Ball-pen probe – a useful tool for measuring the plasma potential in magnetized plasma

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Abstract

Methods of direct measurement of the plasma potential and their significance for characterizing the scrape-off layer plasma in fusion devices are briefly discussed. Stress is given to description of the ball-pen probe and its use for plasma potential determination in a broad range of magnetized plasmas.

Introduction

The plasma potential belongs among the most fundamental and most important plasma parameters since it determines the electric field, which in turn controls particle drifts and losses. In spite of its relevance also for theoretical and numerical plasma models, there are very few diagnostic tools to determine the plasma potential directly; in particular, if high spatial and temporal resolution is required. Through the Poisson's equation the plasma potential is determined solely by the number densities of positive and negative charge carriers, i.e. the particle drifts do not influence the plasma potential. In border areas of fusion devices, i.e. in the areas close to the last closed flux surface, plasma fluctuations play a significant role. In this region, simulation and experiment consistently show coherent in-phase fluctuations in density, plasma potential and also electron temperature. Ion-saturation current measurements turn out to reproduce density fluctuations quite well. Fluctuations in the floating potential, however, are strongly influenced by temperature fluctuations and, hence, are significantly distorted compared to the actual plasma potential. Therefore, interpreting them as fluctuations of plasma potential while disregarding temperature effects is not justified near the separatrix of hot fusion plasmas. Here, floating potential measurements led to corrupted results on the $E \times B$ dynamics of turbulent structures in the context of, e.g., turbulent particle and momentum transport or turbulence characterization on the basis of density–potential phase relations [1]. For proper characterization of plasma turbulence in scrape off layer plasma a suitable method for direct display of plasma potential is needed.

The emissive probe

A well-known method for direct measurement of plasma potential is an emitting probe, see e.g. [2]. Emissive probes were used also for measuring the radial fluctuation-induced particle flux and other essential parameters of edge turbulence in magnetized toroidal hot plasmas, see e.g. [3,4]. There are several ways how to use the emissive probe, but for direct measurement of the plasma potential, only the method of a sufficiently emitting probe is suitable. The floating potential of a sufficiently emitting probe adjusts namely close to the plasma potential. For sufficiently high emission, such a probe works also in case of electron drifts or beams in the plasma and is thus the most important diagnostic tool to detect strong potential variations in a plasma, for instance, with double layers and other nonlinear potential structures [5]. There are in principle three methods how to heat the probe in order to emit electrons: (i) direct heating of a suitable wire loop by DC or AC current [3], (ii) indirect heating of a graphite or LaB_6 pellet by an electrically powered heater [6] and (iii) heating of a graphite or LaB_6 pellet by a power laser, typically in infrared region [7]. In construction (i), thoriated tungsten is usually used for the wire loop; the best method of making an electrical connection to the tungsten wire is to crimp it mechanically to copper wire leads, see e.g. [8]. Graphite or LaB_6 were selected in constructions (ii) and (iii) [9] because of their low work function (e.g. W_{LaB6}=2.66 eV). The emissive probe does not need a magnetic field for its operation, but it can be used also in magnetized plasmas. For tracing the plasma potential fluctuations it is vital to ensure sufficiently high bandwidth of the data acquisition system.

The problem with the emissive probe, apart from the fact that it is a comparatively fragile device, consists in the difference between the floating potential of a sufficiently emitting probe and the "true" plasma potential. In earlier works, see e.g. [10], it was referred that the floating potential of a sufficiently emitting probe was always lower than plasma potential by approximately 0.7 times the electron temperature in volts. Newer works disclosed the dependence of this difference on the plasma electron temperature and showed that for lower plasma electron temperature the floating potential of a sufficiently emitting probe might be a good indicator of plasma potential or even can exceed the plasma potential, see e.g. [11,12,13,14]. Fig. 1 shows a sample of the results of a simple 1D model that was presented in [14].

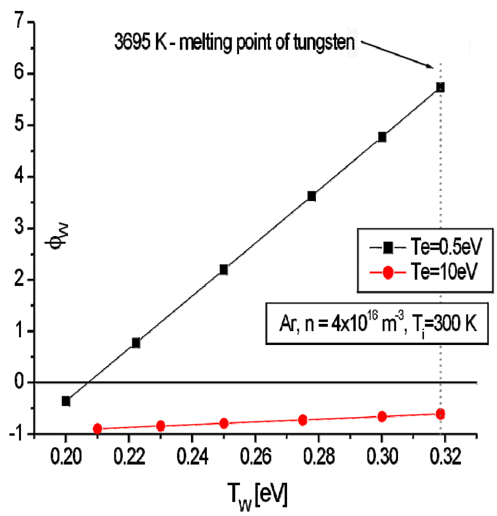

Fig. 1. Potential on the plasma-facing emitting wall for case of tungsten and Maxwellian distribution of emitted electrons [14].

