ESTIMATION OF TUNGSTEN AND ODS TUNGSTEN DAMAGES AFTER DENSE PLASMA EXPOSURE IN PF-12 AND PF-1000

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The paper presents experimental investigations of damages in pure tungsten and ODS (oxide dispersed strengthened) tungsten under dense plasma shots. The experiments were performed with plasma focus devices PF-12 and PF-1000 with a power flux density of 10^6…10^{12} W/cm^2 using deuterium. The surface morphology of the targets exposed to plasma streams is analyzed using electron and optical microscopy. Due to the plasma effect, different surface structures, such as wave-like structures, a melted layer, a mesh of microcracks, droplets, craters, crevices and holes appear. Both the original and irradiated samples were investigated by local X-ray spectroscopic analysis and by X-ray phase-shift analysis.

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INTRODUCTION

At present the construction and planning of a number of large fusion facilities (ITER, NIF, LMJ) based on different plasma confinement principles is under way. Thus it is necessary to contribute to the knowledge-based understanding of the performance and adequacy of pure tungsten (different grades), beryllium, CFC (carbon fiber composite) under extreme energy and particle loads [1,2].

ODS tungsten strengthened by different metal oxides such as Y_2O_3, CeO_2, ZrO_2, ThO_2 (in this study, by La_2O_3) may be a suitable candidate for divertor targets of thermonuclear reactors [3]. Interest in these materials can lead to new ways of improvement of the mechanical properties of the materials. Therefore, it is of importance to analyze different tungsten grades and alloys under various irradiation conditions. In our research, plasma focus devices enabling different regimes of irradiation are used as high energy plasma and radiation generators.

1. EXPERIMENTAL DEVICE

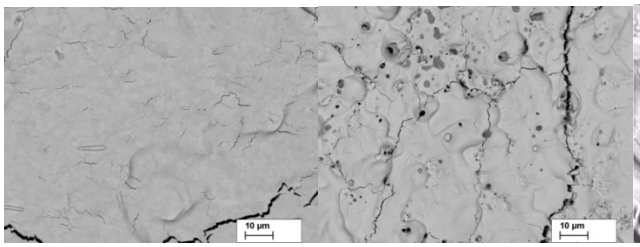
Samples of tungsten and tungsten doped with 1% of La_2O_3 (WL10) have been exposed to a varying number of pulses of deuterium plasma streams produced by plasma focus devices PF-12 and PF-1000 [4,5]. In PF-12 the distance from the anode was 3.5 – 10.5 cm, while the power flux density was about $5\cdot10^8$, $5\cdot10^7$, $5\cdot10^6$ W/cm^2. The energy of fast ions was about 100 keV and the slow plasma 0.1…10 keV. Pulse duration of the distance of 3.5 cm was 200 ns and at 10.5 cm is 0.1 ms (secondary plasma with an energy of a few eV). In PF-1000 the distance from the anode was 7.5 cm, the power flux density was about 10^{12} W/cm^2 and the pulse duration was 200 ns.

The target samples (manufactured in PLANSEE) were prepared using methods of powder metallurgy including tungsten restoration from WO_{3-x} oxide, isostatic pressing, sintering and rolling. The lanthanum oxide particles were finely distributed. The 20x20 mm W and WL10 samples were 2 and 4 mm thick, respectively.

2. EXPERIMENTAL RESULTS

The surfaces of irradiated specimens were investigated by using scanning electron microscopy (SEM) and optical microscopy (Fig.1 and Fig.2). After plasma processing surface and volume defects can be found on the materials. On the samples surface there are relief changes, which allow to estimate and characterize the defects density on the surface layer.

Analysis shows that all samples are covered with a melted layer, a mesh of microcracks and bubbles. On some materials a smoothing of the surface has occurred as a result of a long exposure to plasma. The duration of such influence can reach tens or, maybe, hundreds of microseconds.



a b

Fig. 1. SEM views of exposed W (a) and WL10 (b) surface after 2 PF-12 plasma pulses of a power flux density of 500 MW/cm^2

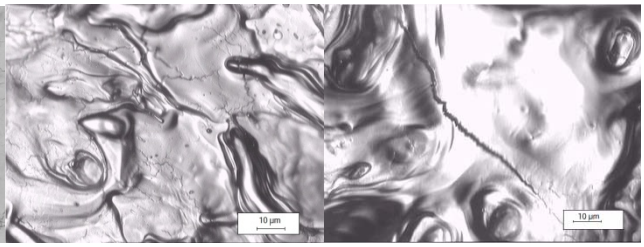


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Fig. 2. SEM views of exposed W (a) and WL10 (b) surfaces after 2 PF-1000 plasma pulses of a power flux density of 10^{12}W/cm.^{2}

