WHITEPAPER

ONE-DIMENSIONAL MODELING OF CAPACITIVELY COUPLED PLASMA WITH SELF-BIAS

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Overview

For a plasma etching process, ion impact energy angle distribution(IEAD) is one of the most important parameters to control a hole shape. These days narrower and deeper holes are required in an etching process. To achieve this requirement, dual/triple frequency capacitively coupled plasma(CCP) and a pulsing technique are frequently used. In the dual-frequency CCP case, very high-frequency excitation, for example 100 MHz, are used for a plasma source, and low-frequency bias, for example 0.1 MHz, are used to control ion impact energy. In the pulsing case, the frequency of the pulsing is typically the order of the kilo Herz.

To get a realistic IEADF by a plasma simulation, there are some key features should be included.

- Self-bias effect
- Particle model

The self-bias effect is important to estimate the impact energy of ion. In the RF circuit with a blocking capacitor system, this effect is induced by the difference between the surface area of grounded electrodes and the surface where the circuit is connected.[1] Usually the circuit-connected surface is smaller than the grounded surface, the circuit-connected surface is biased negative and then positive ions gain biased energy when they bombared the surface.

The particle model is important since it treats collisions more precisely. Particles are represented as super-particles with statistical weights, and their trajectories are tracked. Collisions are calculated by the Monte-Carlo method with particle-energy-dependent crosssections. On the other hand, in the fluid model, collisions are taken into account in all cells through the mobility and the diffusion coefficient. In many case collisions are overestimated. Moreover, values represented by the fluid model are averaged values by Maxwellian distribution. So they cannot repplicate distribution comes from thermal energy.

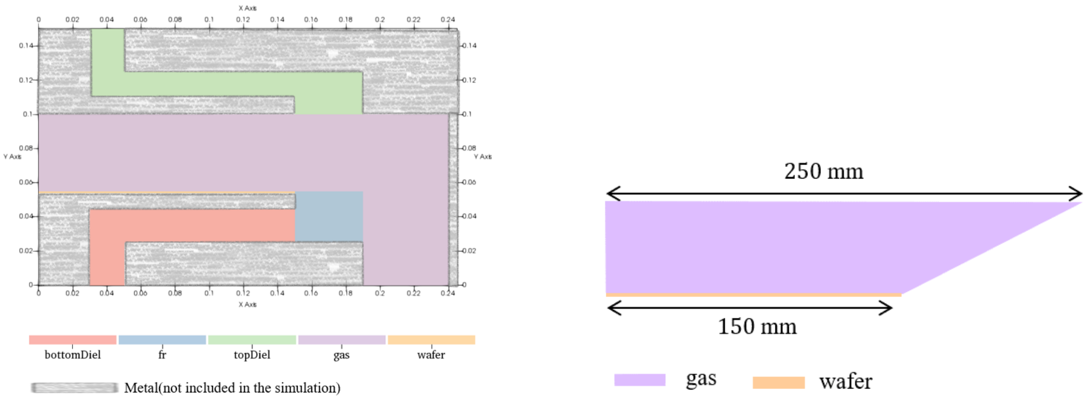
Since a particle doesn't have a distribution in the properties such as velocity, to get a such physical quantity, sampling and averaging are needed, and this procedure introduces the statistical error. To get fewer noise statistics, long time simulation and a large number of simulation particles are necessary but these requirements are computationally expensive especially low-frequency bisas cases. In this case, one-dimensional simulation including self-bias effects would be very powerful tool.

Objective

In this paper, we focus on establishing a one-dimensional model with self-bias. By comparing fluid IED at wafer and the connection voltage at a circuit and a wafer of a two-dimensional simulation and a one-dimensional simulation, we show how one-dimensional simulation works. Comparing particle results will be future work.

Simulation setup

The two-dimensional simulation setup is shown in Figure 1a and the corresponding one-dimensional model is shown in Figure 1b. In the two-dimensional simulation, we assume axisymmetry to the y-axis, and the circuit has 100 pF capacitor and 1 Ohm resistance. The excitation frequency is 13.56 MHz, and the power measured at the power supply is 300 W. In the one-dimensional simulation, the capacitor, the resistor and the power are scaled properly. In both cases, the circuit is connected under the wafer. We tried two pressure: 2 and 6 Pa. Ar chemistry for low pressure is used.



