

Novel plasma monitoring technique based on modulated optical emission from the processing discharge

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We report a novel plasma monitor technique based on the detection and monitor of the modulated light emission from a processing discharge. The modulated light emitted from the plasma is mainly originated at the plasma sheaths due to the time varying electron density, driven by the radio-frequency current. The proximity of the sheath to the wafer/substrate surface makes the technique sensitive to the etch process. Test measurements are made on a capacitive coupled tool with argon/oxygen plasma. Time domain results show light modulation at the driving radio-frequency (13.56MHz) and the second harmonic.

Introduction

Typical optical monitoring techniques for processing plasma are based on optical emission spectroscopy (OES): a sensor detects the light emission from the plasma at a particular wavelength, which is tracked throughout the process and used to determine the endpoint. OES is a preferred detection technique due to its simplicity. Other techniques, including laser reflection interferometry, mass spectrometry, ellipsometry and plasma impedance monitor, consist of more complicated set-up.

Single wavelength OES detectors are common in the semiconductor manufacture environment and have been very useful on the endpoint detection context for a long time. But on the last decade, the use of these types of sensors has declined for endpoint applications of the most challenging etch processes. The semiconductor industry is currently facing the need for improved etch endpoint detectors in more demanding situations, such as low open area etching; i.e. 1 to 0.5% area of the wafer exposed for etching.

The current trend for OES detection technique and the etch endpoint detection systems is to move from single wavelength to multi-wavelength optical emission detectors where multivariate based analysis is applied to the various wavelengths detected to compile the process information into a smaller set of signals or a single signal for endpoint detection.

In this paper we present a novel processing plasma monitor technique based on the detection and monitor of modulated light emitted from the discharge. The light emission from the plasma is the result of optical de-excitations from atoms, molecules and/or ions in the plasma including etch-by-products in processing discharges. Outer shell electrons in these are excited to a higher energy level (from which they emit back to ground or to intermediate levels) mainly by electron impact excitation. The presence of a population of electrons with a certain energy distribution in typical processing plasmas is the kernel for the light emission observed from the plasma. The absence or low density presence of electrons results in none or low light emission. This happens in the sheath where the electron density is lower than on the plasma bulk. Furthermore, in the sheath the electron density is modulated, therefore the light emission is modulated by the driving radio-frequency and the optical emission from the sheath contains modulated components at the driving radio-frequency and harmonics. By detecting the modulated optical emission, the light emitted from the sheath is separated from the continuous plasma bulk emission. And by monitoring the amplitude of the modulated light it is possible to monitor the process. Applications for this new plasma monitoring technique include etch endpoint detection.

The first experimental work on the light modulation detection in capacitive plasma was reported by Gans et al [1].

Experimental

These technique has been tested in a capacitive etch reactor (Plasmalab80Plus, Oxford Instruments). The feedstock gas mixture is set to 5SCCM oxygen and 100SCCM argon; where SCCM stands for standard cubic centimetres per minute. The chamber pressure is set to 100mTorr and the applied radio-frequency power is set to 300W at 13.56MHz.

Phitell™, Lexas Research Endpoint Detection System, includes a proprietary optical sensor which is used to monitor the etch process. The sensor detects the discharge and output a Fast Fourier Transform (FFT) to a computer or controller for monitor and recording at an output rate up to 10Hz. Specific frequencies from the output FFT may be monitored or multivariate techniques may be used to analyse and compile the data. The sensor detects the modulated light intensity and presents the data as a Fourier spectrum (0.25-24MHz). Harmonics above 24MHz are not missed by the sensor, but they are observed on the spectrum as lower frequencies

The plasma light is input to the sensor through a fibre optical light guide bundle. The fibre bundle input is placed in front a view port on the etcher and tilted towards the wafer, with an angle between 25 and 45 degrees respect to a horizontal axis parallel to the wafer. It is observed that the vertical orientation of the fibre bundle has a considerable effect on the modulated light intensity. If set for a horizontal view, parallel to the wafer surface, as in a typical OES measurement set-up, it results in poor performance of the technique presented here. This observation is in agreement with the physical picture that the modulated light from the discharge is mainly generated at the capacitive sheath.

Results

Figure 1 shows a sample output FFT for the argon plasma. Note the driving-frequency (13.56MHz) is detected as the largest peak while the smaller peak corresponds to the second harmonic (27.1MHz).

Figure 2 shows the time evolution of the driving radio-frequency; this data show the initial transient for the onset of the discharge.

Conclusions

The results here show that the light modulation technique presented is capable of plasma process monitoring. The etch endpoint

application is currently under development with very successful results up to date. Furthermore, current work in our laboratories demonstrates exciting possibilities for the future.

References

- [1] T. Gans *et al.*, Phys. Rev. A. **67**, 012707 (2003)

Figures

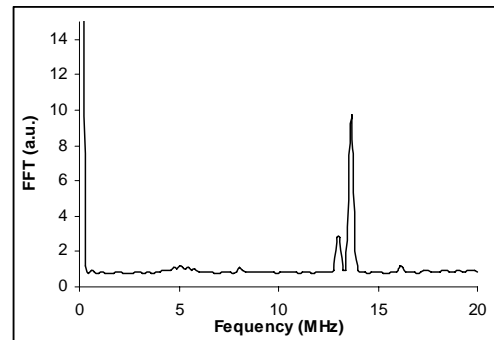


Figure 1

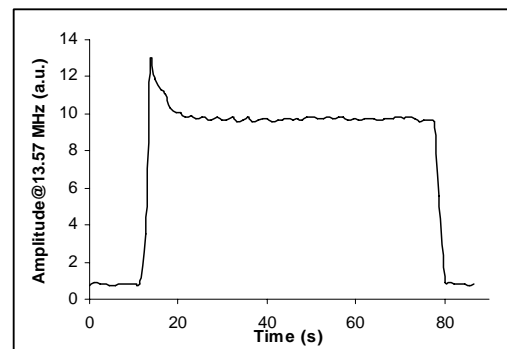


Figure 2