Fast measurements of the electron temperature in divertor region of the COMPASS tokamak using ball-pen probe

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1 Introduction

Investigation of the electron temperature and consequently the parallel heat flux on the divertor target during Edge Localized Modes (ELMs) is of importance for the ITER tokamak in order to determine the physical sputtering and melting of the plasma facing components and, consequently, the life time of the divertor targets. The electron temperature in divertor regions of present-day devices is typically measured by swept Langmuir probes or triple probe technique [1]. However, the measurement of its evolution during ELM filaments requires high temporal resolution, which has not been achieved by these techniques yet. Alternative option how to determine the electron temperature with high time resolution is to use direct measurements of the plasma (Φ) and floating (V_{fl}) potentials. The electron temperature T_e is consequently determined from the difference of both potentials normalized by the proper coefficient for specific gas and magnetic field [2, 3, 4]. The floating potential is routinely measured by Langmuir probe (LP) and the plasma potential can be directly measured by ball-pen probe (BPP) [4]. The BPP was used to measure plasma potential in the edge plasma on COMPASS [3, 5], ASDEX Upgrade [2, 3, 5], MAST [6] and ISTTOK [7] using probe manipulator. Recently, a new array of BPPs and dome-shaped Langmuir probes was installed also in a divertor target of the COMPASS tokamak. The first results of fast measurements of the electron temperature on divertor during ELMy H-mode with sub-microsecond time resolution are reported in this paper.

2. Divertor BPP and LP construction and experimental set-up

The new array of BPPs (labelled A to L) has been implemented directly to the graphite divertor target on the COMPASS tokamak as shown in Fig. 1. Each ball-pen probe is made of stainless-steel collector with 3 mm diameter and boron-nitride shielding tube with 6 mm diameter and. The collector is retracted at h ~ 0.7 mm below the graphite surface. Four additional dome-shaped LPs (Q, N, R, P) are also mounted on the same divertor target as seen in Fig. 1. The LPs are made of graphite with 4 mm diameter and protruding 1.3 mm to the plasma. Toroidal distance between neighbouring LPs is roughly 6 cm and similar distance is applied also for BPP and LP. In current configuration, a set of probes BPP_H, LP_Q, LP_N is located at the

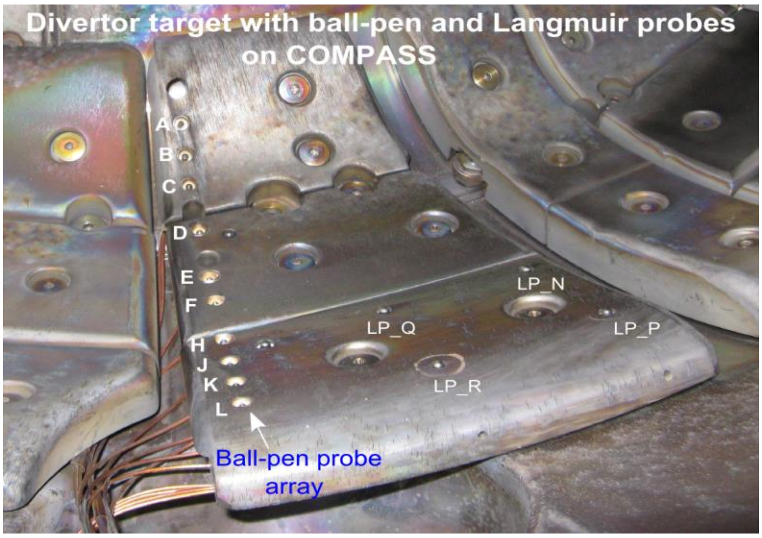

Fig. 1: Picture of the ball-pen probe (BPP) array and few dome-shaped Langmuir probes mounted on divertor target on COMPASS. The toroidal distance between BPP and LP is roughly 6 cm.