(a) 2D simulation setup

(b) 1D simulation setup

Figure 1: Model setup of simulations for (a) the 2D model and (b) the 1D model.

Modules used for this study are shown in Table 1

Table 1: Modules used for simulation

Module	Description
Non-Equilibrium Plasma	Two-temperature cold plasma model

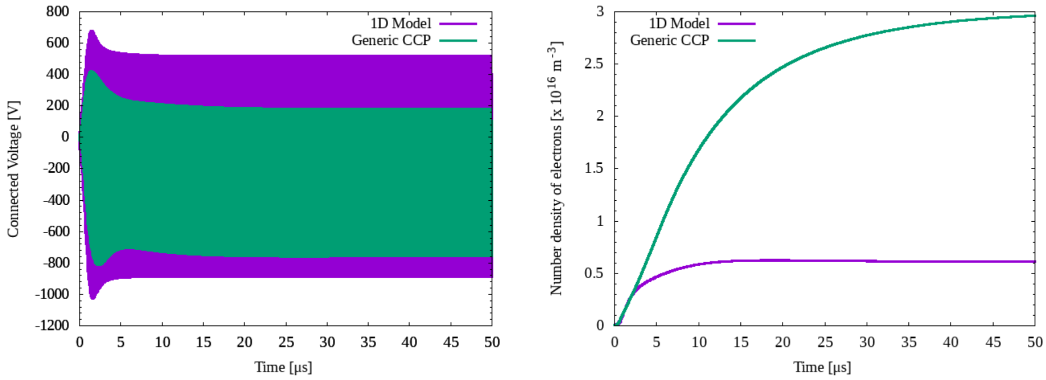
VizGlow™ (Non-equilibrium plasma modeling tool)

In CCP, electrons are accelerated within parallel electrodes with AC circuits. When the accelerated electrons collide neutrals, they are ionized and this process sustains the plasma. In the plasma, the temperature of electrons is different from that of other heavy species, especially at low pressure. The electron temperature is much higher than the gas temperature, and this plasma is defined as non-equilibrium plasma. *VizGlow*™ solves electron temperature equations, bulk temperature equations, species equations, and other equations that are needed for non-equilibrium plasma in the fluid model.

Results

The connection voltage under the wafer is shown in Figure 2a for 6.64 Pa. The green line is the value of the 2D axisymmetry model and the purple line is that of the 1D model. In the 2D model (purple), after it reached to the periodic steady-state, the maximum voltage is about 180 V and the minimum voltage is about -760 V, so the self-bias is about -290 V. On the other hand, the 1D model (green line) predicts a little higher voltage, that is about 520 V for the maximum, and the lower for the minimum, it is about -900 at the periodic-steady state. And the self-bias voltage is about -180 V. Since the 1D model doesn't have an edge effect, it usually needs higher applied voltage.

The transient of the number density of electrons at the center of electrodes is shown in Figure 2b. For the 2D model, the monitoring point is on the symmetry axis, i.e. $r = 0$. The difference is within one order of magnitude. The difference is mainly comes from the estimation of the volume of plasma that is used for the



(a) (b)

Figure 2: 6.64 Pa simulation results. (a) Connection voltage of the 2D model(green) and the 1D model(purple). (b) Transient of the number density of electron in the middle of the gap. The green line is the 2D model(r = 0), and the purple line is the 1D model.

power scaling for 1D. In this case, the volume is overestimated in terms of the plasma density.

The connection voltage under the wafer is shown in Figure 3a for 2 Pa. The green line is the value of the 2D axisymmetry model and the purple line is that of the 1D model. In the 2D model (purple), after it reached the periodic-steady state, the maximum and the minimum voltage is about 180 V and -760 V respectively. So the self-bias is about -315 V. The maximum voltage of the 1D model is about 830 V and the minimum is about -1450 V. The self-bias is about -310 V.

