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Biasing experiments with solid and porous electrodes

V. Weinzettl[1], V. Piffl[1], J. Matejicek[1], E. Dufkova[1], J. Zajac[1], R. Dejarnac[1], V. Perina[2]

[1] *Institute of Plasma Physics, Prague, Czech Republic*

[2] *Institute of Nuclear Physics, Rez, Czech Republic*

1. Introduction

A suitable tool for the active control of plasma boundaries and the access to enhanced performance regimes is the edge plasma biasing, what has been demonstrated in numerous experiments. A modification of the radial electric field profile caused by a biasing can consequently significantly affect a plasma confinement. The edge plasma biasing has been investigated on the CASTOR tokamak since 1998 and the impact of the edge plasma biasing on the line averaged density and electrostatic turbulence suppression has been shown [1]. In presented paper, the study on dependence of the biasing effect on the biasing electrode material and changes of the biasing head surface is presented and modifications of edge electron density, floating potential and radiated power profiles are discussed.

2. Experimental setup

Measurements were performed on the small-size CASTOR tokamak with a circular plasma cross-section equipped with a poloidal molybdenum limiter (R=0.4 m, a=0.85 m, B_T=1.3 T, n_e~0.5-1.5x10^{19} m^{-3}, T_e~100-200 eV, L-mode: 30 ms pulse length, P_{OH}=30 kW). A movable holder with a changeable biasing head, 2 cm in diameter, was constructed that allows setting of the insertion radius from 100 mm (shadowed in a diagnostic port) up to 30 mm (deep in a confined plasma region). A surface of biasing heads was chosen in correspondence with the possibly used materials in plasma facing components and their supports in future fusion devices: graphite, bulk tungsten, plasma-sprayed tungsten, copper-tungsten composite and solid copper for a comparison. Tungsten and tungsten-copper composite coatings of 0.3 mm thickness were plasma sprayed by the WSP plasma torch on copper substrates. Pure tungsten powder (63-80 mm) and a 50:50 vol. % mixture of tungsten and copper powders were used. A basic description of the above mentioned plasma-sprayed surfaces behaviour in hot plasma was done in [2]. Carbon and Tungsten inflows, as a result of biasing head erosion, were monitored by photo multipliers equipped with the interference filter for C III line at 464.7 nm and W I line at 400.9 nm, respectively. The biasing electrode was inserted into the plasma column and biased in a stationary phase of the discharge for 5 ms. Broad scans over the biasing potential U_B (from -350 V up to +300 V) and the electrode position r_B (from the plasma edge at 80 mm to the core region at 45 mm) were performed. The edge electron density, electron temperature, and floating potential U_{fl} profiles were deduced from the rake of the Langmuir probes with the spatial resolution of 2.5 mm (the probe voltage was constant at –100 V, swept by predefined waveform or floating). The radiated power and its profile evolution were monitored by the 16-channels fast AXUV-based bolometers.

3. Results and observations

A plasma response to the applied potential varies from nearly no change of discharge parameters, if $|U_B-U_{fl}| \leq$ 50-100 V, through the regimes with an improved confinement, where $|U_B-U_{fl}| \sim$ 100-300 V typically, up to the disruptions, if the difference is high enough to induce arcs from the biased electrode and its erosion. The dependency of biasing current I_B on applied voltage U_B is strongly asymmetric for all used materials, see Fig. 1. Magnitude of the biasing current grows with increasing applied positive potential up to an arcing level given by the electrode material and strongly depends on the electrode position, whereas it is nearly independent on applied voltage and close to a zero level, if U_B<0 V. The exception seems to be the bulk tungsten head located at the hot core region showing a nearly symmetric behavior for both positive and negative polarities. For high negative magnitudes of U_B, arcing is also observed. For graphite and solid Copper, arcing is seen only if positive potential of +300 V was applied, I_B=150 A and 400 A respectively. Bulk Tungsten creates arcs only for negative potentials below –250 V. For sprayed W and W+Cu, arcing occurs for both polarities at the same levels of the applied potential as was mentioned above and

