New results on a laser-heated emissive probe

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Abstract: We have developed and investigated emissive probes which are heated by a focused infrared laser beam. Such a probe consists of a pin of LaB_6 or graphite of 2 mm length and 1 mm diameter. It has several advantages as compared to a conventional emissive wire probe, such as higher probe temperature, higher emissivity, longer lifetime, no deformation in a magnetic field due to the heating current, no potential drop along the probe wire, faster time response due to just one electric connection to the probe. With a LaB_6 pin we can produce an emission current up to several amperes. Here we show the basic behaviour of the probe in the VINETA helicon discharge plasma and its suitability for measuring potential fluctuations.

1. Introduction

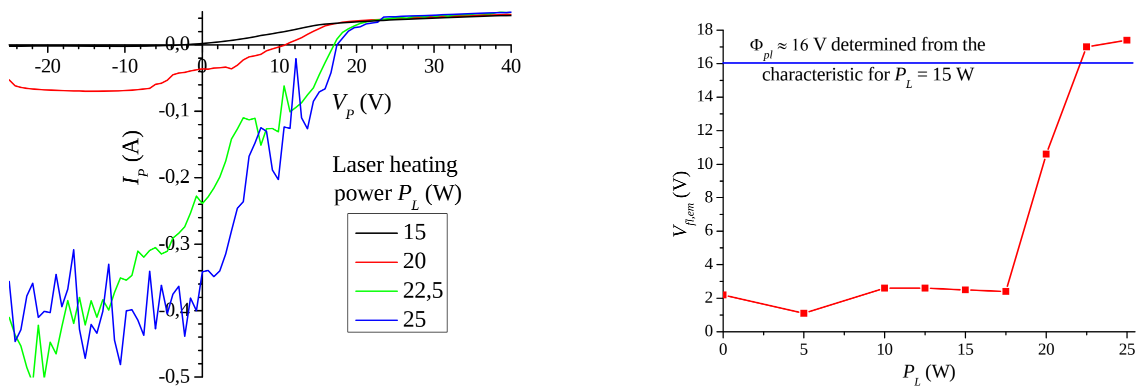
Electric fields are decisive for the overall stability of a plasma and particle transport therein. They appear whenever the plasma potential Φ_{pl} has a gradient. Thus a precise knowledge of the spatial profile and temporal variation of Φ_{pl} is vital for many cases. Stationary electric fields can appear due to localized potential structures, such as double layers [1] or fireballs [2]. On the other hand, fluctuating electric fields are the main cause of radial transport in magnetized toroidal plasmas (see e.g. [3,4]). The main advantage of an emissive probe is that under ideal conditions its floating potential is equal to the plasma potential and no longer dependent on the electron temperature T_e. Recently it was pointed out that the usual way to determine electric fields by the difference of the floating potentials of two cold probes, can lead to considerable errors [3,5] due to the influence of T_e.

Usually emissive probes are made of a loop of refractory metal wire heated by an electric current until sufficient electron emission. The disadvantages of this probe type can be avoided by an indirectly heated probe, for instance heated by a focused laser beam [6].

2. Probe construction, results and discussion

The experiments were carried out in VINETA [7]. The plasma is produced by a helicon discharge with an RF power of 2 kW, densities up to about 10^{19} m^{-3} and an electron temperature between 3 and 5 eV. The background magnetic field is 100 mT and the neutral argon pressure is in the range of tenth of Pa. The plasma column radius is around 10 cm and the maximum density is reached in the center. The emissive probe is heated by a water-cooled diode laser type JenLas HDL50F of JenOptik, Jena, Germany, with a maximum output power of 50 W and a wavelength of 808 nm. The laser beam is coupled into a conventional glass fiber cable of 3 m length that terminates in the collimator.

The set-up of our last type of laser-heated probe is described in detail in [8]. This probe can be shifted radially through the plasma column while being constantly heated. The glass-fibre cable from the diode laser enters a collimator, which is fixed directly on a quartz window of VINETA. The laser beam exiting from the glass fibre cable is collimated by a first quartz lens into a parallel beam of 20 mm diameter. After penetrating the quartz window, inside the vacuum chamber the parallel beam is focused by a second quartz lens onto the probe pin. This pin consists either of graphite or lanthanum hexaboride (LaB_6) having a diameter of 1 mm and 2 mm length. The diameter of the focus of the laser beam is about 0,6 mm. The probe is mounted mechanically stable on the same shaft as the second lens so that the distance between them is constant. Thus the probe shaft can be moved radially over a range of about 10 cm while the laser beam focus stays constantly centred on the probe pin.



