DETERMINATION OF ENERGY DISTRIBUTION FUNCTIONS OF FLUXES IN A D.C. MAGNETRON DISCHARGE.

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Abstract
The gaseous phase of a D.C. magnetron reactive deposition device has been investigated. The vanadium target was sputtered by an Ar-N_2 mixture. Both Ion Energy Distribution Functions (IEDF) (i.e. V^+, Ar^+, Ar^{2+}, N^+, N_2^+) and vanadium atomic emission measurements were carried out in connection with the variation of the gas mixture nitrogen content. The very-well known "target poisoning effect" has been pointed out in agreement with previous studies [1] [2]. The IEDF shapes of the different species are compared and discussed.

1. Experimental details
Our experimental apparatus has been extensively described elsewhere [3]. We will only remember that this turbomolecular pumped, to a pressure below 10^{-5} Pa, deposition device is backfilled with argon (purity$\geq$ 99,9996%). The reactive species is nitrogen (purity$\geq$ 99,999%). The working pressure regulated with a throttle gate valve remained constant at 2Pa. The 2 inches diameter vanadium target was 99,7% pure. A very wide range of magnetron power has been investigated (i.e. from 150W to 500W). The target to mass spectrometer diaphragm distance has been fixed at 45 millimeters. To determine where does exactly appear the "target poisoning effect" [2], [4], [5], [6], the 437.92nm vanadium atom radiative transition, which does not present any self-reversed and self-absorption effect [2], has been recorded. Thus, we have chosen five nitrogen amount corresponding to the metallic mode, the non-metallic mode, the beginning, the middle and the end of the transition zone between both of them. For each nitrogen concentration the five IEDF have been recorded. Although our experimental apparatus allows us to investigate an energy range up to 500eV, we will only mention the 0 to 15eV one. We detected indeed no signal at higher energy.

2. Results
Fig. 1 exhibits the "target poisoning effect" occuring in a gas discharge with increasing   reactive gas amount. It can be pointed out that this characteristic is strongly attenuated for high magnetron target power. So a study for this latter

particular condition might be of prime interest. Unfortunately, with such a high power, the target surface evolution is fast and seems to have a noticeable influence on the recorded results in accordance with the IEDF. Thus, to investigate the transition zone shown in Fig. 1, and with reasonable nitrogen mass flow rate, we fixed the magnetron target power at 250W.
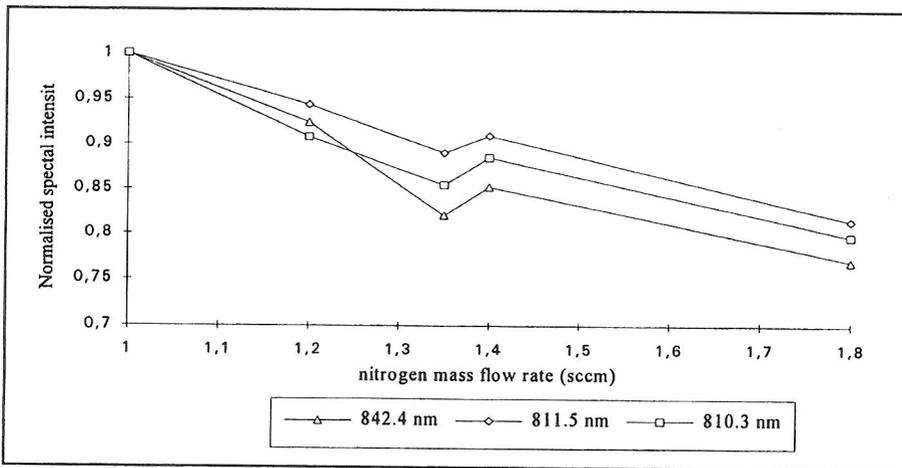

Figure 1: Variation of the 437.92nm vanadium emission line with magnetron power and nitrogen mass flow rate.

