Measurements of Plasma Parameters Using a Fast Sweeping Langmuir Probe in the VINETA-II magnetic reconnection experiment

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Electrostatic probes are a commonly used technique to measure density n_e, temperature T_e, and electric potential ϕ_p in low temperature plasmas as well as at the edge of fusion machines. The method consists of applying a known voltage to a conducting probe pin immersed into the plasma and measuring the current drawn by it. Depending on the value of the probe bias potential V with respect to the local plasma potential ϕ_p the probe's exposed surface repels the surrounding electrons or ions and drains an electric current from the plasma $I(V)$. The local plasma parameters could be derived from these current voltage (IV) characteristic curves.

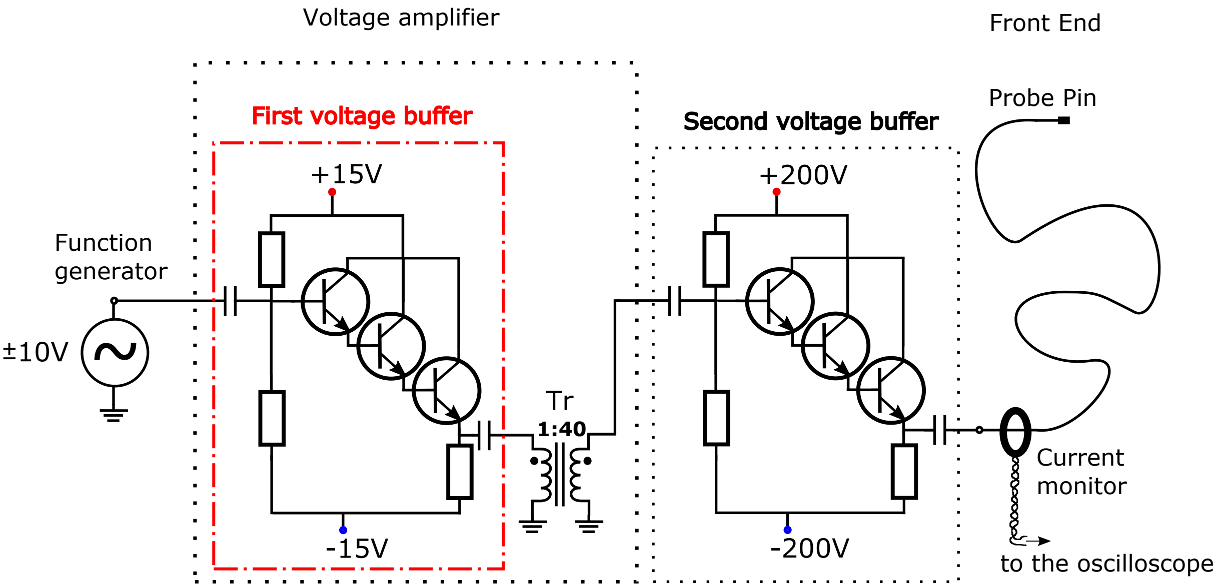

Figure 1: Schematics of the fast sweep probe electronic circuit. The sinusoidal ± 10 V signal of the function generator is amplified to ± 180 V using the step–up transformer Tr. The amplified signal from the transformer output is applied to the probe pin through the second voltage buffer, which is implemented to minimize the loading effect on the primary side of the transformer and the first voltage buffer.

In some applications a high-voltage fast sweep probe is needed to resolves wide range changes of plasma potential or(and) electron temperature, , as for instance plasma guns, pulsed Helicon plasmas and plasmas undergoing magnetic reconnection. In this paper we present the design and performance of a electronic circuit developed for fast swept measurement of Langmuir probe *IV* characteristics for a high voltage range. The developed probe has been used to diagnose a plasma produced by the plasma gun at the VINETA-II magnetic reconnection experiment.

The temporal evolution of n_e and T_e can be deduced simultaneously if the probe bias voltage is actively swept faster than the typical time scale of the plasma gun discharge ($\tau_{gun} \approx 60\ \mu s$), with the frequency of few hundred kHz.

The electrical circuit for fast sweep probe bias is shown in Fig. 1. Our circuit consists of several parts: function generator, voltage amplifier and current amplifier. In the first step the function generator generates the sinusoidal or linear wave form with an amplitude of ± 10 V. This signal is amplified by the step-up transformer *Tr* (with the transformation coefficient of 18) to ± 180 V. There is the separate buffer amplifier in between.

