Laboratoire Plasma et Conversion d'Energie

FVTD Modeling of a Localized Microwave Plasma Discharge in Microstrip Wave Guide

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Context

▪The transport and generation of High Power Microwave (HPM) can be affected by breakdown. The physics of volume microwave breakdown is better understood but there is a lack of accurate numerical models able to cope with the strong non-linearity and large plasma density gradients associated with plasma formation after breakdown at high pressure.

▪The plasma density gradients during microwave breakdown at high pressure may by quite large and a very fine grid may be needed. For example, breakdown at atmospheric pressure and with a microwave frequency around 100 GHz, a grid spacing as low as λ/1000 has been used to obtain an accurate solution.

▪A major drawback of the FDTD method, is the uses of structured cartesian meshes. It can increase dispersion effects when non uniform grids are used. Unstructured Finite Volume methods are more suited to problems where the grid spacing must be very small in some regions (i.e. the plasma region).

Goal

▪ Solve the Maxwell-plasma problem using a original Finite Volume Time Domain (FVTD) approach.

▪ Illustrate this method by studying a localized microwave plasma discharge in microstrip waveguide.

Physical Model

It couples the Maxwell equations with the plasma dynamics through the electron density current.

▪ Maxwell equations :

$$\begin{cases} \nabla \times E + \mu_0 \dfrac{dH}{dt} = 0 \\ \nabla \times H - \varepsilon_0 \dfrac{dE}{dt} = j \end{cases}$$

▪ Plasma equations :

$$\frac{\partial n_e}{\partial t} - D_{eff}\,\Delta n_e = \nu_{eff}\, n_e - r_{ei}\, n_e^2$$

$$\frac{\partial v_e}{\partial t} = -\frac{eE}{m_e} - \nu_m v_e$$

▪ Microwave-plasma coupling :

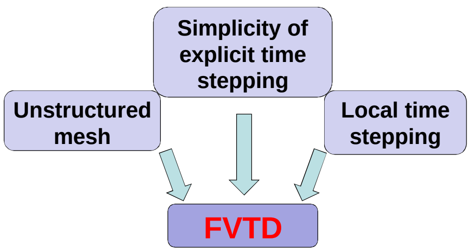
$$j = -e n_e v_e$$

• $\nu_{eff} = \nu_i - \nu_a$ is function of local effective field.

• $\nu_m = 5.3\ 10^9\, p$

• $D_{eff} \cong \dfrac{\alpha D_e + D_a}{1+\alpha}$ • $\alpha = \lambda_D^2 \nu_i / D_e$

Numerical Approximation



Stability condition

A second-order « predictor / corrector » scheme is used for the Maxwell's equation and Euler scheme for the plasma equations.

$$dt_{ne} < \min_i\Big(\frac{S_i}{D_e \sum_{k=1}^{3} l_{i,k}}\Big)^2,\ dt_M < \min_i\Big(\frac{S_i}{c \sum_{k=1}^{3} l_{i,k}}\Big)$$

To decrease the huge computational time, local time stepping and parallel coding are used.

Local time stepping

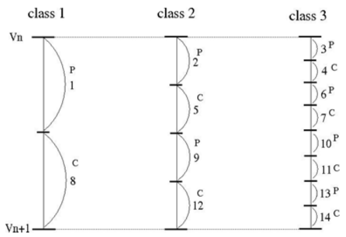


Fig 1 : Operation numbering on the local time stepping strategy for 3 classes (p:predictor step , c:corrector step).

Parallel strategy

Despite of the use of local time stepping and a local refinements, the simulation need a lot of cells (λ/200) in the plasma area. Then the CPU time is drastically increased.

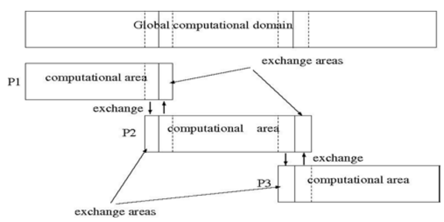


Fig 2 : Difinition of areas and exchange operations in a configuration with 3 processors (P1,P2,P3).

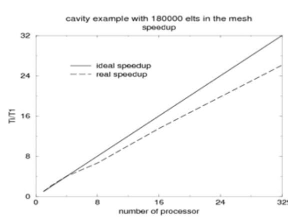


Fig 3 : Gain in CPU time by increasing the number of processors

Results

We are interested by studying the effect of the plasma located in one hole in the dielectric substrate of a microstrip line. This wave guide is assumed to be TEM and the edge effects are then neglected.
The hole diameter is 1 mm.
The pressure is p=200 torr.

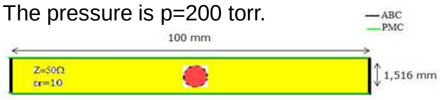


Fig 4 : Studied configuration.

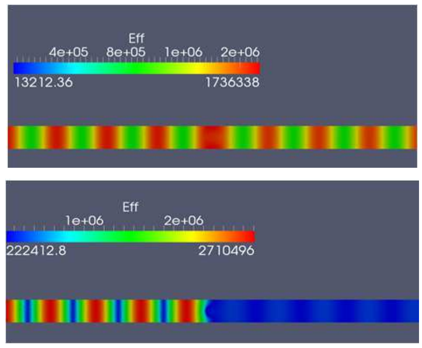


Fig 5 : Effective field at t=1 ns and 50 ns

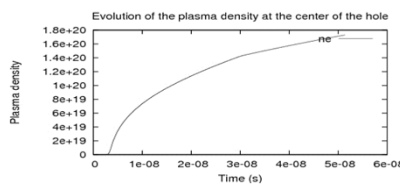


Fig 6 : Evolution of the plasma density

Conclusion

The FVTD method appears to be more efficient both in memory storage and computational time than usual FDTD.
The results on top show that the behaviour of a basic plasma limiter can be achieved. Further comparisons with experiments are under work and basis of adaptative meshing are studied.

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