Analysis of Fast Neutrals in Plasma Monitoring

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(Poster presented at the 46th ASMS Conference on Mass Spectrometry and Allied Topics, Orlando, Florida, June 4, 1998)

Plasma processes generate ions as well as fast moving neutrals. In-depth analysis of all these species from the plasma process demands high performance from a quadrupole mass spectrometer. For example, the kinetic energy of the fast moving neutrals in a magnetron ion source can be as high as a few hundred electron volts. Our calculations show that ionization efficiency for these fast neutrals is inversely proportional to their velocity. Because thermal gas species can have orders of magnitude higher ionization probabilities than fast moving neutrals, ion signals from thermal residual gas background can easily overwhelm the ion signals from the fast neutrals. Thus the analysis of these fast moving neutrals using a mass spectrometer requires high overall detection sensitivity to overcome the inherently lower ionization probabilities, as well as energy analysis capability to differentiate these fast neutrals from the thermal residual gas background.

In this presentation we show some results from the analysis of fast moving aluminum and copper atoms from magnetron sputtering. Aluminum and copper are commonly used in semiconductor fabrication. The detection of these fast-moving neutrals is hindered by residual hydrocarbons and chamber contamination from pump oil. In these examples, the ion signals from background hydrocarbons and pump oil components are much more intense than the signals from the fast moving neutrals. The quadrupole mass spectrometer used in these experiments has a biasable quadrupole mass filter coupled to a tandem axial ionizer with axial energy filter. This allows for the monitoring of the fast moving Al and Cu atoms from a magnetron sputtered plasma through a single sampling aperture.

I. INTRODUCTION

When an electron impact ionizer is used to ionize a residual gas, the ion current coming out of the ionizer is proportional to the gas density seen by the ionizing electrons.

When the velocity of the neutral molecules to be analyzed is increased, there is an inversely proportional decrease in the ion current leaving the ionizer. When one considers the fact that the energy of fast moving neutrals can be 1000 to 100,000 times as large as the energy of residual background species, the velocity is orders of magnitude higher for the fast moving species with an effective sensitivity orders of magnitude lower. This presents a problem when one is trying to monitor low levels of fast moving species (greater than a few eV in energy) in a chemical soup background of thermal species, especially when there are background species at the same mass as the target analyte species.

An energy filter can be used in between the ionizer to help differentiate ions which came from thermal molecules from ions originating from fast moving neutrals. Figure 1 shows the background mass spectrum around m/z 27 where the fast moving aluminum will be detected. This spectrum was collected with the energy filter tuned to a wide energy window (~10 eV). In other words, the ions are not energy filtered. The ion signal in this background spectrum at m/z 27 comes from background hydrocarbons. Because the plasma from the magnetron sputtering is sampled through a small aperture (differentially pumped for pressure reduction), and the energy of the fast moving Al atoms from the plasma is about 2-5 eV, the overall signal from the fast moving Al would be much smaller than the residual background at m/z 27. Indeed, the spectrum from the system with wide energy window with the magnetron on, is virtually identical to the background spectrum shown.

Figure 2 shows the results from the optimization of the energy analyzer for fast moving Al atoms. Here all the ions from the plasma source are rejected by a set of einzel lenses in front of the mass spectrometer, and thus only the neutral species reach the mass spectrometer. The gain of the electron multiplier was increased about 1000 times compared to the case shown in Figure 1. The energy window of the energy analyzer

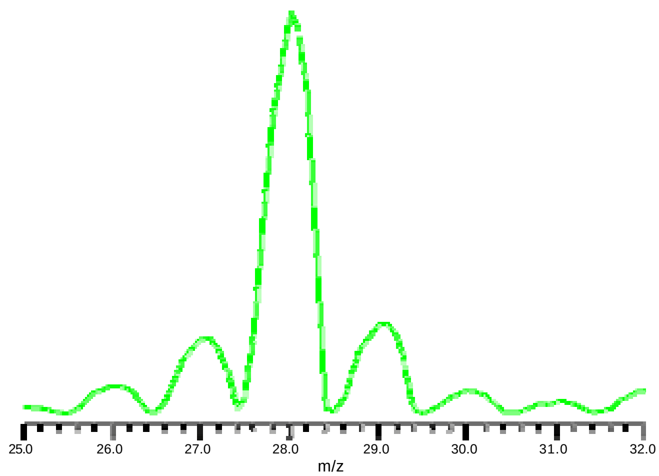

Figure 1. Background mass spectrum around m/z 27. The spectrum is taken without ion energy filtering.

