Two different techniques to obtain reliable electric field measurements in plasmas

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Résumé

The electric field is one of the most relevant characteristics when studying plasmas, due to the fact that it dominates charged particles fluxes, their energy distributions and the charge densities. Over the years, diverse strategies were develop to measure E-field present in different kind of plasmas: RF discharges, plasma jets, glow discharge, etc. In this work, two different methods to measure E-field strengths are presented. Both of them are non-intrusive methods that take advantage of the Stark effect on the 2S level of hydrogen, but the experimental approach of both techniques is very different.

The first one is a laser spectroscopic technique, by means of two-photon excitation of the 1S–2S transition followed by subsequent photo-ionization. The measurements are performed in the cathode fall region of a hollow cathode discharge (HCD) operated in pure hydrogen and deuterium. The technique is based in the shifting and splitting of the 2S level of hydrogen and deuterium caused by the Stark effect. Two photon excitation of the 1S-2S transition is induced by two counter propagating circularly polarized laser beams of opposite directions (ΔL=0), providing Doppler free measurements, and followed by optogalvanic detection. The local E-field strength value is determined measuring the separation in GHz of the $2P_{1/2}$ and $2P_{3/2}$ components and comparing it with the theoretical calculations. The UV radiation is generated by an injection seeded Q-switched Nd:YAG laser (repetition rate of 10 Hz), pumping a second laser based of non-linear crystals (OPO-OPA-SFG). The 243 nm obtained radiation works in single-longitudinal mode, with energy up to 5 mJ, a temporal duration of 2.5 ns and 300 MHz bandwidth. The two counter propagating beams are focalized in the upper central part of the discharge, in a tiny overlapping volume of 100 mm in diameter and 10 mm in length and parallel to the cathode surface. The plasma is generated in a home-made HCD, with two stainless steel peaked anodes, and a cylindrical cathode placed between the anodes. The electric field measurement can be performed in a wide range of plasma conditions (from 400 to 900 Pa) and currents (from 50 to 300 mA) [1], with cathodes of different diameter and material [2], even changing the buffer gas (hydrogen or deuterium).

The second one is called EFILE (electric field induced Lyman-α emission) is based on the Lyman-α emission of a probing hydrogen atomic beam. It is known that the $2S_{1/2}$ state does not have exactly the same energy as the $2P_{1/2}$ state. It lies higher by a small amount of an energy corresponding to a frequency of 1057 MHz (Lamb-shift). The $2S_{1/2}$ level is metastable, the transition to the ground state $1S_{1/2}$ being forbidden. The lifetime of $2S_{1/2}$ is about 0.14 s, which is very long compared to 1.6×10^{-9} s, the lifetime of the $2P_{1/2}$ state. In the presence of an externally applied electric field, quenching of the metastable 2S state of hydrogen and hydrogen-like atoms leads to the production of Lyman-α radiation, resulting from so-called Stark mixing between the $2S_{1/2}$ and $2P_{1/2}$ levels. A weak electric field introduces a perturbation to the full energy of an electron in a given state. The perturbation approach is valid as long as the Stark shift induced by the electric field is small in comparison to the energy difference between the studied levels. In the limit of a constant field, we find Lamb's result with a quadratic dependence of the measured Lyman-α radiation versus electric field amplitude. At the resonance corresponding to an oscillating electric field with frequency around 1057 MHz, the above calculation gives an amplification factor of more than two orders of magnitude, which is independent of the value of the field. This technique has been successfully tested in vacuum and in plasma [3], with a constant and RF external electric field [4]. The next step is to transfer this diagnostic to a linear magnetized plasma column [5], to measure precisely the radial electric field distribution in the plasma.

Références

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