

## 2D AXIAL SYMMETRICAL COMPUTER SIMULATION OF MICROWAVE INDUCED PLASMAS USING PLASIMO

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### 1. Introduction

Microwave Induced Plasmas (MIPs) are interesting for industrial and academic purposes: surface treatment, creation of radicals, light sources, etc. In the particular case of surface wave discharges (SWDs), the electromagnetic waves propagate along the plasma column which acts as a propagating medium. An essential part of SWDs is the field applicator or launcher, i.e. the metal structure which convert the wave modes coming from the power supplier into surface wave modes. Well known type of launchers are the surfatron, waveguide-surfatron and surfaguide [1, 2].

For creating a SWD model, three important modeling aspects are needed: The transport of species inside the plasma, the chemical compositions and the interaction between electromagnetic (EM) waves and plasma. Due to the several non-linear equations involved in the process, it is necessary to use a self-consistent computer model. For this reason the Plasimo toolkit [3-5] is used as it offers a high flexibility to deal with different settings of the chemistry, flow and power coupling equations. The modular design of Plasimo allow the user to compose a new model: using the different (sub)models available and/or adding new models.

We have extended Plasimo including a new electromagnetic model. This model permit us to include multiple electromagnetic configurations. In order to present the new electromagnetic model, we have considered an argon plasma at different pressures in two cases: surfatron and waveguide-surfatron configurations.

### 2. Theory

The model is composed by three (sub)models: flow, kinetic and electromagnetic.

The flow part is formed by the mass continuity and momentum balance equations, which give the pressure, velocity and mass density of the fluid plasma. They are solved using the Semi-Implicit Method for Pressure Linked Equations SIMPLE [6].

In the kinetic part, we have considered a non-LTE (local thermodynamic equilibrium) plasma. For an argon plasma, we have considered 5 species divided into two groups: heavy

species, Ar, Ar(4s) - a block of excited states -, Ar+, Ar2+, and electrons. The processes included in the model are elastic scattering, excitation, deexcitation, ionization from the ground and excited states, dissociative recombination, diffusion, atomic ion conversion, molecular ion dissociation, electron impact, and atom impact. We refer to [7] for more information about the processes included. The electron and heavy particle temperatures are obtained by solving the energy equations, respectively. Note here that we use the term electron temperature as an effective quantity related to the mean electron energy.

The electromagnetic model is based on the finite differences frequency domain, FDFD, method [8, 9]. We improved the model by generalizing the harmonic Maxwell equations in ortho-curvilinear coordinates. In FDFD method the finite electromagnetic field are defined into a Yee grid [9]. This grid only allows continuous component of the electromagnetic field to be defined at the material interfaces, which helps to fulfill the divergence free condition. The new model allows the drawing of different electromagnetic configurations using different dielectric and metal materials (see Fig. 1), which can be done in an input file or via the graphical users interface. We assume a transversal magnetic (TM) surface wave mode in cylindrical coordinates propagating in the axial direction, i .e. three field components  $E_z$ ,  $E_r$ ,  $H_\phi$ . The output of this model is the power dissipated into the plasma region.

The coupling between the three parts or the model is handled through the iterative scheme shown in Fig. 2.

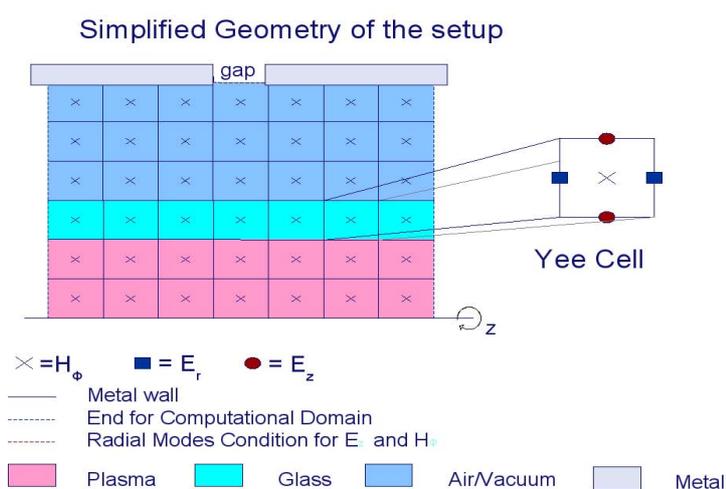


Fig. 1: Example of electromagnetic configuration created with 4 materials: Plasma, Glass, Air and Metal. The continuous field components are defined at the boundary of the cell ( $E_z$  at North-South boundary and  $E_r$  at West-East boundary).

