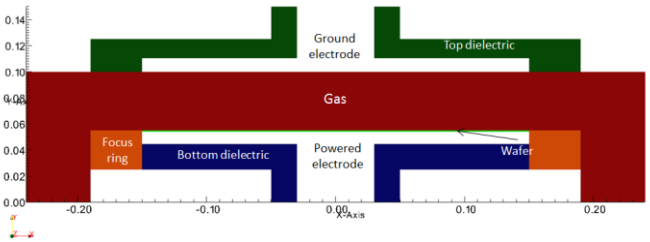
EsgeeTechnologies Inc.
Analysis and Design through High-Fidelity Simulations

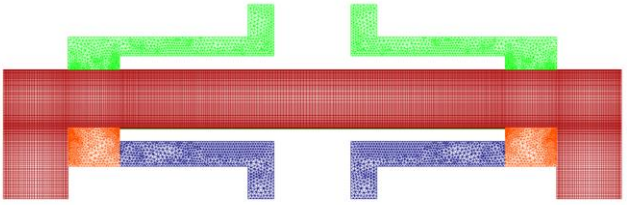
VizGlow Application Note

Simulation of a Capacitively Coupled Plasma (CCP) Reactor Used in Semiconductor Materials Processing

Capacitively Coupled Plasma (CCP) discharges in parallel-plate configuration are commonly used in semiconductor and other materials processing applications. These discharges provide a compact platform in which a plasma can be generated to process a flat wafer surface. The highly directional ion impact at the wafer surface with high ion impact energies is beneficial to a number of wafer processes; in particular for etch processes. This application note discusses the simulation of a typical CCP reactor used in the semiconductor process industry. The *VizGlow Plasma Modeling Software Package* is used.



(a) CCP reactor geometry



(b) Mesh for CCP reactor

Figure 1: **Geometry and mesh for Capacitively Coupled Plasma (CCP) reactor.**

The geometry and computational mesh for this problem is shown in Fig. 1. The mesh contains about 21,000 cells, and is divided into 6 physical subdomains. The geometry includes a gas subdomain where the plasma is formed, a top grounded electrode, a bottom powered electrode that holds a wafer, a top dielectric that isolated the top electrode from the grounded reactor wall, a bottom dielectric that isolates the bottom powered electrode from the reactor walls, and a focus ring that defines the edge geometry for the wafer and the powered electrode. The mesh comprises a mix of quadrilateral and triangular cells in domain. Specifically the plasma (gas) subdomain is meshed with quadrilateral cells that have non-uniform resolution to capture the sheaths at wall and wafer boundaries accurately.

The wafer has a standard 300 mm dia. The wafer is assumed to be made of silicon, the dielectrics are made of alumina, and the focus ring is made of quartz. The powered electrode is driven by a 100 MHz excitation frequency that delivers 300 W radio-frequency (RF) power to

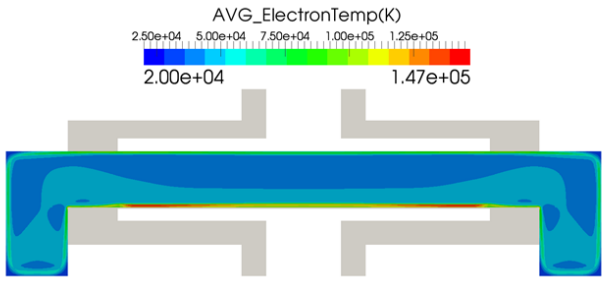


Figure 2: **Cycle-averaged electron temperature in the CCP reactor.**

the plasma. A pure argon gas at 50 mTorr pressure is assumed. The plasma gas phase chemistry is represented by 4 species (electrons E, argon ions Ar^+, argon metastables Ar^*, argon neutrals Ar). The plasma chemistry comprises 6 reaction including electron impact excitation and direct ionization, stepwise ionization, Penning ionization, and metastable quenching. The simulations are run to a periodic steady state. The *VizGlow Plasma Modeling Software Package* is used in self-consistent mode to solve for the CCP plasma phenomena. These simulations are performed without including electromagnetic (EM) wave effects that are known to redistribute power deposition in the reactor. The effect of EM wave will be discussed in another application note.

Figure 2 shows a cycle-averaged electron temperature in the reactor. The electron temperature is nearly uniform in most of the reactor volume with a value of about 20,000 K (~2 eV). In the vicinity of the powered electrode/wafer the averaged electron temperature is about 150,000 K (~ 15 eV). The electron temperature is non-uniform along the radial length of the wafer and peak near the radial edge of the wafer.

