EFFECT OF IRRADIATION IN THE PLASMA FOCUS DEVICE ON THE STRUCTURE OF THE VANADIUM SURFACE

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The effect of various regimes of plasma irradiation in the "Plasma focus" device on the surface structure of vanadium has been studied. It is established that at the plasma power density values of 10^8-10^{10} W/cm^2 there are pores, microcracks and gas bubbles in the structure of material. In addition, as a result of the plasma action, the ejection of individual pieces of material from the irradiated vanadium surface was observed

Introduction

Vanadium and its alloys have a high decay rate in the induced radioactivity after neutron irradiation. Therefore, these low-activated materials are of interest for their possible use as structural materials of the first wall of a thermonuclear reactor (TNR). However, before their application in TNR it is necessary to thoroughly investigate their behavior under conditions close to the operating conditions of TNR. The irradiation parameters in the "Plasma focus" device are close to the parameters of irradiation for material at the first wall of TNR [1]. In this connection, in this study, we investigated the structural damage of vanadium when it was irradiated by powerful streams of high-temperature plasma in the "Plasma focus" device.

Main part

Irradiation of samples was carried out in the PF-6 Plasma focus device (Poland). The energy resource of the installation was 2 kJ, working gas was deuterium. Density of particles in the plasma flow was $\sim 10^{18}$ cm^{-3}. The power density of the deuterium plasma flow was equal ~10^7-10^{10} W/cm^2, and the flow of the deuterium ions was in the range 10^8 – 10^{12} W/cm^2. The duration of the plasma pulse was 50 ns. The device had a copper anode with insert of rhenium.

Figure 1 shows a REM photograph of the microstructure of the vanadium surface after irradiation by two plasma pulses at a distance of 3.5 cm from the anode. It can be seen that a wave-like relief is formed on the irradiated surface of the sample. Waves are fixed due to superfast crystallization of the melt. They are usually associated with surface capillary waves.

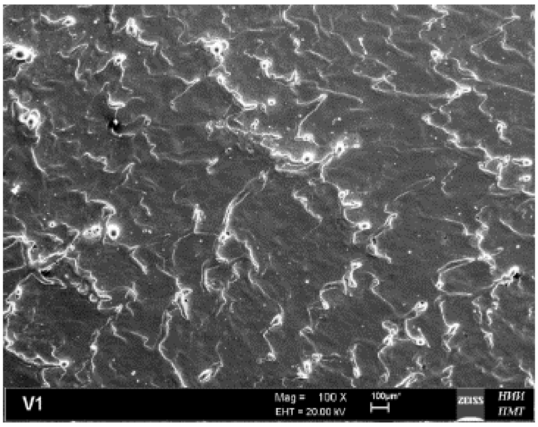

Fig. 1. Surface microstructure of vanadium irradiated by two pulses of a deuterium plasma at a distance of 3.5 cm from the anode

Moreover, on the tops of many waves, the metal crystallizes as if in a spiral (Fig. 2). The formation of such structure is probably due to two reasons. Perhaps their formation occurs in a liquid state, when at the tops of the waves the metal is twisted in the form of a spiral. Further, with the ultrafast crystallization, these configurations are fixed. Another possible process may be the crystallization in the layered-spiral mechanism [2]. In this case, the process of growth goes on an already solidified surface having micro-roughness.

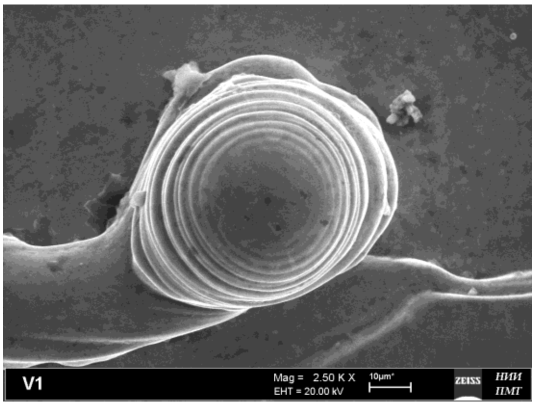

Fig. 2. Spiral structure formed on the tops of surface waves in irradiated vanadium

A characteristic feature of the damage of the vanadium surface during irradiation by a deuterium plasma is the appearance of gas-filled bubbles (blisters), Fig. 3. They appeared at all values of the power flux density of plasma. In our case, the blisters appear under specific conditions created in the PF device, with a joint impact on a sample of ultrashort flows of deuterium ions and deuterium plasma in the conditions of occurrence of large temperature gradients and shock waves.