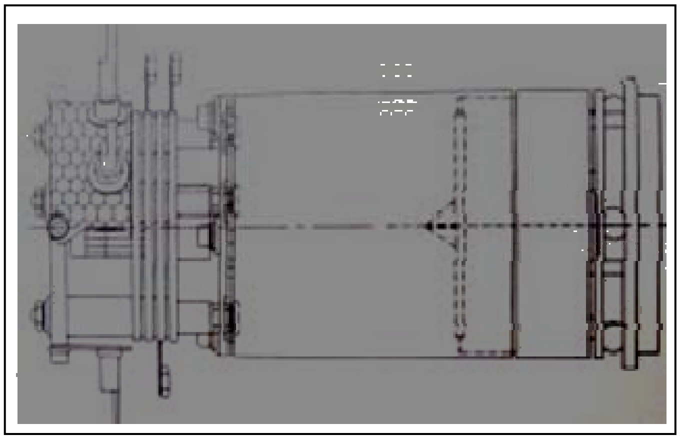

Figure 3. Schematic for the ionizer with energy filter.

was optimized to effectively remove all the slower moving background ions (< 2 eV energy window). The effect of the ion energy filtering is demonstrated by the disappearance of the peaks at m/z 27 and 28 in the background spectrum. With the energy filter in tandem with the ionizer, effective MS sensitivity is enhanced for the fast neutrals from a plasma source.

II. EXPERIMENTAL

Fast neutrals are produced through magnetron sputtering. The plasma from the sputtering process is sampled through a small aperture using an Extrel Quadrupole Mass Spectrometer with a tandem ionizer/energy analyzer and 500 amu mass range.

The quadrupole mass filter housing is biasable to optimize the transmission for higher energy ions. Data acquisition and instrument control was performed using the Extrel Merlin data acquisition system.

An einzel lens set was installed in front of the mass spectrometer ionizer. These lenses were used to reject the ions from the plasma source when fast neutrals were monitored. These lenses can also be used for ion focusing for the analysis of the ions from the plasma source.

Figure 3 shows the schematic for the einzel lens set and the tandem ionizer/energy energy analyzer used in the experiments. Experiments were performed using fast Al and Cu neutrals from a magnetron sputtering source. The flux and average kinetic energy of the fast neutrals from the plasma source is controlled by the magnetron sputtering current.

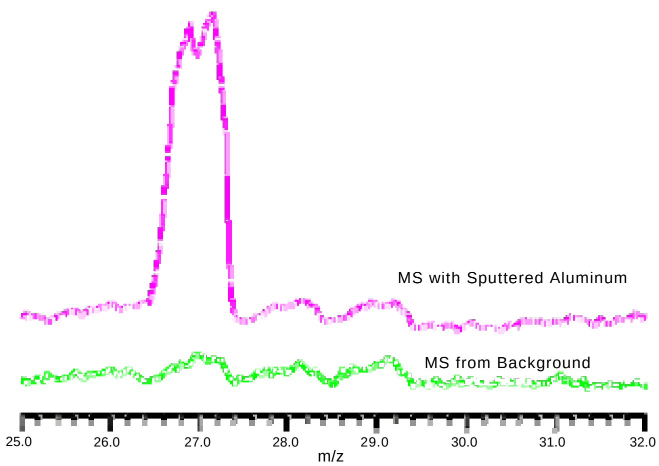

Figure 2. Optimization for fast moving Al atoms with ion energy filtering.

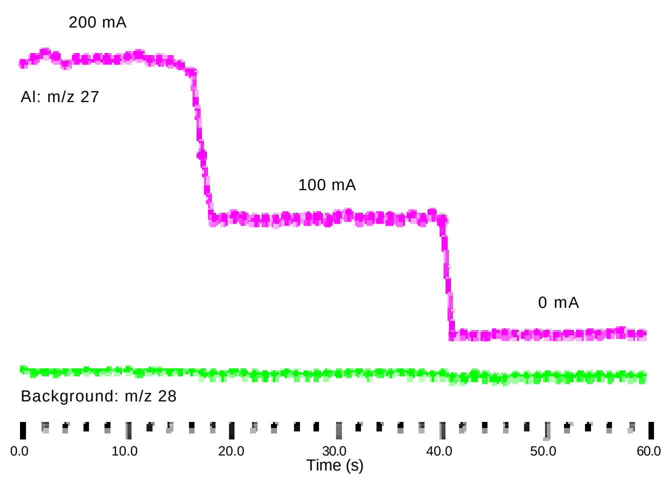

Figure 4. Response of the aluminum fast neutrals vs. sputtering current.

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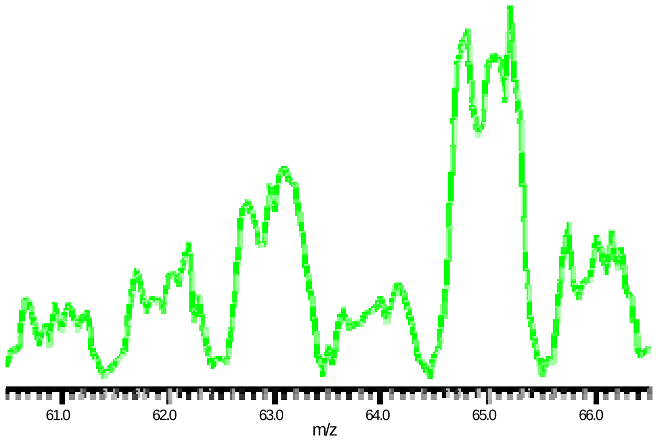

Figure 5. Background mass spectrum around m/z 63. The spectrum is taken without ion energy filtering.

