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MODELING OF Cl_2-He POLYSILICON ETCHING WITH A GLOBAL MODEL FOR HIGH PRESSURE ELECTRONEGATIVE RADIO-FREQUENCY DISCHARGES

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Abstract

The recently developed global model[1] for high pressure electronegative radio-frequency discharges was used to model the Lam 4400 plasma etcher. The impedance of the discharge is obtained using an equivalent circuit in which the RF current and voltage, together with their relative phase angle are calculated. Both the plasma resistance and the sheath resistance and capacitance are obtained self consistently using the global model. The results for the RF current and voltage and the discharge impedance are compared to experimental measurements from a Comdel RF monitor which is connected to the Lam 4400 plasma etcher at the Berkeley Micro-Fabrication Laboratory. The results agree reasonably well with measurements when the measured parasitic capacitance of the etcher is included in the calculations.

I Introduction

A global model[1] for radio - frequency capacitively driven discharges has been developed and applied to the Lam 400 and Lam 4400 plasma etchers with either mixed chlorine/helium feedstock gases or chlorine feedstock gas. Global model is a class of models in which the plasma profile can be considered to be known and fixed. The discharges in these Lam 400 and Lam 4900 plasma etchers are typically operated at an inlet pressure of few hundred mTorr and a radio frequency (RF) power of several hundred watts. At these operating conditions, the discharge is highly electronegative. As a result, the discharge can be divided into only two regions, the electronegative plasma and the sheath. The electropositive region is neglected because it is small at high electronegativity.

In this report, we apply the global model to the Lam 4400 plasma etchers. The densities of the neutral species are assumed uniform throughout the discharge. Throughout the plasma, the electron density and temperature are also assumed uniform. In the plasma, the densities of the neutral and charged species are determined by the particle balance equations that includes volume generation and destruction and diffusion losses to the wall. Neutral species also flow into and out of the discharge as a result of pumping. In the plasma, the positive and negative ions are described by a parabolic profile with the scale length determined by the gap spacing of a discharge. In Fig. 1, we show schematically the density profile and the cross section of the discharge. The ambipolar diffusion coefficient of the positive ions is taken to be constant throughout the plasma, which include both electrons and negative ions. The flux of positive ion loss to the wall is then calculated by using the ambipolar diffusion coefficient and the parabolic profile. Negative ion loss to the wall is neglected since these ions are strongly confined by the ambipolar potential. The gas and ion temperatures are assumed to be constant, independent of the discharge operating condition. The electron temperature is determined by the particle balance of the charged species in the discharge.

In the global model, the RF power is delivered to the electrons via ohmic heating (with sheath heating of electrons neglected at the high pressures considered) and in those ions accelerated across the DC sheath potential. The power transfered to the electrons balances the energy losses due to the processes of electron-neutral collisions such as elastic scattering, rotation, vibration, electronic excitation, ionization, dissociation, dissociative attachment, and electron detachment. The DC voltage across the sheath is calculated self-consistently with the densities and the electron temperature by using a collisional Child law sheath model[2].

In applying the recently developed global model to the Lam 4400 plasma etcher, the following improvements to the model were made:

(1) The plasma length is calculated consistently in terms of the gap spacing and the sheath width.

(2) The electron collisional frequency includes the contribution from electron-helium scattering.

(3) The ion mean free path is calculated to include ion-helium interaction.

(4) The circuit model includes the contribution of parasitic capacitance as shown in Fig. 2.

In the next section, we compare the results from the global model to the measurements[3] obtained from a Comdel RF monitor connected to the Lam 4400 plasma etcher[4]. In Section 3, we discuss the possible improvements for the global model. The conclusion of this report are presented in Section 4.

II Comparision with Measurements

We compare the results calculated using the global model to measurements obtained from the Comdel RF monitor connected to the Lam 4400 plasma etcher . In the experiments, the input parameters; inlet pressure, RF absorbed power, helium and chlorine flowrates, and gap spacing are varied over a range of $\pm 11\%$ to $\pm 19\%$ from the nominal values[4]. The time-dependent RF currents and voltages are measured using the Comdel RF monitor. In a typical experiment, the current and voltage remain fairly constant over a long period of time. In this section, we compare the values over these time intervals to the results given by the global model.

During the development of this model, it was necessary to measure the parasitic capacitance of the Lam 4400 plasma etcher. To carry out the measurements, we had to open the metal case of the etcher. We have measured the capacitance over a range of gap spacings. The results are given in Fig. 3. This capacitance is included in the circuit model for the calculation of the RF current and voltage and the impedance of a discharge.

