

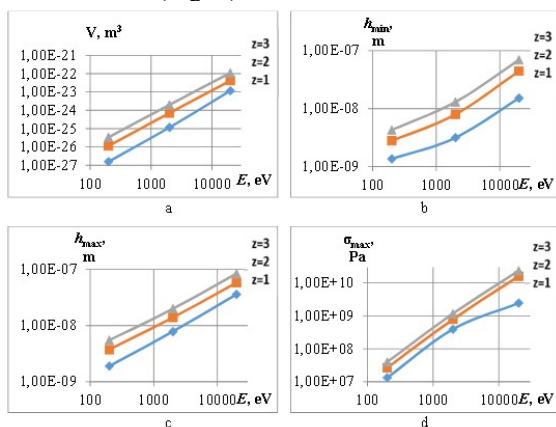
### CREATION OF NANOSTRUCTURES ON ZIRCONIUM ALLOYS

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The action of ions was considered  $B^+$ ,  $C^+$ ,  $N^+$ ,  $Si^+$ ,  $Al^+$ ,  $V^+$ ,  $Cr^+$ ,  $O^+$ ,  $Fe^+$ ,  $Ni^+$ ,  $Co^+$ ,  $Y^+$ ,  $Zr^+$ ,  $Mo^+$ ,  $Hf^+$ ,  $Ta^+$ ,  $Pt^+$  with charge numbers 1, 2, 3 and energies 200, 2000, 20000 eV, calculated temperature fields, their growth rates and temperature stresses, which were selected areas of the material, which implemented the criteria for the formation of nanostructures: temperatures lie in the range 500–1500 K, their growth rates exceed  $10^7$  K/s or temperature stresses exceed  $10^{10}$  N/m<sup>2</sup> and calculated the volume of grain  $V_i$ , the minimum  $h_{min}$  and maximum  $h_{max}$  depth of its occurrence.

So, for the case of action of boron ions have a grain volume range of  $1.57 \cdot 10^{-27}$  to  $10.8 \cdot 10^{-22}$  m<sup>3</sup> with a minimum depth of  $1.35 \cdot 10^{-9}$  to  $6.39 \cdot 10^{-8}$  and the maximum of  $1.9 \cdot 10^{-9}$  to  $8.47 \cdot 10^{-8}$  m, and the temperature voltage from  $8.1 \cdot 10^6$  to  $1.3 \cdot 10^6$  m (Fig. 1).



**Fig. 1. Dependence of the nanocluster (NC) volume (a), minimum (b) and maximum (c) depth of occurrence of NC, maximum temperature stresses (d), under the action of boron ions ( $B^+$ ) with different charge ( $z = 1, z = 2, z = 3$ ) on zirconium alloy Zr1Nb**

For carbon ions ( $C^+$ ) we have a change in the volume of NS from  $1.58 \cdot 10^{-27}$  to  $7.9 \cdot 10^{-23} \text{ m}^3$ , and the depth of occurrence: minimum from  $1.16 \cdot 10^{-9}$  to  $5.94 \cdot 10^{-8} \text{ m}$  and maximum from  $1.81 \cdot 10^{-9}$  to  $7.47 \cdot 10^{-8} \text{ m}$ , and  $\sigma$  from  $1.6 \cdot 10^7$  to  $1.2 \cdot 10^9 \text{ Pa}$ . The first paragraphs that follows a table, figure, equation etc. does not have an indent, either.

For  $N^+$  ions we have a range of grain volumes from  $1.51 \cdot 10^{-27}$  to  $6.24 \cdot 10^{-23} \text{ m}^3$ , and the voltage  $\sigma_{\max}$  from  $7.14 \cdot 10^7$  to  $4.8 \cdot 10^8 \text{ Pa}$ . As well as for boron and carbon ions, with an increase in energy or a charge number, the NS volume increases with temperature stresses.

It can be seen that with the growth of energy and charge and the value of temperature stresses, the volume significantly increases.

Transition to aluminum ions ( $Al^+$ ) the values of the volumes of NS lie within the range of  $1.4 \cdot 10^{-27}$  to  $4 \cdot 10^{-23} \text{ m}^3$ , and the depth from  $7.5 \cdot 10^{-10}$  to  $4 \cdot 10^{-9} \text{ m}$  minimum and from  $1.7 \cdot 10^{-10}$  to  $5.2 \cdot 10^{-8} \text{ m}$ . The growth of NS and temperature stresses and depths of the ion energy and its charge remains.

For vanadium ion ( $V^+$ ), values of the volumes are in the range of  $1.06 \cdot 10^{-27}$  to  $2.45 \cdot 10^{-23} \text{ m}^3$  and the depth of it: minimum of  $5.02 \cdot 10^{-10}$ – $3.29 \cdot 10^{-8} \text{ m}$ , maximum  $1.69 \cdot 10^{-9}$ – $4.72 \cdot 10^{-8} \text{ m}$ , and  $\sigma_{\max} = 6.77 \cdot 10^6$ – $7 \cdot 10^7 \text{ Pa}$ .

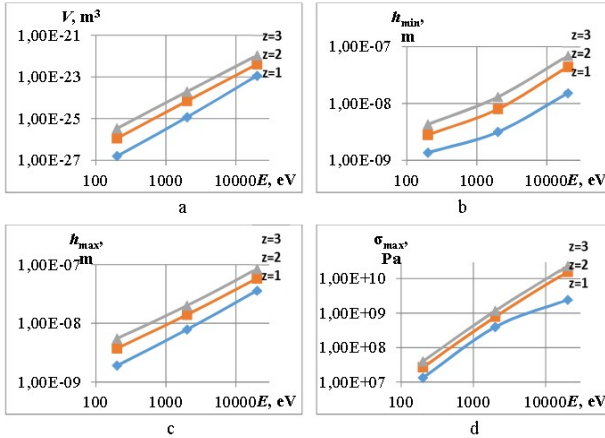
The growth of these values with increasing energy and ion charge is maintained. The growth of vanadium by ion mass is significantly reduced.

