Modification of the tungsten surface under the beam plasma discharge plasmas

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1. Introduction

At the present moment, tungsten is considered one of the most promising candidates for plasma-facing components (PFC) due to its high melting temperature, low sputtering yield, and tolerable thermal conductivity [1]. However, despite these unique properties, intensive plasma irradiation combined with high surface temperature as it expected in the future fusion devices can create conditions for a significant surface structure modifications that can lead to changes of material properties. For example, under helium plasma exposure, one can expect formation of highly porous structures on the tungsten surface known as fuzz [2]. The conditions for the fuzz formation have been well established through the multiple experiments on linear devices such as Magnum-PSI [3].

The present contribution presents the new type of PFC material testing facility based on beam-plasma discharge (BPD). In this work the results of ion mass-spectroscopy, *in situ* thermal desorption spectroscopy (TDS), scanning electron microscopy (SEM) analysis and *in situ* infrared (IR) measurements are presented.

BPD formation in the presence of magnetic field, occurs with abrupt increase of plasma density n_e at a certain threshold value of the electron beam current I_{beam}, when $B^2/8\pi >> n_eT_e$. Because of unique properties of this type of discharge it is possible to create a plasma with electron density $n_e = 1\times10^{17}$-5×10^{18} m^{-3} and T_e = 1-30 eV, with a presence of high energy electron component (with energies up to the applied accelerating voltage value). It becomes possible due to the Landau damping mechanism of electron heating. This allows to perform study of the interaction between plasma flows with high energetic electron fraction and the tungsten surface.

2. Experimental setup

The device consists of two vacuum vessel units connected with pressure-differential water-cooled tube: the main chamber unit where the BPD plasma forms and an electron gun unit. Each unit is pumped out by a 300 l s^{-1} turbo-molecular pump which is backed by a scroll pump providing residual pressure of $1{\times}10^{-6}$ torr in the main chamber unit and $1{\times}10^{-7}$ torr in the electron gun unit. Such vacuum setup allows to create a significant pressure level difference between both units and consequently ensures that electron gun do not go into arc regime. Typical pressure difference between both units is $p_{chamber}/p_{gun} = 10$. For additional pressure level requirements, a bake-out system of the vacuum chamber is implemented. Gas is supplied to the chamber through a mass flow controllers.

A steady-state plasma is produced by an electron gun using a LaB_6 indirectly heated cathode. It was driven by the power supply with maximum output power of 2 kW (an accelerating voltage – up to 2 kV, an emission current – up to 1 A). Filament power heating is frequency modulated. The magnetic field strength of 50 mT is provided by Helmholtz coil. An additional set of magnetic lenses is installed for the focusing purposes.

For plasma diagnostics, a reciprocating Langmuir probe head is mounted in the central port of the main chamber unit. The surface temperature measurements of the tungsten samples were performed by using an IR camera mounted on the side port of the device. To validate the surface temperature measurements, a thermocouple was welded to the back of each sample. During the plasma exposure experiments the W-Cu water-cooled beam dump is used, the position of the sample holder is also shown. For ion flux estimation, an additional Wien filter-based modification can be installed. The overall scheme of the device is schematically shown in figure 1.

