Plasma Diagnostics
Application Note 242

EQP

Energy distributions of ions and atoms from a Magnetron Source

Summary

For many plasma/surface interaction situations it is of interest to know the energy distributions of the ions and atoms arriving at the target surface. There have been many studies of the energies of positive ions arriving at target surfaces, a much smaller number of studies of negative ions and only two or three studies of the energies of neutral species generated in the plasma and arriving at the target surface. The shortage of published measurements of the energies of neutral species reflects in part the comparative difficulty of carrying out the measurements for mass identified species for plasmas in which they have acquired their kinetic energy in collisions with fast ions and in which the energy gained is then largely lost in subsequent collisions with other, thermal, gas atoms/molecules. For magnetron plasma sources the production mechanism for energetic neutral species is fundamentally different, the neutral particles acquiring their kinetic energy as the result of the bombardment of the target electrode (cathode) of the magnetron by the energetic ions of the working gas. The neutral particles leave the cathode with a range of energies which are then modified by collisions with gas molecules as in the case of other plasma reactors. Since the operating gas pressure for magnetron plasmas is often quite low, however, the number of such thermalising collisions is in general lower than for many other types of reactor and significant numbers of energetic neutral species can reach the surface of the substrate which is to be modified by the plasma. The present note describes measurements of the energies of atoms, and ions, generated in a magnetron source and reaching a grounded surface placed up to 6 cm from the magnetron.

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Experimental

The magnetron used for the experiments was a small d.c. device incorporating a target cathode 5 cm in diameter biased negatively with respect to the grounded casing of the device. Argon was used as the working gas at a pressure in the range 10^{-4} to 10^{-3} Torr. The magnetron was positioned facing the grounded sampling electrode of an EQP probe, the entrance orifice in the sampling electrode being 500 μm in diameter. The pressure in the ionisation source of the EQP was generally in the range 2 to 20 x 10^{-7} Torr. For the first two series of measurements the gap separation between the magnetron and the EQP's sampling orifice was 6 cm, with this distance being reduced to approx 3 cm for the final measurements. The magnetron discharge operated at a d.c. voltage of between 300 and 380 V and at a current in the range 15 to 150 mA. The majority of the data reported here was for magnetron powers of around 15 W. Three magnetron cathodes were employed - copper, aluminium and a copper electrode partially covered by three 6 mm wide strips of molybdenum foil.

Results

Experiment 1

For the copper cathode, the positive ion and neutral atom mass spectra both showed the presence of the Cu63 and Cu65 isotopes in the naturally occurring ratio of 2.3:1. For the copper ions at a magnetron input power of 5 W at a gas pressure of 10^{-3} Torr with the EQP's sampling orifice 6 cm from the magnetron's cathode the energy distribution was as shown in figure 1. The same data are plotted on a logarithmic scale in figure 2. The data were obtained with the EQP operated in its positive ion mode with the instrument's internal ionisation source switched off. Figure 2 shows clearly the presence of ions with energies of up to 50 eV.

For similar plasma conditions, Figure 3 shows the data obtained with the EQP operated in its RGA mode to examine neutral species sampled from the plasma. The sampling optics were arranged to reject ions from the plasma. The ion energy distribution shown in Figure 3 is interpreted as showing that copper atoms with energies from thermal energies up to approximately 8 eV arrived at the sampling orifice of the EQP, (those arriving with thermal energies appearing in the figure at an energy of 2 eV and those with an energy of (E)eV appearing at an ion energy of (E +2)eV, the additional 2 eV of energy being due to the energy gained from the ionisation source of the EQP).

Experiment 2

The measurements described above for copper were repeated using an aluminium cathode in the magnetron. Figure 4 shows the energy distribution obtained for aluminium ions for a magnetron power of approx 10 W at a gas pressure of 5.10-4 Torr. (The peak energy of 18 eV is obviously lower that that for the copper ions of Figure 1 but since the plasma conditions were significantly different, even as judged from the visual appearance of the plasma, no direct comparison should be made).

