Plasma parameters and silicon dioxide etch rates in a carbon tetrafluoride plasma

PLASMA PARAMETERS AND SiO_2 ETCH RATES IN A CF_4-PLASMA

T.J. Bisschops, F.J. de Hoog, D.C. Schram

Eindhoven University of Technology, Physics Department,
P.O.Box 513, 5600 MB Eindhoven, The Netherlands

INTRODUCTION

In this contribution a number of experimental data concerning a well-defined RF-discharge, similar to those applied in surface processing of semiconductor material, will be presented. The discharge configuration is a plane-parallel electrode device, operating with e.g. CF_4-gas at pressures from 5.10^{-2} torr up to 0.5 torr and RF-input powers of 5.10^{-2} - 1 W/cm^2. The RF-frequency was 13.5 Mhz. This discharge was observed to etch a silicon oxide layer in a silicon substrate. Electron densities were determined with a microwave method. The etch rate was measured real time by using fast ellipsometry. Parameter studies of the intensities of several spectral lines gave insight both in the geometry of the discharge and the occurence of the various species.

EXPERIMENT

1. The CF_4-plasma was generated in a single wafer etch configuration with plane parallel electrodes, one of which is powered by the 13.5 Mhz RF voltage [1]. For the determination of the electron density the grounded electrode was replaced by one with a box-like geometry so that the electrode system also formed a microwave cavity. The microwave setup is quite convential. A circulator in the input line of the cavity diverts the energy reflected from the cavity to a detector. While the oscillator frequency is swept within the range of interest, the dependence of the detector signal on the frequency is displayed on an oscilloscope. The detected signal shows absorption of power at the resonant frequencies of the cavity. When plasma is present these dips shift to higher frequencies. The relation between the frequency shift $\Delta\omega$ and the plasma density n_e in the case of a plasma dispersed homogeneously within the cavity is

$$\Delta\omega = \frac{1}{2\omega} \frac{\int \omega_p^2 \, E^2(\vec{r}) \, d^3r}{\int E^2(\vec{r}) \, d^3r} , \qquad (1)$$

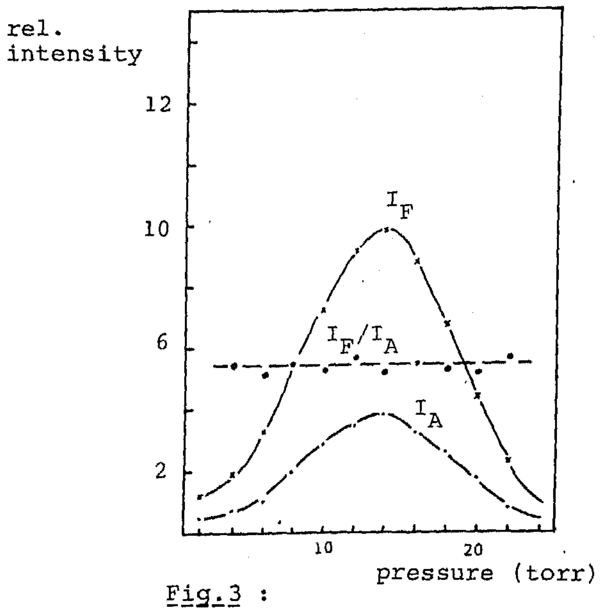

Fig.3 :
Line radiation of F- and A-atoms as a function of axial position in a plane parallel reactor

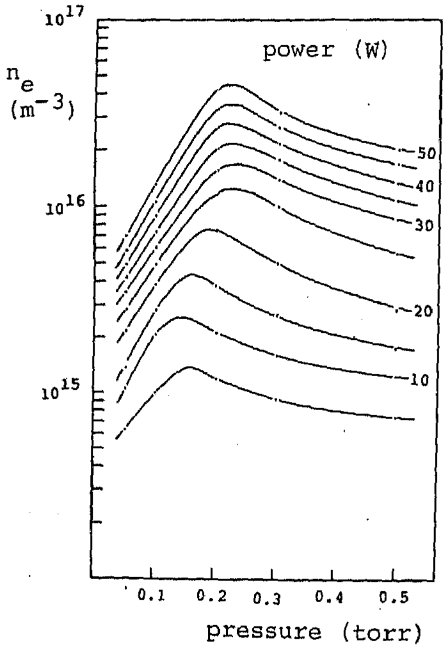

Fig. 4a :
Electron density vs. discharge pressure at various power levels in a CF_4-plasma

the density of F-atoms in the pertinent discharge parameter range. Relative F-atom densities were determined as a function of the various discharge parameters by measuring the 703.7 nm F-line. Also an actinometric comparison has been made by monitoring the 703.0 nm A-line. To this end argon was injected in the CF_4-flow in a mass flow ratio of 10 : 1. From Fig.3 e.g. it can be seen that the relative intensities of both emissions as a function of position measured perpendicular to the electrodes show a cosine-behaviour, but the ratio of the emissions appears to be independent of position. This indicates that the distribution of F-atoms in the discharge volume is the same as that of the A-atoms. Assuming the latter to be homogeneously dispersed, we concluded that also the F-density is homogeneous.