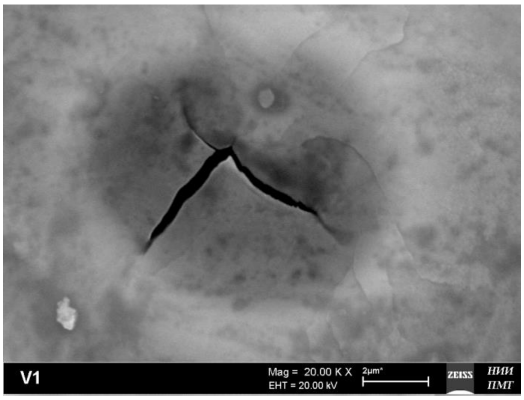

Fig. 3. Blisters on the irradiated vanadium surface

It is believed that the formation of gas-filled bubbles occurs in the process of boiling of the liquid phase due to evaporation into the micropores of gas-forming elements, such as implanted deuterium atoms, as well as impurities of carbon, oxygen and their compounds. Vanadium is a plastic enough material, so the domes of the blisters, in according with [3], are broken mainly in the central zone (Fig. 3). In brittle materials, the opening of blisters, as a rule, occurs on the periphery.

Typical damages in the samples of vanadium irradiated in the PF device are the microcracks (Fig. 4), related to thermomechanical processes occurring as a result of ion-plasma action.

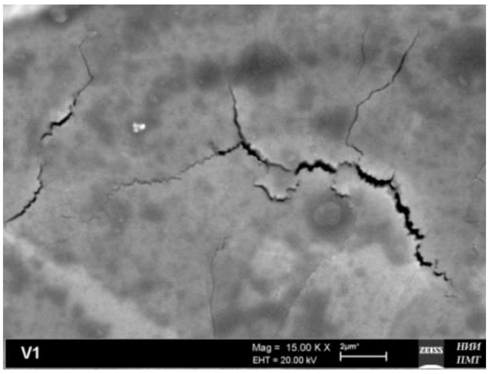

Fig. 4. Cracks on the irradiated vanadium surface

In addition, as a result of the plasma action, the ejection of individual pieces of material from the irradiated vanadium surface was observed. These pieces (chunks) had an arbitrary shape, their sizes were equal from 1 micrometer to several tens of micrometers (Fig. 5). The ejection of the pieces occurred, apparently, due to the output of the unloading wave formed in the bulk of the sample onto the irradiated surface. The nature of these injuries differed sharply from those caused by thermomechanical stresses. On these particles, traces of surface reflow were visible. It is also possible to note the directed motion of the extracted particles (apparently in the direction of propagation of the unloading wave).

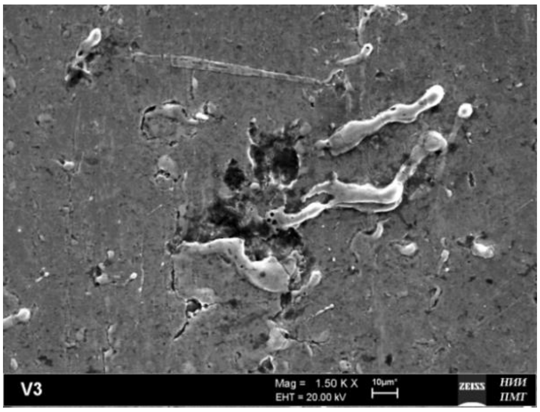

Fig. 5. The ejection of pieces (surface fragments) of an arbitrary shape in a sample irradiated with four pulses at q = 10^7 - 10^8 W/cm^2

The character of damage of vanadium surface was influenced by the distance between the irradiated sample and the anode of the PF device. With a significant removal of a sample from the anode (13-14 cm), a microstructure is formed in the samples in the form of blocks of regular rectangular shape. With a small number of pulses (N = 2-4), blocks are formed only in some areas. At N = 12, the block structure is formed on the entire surface of the sample. Similar structural changes were observed on a single-crystal sapphire upon exposure to a sliding plasma beam [4]. The boundaries of the blocks are treated as thin cracks spreading over the surface, their formation is associated with the relaxation of internal stresses during fast cooling of a thin surface layer.

Conclusion

The study of structural changes of the surface vanadium in dependence of irradiation regimes by pulsed streams of deuterium ions implanted and high-temperature deuterium plasma in the “Plasma focus” device has been done. It was found that at a power density of the plasma flow in the range of q = 10^8 – 10^{10} W/cm^2, and the ion fux in the range of q = 10^{10} – 10^{12} W/cm^2, there were the processes of partial evaporation, melting and crystallization of the surface layer of vanadium. In vanadium structure it has been observed a wave-like surface relief, the presence of pores, micro-cracks, as well as gas-filled gas bubbles (blisters) and traces of their destruction.

References

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