

A Laser-Heated Emissive Probe for Fusion Applications

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1. Introduction

Emissive probes are well known tools in laboratory plasma physics for a quick way to determine the plasma potential Φ_{pl} directly. In the last years emissive probes have been applied for the first time also in fusion experiments for measuring Φ_{pl} and related parameter like the electric field and potential and electric field fluctuations [1,2,3,4]. The floating potential $V_{fl,em}$ of a probe, emitting a sufficiently high electron current, yields a fairly accurate measure of Φ_{pl} and its fluctuations. This is an advantage as compared to the conventional Langmuir probe where, after determination of the electron temperature T_e , the plasma potential is derived from the well-known formula $\Phi_{pl} = V_{fl} + \alpha T_e$. The factor $\alpha = \ln(I_{es}/I_{is})$ is a function of the ratio of the electron to the ion saturation currents and is in general around 2.4 for hydrogen in a magnetised plasma [1]. A typical conventional emissive probe is realised by a loop of tungsten wire of about 0.2 mm diameter and about 8 mm length, which is inserted into a double-bore ceramic tube. The probe is heated by an external power supply or battery until electron emission starts. Drawbacks of this design are the limited life time of the tungsten wire, the low electron emissivity of tungsten and the voltage drop across the wire.

2. Probe design

We have developed a prototype of a new type of emissive probe, which is heated by an infrared high-power diode laser JenLas HDL50F from the company JenOptik, Jena, Germany, with a maximum output power of 50 W and a wavelength of 808 nm. The laser beam is coupled to a conventional glass fibre of about 3 m length that ends in a lens head, by which, in a distance of 15 cm, a focus of 0.6 mm diameter can be produced. This laser-head was positioned directly on a quartz-glass window perpendicular to the direction of the probe insertion. Fig. 1 shows this set-up schematically.

The probe consists of a small cylinder of LaB₆ with a diameter of 3.2 mm and a height of 2.2 mm. The LaB₆ electrode is connected to a molybdenum wire of 0.2 mm diameter, which also provides the electrical connection to the probe. The Mo-wire was spliced with a

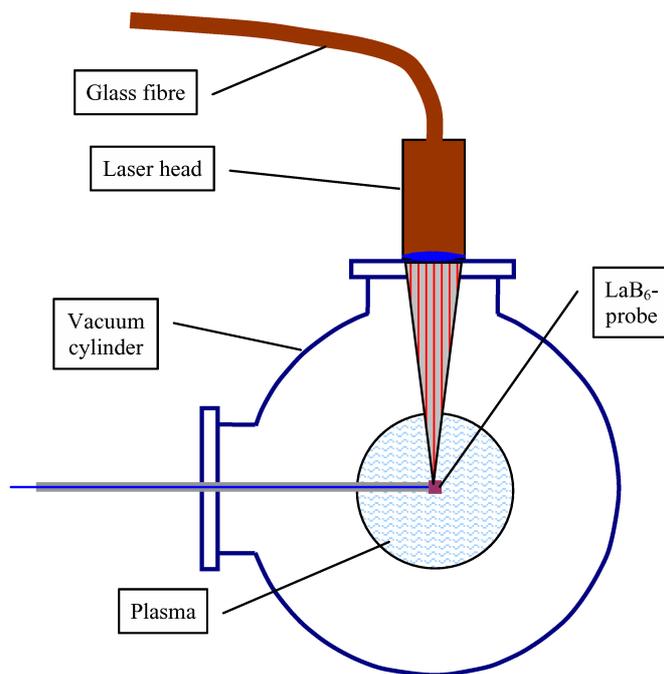


Fig. 1. Schematic of the laser-heated probe

the temperature of the LaB₆ piece versus the laser power, which was determined without plasma. We see that for 50 W laser power the temperature of the LaB₆ probe piece reaches more than 1800°C, at which temperature this substance emits a very high electron current density.

Fig. 3 shows a set of I - V -characteristics of the laser-heated emissive probe in the plasma with increasing laser heating power. The typical behaviour of a probe with increasing electron emission current is very well verified. At first, when the probe is not heated at all (black line), the IV -trace is that of a cold probe with a very small ion saturation current on