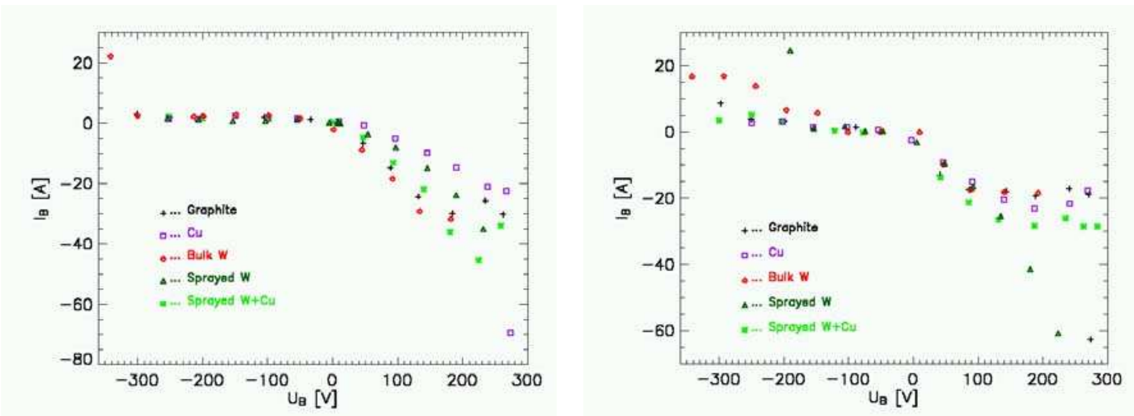

Fig. 1. Dependency of biasing current I_B on biasing voltage U_B for biasing electrode at radius r_B=65 mm (left) and 50 mm (right) for different head materials, averaged over a biasing period of 5 ms. On the left image, two points with high-current arcs for sprayed W at U_B=-250 V, I_B~100 A and sprayed W+Cu at U_B=-200 V, I_B~190 A were omitted. On the right image, the point with high-current arc for Cu at U_B=+300 V, I_B~400 A was omitted.

with currents ranging from tens to several hundreds Amps. Discharge disruptions then come with high current arcs (I_B>150 A) accompanied by the electrode erosion. A clear growth of the C III line intensity measured over the central chord, as a result of the graphite head erosion, was observed for the positive biasing at all electrode positions. A non-zero signal of W I line was obtained only if arcing occurs that indicates a very low erosion of the tungsten surfaces by the standard biasing currents of order of tens Amps.

Measurements by the swept rake probe of a few ms time resolution indicate a nearly independent edge electron temperature profile on both the electrode position and biasing voltage. The local plasma density was computed from the ion saturation current signal including a correction to the electron temperature profile. The biasing, if applied potential is positive, modifies the edge electron density profile that the local maximum appears near the electrode, and sets the maximum of floating potential at the electrode position. Moreover, when the electrode is located near the separatrix in the scrape-off layer, a drop of the electron density is observed in front of the electrode. In Fig. 2, changes of the radial profiles of the floating potential and the plasma density with the applied biasing voltage are demonstrated. Close to the plasma edge, only a positive biasing affects the monitored plasma parameters. Inside a confined plasma region, a weaker effect of the negative biasing is also observed. Decreasing r_B the induced increase of the plasma density becomes more intensive.

An expansion of radiated power profile is measured bolometrically at both biasing polarities, if the difference between floating and biasing potentials is higher than about 50 V. The total radiated power slowly increases, meanwhile the ratio of the total radiated power and the ohmic input power decreases. In the biasing experiments with the electrode inserted deeply in a hot plasma region the relaxation events and fast oscillations were induced [3].

