Experiments with tin liquid-metal capillary porous system in the PLM device

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Abstract. Plasma tests of a tin capillary-porous system (CPS) were carried out on the PLM plasma device. This CPS is made similar to the lithium CPS used in experiments in tokamaks T-10, T-11M. The CPS system was immersed in the PLM plasma device and tested for 3 hours in a stationary helium discharge with plasma load of 1 MW / m². The tin CPS has not damaged after such plasma load suggesting it as plasma facing component in fusion reactors and plasma engines.

1. Introduction

The use of capillary-porous systems (CPS) with liquid metals is considered to solve problems of plasma-facing in-vessel components of a fusion neutron source and a DEMO reactor [1-3]. The main advantages of CPS in comparison with solid materials are their resistance to the degradation of properties and the ability to self-healing the surface based on capillary forces under high-heat plasma loads, like ELMs and disruptions in a fusion reactor. Lithium Li, tin Sn, gallium Ga are considered as candidate materials for use in the CPS to be used in tokamaks [1-3]. The upper limit of the operating temperature for all such metals considered is in the range of 550–600 °C. For the lithium CPS, the disadvantage is the restriction on the permissible flux of atoms into the plasma, for Sn the corrosion resistance of structural materials. The upper limit of thermal loads for CPS with liquid metals Li and Sn in the stationary mode of operation is close to 18–20 MW / m². From the analysis of physical properties [1], it follows that a significant advantage of Sn is a low saturated vapor pressure above the surface of the melt (high boiling point) compared with Li. For Sn, the temperature limit of use determined by the maximum permissible flux of vaporized atoms into the plasma, is above 600 °C, which is the main motivation for considering it as a plasma facing material in tokamaks. In this article we present the result of test of tin CPS in stationary plasma of the PLM plasma device.
2. Tin CPS irradiated with He-plasma

In the PLM plasma device [4], plasma tests of a tin capillary-porous system (CPS) were carried out. The tin CPS was manufactured at Red Star, it consists of tin tile of 15x15x1 mm in size, located between two molybdenum nets (mesh), Fig. 1a. This CPS is of the same type as the lithium CPS used in experiments on tokamaks T-10, T-11M. Such CPS construction is proposed as a plasma-facing component to provide improved characteristics of the first wall under the plasma load. This tin CPS was tested in stationary plasma for the first time. The CPS was fixed in a stainless steel (of grade 12X18H10T) cylindrical bath with a diameter of 20 mm and a height of 2 mm, Fig. 1a. A test module in the form of a plate was welded to this bath, on which a reference tin plate of 3x3x3 mm³ was fixed.

![Fig.1. Capillary-porous system with molybdenum mesh filled with Sn tin in a stainless steel bath: (a) before testing, (b) after plasma irradiation in the PLM device.](image)

3. Experimental results

The plasma irradiation of the tin CPS were performed on the plasma linear multicusp (PLM) plasma device [4]. The PLM device is a linear plasma trap with a multi-cusp configuration of a magnetic field and a stationary plasma discharge that provides the powerful plasma-thermal load up to 5 MW/m² on test materials. The test samples were irradiated with helium plasma of discharge duration up to 200 min. Plasma parameters measured by Langmuir probe and spectroscopic diagnostics were as follows: plasma density was up to 3·10¹⁸ m⁻³, the electron temperature was up to 4 eV with a fraction of hot electrons of temperature up to 50 eV, the ion plasma flow onto the test sample was up to 3·10²¹ m⁻² s⁻¹, discharge current reached the value of more than 15 Amps. Magnetic field was of 0.01 Tesla on the trap axis and up to 0.1 Tesla in the cusps. The target samples have no active cooling in these experiments, plasma heat load on test target was of 0.5 - 1 MW/ m².

The tin CPS was immersed in the plasma of the PLM and was tested for 3 hours in a helium discharge with plasma parameters: density is 1 · 10¹² cm⁻³, electron temperature is of 2-5 eV. During the exposure, pyrometers registered its heating to the temperature of 700 °C (Fig. 2a) and the melting of the reference tin module was visually observed. Plasma load was estimated of 1 MW / m². Optical spectra were measured, atoms and ions of tin in plasma was registered by spectra (Fig. 2b, c, d). After exposure, the materials of the tin CPS were inspected. Significant zones (several square millimeters) of melting of the stainless steel bath were found, Fig. 1b. At the same time, the shape of the tin CPS did not change, no outflow was found and no significant losses of tin from the CPS. The experiment demonstrated satisfactory tin CPS survival under stationary plasma loads. Plasma-surface interaction and plasma-facing material (see [5-19]) can be influenced under effect of the tin CPS. This experiment can be in favor for further studies of the tin CPS as in-vessel components at high plasma loads and the assessment of the prospects for use in a fusion reactor and plasma engines.
Conclusion

In the PLM plasma device, plasma tests of a tin capillary-porous system were carried out. The tin CPS was manufactured at Red Star, it consists of tin tile of size 15x15x1 mm, placed between molybdenum nets. This CPS is similar to lithium CPS used in experiments on tokamaks T-10, T-11M. The tin CPS was tested for the first time in stationary plasma. Such a system was immersed in the plasma of the PLM device and tested for 3 hours in a helium discharge with plasma parameters: density about $1 \times 10^{12}$ cm$^{-3}$, electron temperature up to 5 eV with a fraction of hot electrons up to 50 eV. During the exposure, pyrometers registered the CPS heating to a temperature of 700 °C, and the melting of the reference tin module was visually observed. The plasma load was at the level of 1 MW / m$^2$. The optical emission spectra registered from the plasma detecting tin atoms and ions. Post-mortem inspection of the CPS after plasma irradiation revealed significant zones (of several square millimeters) of the stainless steel bath melting. At the same time, the shape of tin CPS has not changed, no outflow has been detected and significant losses of tin from CPS. The experiment can be the basis for further large-scale tests of tin CPS at high plasma loads and assess the prospects for use in fusion devices and plasma engines. This work suggests that the tin CPS as plasma facing component can be considered in a future fusion reactor and plasma engines.

Fig. 2. (a) A view of the tin CPS in plasma discharge of the PLM, (b) - (d) optical spectra of plasma radiation.
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