FORMATION OF A DEFECT STRUCTURE IN ALLOYS OF THE Zr-Nb-H SYSTEM UNDER IRRADIATION WITH A PULSED ELECTRON BEAM*

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In recent years, surface modification by electron beam irradiation has been used to improve the performance of metallic materials and create protective coatings. Under the electron beam exposure in the surface layers of the material, large gradients of temperatures and stresses arise, resulting in the formation of defects. The presence of hydrogen in the material can significantly change the density and type of defects formed during irradiation. It is known [1] that hydrogen can induce the formation of new defects in the material and actively interact with existing structural defects. The resistance of the material to hydrogen embrittlement depends on the type and amount of certain defects in it [2].

In this work, we performed a comparative study of the effect of pulsed electron beam irradiation on the defect structure of zirconium Zr-1 wt.% Nb alloys with a hydrogen content of 0.0014 and 0.25 wt. % (hereinafter Zr-1Nb and Zr-1Nb-H alloys).

In the initial state, the zirconium Zr-1Nb alloy contains two phases: α-Zr and β-Nb. In the Zr-1Nb-H alloy, in addition to the indicated phases, ZrH and ZrH_2 hydrides are observed. The β-Nb phase in the form of particles, ranging in size from several tens of nanometers to several microns, is present in the bulk and at the grain boundaries of the α-Zr phase.

The alloys were irradiated with a pulsed electron beam in the SOLO facility having a pulsed electron source. Two irradiation modes were used: surface melting mode (energy density 12 J/cm^2) and surface non-melting mode (energy density 5 J/cm^2).

It was established that irradiation with a pulsed electron beam without surface melting does not change the average grain size, volume fraction, and distribution of particles of the β-Nb phase in Zr-1Nb and Zr-1Nb-H alloys. At the same time, the dislocation density (ρ) and the crystal lattice microdistortion (Δε) of the α-Zr phase increase in the surface layer of both alloys. In the surface layer of the Zr-1Nb alloy, ρ increases from $1.6\cdot10^{13}$ to $1.5\cdot10^{14}$ m^{-2}, and Δε grows from $3.2\cdot10^{-4}$ to $1.0\cdot10^{-3}$. In the Zr-1Nb-H alloy, the dislocation density increases from $3.0\cdot10^{14}$ m^{-2} to $6.7\cdot10^{14}$ m^{-2}, and the value of the microdistortions of the α-Zr crystal lattice – from $1.4\cdot10^{-3}$ to $2.1\cdot10^{-3}$. In the main bulk of the alloys, the values of the crystal lattice microdistortions and the dislocation density are practically unchanged.

As a result of irradiation with a pulsed electron beam in the melting mode, a lamellar structure is formed in the surface layer of both alloys (8-12 μm in width) with sizes of parallel plate packets of 1-2 μm. The width of the plates in the packets ranges from 20 to 300 nm. The plates are α and α" zirconium phases. There are no precipitates of the β-Nb phase in the modified layer. In the Zr-1Nb-H alloy, no hydrides are observed in the surface layer of ~1 μm width. At the same time, the total concentration of hydrogen in the alloy decreases slightly (by 0.002-0.004 wt.%). The dislocation density in the modified layer of the Zr-1Nb and Zr-1Nb-H alloys increases to $3.2\cdot10^{14}$ and $7.4\cdot10^{14}$ m^{-2}, correspondingly, and the value of the crystal lattice microdistortions rises to $1.3\cdot10^{-3}$ and $2.0\cdot10^{-3}$, respectively. In the main bulk of studied alloys, the indicated structure parameters practically do not differ from the initial values.

Positron annihilation spectroscopy studies have shown that electron beam irradiation in the melting mode results both in growth in the density of defects that increase the free volume (dislocations, vacancies, and vacancy complexes), and the dissolution of β-Nb phase and the formation of defects of "vacancy-impurity" type in the surface layer of alloys. The presence of hydrogen promotes the formation of complex hydrogen-vacancy complexes in the surface layer of the Zr-1Nb-H alloy upon pulsed electron beam exposure in the melting mode. In this case, dislocations remain the main type of defects.

REFERENCES

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