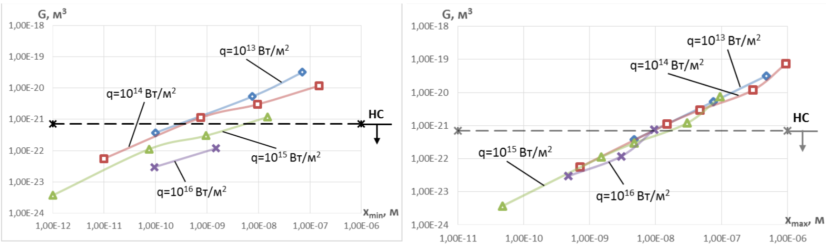
The fraction of nanostructured grains decreases significantly, which can be clearly seen by comparing the location of the dashed lines in Fig. 5, *a*, *b* with the same in Fig. 4, *a*, *b*. It is seen that an even larger proportion of grains in the case of a spot size with $R = 10^{-6}$ m goes into the region of sub-microstructures, which allows one to choose the size of the LI spot and its technological parameters.



a *b*

Fig. 4. Dependence of the nanocluster volume *G* on the minimum (*a*) and maximum depth (*b*) when exposed to laser radiation with different heat flux densities *q* laser radiation for TC VK8 with spot radius $R = 5 \cdot 10^{-7}$ m

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NITRIDE, CARBIDE, BORIDE, SULPHIDE, PHOSPHIDES AND OXIDE NANOCOATINGS ON HARD ALLOY

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The possibility of creating high-entropic nitride, carbide, boride and oxide coatings on a solid T12A alloy was researched, and the possibility of applying nitrides, carbides, borides and oxides of hafnium, zirconium, molybdenum, tungsten, yttrium and nickel was considered. For that, on the basis of the joint problem of thermal conductivity and thermo-elasticity, the volume of grain and the depth of occurrence for the elements considered, as well as nitrogen, carbon, boron and oxygen were determined. For nitrogen, the dependence of the grain volume of the maximum and minimum depth of occurrence was found. It was determined that the volume for low energies of the order of 200 eV corresponds to the nanograins, whereas at higher energies it exceeds them, the depth of occurrence of the volume in the first case lies in the range $8.6 \cdot 10^{-10}$–$3.9 \cdot 10^{-9}$ m – the minimum and $2.7 \cdot 10^{-9}$–$6.8 \cdot 10^{-9}$ m – the maximum.

The production of carbides requires the supply of carbon ions, which can be obtained directly from the carbon electrode by using a magnetron or from gases containing carbon. For carbon, dependences of the grain volume, the minimum depth, and the maximum depth of occurrence allow to obtain a space picture of the formation of grain in the zone of of the carbon ion actis. It seen that nanograin can be obtained at ion energies from 200 to 2000 eV, while near 20 keV the probability of its formation is low, and for charge numbers 2 and 3 it is generally impossible. The range of minimum depths of occurrence is $1.2 \cdot 10^{-9}$–$9.29 \cdot 10^{-8}$ m, and the maximum depth of occurrence is $2.94 \cdot 10^{-9}$–$1.07 \cdot 10^{-7}$m. It can be seen that in this case the maximum depth of the zone where the grain is formed is increased, practically up to ten micrometers, which in the last case forms submicrograin.

For the case of the action of boron ions, the grain size increases: it lies in the range of $4.4 \cdot 10^{-9}$–$1.364 \cdot 10^{-7}$ m. So, in the last case we deal with submicrograin, the depth of its occurrence: the minimum lies in the range of $1.2 \cdot 10^{-9}$ –$9.29 \cdot 10^{-8}$ m, and the maximum – $2.9 \cdot 10^{-9}$–$1.07 \cdot 10^{-7}$ m. In this case, the depths of occurrence exceed all the previous ones, so well as the grain size.

The transition to oxygen ions (for the formation of oxides) leads to a significant reduction in grain size to $3.94 \cdot 10^{-9}$ –$1.04 \cdot 10^{-7}$ m, the latter value already corresponds to submicrograin. The range of depths of occurrence of the grain: $7.49 \cdot 10^{-9}$–$6.4 \cdot 10^{-8}$ m - the minimum and $2.65 \cdot 10^{-9}$–$7.7 \cdot 10^{-8}$ m - the maximum values.

It was found that the volume corresponding to the NS is realized up to an ion energy of the order of 700–800 eV and a depth: for a minimum of 0–$2.2 \cdot 10^{-8}$ - m; for the maximum – $1.8 \cdot 10^{-9}$–$3.2 \cdot 10^{-8}$ m. It is seen that with increasing of ion mass, the volumes of NS and the depth of their occurrence are significantly reduced. This trend is tracked for practically all the ions considered. In order for nitrides to form, it is necessary that the charge and energy of the nitrogen ions be suchlike, and the depth of its occurrence were close to that obtained for hafnium.

Turning to the zirconium (Zr +) dependencies, we find that NS is realized for practically all the energies studied. Moreover at 200 eV the depths of occurrence are: the minimum – 0–$6.3\cdot10^{-10}$ m; the maximum $3.34\cdot10^{-9}$–$5.43\cdot10^{-9}$ m. At 2000 eV the minimum – $6.37\cdot10^{-10}$–$5.37\cdot10^{-9}$m; Maximum – $5.4\cdot10^{-9}$–$1.25\cdot10^{-8}$ m. For 20 keV, the minimum depth of occurrence is $4.6\cdot10^{-9}$–$2.48\cdot10^{-8}$ m; the maximum is $1.54\cdot10^{-8}$–$3.52\cdot10^{-8}$ m.

