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Dust as a diagnostic tool to measure potential distribution in a plasma

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Here we present a novel use of small dust particles to try to obtain the electrical potential distribution in the Inertial Electrostatic Confinement (IEC) plasma and sheath of a planar rf-discharge. For IEC plasma, the idea is to analyse the trajectories of dust particles as they fall, acquire charge, and subsequently get deflected. For sheath, the diagnostic technique is based on measurement of the equilibrium position of different size dust grains levitated above the powered electrode in an rf-discharge. Because the dust charge is a function of multiple plasma parameters, and the dust charge adjusts itself upon changes in plasma conditions instantly, dust particles are an ideal diagnostic tool. The main advantage of such diagnostic system is its simplicity. This is because the key measurements in such diagnostic system are the position of the dust particle and its motion following a perturbation. This technique only requires access to a discharge chamber, dust particles, an illumination laser and a camera to capture the motion of the dust.

The use of electrostatic fields to confine fusion plasma was first reported in [1]. Nuclear fusion in such case can be achieved by injecting ions into a spherically or cylindrically symmetric electrostatic potential well where ions concentrate at the centre, resulting in a core of increased ion density. The technique where particles are trapped in an electrostatic well is called IEC and is being used for fusion with large neutron counts readily being achieved. The profile of electrostatic potential well is a key factor for the whole process, but the electrical potential in the plasma in such devices has not been mapped properly.

Therefore the aim of our study is to find the “virtual anode” at the centre of the cathode by [2] using a dust as a diagnostic tool. In the case of an IEC, the virtual anode is an area with higher number of positive charge (higher positive ion density) than the surrounding area. In a negative potential well, this will appear as a bump in the well which repels positive charge and attracts negative charge like an anode even though there is no physical structure with a potential imposed on it (such as metal rings).

The experiment was conducted in a cylindrical stainless steel vacuum chamber with a 40 cm inner diameter and a height of 30 cm. The IEC consists of an anode outer grid which was a 11.5 cm diameter cylinder made of fine-mesh stainless steel with a wire spacing of 2mm which is comparable to the Debye length. The inner grid consisted of two parallel rings with a diameter of 20mm and separated by 20mm. A negative bias is placed on the cathode with respect to the anode, which was kept at ground potential. This potential difference was used to break down the hydrogen gas and create a discharge. The cathode was illuminate with a Helium-Neon laser which was shone along the ion channel. A schematic diagram can be seen in Figure 1. A CCD camera was positioned perpendicular to the ion channel focused on the centre of the rings.

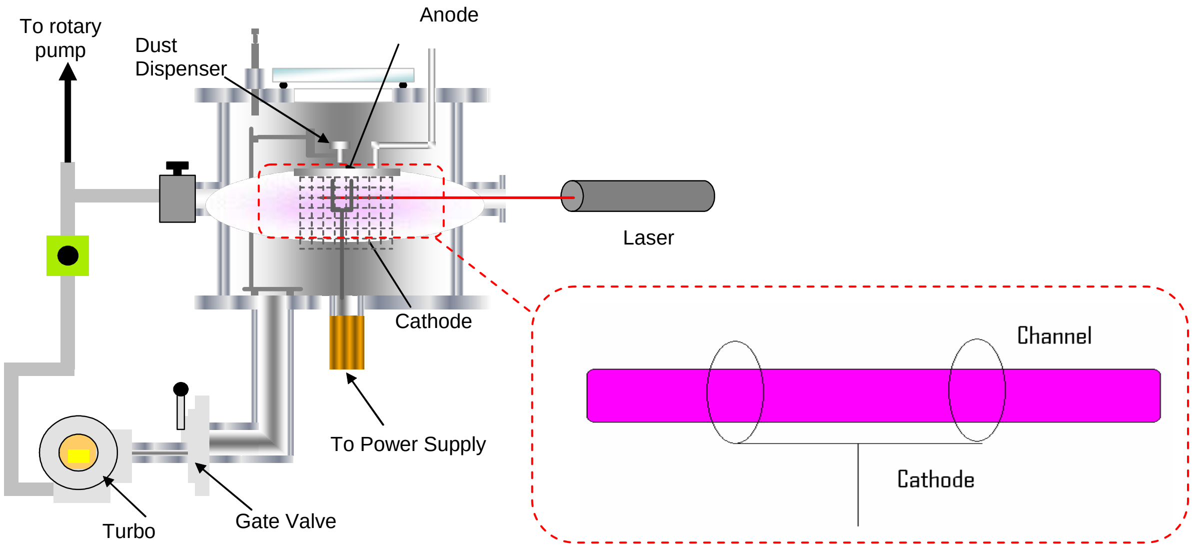

Figure 1. Schematic diagram of setup (on the insert the schematic diagram of cathode and ion channel)

The dust particles were dropped from an electrically operated shaker located 4cm directly above the cathode such that the dust particles are dropped approximately between the cathode rings. The trajectories of the dusts are captured by a CCD camera. The images were later captured onto computer where they were analyzed using the appropriate software to measure the trajectories of the dusts. As a control, dust was dropped into the system with the same pressure and no discharge present. These images were captured to be used for a comparison with the discharge pictures.