(a) **(b)**

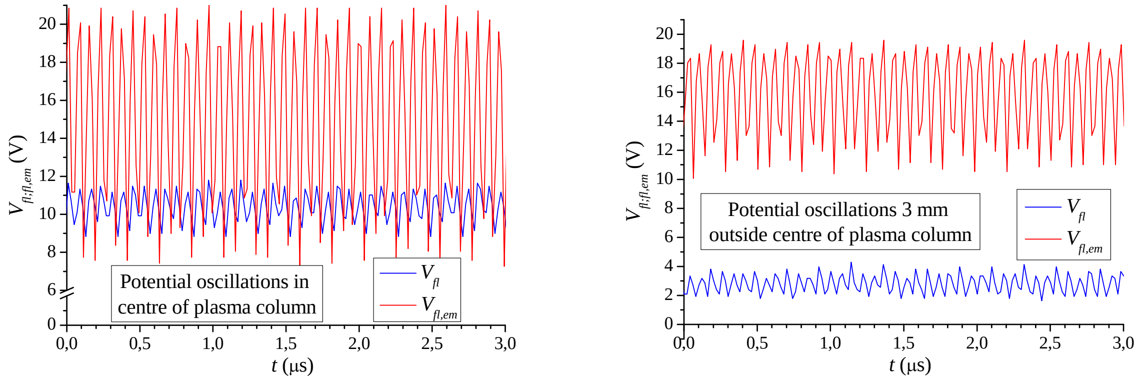
Fig. 1. (a) Current-voltage characteristics of the radially moveable laser-heated probe with an LaB_6 probe pin inserted into the centre of the VINETA helicon plasma for increasing laser heating power. (b) Floating potential of the probe versus increasing laser heating power. The blue horizontal line shows the value determined from the inflection point of the cold characteristic.

Fig. 1 elucidates the most important facts proving the reliability as emissive probe. In this case the pin consists of LaB_6 with a work function of W_{LaB_6} = 2,66 eV, and a Richardson constant of $A^*_{LaB_6}$ = 29·10^4 A/m^{2}K^2 [9]. For a temperature of typically 2100 K, theoretically an electron current density of about 5,4·10^5 A/m^2 can be emitted under field-free conditions. Unfortunately it turned out that with a graphite pin ($W_C \cong$ 4,8 eV and $A^*_C \cong$ 48·10^4 A/K^{2}m^2 [10]), no sufficient electron emission could be produced under the given conditions in VINETA.

Fig. 1a shows typical *IV*-characteristics of the laser-heated LaB_6 emissive probe for increasing laser-heating power P_L. The probe was inserted in the centre of the plasma column. The black line shows the characteristic for P_L = 15 W where the probe already glows but is not yet emissive. This was done to remove any possible contamination from the probe surface. The electron temperature was determined as $T_e \cong$ 2,9 eV. In this case sufficient emission does not start before about $P_L \geq$ 18 W. In agreement with the usual behaviour of an emissive probe, at this value the floating potential of the probe, $V_{fl,em}$, starts to shift strongly to the right-hand side. This we also see in Fig. 1b which shows $V_{fl,em}$ versus P_L. For $P_L \geq$ 20 W, $V_{fl,em}$ reaches values even slightly above the value of $\Phi_{pl} \cong$ 16,0 V determined from the inflection point of the characteristic for P_L = 15 W. Above P_L = 25 W no further shift of the of $V_{fl,em}$ occurs although the magnitude of the emission current still further increases. Such a relatively good agreement between theses values was also seen in similar recent investigations with laser-heated [8] and conventional wire probes [11,12].

On the left-hand side of the characteristics, for $P_L \geq$ 20 W, we see strong fluctuations in the emissive current (green and blue lines). This is effect shows the perturbation of the plasma by the emissive probe, however, *only* when the emission current can really enter the plasma, i.e. for $V_P < \Phi_{pl}$. If the difference between the plasma potential and the probe bias becomes larger than the ionization potential of the background gas, additional ionization occurs by the emitted electrons which are accelerated into the plasma through the probe sheath [13]. However, as long as the probe floats on the plasma potential, i.e. $V_{fl,em} = \Phi_{pl}$, the emission current (plus the usually very small random ion current) perfectly compensates the plasma electron current, there is no current through the probe and no sheath around it. Thus the perturbation of the plasma by the probe is almost negligible [12].

Fig. 2 shows as an example the high frequency fluctuations picked up by the probe, once when it was unheated (blue lines) and once when it was heated to emission (red lines). In the former case the probe shows the fluctuations of the cold floating potential V_{fl} which therefore contain also the fluctuations of the electron temperature (see [3] for a detailed discussion of this problem). Only in the latter case the probe shows the true fluctuations of the plasma potential $\Phi_{pl} = V_{fl,em}$. In both cases we see an oscillation with a frequency of 13,56 MHz, which is the RF of the helicon discharge naturally superimposed on the plasma. Both the amplitude and the mean value of the Φ_{pl} oscillations (red lines) are much larger than these values in case of V_{fl} (blue lines). The difference between the two values is proportional to the electron temperature so that we arrive at the conclusion that there are also strong oscillations of T_e due to the RF discharge frequency. Further details will be published in a subsequent paper.



(a) **(b)**

Fig. 2. Potential oscillations in the VINETA plasma, once for the probe emissive and thus showing $V_{fl,em} = \Phi_{pl}$ (red lines), once not heated and thus showing the cold probe floating potential V_{fl}; (a) in the centre of the column, (b) in a radial distance of 3 mm from the centre.

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