1 Initial Condition

1.1 Introduction of Inductivly Coupled Plasma

Low-pressure high-density plasmas are widely used for semiconductor processing. High density results in high ion fluxes, which increase the etch rate. So the throughput of wafer processing can be increased. Low pressure results in the collision frequency, from which ions reduces energy loss. So the ion energy to the wafer can be high, benefiting the desired etch process. Inductively coupled plasma (ICP) meets these requirements and becomes widely used strting in 1990s. The "inductively" in the name comes from the way the electric field is produced. An electromagnetic field is created by radio frequency (RF) current flowing in a coil, which can be seen in the figure below. The current flowing through the coil creates B-field, which in turn creates the E-field below the dielectric window. The underline E-field delivers the energy to the electrons, which creates the plasma. The plasma current in the azimuthal direction also feedbacks to the coil current. Therefore, the coil and plasma are tightly coupled together.

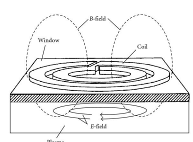

Figure 1: RF magnetic field (B-field) and RF electric field (E-field) created inside the ICP by applying RF power to the planar coil through the dieletric window.

1.2 Model Geometry

A typical ICP geometry is shown below. The whole domain is defined by the outmost boundaries. However, the equations in the Reactor Model are solved in different domains.

- ICP field equation is solved within the domain except all metals, plus coils although coils are metal too.
- Poisson's equation is solved within the domain except all metals. Coils are not counted.

- Plasma equation is solved only within the vacuum area, which is the domian minus all metals and dielectrics.

The material properties:

- Coil current - I_{coil} is determined by the total power coupled to plasma. It is not easy to determine the initial current value. Users have to try out in a large range from 0.001 A to 10.0 A.

Dieletric constat (relative) (absolute permittivity = $8.85 \times 10^{-12} m^{-3} kg^{-1} s^4 A^2$):

- Vacuum, air - 1.0
- Quartz - 3.8 - 4.2 depending on what kind of quartz, 4.0 can be used for most cases
- Metal - 1.0, metal does not have dieletric constants. It is assigned 1.0 only for computation.

Conductivity:

- Vacuum, air - 0.0
- Quartz - very small, 1e-6 to 1e-3 S/m. Users can use 0.0. Quartz is designed to have very small conductivity so that magnetic field can penetrate through it.
- Metal - infinity. Metal serves as boundary condition. Users can assign metal with conductivity of 1.0e6 S/m.

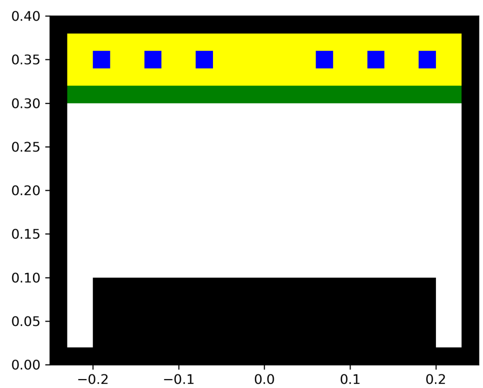

Figure 2: Geometry of an ICP. White - Vacuum; Black - Grounded metal; Blue - Coil; Yellow - Air; Green - Quartz.

1.3 Initial Condition

A typical ICP case is given here with all necessary initial conditions, which can be used as a test for Reactor Model.

Operation conditions:

- Pressure - 10 mT
- Power - 100 W
- RF frequency - 13.56 MHz
- Room Temperature - 300 K

Plasma conditions:

- mass - $m_e = 9.1 \times 10^{-31} kg$, $m_{Ar} = 40 \times 1.66 \times 10^{-27} kg$
- elementary charge - $e = 1.6 \times 10^{-19}\,C$
- neutral density - $n_{Ar} = P(mT) \times 3.3 \times 10^{19}\,m^{-3}$
- metastable density - $n_{Ar^*} = 1\% \times n_{Ar}$
- electron density - $n_e = 10^{-4} \times n_{Ar}$
- ion density - $n_{Ar^+} = n_e$
- electron temperature - $T_e = 1.0\,eV$

- ion temperature - $T_{Ar^+} = 0.1\, eV$
- neutral temperature - $T_{Ar} = T_{Ar^*} = 0.025\, eV$