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B.S. Schneider

Robust Highly Emissive Probe for Plasma Potential Measurements in the Edge Region of Toroidal Plasmas

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PROCEEDINGS OF SCIENCE

Robust Highly Emissive Probe For Plasma Potential Measurements In The Edge Region Of Toroidal Plasmas

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B.S. Schneider[*][a], **S. Costea**[a], **C. Ionita**[a], **R. Schrittwieser**[a], **V. Naulin**[b], **J.J. Rasmussen**[b], **R. Stärz**[ac], **N. Vianello**[d], **J. Kovacic**[e] **and T. Gyergyek**[f]
[a]*Institute for Ion Physics and Applied Physics, University of Innsbruck*
Technikerstr. 25, 6020 Innsbruck, Austria
[b]*DTU Physics, Technical University of Denmark*
Anker Engelunds Vej 1, 2800 Kgs. Lyngby, Denmark
[c]*Mechatronic Department, Management Center Innsbruck*
Universitätsstraße 15, 6020 Innsbruck, Austria
[d]*Centre de Recherches en Physique des Plasmas, Ecole Polytechnique Fédérale de Lausanne*
CH-1015 Lausanne, Switzerland
[e]*Jozef Stefan Institute*
Jamova cesta 39, 1000 Ljubljana, Slovenia
[f]*Faculty of Electrical Engineering, University of Ljubljana*
Trzaska 25, 1000 Ljubljana Slovenia
E-mail: `bernd.s.schneider@uibk.ac.at`, `stefan.costea@uibk.ac.at`, `codrina.ionita@uibk.ac.at`, `roman.schrittwieser@uibk.ac.at`, `vona@fysik.dtu.dk`, `jjra@fysik.dtu.dk`, `Ronald.Staerz@mci.edu`, `nicola.vianello@epfl.ch`, `jernej.kovacic@ijs.si`, `tomaz.gyergyek@ijs.si`

In this work we present results of a newly developed highly emissive Langmuir probe with LaB_6, TiC and pure carbon probe tips for the use in high temperature plasmas and dense technical plasmas. The work function, the main parameters for electron emission, of LaB_6 is 2,7 eV, that of TiC 3,4 eV, and 4,6 eV for C. Electrical probes have the advantage of measuring the plasma potential directly with high temporal resolution at the position of the probe. First measurements are carried out in a Double Plasma machine with 1,0 or 1,5 mm diameter probe tips of LaB_6, TiC and C.

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[*] Speaker.

1. Introduction

Electron-Emissive Probes (EEP) have first been mentioned in 1923 by noble prize winner Irving Langmuir [1]. He also first described how to determine the plasma potential from the current-voltage (*I*-*V*) characteristic of a cold probe. Since then, a great variety of probes, utilizing various measuring techniques in all kinds of plasmas, have been developed, with the research and development continuing also today.

For plasma diagnostics electrical probes have the advantage of measuring plasma parameters directly at the position of the probe. In particular, since EEPs float on or close by the plasma potential they are able to display this highly important plasma parameter directly with the temporal resolution limited practically only by the data acquisition system. With a cold probe, the plasma potential can be determined only indirectly, either from its floating potential, provided the electron temperature is known too, or from the electron saturation current "knee" of its *I*-*V* characteristic [2–6].

Here we present a detailed comparison between plasma potential measurements by means of a newly developed highly emissive and robust EEP and two other methods: (i) from a cold probe I-V characteristic using the "knee method", and (ii) from the inflection point of the EEP characteristic [2–7]. With sufficient heating of the probe pin, the EEP's floating potential does indeed become more positive to eventually reach a value which agrees very well with the values of the plasma potential determined by the above-mentioned methods [7–13]. Having a probe head with several suitably arranged emissive probes, also electrical fields and their fluctuations can be determined [9, 11, 13, 14]. Electric field fluctuations are directly related to cross-field particle transport in tokamaks and stellarators, which can affect plasma confinement.