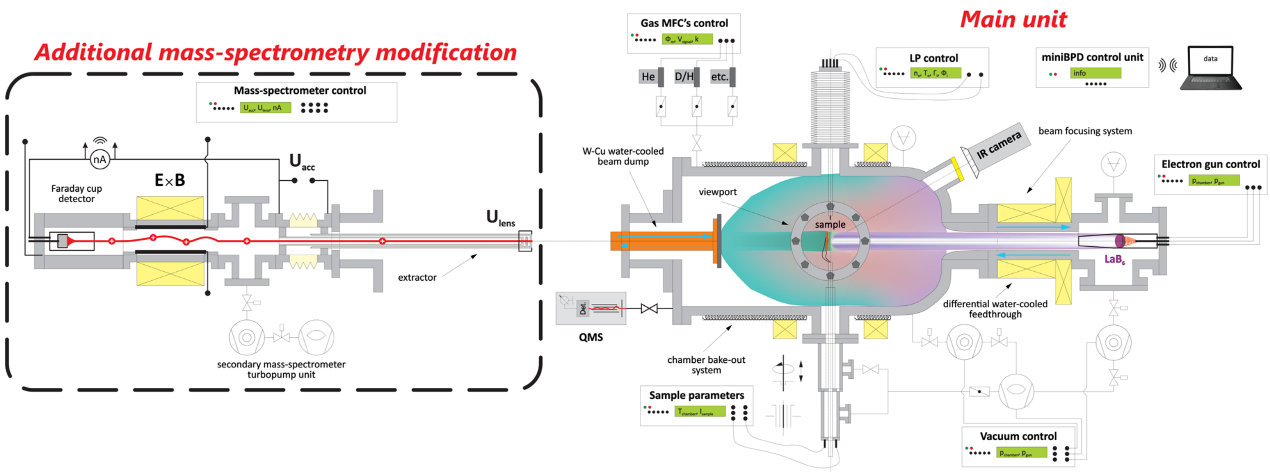

Figure 1. *miniBPD experimental setup scheme.*

3. Ion flux measurements

Ion flux measurements indicates the presence of several ion species in corresponding gas mixture plasma. A non-linear evolution of the ion content is visible with the increase of impurity content in plasma, especially in the He/D plasma case. Results of ion mass-spectrometry measurements of He/H and He/D plasma are presented on figure 2.

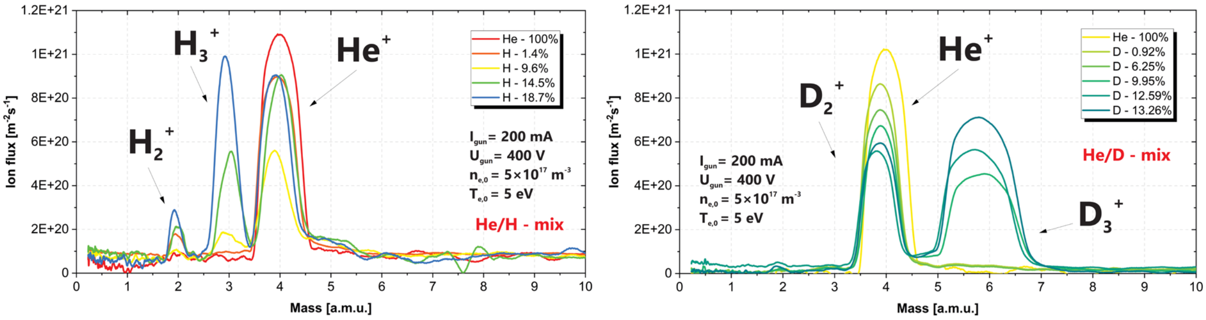

Figure 2. *Ion flux measurements: He/H plasma (right), He/D plasma (left)*

4. IR and SEM analysis results

During surface modification experiments, a thin square tungsten samples of 10 mm diameter and 0.2 mm thickness (purity of 99.999 %) were used. The samples were electrically biased to provide ion bombarding energies of 150 eV. The plasma operating pressure was set to $p_{chamber} = 5\times10^{-2}$ torr. The BPD plasma itself (through high energetic electron beam bombardment) was used to heat the tungsten samples in the range 1000-1500 K. During the experiment, optimal conditions for tungsten fuzz formation under the beam plasma discharge plasmas was found. Results of *in situ* IR measurements as well as SEM data and corresponding flux and total dose are presented on figure 3. Measured plasma parameters profiles and estimated emissivity coefficients are shown on figure 4.