For the neutral species sampled from the plasma, the signal at a mass of 27 amu included a contribution from a gaseous hydrocarbon impurity, which also gave a signal at a mass of 26 amu. Figure 5 shows the signal at 27 amu with the magnetron on and off, (blue and red traces respectively), and shows the arrival at the EQP sampling orifice of aluminium atoms with energies of up to about 6 eV. As in the case of the copper atoms, 6eV aluminium atoms appear at 8eV in figure 5 because of the additional 2eV acquired in the ionisation source. Supporting evidence is provided by figure 6 which shows the energy distribution obtained, with the magnetron on, for the adjacent 26 amu species. The distribution doesn't show the high energy 'tail' of the blue trace in figure 5 which it is logical, therefore, to attribute to aluminium atoms from the magnetron cathode.

Experiment 3

For the final experiment described here the magnetron was fitted with a copper cathode whose front surface was partially covered with three strips of molybdenum foil. The distance between the magnetron cathode and the EQP front plate was reduced to 3cm. Part of the positive ion mass spectrum obtained from the magnetron plasma is shown in Figure 7. The copper peaks at 63 and 65 amu are clearly seen, together with the Ar2+ peak at 80 amu and the molybdenum isotopes at 92, 94, 95, 96, 98 and 100 amu.

Typical energy distributions for the copper and molybdenum ions are shown in figures 8 and 9. The distributions for the copper and molybdenum ions are similar, except that the molybdenum ions appear to have a somewhat wider range of energies for the identical plasma conditions. Running at an increased magnetron power of about 40 W, larger numbers of energetic copper atoms were observed. As shown in Figure 10 the energy distribution extended to around 15 eV. With the plasma turned off no particles with energies above thermal values were seen. The small increase in signal seen in Figure 10 at energies above 15 eV is real and is attributed to copper ions not rejected by the EQP's entrance optics. This was confirmed by measurements made with the plasma operating but the EQP's ionisation source switched off.

Conclusions

The work described above demonstrates clearly that the EQP instrument may be used to determine the energy distributions of both positive ions and neutral atoms from magnetron plasma sources. The data obtained for neutral copper and aluminium atoms are of particular interest in view of the very limited number of published measurements of the energy distributions of neutral particles from processing plasmas.

