Parallel Plate Plasma Etching For MEMS Processing- Reactor Modeling

Florin Babarada*, Camelia Dunare**, Marcel Profirescu*

*University Politehnica of Bucharest, Romania,
tel.: +4021 4113193, email: profires@edil.pub.ro
** University of Edinburgh, UK, email: camelia.dunare@ee.ed.ac.uk

ABSTRACT

Polysilicon is often used for microelectronic fabrication. The model presented in this paper analyses the uniformity of the dry etching process of the polysilicon films used in resonator cavity for MEMS fabrication [1].

The uniformity of the dry etching process is very important for MEMS because the dimensional configuration and precision of the mechanical structures have a direct influence on the mechanical properties.

It was found that the uniformity could be improved by decreasing the power and pressure or by increasing the flow rate.

Keywords: plasma etching, modelling, microsensors, MEMS.

1 INTRODUCTION

Chemically reactive plasmas are widely used in surface microresonators fabrication for etching and deposition of thin films [2]. In developing models of the plasma etching processes there is a number of important phenomena that needs to be considered: glow discharge chemistry [3], [4], electron density and energy distribution [5], [7], [8], ion transport in the sheath [9], [11], heat and mass transfer, heterogeneous reaction kinetics [12], [14].

Because of the complexity of plasma etching process, mathematical models must be tested with experimental data taken in under well-controlled conditions. In-situ plasma diagnostics (optical emission spectroscopy and laser induce fluorescence [15], mass spectroscopy and ion energy analysis [16], Langmuir probe measurements [17]) were developed to gain understanding of reactive plasmas. Optical diagnostics are attractive because of their non-intrusive nature.

The goal of plasma etching is to obtain high and uniform etch rate with good anisotropy and selectivity and without radiation damage. Uniformity problems may become worse as the wafer size increases and new gas formulations yielding faster etch rates are developed. No uniformity etching necessitates over etching that may cause substrate damage and/or rapid mask undercut owing loading and so the device yields may be decreased.

The etching non-uniformity may be the result of gradients in etching solution concentration, ion bombardment flux and/or energy, wafer surface temperature.

Nagy and Selwyn [18] found etching solution concentration gradients at the boundary where two surfaces with different reactivity met. Such concentration gradients are thought to be responsible for the often-observed "bullseye" pattern. By manipulating reactor-operating conditions, flow rate for example, the "bullseye" pattern could be reversed or changed to a leading edge-trailing edge clearing pattern [19], [20].

Recently, a transport and reaction model of a single-wafer parallel plate plasma reactor was formulated [21]. The oxygen plasma etching polymer was chosen as a model predictions and measured etch rates as a function of pressure, power and flow rate.

The 2-D model presented in this paper is capable of predicting both etch uniformity and anisotropy. The present paper emphasizes the good etching rate for polysilicon layers with very well uniformity.

2 MODEL FORMULATION

Glow flow resembles three-dimensional, axisymmetric stagnation point flow [22]. The model was developed for a radial symmetric single-wafer parallel plate plasma reactor shown schematically in figure 1.

Feed gas enters uniformly through the porous upper electrode. Etching products and unreacted feed gas are pumped radial outwards.

The wafer is in good thermal and electrical contact with the lower grounded electrode. The etching surface temperature is assumed to be constant.

Gas temperature variations are neglected. Due to the consumption on the wafer surface large concentration gradients may develop at the boundary between the wafer and the surrounding electrode. Because the etching rate is usually a function of the local etching solution concentration, the result is etching nonuniformity.

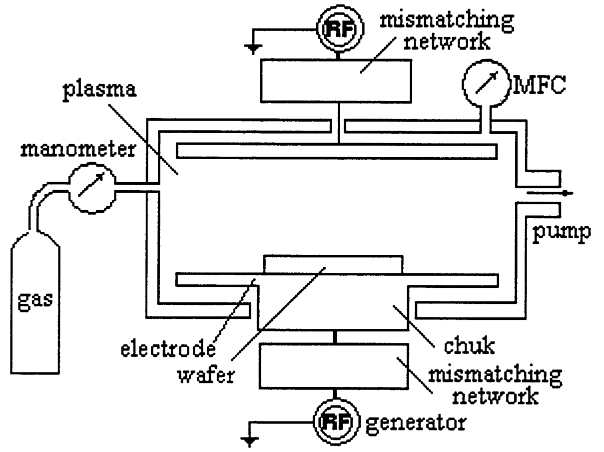

Figure 1: Parallel single-wafer etcher

Assuming constant gas physical properties and negligible volume change during reaction, the momentum equations can be decoupled from the mass and heat transfer equations.

