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A combination sensor for the diagnostic of particle and energy fluxes in process plasmas

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Particle and energy fluxes play an important role for the growth of thin films on substrates and the modification and activation of surfaces [1]. Specifically, ion fluxes and energies and, subsequently, the resulting substrate temperature can have a significant impact on film hardness, adhesion and density [2, 3, 4]. Here, we present an in-house built combined diagnostic for the study of ion fluxes and energy distributions as well as the determination of energy flux contributions of ions and neutrals to the substrate [5]. This combination sensor consists of a Retarding-Field-Analyzer (RFA) grid system and a Passive-Thermal-Probe (PTP) as a collector [6, 7] and is, hence, called Retarding-Field-Thermal-Probe (RFTP). The RFA grid system enables energy filtering of ions, while the PTP allows for an almost simultaneous measurement of the energy flux density to the substrate.

The RFTP consists of a three-grid RFA system for energy filtering of charged particles in combination with a PTP as the collector (see Fig. 1). The grids are stainless steel with hexagonally aligned holes with a diameter of 0.4 mm and a center-to-center distance of 0.5 mm. They are vertically spaced in a distance of 0.3 mm by PEEK grid holders. The collector is placed 2 mm below the first grid resulting in a probe length of 3.5 mm.

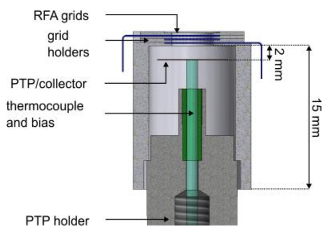

Figure 1: RFTP grid system and collector.

To determine the field of application and capabilities of the probe it was employed in three different process plasmas, namely an asymmetrical 13.56 MHz CCRF plasma, a DCMS and a HiPIMS. Parameters such as pressure and power were varied. Across these experiments ion energy distributions (IEDs) as well as retarding-potential dependent energy flux density (EFD) measurements were carried out.

Measurements of the IEDs in all process plasmas show the expected results. For the CCRF plasma ions free falling from the plasma potential onto the grounded probe orifice are detected. In case HiPIMS thermalized ions at a 1-2 eV are visible. Additionally, the characteristic high energy tail of HiPIMS can clearly be observed in the results for the HiPIMS case. From pressure variation it becomes apparent that between 5 Pa and 10 Pa the signal intensity drops significantly. This is attributed to a strong increase of charge exchange collisions of the ions inside the probe, resulting in fewer ions reaching the collector. Therefore, we conclude an upper pressure limit of approximately 10 Pa for the operation of the probe.

More insight into the energy flux to the substrate can be gained by examining the retarding potential dependent EFD measured by the RFTP. A clear reduction in the EFD with increasing retardation voltage can be observed in the results. This is consistent with a reduction of the EFD due to the retardation of ions which, consequently, do not reach the collector. However, the EFD for high retardation voltages does not approach zero. Instead, a residual EFD remains, which has to be carried by neutral species. From this data an ionization flux fraction is calculated by

$$a_{ion} = \frac{j - j_n}{j}.$$

By determining the ionization flux fraction for different pressures in the CCRF plasma, it becomes evident that a_{ion} increases with rising pressure, as the plasma density also rises. In HiPIMS calculating a_{ion} yields higher values for DCMS. This result is in contrast to the literature where experiments show a higher ionization flux fraction for HiPIMS [8] and warrants further measurements with our diagnostic to verify the data.

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