A typical record of the V^+ IEDF, in the metallic mode (i.e. $d_{N2}=1sccm$) is presented in Fig. 2. All the other IEDF of the detectable species are globally similar.

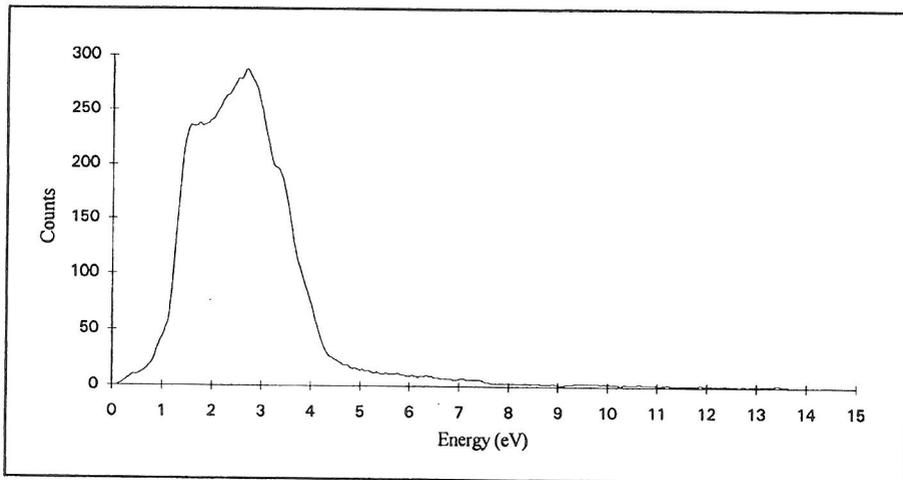

Figure 2: V^+ IEDF in the metallic mode, $d_{N2}=1sccm$.

They present a main peak located between 2 and 3eV but within a structure extending from 0 to 6eV (only V^+ EDF extend above 6eV). However, differences such as shoulders or extension towards higher energy occur for some of them depending on the deposition parameters. Moreover, the detection, in the metallic mode, for both the nitrogen species (i.e. N^+, N_2^+) is very difficult because of their consumption by the target surface, the gettering at the part of the chamber wall that receives sputtered particles and the evacuation by thre pumping group as described by Larsson [7]. As a confirmation, Fig. 3 shows the variation of the normalised integrated signal of each IEDF over the whole 0 to 15eV range.
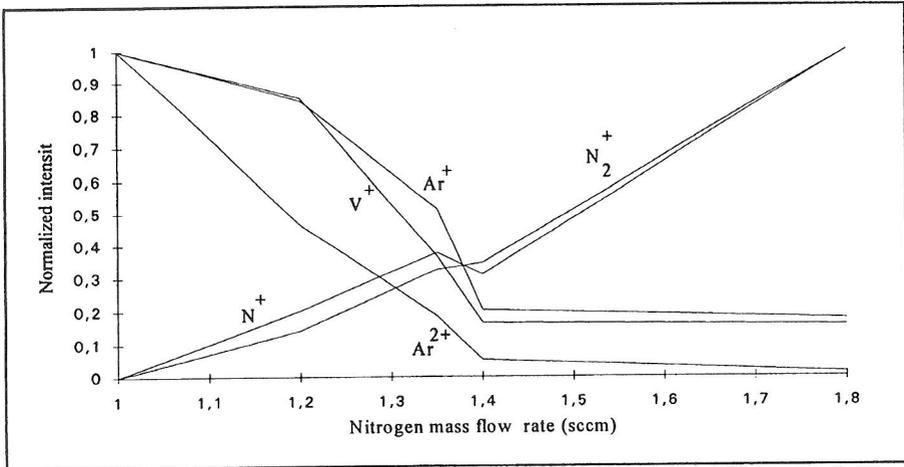

Figure 3: Variation of the normalized integrated signal of each IEDF with the nitrogen mass flow rate introduced in the deposition chamber.

