PHYSICAL ANALYSIS OF A RF ETCHING PLASMA

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ABSTRACT

Diagnostics of an electrodeless RF plasma is achieved. The plasma gas is an argon-hydrogen mixture with variable concentrations. It is used to selectively etch silicon. A modelling of the plasma equilibrium reveals an important concentration of suprathermal electrons.

1. INTRODUCTION

The aim of this work is to characterize an argon hydrogen plasma which is able to selectively etch a silicon film. Fast etch rate involves a sufficiently ionized plasma. Moreover, the anisotropy of the etch profiles can be greatly improved by an independent control of the substrate biasing and of the creation of the plasma.

A particularly efficient, electrodeless RF coupling to the plasma is developed with this goal. Excitation of hybrid resonance leads to high ionization and dissociation rates for the pressure range 2-20 mTorr and the 13.56 MHz RF power range 200-500 W.

2. EXPERIMENTAL SET UP AND DIAGNOSTICS (Fig. 1)

The experimental set up and the diagnostic tools have been described in previous papers (1-3). A four wire antenna which couples the RF power to the plasma surrounds the silica plasma tube (d = 5.5 cm). A capacitive adaptation network allows a high efficiency of the coupling (power density 0.3 to 1 W/cm²). A static magnetic induction parallel to the tube axis can be added for limiting the electron radial diffusion and increasing the electron conductivity in this direction.

The concentration of gas is regulated by mass flow controllers. An oil diffusion pump allows a working pressure of about 10 mTorr for a 5 sccm gas flow. Plasma diagnostics involve optical spectroscopy and microwave interferometry (4 mm).

With identical RF input power and hydrogen flow rate, the presence of argon increases greatly the electron density. The argon metastable state (3P₂) concentration is deduced from autoabsorption line measurements. The calibration of emission line intensities with the aid of a tungsten ribbon lamp gives absolute concentration of excited species.
The repetitive pulsed mode of RF power excitation is generally used giving physical insight of the plasma kinetic evolution to the stationary state. For instance, the dissociation time of hydrogen is measured (~1 ns)

3. RESULTS

Fig. 2 and Fig. 3 show the evolution of Ar, H, H₂ line intensities and Ar¹P₂ metastable state concentration during the beginning of a pulse respectively. From the comparison of these curves, it can be seen that hydrogen atoms are more efficient than corresponding molecules for the quenching of the ³P₂ metastable. The quenching coefficient can be evaluated to be about 7.10²⁹ cm³ s⁻¹ for the discharge temperature 1000-2000 K. This last quantity is deduced by Doppler effect on atomic hydrogen lines and by rotational equilibrium between molecular hydrogen excited states.

Silicon etching modifies the chemical composition (e.g. [H]/[H₂]) but not the electron concentration (direct measurement) or the mean electron energy (argon line intensities). So, comparison of line intensities for atomic (H) and molecular (P₂) hydrogen lines leads to the dissociation rate of the plasma (respectively 30% with and 70% without silicon etching). Then, assuming the dissociation mechanisms occur in the plasma phase when recombination of hydrogen atoms is due to surface interaction (SiO₂ tube, Si sample), we can deduced a value for the sticking coefficient on SiO₂ and Si surfaces. The value for SiO₂ (2.5 10⁻⁹) agrees with previous data (4) whereas the value for polysilicon is close to unity.

4. MODELLING

The experimental values of the excited state and electron densities have been used in the particle conservation equations. In the stationary state of the plasma:

\[
\frac{\partial n_i}{\partial t} = 0 = n_i - \frac{n_i}{\tau_i}
\]

where Si includes all terms leading to the creation of the jth species and \( \tau_i \) is the corresponding effective lifetime. Writing the equation for both metastable and radiative excited states of argon shows that the distribution function for electron energy is not Maxwellian. Indeed, the equilibrium between 4p and 4s argon configurations requires a mean energy for the measured electron concentration of about 1 eV. Therefore, the proportion of electron with an energy greater than the threshold for excitation, dissociation or ionisation processes leads to a high population of suprathermal electrons. Fig. 4 shows this proportion, calculated from the argon metastable rate equation, as a function of the total electron density. This result agrees with the measured hydrogen dissociation frequency and the corresponding published cross sections. The measured and calculated concentrations of excited argon states 4p (2P₆ and 2P₇ in Paschen notation) is a function of the electron density are shown on figure 5 for two hydrogen flow rates.

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REFERENCES


Fig. 1. Experimental Set-up.
Fig. 2. Evolution of Ar, H, H₂ lines at the beginning of a pulse.

Fig. 3. Evolution of Ar³P₂ metastable at the beginning of a pulse \((i,j)\) indicates the flow rate (in sccm) of argon and hydrogen respectively.
Fig. 4. Calculated concentration of suprathermal electrons $N_F$ versus electron density.

Fig. 5. Concentration of 2p6 and 2p4 excited states of argon versus electron density
($\Delta$, 0) experimental points; --, --- calculated curves.)