Basic investigations of blob dynamics and control in the TORPEX device

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Introduction

A requirement for a future tokamak fusion reactor is the control of heat loads from the scrape-off layer (SOL) onto the divertor, which can be generated from both steady state fluxes and impulsive bursts that are associated with plasma instabilities. Handling transient heat loads associated with ELMs under H-mode operation constitutes a serious issue for ITER, while in next-step devices, such as DEMO, even steady state fluxes can become unacceptably large. It has been proposed that externally induced poloidal electric fields and convective cells in the SOL could increase its width and reduce divertor heat loads. This can be obtained by active toroidal or poloidal asymmetric biasing, using asymmetric divertor biasing schemes or inserting electrodes into the SOL. Toroidal or poloidal asymmetric biasing has already been tested in several tokamaks using biased divertor plates [1-3] or electrodes directly immersed in the SOL [4]. These experiments demonstrated effects on SOL profiles and evidence of convective cell formation, leading to modifications of the heat flux profile onto the divertor. Advances in the understanding of these fundamental processes can be achieved in basic plasma physics devices, which allow for full diagnostics access together with relatively simple geometry and high flexibility in control parameters.

Here, we review recent experiments on the TORPEX device using biased electrodes [5, 6] that reveal the formation of convective cells with a high degree of uniformity along the magnetic field. We focus on the effects of convective cells on blob dynamics, showing that, depending on the biasing scheme, radial and vertical blob velocities can be varied significantly. A high level of cross-field currents limits the achievable potential variations to values well below the applied bias voltage. Furthermore, the strongest potential variations are not induced along the biased flux tube, but at a position shifted in the direction of plasma flows.

Experimental setup and results

TORPEX, a toroidal device dedicated to basic plasma physics investigations, features a simple magnetized toroidal configuration with a dominant toroidal magnetic field B_T and a small vertical field component B_z. This leads to helical field lines that wind around the torus and intercept the vacuum vessel at the bottom and the top, as sketched in Fig. 1. Low density

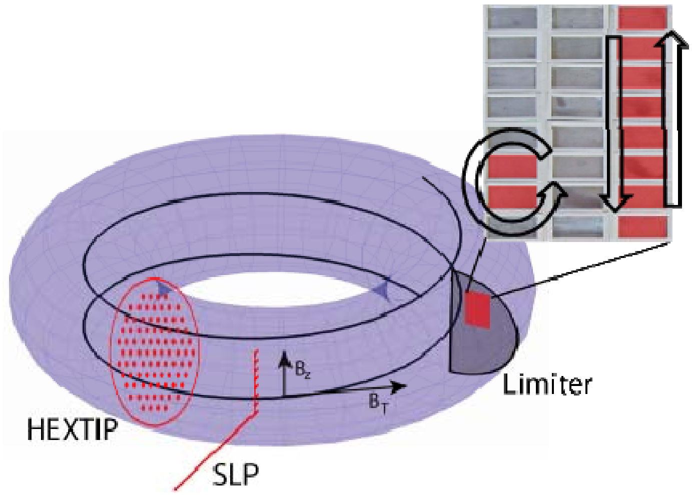

Fig. 1 Sketch of the TORPEX vacuum vessel and electrodes installed on the conducting limiter. The expanded view shows possible biasing schemes. Shaded areas indicate positively biased electrodes and arrows show the expected flow pattern.

and temperature plasmas (n_e~1-3×10^{16}m^{-3}, T_e~5-15eV) are produced and sustained by microwaves in the electron cyclotron range of frequencies. In TORPEX, blobs are generated from ideal interchange modes [7] and, driven by grad B and curvature-induced charge separation, propagate radially outwards with a radial velocity determined by the available current paths (parallel or cross-field currents) to damp charge separation [8]. Regimes dominated by either of the two currents are achieved by using different gases. An analytical expression for the blob velocity shows good quantitative agreement with the experimental data [8]. For the present experiments, we installed a grounded stainless steel limiter in the blob propagation region with an array of 3×8 electrodes attached on its surface (expanded inset in Fig. 1). Each electrode can be biased individually thus allowing for flexibility in the biasing scheme.