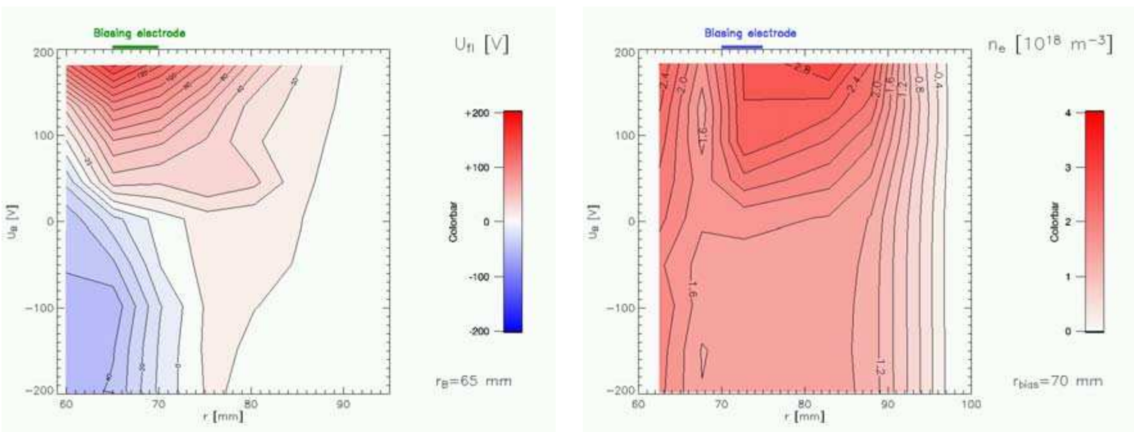

Fig. 2. Changes of the radial profiles of the floating potential (left) and plasma density (right) with the applied biasing voltage in the shots with the bulk Tungsten electrode.

4. Surface changes of biasing heads

Changes in surface morphology were observed off-situ by scanning electron microscopy (SEM). Electron probe microanalysis (EPMA) in an SEM equipped with an energy dispersive spectrometer was used for determining local chemical composition (W, O, C elements). No deep melting or erosion was observed on the plasma-sprayed surfaces. Only narrow bright 'traces' (~100 μm wide), roughly perpendicular to the plasma current direction, were seen as a result of arcing (Fig. 3). Inside these traces, removal of the thin oxide layer from the high temperature manufacturing process was observed. This was also confirmed by the EPMA results: oxygen content inside the trace was 0.15 ± 0.08 % wt., compared to 0.69 ± 0.22 % wt. outside. Carbon content had a rather large scatter from 0 to 1 % wt.; averaging about 3x higher inside the trace. Moreover, a clear deposition of Carbon in a thin surface layer over the whole head was measured by Rutheford Backscattering Spectrometry (RBS) and Elastic Recoil Detection Analysis (ERDA) methods. The same methods show only a small increase of Hydrogen and a decrease of Oxygen over the surface. The bulk biasing heads (Copper, Tungsten and graphite) don't show any visible surface changes, excluding small craters of about 200 μm in diameter formed in the graphite head.

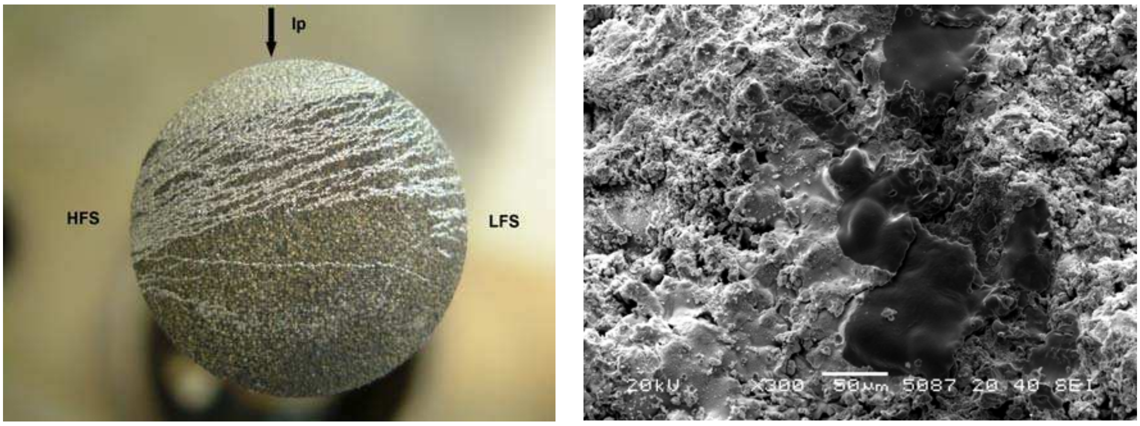

Fig. 3. Surface of the exposed plasma sprayed W coating, showing a detail of the arc trace imaged by SEM. Arcing traces are seen by eye as white (left picture) or by SEM as dark areas (right picture). The as-sprayed surface exhibits a 'powdery' coverage of WO_3; in the trace where this oxide is removed, smoother surface can be seen. Similar traces were found also on the W+Cu specimens.

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