Ion Energy Distribution Functions in Inductively Coupled RF Discharges in mixtures of Chlorine and Boron Trichloride

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Abstract

Weare using a gridded energy analyzer to measure positive ion energy distributions and fluxes at the grounded electrode of high-density inductively-coupled rf discharges. In this paper, we present details of ion energies and fluxes in discharges containing mixutres of chlorine and boron trichloride

Introduction

Plasma discharges involving mixtures of chlorine and boron trichloride are widely used to etch metals in the production of very-large-scale-integrated cirucits.[1,2] Energetic ions play a critical role in this process, influencing the etch rates, etch profiles, and selectivity to different materials. In addition, energetic ions can contribute to device damage in the circuits being processed. Inductively coupled or "transformer coupled" discharges are becoming increasingly popular for semiconductor processing due to the high plasma densities and low pressures achievable, the relative independence of ion flux and ion energy they provide, and the relative simplicity of the apparatus. In order to better understand these inductively coupled discharges, several groups are developing computational models [3-8] and making detailed measurements of discharge parameters.[9-13] As part of this effort, in this paper we report ion fluxes and ion energy distributions made with a gridded energy analyzer in inductively-coupled rf discharges in mixtures of chlorine and boron trichloride.

Apparatus

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Our experiments were carried out in a Gaseous Electronics Conference Reference Cell (GEC Ref. Cell)[14,15] which had been modified to produce inductively-coupled discharges.[16] A schematic of our cell, including the five-turn planar induction coil at the the top of the cell and the ion analyzer at the bottom of the cell is shown in Fig. 1. To excite the plasma, rf energy at 13.56 MHz was coupled from the rf coil, through a quartz window, to the discharge region. The stainless steel lower electrode was grounded for these experiments. The pinholes were laser-drilled in thin stainless steel discs which were glued into the center of the electrode with conductive epoxy.

The ion analyzer used in these experiments was a gridded energy analyzer. This analyzer has been described in detail previously[11,12] and only a brief summary of its operation will

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be given here. A schematic of the ion analyzer is shown in figure 2. The detector contains three screen grids and a series of annular current-collecting electrodes. The three grids and the electrodes all form sections of concentric hemispheres which are centered on the 10 μm diameter pinhole. Forming the grids and electrodes into sections of concentric hemispheres allowed the detector to accurately measure the ion energies regardless of the angle of the ion's trajectory when it passed through the pinhole. This hemispherical design and the annular electrodes also allowed the detector to measure ion angular distributions, but this capability was not used in these experiments. The first grid (nearest the pinhole) was grounded and the third grid was held at a negative potential to suppress secondary electron emission from the electrodes. The voltage on the second grid was varied from 0 to +40 volts to sweep out the ion energy distribution function. Only ions with energies greater than the voltage on the second grid were passed by the grids and detected by the collecting electrodes. Thus, the ion energy spectrum was the derivative of the signal at the collecting electrodes as a function of the voltage on the second grid. In these experiments, all of the electrodes were tied together, and the ion currents were measured with a picoammmeter. Once the pinhole size and the screen transmissions were collected for, the ion signals could also be used to determine the ion flux to the lower electrode.

Results and Discussion

Figure 3 shows ion fluxes versus pressure for a number of Cl_2/BCl_3 mixtures. Power to the matching network feeding the rf coil was 200 W for this data. Previous work has shown that approximately 80% of the power to the matching network is dissipated in the plasma. This figure shows that addition of BCl_3 to a Cl_2 discharge can decrease the ion flux to the lower electrode by a factor of two to three, depending on the pressure. Note that ion flux in discharges containing BCl_3 decreases as pressure increases. This is in contrast to discharges in pure Cl_2 in which ion fluxes increased slightly as pressure increased.[20] Also, the fluxes in pure BCl_3 discharges are almost an order of magnitude lower than fluxes in pure Ar discharges under equivalent conditions. [11]

