ETUDE DU RÉGIME LUMINESCENT SOUS IMPULSION DE HYPER-PUISSANCE

STUDY OF THE GLOW REGIME IN HYPER POWER PULSED MODE

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, transition à l'arc, diagnostic des plasmas

low pressure plasma, magnetized plasmas, HiPIMS, glow to arc trasition, plasma diagnostic

Description de la problématique de recherche - Project description

L'équipe TMP-D&S du LPGP a réussi récemment a stabiliser une décharge luminescente de très forte puissance à l'aide d'une cathode E x B. Ce nouveau régime de fonctionnement est caractérisé par des courant extrêmes qui correspondent aux arcs électriques, mais la décharge reste en mode luminescent.
L'objectif de la thèse est de caractériser ce nuoveau plasma et de comprendre les mécanismes responsables pour l'entretien de ce mode non-standard. L'impulsion de très forte puissance est nommée 'hyper-puissance' (allant jusqu'à 1 MW/pulse). Elle est coupée après 1 ms simplement pour éviter la détérioration du dispositif expérimental. Ainsi, le mode hyper-puissance peut être assimilé à un fonctionnement quasi-continu.
La cinétique des espèces formant le plasma, la pulvérisation et leur dynamique dans ce type de décharge reste à découvrir.
Des études préliminaires ont permis d'isoler les conditions es plus propices au fonctionnement du plasma dans ce régime. Le programme de cette thèse se foncalisera sur la caractérisation expérimentale de ces conditions non-standard d'opération et explorera les particularités de ce plasma dans des conditions extrêmes. Il est également possible d'avoir un volet modélisation pendant cette thèse en élargissant le modèle global mis au point pour les décharges HiPIMS (High Power Impulse Magnetron Sputtering) vers les décharges hyper-puissance.

TMP-D&S team of LPGP has recently succedded to glow a very high power discharge using an E x B cathode. This novel regime operates for current densities typical for arcs, but the discharge remains in glow mode. The goal of the thesis is to characterize this novel plasma and understand the
mechanisms responsible for this unusual operation mode. Very high power pulsed called 'hyper-power' (up to 1 MW/pulse) are applied and the power is cut off after 1 ms just for preserving the set up. So, the hyper-power mode can be assimilated to a quasi-continuous operation.
The kinetics of plasma species, the sputtering and their dynamics in this kind of discharge remain to be discovered.
Preliminary studies demonstrated the conditions to achieve the hyper power glow regime. The thesis program will focus on the expérimental characterization of this non-standard operation condition, exploring the particularities of the plasma in these extreme situations. Additional modeling can be addressed during the thesis extending the global model developped for HiPIMS (High Power Impulse Magnetron Sputtering) to hyper-power discharges.

Thématique / Domaine / Contexte

Experimental diagnostic of plasmas, magnetized plasmas, heavy species transport, multi-ionized species, sputtering
Additional, global (OD) modeling can be performed

Plasmas physics, Spectrocopical plasma diagnostics, 0D kinetic 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 understand the novel discovered operation mode of a magnetized plasma in a glow regime but with extremely high curent densittis (up to 50 A/cm^2). The discharge operated at low pressure and hyper high power has features different from the typical HiPIMS (High Power Impulse Magnetron Sputtering).
The spectroscopy is the most powerful technique to characterize this type of plasma. It gives absolute information (heavy species density and temperature) by laser absorption using tuneable solid laser diodes, but it is also time-resolved. Hence, it is possible to distingush, during the pulse, the moment when each important species play a role in the discharge.
At such a power, multiple ionized species (gas or elements sputtered from the target) are expected to play. Their analysis will be performed using optical emission spectroscopy, in a first time.
However, the fluxes of the sputtered material is accessible by aser induced fluorescence, and this technique will be implemented, particularly for the metal (cathode) species.
Another issue is themomentum transfer between energetic species and the neutral ags, that can lead to gas rarefaction in the ionization region facing the cathode (magnetized trap). This will be also evaluated using spectrocopical methods.
Evantually, the electron density and temperature could be obtained by Thomson scattering, collaboration with ICARE laboratory.
Alltogether, this information must lead to a global understanding of the plasma behavior in this novel glow regime. The experiment can be guided or vice versa by the direct comparison to the modeling results provided by a global (0D) kinetic model, as part of the thesis.
Moreover, the optimization of the hyper-power discharge is the final goal of the present work.

Méthode

The main experimental techniques are :
- optical emission spectroscopy
- laser absorption spectroscopy
- laser induced fluorescence
- Thomson scattering
- ion flow-meter

Based on the obtained results, the best configuration (optimum) of this hyper-power discharge will be identified. Also the physical mechanisms leading to the plasma sustain will be identified.

Résultats attendus - Expected results

The experimental characterization of this new glow operation mode is expected.
Find the reason avoinding the (expected) transition towards the arc.
Explain the stable regime (pressure, current, gaz, target material, etc.)
Characterize the very high density of this plasma (> 10^20 m^-3), in spite of the low pressure (10 Pa).
Developing novel diagnostics for magnetized plamas.

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 Université Paris-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 will provide the spectroscopical equipment and the framework for developping advanced plasma diagnostics.
If the student is interested in modeling as well, we will provide an early version of HiPIMS ionization region model to be adapted to hyper-power regime.

Ouverture Internationale

The operation is this hyper-power regime has been reported before only twice, and for pulse duration < 100 µs. We were able to operate in glow mode for 1 ms (at least ten times longer) without transition to arc. Better understanding this plasma is absolutely novel at international level.
Tight collaboration with Sweden (KTH, Linckoping University) and Germany (IOM) is planned.

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 magnetized plasma diagnostic using Thomson scattering. 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 diagnostic des plasmas et particulièrement en spectroscopie. Des connaissances sur le transport des espèces chargées en plasmas magnétisés seraient un plus.
Egalement, des connaissances en cinétique réactionnelle et environnement de calcul scientifique (Matlab) seraient fortement appréciées.
The candidate should have solid knowledge of fundamentals in plasma physics and plasma diagnostics, particularly in spectroscopy. The knowledge on the transport of charged particles in magnetized plasmas would be well received. Finally, knowledge in plasma kinetics of heavy species and mathematics libraries (e.g. Matlab) would be highly appreciated.

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