Figure 2 presents how blob propagation is modified by two different biasing schemes (vertical stripes of biased electrodes on the left and four biased electrodes on the right) [5]. In a first phase of the discharge, the "bias on" phase, these electrodes are biased to +40 V. During a second phase, the "bias off" phase, they are grounded. Figure 2 shows successive time frames

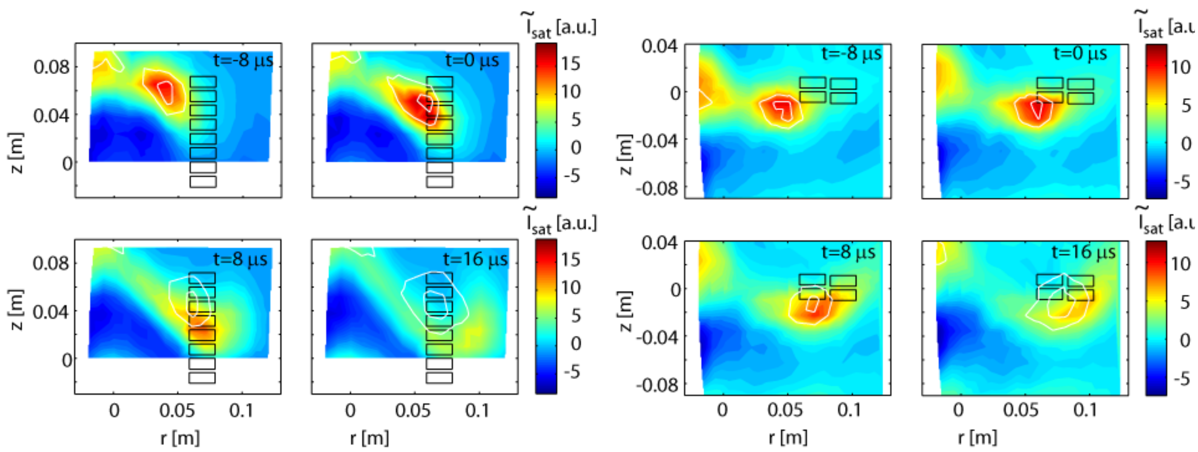

Fig. 2 Conditionally averaged blob propagation (ion saturation current fluctuations in the color plots) for the cases where a vertical stripe of electrodes (left) or four adjacent electrodes (right) are biased at +40 V. For comparison, white contours indicate the results of the same analysis when all electrodes are grounded.

of blob conditionally sampled ion saturation profiles during the bias on (color plots) and bias off (white contours) phase. While early in time the blob propagation is similar in the two phases, clear differences are observed later on, revealing the effect of the biasing. In Fig. 2-left, the blob is strongly pushed downwards due to the biased electrodes. Instead, when a set of four electrodes is used to induce a counter-clockwise rotating cell (Fig. 2-right), blobs passing below this set of electrodes are radially accelerated.

Fig. 3 illustrates the changes in blob velocity for the biasing case in Fig. 2-right and compares them with the $v_{E\times B}$ flow deduced from the measured changes in floating potential. Fig. 3 (a) and (b) show the blob radial and vertical velocity as a function of time for the bias off (blue) and the bias on case (red). In Fig. 3 (c), we show the measured change δV_{fl} of the time-averaged floating potential profile caused by the biasing. δV_{fl} is measured with HEXTIP [9] and linearly interpolated between the measurement points. Also shown is the field-line mapped position of the biased electrodes (black rectangles) and the trajectory of the blob for the bias off (white) and the bias on (black) phase. The black vectors indicate the perturbations of the E×B flow, dubbed $\delta v_{E\times B}$, deduced from δV_{fl}. Qualitatively, we see that the deviation of the trajectory for the biased blob occurs in the direction of $\delta v_{E\times B}$. Together with Figs. 3(d) and (e), these results demonstrate that biasing allows changing both radial and vertical blob velocities in quantitative agreement with the convective motion deduced from the measured profile of δV_{fl}. However, as shown in Fig. 3 (c), the latter can differ from what one would expect from the bias configuration.