In Fig 4, we plot the RF current and voltage as a function of wafer number. Each wafer number represents an experiment with a different set of input parameters[3]. Also given in the figure are results from the global model. In the calculations, I have used the value of the parasitic capacitance given in Fig. 3. The comparisons show reasonable agreement between calculation and experimental measurements. Although the agreement between measurement and calculation is within 20% to 50%, there is a very strong correlation between them as the input parameters are varied in different experiments. This clearly suggests that the global model could be used to predict the change in the plasma condition due to the change in the operating conditions of a discharge.

To investigate the effect of the parasitic capacitance on the total current in the discharge, we show in Fig. 5 the RF current calculated with and without the effect of parasitic capacitance. About 50% of the RF current measured in the Comdel monitor flows through the parasitic capacitance.

In Fig. 6, we compare the real and the imaginary parts of the impedance of the discharge. Again, the comparison show resonable agreement between calculation and experimental measurements.

III Possible Improvements for the Global Model

(a) Profile scale length

In the global model, the positive and negative ions are described by a parabolic profile with the scale length given either as $l_s/2$ or $l_p/2$ where l_s and l_p are the gap spacing and the plasma length, respectively. Although these are resonable approximations at high pressures, the scale length of the profile in principle is determined by the Bohm condition applied at the edge of the plasma. The global model could be modified to use the scale length from the Bohm condition or other more appropriate length. This could be carried out with a small effort.

(b) Mobility and diffusion coefficients

Both the mobility and diffusion coefficients are assumed constant in the global model because of high pressures. This could be improved by using a variable mobility and diffusion model with the coefficients explicitly depending on the ion drift velocity. This improvement together with (a) will make it possible to apply the model to low pressure discharges such as those in a Transformer - Coupled Plasma. To implement a variable mobility and diffusion model in the global model would require a fair amount of effort.

(c) Rate constants and transport coefficients

In the global model, the plasma resistance and both the sheath resistance and capacitance are calculated using a set of rate constants and transport coefficients. These constants and coefficients are obtained either from published literature or are estimated from similar reactions. For many reactions and transport processes, it is very difficult to assess the quality of the data due to lack of measurement and first principle calculation. Therefore, it would be very useful and necessary to normalize the data used in the global model by fitting the results from it to a set of experiments over a wide range of input parameters and operating conditions. Then, the model could be applied to predict the change in the plasma source due to the change in the discharge operating conditions. This task could be carried out with some effort.

(d) Computer code based on the global model

A computer code based on the global model has been developed and used to calculate the results presented in the previous section. Presently, the code runs rather slowly and it is also difficult to add new species and reactions to the code. One can improve all of these with only a moderate effort. Before the code is used either in-line or off-line in support of manufacturing, it would be better to re-write the code with more efficient numerical algorithms.

IV Conclusion

In this report, we improved the global model recently developed for high pressure electronegative radio-frequency discharges and have applied it to the Lam 4400 etcher. The improvements include the following: (1) The plasma length is calculated consistently in terms of the gap spacing and the sheath width in a discharge, (2) The electron collision frequency includes the contribution from electron-helium scattering, (3) The ion mean free path is calculated including ion-helium scattering, (4) The circuit model includes the contribution of parasitic capacitance. Using the plasma resistance and the sheath resistance and capacitance from the global model, we have calculated the RF current and voltage and the impedance of the discharge. The results are compared to experimental measurements obtained from the Comdel RF monitor connected to the Lam 4400 etcher. The comparison agrees reasonably well when the measured parasitic capacitance of the etcher is included in the calculations.

Acknowledgements

I would like to thank C. Williams for his valuable help in the measurement of the parasitic capacitance of the Lam 4400 plasma etcher and R. Chen and Professor C. Spanos for many discussions on the measurements and modeling.

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(1) Y. T. Lee, M. A. Lieberman, A. J. Lichtenberg, F. Bose, H. Baltes, and R. Patrick, "Global Model for High Pressure Electronegative Radio - Frequency Discharges", Submitted to J. Vac. Sci. Technol., 1996.

(2) M. A. Lieberman, " A Collisional Capacitive Sheath Model", IEEE Trans. Plasma Sci. **17**, 338, 1989.

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(4) S. F. Lee, "Semiconductor Equipment Analysis and Wafer State Predication System Using Real-Time Data", Ph. D. Dissertation, University of California, Berkeley, 1995.

Figure Captions

Fig. 1 Schematic drawing of the cross section of the discharge. l_s is the gap spacing of the discharge and l_p is the height of the plasma column in the discharge. $l_2/2$ is the profile scale length for the heavy species which is assumed to be equal to $l_s/2$.

