Electron density, optical emission spectroscopy and fluorocarbon deposition rate measurements in a high density inductively coupled C_4F_8 plasma

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The bulk plasma electron density and optical emission spectra are measured in a high density, high volume inductively coupled C_4F_8 plasma with a trace amount of Ar for actinometry purposes. The bulk plasma chemistry and electron density are measured and the influence of the bulk plasma properties on polymer deposition rates investigated. Fluorocarbon emissions are monitored across the experimental parameters. Electron density and polymer deposition rates scale linearly for all input parameters indicating the bulk electron density an effective measurement of C_4F_8 dissociation. It is found, that above other species emissions, the CF 202.4nm bulk emission scales with polymer deposition rates for all input parameters, indicating that the deposition of CF molecules on the silicon substrate to be the primary precursor for polymer film deposition.

1. Introduction

Fluorocarbon plasmas are also gas frequently employed in high aspect ratio silicon etching in a process known as the Bosch process[1]. The Bosch process can be briefly described as consisting of sequential etching and passivation steps using appropriate gas chemistry in each step (SF_6 for etching, C_4F_8 for passivating). The passivation technique of fluorocarbon polymer deposition therefore is a critical step in the control of trench width, depth and defects such as bowing and lag for silicon trench etching. Polymer thickness can be used to control the wall angle and base radius of curvature in features etched with the Bosch process[2]. Previous work has used C_4F_8 flow rate rather than deposition cycle time as a control for polymer deposition rates[2]. In this work the bulk plasma properties are investigated as a possible diagnostic to evaluate the relationship between these properties and the deposition rate. Conventional density measurements in fluorocarbon plasmas have proved difficult to obtain due to the polymerizing nature of the discharge. In this

work a microwave resonance probe[3] is used to obtain plasma electron density measurements. The principle of operation of the resonance probe allows it to be used in chemically aggressive environments, where conventional probe measurements prove unobtainable. Optical emission spectra are also collected to investigate the role of plasma chemistry in the deposition process.

2. Experimental

All experiments are performed in a high density, high volume Oxford Instruments Inductively Coupled chamber employing an ICP 380 inductive source[4]. Substrates are mechanically clamped to electrode with backside wafer Helium cooling. The resonance probe and optical fibre are placed 124mm above the electrode, with the probe centered, and chamber pressure and electrode temperature are automatically controlled. Wafers are 100mm diameter bare silicon temperature controlled to 20^0C.

3. Results and discussion

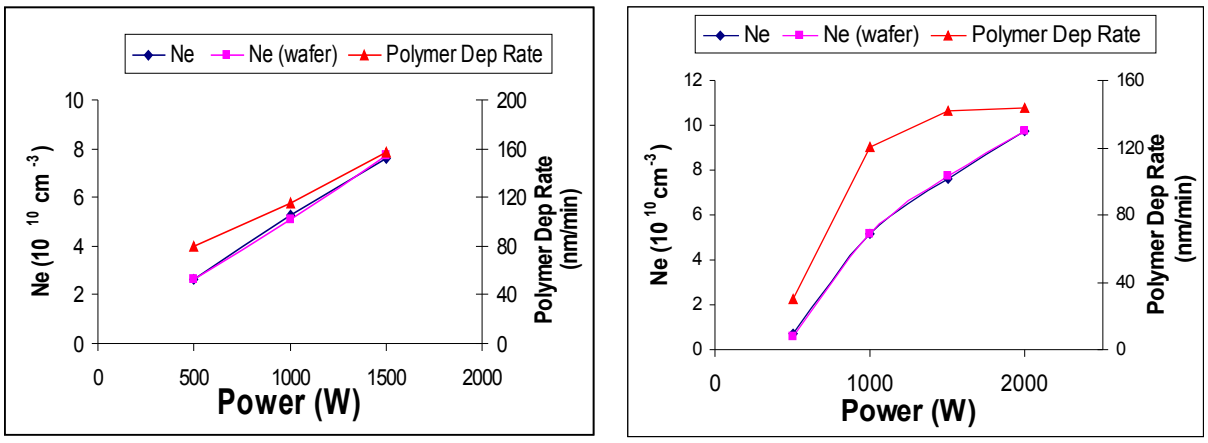

Figure 1. Electron density and polymer deposition rate variation with power at 10mT and 25mT

Figure 1 shows the variation of plasma bulk electron density and polymer deposition rate with power for both 10mT and 25mT pressures. The electron density was shown to increase linearly with power, and display a decreasing trend as the pressure is increased. No significant discrepancy was observed in electron density measurements between wafer present and not present. Polymer deposition rates show a proportional relation to electron density for both regimes. At 10mT electron density and deposition increase linearly with power.

The power variation at 25mT was increased by a data point to 2000W. This pressure regime produced a non linear response to increasing power in both polymer deposition and electron density. The density shows a tapering as power is increased from 1500 – 2000W, indicating a non linear increase for this pressure, and the corresponding polymer deposition rate exhibits a saturation trend.

