[P-01]

Applications of Plasma Modeling for Semiconductor Industry

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Last 10 years in plasma processing area we have a situation, when a practical applications of majority of processes are significantly overtake a level of plasma theory development. That is why, for a process optimization engineers very often use a method of "blind search", which is based only on empirical investigations and results. This method is characterized by three sufficient disadvantages. First, it requires a lot of time. Second, it does not guarantee positive result. And third, in the case of success the results can"t be directly transferred to another system, which is similar but not the same. Term "plasma modeling" is very wide and assumes at least two meanings: theoretical calculations of plasma and process parameters, which can"t be obtained by experiments.

global description of plasma system aimed to connect input parameters of process with a final effect.

Therefore, development of plasma theory and thus plasma modeling methods is able to bring a sufficient contribution to technology.

From the general point of view, plasma modeling may be realized in direct or self-consistent modes. Direct modeling includes step-by-step procedure and requires as input parameters a lot of plasma diagnostics results as well as process conditions (gas pressure and flow rate, power density and plasma excitation frequency). Self-consistent mode requires as input parameters only process conditions, while diagnostics data are used only as model optimization criteria. Nevertheless, there are list of input parameters, which are required for all modes of plasma modeling:

Cross section of electron impact processes;

Reduced electric field strength - E/n_0;

Reduced frequency - $/n_0$

Magnetic field strength

These parameters directly determine characteristics of energy transfer from electromagnetic field to electron gas and from electron gas to "heavy" particles. Moreover, these parameters are used as a "similarity criteria" to adapt a model for the system of various geometry and power density.

As for model output parameters, theirs number is determined by the "dimension" of model. "Dimension" is a specific term, which characterize model abilities for description of spatial and time effects in plasma system. First and simplest level is "zero-dimensional" (0D) model, which allow to obtain mean volume densities of neutral and charged particles and theirs fluxes to the surface. 1D model gives information about radial distribution of particles in reactor chamber. 2D model takes into account radial and axial distributions while a 3D model adds to these features time-dependent effects. Unfortunately high-dimensional models are so complicated that require a CPU time, which comparable with or even more than "blind search" duration.

The best way for the analysis of internal plasma characteristics is to "divide" them to several coupled subsystems, which include processes described by a similar physical or chemical content. Such approach allow to select at least four subsystems:

Subsystem of electron gas;

Subsystem of charged particles;

Subsystem of neutral particles;

Subsystem of heterogeneous chemistry.

It is very important to attract the attention on direct connection between heterogeneous chemistry and electron gas characteristics and this is especially important for etching systems description. The reason is that highly volatile reaction products may change content of gas phase and thus the basic characteristics of all subsystems.

Subsystem of electron gas usually is based on the Boltzmann kinetic equation (as a form of energy conservation law for plasma electrons) and power balance equation. This subsystem describes a combination of physical processes such as transition of energy from electromagnetic field to electrons and energy dissipation during the collisions of electrons with "heavy" particles. Second and third subsystems are based on the kinetic schemes of charged and neutral particles formation and decay including chemical processes and transport effects. Forth subsystem is especially important for etching processes modeling and includes description of adsorption-desorption equilibrium (taking into account both spontaneous and stimulated mechanisms) and a surface chemistry analysis from the point of view of active centers theory. This theory assumes a surface as a combination of active centers, which are able to join chemically active species from gas phase. The etching rate determines by the relative fraction of free active centers while other active centers in amount of *(1-)* may be occupied by reaction products as well as by chemically inert particles.