RESULTS, DISCUSSION

Experimental values of electron densities, etch rates and the ratio of F to A emission as a function of pressure are shown in Fig.4a, b, c. The RF-power into the discharge is indicated as a parameter.

A dominant feature in the three curves is the maximum occuring at pressures of about 0.1 - 0.2 torr. First this indicates consistency in the results and, when regarded with an empirical eye, a possible optimum for etching applications. Second it is still not quite clear what its physical interpretation is. It is not possible to ascribe this maximum to the transition pressure where $\omega = \gamma_m$ and where the electron heating mechanism is changing its character. However, at the experimental value of 0.2 torr the mean free path of the electrons becomes of the order of the thickness of the glow. Vallinga [2] was able to deduce a maximum in the electron density in a planar RF-discharge in CF_4 at a pressure of about 0.2 by a particle conservation argument following a solution of the Boltzmann equation for electrons. This strongly suggest a geometric effect, which is still subject of further experimental investigation.

The authors would like to acknowledge contributions by C. de Zeeuw, W. Boom and H. Störi. The investigations were supported in part by the Netherlands Technology Foundation.

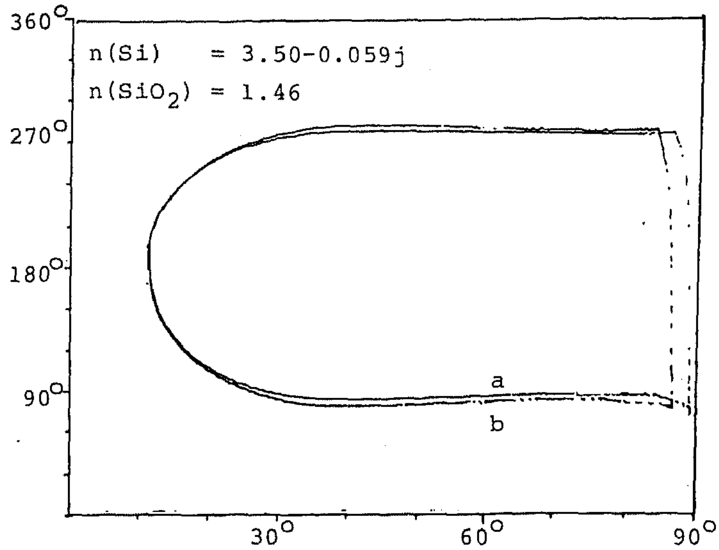

Fig.1 : Ellipsometric track for the SiO_2-Si system in a CF_4(A) etching plasma (a. experiment, b. model calculation)

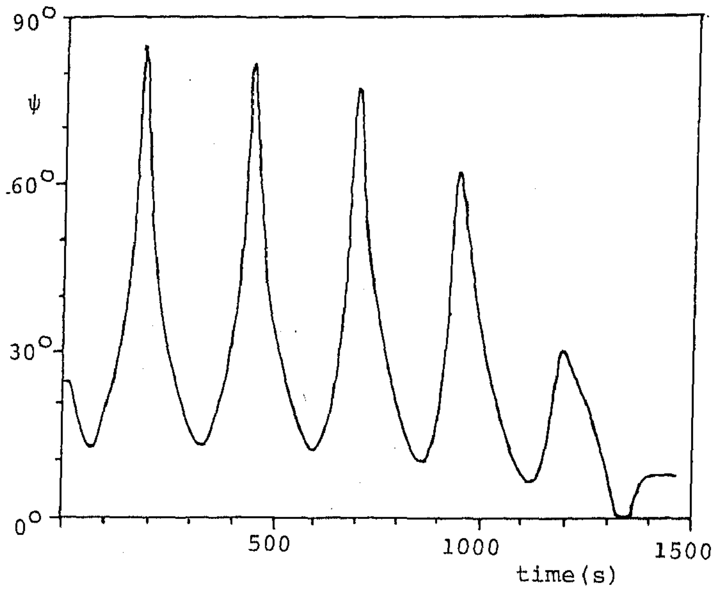

Fig.2 : Development of the ψ as a function of time during etching of the SiO_2-Si-system in a CF_4(A) plasma

from a well defined situation it is possible to determine etch rates from Fig.2.