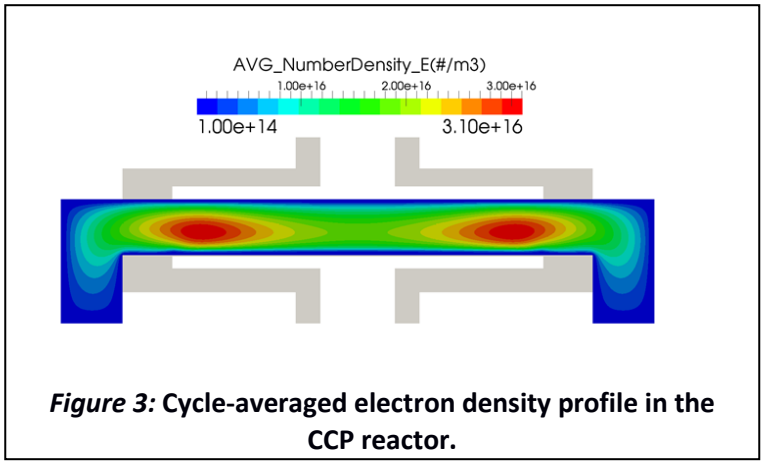


Figure 3: **Cycle-averaged electron density profile in the CCP reactor.**

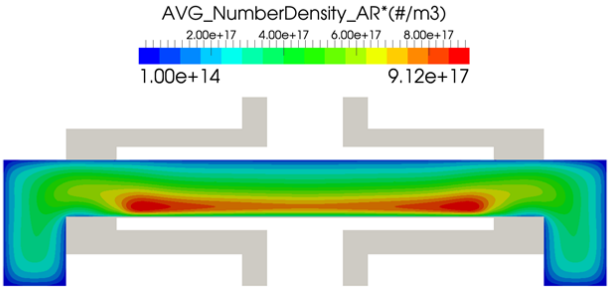


Figure 4: **Argon metastable species density profiles in the CCP reactor.**

Figure 3 shows the cycle-averaged electron density profile in the reactor. The electron densities are seen to be quite non-uniform with a wafer edge peak profile that corresponds to the dominant edge power deposition resulting for wafer edge electrostatic field focusing. Peak electron densities of ~ 3×10^{16} m^{-3} are seen. The argon ion densities correspond closely to electron density profiles.

Figure 4 shows the argon metastable species density profiles in the reactor. An off-axis metastable density peak at a similar radial location to the electron density peak is seen. The metastable densities are however peaked close to the wafer surface close to the regions where the electron temperatures are high.

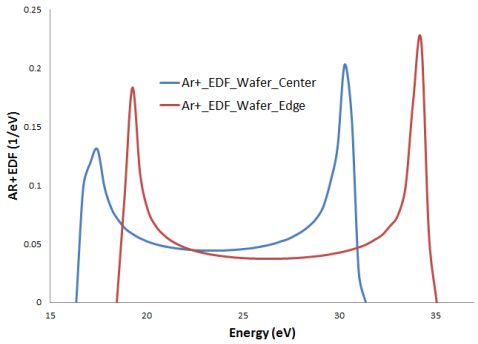


Figure 5: **Ion energy distribution function (IEDF) for AR+ ions at the center and edge of the wafer.**

Figure 5 shows the ion energy distribution function (IEDF) for ion impact at two locations on the wafer surface. The IEDF information is generated automatically by *VizGlow* and is a useful metric for process behavior at the wafer surface. IEDFs for the wafer center and edge are shown. Ions impact the wafer surface with a range of energies depending on the excitation frequencies, mass of ions, and the sheath thickness. A classical bi-modal IEDF is seen. For the reactor condition used in these simulations, the lowest ion impact energies are between 15 and 20 eV and the highest are between 30 to 35 eV. The IEDF width is nearly the same for both the wafer center and edge locations. The wafer edge IEDF is shifted to a slightly higher energy compared to the wafer center.

Finally we provide a note on the numerical convergence of the simulations. CCP simulations can be time consuming and the best judgment for simulation convergence is provided by placing trace points several locations in the simulation domain and tracking the time evolution of various important plasma properties. For example Fig. 6 shows the time evolution of electron and ion species densities and the argon metastable species density at the reactor center line (axis) mid-gap between the electrodes. Although the simulation was run 100 microseconds of simulated physical time, the time evolution of the species densities indicates that a numerically converged solution is obtained in about 40 microseconds.

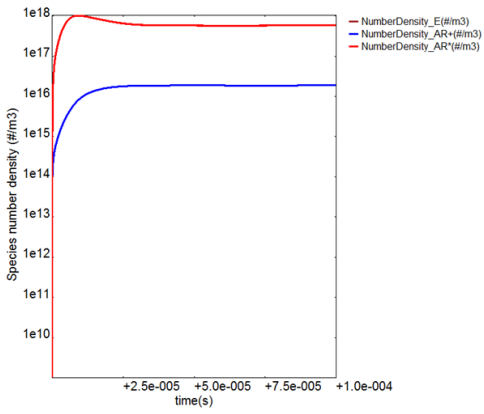


Figure 6: **Time evolution of electron (E), argon ion (AR+) and argon metastable (AR*) species densities at a trace point in the plasma volume. The time evolution of various species and plasma parameters at trace points are used to judge numerical convergence in the simulation.**

In summary, the *VizGlow Plasma Modeling Software Package* provide a wide range of physical models and options that allows one to simulate complex coupled phenomena that are encountered in most plasma discharges. The *VizGlow Plasma Modeling Software Package* is

part of the *Overviz* framework suite which provides an intuitive interface to set-up a project to be solved using *VizGlow*, manipulate multiple projects for parametric studies. *VizGlow* is provably fast, robust, and easy-to-use software and currently a leading industrial plasma simulation tool.

For further information on this application note or details about the *VizGlow* and other software packages you may contact us at

Esgee Technologies Inc.
14, North Peak
Austin, Texas 78746, USA
info@esgeetech.com
www.esgeetech.com