From a comparison of the depths of NS for hafnium and zirconium ions with the penetration of nitrogen ions, we see that many nitrogen energies cannot be used, because the depth of their penetration is greater, and in many of the regimes nitrides, carbides, borides and oxides will not be formed, but there will be a rather large amount of intermetallides that have small physical and mechanical characteristics, so consequently there will be zones in the material with reduced properties, that will not provide the appearance of highly entropic nitride coatings with good characteristics.

For molybdenum (Mo^{+}) the depth of occurrence of NS at an energy of 200 eV is: the minimum – 0–$1.18\cdot10^{-9}$ m, the maximum – $1.89\cdot10^{-9}$–$4.49\cdot10^{-9}$ m. At an energy of 2000 eV: the minimum – $6.12\cdot10^{-10}$–$5.65\cdot10^{-9}$ m; the maximum – $5.59\cdot10^{-9}$–$1.23\cdot10^{-8}$ m. At 20 keV: the minimum – $4.47\cdot10^{-9}$–$2.44\cdot10^{-8}$ m; the maximum – $1.52\cdot10^{-8}$–$3.48\cdot10^{-8}$ m.

For tungsten (W^{+}) ions, similar graphs are presented. The depths of occurrence of the NS at an energy of 200 eV are: the minimum – 0–$9.89\cdot10^{-10}$ m, the maximum – $1.77\cdot10^{-9}$–$4.33\cdot10^{-9}$ m. At an energy of 2000 eV: the – $4.38\cdot10^{-10}$–$5.1\cdot10^{-9}$ m; the maximum – $5.17\cdot10^{-9}$–$1.17\cdot10^{-8}$ m. At 20 keV: the minimum – $3.79\cdot10^{-9}$–$2.19\cdot10^{-8}$ m; the maximum – $1.42\cdot10^{-8}$–$3.20\cdot10^{-8}$ m.

It is seen that the depths of occurrence of HC are significantly different from those required for nitrogen ions, and it is necessary to select very carefully the energies and charges in order to obtain nitrides at a certain depth.

Depths of occurrence of NS for yttrium ions (Y^{+})at an energy of 200 eV are: the minimum – 0–$1.23\cdot10^{-9}$ m, the maximum – $1.92\cdot10^{-9}$–$4.54\cdot10^{-9}$ m. At an energy of 2000 eV: the minimum – $6.53\cdot10^{-10}$…$5{,}79\cdot10^{-9}$ m. The maximum – $5.45\cdot10^{-9}$–$1.25\cdot10^{-8}$ m. At 20 keV: the minimum – $4.65\cdot10^{-9}$–$2.49\cdot10^{-8}$ m; The maximum is $1.55\cdot10^{-8}$–$3.55\cdot10^{-8}$ m.

It is seen that in this case, for almost all energies, the depths are small, except that only the energy of 20 keV, that cannot always be realized in this installation, because the energy of nitrogen is much less, at which their depths are commensurable.

For nickel (Ni^{+}) the dependences of the NS volume and the minimum and maximum depth of occurrence were found. Depths of occurrence of NS at an energy of 200 eV are: the minimum – 0–$1.52\cdot10^{-9}$ m, the maximum – $2.1\cdot10^{-9}$–$4.79\cdot10^{-9}$ m. At an energy of 2000 eV: the minimum –

$9.24\cdot10^{-10}$–$6.63\cdot10^{-9}$ m; the maximum – $5.77\cdot10^{-9}$–$1.35\cdot10^{-8}$ m. At 20 keV: the minimum – $5.7\cdot10^{-9}$–$2.87\cdot10^{-8}$ m; the maximum – $1.7\cdot10^{-8}$–$3.95\cdot10^{-8}$ m.

For nickel, the depth of occurrence is close to the depths of nitrogen deposition, which contributes to the efficient formation of HC from nitrides. The minimum and maximum depths of grain occurrence decrease with ion mass increasing, and grain volumes are decreased significantly. The energy zone where is possible to obtain nanostructures increases, which has a positive effect on the physic and mechanical characteristics of the coating, which for a nanostructured grain has a large microhardness, yield stress, ultimate strength. Corrosion resistance is also increased, while the ability to absorb impact loads due to a decrease in the modulus of elasticity is increased. it is allows us to withstand high loads in the elastic zone, that is, for large deformations we have low stresses.

Dependences of nanocluster volume, minimum and maximum depth of NC on phosphorus ion energy are obtained. It can be seen that the volume of NC ranges from $3.58\cdot10^{-28}$ to $8.56\cdot10^{-24}$ m^3 (200 eV, z = 1 and 20 Kev, z = 3), respectively, the minimum depth from 0–$2.01\cdot10^{-8}$, the maximum is from $1.43\cdot10^{-9}$ to $3.25\cdot10^{-8}$ m (respectively 200 eV, z = 1 and 20 Kev, z = 3).

The transition to sulfur ions (S^+) leads to a decrease in the volume of NC to $3.58\cdot10^{-28}$–$7.82\cdot10^{-24}$ m^3, the minimum depth will be 0–$1.92\cdot10^{-8}$ and the maximum $1.4\cdot10^{-9}$–$3.14\cdot10^{-8}$ m, respectively, at E_i = 200 eV, z = 1 and E_i = 20 Kev, z = 3.

It is seen that the values for these ions are close, but for phosphorus they are greater, since its atomic weight is less (30.97 AE) than that of sulfur (32.068) close values are reduced with a slight difference in the masses of ions. All this allows almost in the same layers to obtain phosphides and sulfides and this layer will increase both wear resistance and performance at sufficiently high temperatures (up to 2000 °C).