*Plasma Analysis*
Application Note 228

# EQP

## Ion Energy Distributions of positive ions in an argon discharge


## Summary

The measurements described in this note were carried out using an EQP instrument to examine the energies of ions in an argon plasma produced in a small test cell at 13.56 MHz. Several types of ion energy distribution were seen and explained in terms of the plasma and the method of monitoring.


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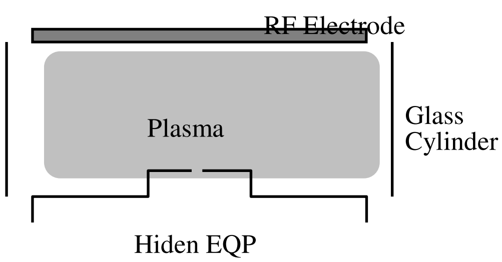
## Equipment

A small RF driven test cell as shown below was used for these measurements. The RF supply was capacitively coupled to the upper electrode, a 5 cm diameter stainless steel disk, and the discharge was produced using the front of the

EQP as the grounded electrode. A glass cylinder was used to help confine the plasma

Gas inlet valves and pumping restrictors were used in conjunction with pressure gauges fitted to the discharge chamber to set the Argon pressure in the chamber.




## Results

For the measurements described here the gas pressure was maintained at 20 mbar.

A scan of the ions produced in the plasma confirmed the presence of large numbers of $Ar^+$ (mass 40) and $ArH^+$ (mass 41) ions. Since these two ion species are affected to markedly different extents by collisions in the plasma sheath, as they cross from the plasma into the EQP, it is interesting to compare the ion energy distributions (IEDs) measured for them using the EQP.

Figure 1 shows the IED measured for $ArH^+$ ions at a nominal discharge power of 0.5W. The self-bias acquired by the driven electrode was -50V. The IED shows the majority of the ions to have energies of about 35 eV, corresponding to the average value of the plasma potential. A small number of the ions suffer collisions in crossing the sheath from the plasma to the sampling orifice (100 µm diameter) of the EQP and show up at energies below the plasma potential, giving a secondary peak at a few eV.

Figures 2, 3 and 4 were taken under the same conditions as for figure 1 except that the nominal discharge power was increased to 2.5, 5.5 and 8.5W, respectively. The self-bias acquired by the driven electrode increased to -150, -250 and -350V in the 3 cases.

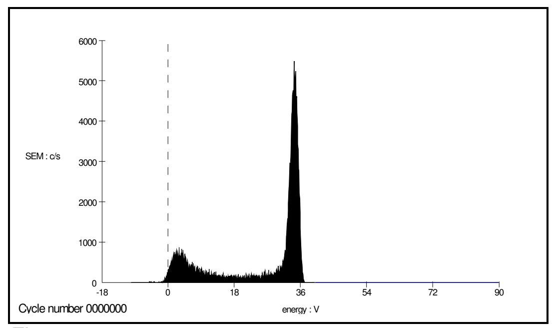



*Figure 1*

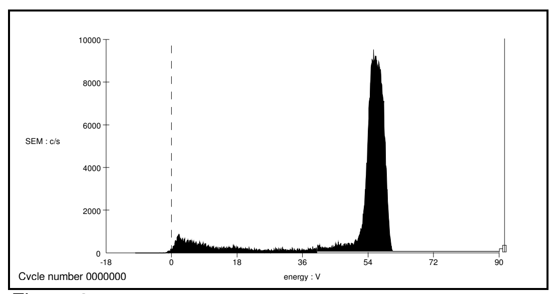



*Figure 2*

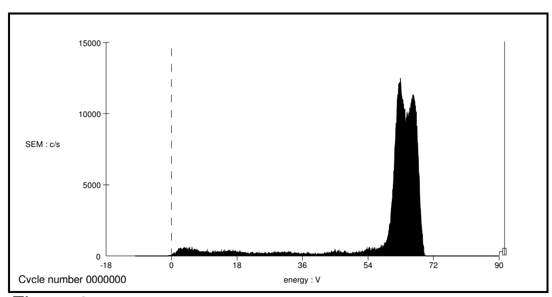



*Figure 3*

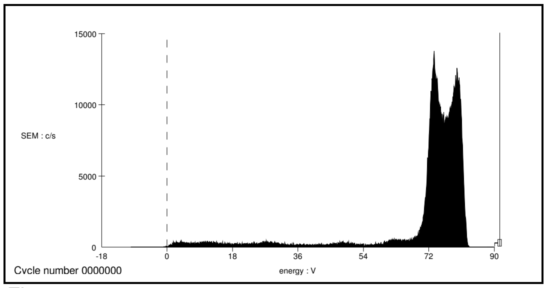



*Figure 4*

Comparison of figures 1, 2, 3 and 4 shows several interesting effects:

The total ion signal (integral of the IED) increases as the input power increases. This is to be expected if the increase in applied power is partly due to increasing the discharge current.