Figure 4 shows ion energy distributions in 3/1 Cl_2/BCl_3 discharges as a function of total pressure. This 3/1 Cl_2/BCl_3 mix ratio is similar to ratios commonly used to etch aluminum contacts. Power to the rf matching network was 200 W. At low pressures, the ion energy distributions form a single peak, similar to the distributions seen in most inductively-coupled discharges.[11,12] At higher pressures, however, the distribution splits into a double-peaked distribution even though the lower electrode and pinhole are at ground potential. The most likely source of this splitting appeared to be oscillations in the plasma potential caused by residual capacitive coupling between the rf coil and the discharge. We therefore inserted a Faraday shield just below the window, between the rf coil and the discharge to short out the capacitive coupling and repeated some of the experiments. Figure 5 shows ion energy distributions in pure BCl_3 with and without the Faraday shield in place. Since our Faraday shield also appeared to reduce the inductive rf power coupled to the discharge, we adjusted the power to obtain equal ion fluxes with and without the shield in place. The double-peaked distribution disappears in figure 5 when the Faraday

shield is in place, verifying our guess that the splitting was due to residual capacitive coupling between the coil and the discharge.

Summary

Addition of BCl_3 to Cl_2 discharges can reduce the flux of positive ions to the lower electrode by a factor of 2 to 3 to levels of 2 - 4 mA/cm^2 . These fluxes are almost an order of magnitude lower than the fluxes seen in pure Ar discharges. At low pressures, the ion energy distributions form a single peak, well separated from zero energy, similar to results in other discharges. At high pressures, the distribution becomes double peaked. This splitting is due to residual capacitive coupling between the rf coil and the discharge. Further details of the experiment and results will be presented.

References

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1.   Dry Etching for VLSI, A. J. vanRoosmalen, J. A. G. Baggerman, and S. J. H. Brader. Plenum Press, New York, 1991.
2.   Principles of Plasma Discharges and Materials Processing, Michael A. Lieberman, Allan J. Lichtenberg, John Wiley & Sons, New York, 1994
3.   J. E. Johannes, T. J. Bartel, R. S. Wise, D. J. Economou, paper PS-MoM7: Comparison of Low Pressure Cl_2 Plasma Simulations With Experimental Data in an Inductively Coupled Source, 42nd National Symposium of the American Vacuum Society, Minneapolis MN, October 16, 1995
4.   R. J. Hoekstra and M. J. Kushner; Predictions of Ion Energy Distributions and Radical Fluxes in Radio Frequency Biased Inductively Coupled Plasma Etching Reactors, Journal of Applied Physics, in press 1996.
5.   C. Lee and M. A. Lieberman, J. Vac. Sci. Technol. A (13)2, March/April 1995, p 368
6.   E. F. Jaeger, L. A. Berry, J. S. Tolliver and D. B. Batchelor, Physics of Plasmas 2 (6) June 1995, p. 2597
7.   E. Meeks and J. W. Shon, J. Vac. Sci. Tech. A 13, (1995), p. 2884
8.   E. Gogolides and H. H. Sawin, J. Appl. Phys, 72, (9), 1 Nov, 1992, p. 3971
9.   G. A. Hebner, J. Vac. Sci. Technol. A14(4) July/Aug 1996, pps. 2158 - 2162
10.   G. A. Hebner, J. Appl. Phys, 80 (6) , 15 Sept. 1996, pps. 3215 - 3220.
11.   J. R. Woodworth, M. E. Riley, D. C. Meister, B. P. Aragon, M. S. Le and H. H Sawin, J. Appl. Pysi. 80 (3), 1 Aug. 1996, pps. 1304 - 1311
12.   J. R. Woodworth, M. E. Riley, P. A. Miller, G. A. Hebner and T. W. Hamilton, J. Appl Phys, in press, 1997

13. J. Liu, G. L. Huppert, and H.H. Sawin, J. Appl. Phys 68 (8) 15 Oct, 1990, pps. 3916 - 3934

14. P. J. Hargis, Jr. , et. al Rev. Sci. Instruments, 65, (1994) p. 140

15. J. K. Olthoff and K. E. Greenberg, Journal of Research, National Institute of Standards and Technology 100 (4) July-August, 1995, p. 327