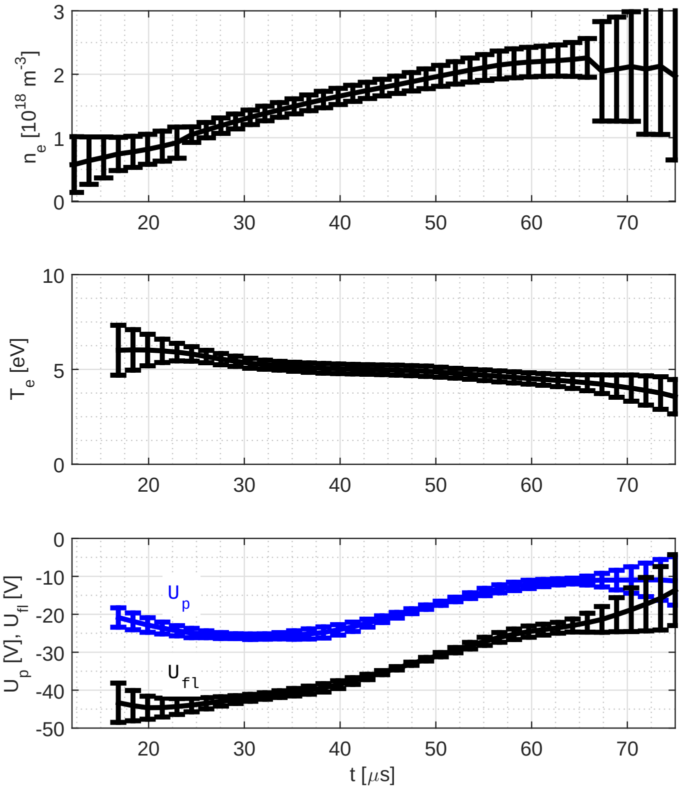

Figure 2: The typical time trace of plasma density (a) and electron temperature (b) as statistically averaged over 8 measurements. The radial position of these measurements corresponds to the center of the VINETA vessel. Error bars represent the scattering of an individual measurements around mean values.

In order to demonstrate the capability of the developed system, we show an exemplary measurement result of the gun argon plasma. The typical time traces of n_e and T_e, measured in the center of the vacuum vessel are shown in Fig. 2. The traces were averaged over 8 independent measurements. The radial position of these measurements corresponds to the center of the plasma, i.e $\rho = 0$. The density time trace has rising phase, which lasts for about 60 μs, which is the length of the gun discharge pulse. It is visible that the typical deviation of the I−V characteristics from the mean value is about 10–15 % for the density and 3-5 % for the electron temperature.