2. Probe Design

Prototypes of such probe have been developed using 1 mm and 1,5 mm diameter pins of LaB_6, TiC-covered carbon and pure carbon. While the work function of LaB_6 is 2,7 eV [15] and that of TiC 3,4 eV [15], carbon's work function is 4,6 eV [16]. The melting points of these three materials are 2482 K [16] (LaB_6), 3430 K (TiC) [18] and 4023 K (C) [19]. Although carbon has the highest heat resistance, its high work function makes it necessary to heat it to much higher temperatures to emit an electron current density equal to that emitted by LaB_6 or TiC. The probe tip of the LaB_6 EEP (LaBP) consists of a LaB_6 rod with a diameter of 1,5 mm and a total length of 10 mm. The rod is electrically heated through a carbon ring contact in the front and a Mo cylindrical holder at the rear end of the LaB_6 rod. The carbon contact ring acts as one of the few materials that sufficiently resists the heat load during the total measurement time without risk of oxidizing or melting. For the emissive TiC and C probe (TiCP and CP) the rear Mo holder has been exchanged by a graphite holder to resist even higher temperatures. The front contact ring has been pushed further to the tip for more stable operation. The heated TiC covered graphite probe and pure graphite tip has a diameter of 1,0 mm and a total length of 30 mm. The outer shielding material of the probe has been exchanged by graphite instead of Al_2O_3 massively reducing O_2 poisoning of the plasma, when the probe is heated. The inner heating circuit of both probes is partly isolated by ceramic tubes. The probe tip of both probes protrudes 3 mm from the isolation into the argon plasma used for tests.

3. Experimental device

The plasma is produced by a gas discharge in a 900 mm long, 500 mm diameter large cylindrical vacuum chamber, the Innsbruck DPM (Double-Plasma Machine). The operating gas pressure range is between p_{cham} = 5·10^{-4} and 10^{-2} mbar. Two negatively biased 0,15 mm tungsten filaments at the top of the chamber are heated by two additional power supplies as sketched in Fig. 1. Adjusting the heating current of the filaments $I_{heat,fil}$ accordingly a stable, almost homogeneous plasma can be produced with a discharge current $I_{discharge1,2}$ from the filaments to the chamber wall, each lying between 50 and 1000 mA. In this case the discharge voltage, $V_{discharge1,2}$ = 78 V. The achieved plasma density in the chamber lies between 10^{14} and 5·10^{17} m^{-3} with an electron temperature T_e ranging between 0,5 to 2 eV. Under these plasma conditions the probe pin temperature necessary to produce an electron current density approximately equal to that of the plasma ranges between $T_{W,LaB6}$ = 1250 and 1750 K for LaB_6, $T_{W,TiC}$ = 1320 to 1800 K for TiC and $T_{W,C}$ = 2000 to 2500 K for C. The emissive probe is mounted on the axis of the vacuum cylinder at one end of the chamber reaching 100 mm far into the plasma. A 60A-20V power supply ensures the necessary power to heat the emissive probe tips to the necessary temperatures for both 1 mm and 1,5 mm diameter LaB_6 and TiC rods. A computer controlled source meter is used to sweep the EEP at the wires 1, 2 and 3 (see Fig. 1) (wire 3 is used only for the TiC and pure C probe), as well as two cold Langmuir probes to record *I-V* characteristics. A pyrometer is aimed on the probe tip from outside the chamber through a quartz window, recording temperatures from 1263 K to 3273 K. Two different cold Langmuir probes are used to compare the obtained plasma parameters of the emissive probes: one thin 5 mm diameter brass disk, which is mounted about 50 mm below of the emissive probe tip and one 0,15 mm thin, 3 mm long cylindrical tungsten probe mounted 40 mm directly in front of the emissive probe tip.

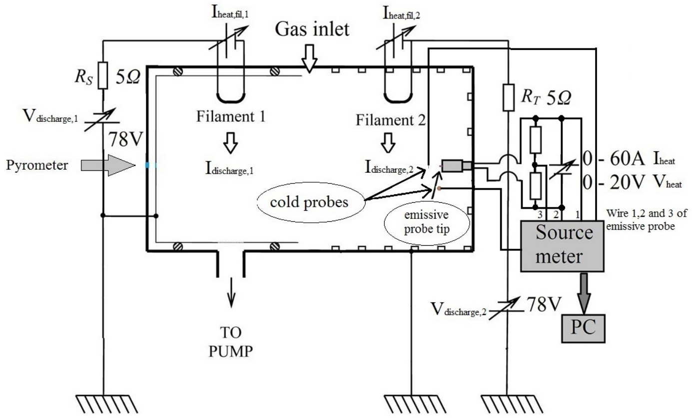

Figure 1: Experimental setup for probe measurements in the DPM.

