Electron density measurements in a single wafer etch reactor

Citation for published version (APA):
Bisschops, T. H. J., Störi, H., Engels, J. A., Hoog, de, F. J., & Schram, D. C. (1985). Electron density measurements in a single wafer etch reactor. In C. J. Timmermans (Ed.), *ISPC 7 : international symposium on plasma chemistry : 7th, Eindhoven, July 1-5, 1985, Vol. 2* (pp. 599-604)

Document status and date:
Published: 01/01/1985

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 04. Oct. 2023

ISPC-7 Eindhoven, July 1985
Paper number P-8-1

ELECTRON DENSITY MEASUREMENTS IN A SINGLE WAFER ETCH REACTOR

T.J. Bisschops, H. Störi [x)], J.A. Engels, F.J. de Hoog, D.C. Schram

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

x) Technical University of Vienna, Vienna, Austria.

ABSTRACT

Using microwaves, absolute values of electron densities have been obtained in a modified single wafer etch reactor. Using CF_4 as the etch gas electron densities are found to be in the range of 2.10^{14} to 5.10^{16} m^{-3} in the pressure range 5.10^{-2} --- 0.5 torr and powers of 5.10^{-2} --- 1 W/cm^2. Also the decay time of the electron density has been measured and is in the range of 1.7 --- 7 μsec.

1. INTRODUCTION

Plasma etching is an increasingly important process technology in the semiconductor industry [e.g. 1] and stimulates the interest in investigations of the physical and chemical properties of the plasmas used. In the present work a CF_4-plasma used, for the etching of SiO_2, is studied in a single wafer etch reactor.

2. THEORY

Measuring electron densities with microwaves is a well known technique [2,3]. The simplest method is to measure the shift of the resonance frequency of a cavity when a medium with dielectric properties differing from vacuum (i.e. a plasma) is inserted.

In the case of a low density plasma, $\nu \ll \omega$ and $\omega_{pe} \ll \omega$ the frequency shift reads :

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

Since the method used is essentially integral, an assumption has to made for the radial distribution of the electron density.

In figure 1a we show the geometry of the cavity. Based on our observations we make a distinction between the central part of the plasma in front the RF electrode and the outside plasma.

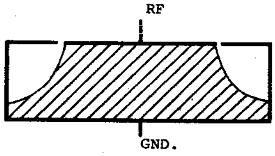

Fig.1a : Plasma in the cavity.

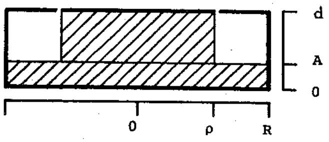

Fig.1b : Dimensional parameters.

We assume that plasma is present in the entire cavity; in the central region it has a density n_e and in the outer region another, normally lower, density characterized by A (fig. 1b):

$$n_e(r) = \overline{n}_e \qquad 0<r<\rho$$

$$n_e(r) = \overline{n}_e \cdot A \qquad \rho<r<R$$

where ρ = radius of the electrode
R = radius of the cavity
n_e= electron density in the central region
A = form factor $(0<A<1)$

Equation (1) can now be transformed to:

$$\Delta\omega = \frac{1}{2} \cdot \frac{1}{\omega} \cdot \frac{e^2}{{}_o m_e} \cdot \overline{n}_e \circ \frac{(1-A)I(\rho) + A\,I(R)}{I(R)} \tag{2}$$

where $I(\rho) = \iiint_0^{\rho} \underline{E}^2(r)d^3r$

$$I(R) = \iiint_0^{R} E^2(r)d^3r$$

where A is a form factor to be determined.
Simultaneously measuring the shift of different modes (different $E(r)$) allows for solving both n_e and the form factor A. In our experiment only TM_{nmo} -modes have been used resulting in electron densities averaged along the direction perpendicular to the RF electrode. A correction for the nearly empty dark spaces has not been performed but would lead to slightly higher values for $\overline{n}_e$.

3. EXPERIMENTAL

The measurements were performed in a specially designed 0.3 m diameter etch reactor. Used in the single wafer etch mode, two electrodes (0.069 m diameter) are inserted. The electrode distance can be varied by means of a bellows device in the RF-powered electrode. For the present experiments, the distance was taken to be 20 mm. For the microwave measurements the grounded electrode, normally carrying the wafer, is replaced by the cavity.

The RF-frequency used is 13.56 MHz with power flux levels up to 1 W/cm.

The gas flow (usually CF_4 ,H_2) is controlled by two mass flow controllers. The pumping system consist of a 250 m^3/h roots blower backed by a 30 m^3/h rotary vane pump. A variable orifice valve permits the independent adjustment of both pressure and gas flow.

The microwave set-up is very simple, similar to the one used by Biondi and Brown [2]. Instead of the standing wave detector a circulator is used to divert the energy reflected from the cavity coupler 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 detector signal, representing essentially the reflected power from the cavity coupler, shows dips at the resonant frequencies of the cavity, indicating absorption of power. When the plasma is ignited the dips in the spectrum shift to higher frequencies. Although the RF-electrode is part of the cavity a quality factor of 600...3000 can be achieved using $\lambda/4$ chokes.