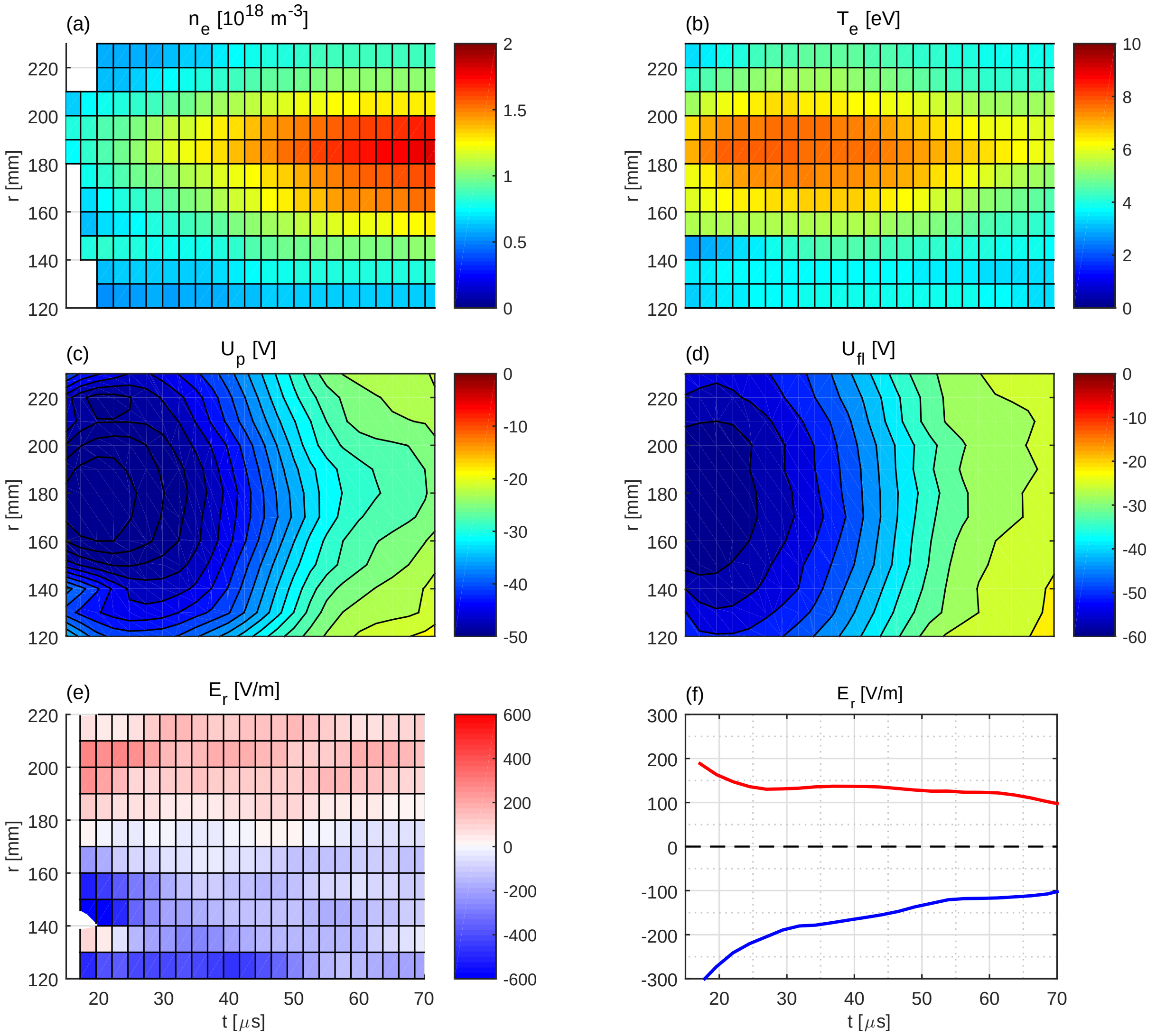

Figure 3: Spatiotemporal development of VINETA plasmas produced by the plasma gun discharge. Temporal evolution of the radial profiles of the electron density (a), temperature (b), plasma and floating potentials (c) and (d). Radial electric field (e) was evaluated as a gradient of the plasma potential. Contrary to the peaked n_e profile, the radial profile of T_e is flat within the probe's scanning range.

A more systematic measurement of an electron density and temperature have been done using fast sweep probe and the linear positioning system at VINETA-II. Using both systems the spatiotemporal development of VINETA-II plasmas has been measured. Results are presented in Fig. 3. Figure 3(a) shows the temporal evolution of a radial profile of the electron density. The radial extension of the profile (taken as a FWHM) varies in time only marginally from approx. 7 cm in the beginning of the discharge (at $t = 25\ \mu s$) to approx. 8 cm in the end (at $t = 70\ \mu s$)

. The spatiotemporal development of T_e shows a similar pattern. It varies only slightly within the considered spatial and time domains, similar to the results in Fig. 2(b). Based on the direct measurements of the plasma potential spatial profile we are able to evaluate the spatiotemporal profile of the radial electric field formed in the current sheet, which plays a key role in the current sheet force balance.

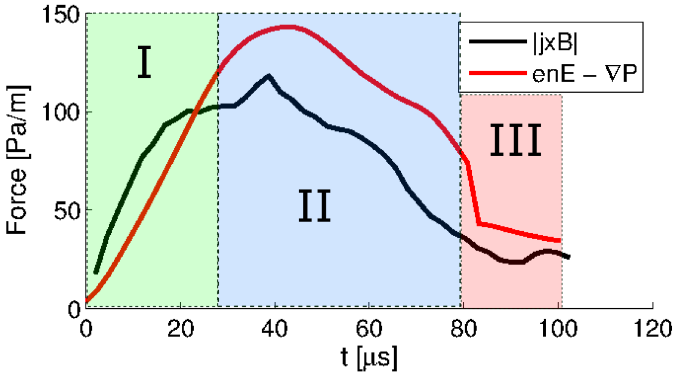

Figure 4: The main contributor determining the current sheet in-plane force balance. The $\vec{j}\times\vec{B}$ force is pretty well balanced by the -$\nabla P - enE$ forces.

One of the issues related to the reconnection process in the VINETA plasma is what forces play a key role in the current sheet stability. This issue has been experimentally investigated by us considering different terms in the force balance equation for electrons, assuming that the ion contribution in the net force balance is negligible.

$$\frac{d\vec{v}}{dt} = -en\vec{E} + \vec{j}\times\vec{B} - \nabla\vec{P} \qquad (1)$$

All corresponding quantities have been evaluated on the basis of the data measured using both fast sweeping Langmuir probe (for plasma density and electric field) and B-dot probes (for current density and magnetic field). The results are presented in Fig. 4. Each quantity in this figure are averaged over 4 different representative points in the current sheet. The black line represents the $\vec{j}\times\vec{B}$ compression force formed in the reconnecting current sheet due to in-plane current. The red line represents the sum of the ∇P and the radial electric field $-enE$ expansion forces. One can notice that the $\vec{j}\times\vec{B}$ force is within 30% balanced by the -$\nabla P - enE$ forces. In the beginning of the discharge (area I in the figure), when the plasma pressure (and ∇P) is small, the electrical force plays the primary role to compensate the $\vec{j}\times\vec{B}$ force, whereas in the end of the discharge (area III), when the plasma potential profile is flat and the corresponding radial electric field is negligible, the in-plane current is primarily determined by the diamagnetic drift. In the time domain II all terms contribute similarly in the force balance.

References

[1] H. Bohlin et al., Rev. Sci. Instrum. **85**, 023501 (2014)