3. Finally measurements are reported of the intensity of radiation from the atomic fluorine system. These were carried out mainly to relate electron densities and etch rates with

with

$$\omega_p^2 = \frac{e^2}{\varepsilon_o m_e} n_e ,$$

and $E(\vec{r})$ the electric field distribution of the eigenmode with frequency ω.
Conditions for relation (1) to be valid are

$$\omega_p < \omega \text{ and } \gamma_m < \omega ,$$

with γ_m the rate for momentum transfer by electrons.

2. In order to measure the etch rate of a SiO_2-Si substrate in a CF_4-discharge we used a fast ellipsometric setup. As a source a helium-neon-laser was used and after reflection at the substrate the incident linearly polarized wave was analyzed by a rotating analyzer and detected. To carry out the analysis real time, the analyzer had a angular frequency of 328 rad/s which, in combination with an M68000-processor, made it possible to measure a value of (ψ,Δ) every 10 ms. Using known values of the refractive indices of SiO_2 and Si the ellipsometric angles ψ and Δ should complete a full lap in the (ψ,Δ)-plane every time a layer of a certain thickness is etched away. This thickness is proportional to the wavelength of the light. The proportionality constant is determined by the refractive indices and the angle of incidence. In Fig.1 a measured track in the (ψ,Δ)-plane is shown, together with a track calculated for the SiO_2-Si system with values for the refractive index as indicated in the figure. In Fig.2 experimental values of ψ vs. time are shown. Etching conditions are : A 50%-50% mixture of CF_4-A with a flow of 2.5 sccm at a pressure of 0.06 torr and a total discharge power input of 50 W. From Fig.2 one can see that after the removal of approximately half the SiO_2-layer deviations from the ideal track of Fig.1 occur. These are due to changes in the morphology of the reflecting interface. E.g. the (ψ,Δ)-tracks at this stage of the etching process can be simulated assuming an intermediate layer between the SiO_2-and the Si-substrate with a graded index of refraction. Although monochromatic ellipsometric analysis can not give unambiguous answers as to an unknown morphology, starting

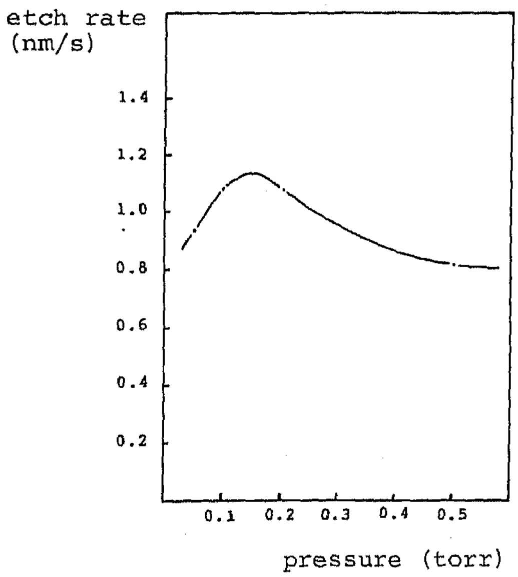

Fig. 4b :
Etch rates vs. pressure
in a CF_4(Ar) discharge
at a power of 50 W

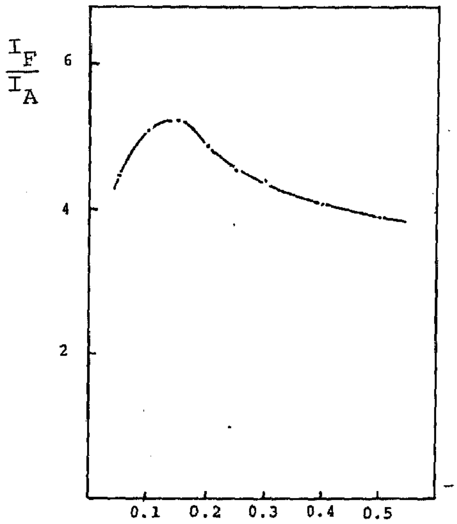

Fig. 4c :
Rate of F vs. A
line emission vs. pressure
in the center of a CF_4(A)
discharge at a power level
of 50 W

REFERENCES

[1] T.J. Bisschops, H. Störi, J.A. Engels, F.J. de Hoog, D.C. Schram in Proc. of the 7th Int.Symp. on Plasma Chemistry edited by C.J. Timmermans (Eindhoven, 1985) pp.599-604.

[2] P.M. Vallinga, T.J. Bisschops, H.T.C. Stoof, ibidem pp.1399-1404.