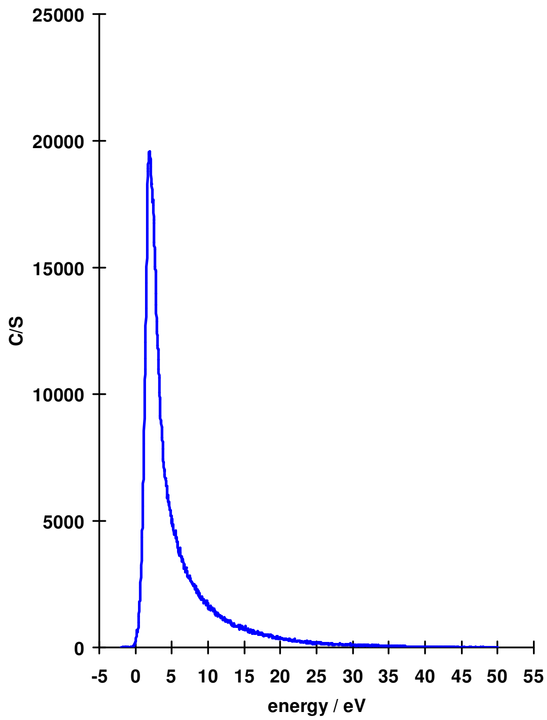

Figure 1   Cu Ion Energy Distribution

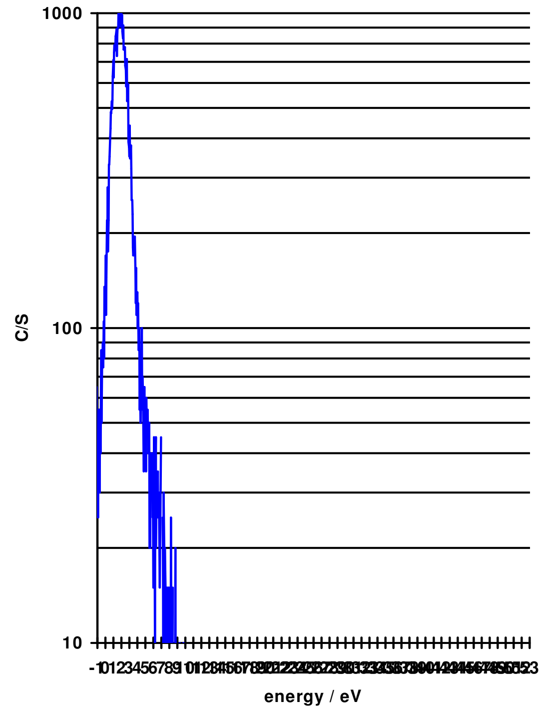

Figure 3   Cu Atom Energy Distribution

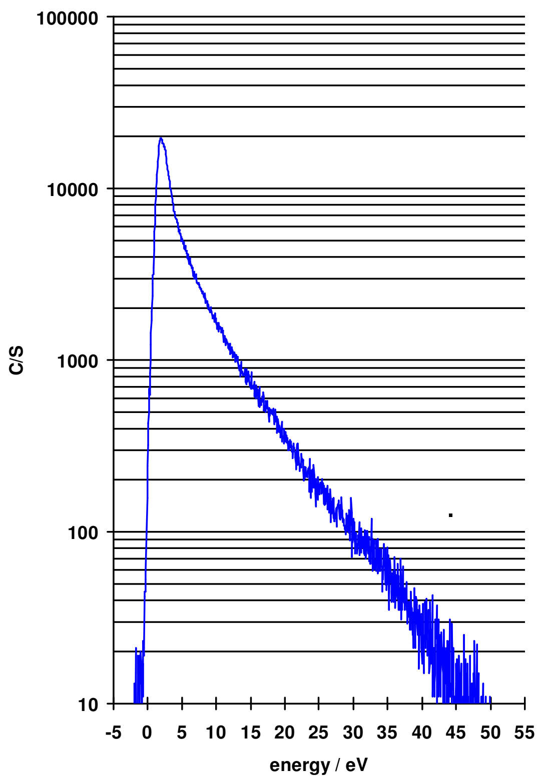

Figure 2   Cu Ion Energy Distribution (logarithmic plot)

