# VizGlow Application Note

## Simulation of Inductively Coupled Plasma (ICP) Reactor with Large Process Gas Chemistries

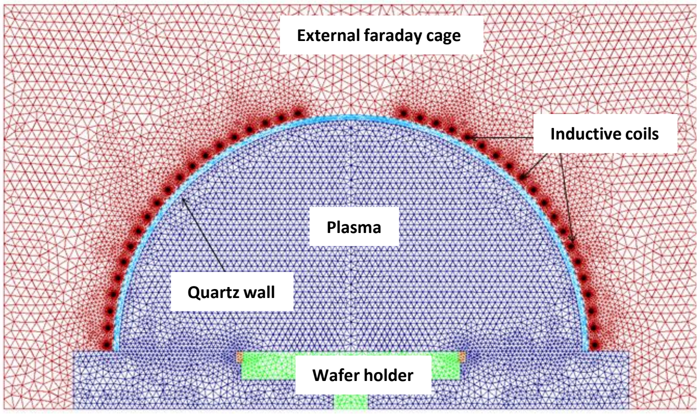

***Figure 1:* Geometry and mesh for dome-shaped Inductively Coupled Plasma (ICP) reactor.**

Plasma processing reactors are used to accomplish a variety of unit steps in a semiconductor integrated circuit manufacture. In most cases, complex feed gas mixtures are used in a plasma reactor to realize precise etch, deposition, doping, cleaning and other types of processes. The *VizGlow Plasma Modeling Software Package* provide capability for modeling plasma reactors with complex reactive plasma chemistries in the gas phase and at reactive surfaces. This technical note discusses the simulation of a hydrogen bromide (HBr) plasma in a dome-shaped Inductively Coupled Plasma (ICP) reactor representative of several real industrial reactor systems. HBr gas and mixtures of HBr with other gases are used commonly in the anisotropic etching of silicon-based material surfaces.

Figure 1 shows the geometry and mesh for the plasma reactor simulation discussed in this note. The geometry is represented by6 subdomains (plasma, dome-shaped quartz wall, inductive coils, external Faraday cage in which the coils are present, the wafer holder, and a wafer edge focus ring). The radius of the reactor quartz dome wall is 20 cm with a 200 mm dia. wafer. The inductive coil system comprises 20 turns. The mesh comprises a total of about 28,000 cells in the domain.

The pure HBr plasma is generated by driving 2 kW of power through the inductive coils with 460 kHz radio-frequency (RF) excitation. The HBr plasma is represented by 15 species (E, $Br^+$, $Br_2^+$, $HBr^+$, $H^+$, $H_2^+$, $Br^-$, Br, $Br_2$, Br*, $Br_2$*, H, $H_2$, H*, HBr)and 51 reaction. The reaction mechanism includes electron impact dissociation, excitation, and ionization reactions, attachment reactions for negative ion formation, ion-neutral reactions, ion-ion reactions, and reactive neutral chemistries. The surface chemistry is represented by simple quench chemistries for all reactive ions and radicals to form their corresponding stable neutral species which are then injected back into the plasma.A pressure of 5 mTorr is assumed for the simulations.

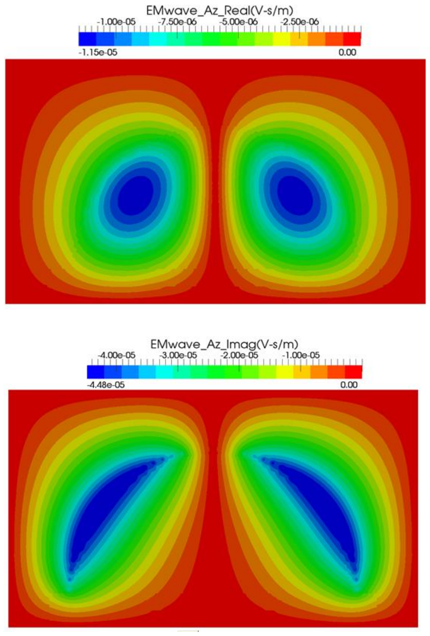

***Figure 2:*** **Electromagnetic wave field in the reactor. (Top) real and (Bottom) imaginary part of the $E_\theta$ polarized magnetic vector potential.**

The complete model representation of the reactor is provided by inductive wave physics, plasma dynamics and reactive plasma chemistries. The electromagnetic (EM) wave frequency domain solver from the *VizEM Electromagnetics Modeling Package* is solved in a coupled fashion with the core VizGlow package. The EM wave generated by the coils is $E_\theta$polarized, meaning that the only non-zero component of the wave *E* field is in the direction perpendicular to the domain representation. The high-density HBr plasma is represented using the quasi-neutral formulation. A flow residence time formulation is used to represent the effect of gas flow in the reactor. The plasma gas-phase and surface chemistries are managed by the *Gasact* and *Surfact* modules within VizGlow. Results at steady-state are reported here. A steady-state is found to be achieved in about 2 milliseconds of physical time in the simulation. This time corresponds to the ion ambipolar diffusion time scale for the reactor geometry. Figure 2 shows the real and imaginary parts of the magnetic vector potential of the $E_\theta$polarized EM wave.