From the images of cross-sections (Fig. 3) it can be seen that the melted layer is about 5 μm thick. The exposure of a dense plasma flux, which is considered as a continuous medium, leads to the development of waves on the melted surface. The mesh of cracks that appears on the surface is caused by crystallization of the melted layer by fast cooling. As lanthanum doping lowers the melting temperature, melting bubbles appear on the materials. Atomization of the surface continues until the alloy's melting temperature is reached.

Fig. 3,a,b present etched cross-section of samples. One can see the rolling layers, while the section has been made perpendicular to the rolling direction. The second phase (see Fig. 3,b) involves strokes elongated along the rolling direction.

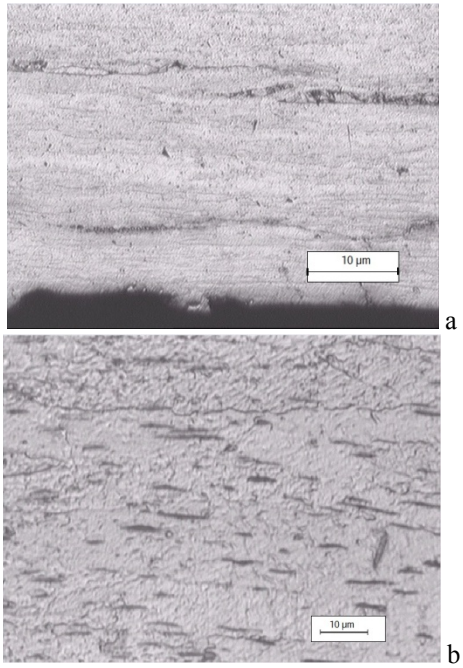

Fig. 3. Cross-sections of irradiated etched W (a) and WL10 (b)

The lanthanum doping changes the picture of the defects developed on the surface. This fact is confirmed by local X-ray spectroscopic analysis and X-ray phase-shift analysis. The X-ray diffractograms were made in Moscow A. A. Baikov Institute by a Dron-6 device using $Cu_{K\alpha}$ radiation. Analysis shows second phase particles, which play a major role in the cracks formation and development. The phases data for both materials are presented in Table.

The results of W and WL10 X-ray phase-shift analysis

Condition of alloy	Second phases in W	Second phases in WL10
Non-irradiated sample	W-99%; W_3O-1%	W_3O; WO_3; La_2O_3; $La_2W_{1,25}O_{6,75}$; $La_2O_3.3WO_3$
Irradiated sample after irradiation with 2 deuterium plasma shots, $q=10^{12}$ W/cm^2	W-98%; W_3O-1%; WO_3-1%	W_3O; La_2O_3; La_2WO_6; $La_2O_3.3WO_3$

Thus in the composite alloy there are second phase particles, which are situated close to each other, having their own physical, chemical and mechanical properties and influence on the material behavior. The X-ray diffraction results show that non-irradiated samples have a rolling texture in the (200) direction, which is absent in the surface melted layer of the irradiated samples (see Fig. 4). On the samples of pure tungsten such texture is not found.

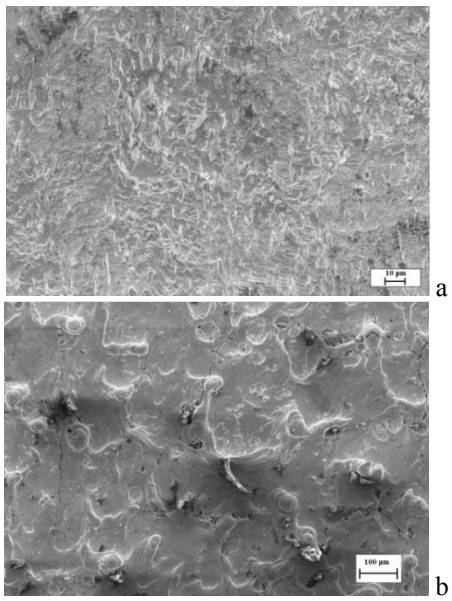

Fig. 4. SEM view of the WL10 original sample (a) and WL10 exposed sample (b)

The analysis shows a decrease of the tungsten lattice parameter and the volume of the elementary cell in the alloy after irradiation, which may be associated with the interstitial atoms withdrawal (N, H, O).

