

Spatially Resolved Energy Analyzer Measurements of an Ion Beam on the Low Potential Side of a Current-Free Double-Layer

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Abstract—Spatially resolved measurements of a supersonic Ar⁺ ion beam are obtained using a movable retarding field energy analyzer positioned on the low potential side of a current-free helicon double-layer (DL). The DL is generated near the open end of the helicon source where the fairly “collisionless” argon plasma is expanding in a diverging magnetic field for a radio frequency power of 250 W and a pressure of about 0.35 mtorr. The potential drop of the DL induces ion acceleration and the formation of an ion beam which propagates downstream of the DL. An image showing the ion beam spatial properties 12 cm downstream of the DL is presented.

Index Terms—Double-layer, energy analyzer, expanding plasma, ion acceleration, ion beams, supersonic.

COLLISIONLESS plasmas expanding in a diverging magnetic field are thought to be associated to space and astrophysical electric double-layers (e.g., aurora, solar wind, extragalactic jets, etc.) in the form of large single and small multiple potential structures [1]. Although ion acceleration in expanding plasmas has been extensively studied [2], it is only recently that laboratory evidence of the formation of a supersonic ion beam from ion acceleration across a current-free electric double-layer (DL) has been shown [3]. In this paper, we present an image generated from spatial measurements of this supersonic Ar⁺ ion beam using a retarding field energy analyzer (RFEA).

The experimental system CHI KUNG has been described previously [3]: it consists of a 15-cm diameter helicon source operating at 13.56 MHz (32-cm long cylindrical glass tube terminated with a 1-cm thick glass plate at $z = 0$ cm and surrounded by a 20-cm long double-saddle antenna) attached contiguously to a 30-cm long 32-cm diameter earthed aluminum diffusion chamber. The DL and the RFEA locations on the main z axis are 25 and 37 cm, respectively. The internal radii of the source and chamber are 6.8 and 16 cm, respectively, and the RFEA can be moved across the chamber diameter (r axis). The argon feed gas is introduced on the side of the chamber, and a turbo-molecular/rotary pumping system is connected to the sidewall of the chamber. The base pressure is 2×10^{-6} torr, the pressure being measured with an ion gauge and a baratron gauge. Two solenoids situated around the source are used to create an expanding magnetic field of about 120 and 25 G at

the position of the DL and of the RFEA, respectively. The radio frequency (RF) power and operating pressure are kept constant (250 W and 0.35 mtorr) and the RFEA ion current versus discriminator voltage $I(V_d)$ characteristics are obtained on the r axis every centimeter in a contiguous run with the RFEA facing the DL. The RFEA is connected to a LABVIEW data acquisition system run by a PC computer and the acquired data files are sent over the network to a G3 MAC computer. In this configuration, the $I(V_d)$ characteristic corresponds to the measure of the energy of the ions falling through the DL and the sheath surrounding the earthed analyzer. Using a method described in [3], the derivative of each measured $I(V_d)$ characteristic, which we call the ion energy distribution function (IEDF), is fitted by the sum of one to three gaussians [3] and normalized using the data processing software IDL. The normalized IEDFs are combined into a three-dimensional (3-D) matrix ($x = V_d$, $y = r$ and $z = \text{IEDF}$) with a two point linear fit between each value of r using MATLAB on a G4 MAC. Fig. 1 shows the normalized IEDF measured across the chamber diameter plotted using the *imagesc*(x, y, z) MATLAB function and a linear color scale from 0 (blue) to 1 (red).

Outside the projection of the helicon source tube ($|r| > 6.8$ cm), a single peak IEDF around the local plasma potential V_p (red band at ~ 25 – 30 V) is measured. In the projection of the source ($|r| \leq 6.8$ cm), a two-peak distribution is measured with the high-energy peak (red band at ~ 45 – 50 V) corresponding to an ion beam of velocity about twice the sound speed and of density as high as about 15 % of the local plasma density [3]. The velocity uniformity (voltage difference between the 2 red bands) is fairly good across the source diameter, showing that the potential drop of the DL is rather constant radially. However, the high energy band color change from red (~ 1) to yellow (~ 0.6) when $|r|$ is increased from 0 to ~ 7 cm indicates the bell shape of the beam density, as one would expect from a radial density profile in cylindrical geometry. The light blue (~ 0.3) region between the two red bands shows the effect of some charge exchange and elastic ion-neutral collisions.

The image suggests that the ion beam is not magnetized in agreement with the large values of the Larmor radius for supersonic ions in this region (> 20 cm). The radial variation of the local plasma potential shown by the curvature of the low energy red band seems to be a result of the downstream plasma radial and axial diffusion.

