MBMS for Preformed Ions

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In order to accurately characterize a plasma or other 'high' pressure reaction cell, you need to obtain a representative sample. Sampling the plasma as a molecular beam through rapid pressure reduction immediately after ions, radicals and neutrals leave the plasma, allows for an unadulterated snapshot of the plasma chemistry. With molecular beam sampling, you are looking directly at the chemical soup which comprises the plasma. This includes noise sources such as photons, electrons, metastable neutrals, and even particulates in addition to the ions, neutrals and radicals to be monitored.

A cross beam ionizer allows for the separation of the analyte signal, which is comprised of plasma ions and ions created in the ionizer from plasma molecules and neutrals, from these sources of noise. The use of a cross beam ionizer will also protect the quadrupole analyzer and detector from direct bombardment with the reactive species common to plasmas used in semiconductor applications. We have developed a novel two stage molecular beam sampling system centered around a new cross beam deflector ionizer [1], yielding a compact vacuum system with efficient pumping in both stages. This presentation focuses on the characterization of the energy filtering capability of this new system, using a DC glow discharge as a 'mono-energetic' source of pre-formed ions.

I. SAMPLING A CHEMICAL SOUP

There are a wide variety of species present in a high pressure source such as a plasma: metastable neutrals, radicals, positive ions, negative ions, electrons, photons, clusters and particulates.

A plasma monitoring system must allow selective monitoring of these various species, without interference from the others. In order to obtain a representative sample, a molecular beam can be generated through rapid pressure reduction to a collision-free vacuum level. Ions present in the sampled gas need to be separated from the bulk gas flow, preferably using an energy filter for increased selectivity. Figure 1 illustrates a typical two stage molecular beam plasma sampling system configured with focusing lenses in the intermediate pumping stage for focusing pre-formed ions.

II. WHY USE A CROSS BEAM DEFLECTOR IONIZER?

- Improved Signal-to-Noise: *Photons, metastable neutrals, and energetic ions can cause noise if in line-of-sight with the detector.*
- Reduced Contamination: *Condensables and particulates never see the off-axis mass filter and detector, and therefore cannot contaminate them.*
- Improved Pumping: *With an Axial Molecular Beam Ionizer, most of the pumping load of a molecular beam must be pumped through limited conductance holes in the mass filter housing itself.*
- With the Cross Beam Deflector Ionizer, there is virtually infinite pumping speed for the beam exiting the ionizer, limited only by the size of the pump.
- Energy Filtering for Pre-formed Ions: The integral quadrupole deflector energy filter increases selectivity, allowing for differentiation of the source of the ions.

III. HOW DOES THE CROSS BEAM DEFLECTOR IONIZER FILTER PRE-FORMED IONS?

The Cross Beam Deflector Ionizer combines the high sensitivity ionization region of an Axial Molecular Beam Ionizer with a high transmission Quadrupole Deflector Energy Filter. Ions generated external to the system are focused through the

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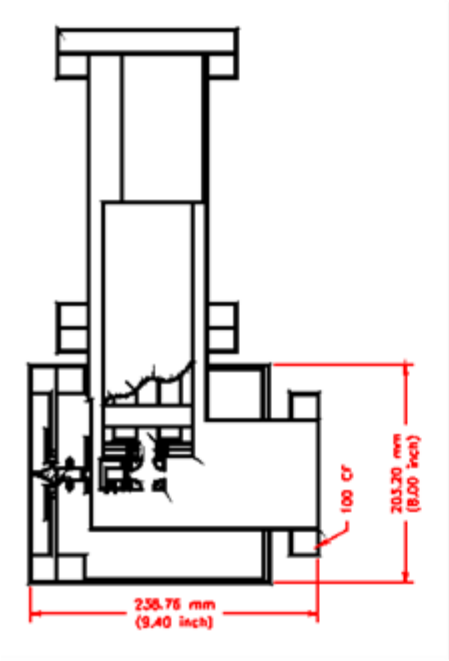

Figure 1. Plasma Monitoring with a Two Stage Molecular Beam Sampling System, using a Cross Beam Deflector Ionizer.