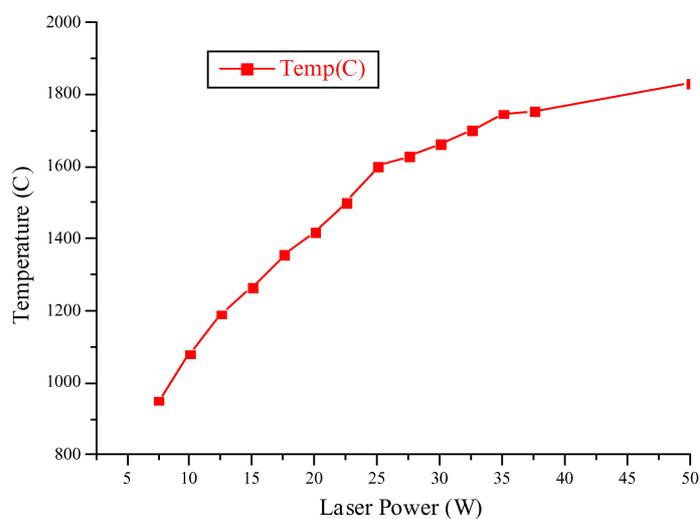


Fig. 2. Increase of the temperature of the probe piece with the laser power.

number of copper threads and pulled through a one-bore ceramic tube [5]. The probe is inserted into the plasma cylinder of VINETA [6], which produces a magnetized argon plasma of 10 cm diameter and 4 m length in a magnetic field up to 0.1 T with a density of about 10^{19} m^{-3} , an electron temperature of 3 eV and an ion temperature of 0.2 eV. The plasma is produced by a helicon discharge at moderate radiofrequency powers of less than 6 kW.

Fig. 2 shows the dependence of

the temperature of the probe piece versus the laser power, which was determined without plasma. We see that for 50 W laser power the temperature of the LaB₆ probe piece reaches more than 1800°C, at which temperature this substance emits a very high electron current density.

Fig. 3 shows a set of I - V -characteristics of the laser-heated emissive probe in the plasma with increasing laser heating power. The typical behaviour of a probe with increasing electron emission current is very well verified. At first, when the probe is not heated at all (black line), the IV -trace is that of a cold probe with a very small ion saturation current on the left-hand side and a much larger electron saturation current on the right-hand side. We notice that the floating potential of the probe is on the negative side. When the laser heating is turned on and the temperature of the probe increases, an electron emission current is produced which superimposes on the ion current. The higher the emission

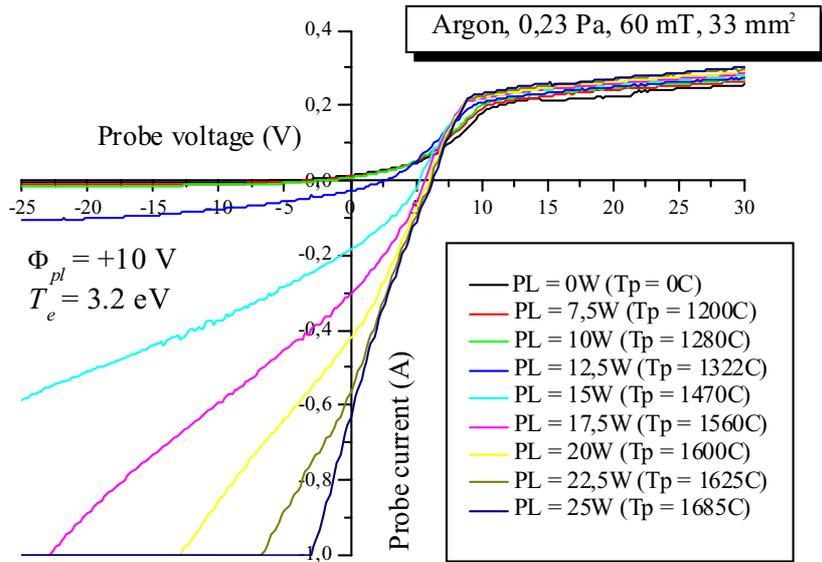


Fig. 3. *I-V characteristic of the probe with the laser power, respectively, the temperature of the LaB₆ probe as parameter. The indicated electron temperature and plasma potential were determined from the cold characteristic for $P_L = 0$ W.*

of the electron temperature, $T_e = 3.2$ eV, and the plasma potential, $\Phi_{pl} = +10$ V, have been determined for comparison.

The next figure (Fig. 4) shows the variation of the floating potential of the probe with the laser heating power for another series of measurements. Starting from the floating potential $V_{fl} \cong -3.3$ V of the same but cold probe, with increasing heating power the floating potential rises. At a laser power of $P_L \cong 13$ W, the floating potential jumps up and reaches a final saturation of $V_{fl,em} = +8.8$ V for $P_L \geq 40$ W. This value lies about $2.9 T_e$ above V_{fl} , consistent with $\alpha = 2.9$.

