sample data.

The other diagnostic technique yielded 2-D images of the ion beam distribution across the entire surface of the acceleration electrode. For this technique, the acceleration electrode consisted of a fine metal mesh and a biased phosphor screen 2 mm behind the mesh. Ion impact on the mesh generated secondary electrons that were accelerated to the phosphor screen. Electron impact on the phosphor generated a visible-light image of the spatial distribution of ions that was captured by a gated ICCD (intensified charge-coupled device) camera. Sample images for three different focusing conditions are shown in Fig. 3.

Significance—Diagnostic techniques that we developed are being used for validation of Sandia's new plasma code Aleph. We are comparing the observed and predicted dynamics of ion beam formation and propagation. This addresses sensitive and critical physics for the code. Successful validation will give confidence in use of the code for design and manufacturing of neutron tubes.

Sponsors for various phases of this work include: Nuclear Weapons Program

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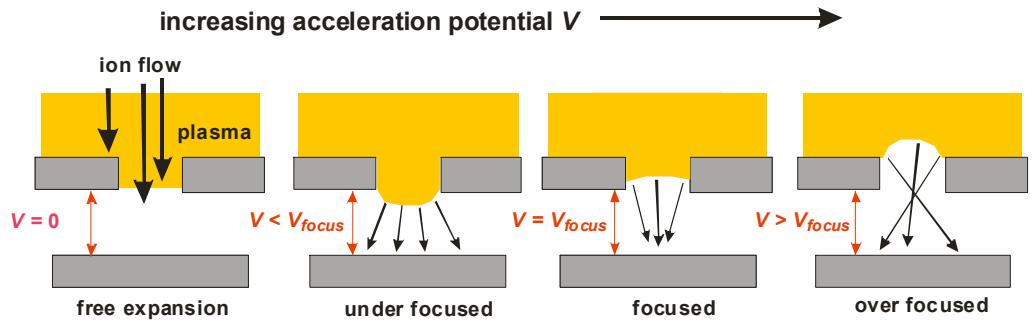

Figure 1. Plasma (yellow) flows downward towards a 1-mm-wide slit in an electrode. A potential V is applied to an ion-extraction electrode (bottom of each picture), accelerating ions through the hole and repelling electrons. A "meniscus" forms at the transition from plasma to ion beam. The shape of the meniscus depends on the plasma density, velocity, electron temperature, and V. The shape of the meniscus is inferred from the distribution of ion current on the extraction electrode.

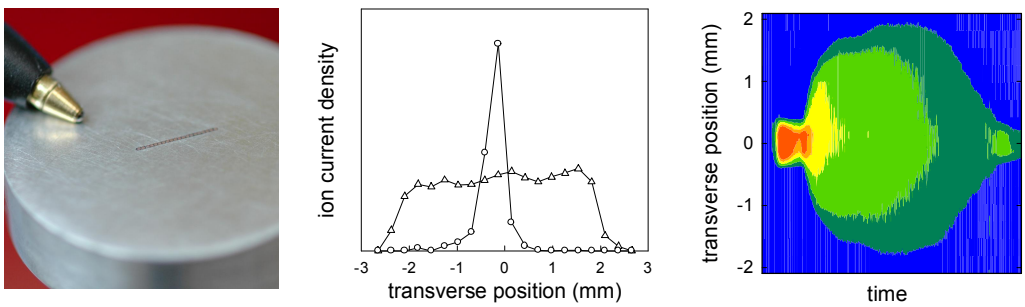

Figure 2. A linear array of ¼-mm-diameter Langmuir probes embedded in the 25-mm extraction electrode (left) measures ion current density. Sample data (middle) shows ion current density J_i measured using 20 probes at two different times (different focusing conditions). Right graph (J_i vs. position and time) shows dynamic focusing and defocusing during a single pulse.

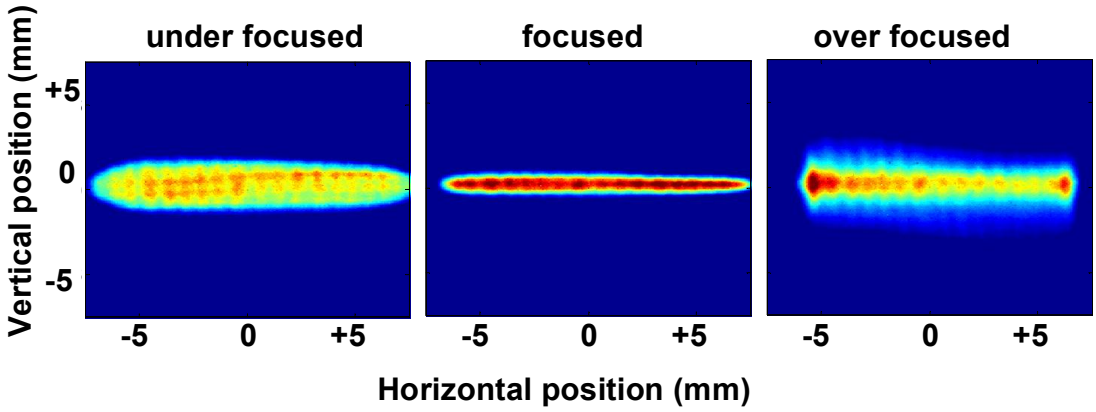

Figure 3. Data from the ion imaging diagnostic technique showing 2-D images of ions impacting the extraction electrode under three different focusing conditions. The images are snapshots at the same time for three different accelerating voltages.