The increase of the reactive species signal is linked with the increase of the nitrogen mass flow rate introduced in the deposition chamber. In the same time, the integrated signal of all the other ionic species dramatically drops. It is important to note that the integrated signals of N^+ and N_2^+ are two orders of magnitude smaller than those of Ar^+ and V^+. The decrease of Ar^+ may be ascribed to the quenching of the electron gas. This latter induces a reducing of the electrons ionization efficiency. This is particularly exhibited for the Ar^{2+} ions which are very sensitive to the electrons temperature. For V+, the drop is provoked by this effect but also by a strong reduction of the sputtering yield of the nitrided target by Ar^+ ions [2]. Fig. 4 presents the variation of some selected argon spectral lines versus the nitrogen amount. They represent some argon excited states which are connected to plasma parameters (i.e. n_e, T_e). We observe a weakening of about 20% of the spectral emission of argon excited states when the variation for Ar ionic species reaches 80%. This difference should be ascribed to a threshold which take into account the overlapping of the ionisation cross sections when the quenching takes place. This has been previously observed in a similar apparatus [8].
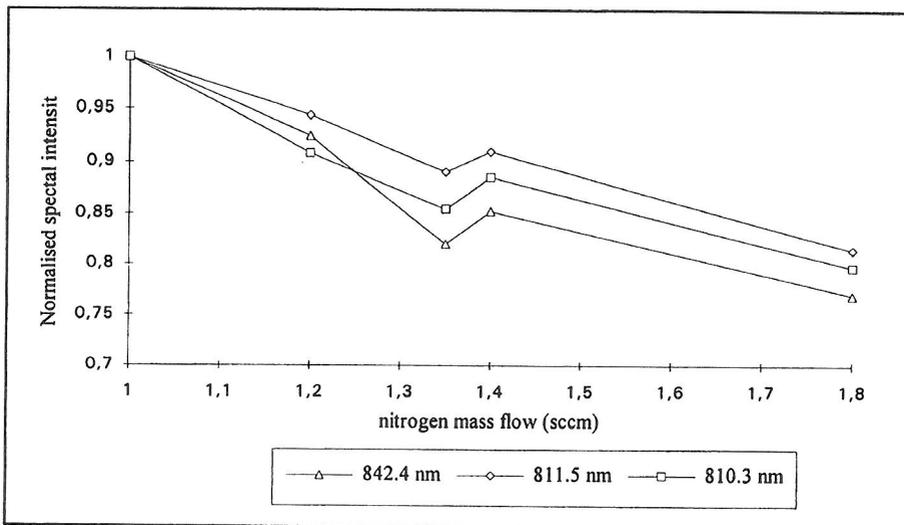
Figure 4: Normalised argon excited states spectral emission vs nitrogen mass flow rate.

The IEDF of different species has been recorded. As previously quoted the main peak is located between 2 and 3 eV, as for all species and more particularly for argon ions which are the majoritary ionic species in the deposition chamber.
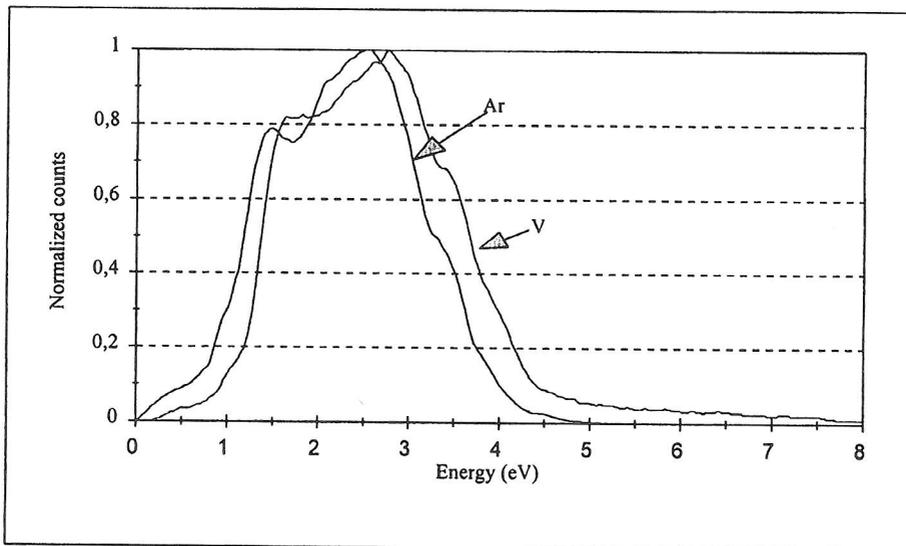