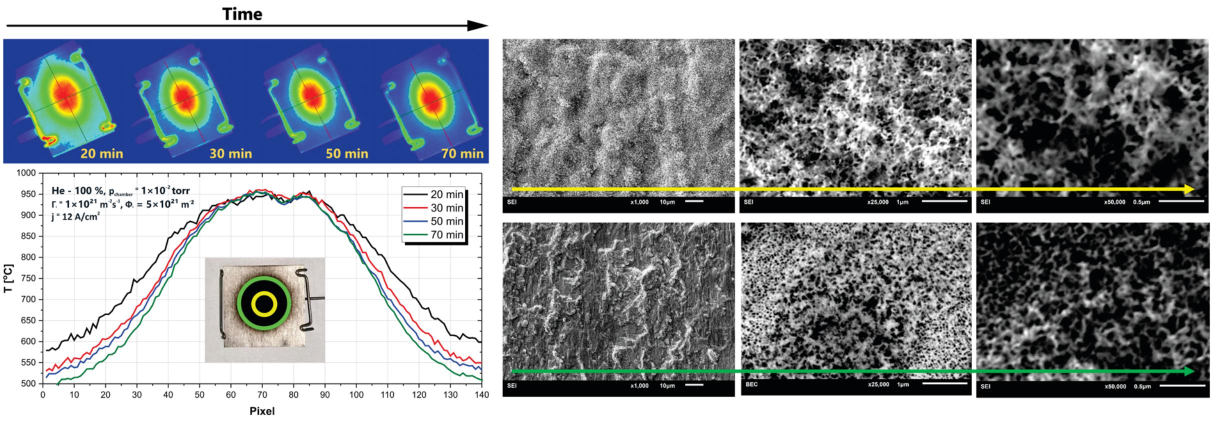

Figure 3. *Results of in situ IR measurements and SEM analysis*

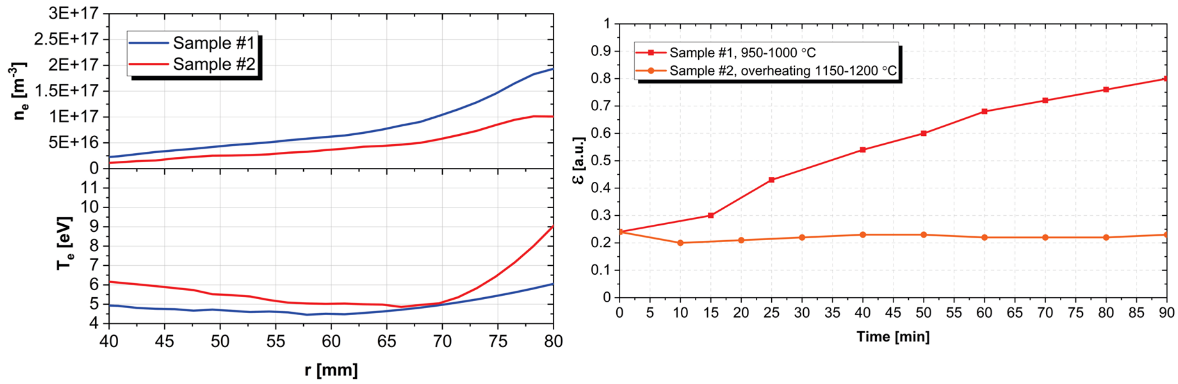

Figure 4. *Measured plasma profiles and estimated emissivity coefficients*

5. In situ TDS measurements

As it was noted, this setup allows to perform an *in situ* TDS measurements directly after the plasma exposure experiment. A controlled heating is done by tuning electron gun into vacuum mode with no gas supplied. Two sets of experiments are shown below: one with pure He and second one with He/H mixture. All QMS data, electron gun parameters and temperature curve are displayed on figure 5. One can admit the presence of helium QMS signal oscillations during the heating which nature is going to be investigated in the future works.

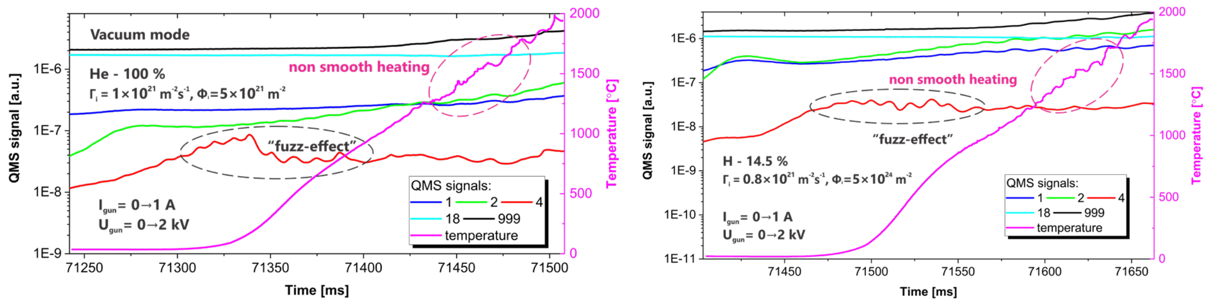

Figure 5. *In situ TDS measurements: pure He plasma exposure (left), He/H mixture (right)*

6. Conclusions

A new multipurpose device is built for PFC material testing and first results are obtained. Ion flux measurements are performed indicating presence of several ion species in BPD plasma. *In situ* IR measurements during pure helium plasma exposure of the tungsten samples are done. Conditions for tungsten fuzz growth are established. SEM data analysis reveals the surface structure after the plasma exposure experiments. A set of *in situ* TDS measurements with different plasma gas content are performed.

Acknowledgements

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References

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