Fig. 2 The circuit used to calculate the current flow into the plasma. C_{par} is parasitic capacitance, C_S is the sheath capacitance, and R_S is sheath resistance. The plasma is represented by a pair of inductor and resistor in series.

Fig. 3 Measured parasitic capacitance of the Lam 4400 plasma etcher versus different gap spacing.

Fig. 4a RF current for different input conditions. The solid curve is the calculation and the dashed curve is the experiment.

Fig. 4b RF voltage for different input conditions. The solid curve is the calculation and the dashed curve is the experiment.

Fig. 5 Comparison of the RF current calculated with and without the parasitic capacitance.

Fig. 6a The real part of the impedance of a discaharge for different input conditions. The solid curve is the calculation and the dashed curve is the experiment.

Fig. 6b The imaginary part of the impedance of a discaharge for different input conditions. The solid curve is the calculation and the dashed curve is the experiment.

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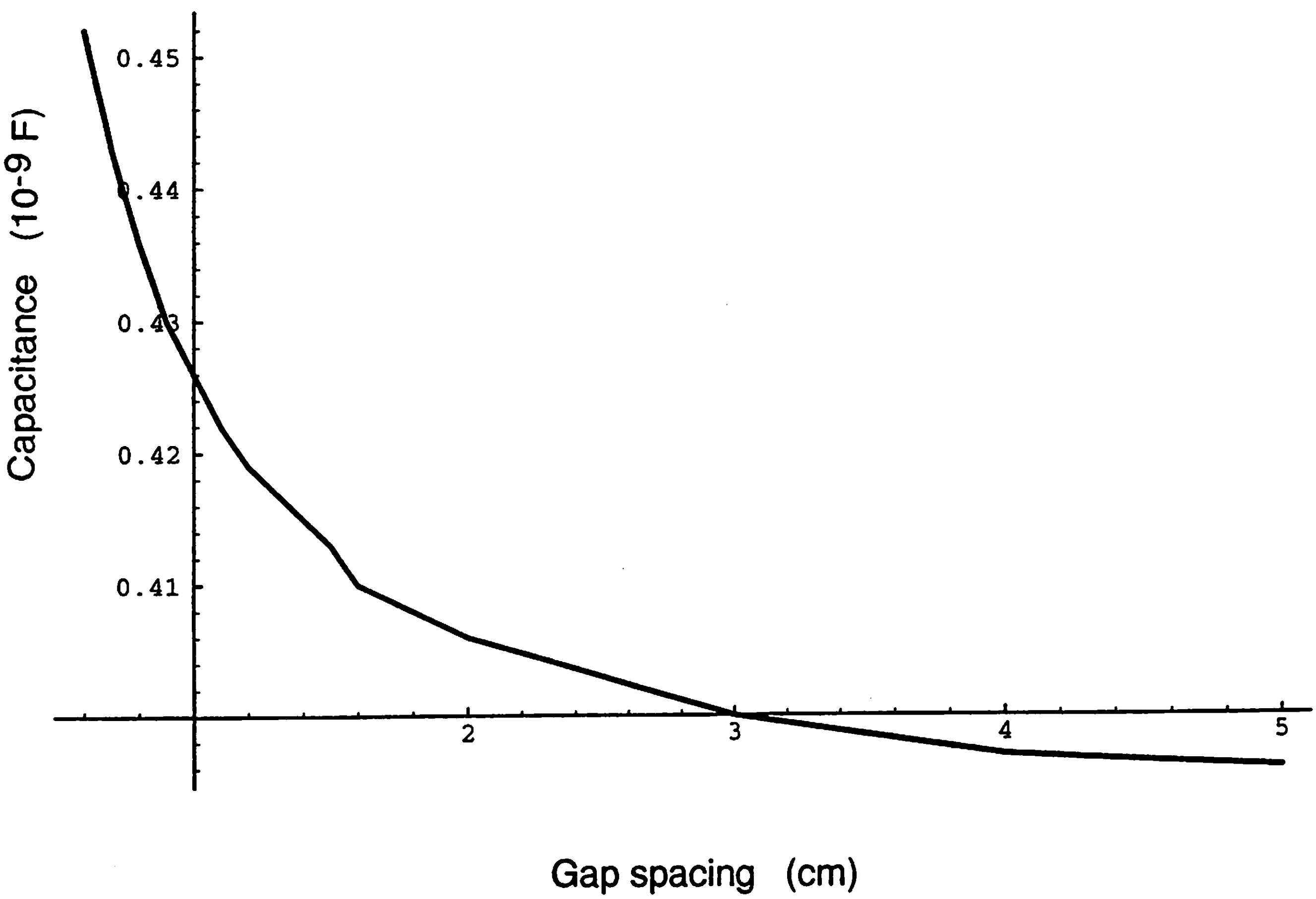
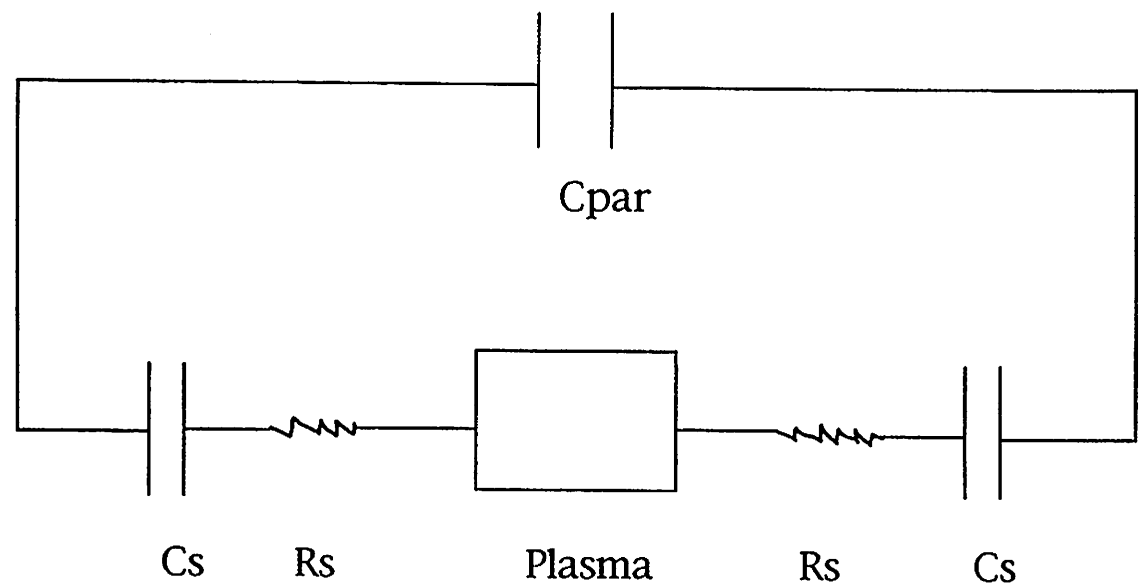
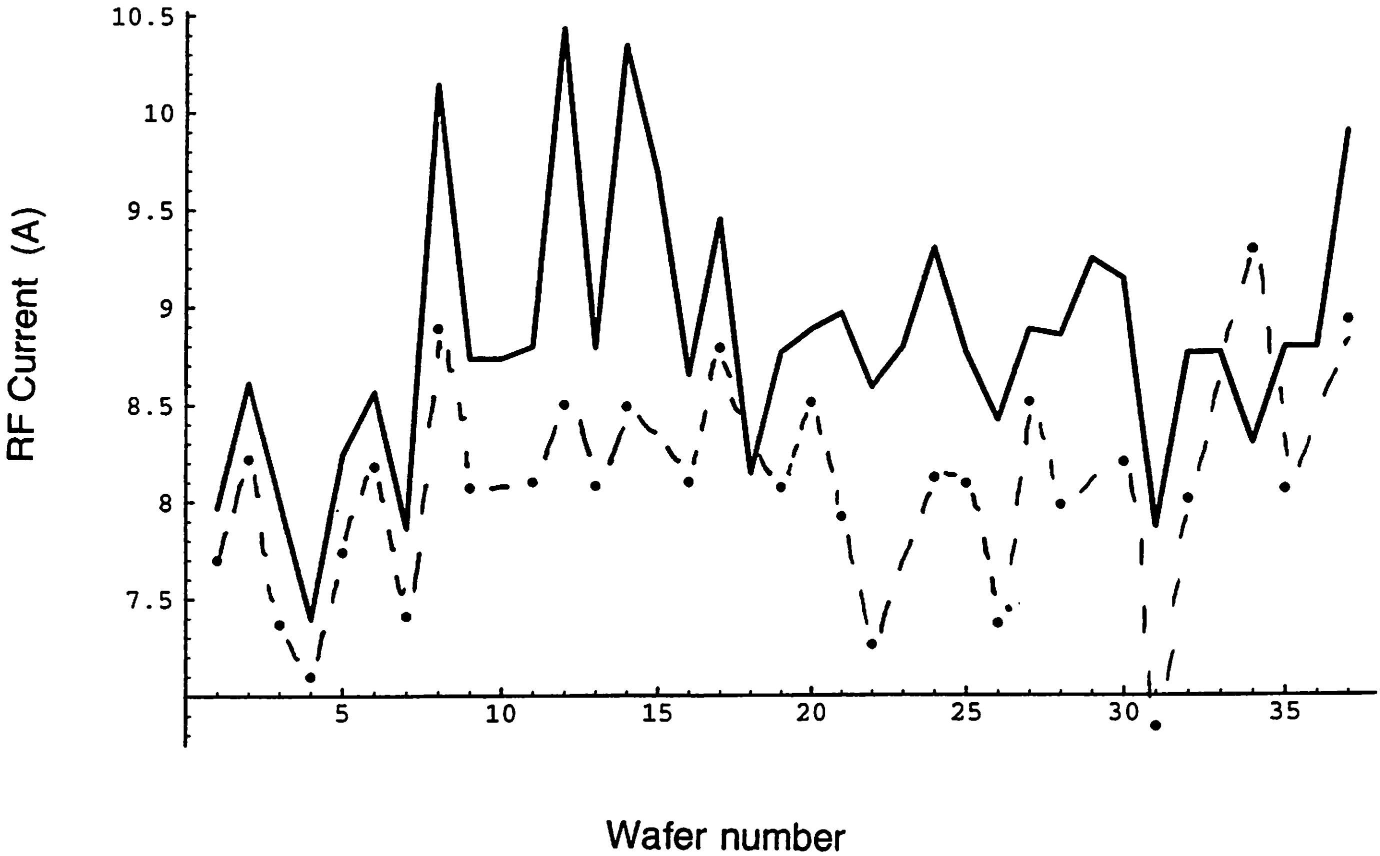
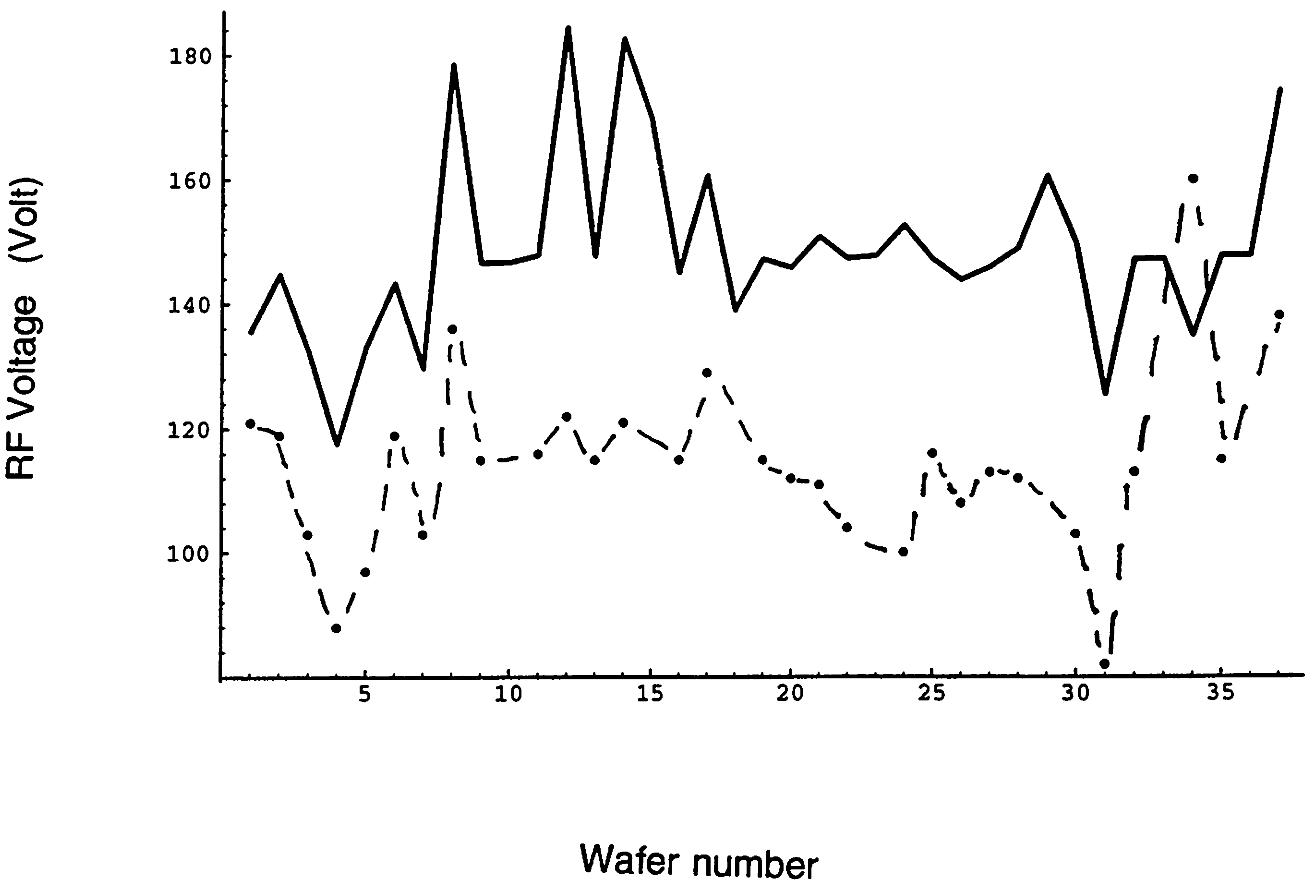