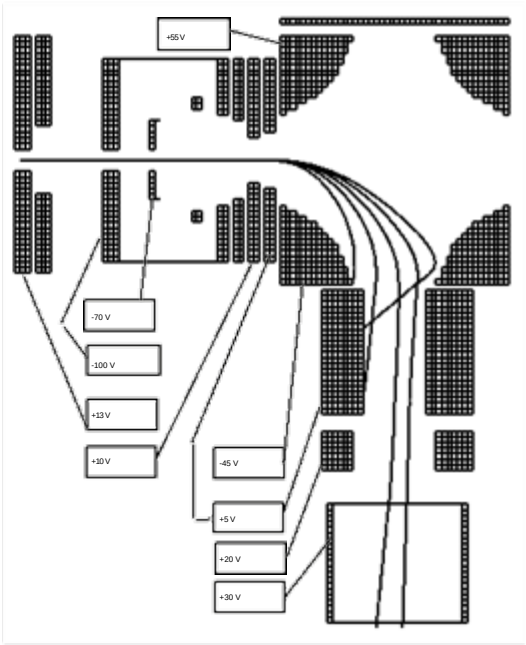

Figure 2. Energy Resolution: SIMION Simulation shows ion trajectories for ions of 8, 16, 24, 32, and 40 eV (left to right) injected into the cross beam deflector ionizer and deflected ninety degrees. Only ions of 24 and 32 eV ion energy get through. This data corresponds with the data point labeled 100 V in Figure 5, experimentally measured to have an energy resolution of 8 eV (FWHM).

ion optics, using the molecular beam apertures and ionizing region as lenses, and are injected into a Quadrupole Deflector Energy Filter where they are deflected ninety degrees into a Quadrupole Mass Filter. Photons, metastables, particulates, and molecular beam gases pass through the Quadrupole Deflector to a pump or cold finger.

The Quadrupole Deflector is an energy filter. The potential difference between the pairs of rods determines the energy band pass, and the average of these potentials determines the center point of the band pass. Previous work has demonstrated virtually 100% deflection efficiency for a well-collimated ion beam [2, 3]. A quadrupole deflector coupled to an ionizer with no collimating lenses has a measured sensitivity about 2/3 of that of the equivalent axial molecular beam ionizer configuration.

We predict that the use of the cross beam deflector ionizer to focus ions generated external to the ion region should demonstrate transmission efficiency approaching unity, since the ion beam is collimated by additional lenses.

IV. GLOW DISCHARGE SOURCE

A DC glow discharge plasma was used as a model 'monoenergetic' ion source. (See Figure 3 .) An argon plasma (1.3 torr) was maintained through application of -1.22 kV at the electrode labeled HV, resulting in a stable discharge current of 3.7 mA. Ions from the plasma were sampled into a biased cone through ion optics into the quadrupole mass filter. Typical lens voltages are indicated in Figure 2. Operating pressures were 1.5 X 10^{-4} torr and 1 X 10^{-6} torr for stages 1 and 2 respectively. The sampling cone and first and second mesh lens voltages were +40 and -20, and -280 V unless specified otherwise.

V. GLOW DISCHARGE CHARACTERIZATION

A Merlin MEXM-500 quadrupole mass spectrometer system (500 amu mass range, 19 mm rod diameter, 1.2 MHz operating frequency) was configured with two optics modules and twelve lens power supplies. The flange mounted mass filter was modified to electrically isolate the quadrupole and multiplier housings from ground using ruby balls allowing the housing potential to be maintained near the pole bias potential, to eliminate peak shape problems due to field imperfections [4].

The lens supply which was used to bias the housings (system bias supply) was also used to bias all other lens supplies in the system except the sampling skimmer and first tube lens. Thus, once the system is tuned to accept a narrow energy range (small potential difference between deflector pole pairs), the housing bias potential can be used to control the centerpoint energy of the system, keeping the sampling skimmer and first lens element constant so as not to affect ion source energetics/

