On the combination of common and non-conventional probe diagnostics for process plasmas

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The wide range and ever-growing applications of plasma processes in research and industry require an equally improved diversity and accessibility of suitable plasma diagnostic methods. In the present study, diagnostics of electrons and ions in plasmas and fluxes of charged and neutral species toward plasma-facing surfaces by non-optical methods will be reviewed and discussed.

To further enhance the determination of different fluxes of species, their energies, and behavior influencing the surface processes, custom-built combinations of plasma process diagnostics have been developed. For example, we present a retarding field energy analyzer where a passive thermal probe substitutes the collector. By doing so, we can determine the energy distribution of the charged ions, their energy flux density at a certain potential, and the power deposited onto a substrate. Another advantage is that the thermal probe can even measure the power deposited by incoming (fast) neutrals and by other contributions (radiation, chemical reactions, film condensation) when the grids suppress the ions.

The focus of this general invited talk (review) is laid on the fundamentals of conventional probe-based plasma diagnostic methods as Langmuir probes (LPs), Faraday cups (FCs) and retarding field analyzers (RFA), but as well as on the principles of non-conventional diagnostics as calorimetric and force probes (CPs, FPs) [1]. These rather simple methods are useful tools for the measurement of overall, not species resolved, ion and neutral fluxes toward surfaces, see Fig. 1.

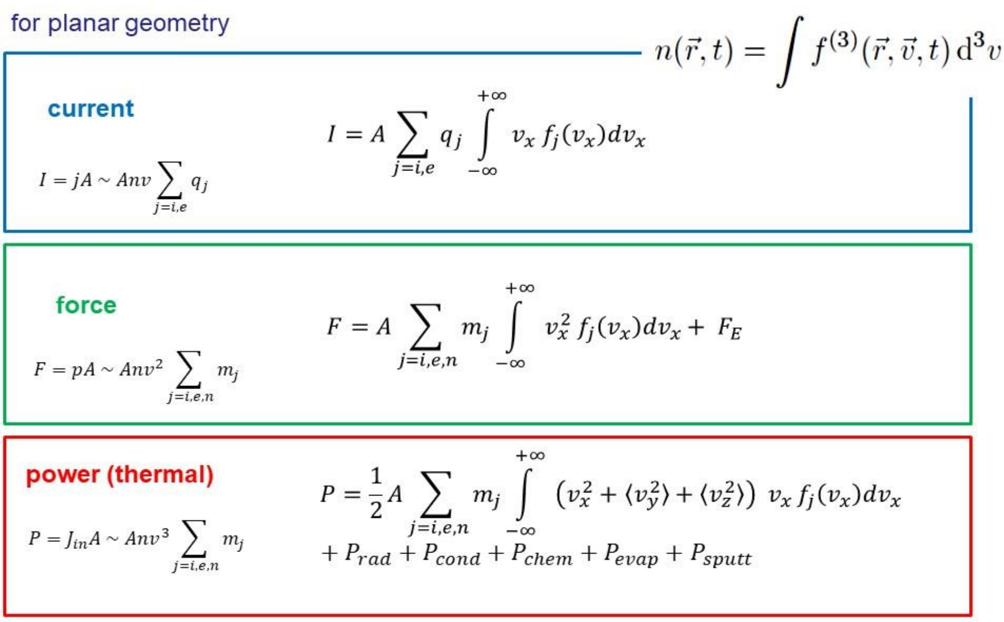

Fig. 1: Moments of the VDF of involved species result in particle flux (current), momentum flux (force) and energy flux (power). In addition, other phenomena can also contribute to the integral fluxes.

For example, RFAs provide overall ion energy distribution functions, whereas CPs and FPs can even deliver information about fluxes of fast neutrals and other contributions which are not related to charge carriers (Fig. 1). Although many of these diagnostics have their roots in the beginnings of plasma research, they were gradually refined to match the requirements of plasma environments in industry, such as rf-discharges, reactive plasmas, dusty plasmas, and atmospheric pressure plasmas. Examples for "non-conventional" diagnostics, which are also applicable in plasma processes, are the determination of the total energy fluxes from plasma to substrate by calorimetric probes [2,3] and the measurement of momentum transfer due to sputtered particles or changes of plasma pressure by force probes [4,5].

Of particular interest is the combination of different types of probes, e.g. retarding field analyzer (RFA) and passive thermal probe (PTP). With a retarding field energy analyzer, one can obtain the ion energy distribution in a plasma by measuring the current at the collector depending on the applied discriminator voltage at the scan grid. A passive thermal probe determines the energy flux density coming from a process plasma by measuring the temperature change of a dummy substrate. The PTP serves as collector, in front of which three centrally aligned grids are operated as the retarding field system [6]. By doing so, we can determine the energy distribution of the charged ions, their energy flux density at a certain potential, and their power deposited onto a substrate. An advantage is that the thermal probe replacing the collector can even measure the power deposited by incoming (fast) neutrals, by the background gas and by other phenomena when the grids keep away the ions. Hence, the ion energy distribution (IED) can be determined regarding the energy exchange of the neutral background gas with the ions extracted from the plasma source. Combining these two powerful diagnostics yields information they neither can deliver on their own. The probe has been tested in three different plasma environments: ion beam source, magnetron sputtering and radio frequency discharge plasma. In Fig. 2 a typical measurement for HiPIMS sputtering of a carbon target in an argon atmosphere is shown. Although the ion current (and also the energy influx by the ions) vanishes above the discriminator voltage of about +20 V which corresponds to the plasma potential, there is still a remarkable energy influx which originates from other contributions like fast neutrals (from the target and due to charge exchange collisions) and carbon thin film condensation at the PTP collector (substrate).