4. Results and discussion

The probe characteristics presented in Fig. 2 have been obtained with the LaB_6 probe and the voltage recorded at connection wire 2, and with the TiC probe and voltage recorded at connection wire 3. Both characteristics show the typical behaviour of emissive probes [1,7–12]: The emission current appears on the negative side of the characteristics superimposed on the ion saturation current, with increasing magnitude when the heating is raised. The electron saturation current, which should in principle remain unaffected by the electron emission, also shows a strong increase.

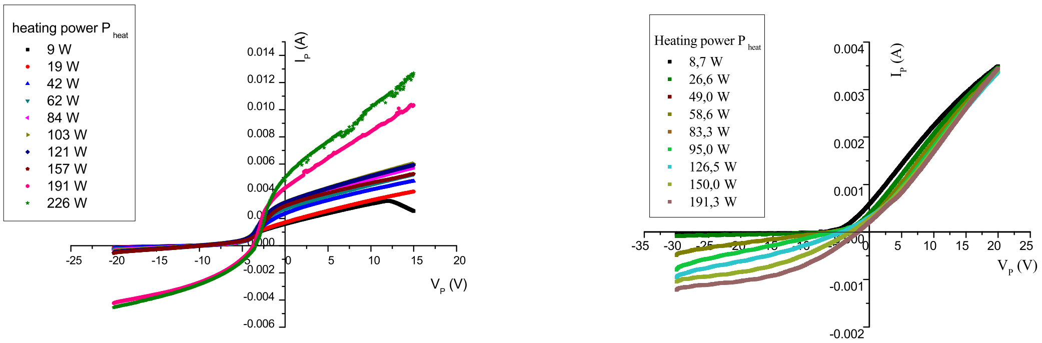

Figure 2: *I*-*V* characteristics of the LaB_6 (left) and TiC (right) probe recorded at different heating powers.

Such effects have been seen also in other cases of emissive probe, but the reasons are not yet clear. On the other hand, this effect does not change the principle property that the floating potential of the EEP is found very close to the plasma potential. Estimates show that in particular with TiC the average electron current density in high temperature plasmas and dense technical plasmas can be compensated by the electron emission current density, which is a prerequisite for the emissive probe to float on the plasma potential.

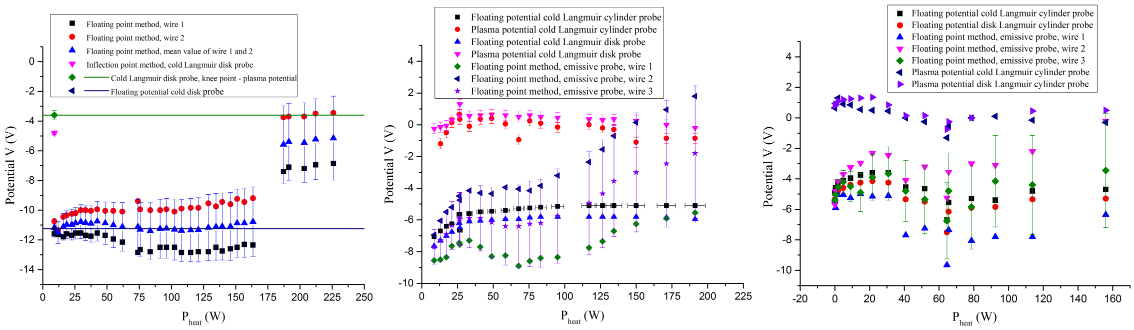

Figure 3: Comparing the floating potential V_{fl} of the emissive LaB_6 probe (left panel), TiC probe (centre panel) and pure C probe (right panel) with the derived plasma potential of the two cold Langmuir probes.