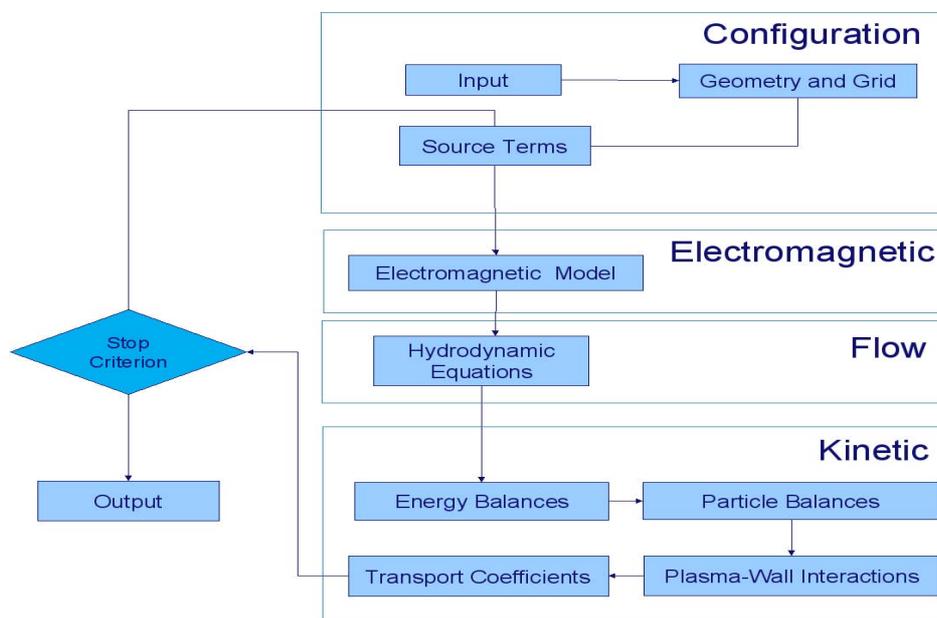


Fig. 2: Flow chart of the iterative scheme.

### 3. Results and Discussion

We present the axial and radial distributions of the electron density in an argon plasma. We used two types of electromagnetic configurations: surfatron (Fig 3.a.) and waveguide-surfatron (Fig 3.b) and three different pressures: 500, 700 and 1000 mbars. The frequency of the surface waves is fixed at 945 MHz.

As we can see from Fig.3.a, the backward column is shorter in the case of a surfatron configuration. An explanation for this is that the metal wall of the surfatron acts as a circular waveguide and allows other modes to propagate, apart from the surface wave modes.

Fig 3 also shows, as it was expected, axial and radial contraction in the plasma, an effect which has been reported experimentally in high pressure plasmas. Both contractions increase with the pressure.

### 4. Conclusion

In this paper, we have presented a flexible MIP model in the particular case of SWDs. The new electromagnetic model allows us to draw different configurations. Furthermore, we have demonstrated the fluid-kinetic-electromagnetic model for two cases: surfatron and waveguide-surfatron at high pressures.