same poloidal position. The Langmuir probes can operate in floating or ion saturation current mode (V_{probe}= -270 V). The total exposed area of LP is approximately 30 mm^2. All signals are acquired with a sampling frequency rate f = 5 MSPS. The BPPs are implemented to the divertor target as flush-mounted probes, which significantly reduce the direct impact of high heat flux on the probe material. On the other hand, the BPPs in the divertor are surrounded by large graphite (conducting) tiles, which is a new probe arrangement in contrast to the BPP mounted on probe manipulator. Therefore, in order to verify their *I-V* characteristics, we have applied swept voltage (+/-200 V, f= 1 kHz) on two BPPs (BPP_J, BPP_D) with significantly different poloidal locations. An example of resulting *I-V* characteristics of both probes obtained during the L-mode phase (B_T= 1.15 T, plasma current I_P = 300 kA, density $n_e = 6{\cdot}10^{19}$ m^{-3}) of H-mode discharge #4259 are plotted in Fig. 2. It can be seen that both probes provide nearly symmetric *I-V* characteristics during the whole time interval. It is also seen that electron and ion branch of the *I-V* does not saturate and therefore the evaluation of the ratio of the electron and ion saturation current $R=I_{sat\_e}/I_{sat\_i}$ requires a linear extrapolation of both branches. The linear fit in Fig.2 is calculated for BPP voltage > +100V on the electron branch and for BPP voltage < -100V on the ion branch. If we assume the floating potential of BPP is close to the plasma potential Φ then the logarithm of the ratio R is found close to ln(R) ~ 0.8. The resulting value ln(R) is close to the value obtained with BPP mounted on probe manipulator on AUG [2]. The determination of the ratio R during ELMs is difficult because of very short time scale of ELM filaments. However, the estimation of the electron and ion saturation current during ELM is shown in Fig. 3. Two similar ELM events, ELM_1 and ELM_2, with the same D-alpha signal, were detected on swept BPP_J and BPP_D during ELMy H-mode phase of the discharge #4259

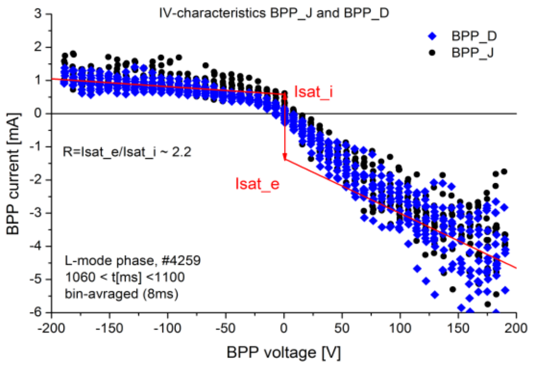

Fig. 2: The bin-averaged *I-V* characteristics of BPP_D (diamond) and BPP_J (circle) during whole L-mode phase of discharge #4259.

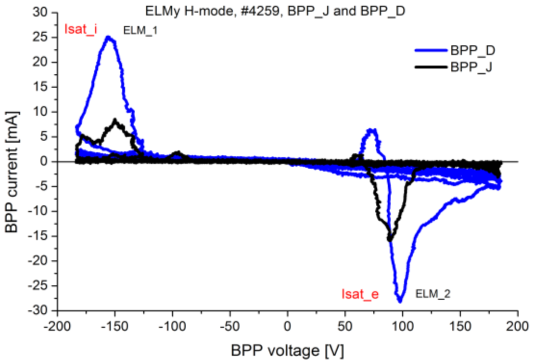

Fig. 3: The *I-V* characteristics of BPP_D (blue) and BPP_J (black) during ELMy H-mode #4259 with two similar ELM events incoming to both probes.

($n_e = 9{\cdot}10^{19}$ m^{-3}) at the moments with opposite value of applied voltage. This confirm that both values I_{sat_e} and I_{sat_i} are also roughly balanced within the ELM, with ratio $1< R <2$ independent on the probe position. Note, the investigation of ratio R of BPP during ELMy H-mode can be also found in systematic measurements on ASDEX Upgrade [2].

