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# MICROSTRUCTURAL STABILITY AND MECHANICAL PROPERTIES OF THE SYSTEM V-NB-TA-TI UNDER HELIUM ION IRRADIATION

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One of the promising areas of research in modern material science is the study of properties and methods for producing high-entropy alloys. High entropy alloys (HEAs) are composed of four or more metallic elements mixed in an equimolar or near equimolar ratio [1]. The introduction of near-equiatomic multicomponent single phase high entropy alloys has changed the conventional alloy design process in which only one or two principal elements determine the material primary properties. It is believed that maximizing the configuration entropy of high-entropy alloys promotes the formation of a single-phase disordered solid solution instead of the formation of complex intermetallic or second phases which might influence point defect recombination phenomena in irradiated materials by modifying the vacancy-interstitial recombination interaction distance, solute diffusivity, or other mechanisms, thereby producing different (superior or inferior) radiation stability compared to conventional single phase alloys [2, 3].

Multicomponent solid solutions based on V-Ti-Nb-Ta were synthesized using high-purity metals (>99.9%) by arc melting followed by homogenization. Then annealing was carried out for 24h and 72h at a temperature of 1150 $^{o}$C with cold rolling up to 85 % reduction in thickness. The samples were irradiated at room temperature with $He^{2+}$ ions with an energy of 40 keV and a fluence of $2\times10^{17}$ cm$^{-2}$.

The calculation of energy losses was carried out in the SRIM 2013 program using the Kinchin-Pease model. The maximum range of helium ions was 275–325 nm, with the maximum damage for vanadium at a depth of 160–170 nm, and for the VNbTaTi alloy, at 120–140 nm. The highest value of the damaging dose is 3.5–6.5 dpa, depending on the samples. The concentration of implanted $He^{2+}$ ions does not exceed 17–23 at.%.

The X-ray diffraction analysis of initial samples showed that, regardless of the number of elements in the alloy, a single-phase solid solution with a BCC lattice is formed in all initial samples. The general view of the diffraction patterns (narrow and intense diffraction peaks) indicates a high crystallinity degree of the alloys; however, the shape of the diffraction lines (their asymmetry) is related to the possible both with the heterogeneity of the structure of the solid solution and for strongly deformed crystal lattices, which is characteristic of high-entropy alloys and is associated with the difference in the atomic radii of the selected elements. The lattice parameter for samples V, VNb, VNbTa, VNbTaTi was 0.3027 nm, 0.3177 nm, 0.3227 nm, 0.3234 nm, respectively. The results of energy dispersive analysis (EDX) confirm the formation of homogeneous equiatomic multicomponent solid solutions.

After irradiation with helium ions with at energy of 40 keV and a fluence of $2\times10^{15}$ cm$^{-2}$, the uniformity of the distribution of elements and the phase composition of a multi-component solid solution based on V-Nb-Ti-Ta did not change, which is confirmed by the results of scanning electron microscopy and X-ray diffraction analysis. The diffraction pattern shows a more explicit asymmetry of the peaks and their shift towards smaller angles, which indicates the deformation of the crystal lattice caused by irradiation. Values of macro-deformation increased and amounted to 0.21%, 0.35%, 0.44%, 0.47% for V, VNb, VNbTa, VNbTaTi, respectively. The magnitude of the micro-deformation calculated by the Holder-Wagner method also increased with the number of elements in the system V-Nb-Ta-Ti, except pure vanadium and size of the coherent scattering regions decreased. The nano-hardness data of the initial and irradiated samples are compared with the results of micro- and macro-strain. In the work, we analyze in detail mechanisms of radiation resistance and the physical cause for this effect.

## REFERENCES

[1] M.C. Troparevsky, J.R. Morris, M.Daene et al., "Beyond Atomic Sizes and Hume-Rothery Rules: Understanding and Predicting High-Entropy Alloys," JOM, vol.67, pp. 2350-2363, 2015.

[2] D.B. Miracle, O.N. Senkov, " A critical review of high entropy alloys and related concepts," Acta Materialia, vol.122, pp. 448-511, 2017.

[3] Ming-Hung Tsai, Jein-Wei Yeh, "High-Entropy Alloys: A Critical Review," Mater. Res. Lett., vol.2, pp. 107-123, 2014.