PLASMA MASS SPECTROMETRY FOR THIN FILM PROCESS CONTROL

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ABSTRACT

An electrostatic lens in combination with a quadrupole mass filter was used to observe ion species produced by a glow discharge of an rf diode sputtering system. The analyzed ions of the deposited cathode material are mostly neutrals ionized in the discharge by a Penning mode at high working pressures. Mass spectra for gold on epoxy polymer, brass on stainless steel, aluminum and copper are shown.

1. INTRODUCTION

Radio-frequency discharges are used in sputter and etching systems (1,2) and in plasma reactors (3).

In these types of plasma the electron energies are much higher than the energies of ions and neutrals, because electrons receive energy from the rf-field.

The energetic electrons primarily ionize but they also split compounds in the plasma. Because the velocity distribution of the electrons in the discharge is made anisotrop by the influence of high frequency, the description of such a plasma is not trivial (4). The microfield between the charged particles sets the plasma in a quasi neutral state where electron- and ion-densities are almost equal. In addition to ion formation by electron impact, particularly by the use of argon, neon and helium; a Penning mode ionization by metastable particles was observed (5,6).

In the following report an arrangement for the extraction of ion species from the plasma is described. The extracted ions are analyzed by a quadrupole mass filter. At the deposition of solids by ion bombardment from an rf-plasma some typical applications will be shown.

2. EXPERIMENTAL

Sputtering typically takes place in the pressure range of 0.05 - some 0.1 mbar. Ions originating from the discharge may not have a collision with neutrals before they are analyzed in the quadrupole system.

Fig. 1 shows an arrangement for the ion analysis in the plasma of a glow discharge.

The vacuum chamber containing the mass filter is adjusted lateraly to the sputter diode. The chamber is pumped differentially and the pressure is typically less than 10^{-5} mbar during gas inlet into the diode. Ions produced at the plasma potential pass a narrow orifice and will be focused into the mass filter by a cylindrical electrostatic lens. The mass filter used in the experiments was a ceramic quadrupole system (type Q 200) with a mass range of 1-200 AMU with internal electron impact ion source (7). In addition, it is possible to control the composition of neutrals at the discharge by using the quadrupole mass filter in the differentially pumped chamber for residual gas analysis as usual.

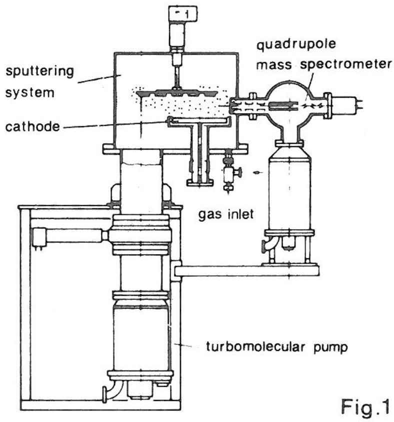


Fig.1

Plasma Mass Spectrometry arrangement with sputtering system

The ion current was measured directly behind the mass spectrometer with a Faraday cup or with a secondary electron multiplier. There may be some interference with ion detection by high frequency of the discharge and high energy neutrals which can eject electrons near the detector if no beam stop for the high energy neutrals is introduced into the ion optics.

A gold sample fixed to a copper target holder by an epoxy polymer was sputtered in an argon atmosphere.

The spectrum received in Fig. 2 shows characteristical organic fragments of the epoxy material beyond the strong Au^+ and Ar^+ lines.

Typical ion species produced by sputtering in the glow discharge such as H_3^+, ArH^+ and Ar_2^+ which is formed by a Hornbeck Molnar reaction (8) are also obtained.

By metastable Argon with maximum energy of 11.72 eV (9), gold, copper, carbon and some organic compounds are Penning ionized. Argon, hydrogen, water and most of the organic material is ionized by electron impact in the plasma.

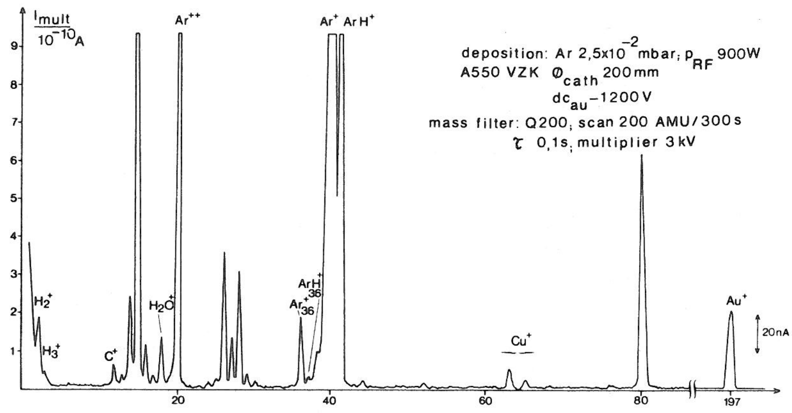
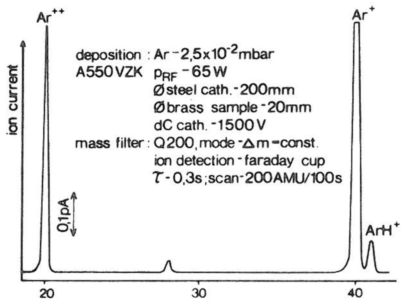


Fig. 2 PMS gold deposition

In Fig.3 a mass spectrum of ions recorded during deposition of a brass sample (57.6 atomic % copper, 42.4 atomic % zinc) on a stainless steel target is shown.