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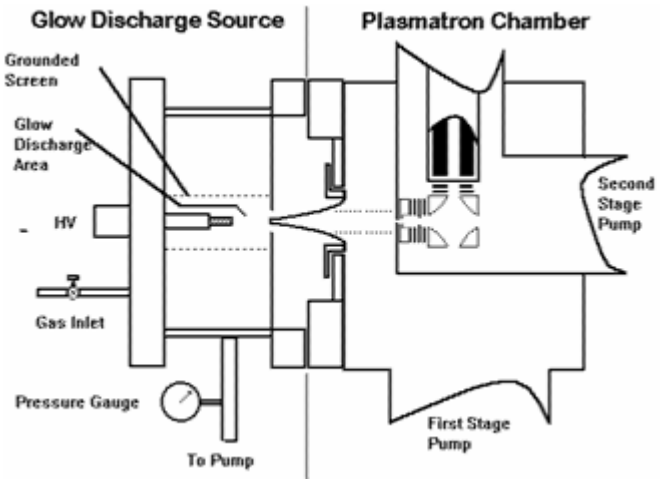

Figure 3. Sketch of Glow Discharge ionization source coupled to plasma monitoring system.

plasma potential. As shown in Figure 4, the potential difference between adjacent poles was maintained at 2.2 volts, with the system bias potential varied in small steps to scan the energy range of the ions emanating from the glow discharge source.

An energy resolution of 1.3 eV was measured (peak width at half max), indicating that the ions sampled appear to have a narrow range of ion energy, 'mono-energetic', smeared by an energy filter of a finite but wider bandpass. The tailing at negative system bias potential is attributed to collisions with gas molecules after the skimmer.

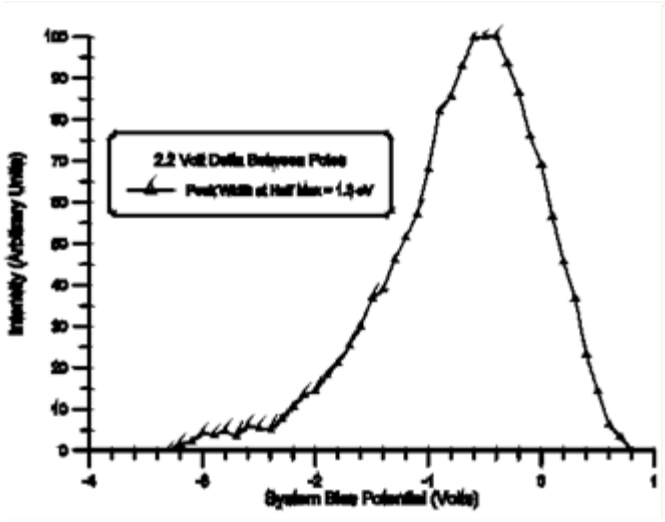

Figure 4. Energy scan of argon plasma showing narrow energy resolution.

Figure 5. Energy resolution of system as measured for various deflector pole voltage pair settings.

VI. ENERGY RESOLUTION CHARACTERIZATION

The voltage difference between deflector poles was systematically varied to characterize the energy resolution of the system. As in the experiment illustrated in Figure 4, the pole potentials were pre-determined, and the system potential was scanned in small steps, with the bias potential which yielded maximum intensity, and half-max on either side of the peak identified for each pole voltage difference.

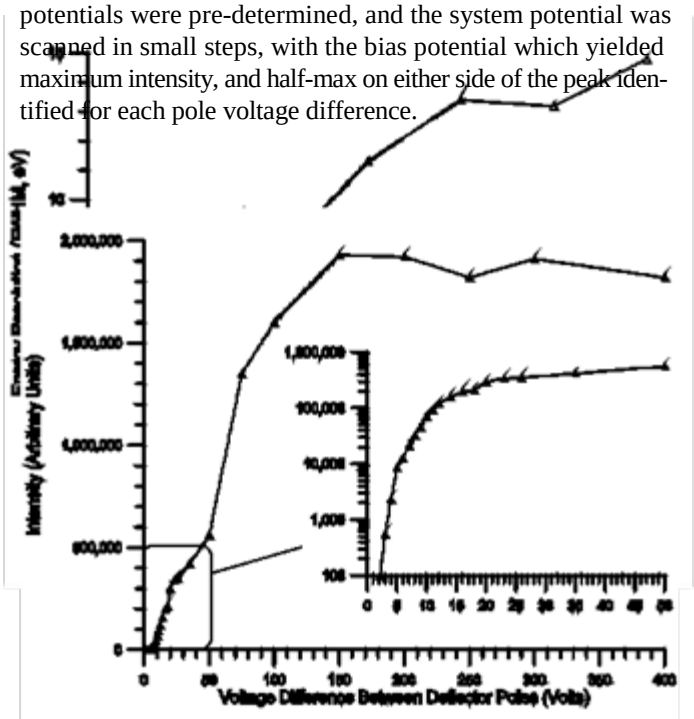

Figure 6. Sensitivity of system as measured for various deflector pole voltage settings.