The main peak of the IED moves to higher energies (35, 55, 65, 78 eV) as the power is increased. This is to be expected if the increase in applied power is partly due to increasing the peak-to-peak amplitude of the RF signal so that (in spite of the corresponding increase in self-bias) the plasma potential increases. The plasma potential increases by a factor of over two as the power increases from 0.5W to 8.5W. Separate measurements of the peak-to-peak voltage of the applied RF signals showed an increase from about 200V to 1000V. Taken together with the self-bias potentials, these values predict plasma potentials which are in good agreement with those deduced from the most-probable ion energy seen in figures 1 - 4.

As the input power is increased it is clear from figures 1 - 4 that the main energy peak becomes broader and develops the well-known saddle-shaped structure. This structure is commonly seen when the transit time of the ions across the sheath is comparable with the period of the RF signal. The energies at the two maxima of the split peak correspond to ions which have left the plasma at the times when the RF voltage across the sheath is at its maximum and minimum values. The extent of the peak splitting is known to be a function of the sheath width and the ion mass. The increase of the separation of the two component peaks with input power is partly attributable to a decrease in the width of the plasma sheath as the power is increased. At low powers, when the sheath is wide and the potential difference across it is low, the drift velocity of the ions is low and the time they take to cross the sheath is several periods of the RF. They therefore appear on the IED plot as a single peak centred at the energy corresponding to the average plasma potential. As the power is increased, the sheath becomes narrower, the drift velocity of the ions increases as the potential difference across the sheath also increases, and their transit time across the sheath decreases to become comparable with the period of the RF and the peak splitting occurs.

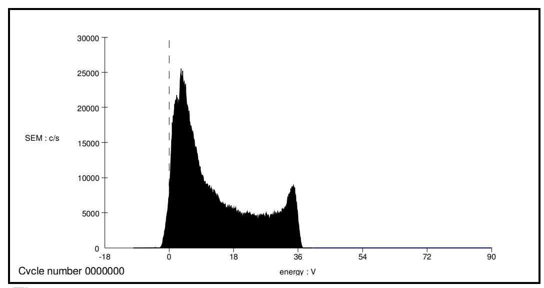



*Figure 5*

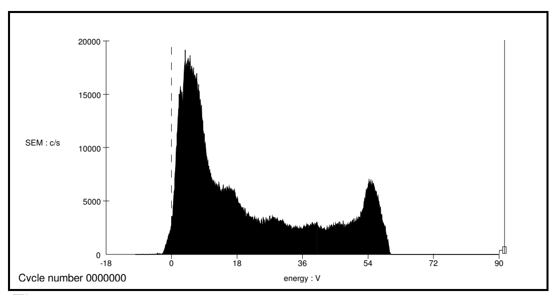



*Figure 6*

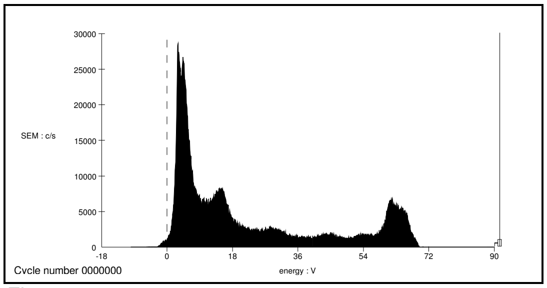



*Figure 7*

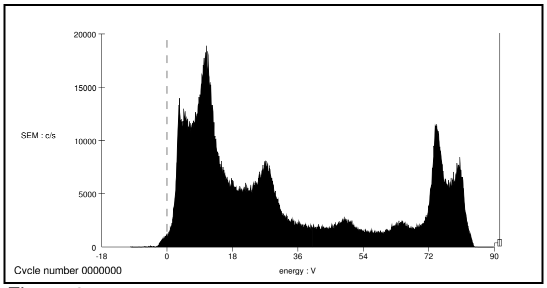



*Figure 8*

Figures 5, 6, 7 and 8 show the IEDs recorded for $Ar^+$ ions under the same experimental conditions as those used for figures 1 - 4. The much larger influence of ion-neutral collisions in the plasma sheath can be seen clearly. Comparing figures 5 and 1, for example, shows that many of the $Ar^+$ ions have been reduced to near thermal energies as the result of collisions with the neutral argon atoms in the sheath. The large difference between the behaviour of the $ArH^+$ and $Ar^+$ ions is due to the fact that the $Ar^+$ ions are strongly affected by the occurrence of charge - exchange collisions:-

$$(fast)Ar^+ + (slow)Ar \rightarrow (fast)Ar + (slow)Ar^+$$

This process is much more probable than;

$$(fast)ArH^+ + (slow)Ar \rightarrow (fast)Ar + (slow)ArH^+$$

In figure 8 the IED shows appreciable structure at intermediate energies. Similar structure has been observed before, by a number of authors (References 1 and 2, for example) and can be predicted, for example by Monte Carlo simulations of the passage of ions across the sheath region (Reference 3, for example).

## References

1. J.K. Olthoff et al. J. Appl. Phys 75, 115, 1994.

2. W.G.J.H.M. van Sark et al. 12th European Photovoltaic Solar Energy Conf. April '94.

3. R. Suroweic et al. 46th G.E.C. Conf., Montreal, 1993.