16. P. A. Miller, G. A. Hebner, K. E. Greenberg, P. D. Pochan,and B. P . Aragon, Journal of Research, National Institute of Standards and Technology 100 (4), July-August 1995, p. 427
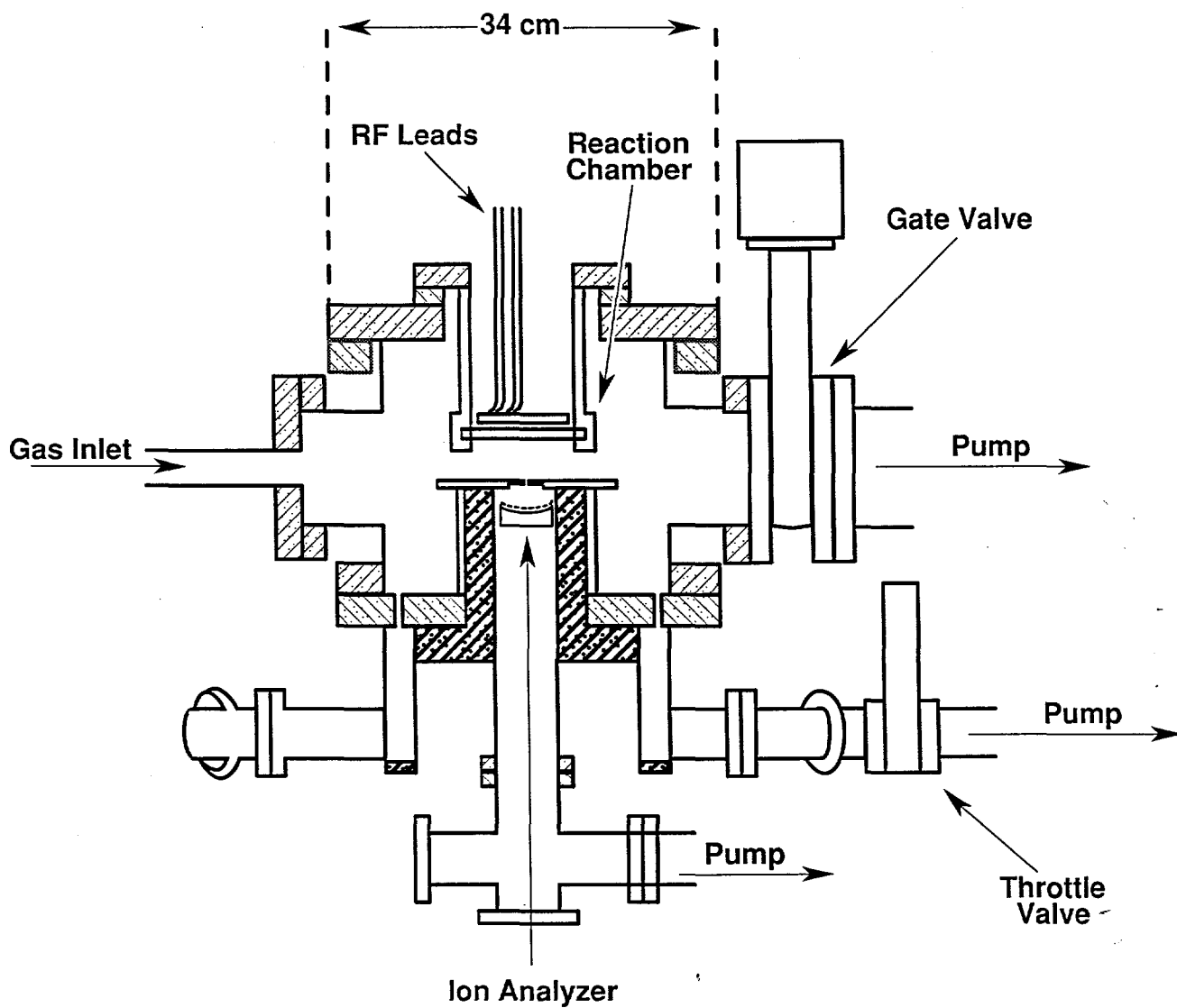
Figure Captions:

Figure 1: Schematic of the GEC Reference Cell used in these experiments. Note that the ion analyzer is located in a separate vacuum system below the grounded lower electrode.
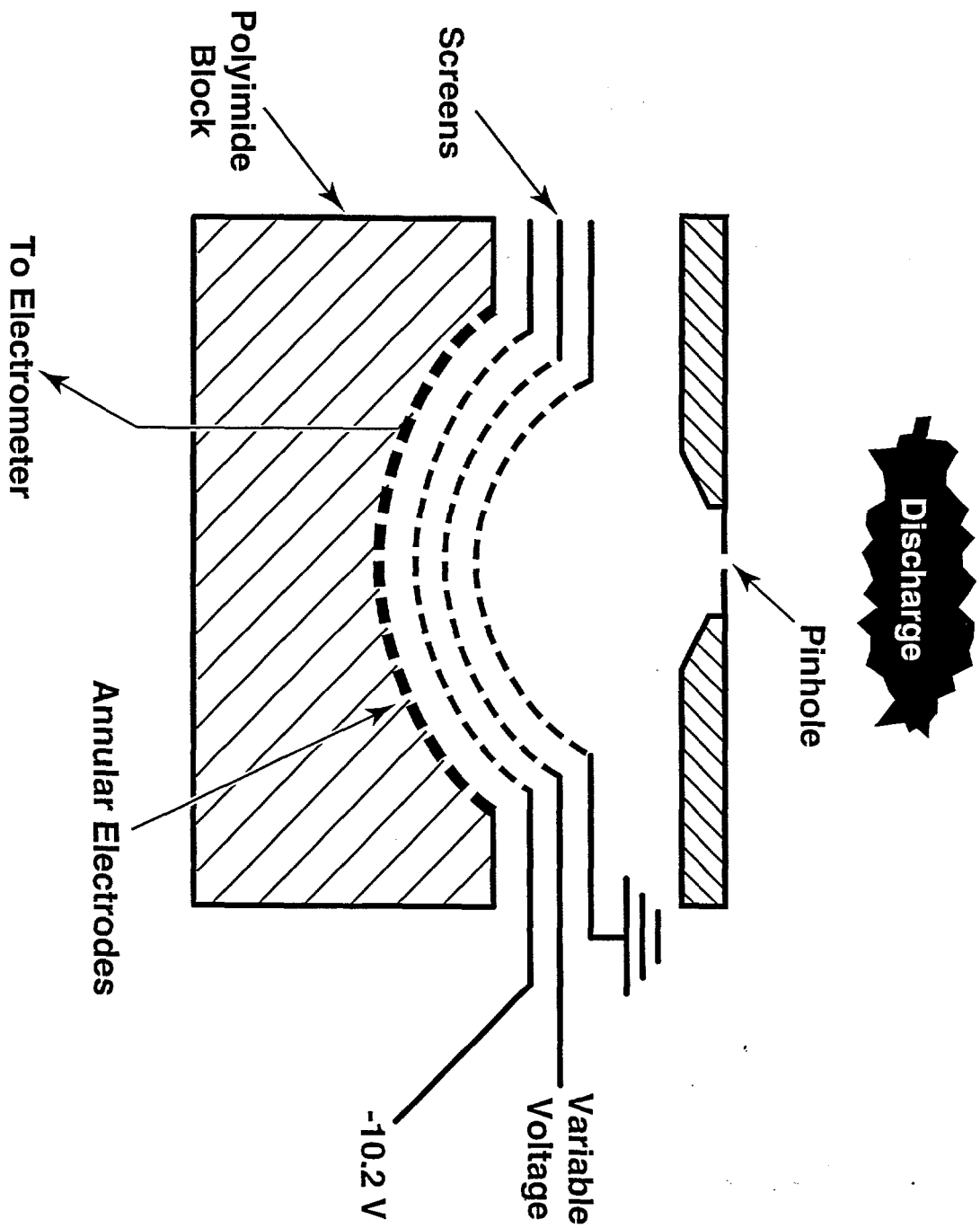
Figure 2: Schematic of ion analyzer. The distance from the pinhole to the collection electrode is 2.3 cm.