Considering the continuum approximation, which is valid for pressure above about 0.25 Torr, the Navie-Stokes equations and the continuity equation are:

$$U\frac{\partial U}{\partial r}+\frac{W}{L}\frac{\partial U}{\partial \xi}= -\frac{1}{\rho}\frac{\partial P}{\partial r}+\upsilon\left(\frac{\partial^2 U}{\partial r^2}+\frac{1}{r}\frac{\partial U}{\partial r}-\frac{U}{r^2}+\frac{1}{L^2}\frac{\partial^2 U}{\partial \xi^2}\right) \quad (1)$$

$$U\frac{\partial W}{\partial r}+\frac{W}{L}\frac{\partial W}{\partial \xi}= -\frac{1}{\rho L}\frac{\partial P}{\partial \xi}+\upsilon\left(\frac{\partial^2 W}{\partial r^2}+\frac{1}{r}\frac{\partial W}{\partial r}+\frac{1}{L^2}\frac{\partial^2 w}{\partial \xi^2}\right) \quad (2)$$

$$\frac{\partial U}{\partial r}+\frac{U}{r}+\frac{1}{L}\frac{\partial U}{\partial \xi}=0 \quad (3)$$

Where

U = radial gas velocity, cm/s
W = axial gas velocity, cm/s
W_W = gas velocity trough the porous upper electrode, cm/s
z = axial coordinate, cm
L = half interelectrode gap, (cm)
r = radial coordinate, cm
ξ = z/L is the reduced axial coordinate

The boundary conditions are:

U = 0 for all r at z=+/- L
W = 0 for all r at z=-L
W = -W for all r at z=L

Setting:

$$U = rf'(\xi)(\frac{W_w}{2L}) \quad (4)$$

$$W = -W_w f(\xi) \quad (5)$$

Where f (ξ) is a function of ξ.
We obtain the following fourth order differential equation:

$$f''''+2R_w ff'''=0 \quad (6)$$

Where R_W is the wall Reynolds number defined as $R_W=W_WL/2\xi$.
Now the boundary conditions are:

f'(+/-1)=f(-1)=0
f(1)=1

The differential equation can be solved only by numerical techniques, but when we consider Rw<1 and by using regular perturbation techniques [23], we can obtain the following approximate solution:

$$U=\frac{W_w}{2L}r\left[\left(-\frac{3}{4}\xi^2+\frac{3}{4}\right)\right]+ \frac{W_w}{2L}r\left[R_w\left(-\frac{1}{160}\xi^6+\frac{3}{32}\xi^4\right)\right]+ \frac{W_w}{2L}r\left[R_w\left(\frac{1}{4}\xi^3-\frac{117}{1120}\xi^2-\frac{1}{4}\xi+\frac{19}{1120}\right)\right] \quad (7)$$

$$W=-W_w\left[\left(-\frac{1}{4}\xi^3+\frac{3}{4}\xi+\frac{1}{2}\right)\right]- W_w\left[R_w\left(-\frac{1}{1120}\xi^7+\frac{3}{160}\xi^5+\frac{1}{16}\xi^4\right)\right]- W_w\left[R_w\left(-\frac{39}{1120}\xi^3-\frac{1}{8}\xi^2+\frac{19}{1120}\xi+\frac{1}{16}\right)\right] \quad (8)$$

For Rw<<1 the above equation is reduced to:

$$U=\frac{3}{8}\frac{W_w}{L}r\left[1-\left(\frac{z}{L}\right)^2\right] \quad (9)$$

Under this condition the radial velocity profile is parabolic and symmetric with respect to the plane z=0.

The 3-D velocity profiles are plotted bellow.

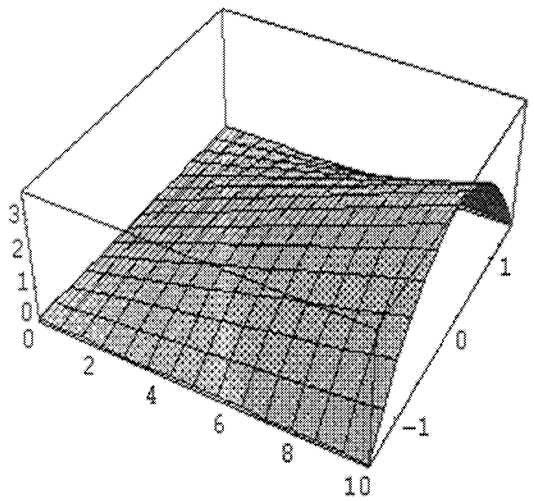

Figure 2: Radial gas velocities as a function of the axial and radial coordinate

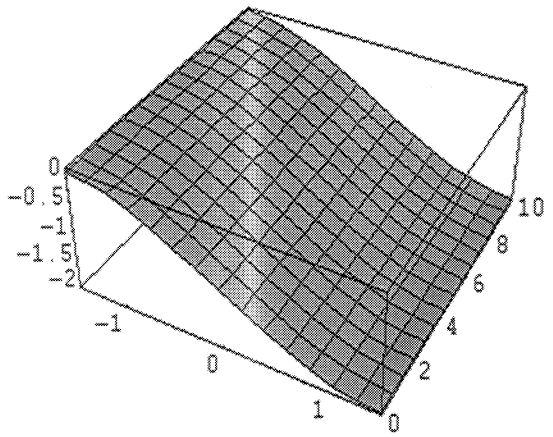

Figure 3: Axial gas velocities as a function of the axial and radial coordinate

3 RESULTS AND DISCUSSION

The parallel single-wafer etcher has a 4" diameter, hard-anodised aluminium powered showerhead upper electrode held at a distance of 3 cm from the lower electrode.