0.45
0.44
0.43
0.42
0.41
2
3
4
5
Capacitance (10-9 F)
Gap spacing (cm)

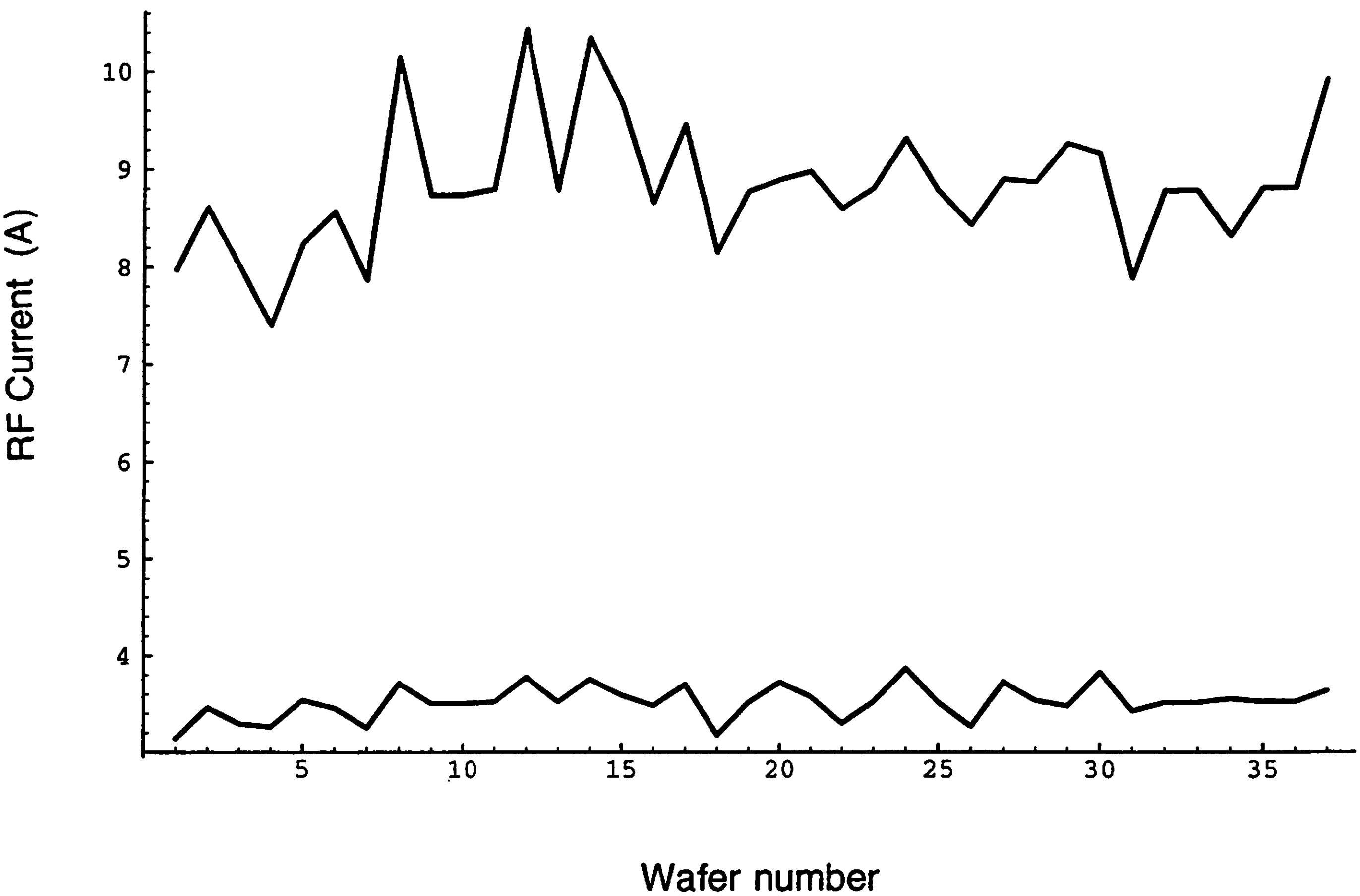

Cpar
Cs
Rs
Plasma
Rs
Cs

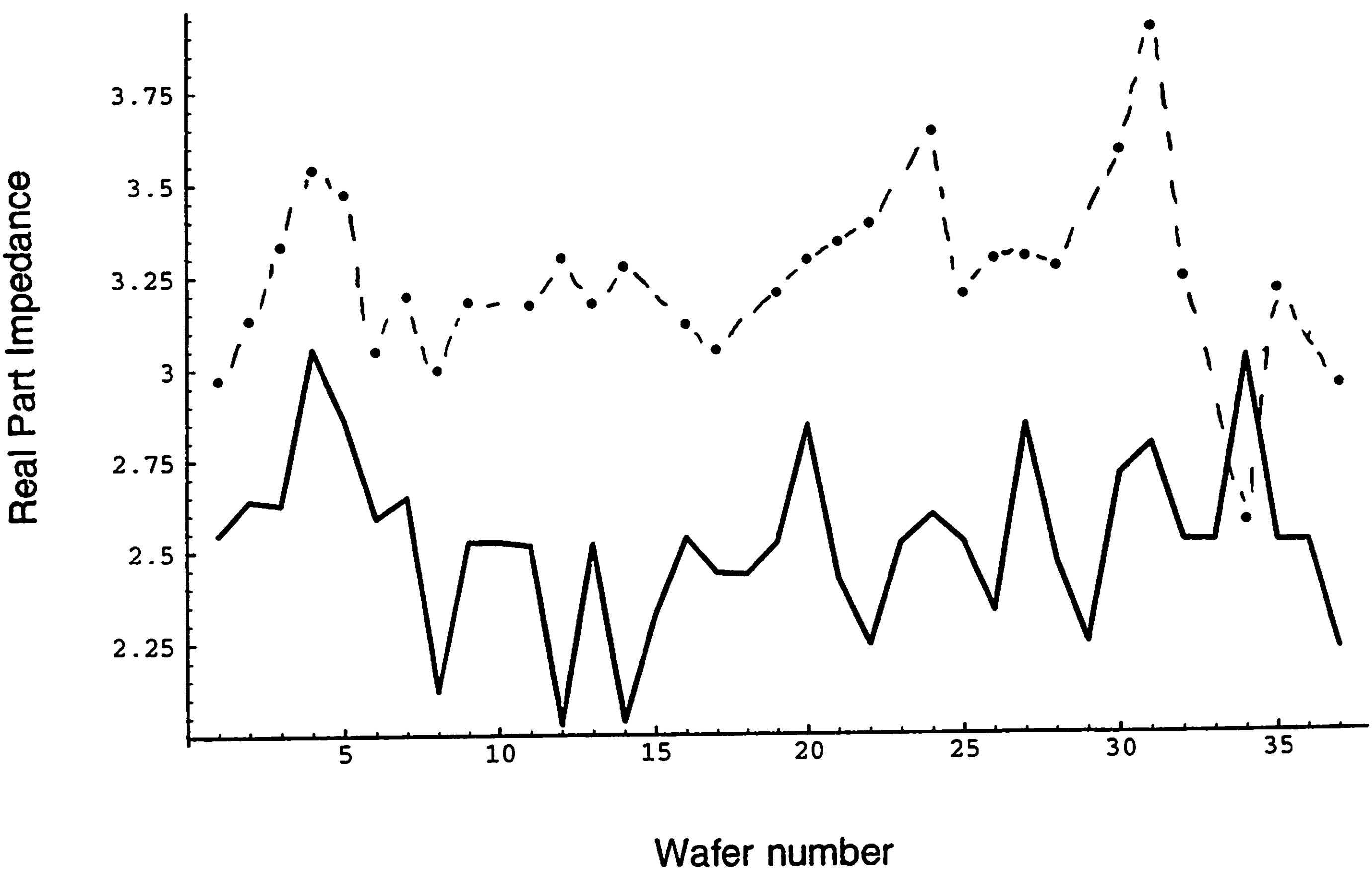


10.5
10
9.5
9
8.5