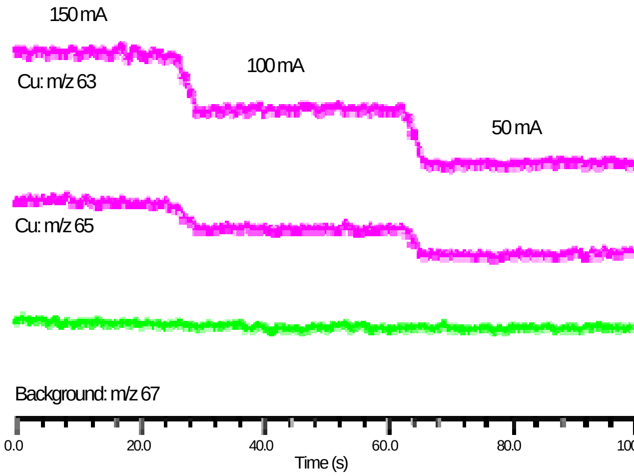

Figure 7. Response of the fast copper neutrals vs. sputtering current.

III. RESULTS AND DISCUSSION

In figure 2 mass spectra are shown with the magnetron sputtering source turned on and off. The energy analyzer had been optimized here to remove the low energy background ions at m/z 27. The effectiveness of this ion energy filtering is also evident from the disappearance of m/z 28 peak from the background spectrum.

The energy analyzer tuning was optimized by first narrowing the width of the energy window until the ion signal due to the residual background was minimized, and then moving the centerpoint of the energy bandpass to maximize the signal associated with the fast Al neutrals.

The combination of an energy analyzer and a biasable mass filter, allows for the selection of only those ions with a specific kinetic energy range, while maintaining a sufficiently low kinetic energy for the optimum transmission through the biasable quadrupole mass filter.

In figure 4 the response of the fast Al neutrals and background signals at m/z 28 to the magnetron sputtering currents are compared. The spectra were collected under the same tuning parameters on the mass spectrometer. The spectra clearly show that the fast neutrals at m/z 27 increase with the sputtering current while the backgound signals barely have any response. Thus, even though the overall intensity from the fast neutrals is weak compared to the residual background, the ion energy selectivity from the energy analyzer makes it possible to monitor the fast Al neutrals from magnetron sputtering.

Figure 5 shows an MS scan around m/z 63 and 65 where the Cu isotopes from the magnetron sputtered plasma are expected. These peaks are attributed to pump oil contamination on the vacuum chamber.

Figure 6 shows the mass spectrum from fast moving Cu atoms from the magnetron sputtered plasma. With the optimization of the energy analyzer, the residual background signals are effectively removed. The correct isotope ratio between m/z 63 and 65 also demonstrates that we are indeed monitoring the fast Cu atoms from the plasma.

Figure 7 shows the response of the Cu isotopes as a function of the magnetron sputtering current. The background at m/z 67 shows no response at all. Here again, the correct isotope ratio is preserved at different levels of the sputtering current.

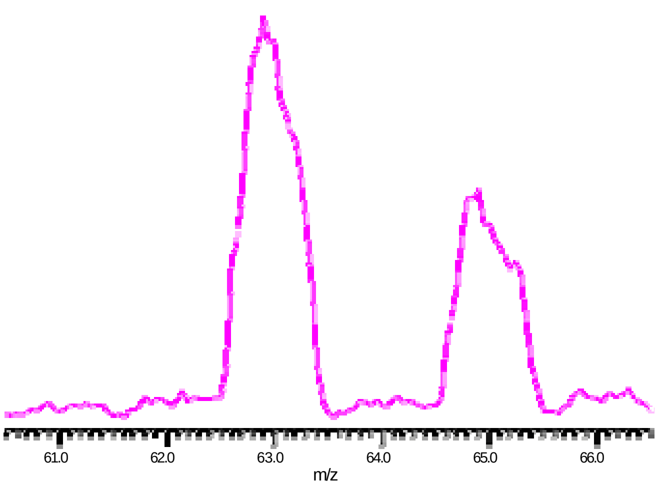

Figure 6. Mass spectrum for fast moving Cu atoms with ion energy filtering.

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IV. CONCLUSIONS

1. Detection of fast moving neutrals from a sputtering source requires a high sensitivity mass spectrometer due to the significant reduction in ionization probability associated with fast moving neutrals.

2. An energy filter is necessary for the analysis of fast moving neutrals to differentiate them from the thermal residual background gas.

3. Rejection of plasma ions when plasma neutrals are to be analyzed requires the use of a retarding potential in front of the ionizer, such as the einzel lens stack used in this experiment.

4. The analysis of energetic neutrals allows for greater insight in to plasma processes, potentially allowing for better control of such processes.

5. As expected, higher sputtering currents result in higher neutral yield in a magnetron sputtering source.

This work was performed in collaboration with Lin Zhu and Bob Bailey at Tosoh SMD, Inc. Their contributions to this work are gratefully acknowledged.

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