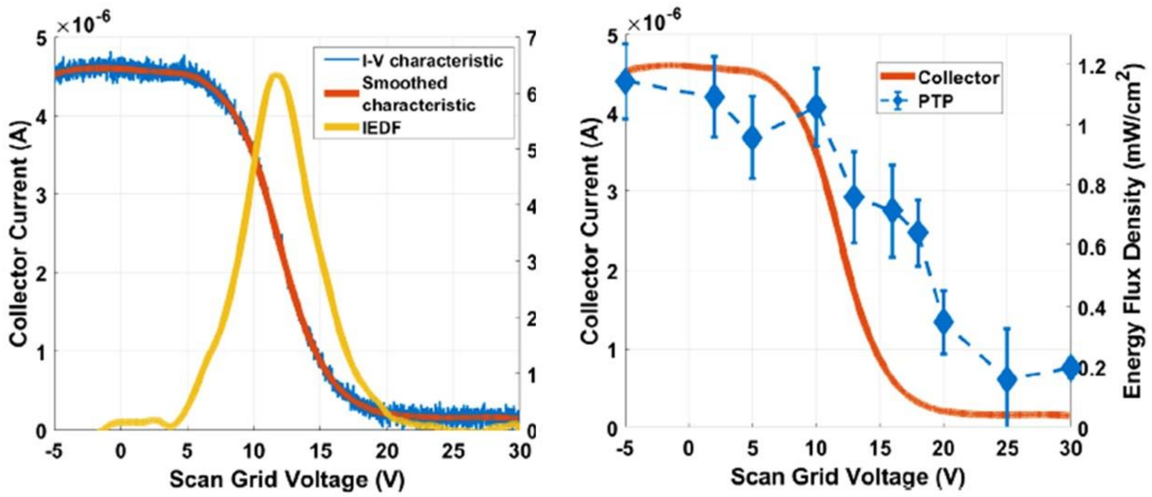

Fig. 2: I-V characteristic of the collector and the derived IEDF measured in a HiPIMS system (left) and comparison of the collector current due to the ions with the integral energy influx (right).
The working gas is Ar at 0,36 Pa and the C target was operated at 800 W.
The combined sensor (RFA + PTP) was placed in the substrate region.

Another example for an advanced probe diagnostic is the combination of a quartz crystal microbalance (QCM) with an interferometric force probe (FP) [6,7]. In the experiment, an aluminum target was sputtered by an ion beam of 1200 eV. The sputtered atoms are deposited either onto a "simple" QCM or onto a FP where the probe is the QCM. The incoming – either sticking or reflecting – species transfer their momentum and contribute to the thin film growth (Fig. 3). The probe (substrate) was scanned around the target in order to observe the angular dependence of ion beam sputtering. The transfer of momentum due to sticking, e.g. film forming particles (at small angles) is about factor 1 and, therefore, smaller compared to larger angles where more reflection (and less deposition) occurs with a momentum transfer of about factor 2. The angular dependence of the deposition rate is vice versa.

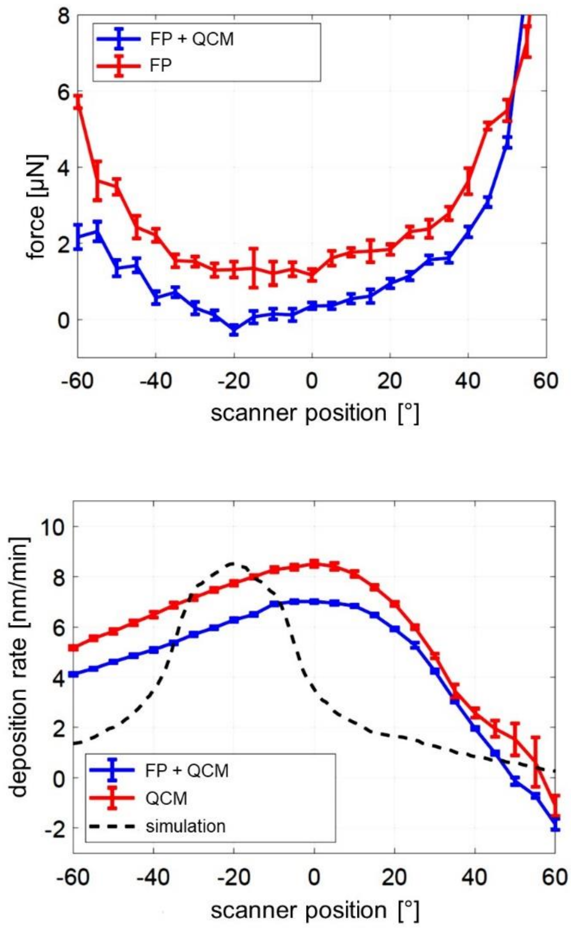

Fig. 3: Measured force (top) and deposition rate (bottom) by "only" the force probe and by the combined FP + QCM in dependence on the angle of the ejected Al atoms which is related to the sputtering angle.

The current trend in the miniaturization of sensors, adopted from the manufacturing of MEMS, will allow more and more measurements with high spatial resolution in miniaturized plasma sources, like plasma jets or micro discharges [8], respectively.

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