In the (200) direction on the diffractogram the maximum possible relative uncertainty of the peak intensity and position is 0.3 with the 95% confidence level. On this basis it can be confirmed that the change of the lattice parameter is in this range. With more accurate measurements the change of this parameter can be more significant, because the intensity of the other lines does not change.

The solubility of interstitial impurities in tungsten is negligible even at tungsten melting temperature [6]. Possibly the openings for exit occur in the second phases on the surface layer, over which the burst of melted material and bursting expansion appear (see Fig. 5).

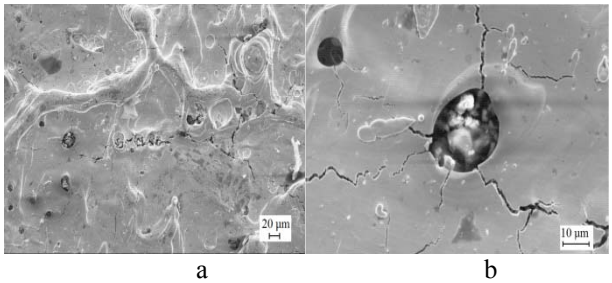

Fig. 5. The irradiated surface of WL10 in different resolutions demonstrating the impurity influence on material damages after dense plasma shots

CONCLUSIONS

Irradiation of pure tungsten and WL10 composite alloy with high-temperature plasma produces surface melting. The melted layer is 5 μm thick, which leads to defective structure formation. The content of dispersive oxides leads to expansion of the material (the expansion may be greater than in the case of pure tungsten) and, in cooling time, to generation of cracks. According to our results, the changes of WL10 caused by a power flux density of 10^{12} W/cm^2 during 200 ns of plasma-material interaction are similar to those found by Klimov et al [7], who used a weaker power flux density but longer interaction. This indicates that the given type of damages are universally important, no matter what the power flux density or duration of interaction, if only the power flux density overpasses a certain threshold value.

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ОЦЕНКА ПОВРЕЖДЕНИЙ ВОЛЬФРАМА И ODS ВОЛЬФРАМА ПОСЛЕ ВОЗДЕЙСТВИЯ ПЛОТНОЙ ДЕЙТЕРИЕВОЙ ПЛАЗМЫ НА УСТАНОВКАХ ПФ-12 И ПФ-1000

В. Широкова, Т. Лаас, Я. Прииметс, Е.В. Демина, М.Д. Прусакова, М. Шольц

Представлены результаты исследований повреждений в чистом вольфраме и вольфраме, легированном дисперсными, оксидами под воздействием плотной плазмы. Эксперименты были проведены на установках плазменный фокус ПФ-12 и ПФ-1000 в дейтериевой плазме с плотностью мощности 10^6…10^{12} W/cm^2. Морфология поверхностей мишеней, облученных плазменными потоками, была исследована с помощью сканирующего электронного микроскопа и оптического микроскопа. На поверхности материала были обнаружены различные дефекты, такие как расплавленный слой, волнообразные структуры, сеть микротрещин, брызги, кратеры, наплывы и поры. Оба материала до и после облучения также исследовались с помощью рентгеноспектрального и рентгеновского фазового анализов.

ОЦІНКА УШКОДЖЕНЬ ВОЛЬФРАМУ І ODS ВОЛЬФРАМУ ПІСЛЯ ВПЛИВУ ГУСТОЇ ДЕЙТЕРІЄВОЇ ПЛАЗМИ НА УСТАНОВКАХ ПФ-12 ТА ПФ-1000

В. Широкова, Т. Лаас, Я. Прійметс, Є.В. Дьоміна, М.Д. Прусакова, М. Шольц

Представлені результати досліджень пошкоджень у чистому вольфрамі та вольфрамі, легованому дисперсними, оксидами під впливом густої плазми. Експерименти були проведені на установках плазмовий фокус ПФ-12 та ПФ-1000 на дейтерієвій плазмі з густиною потужності 10^6…10^{12} W/cm^2. Морфологія поверхонь мішеней, опромінених плазмовими потоками, була досліджена за допомогою скануючого електронного мікроскопа та оптичного мікроскопа. На поверхні матеріалу були виявлені різні дефекти, такі як розплавлений шар, хвилеподібні структури, сітка мікротріщин, бризки, кратери, напливи і пори. Обидва матеріали до і після опромінення також досліджувалися за допомогою рентгеноспектрального й рентгенівського фазового аналізів.