MODÉLISATION DES DÉCHARGES HIPIMS ET INSTABILITÉS EXB

MODELLING OF HIPIMS DISCHARGES AND EXB INSTABILITIES

Etablissement **Université Paris-Saclay GS Physique**

École doctorale **Ondes et Matière**

Spécialité **Physique**

Unité de recherche **Laboratoire de Physique des Gaz et des Plasmas**

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Mots clés - Keywords

plasma basse pression, plasma magnétisé, HiPIMS, instabilités, modélisation

low pressure plasma, magnetized plasmas, HiPIMS, instabilities, modeling

Description de la problématique de recherche - Project description

TMP-D&S team of LPGP is developing several models using different approaches aiming to describe and understand the behaviour of pulsed high power ExB discharges. The best example is the high Power Impulse Magnetron Sputtering (HiPIMS) discharge, operating at low pressure (< 1 Pa) and high current (~100A) during the pulse. The dynamic of this kind of discharge is very fast (~µs) and the time dependence is required in all the models to capture the main phenomena gouvering the discharge.
Several 0D and 2D models have been successfully developed, but especially the 3D modeling of the electron instabilities was the major achievement. The thesis program will focus on the non-standard operation condition, exploring the particularities of the plasma in these extreme situations.
It becomes thus possible not only to describe the magnetized plasmas but also to quantify the electron transport across the magnetic barrier, the aim of this thesis.

The modeling of pulsed high power ExB discharges using 2D is already performed in TMP-D&S team for very short pulses and in standard operation conditions. We developped a global model describing the average behaviour of the plasma in the Ionization Region (IR), but also a novel approcach called 'pseudo-3D' allowing to model very high density plasma, but particularly interesting to describe the electron instabilities in magnetized plasmas and the electron transport across the magnetic barrier.
New approaches are possible to be implemented, for instance implicit PIC (Partcile-in-Cell).
(Year 1): IR Model (IRM) will be run for non-standard operation conditions followed by the Pseudo-3D model implementation for very high plasma density and several magnetic field configurations.
(Year 2): Development of specific routines for the data processing allowing the numerical diagnostic of the plasma (e.g. electron diffusion, plasma oscillations, flares propagation, etc.)
(Year 3): Optimization of the model and comparison to experimental results obtained in other European research teams, partners of this project.

Thématique / Domaine / Contexte

Numerical modeling of plasmas, magnetized plasmas, electron transport across magnetic field, diffusion and instabilities

Plasmas physics, Plasma modeling

From the begining of the thesis several modeling codes are available, namely IRM Ionization Region Model), OHIPIC (Orsay High density Particle in Cell) that gave very interesting results for standard operation of the discharge. These codes are parallelized and they are able to give the deep microscopic picture of the phenomena involved in the plasma sustain and development during the power rise-up phase, during the plateau and at the end of the pulse.
All these models can be improved and especially can be exploited to better characterize the high-density low-pressure plasma of HiPIMS discharges beyond the regular operation range.

Objectifs

The thesis aims to develop new models using global and self-consistent approaches for magnetized plasma discharge operated at low pressure and very high power, as it is the case for HiPIMS (High Power Impulse Magnetron Sputtering). The validation of the model by the direct comparison to experimental results is part of the thesis. Moreover, the optimization of the HiPIMS discharge is the final goal of the present work.

Méthode

The method Pariscle-in-Cell (PIC) will be extensively used. It is couped to the Monte Carlo collision (MCC) approach to take into acocunt the interactions between the plasma species in gas pahse.
A novel implicit PIC algorithm will be implemented and tested from the begining of this thesis. In parallel intensive parallel calculations will be performed corresponding to the parametric sutdy of the discharge.
Based on the obtained results, the best configuration (optimum) of this discharge will be proposed and compared to experimental results.

Résultats attendus - Expected results

The new version of the model OHIPIC is expected to be:
- more stable, allowing to tackle higher density plasmas (> 10^19 m^-3);
- faster than the present models;
- extending the modeliing to 3D, first by pseudo-3D approach and, if possible;
- developing a full 3D model of magnetized plamas.
Using such an advanced simulation tool, it is expected to obtain a refinate description of the instabilities formation in ExB field structures and to better understand the electron transport across the magnetic barriers.

Références bibliographiques

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Précisions sur l'encadrement - Details on the thesis supervision

Le (la) doctorant(e) travaillera dans l’équipe TMP-D&S – Théorie et Modélisation des Plasmas – Décharges et Surfaces du LPGP. La direction de thèse sera assurée par T. Minea (PU UParis-Saclay) avec une forte implication d’un IR en méthodes numériques. Pendant la thèse, un rapport d'avancement annuel sera rédigé et le travail sera présenté dans le cadre d'un réseau Européen.

Conditions scientifiques matérielles et financières du projet de recherche

The student will join the LPGP, which is a Restricted Research Area (ZRR).
We give access to our computing cluster (~400 CPUs) and provide all the infrastructure.

Ouverture Internationale

The topics of electron transport across the magnetic barriers is very challeging nd interesting. It is of high interest for several laboratories in Europe that decided to collaborate and to exchange information mixing the data relative to three typical configurations: (i) magnetron discharges and HIPIMS; (ii) Hall ion thrusters; (iii) ECR plasmas.

Objectifs de valorisation des travaux de recherche du doctorant : diffusion, publication et confidentialité, droit à la propriété intellectuelle,...

The interest of this topics is very high and the sound publications in International Journals are planned to be performed during this Ph.D. Also, oral communication will be performed in International conferences.

Collaborations envisagées

Strong collaborations are in progress with the laboratory ICARE (CNRS, Orleans, France) providing the experimental part of the work on plasma instabilities in magnetized structures. Other laboratories in Europe such as IOM (Leipzig, Germany), KTH (Stockholm, Sweden).

Profil et compétences recherchées - Profile and skills required

Les prérequis nécessaires pour cette thèse sont des bases en physique des plasmas, des connaissances en simulation numérique, ainsi que des connaissances sur le transport des espèces chargées en plasmas magnétisés. Des connaissances sur les instabilités plasma seraient bien appréciées.
The candidate should have solid knowledge of fundamentals in plasma physics and numerical simulation, but also a good understanting of the transport of charged particles across magnetic barriers. The knowledge about plasma instabilities would be highly appreciated.

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