Figure 3: Ion fluxes to the lower electrode in Cl_2 BCl_3 discharge mixtures with 200 W rf input to matching network.
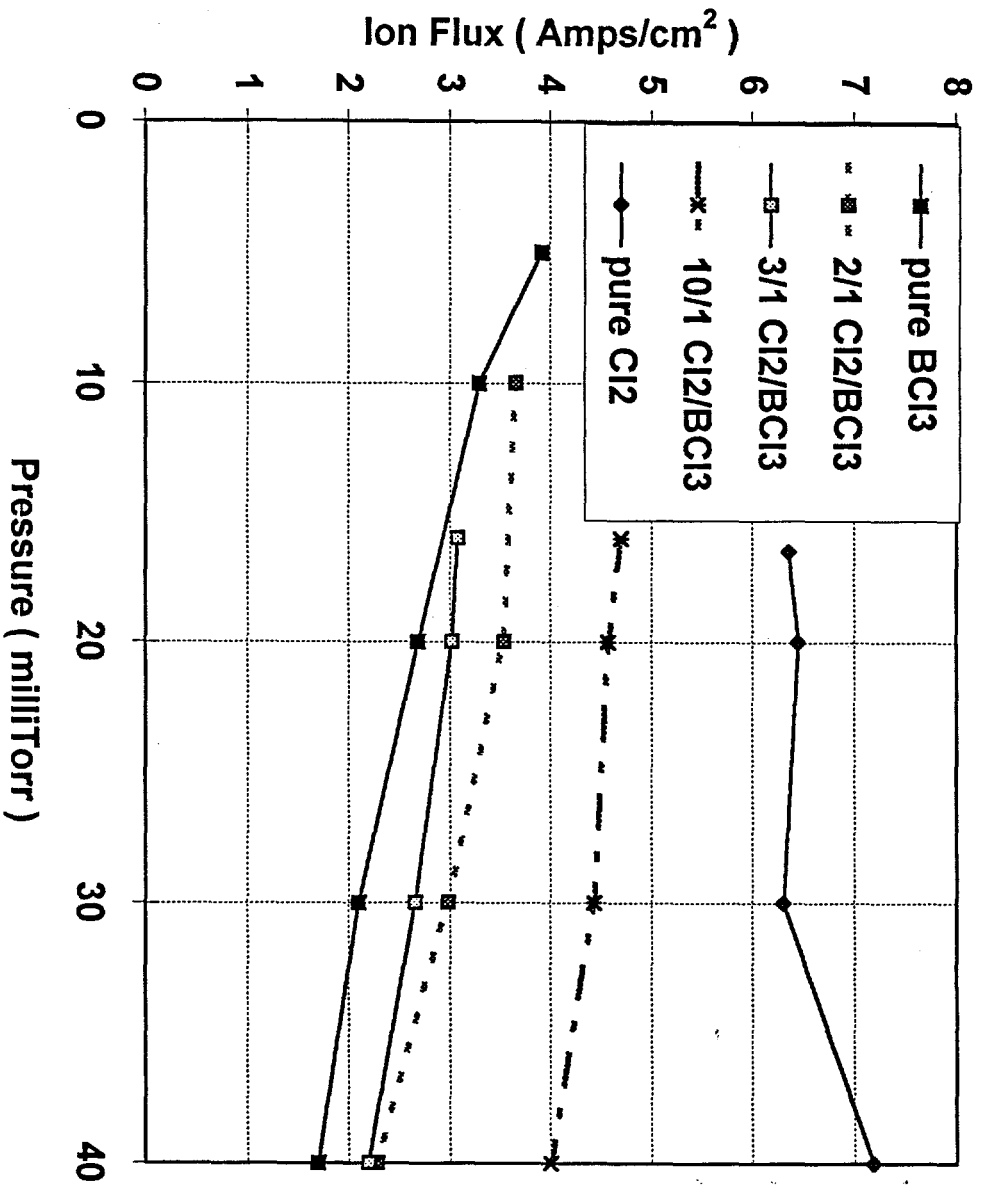
Figure 4: Ion Energy distributions in 3/1 Cl_2/BCl_3 discharge mixtures.
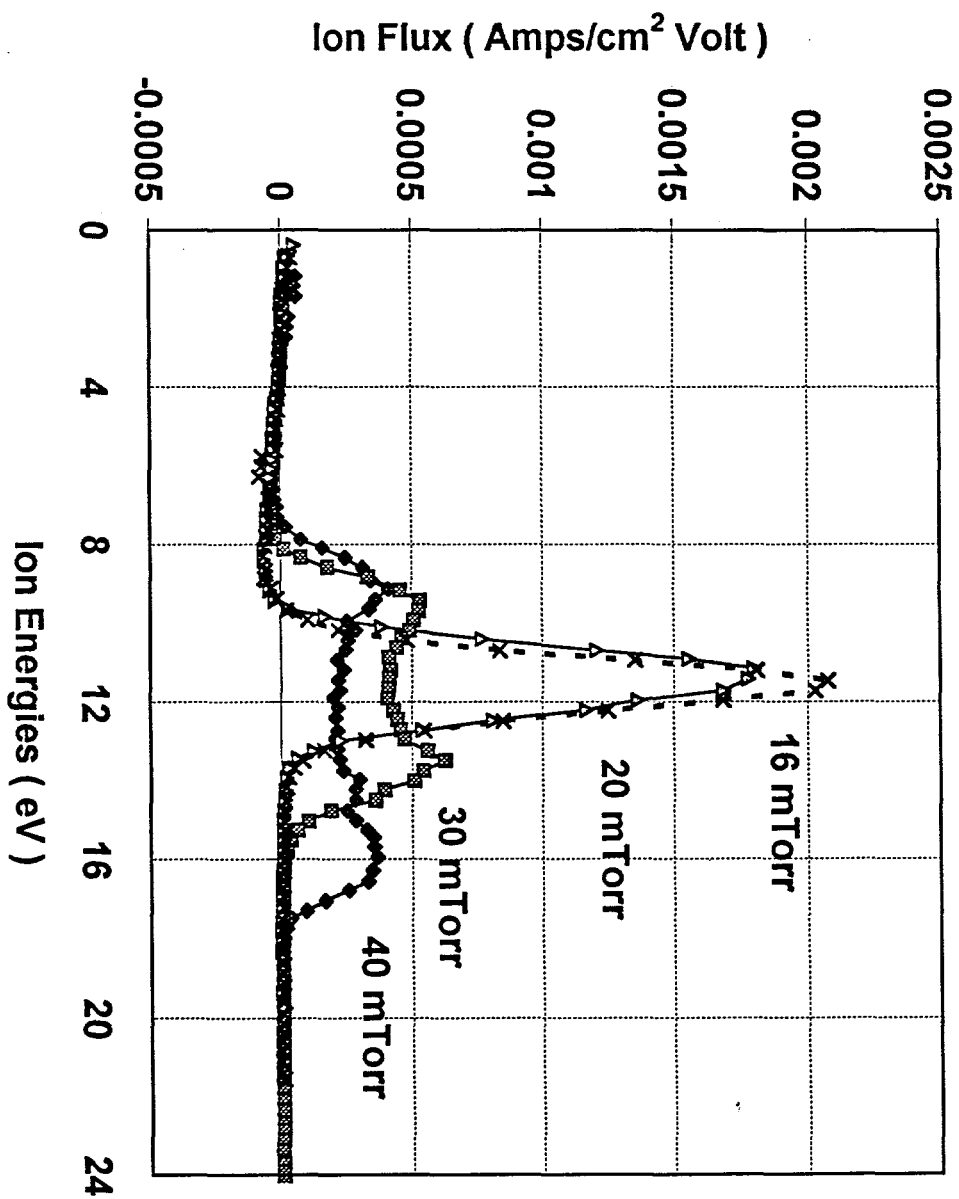
Figure 5: Ion Energy distributions in pure BCl_3 with and without Faraday shield in place.

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Polyimide
Block

Screens

To Electrometer

Annular Electrodes

Pinhole

Discharge

-10.2 V

Variable
Voltage

T370 CP4187.02

Chart3

Ion Flux (Amps/cm^2)

Pressure (milliTorr)

Legend:
- pure BCl3
- 2/1 Cl2/BCl3
- 3/1 Cl2/BCl3
- 10/1 Cl2/BCl3
- pure Cl2

bclclsum.xls

Chart1

Ion Flux (Amps/cm^2 Volt)

Ion Energies (eV)

16 mTorr

20 mTorr

30 mTorr

40 mTorr

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Chart3

b11796a.xls

Ion Flux (Amps/cm^2 Volt)

with faraday shield

no faraday shield

—♦— 30 mT, 200 W

- ■ - 30 mT, 300 W

Ion Energies (eV)