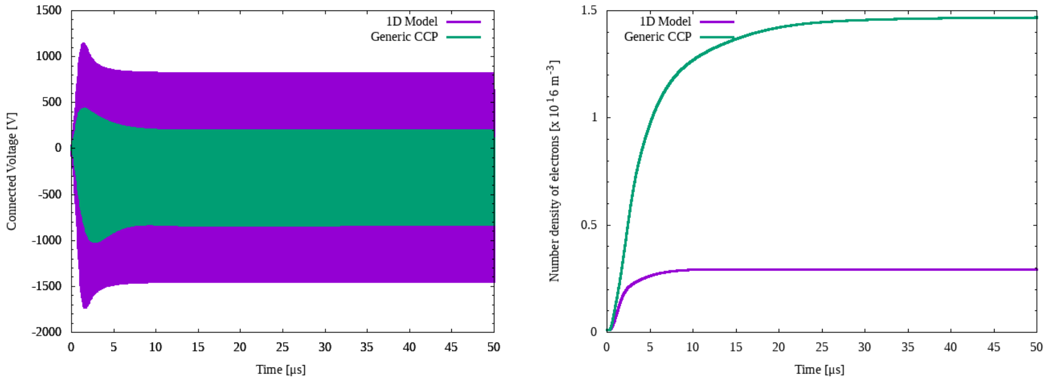
The transients of the number density of electron for each model are shown in Figure 3b. The trend, the 1D model underpredicts the density, is the same as the 6.67 Pa case.

Finally, IED for each model and the pressure are shown in Figure 4. In the pictures, the purple line represents the 1D model result and the green line is the result of the 2D model. In both pressures, 1D model results captureing the trend of the 2D model.

In this study, we introdeced the results of the self-bias, the number density of electrons, and IED. In the 1D model, some variables are overestimated and others are underestimated. These differences can be calibrated by the estimations of the plasma volume and the grounded surface area. These parameters are used in the scaling factors for the circuit and the geometrical settings.

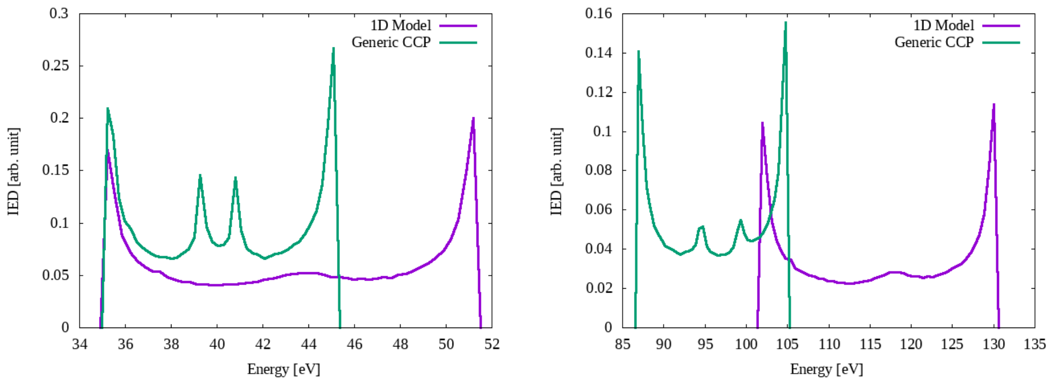
References

[1] M. Lieberman and A. J. Lichtenberg, *Principles of plasma discharges and materials processing*. Hoboken, New Jersey: Wiley-Interscience, 2005.



(a) (b)

Figure 3: 2 Pa simulation results. (a)Connection voltage of the 2D model(green) and the 1D model(purple). (b) Transient of the number density of electron in the middle of the gap. The green line is the 2D model($r = 0$), and the purple line is the 1D model.



(a) (b)

Figure 4: Fluid model IEDFs of (a)6.64 Pa and (b)2 Pa. In each figure, purple liens are at the wafer center of the 2D model, and green lines are the 1D model results.

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