Figure 3 shows the EM wave power absorbed by the plasma. The wave power absorption is determined by the plasma conductivity (determined by plasma electron density and electron temperature) and the magnitude of the wave electric field. For the relatively low excitation frequency of 460 kHz, the skin depth of the plasma is sufficiently large that EM wave power is absorbed relatively deep within the plasma, away from the quartz dielectric wall.

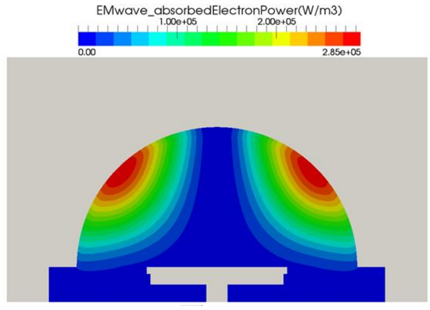

***Figure 3:*** **EM wave power absorbed by the plasma.**

Figure 4 shows the structure of the plasma as identified by the dominant charges species in the plasma. Under the condition chosen for the simulation the plasma is largely electropositive (meaning that the negatively charged ion densities are much smaller than positively charges ion densities). The peak electron (E) densities are located on the axis of the reactor and have a magnitude of $5x10^{16}$ $m^{-3}$. The dominant ion is $Br^+$ which has a spatial profile and magnitude similar to the electrons. The $HBr^+$

ions are also shown in the figure and have a peak profile that is off the reactor axis. Note that the electron and other charges species peak at locations that are far from the location of the EM wave power absorption peak which occurs close to the quartz dielectric wall (see Fig. 3). This has to do with the non-local nature of the plasma at the very low pressure of 5 mTorr.

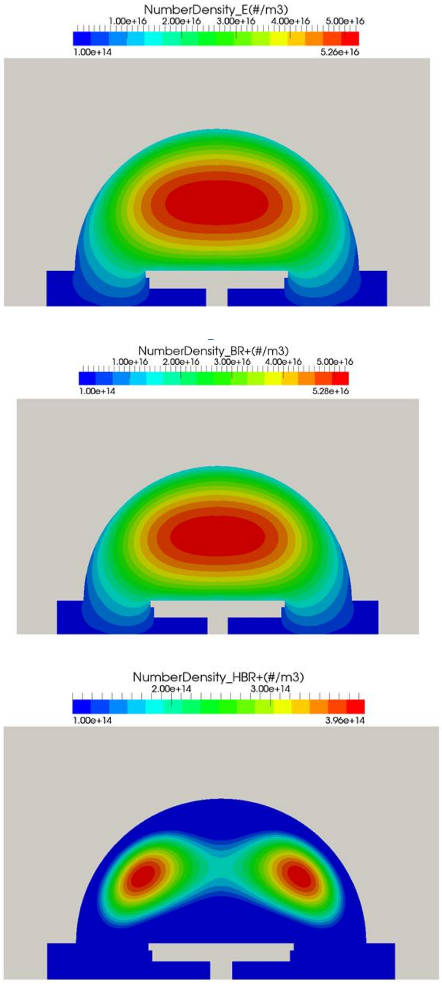

***Figure 4:*** **Charged species density profiles in the dome-shaped ICP reactor.**

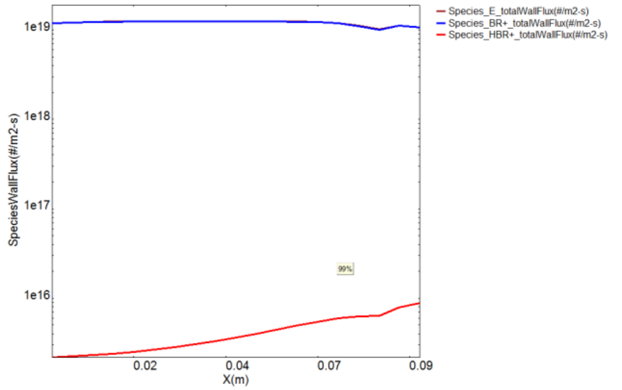

***Figure 5:*** **Dominant charged species fluxes to the wafer surface.**

Figure 5 shows the radial profiles for the dominant charged species fluxes to the wafer surfaces. This information is important to determine the uniformity of the process at the wafer. The dominant ion is $Br^+$ whose radial profile is relatively uniform throughout the radius of the wafer with slight non-uniformity seen at the edge of the wafer. Other ions such as HBr+ have much lower flux to the wafer surface.

In summary, the *VizGlow Plasma Modeling Software Package* provides 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.

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Analysis and Design through High-Fidelity Simulations

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

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