Seminar

Institute for Plasma Research

Title : Investigations on the effect of plasma boundary and electrode asymmetry on plasma behavior in planar DC discharges

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Abstract: Plasmas are used in industry to control, enable various plasma-based chemical processes, tailor surface properties of materials, etc. It may be recalled that each material surface in contact with the plasma presents a boundary to the plasma with which the plasma interacts via the intervening sheath. A case in point is fusion plasmas where, as is well known, the first-wall properties play a crucial role in determining the edge plasma properties, which in turn determine the overall plasma behaviour – its heating, stability, confinement, etc. There are industries like the semiconductor industry where plasma is a basic tool for carrying out a wide variety of plasma-driven processes where strict control over the plasma parameters is of paramount importance. In such systems, the plasma interacts with a complex array of surfaces comprising the vessel wall, the target material, the substrate, etc., in the presence of different reactive gases. Although extensive investigations have been carried out as to how plasmas react with different material surfaces, alter and shape their properties, etc., very little is known about how these materials (Plasma boundary) affect the plasma in turn. In this regard, the work presented in this talk is an attempt to determine the effects of different surfaces / boundaries have on properties of plasma using the simplest possible combination of materials *viz*, conductors and insulators etc. in DC discharges.

In DC discharges, it is standard practice to use a conducting vacuum vessel that is electrically grounded. Since the cathode is also grounded, the conducting chamber works as an extension of the cathode, providing an unlimited auxiliary cathode area relative to the anode. Such a system with a conducting chamber is labelled the Conducting Boundary or CB configuration in this work. To provide alternate boundary conditions to such a scenario, two more boundaries were considered. In one of these, the entire chamber wall along with other conducting surfaces were insulated with mica/glass tubes, *etc.* except the plasma-facing surfaces of electrodes. Such a system is termed the Large Volume Insulating Boundary (LVIB) configuration. One sees immediately that the latter configuration limits the cathode area severely. In effect, plasma in the entire chamber is driven by the planar anode and cathode only. To provide an alternative to the LVIB system in terms of volume, another insulated boundary system, the Small Volume Insulating Boundary (SVIB) system was configured, in which the electrodes are enclosed in a glass tube with mica sheets used for blocking escape of the plasma from the top and bottom. It was observed that the discharge shows completely distinct behaviour with the two contrasting boundaries (conducting vis-à-vis insulating). A relatively much higher discharge voltage is required to maintain the plasma in LVIB/SVIB than in CB configuration. In addition to these, a leaky boundary was also created by introducing an annular gap in SVIB, which provides a new configuration termed the Leaky Boundary (LB) system in this work. LB discharges have exhibited several interesting nonlinear properties like Negative Differential Resistance (NDR), hysteresis in the $V-I$ characteristics, anode glows that exhibit

features like splitting into multiple blobs, spontaneous rotation of blobs, etc. Physically and electrically, LB discharges are found either to operate in the SVIB mode or the CB mode, depending on the ratio of the Debye length (at the gap) to the gap width. If this ratio is greater than unity, the plasma produced in the glass tube is unable to escape into the outer conducting chamber and the LB discharge behaves predominantly as an SVIB discharge with almost matching $V-I$ characteristics. On the other hand, as the plasma density rises with increasing discharge current, a point is reached when the ratio of the Debye length to the gap width falls below unity and the plasma escapes into the outer conducting chamber. In the latter case, the $V-I$ characteristic of the LB discharge mimics that of the CB discharge. It is during the switch from the SVIB to CB regime of operation that the NDR mentioned above is observed.

This talk will discuss the above in more detail in light of sheath and other nonlinear phenomena.

References:

[1] Prashant K. Barnwal, A. Ganguli, R. Narayanan, and R. D. Tarey, *Effect of plasma boundary and electrode asymmetry in planar DC discharge system*, Phys. Plasmas 29, 072102 (2022).

[2] Prashant K. Barnwal, S. Kar, R. Narayanan, R. D. Tarey, and A. Ganguli, *Plasma boundary induced electron to ion sheath transition in planar DC discharge,* Phys. Plasmas 27, 012110 (2020).

[3] Prashant K. Barnwal, A. Ganguli, and R. Narayanan, *Observation of plasma boundary induced Negative Differential Resistance (NDR) in planar DC discharge system* (Manuscript under review, Physica Scripta. Nov 2022).

[4] *Investigation on rotating anode glows at high pressures in parallel plate DC discharge system* (Manuscript under preparation 2023).