8
7.5
RF Current (A)
5
10
15
20
25
30
35
Wafer number

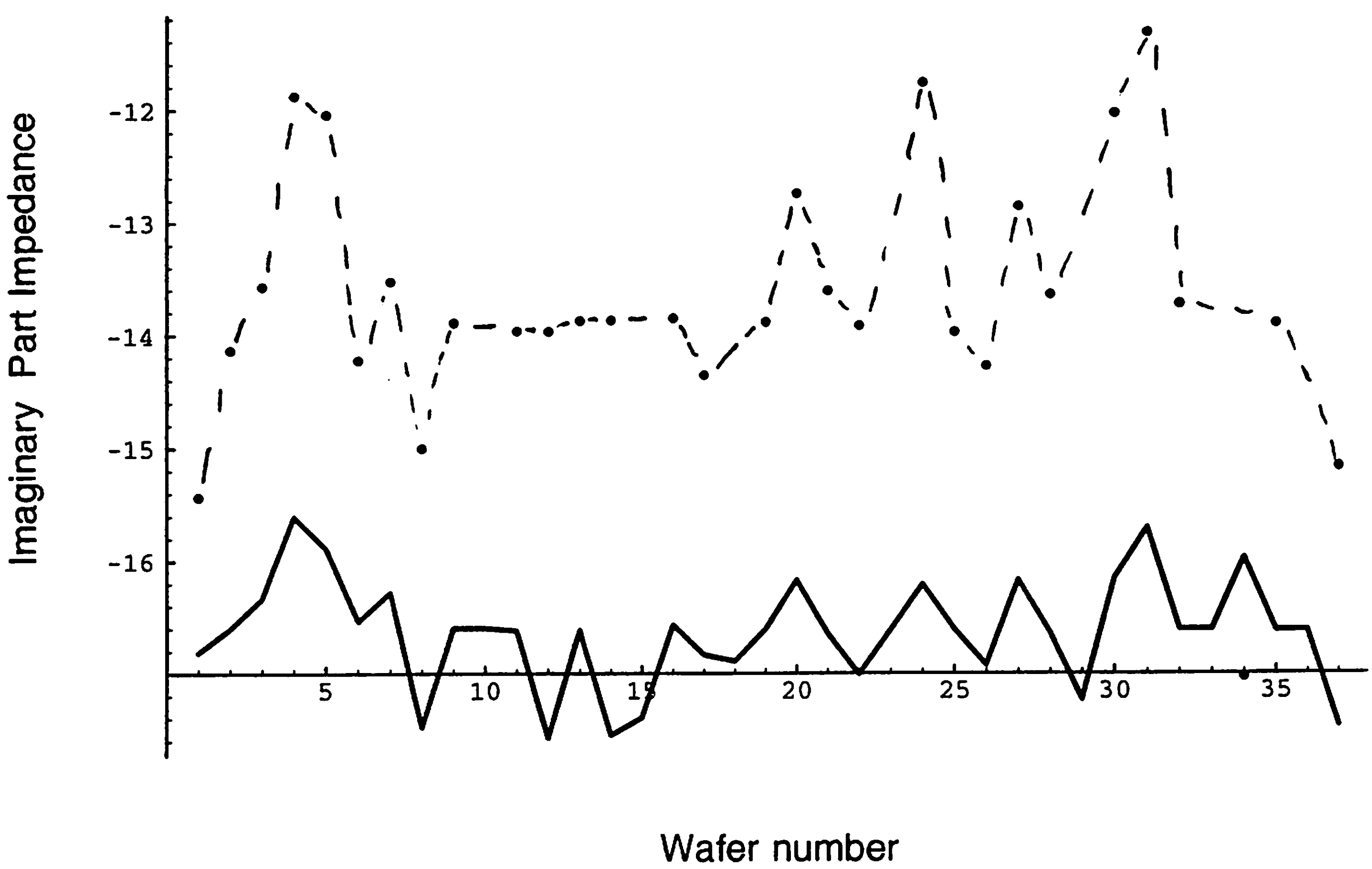


RF Voltage (Volt)
180
160
140
120
100
5
10
15
20
25
30
35
Wafer number


RF Current (A)
10
9
8
7
6
5
4
5
10
15
20
25
30
35
Wafer number



Real Part Impedance
3.75
3.5
3.25
3
2.75
2.5
2.25
5
10
15
20
25
30
35
Wafer number



Imaginary Part Impedance
-12
-13
-14
-15
-16
5
10
15
20
25
30
35
Wafer number