The ball-pen probe

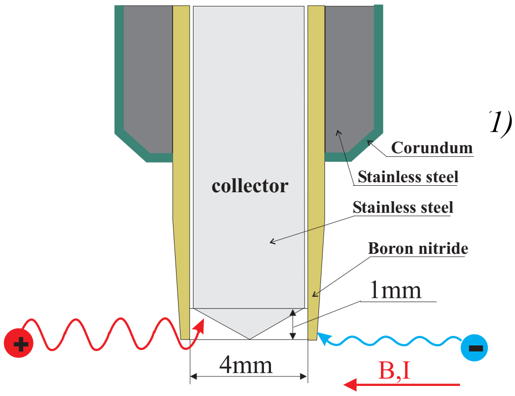

Fig. 2. Schematic cross section of the ball-pen probe with the Boron nitride shield [15].

The ball-pen probe is a specially designed probe that was developed for direct measurements of the plasma potential in magnetized hot plasma. The principle of this method is to reduce the electron saturation current to the same magnitude as that of the ion saturation current. Provided that the plasma is Maxwellian and the saturated ion and electron current can be assumed constant (i.e. the sheath thickness is small compared to the probe radius), the floating potential of the probe becomes in such case identical to the plasma potential. This goal is attained by a shield, which screens off an adjustable part of the electron current from the probe collector due to the much smaller gyro–radius of the electrons, see Fig. 2 [15]. First systematic measurements have been performed in the CASTOR tokamak [16,17]. The ball-pen probe consists of a metallic collector, which is shielded by an insulating tube; the probe head itself must be oriented perpendicular to magnetic field lines. Its construction is similar to katsumata type probe, which however, uses metallic shield [18]. For its simplicity and rugged construction the ball-pen probe presents a promising diagnostic tool for tokamak-like plasma and for this purpose was already frequently used, see e.g. [19,20,21,22]. The ball-pen probe belongs to the group of ion-sensitive probes that are subject to intensive 3D modeling [23].

In the plasma-aided deposition systems, e.g. magnetrons, it is often sufficient to know just the spatial course of the plasma potential; for that the ball-pen probe would be an ideal diagnostic tool. However, the typical values of magnetic field used in such systems are by orders of magnitude lower than in tokamaks. Moreover, magnetrons operate with low-temperature plasmas. Our results represent therefore the first systematic measurements with the ball-pen probe in a low-temperature and weakly magnetized plasma. In Fig. 3 we present the systematic measurements of the radial courses of floating and plasma potential with ball-pen probe in Ar DC discharge in cylindrical magnetron. The experimental system is described in detail in [24]. We have used a radially movable ball-pen probe with movable collector 1.2 mm in diameter accommodated

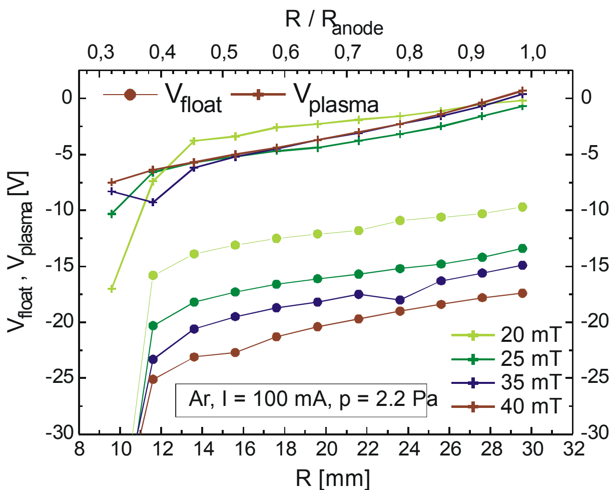

Fig. 3. Radial profiles of floating potential and plasma potential in the cylindrical magnetron measured by ball-pen probe with the magnetic induction as a parameter.

within a ceramic shielding tube. The floating potential was measured by ball-pen probe with collector protruding by 2 mm, the plasma potential with collector retracted by 10 mm with respect to the ceramic shielding tube edge. In more detail our results can be found in [25,26]. It can therefore be concluded that our experiments performed in the cylindrical magnetron system suggest that the ball-pen probe can be successfully applied for the direct display of the plasma potential also in the low temperature slightly magnetized low pressure plasma.

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