Plasma Scaling Leads the Transition From 2D to True 3D Models

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Abstract

Introduction: In inductively coupled plasma (ICP) systems the inductive antenna is coupled to the excited plasma inside the low pressure gas reactor. A multi-ICP system can be used for increased area processing and provide additional variables for controlling the plasma. However, assembling the source from individual sources changes the symmetry of the system. Simulation of plasmas in technological reactors is typically using advantage of axial symmetry, thus reducing models into 2D space - axially symmetric geometry. However, some systems (Fig.1) do not have an ideal axial symmetry. Moreover, reactor walls are imposing stronger boundary conditions on distribution of the radicals and by-products in plasma, specially, in reactive plasmas. Approximation of asymmetric configuration by pseudo-symmetric 2D axial models (Fig. 1) is not good enough to determine plasma distribution and its properties. In such case it is necessary to explore full 3D model of plasma reactor.

Use of COMSOL Multiphysics®: The numerical simulation techniques commonly used for simulating low-temperature plasma discharge mainly include fluid dynamic, kinetic and hybrid models. These models are significantly different in principles, strengths, applications and limitations. The fluid models are used widely for simulation of plasma tools because of its efficient computational cost. This option makes special significance when the technical solution brings additional factors into consideration such are the asymmetry, dimensional scale, complex shape, transient performance, etc. In this work we implemented COMSOL Multiphysics® software and the Plasma Module (v.4.4 - v.5.0) for asymmetric ICP reactor both in 2D and 3D versions. The Plasma Module is supported by the capabilities of the RF Module. To consider various gas flow path and chemistry, the laminar flow is included.

Results: To perform our investigation we formulated 2D a 3D plasma fluid models. The Plasma Module is time-efficient for computation for the most of the 2D of the ICP models in inert gas and flexible in setting the geometry of the actual chamber. The 3D implementation of the ICP model is computationally more costly. For illustration in Fig. 2 a comparison of 2D pseudo-axial model with full 3D plasma model is presented. The 3D model provided more accurate results and allows identifying the plasma parameters within an arbitrary location on computational domain. Besides the inert gas (Ar) also molecular gas (CO and H_2) models with more complex reaction schemes were computed.

Conclusion: We found that even large scale asymmetric ICP reactor models in 3D space are

possible to solve with the support of COMSOL software. Increased level of asymmetry is extending computational time but provides still reasonable turnover of the cases. Enhanced chemistry might require HPC resources. We were able to evaluate multiple combinations of the multi-coil ICP configurations in inert gas and generate transient sequences of them. Plasma simulation is becoming an essential technology used to develop new semiconductor manufacturing equipment and develop improved process control schemes.

Figures used in the abstract

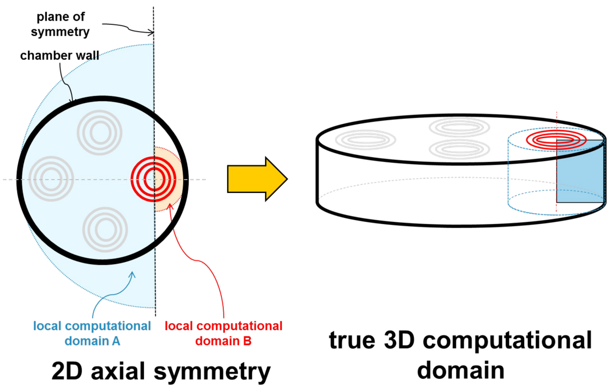

Figure 1: The ICP asymmetric configuration with off-axis antenna used in large reactors is formulated using dual axial symmetry (left) with respect to the boundary conditions at the surrounding wall and a full true 3D formulation (right).

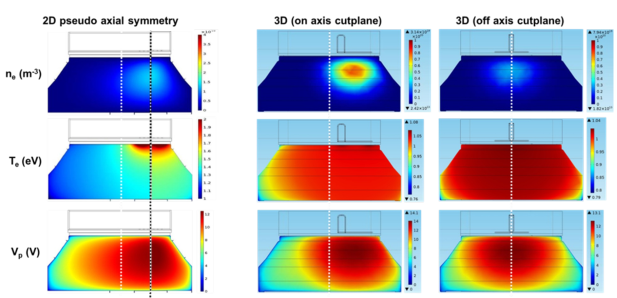

Figure 2: Comparison of the basic plasma parameters in the case of a pseudo 2D axial model (1st column) and 3D model (2nd and 3rd columns).