A thermostat controls the temperature for the lower electrode. A two-stage rotary vane pump pumps gases and the base pressure is 10^{-4} torr. A pressure transducer, an exhaust throttle valve and a controller independently controlled chamber pressure and gas flow rate. Power is applied to the upper electrode by a 13.56 MHz, 200W RF generator. A matching network minimizes reflected power. Two needles monitor both forward and reflected power.

The light from plasma is collected through a quartz side window through a pair of iris diaphragms to attain spatial resolution. The light is focused onto one end of an optical fibber and is detected by a photomultipier tube driven by a photometer.

A long pass filter is used to avoid second-order interference in the light emission spectrum that is displayed on a strip chart recorder.

For a polysilicon film with x_{poly}=200nm we obtain the results given in Table 1. The film was LPCVD deposited on n type, <100> wafers and the oxide under the nitride is a thermal one and has the thickness x_{SiO2}=100nm. The uniformity was statistically determined by measurements in nine uniformly distributed points in the wafer area. The target was to obtaining a good etching rate without neglected the etching uniformity.

Power density (W/cm^2)	Etch rate (nm/min)	Uniformity (%)
2.54	132.8	84
1.9	85.1	85
1.27	54.5	87
0.64	34.9	95

Table 1: Etch rate and uniformity for a polysilicon film as a function of power density

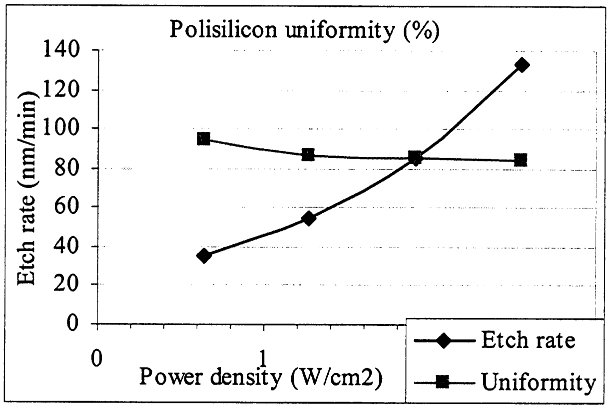

Figure 4: Polysilicon etch rate and uniformity as a function of power density

Using the same polysilicon thickness film, x_{poly}=200nm and changing the reactor pressure we change also the gas flow velocity and the influence in etching uniformity is presented in table 2. The film was LPCVD deposited on n type, <100> wafers and the oxide under the polysilicon is a thermal one and has x_{SiO2}=100nm.

Pressure (torr)	Etch rate (nm/min)	Uniformity (%)
0.1	46	93
0.2	85.1	89
0.3	126	84
0.4	177	82
0.5	231	80

Table 2: Etch rate and uniformity for a polysilicon film as a function of pressure

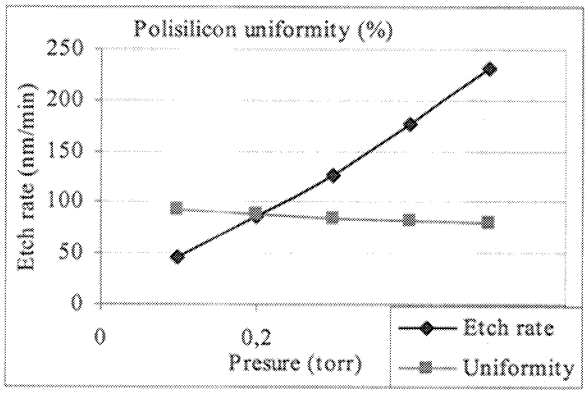

Figure 5: Polysilicon etch rate and uniformity as a function or pressure

4 CONCLUSIONS

The radial velocity from figure 2 is zero in the reactor center and increases linearly towards the exit. For Rw<<1 this velocity has a parabolic profile.

The axial velocity presented in figure 3 has a maximum value at the upper electrode, where gas enters and $\xi=1$ and decreases monotonically with axial position and is zero at the lower electrode where $\xi=-1$. We can observe that this velocity is independent of radial position. The model predictions were very useful to optimisation of etching rate and prevent the decreasing of the etching uniformity.

The experimental data were in good agreement with the results for modelling and simulation. The results show the possibility of the parallel plate single wafer plasma etching, usually used in CMOS-IC fabrication, for MEMS processing with successfully.

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