Ion Energy Distributions for a DC Plasma

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Introduction

DC plasmas at low pressures are among the wide range of discharges currently used for the preparation of metallic, non-metallic and semiconducting surfaces. The surface treatment is a strong function of the number, identity and energy of the positive ions arriving at the surface to be modified, which is generally part, or all of, the cathode electrode.

It is important in plasma discharges, especially in ionization assisted deposition systems, to know the relationship between the ion energy transportation and the cathode fall length (or cathode sheath). This can help to optimise the plasma conditions, resulting in improvements to the coating process.

The energy distributions for Ar^+ and other ions in an argon DC discharge have been studied using a Hiden EQP mass/energy analyser. Experiments have been performed for different pressures and voltage discharges in order to determine the ratio of the cathode fall length to charge exchange mean free path.

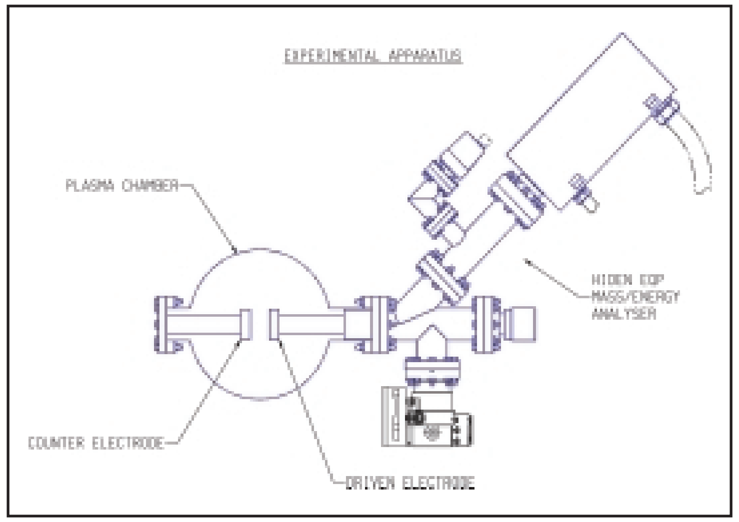

Fig. 1 *Schematic diagram of the experimental apparatus, showing the Hiden EQP mass/energy analyser sampling through the cathode electrode.*

Experiment

The main components are the plasma reactor and the Hiden EQP mass/energy analyser as shown in figure 1. The discharge is maintained between the grounded counter electrode (and the metal walls of the chamber) and the driven electrode (cathode). The EQP is located behind the driven cathode.

Ions arriving at the cathode are sampled through a central 100 micron orifice. The EQP measures the energy distribution functions of the mass identified ions created between the anode and the driven electrode.

The plasma was generated for a range of pressures from 30 to 60 mTorr and a range of voltages up to 800V between the grounded, planar anode and the powered electrode.

The energies obtained are measured with respect to a Reference Potential set equal to the cathode potential so that the energy scale of figure 2 shows directly the energies of the ions as they impact on the cathode.

Results

Under certain conditions the dominant ion in the argon plasma was Ar^+. These ions are strongly affected by symmetrical charge exchange collisions with the background gas as they travel from the plasma to the cathode. A simple ion-neutral collision model described by Davis & Vanderslice [1] predicts that for suitable values of the mean free path for charge exchange and the width of the sheath formed in front of the cathode, the ion current as a function of the ion energy will be semi-logarithmic in form. The data in figure 2 approximate closely to such a variation.

The expression for the energy distribution function f(E), the cathode ion-energy distribution function, from the model of Davis & Vanderslice makes the following assumptions :-

- There is no ionization in the sheath, the measured ions are formed in the bulk plasma
- Symmetrical charge transfer occurs, an ion that undergoes a collision loses all its kinetic energy
- The mean free path for ion-neutral collisions, λ, is energy independent
- The electric field in the sheath is linear

f(E) is then represented by the following equation:

$$f(E) = \frac{1}{m}\frac{s}{\lambda}(1-E)^{(1/m)-1}\exp\left\langle -\frac{s}{\lambda}\left(1-[1-E]^{1/m}\right)\right\rangle \qquad \text{(equation 1)}$$

Results

As the potential to the driven electrode is increased, there is a corresponding increase in the number of high-energy ions. The cathode sheath width decreases, there is a reduction in ion/neutral collisions and the ion energy distribution function is shifted towards higher values. Typical ion energy distributions are shown in figure 2.

The results imply not only that equation 1 is a good first approximation but also that the transmission function of the EQP analyzer is essentially independent of the ion energy for the experimental conditions examined.