To observe the time dependent electron density in the afterglow, a modification of this technique, well known for earlier afterglow experiments [2,3] is applied. The microwave generator is set to a fixed frequency between a resonant frequency of the empty cavity and the corresponding shifted frequency of the plasma filled cavity. After interrupting the supply of RF power the passage of the resonant frequency of the cavity across the oscillator frequency is observed on an oscilloscope. By repeating the experiment for different oscillator frequencies a plot of the frequency shifts of the cavity as a function the time after cut off of the discharge is obtained. This represents the decay of the electron density. Decay time constants are easily obtained from these plots.

4. RESULTS

The electron densities measured in a CF_4-plasma are shown in figure 2

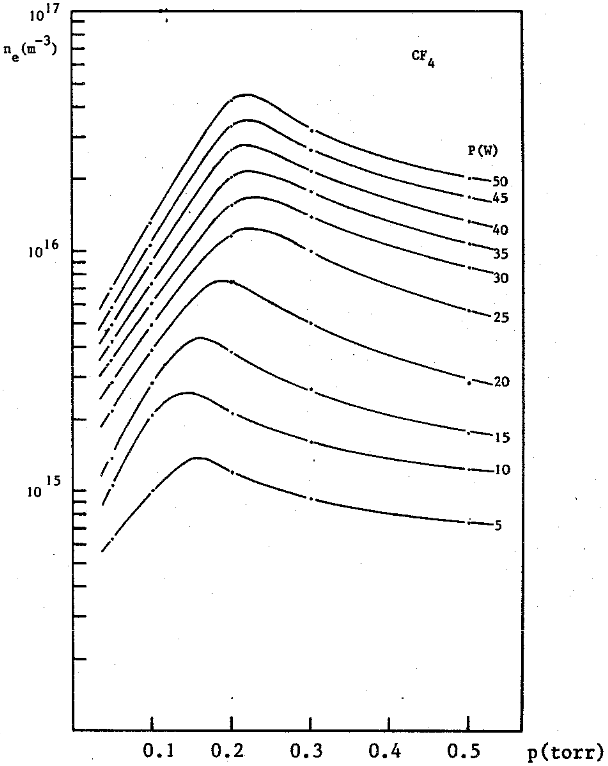

Fig.2 : Electron density in CF_4 as a function of pressure and total discharge power.

For various power levels there is a maximum in the measured electron density at a pressure of 0.2 torr. A theoretical investigation presented in these proceedings [Vallinga et al] also indicates a maximum at ~ 0.2 torr ($\Lambda_e \approx 10$ cm). For comparison electron densities have been measured in an argon discharge (see figure 3), and prove to be a factor of 10 higher than for CF_4, also no maximum is found. For the CF_4 discharge A-values are ~ 1 indicating a homogeneously filled cavity, for argon A-values are ~ 0.3. To investigate the feasibility of negative ion detection in an afterglow technique, also the decay of the electron density has been studied. The results are presented in the form of loss rates.

To investigate the pressure dependence of the electron density in CF_4, the electron density in another molecular gas (e.g. N_2) has been measured. The electron densities for N_2 are a factor of 5 lower than for CF_4, and show a similar pressure and power dependence ~~as~~ argon. In the case of nitrogen also no maximum is found in the same parameter range.

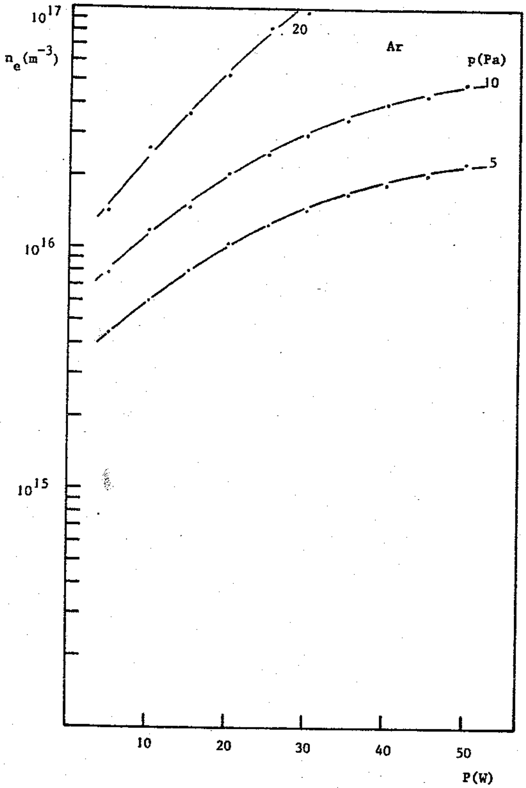

Fig.3 : Electron density in Ar as a function of power and pressure.

Fig. 4a shows the electron loss rates (inverse lifetimes) obtained for different pressures in CF_4. The electron loss rate strongly increases with increasing pressure. The electron loss rate did not depend on the RF power fed into the discharge, or the RF pulse rate.

Fig. 4b shows for comparison loss rates obtained in argon afterglows. These are considerably lower then corresponding CF_4 data, moreover, loss decreases with increasing pressure, as expected for a loss dominated by diffusion. The loss rate at low pressures is however higher than that expected in a clean argon afterglow at an assumed gas temperature of 400 K by a factor of roughly 7 [4].