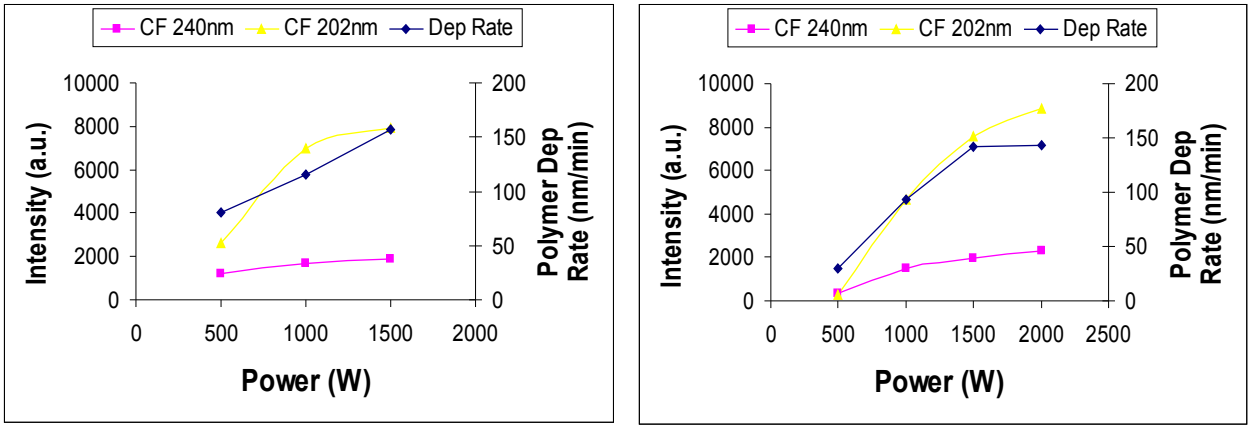

Figure 2. Variation of CF 202.4nm and CF 240nm emission intensity with power at 10mT and 25mT

A similar polymer deposition saturation is observed in the emission of CF 202.4nm at 25mT as the coil power is increased to 2000W. Maximum dissociation occurs at high powers and electron density measurement show a decrease in the rate of increase as this power is approached at 25mT, indicating a high degree of dissociation. CF can produced by various reactions[5] however the steady state emission at 2000W indicate a maximum production level is reached, more so than any other emission line in the spectra. The corresponding saturation of deposition indicate that the production and subsequent transport and absorption of CF to the wafer surface to be the dominant mechanism by which the polymer film is deposited. The relationship between electron density and polymer deposition rates for all experimental conditions is displayed in figure3(a). The results show the increase in dissociation of C_4F_8 and resulting increase in electron density to be a contributing factor in the rate of deposition of the polymer film. The emission of CF 202.4 nm and polymer deposition rate are plotted against electron density for 10mT and 25mT in figure 3(b), show the dependance of the polymer deposition rate on both electron density and CF production. Mechanisms of CF production studied elsewhere[6] indicate the primary source of CF is dissociation of CF_2, therefore it may be concluded the limiting step in film deposition in C_4F_8 is the production of CF_2, the optical analysis for this process shows that the deposition rate of that film is governed by the relative density of CF present in the discharge.

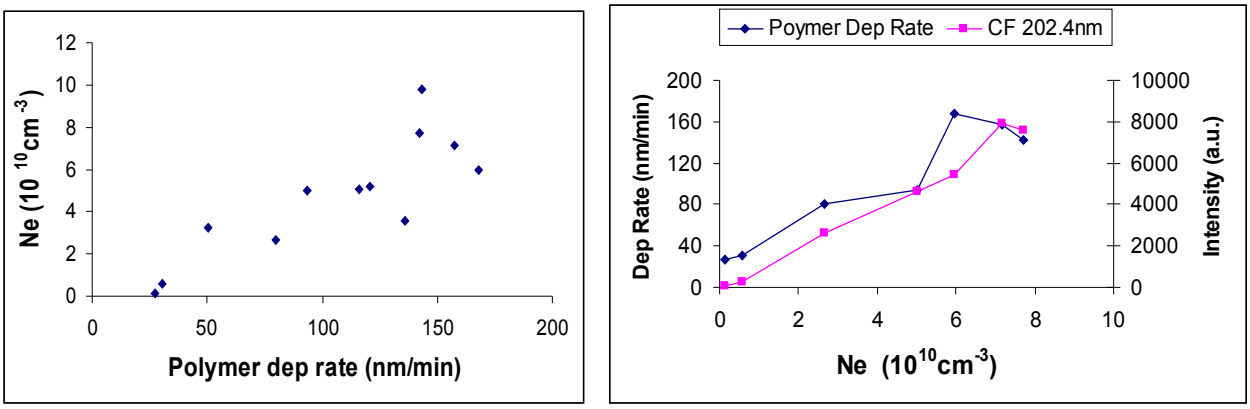

Figure 3. (a) Variation of electron density with polymer deposition rate for 10mT, 25mT and 40mT. (b) Variation of deposition rate and CF 202.4nm emission with electron density for pressures of 10mT and 25mT

4. Conclusions

From experimental analysis of electron density and emission of a C_4F_8 plasma it is shown that the the primary factors in polymer deposition on a silicon substrate are dissociation of feedstock gas and CF production in the discharge. Maximum deposition rates occurred where emission of CF was maximum in the plasma bulk. The results indicate the possibility of prediction and therefore control of deposition rates at the surface from measurements obtained in the plasma bulk.

5. References

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