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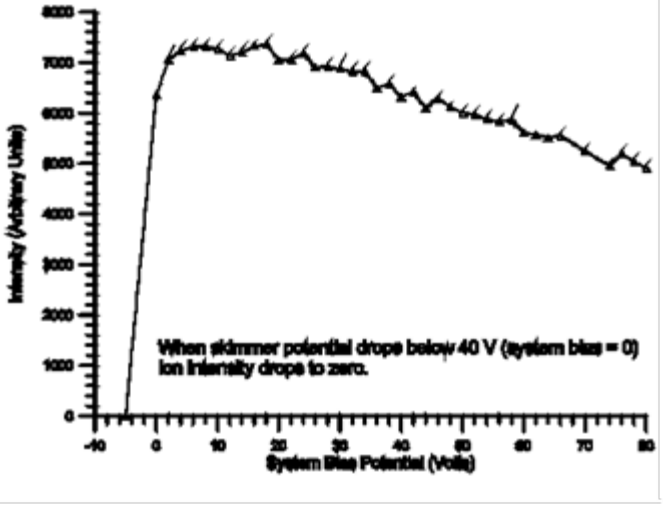

Figure 7. Ion transmission for various system bias potentials.

The ion region, extraction lens, and quadrupole entrance lens (entrance and exit of the quadrupole deflector) were optimized at each pole voltage setting. The rest of the lens voltages were similar to those shown in Figure 2, with the pole bias, skimmer and first lens maintained at constant potentials (+30, +40, and -15 respectively).

Figure 5 demonstrates that there is a loose correlation between pole voltage difference and energy bandpass. It is unclear why ion energy bandpass seems to plateau at 2-3 eV for small differences in deflector pole voltages. Figure 6 contains the corresponding intensities plotted as a function pole voltage difference. From this figure, it is evident that a steep penalty in sensitivity is paid for voltage differences less than ten volts. From these two figures, it would be expected that a pole voltage difference of 10 to 50 volts yields a reasonable compromise between energy resolution and sensitivity.

VII. ION TRANSMISSION AS FUNCTION OF SYSTEM POTENTIAL

Another important consideration in a plasma monitoring system is the effect of system potential on ion transmission. Specifically: Does the system float potential cause discrimination against ion transmission?

The system was reconfigured to allow the system bias to float all optics elements including the sampling cone and first tube lens. The deflector pole voltage difference was 150 V. Pole bias was adjusted synchronously with the system bias potential. The skimmer potential was biased with the system bias. Since the plasma potential rides on top of the skimmer, it is assumed (hoped) that the sampling efficiency is independent of plasma potential in this experiment.

The results of this study are shown in Figure 7, demonstrating a nominal drop in total intensity as the system is biased 80 volts from the optimum settings. The smoothness of the curve, and its flatness over a wide range suggest that there is minimal energy discrimination in the system.

Previously [4], it was demonstrated that the system response of an axial ionizer mounted to a quadrupole with the system electronics biased from ground had flat response over a wide range of system bias potentials. This work extends that characterization to include an energy analyzer.

VIII. CONCLUSIONS

In Figure 4, it was shown that the ions extracted from the glow discharge had a narrow energy range (<2 eV).

In Figures 5 and 6, it was shown that the key parameters which control transmission and energy resolution of the deflector is the voltage difference between deflector poles. With deflector pole voltage differences greater than 150 volts, the transmission of the deflector is essentially constant.

In Figure 7, it was shown that the system bias potential has nominal discriminating effect on ion transmission, suggesting that the system is suitable for wide range energy scans.

It is expected that this system design could be used effectively in a wide range of applications, both in molecular beam sampling and in monitoring plasmas and other high pressure ion sources.

Examples include the monitoring of:

- semiconductor plasmas (PECVD and sputtering)
- API
- electrospray
- flow tubes
- combustion systems
- catalysis
- glow discharges
- ICP and other types of plasmas

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