Figure 5: V^+ and Ar^+ EDF in metallic mode.

This traduces that the energy distribution should correspond to the magnetron discharge electric field distribution. The comparison between both V^+ and Ar^+ EDF exhibits a shift of 0.2 eV. It corresponds to the atomic mass ratio as shown in Fig. 5. The shapes of the IEDF are very sensitive to the gas mixture nitrogen amount as displayed in Fig. 6. They have been normalised to unity in order to allow an easier comparison and discussion (let us note, for example, that the maximum intensity ratio between the 1sccm IEDF and the 1.8sccm, the 1.4sccm and the 1.35sccm ones is respectively equal to six, six and three).
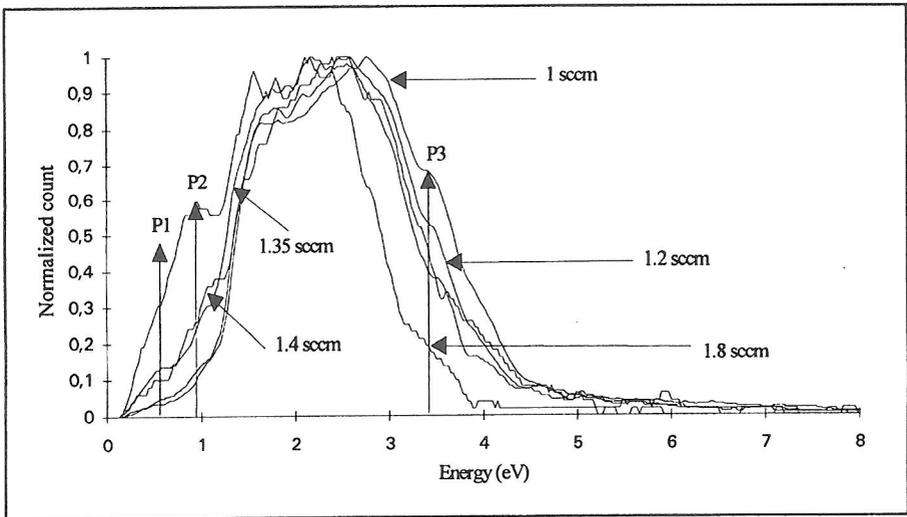

Figure 6 : V^+ Energy Distribution Function recordings normalized to unity for the five nitrogen mass flow rate.

The high energy shoulder (P3) drops when the nitrogen amount increases. We observe low energy peaks (P1) and (P2) when the target runs in reactive mode. Each of them represents the interaction between vanadium and nitrogen species and must be described more precisely. But they traduce well the important effect of nitrogen on the species energetic measurements.

3. Conclusion

This first approach of the ion energy analysis of a reactive D.C. magnetron discharge pointed out some interesting characteristics. The IEDF shift towards lower energy with an increased nitrogen amount and the appearance of low energy peaks as displayed in Fig. 6. This energetic slowing-down is confirmed by spectroscopic measurements of the different emission lines.

However, the very complex shape of the different IEDF and their complete interpretation need further analysis to confirm this first trend of results.

References

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