The Ar^+ energy distributions were also measured at a fixed cathode voltage of 800V at a range of pressures as shown in figure 3. No significant changes were observed in the ion energy distributions under these conditions. As the pressure (or the mean free path) changes, the energy spectra essentially stay the same, which is evidence of a corresponding change in the sheath thickness. These observations are consistent with the work of Budtz-Jørgensen et al [2].

In addition to measurements for Ar^+ ions, we have also examined the energy distributions for Ar^{++}, ArH^+ and the impurity ion H_3O^+ in the same argon plasma. A sample set of energy distributions is shown in figure 4. The ion energies have been plotted with respect to ground potential to demonstrate clearly that the maximum energy of the ions (of all species) impacting on the cathode corresponds to the anode potential (0V). For the H_3O^+ ions, produced from traces of water vapour in the chamber, there are essentially no ions with energies other than the full anode/cathode potential differences. The lower energy ions are formed within the dark space itself and their energy reflects the potential at which they are formed.

For the ion energy distribution data from an argon discharge of 60mTorr pressure and 800V cathode potential, we estimate the value of the cathode sheath to mean free path ratio to be $s/\lambda = 14.5$ when assuming $m = 4/3$. Entering these values into equation 1 provides the fitted plot shown in figure 5. Good agreement between the fitted and experimental data is obtained.

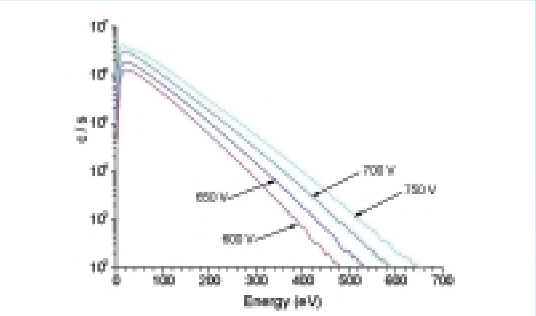

Fig. 2 *Energy distributions of Ar^+ from an argon discharge for cathode voltages of 600, 650, 700 and 750V, obtained at a pressure of 60 mTorr. The range of ion energies for each cathode voltage corresponds to the full electrode bias potential.*

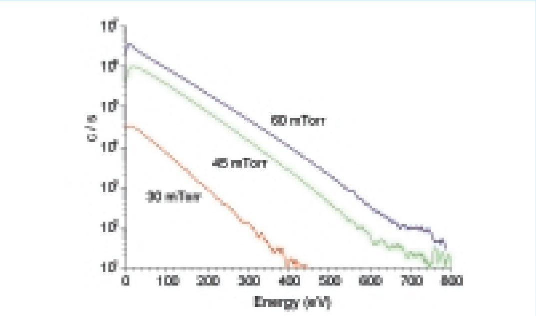

Fig. 3 *Energy distribution function of Ar^+ from an argon discharge for pressures of 30, 45 and 60 mTorr, obtained with a cathode voltage of 800V.*

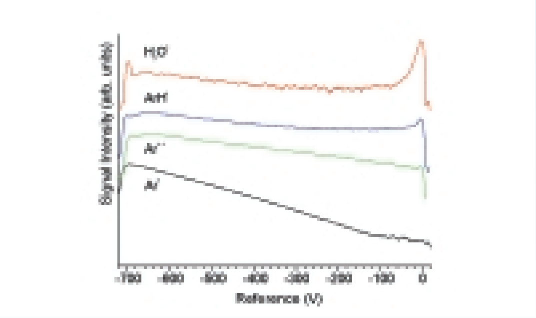

Fig. 4 *Distributions of Ar^+, ArH^+, Ar^{++} and H_3O^+ from an argon plasma at a pressure of 60 mTorr and cathode voltage of 700V.*

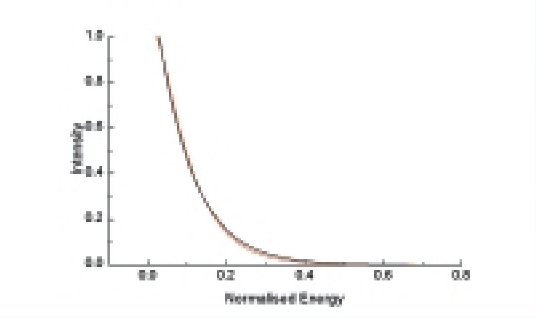

Fig. 5 *Fit (red) for the energy distribution function of Ar^+ (black) from an argon discharge of pressure 60 mTorr and a cathode voltage of 800V. The energy has been normalised with respect to the cathode voltage.*

References

[1] W.D.Davis and T.A.Vanderslice,
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[2] C.V.Budtz-Jørgensen, J.Bøttiger and P. Krinhøj,
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