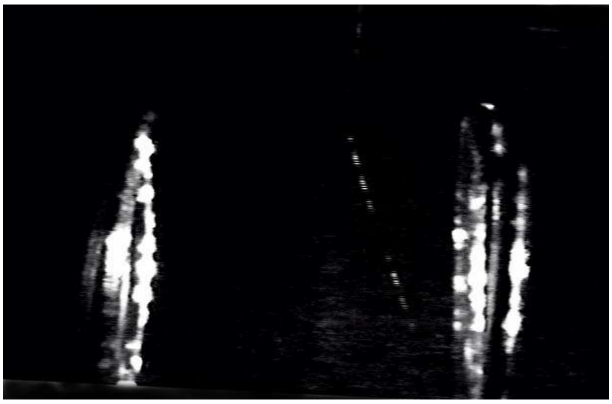

Figure 2. Dust deflection, dust particle being deflected towards the rings are visible on the left hand side

Our observations of deflection away from the centre of the device between the two rings of the cathode (see Fig. 2) are in contradiction with the expected attraction of negatively charged particle towards the virtual anode. A possible explanation for this can be referred to the influence of ion drag force [3]. But this in turn contradicts with the accepted model of ICP fusion which states that "fusion occurs due to injecting ions into a spherically or cylindrically symmetric dual-grid with a hollow cathode as the inner grid, a negative bias voltage is put on the cathode creating a potential well at the centre of the device". The ions are accelerated to the centre of the grid where they will collide with each other. However, our data showed that the ion flux is actually directed away from the centre of the device. Analysis of the dust trajectories gave qualitative information about the shape of the potential well in the ion beam. In the future, such technique promises to give quantitative measurements of the electric field and provide additional information on the direction of the ion beam.

To measure the width of the sheath, we measured the levitation height of nanometre sized particles. According to [3], the particle size becomes smaller as the potential required for levitation becomes very small. Essentially, if the particles are sub-micrometer sized, they will effectively be levitated on the edge of the sheath. As seen in Figure 3, the width of the sheath is well defined and can be measured directly.

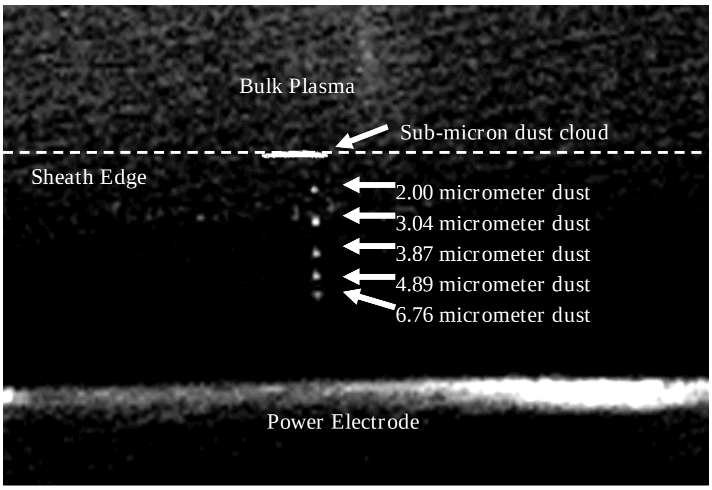

Figure 3 Levitation of sub-micrometer particle used in the determination of sheath width

It is well known that dusts of different sizes are levitated in positions within the sheath corresponding to their values of non-uniform sheath electric field [3]. The image on Fig 3 is a combination of six images, each from the same discharge parameters, but with different dusts used. The profiles of E were determined by using particle of different sizes levitated at different heights in the sheath for different discharge parameters. Typical E vs h dependence is presented on Figure 4.

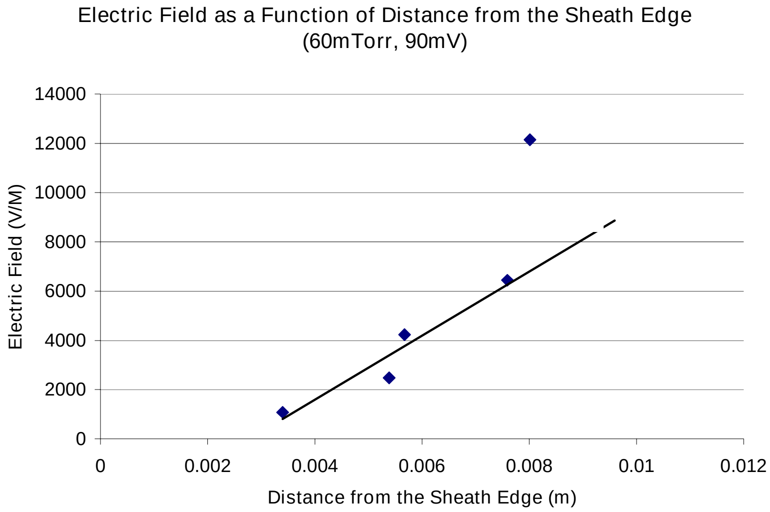

Figure 3 Graphs showing the electric fields calculated at various heights of the sheath

The main advantage of measuring the electric field by using dust levitation height is that only the dust charge is required which can be obtained accurately by using VRT [4]. This suggests the viability of a plasma monitoring system by using dust levitation height measurements. The results also showed the validity of the parabolic sheath model and indicated the invalidity of the dust charge approximation using the plasma floating potential as in cases where the dust is levitated deeper in the sheath. This approximation fails as the ion and electron densities in the sheath differ significantly from that of the bulk plasma. By locating the point at which this approximation fails, one can identify the sheath and the presheath interface which is consistent with current models.

References

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