Interaction of plasma with beryllium

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Abstract. In this work shows some results of studying the microstructure of HP-56 beryllium after plasma irradiation. The experiments revealed a change in the microstructure of beryllium after irradiation with hydrogen, deuterium and helium atoms. The pore diameter and their bulk density increase depending on the plasma parameters.

1. Introduction

In ITER, there are two values of the heat load for the blanket, depending on the location on the sectional plane of the chamber [1]: “normal” – 2 MW/m\textsuperscript{2} and “increased” – 4.7 MW/m\textsuperscript{2}. The aim of this work is to experimentally estimate the service life of a beryllium coating after irradiation with an electron beam, hydrogen and helium plasma under the operating conditions of a fusion reactor. The article presents the results of studies of beryllium grade HP-56 figure 1, carried out on a plasma-beam installation (PBI) [2].

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Experiments to evaluate the resistance of various grades of beryllium for thermonuclear installations.}
\end{figure}
2. Experimental conditions
This paper presents the implemented tasks for the experimental study of beryllium grade HP-56 [3] under conditions of irradiation with helium and hydrogen plasma on a PBI in figure 2. The electron gun forms an axially symmetric electron beam, which interacts with the working gas in the plasma-beam discharge chamber, forming a beam-plasma discharge. Beryllium was placed on the PBI target assembly. The electromagnetic system creates a longitudinal magnetic field on the axis of the installation. The plasma-beam discharge was transported to the interaction chamber, where the interaction of the ions of the low-temperature plasma with the material took place. Plasma parameters were determined using a Langmuir probe.

The parameters of the experimental work are presented in table 1.

| Sample | Gas | Ion energy (eV) | Ion current (mA) | Electron temperature (eV) | Ion concentration \((10^{17} \text{ m}^{-3})\) |
|--------|-----|----------------|----------------|--------------------------|-------------------------------|
| 1      | \(\text{H}_2\) | 0              | 0              | -                        | -                             |
| 2      | \(\text{H}_2\) | 1200           | 730            | 11.7                     | 5.84                          |
| 3      | \(\text{D}_2\) | 1600           | 700            | 10.2                     | 4.68                          |
| 4      | \(\text{D}_2\) | 1200           | 330            | 10.6                     | 3.04                          |
| 5      | \(\text{He}\) | 1200           | 290            | 7.29                     | 5.16                          |

The beryllium sample was fixed in the center of the cooled target assembly. At a given ion energy, the power of the electron beam was increased to reach a sample temperature of \(1100 \pm 50^\circ\mathrm{C}\) in all experiments, which was controlled by an IMPAC ISR 6 pyrometer. The exposure time was 30 minutes for each experiment. Figure 3 shows the process of irradiation of beryllium samples located in the interaction chamber at the time of irradiation with hydrogen (left) and helium (right) plasma. The
working gas pressure in the experiments was $\sim 10^{-3}$ Torr. The measuring electrode of the Langmuir probe is located in the upper part of the target assembly in figure 3.

![Figure 3. Plasma irradiation of beryllium.](image)

3. Research methods
The study of the structural components and surface morphology of beryllium samples after their irradiation was carried out using a JSM-6390 scanning electron microscope. Images of the surface on a JSM-6390 scanning electron microscope were obtained in secondary electrons at an accelerating voltage of 20 kV.

The determination of the qualitative and semi-quantitative elemental composition was carried out using a JED-2300 energy dispersive spectrometer on a scanning electron microscope.

Beryllium samples are 10.2×10.2 mm plates and 5.2 mm thick. Photographs of the samples after irradiation are shown in figure 4 (Be 1–Be 5). A visual examination of the irradiated beryllium samples revealed a darkening of the surface facing the plasma and a change in the surface roughness.

![Figure 4. General view of beryllium samples.](image)

Investigations of the microstructure of beryllium on a scanning electron microscope showed that in the initial state on the surface of the sample there are pores of small size and small number, which are mainly located at the grain boundaries in figure 5 (initial). After irradiation, the main radiation defect is the formation of pores of different volumetric density, figure 5 (Be 1–Be 5), which depends on the irradiation mode and the plasma-forming gas. Under the influence of irradiation, the pores in beryllium are filled with atoms of hydrogen, deuterium and helium, which leads to an increase in the pressure inside the pores and, consequently, to an increase in various kinds of stresses at the grain boundaries.

The increase in the size and concentration observed in the initial state of the pores occurs due to the anisotropy of the swelling of individual crystallites, since there is a tendency of the grains to move relative to each other due to the resulting stresses at the grain boundaries. In this case, the significant
accumulation of hydrogen, deuterium and helium in beryllium is also decisive for the process of pore formation, since the diffusion mobility of helium atoms under irradiation is sufficient for their mass movement.

Figure 5. Images of microstructural studies of the beryllium surface.

As a result of energy dispersive analysis, in the near-surface layer of the samples, in addition to the element of the material itself mBe ≥ 90%, the presence of carbon, oxygen, and nitrogen was identified. An increase in the carbon content in comparison with the initial state was revealed. The results of the energy dispersive analysis in the near-surface layer of beryllium samples are shown in figure 6.

Figure 6. Results of microstructural studies of beryllium.

4. Conclusions
Experimental work was carried out on the effect of plasma on beryllium when helium ions and hydrogen isotopes hit the beryllium surface at an angle of 90°. The first data on the behavior of the material as a result of the action of plasma on HP-56 beryllium were obtained.

The results of electron microscopic studies confirm that the porous structure predominates in the samples after irradiation. It was found that in beryllium samples irradiation with a plasma beam leads to an increase in the pore size by 5-10 times, which leads to a decrease in the density of the material.
As a result of surface irradiation, some beryllium samples acquired a spongy structure. Spreading drops are visible on the surfaces of the samples. These are the products of erosion that returned back to the sample during irradiation, as evidenced by the formation of droplets in the cracks.

As a result of the energy dispersive analysis in the near-surface layer of the samples, the presence of carbon was identified along with the element of the material itself. An increase in the carbon content in comparison with the initial state was revealed.

Currently, work is underway to assess the possible melting and erosion of the panels of the first ITER wall at the boundary between the gaps of the protective coatings facing the plasma during transient processes, plasma disruptions based on the operation of the ITER.

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