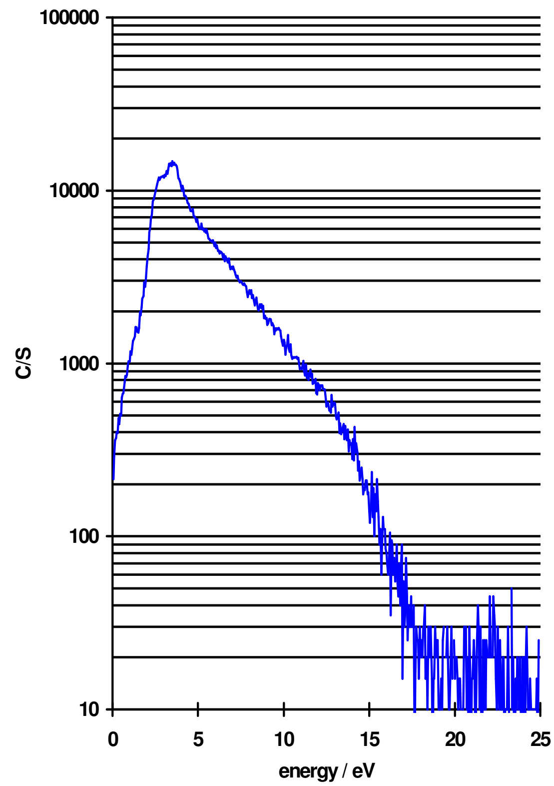

Figure 4   Al Ion Energy Distribution

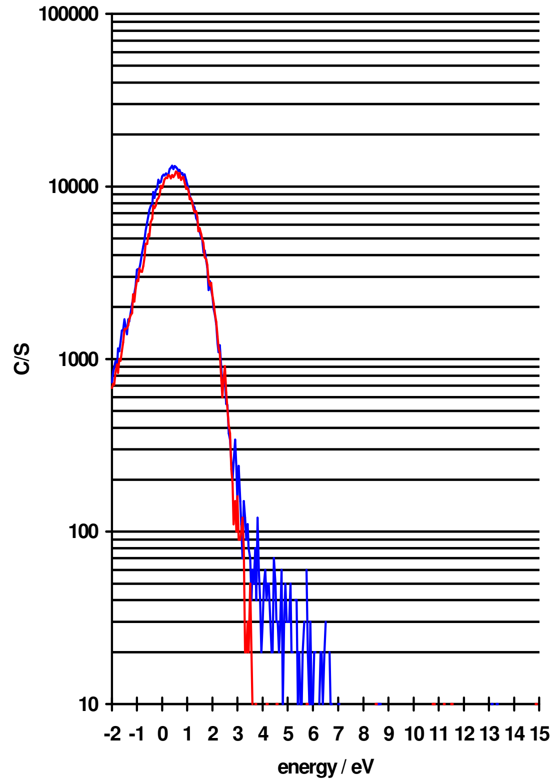

Figure 5 Al Atom Energy Distribution
Red Trace - Plasma Off
Blue Trace - Plasma On

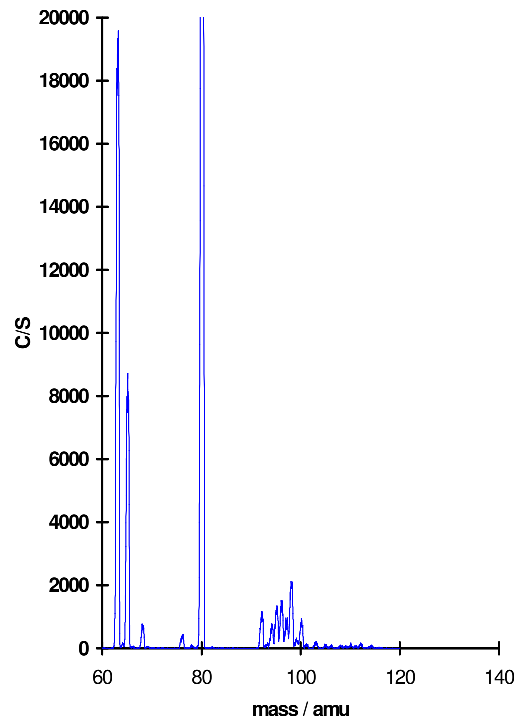

Figure 7 Positive Ion Mass Spectrum

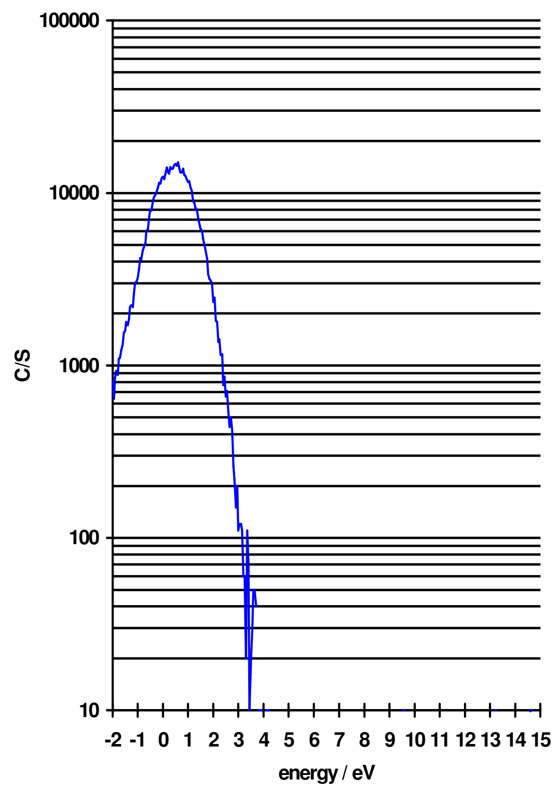

Figure 6 m/e=26 Atom Energy Distribution (Plasma On)