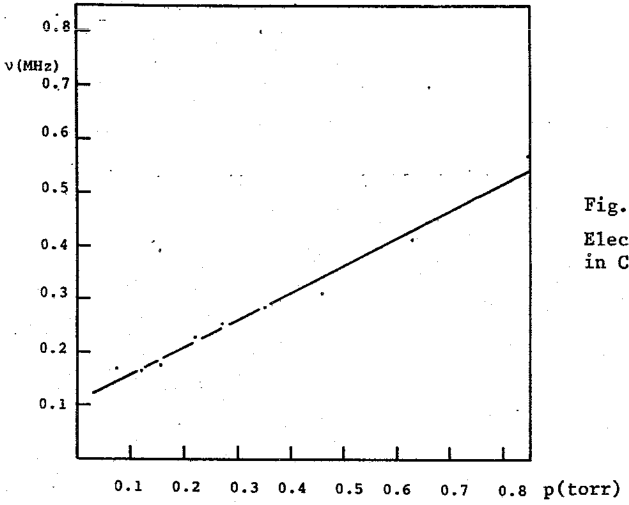

Fig.4a :

Electron loss rate in CF_4.

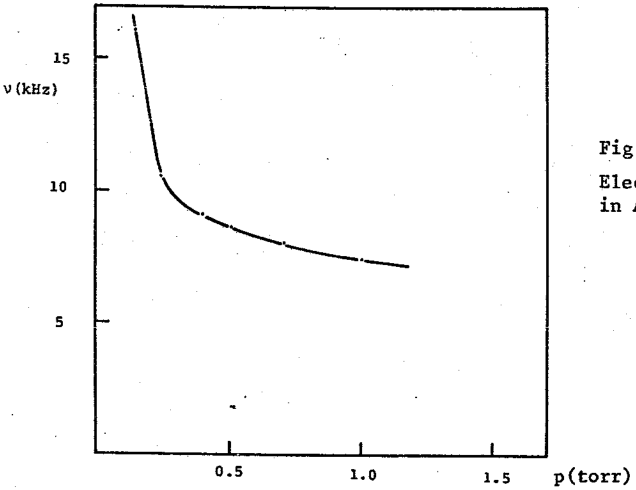

Fig.4b :

Electron loss rate in Ar.

5. DISCUSSION AND CONCLUSION

Using simple microwave techniques, electron desities can be measured in an accurate and reliable way. For pressures in the range of 0.05-0.5 torr and RF power fluxes of 0.05 to 1 Watts/cm^2 electron densities in a CF_4 -discharge range from 5.10^{14} to 5.10^{17} m^{-3}. At the electrode separation of 20 mm, which was used throughout the present investigation, the electron density rises monotonically with increasing RF-power. As a function of pressure however, the electron density shows a maximum around 0.2 torr.

The afterglow experiments show that a loss mechanism for electrons far more efficient than ambipolar diffusion is present in the CF_4 -afterglow. The loss rate remains unchnged while the power supplied during the discharge pulse is modified by a factor of 6. The increase of the loss rate with increasing pressure indicates, that electrons are lost by attachment to electronegative species. Recombination is ruled out as a possible mechanism by order of magnitude estimates and by the observed exponential decay of the electron density. The evidence obtained from other investigations [5-8] shows however, that dissociative attachment to ground state CF_4 is very slow at electron temperatures below 2.5 eV.

The electron loss in argon decreases with increasing pressure, as expected from a loss mechanism dominated by diffusion. The difference in absolute magnitude of the observed loss rate and literature data obtained in specially designed ultra high vacuum systems might be explained by impurity ions wich have generally a higher coefficient of diffusion than argon ions themselves, by a slower rate of cooling of the electrons than expected or by a disturbance produced by the large amount of positive space charge present in the active RF plasma or possibly by any combination of the effects mentioned above.

6. ACKNOWLEDGEMENTS

The Authors would like to thank M.J.F. van der Sande for his skillful technical assistance. These investigations were supported in part by the Netherlands Technology Foundation.

7. REFERENCES

[1] L.M. Ephrath, Solid State Technology, July 82, p.87

[2] M.A. Biondi and S.C. Brown, Phys. Rev. 75, 1700 (1949)

[3] M.A. Biondi, Phys. Rev. 109, 2005 (1958)

[4] M. Groessl, M. Langenwalter, H. Helm and T.D. Maerk, J. Chem. Phys. 74, 1728 (1981)

[5] L.G. Christophorou, S.R. Hunter, J.G. Carter S.M. Spyrou and U.K. Lakdawala, 4th IEEE Pulsed Power Conference, Proc. p. 702 (1983)

[6] M. Shimozuma, H. Tagashira and H. Hasegawa, J. Phys. D 16, 97 (1983)

[7] P.W. Harland and J.L. Franklin, J. Chem. Phys. 61, 1621 (1974)

[8] S.M.Spyrou, I. Sauers and L.G. Christophorou, J. Chem. Phys. 78, 7200 (1983)