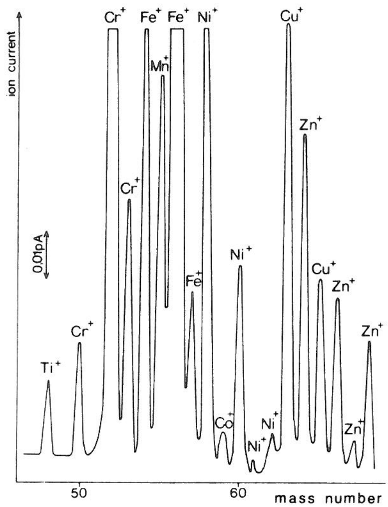


Fig. 3

PMS brass and stainless steel deposition

The cross sections for the Penning mode ionization of different metals in sample and target only have differences of some percents. So the composition of the sputtered material can easily be investigated quantitatively.

The manganese peak at mass 55 represents less than 2 atomic % of the stainless steel composition. The composition of the sputtered particles from the surface of the sample gives a direct indication of the composition at the surface but not the bulk composition. The spectrum shown in Fig. 4 was recorded during aluminum deposition. Copper and iron traces in the target material can be observed.

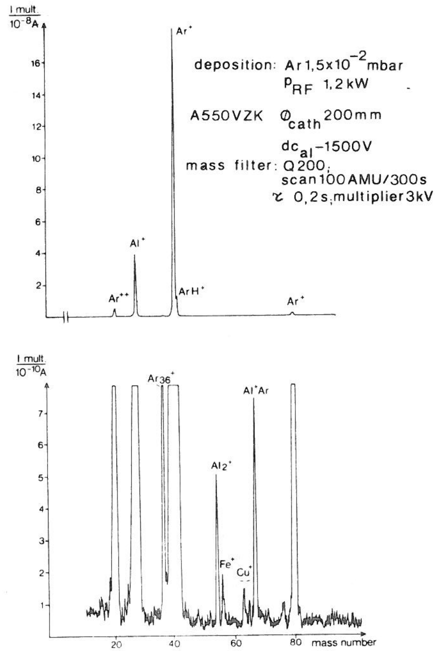


Fig. 4 PMS aluminium deposition

The $Al^{+}Ar$ complex is typically given by assoziative ionization of the aluminum by metastable Argon atoms.

After introduction of water vapour into the sputtering system and pumping over 2 hours, a total pressure of 10^{-5} mbar was reached. For the sputter deposition, neon gas was introduced pressure controlled at 2.5 x 10^{-2} mbar. The spectrum recorded in Fig. 5 shows the ions of the plasma at deposition.

For metastable neon atoms energy levels for ionization up to 16.71 eV (9) are in the range of the penning process. That is why H_2O^+ (13eV), O^+ (13.6 eV), CO^+ (14.1 eV) and H_2 (15.8 eV) peaks are of high intensity.

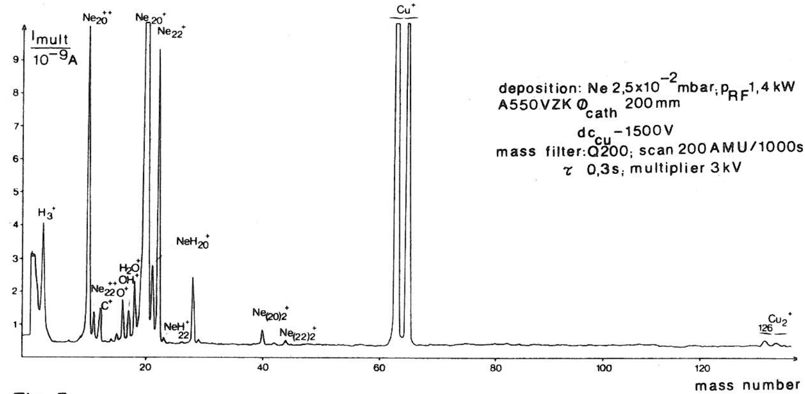


Fig. 5 PMS copper deposition

The line intensity for the Ne_{22} isotope corresponds to a partial pressure of 2.45×10^{-3} mbar.

The intensity of the $Cu_{63}{}^+ Ne_{20}$ peak measured in the current range of 10^{-10} A is more than a factor of two lower than that of the $(Cu_{63})_2$ line. In contrast to this result, the deposition of copper with comparable parameters war found to give a $Cu_{63}{}^+Ar$ peak which has a slightly higher intensity than the $(Cu_{63})_2{}^+$ line.

Plasma mass spectrometry can be used to monitor sputtering - and etching-techniques, depth profiling and for the study of plasma reactor experiments.

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