Similar features for chromium ion ( $Cr^+$ ) show that the volume of NS lies within  $6.25 \cdot 10^{-28}$  to  $1.14 \cdot 10^{-23} \text{ m}^3$ , and the depth of  $1.41 \cdot 10^{-10}$ – $2.23 \cdot 10^{-8} \text{ m}$  and  $1.6 \cdot 10^{-9}$ – $3.58 \cdot 10^{-8} \text{ m}$ , respectively, minimum and maximum,  $\sigma_{\max} = 1.48 \cdot 10^7$ – $7.69 \cdot 10^7 \text{ Pa}$ . Character of dependence was saved.

At transition to oxygen ions the range of volumes of NS lies within  $6.25 \cdot 10^{-28}$  to  $1.09 \cdot 10^{-23} \text{ m}^3$ , and depths of occurrence within  $1.3 \cdot 10^{-10}$ – $2.18 \cdot 10^{-8} \text{ m}$  and  $1.61 \cdot 10^{-9}$ – $3.52 \cdot 10^{-8} \text{ m}$ ,  $\sigma_{\max} = 4.7 \cdot 10^6$ – $7.5 \cdot 10^7 \text{ Pa}$  accordingly. For iron ion ( $Fe^+$ ) amounts of NS are in the range of  $1.43 \cdot 10^{-27}$  to  $5.13 \cdot 10^{-23} \text{ m}^3$  and depth  $8.9 \cdot 10^{-10}$  –  $1.7 \cdot 10^{-8} \text{ m}$  and  $1.78 \cdot 10^{-9}$ – $6.25 \cdot 10^{-8} \text{ m}$ , and  $\sigma_{\max} = 1.47 \cdot 10^7$ – $1.07 \cdot 10^8 \text{ Pa}$ , respectively. The values correlate with the ion mass: the greater the mass, the smaller the value. The NS volume for the case of the action of nickel ions ( $Ni^+$ ) is the value of  $5.8 \cdot 10^{-28} \text{ m}^3$ , and the depth of  $8.09 \cdot 10^{-11}$ – $2.98 \cdot 10^{-8} \text{ m}^3$  and  $1.61 \cdot 10^{-9}$ – $3.4 \cdot 10^{-8} \text{ m}$ , a  $\sigma_{\max} = 4.64 \cdot 10^6$ – $7.28 \cdot 10^7 \text{ Pa}$  respectively.

For cobalt ion ( $Co^+$ ) the volumes are in the range  $5.42 \cdot 10^{-28}$  –  $9.28 \cdot 10^{-24} \text{ m}^3$  and depth  $4.61 \cdot 10^{-10}$  –  $1.99 \cdot 10^{-8} \text{ m}$  and  $5.45 \cdot 10^{-9}$ – $3.32 \cdot 10^{-8} \text{ m}$ ,  $\sigma_{\max} = 4.54 \cdot 10^6$ – $7.2 \cdot 10^7 \text{ Pa}$  respectively. Similar dependencies for yttrium ion ( $Y^+$ ) give the values of volume NS  $5.1 \cdot 10^{-28}$ – $9.59 \cdot 10^{-24} \text{ m}^3$  and depth  $6.33 \cdot 10^{-10}$ – $2.04 \cdot 10^{-8} \text{ m}$  and  $4.16 \cdot 10^{-9}$ – $3.36 \cdot 10^{-8} \text{ m}$ ,  $\sigma_{\max} = 4.59 \cdot 10^6$ – $7.41 \cdot 10^7 \text{ Pa}$  respectively. The use of zirconium ions leads to change of the grain volume HS

$V=4.15 \cdot 10^{-28} - 6.9 \cdot 10^{-24} \text{ m}^3$ ,  $\sigma_{\max}=4.8 \cdot 10^6 - 6.69 \cdot 10^6 \text{ Pa}$  that is, the trend continues. For molybdenum ions have  $V=4.48 \cdot 10^{-28} - 6.7 \cdot 10^{-24} \text{ m}^3$ ,  $\sigma_{\max}=4.4 \cdot 10^6 - 6.88 \cdot 10^7 \text{ Pa}$ . Transition to hafnium ions gives volume HS  $V=3.24 \cdot 10^{-28} - 5.22 \cdot 10^{-24} \text{ m}^3$ ,  $\sigma_{\max}=3,15 \cdot 10^7 - 6,48 \cdot 10^7 \text{ Pa}$  (Fig. 2). For tantalum, tungsten, and platinum ions we have a close value.



**Fig. 2. Dependences of NC volume (a), minimum (b) and maximum (c) depth of occurrence of NC, maximum temperature stresses (d) of hafnium ions ( $\text{Hf}^{z+}$ ) with different charge ( $z = 1, z = 2, z = 3$ ) for zirconium and its alloy Zr1Nb**

According to the research, the following conclusions can be drawn:

1. It is shown that it is possible to obtain layers of nanostructures of sufficient size up to 0.1 mm by varying the energy of ions, its varieties and charges.
2. To reduce the probability of passing unnecessary reactions can be used zirconium ions and niobium, it's presents in the zirconium alloy Zr1Hb.
3. Considering the neutrality of materials to water, oxygen and other reagents, you can choose the cheapest ions of heavy metals for the treatment of zirconium alloys.

## References

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