Measuring IVDF through high-aspect holes in pulsed ICP plasmas

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1. Introduction

Plasma etching of nanometric size, high aspect-ratio structures is difficult for many reasons. Several issues originate from the angular distribution of the ions which bombards the wafer. Even with a significant dc self-bias voltage to accelerate ions in a direction perpendicular to the surface, their angular distribution remains significant. As a result the feature sidewalls are bombarded by energetic ions leading to profile control issues and to a reduced ion flux at the bottom of the features. Indeed ions incident on the wafer with an off normal velocity vector are believed to be responsible for typical feature profile distortion such as bowing, notching and microtrenching.At high pressure, the ion angular distribution originates from ion/neutrals collisions in the sheath. By contrast in ICP reactors at low pressure, this angular dispersion is due mainly to the finite transverse velocity component of the ions when they enter the sheath region (it corresponds to their thermal velocity at sheath edge, which can be significant). Since ions get neutralized and loose energy when colliding with the feature sidewalls, it follows that the flux of energetic ion which reach the bottom of the etched feature drops when their aspect ratio is increased. Furthermore, ion transport inside the features can be significantly impacted by charging effects, which may further deflect the ions from their vertical trajectories and reduce the ion flux and energy at the bottom of the features[1]. The issue of feature charging (which leads to electrical damages of ultrathin gate oxides) has motivated the introduction of pulsed ICP plasmas in the 90's. However, the impact of plasma pulsing on the elimination of charging and on ion transport inside features has never been investigated experimentally.

2. Results and discussion

We have measured the IVDF at the wafer surface in an industrial ICP reactor (from AMAT and designed to etch 300 mm diameter wafers) by using multigrid ion energy analyzers (RFA) from IMPEDANS (Semion^{TM} system). The peculiarities of this diagnostic technique, especially when used in pulsed plasmas will be discussed. The ICP plasma is operated in 4 different chemistries (Ar, He, H_2 and CF_4), with several rf bias power and in various mode of operation (CW, synchronously pulsed plasmas and bias pulsed plasmas). To analyze ion transport through high aspect hole, we place 0.4mm thick capillary plates with holes of 25 µm, 50µm and 100 µm diameters in front of the RFA analyzer, which then probes IVDF at the exit of holes with AR of 16, 8 and 4 respectively.

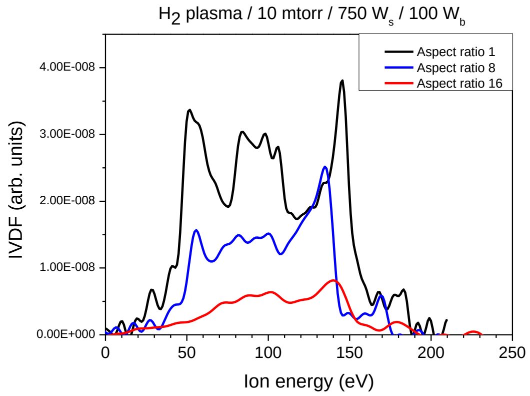

Figure.1: IVDF measured by RFA analyzer on the wafer without capillary plate and with capillary plates of aspect ratio 8 and 16 in H_2 plasma. The different peaks in each IVDF correspond to H_2^+ and H_3^+ ions (plus parasitic Al^+).

For example, Figure.1 shows the IVDF observed through holes of several aspect ratio. It is clear that ion transport depends strongly on the AR of the features: the ion flux (integral of the IVDF) drops dramatically when the AR is increased. Furthermore the "saddle" shape of the IVDF is lost: the low energy ions flux is much more impacted by the AR than the flux of higher energy ions. From such measurement, we can plot a transmission curve of the ions as a function of their energy. Furthermore, by comparing data in Ar, He, CF_4 and H_2 we can also investigate the impact of the ion mass on their transport. We will compare electropositive versus electronegative gases and since experiments are also carried out in pulsed plasmas we will discuss the impact of plasma pulsing on charging effects. These results provide an unprecedented insight into the role of ion angular distribution and charging effects on ion transport in high aspect ratio features and thus on very well known issues related to plasma etching such as RIE Lag, ARDE, etch stop and profile deformation

References

[1] K Kurihara and M Sekine, Plasma Sources Sci. Technol. **5** (1996) 121–125[1-3].