Manuscript received May 18 2004; revised September 8, 2004.

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Digital Object Identifier 10.1109/TPS.2005.844958

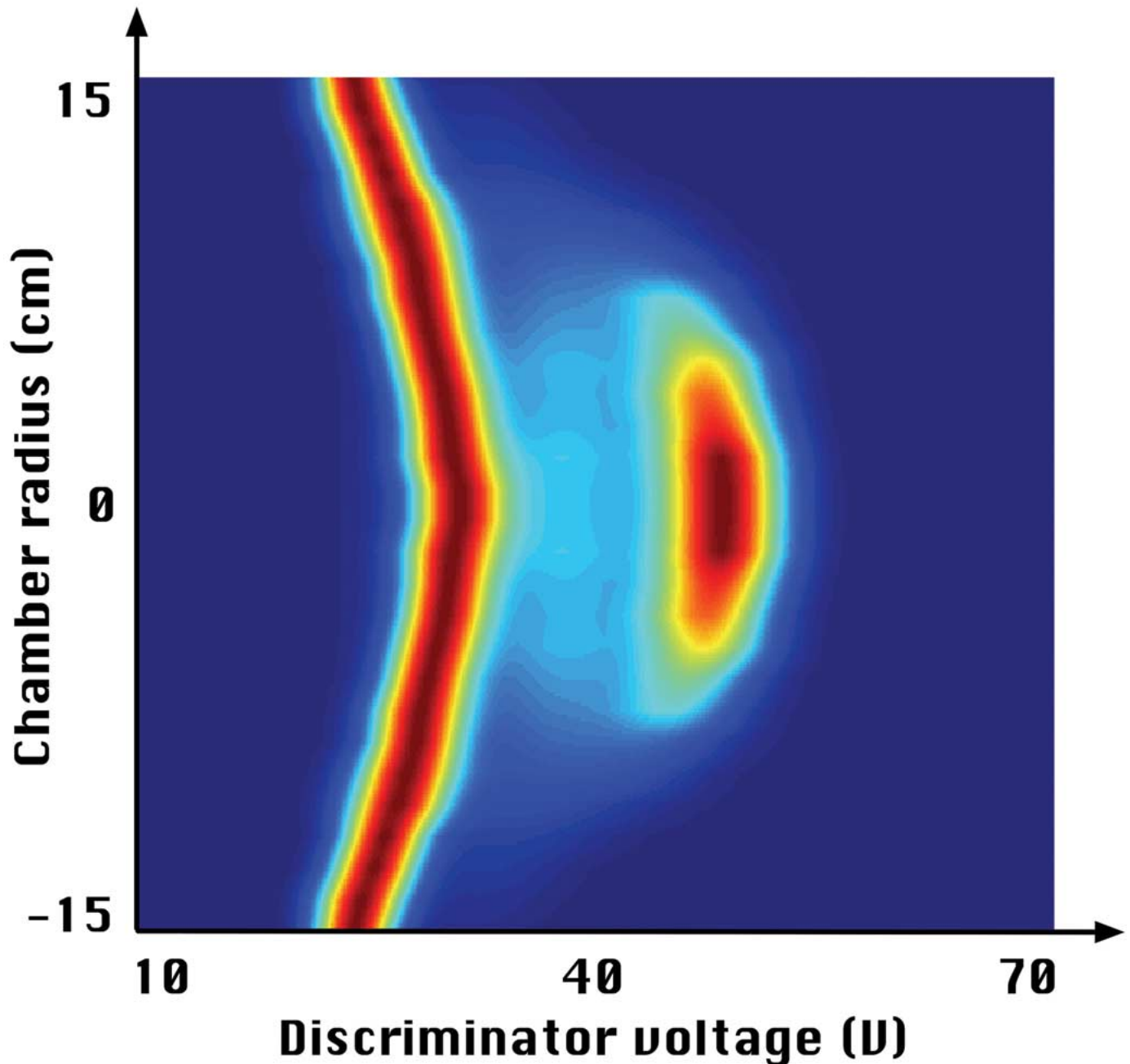


Fig. 1. Normalized IEDFs obtained with the RFEA along the chamber diameter; linear scale from 0 (blue) to 0.6 (yellow) to 1 (red). Energy resolution of the RFEA is about 1 eV.

In conclusion, an image of an ion beam created by acceleration through a current-free electric DL and measured using an energy analyzer has been presented. It provides useful information on the geometry and effect of the double layer.

ACKNOWLEDGMENT

The authors would like to thank A. Aanesland, A. Caillard, and A. Meige for their help with IDL and MATLAB.

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