The behaviour of the floating potential of the EEPs when heated is represented in Fig. 3 for all three probes. When the electron emission current density of the probe tips approaches the plasma electron current density onto the probe surface, the floating potentials of the EEPs attain the actual plasma potential. If the electron emission of the probe is equal or greater than the value of the incoming plasma electron current density, the floating potential of the emissive probe stagnates more or less at the plasma potential, as seen in Fig. 2, left panel. The error bars in Fig. 3 and Fig. 4 represent $V_{heat}/2$, where V_{heat} is the heating voltage of the probe.

The EEP construction fails for the floating point method, when using 1 mm pure carbon rods. Before a sufficiently high electron emission is reached, the probe tip cracks in the middle of its length. In general the heat transfer from the hottest parts of the rods to the plasma facing area is still not efficient enough and therefore the probe design is still under further development.

Fig. 4 shows the results of the inflection point method for all three EEP pins: The inflection points are only compared to the plasma parameters of the two cold Langmuir probes close to the EEP pins. The technique works well for the connection wires 1 and 2 of the emissive probe (see Fig. 1), but suffers from large noise for all three EEP types for the connection wire 3 (data therefore not illustrated in Fig. 4), making it impossible to obtain the inflection points of *I*-*V* characteristic.

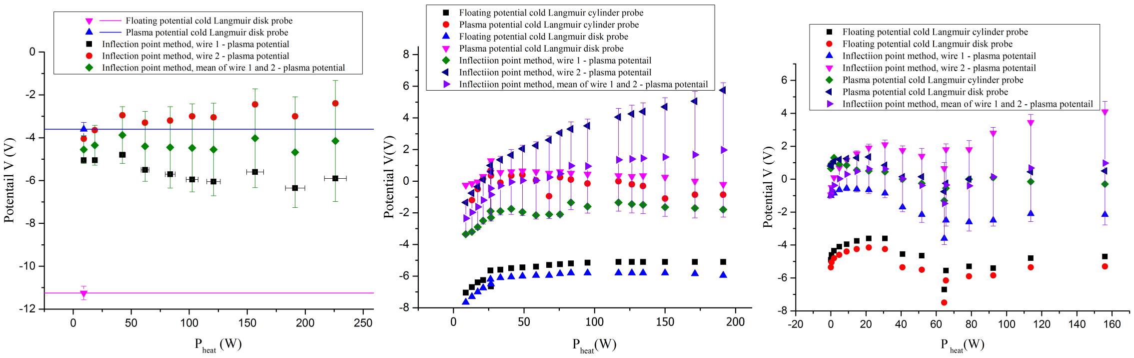

Figure 4: Using the inflection point method with an emissive LaB_6 probe (left panel), TiC (centre panel) and pure C (right panel) pin to obtain the plasma potential.

5. Conclusion

It has been demonstrated that an ohmically heated LaB_6 and TiC probe tip can be used as an electron-emissive probe. In contrast to earlier directly heated probes, in our case we use a LaB_6 rod of 1,5 mm diameter and 10 mm length and a TiC and pure C rod of 1,0 mm diameter and 30 mm length. The rods are heated only on a part of their lengths, whereas the actual probe tip, protruding from the probe head into the plasma, is heated by conduction. The LaB_6 and TiC probe prototypes are capable of almost attaining the actual plasma potential in the chamber. Yet, there are still technical problems to heat a pure graphite rod to the necessary temperature for high enough electron emission, especially for measurements in high temperature plasma and dense technical plasmas. Due to the higher ohmic resistivity of TiC compared to LaB_6, lower currents are needed to heat the probe tip to necessary temperatures. Additionally, the highest electron emission of TiC is higher than of LaB_6, due to the much higher melting temperature. The rather large uncertainties of the floating point technique indicated by the error bars in Fig. 3 and 4 resulting from the heating bias of the probes can be ignored when measuring in high and dense plasmas. There the additional passive heating by the plasma can be used to keep the probe in the working temperature regime during insertion and measurement time. The active heating of the probe ensures the correct temperature of the emissive probe tips during the entire measurement time. This measurement technique strongly reduces measurement errors regarding electron temperature fluctuations and strongly reduces measurement time scales (kHz to MHz) in fusion plasmas.

Acknowledgments

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