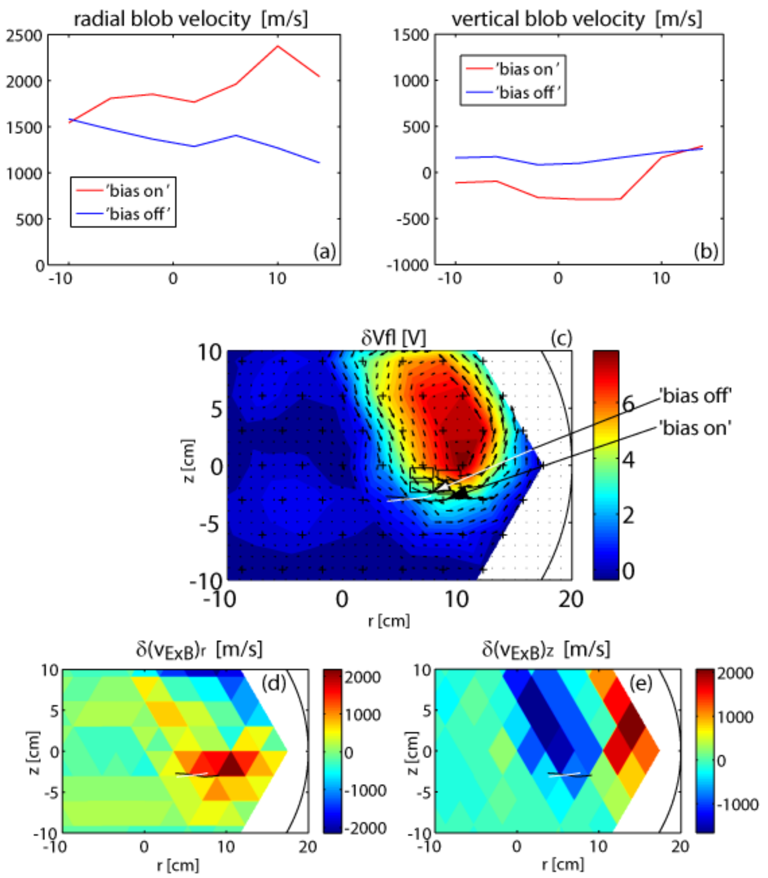

Fig. 3 (a-b): Radial and vertical velocity of the conditionally averaged blob of Fig. 2. (c): Change in time-averaged floating potential induced by the biasing. The blob trajectories in the measurement plane are also shown. (d-e): Profiles of changes in the E×B flow, deduced from δV_{fl}.

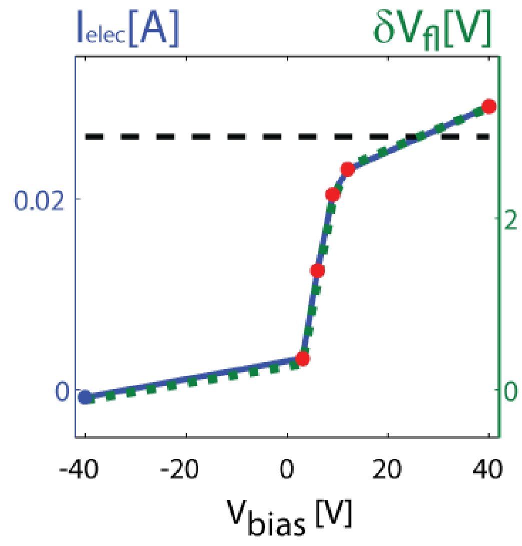

Fig. 4 *Current on the two biased electrodes (left axis, blue solid curve) and resulting potential modifications in the plasma (right axis, green dashed curve) for six different values of bias potential. The black dashed line indicates the expected level of the electron saturation current.*

The mechanisms determining the structure of δV_{fl} were investigated in detail in a series of recent experiments [6]. Here, we briefly discuss the limitation of the achievable changes in plasma potential. We performed a series of discharges with different values of electrode biasing potential and measured the current I_{elec} drawn by them together with the peak value of δV_{fl}. Figure 4 shows a strong asymmetry of I_{elec} for positive and negative bias voltage (see Ref. [6] for details). Furthermore, δV_{fl} is proportional to I_{elec}, which in turns is limited by the electron saturation current, thus setting a limit on the potential that can be induced in these plasmas. At the origin of this is a rather high level of cross-field currents, inferred from the strongly asymmetric current-voltage characteristics of the electrodes. Diamagnetic currents, potentially the strongest contribution, were excluded by comparison with the experimental profiles. The next two most promising candidates, currents due to ion-neutral friction and ion-polarization currents, were further investigated assuming simplified model equations for steady state plasmas. While the ion-polarization current case qualitatively predicts the observed shift of δV_{pl} in the direction of plasma flows, both models give magnitudes of δV_{pl} well above experimental values. The effect of bias was then investigated through nonlinear two-dimensional simulations using a fluid model. Those confirm that neither diamagnetic, nor ion-neutral collision induced, nor ion polarization currents can explain the high level of cross field currents observed in the experiment.

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References

[1] J. Hara et al., Nucl. Mater. 241, 338 (1997).
[2] S. J. Zweben et al., Plasma Phys. Control. Fusion 51, 105012 (2009).
[3] G. F. Counsell et al., J. Nucl. Mater. 313-316, 804 (2003).
[4] J. Stockel et al., Plasma Phys. and Control. Fusion 47, 635 (2005).
[5] C. Theiler, I. Furno, J. Loizu, and A. Fasoli, Phys. Rev. Lett. 108, 065005 (2012).
[6] C. Theiler et al., *Properties of convective cells generated in magnetized toroidal plasmas*, submitted to Phys. Plasmas.
[7] I. Furno et al., Phys. Plasmas 15, 055903 (2008).
[8] C. Theiler et al., Phys. Rev. Lett. 103, 065001 (2009).
[9] S. H. Müller et al., Phys. Plasmas 14, 110704 (2007).