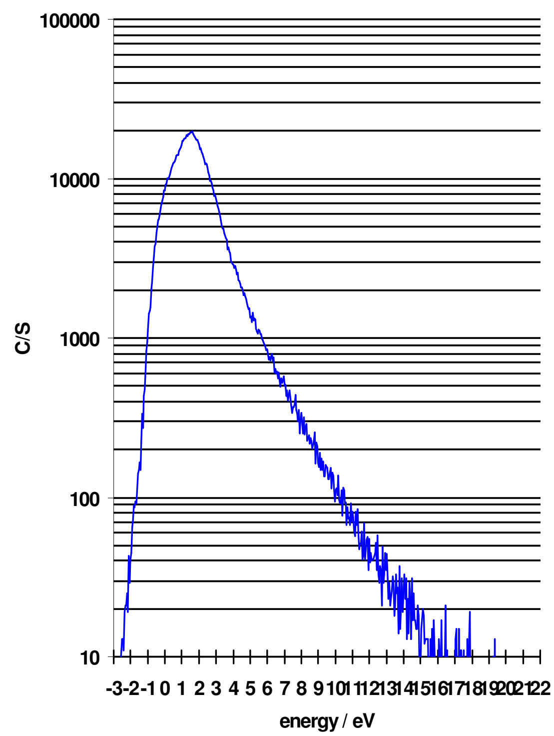

Figure 8 Cu Ion Energy Distribution

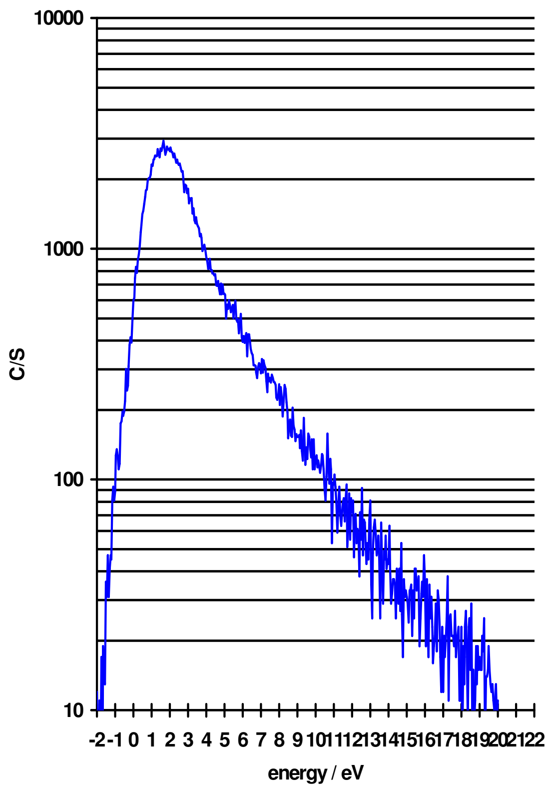

Figure 9   Mo Ion Energy Distribution

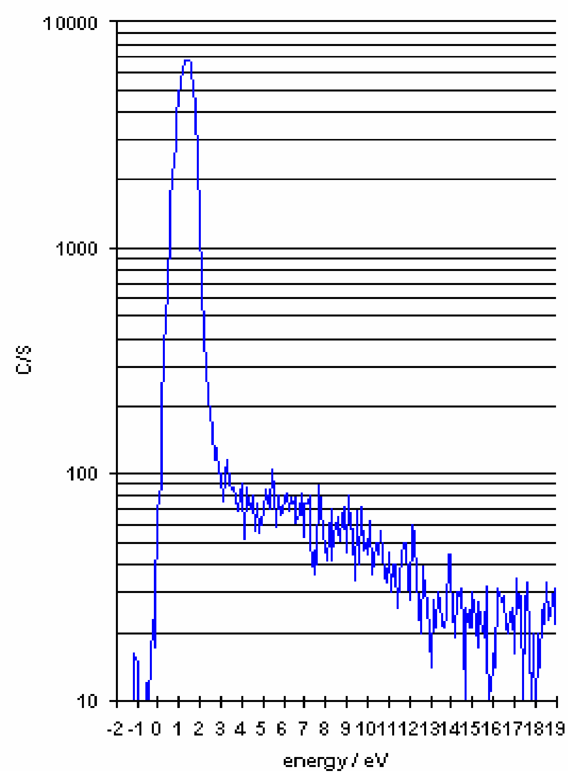

Figure 10   Cu Atom Energy Distribution