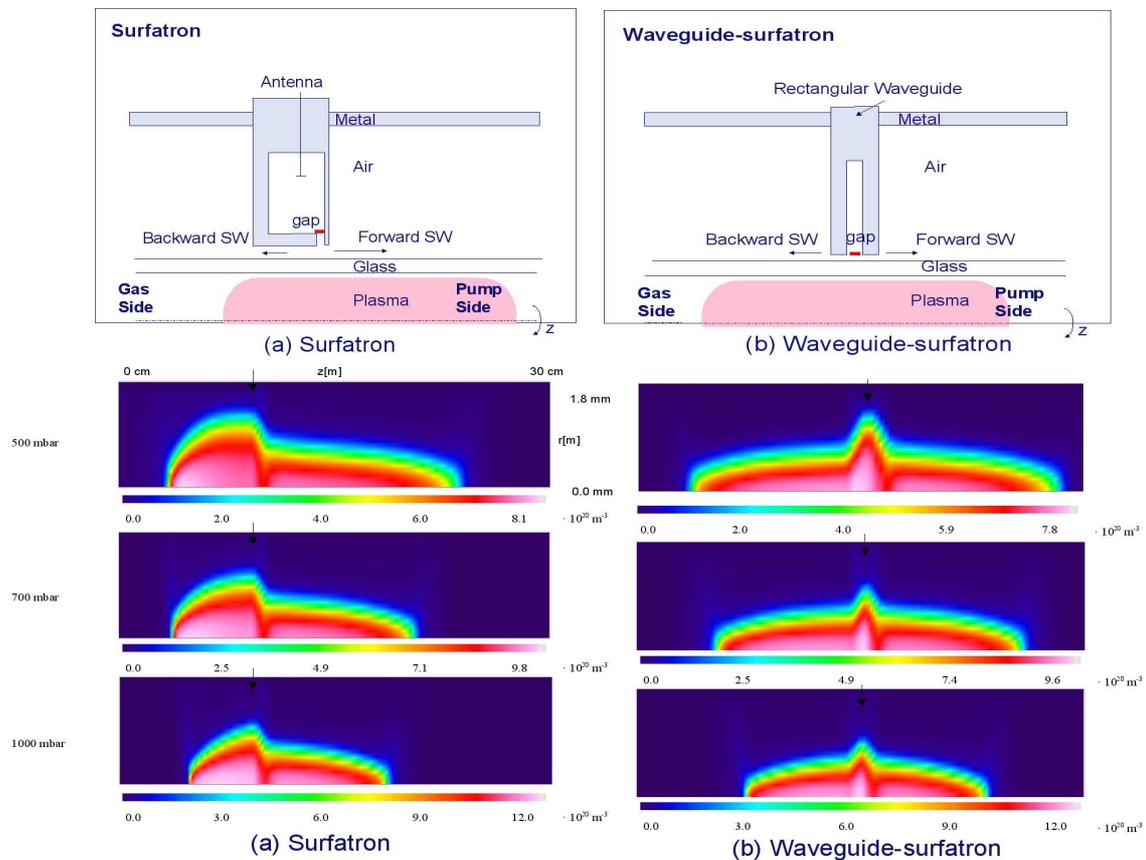


Fig. 3: Geometry and electron density distribution for a) surfatron and b) waveguide-surfatron.

## References:

- [1] M. Moisan, "Microwave Excited Plasmas", Elsevier, (1992).
- [2] M Moisan et al, Plasma Sources Sci. Technol. 3 584-592, (1994).
- [3] BD. Benoy "Modelling of thermal argon plasmas", PhD Thesis Eindhoven University of Technology, (1993).
- [4] G. M. Janssen. "Design of a General Plasma Simulation Model, Fundamental Aspects and Applications", PhD thesis, Eindhoven University of Technology, The Netherlands, 2000
- [5] J. van Dijk. "Modeling of Plasma Light Sources - an object-oriented approach", PhD thesis, Eindhoven University of Technology, The Netherlands, 2001.
- [6] S. Patankar, "Numerical Heat Transfer and Fluid Flow", New York: McGraw-Hill, 1980.
- [7] Y. Kabouzi and D. B. Graves, Physical Review E 75, 016402, (2007).
- [8] C. Yu and H. Chang, Opt. Exp., vol. 12, pp. 1397-1408, (2004).
- [9] K. S. Yee, IEEE Trans. Antenna Propagat. 14, 302-307, (1966).