3 The electron temperature within ELM filaments

The investigation of the electron temperature T_e with a sub-microsecond temporal resolution is based on fast measurements of BPP and LP potentials, Φ^{BPP} and V_{fl}, and on the formula T_e=(Φ^{BPP} - V_{fl})/2.2. The coefficient 2.2 is obtained from the ln(R) = 2.8 of LP in deuterium plasmas (assuming $T_i = T_e$ and no secondary electron emission) minus the ln(R) of BPP. The values of ln(R) of BPP on COMPASS, shown in Fig. 2, and on AUG [2] are in agreement within the error bars. Therefore, we are using value of ln(R) = 0.6 of BPP for both devices. Note, the same formula was already used for comparative measurements of the electron temperature using BPP/LP mounted on the reciprocating manipulator and Thomson scattering on COMPASS [3], AUG [3] and MAST [6] in L-mode plasmas with a very good agreement of both techniques. The first results of fast electron temperature measurements within the ELMs using BPP/LP mounted on horizontal manipulator were performed on COMPASS [8]. However, this is the first time measurement of the electron temperature within ELMs using BPP/LP on the divertor with sub-microsecond time resolution. At first, both Langmuir probes, LP_Q and LP_R, were connected as a floating probe in order to calculate the cross-correlation coefficient. It has been found that cross-correlation coefficient is within the range of 0.8-0.9 for L-mode, ELM free H-mode and ELMy H-mode phases of the discharge #7876. This confirms that both LPs and BPP_H are well magnetically connected. In the following H-mode discharge #7891, the LP_R was switched to the I_{sat} regime (V_{bias} = -270 V). It allowed us to provide simultaneous measurements of the electron temperature T_e by combining BPP_H and LP_Q and ion saturation current I_{sat}. The time evolution of the electron temperature and ion saturation current during one ELM is plotted in Fig. 4. It is seen that the value of the electron temperature is strongly varying within the filament structure. However, it must be noted that a small part of resulting T_e, roughly 9% of total signal during H-mode phase, has values below 0 eV, because in some cases it is observed during ELM filaments that both signals Φ^{BPP} and V_{fl} are slightly shifted in time. This can be caused by a small misalignment of BPP and LP with respect to the magnetic field lines or different dimensions of each probe. However, the major part of T_e values can be used in order to estimate the value of parallel heat flux $q_{//}=7*T_e*I_{sat}/S_{\mathrm{LP}}$, where 7 is the value of heat transmission coefficient [9] and S_{LP} is the total exposed surface of LP_N. The time evolution of $q_{//}$ during one ELM is plotted in Fig. 5. It is seen that value of parallel heat flux during ELMs reaches a couple of MW/m^2. These values are obtained roughly 6 cm from outer strike point. The red line represents smoothed values of parallel heat flux to 0.1 ms (10 kHz), which is comparable to resolution of common IR camera. In such case, the resulting values of $q_{//}$ are below 1 MW/m^2, strongly underestimating the peak heat flux.

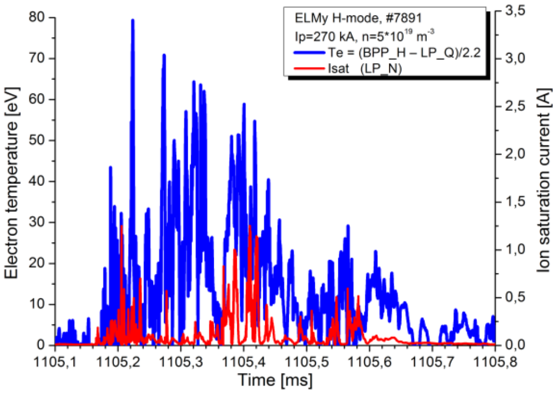

Fig. 4: Temporal evolution of the electron temperature and ion saturation current during one ELM event in H-mode #7891 on divertor on COMPASS.

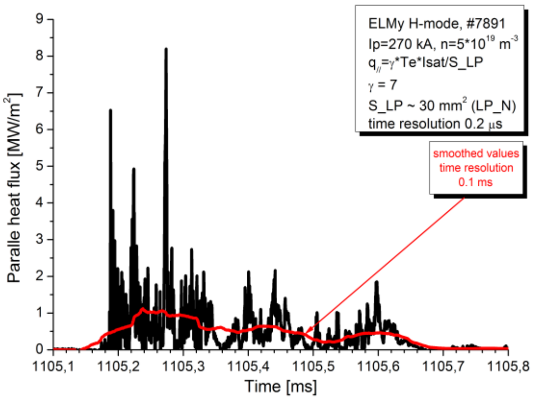

Fig. 5: Temporal evolution of parallel heat flux obtained from T_e and I_{sat} measurements and heat transmission coefficient γ=7 during one ELM event in H-mode #7891.

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