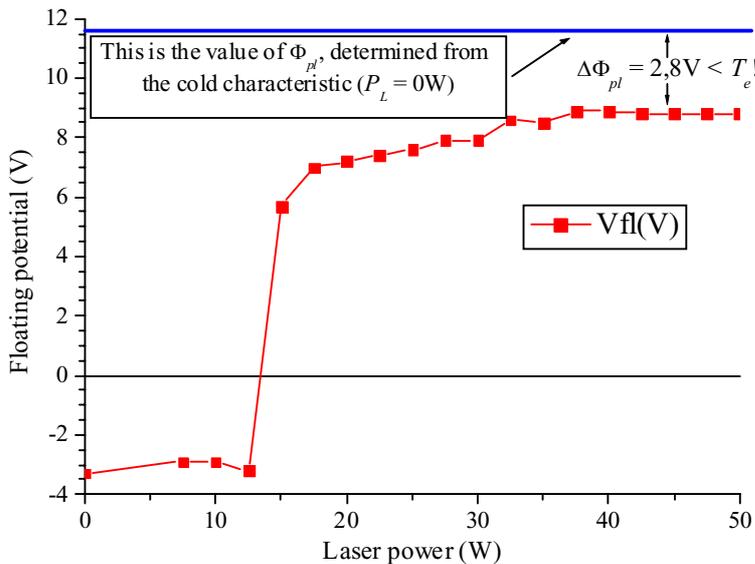


Fig. 4. *Floating potential of the probe versus laser heating power. The blue line shows Φ_{pl} calculated from the cold characteristic.*

current becomes, the more the floating potential shifts to the right-hand side until, above about 20 W a saturation of this value occurs. This is in perfect agreement with the well-known behaviour of an emissive probe [1].

From the cold *I-V* characteristic (for $P_L = 0$ W) the inserted values

of the electron temperature, $T_e = 3.2$ eV, and the plasma potential, $\Phi_{pl} = +10$ V, have been determined for comparison.

There is, however, a slight discrepancy between this value and $\Phi_{pl} = +11.6$ V determined from the characteristic of the same unheated probe (in this case $T_e = 4.12$ eV). This systematic discrepancy is well known [7], and is in our case about $0.68 T_e$, in agreement with simulations [8]. It is ascribed to the formation of a

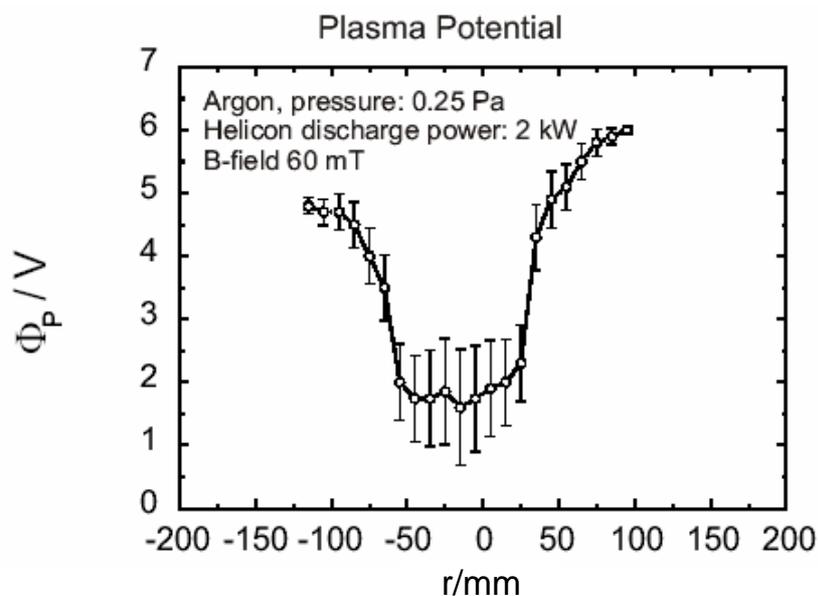


Fig. 5. Radial profile of the plasma potential through the VINETA plasma column, measured with the laser-heated emissive probe.

emitting probe should be around one T_e below the real value of the plasma potential. This is not in keeping with our above-mentioned result.

Finally, Fig. 5 shows a radial profile of the plasma potential through the VINETA plasma column, measured by the laser-heated emissive probe. These results are in keeping with analogous measurements in a Q-machine, but do not agree with other measurements in VINETA. This discrepancy has still to be clarified.

We have succeeded to construct a laser-heated electron emissive probe which can produce a much higher emission current than a conventional emissive wire probe. It has also a much longer life time since we observed practically no evaporation or sputtering of the LaB₆ piece even after many hours of constant strong irradiation with the infrared laser. The probe has also a better time response since no electric heating system with a high internal capacity is necessary.

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space charge sheath around the probe consisting of emitted electrons, which cannot leave the probe even for $V_p \leq \Phi_{pl}$ due their lower temperature as compared to that of the plasma electrons. We note, however, that Ye and Takamura [7] found out that the floating potential of a strongly