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Kostyuk G.I.[1], *Popov V.V.*[2], *Kostyk K.O.*[3]

[1] **National Aerospace University named by N.Ye. Zhukovsky «KhAI», Ukraine, Kharkiv**
[2] **«FED», JSC. Ukraine, Kharkiv**
[3] **National Technical University «Kharkiv Polytechnic Institute», Ukraine, Kharkiv**

DESIGN OF THE CUTTING TOOL MATERIAL TAKING INTO ACCOUNT THE TYPE OF NANOCOATING HARDENING

The article describes the effect of boron, nitrogen, yttrium and hafnium ions on the modified VK10 (WC - 79.7% Co - 9.5% + CrN - 1.3% + AlN - 6.5% + TiN - 3%), VK20 (WC - 80.00%) and VK10 (WC - 90.00%) where the possibility of obtaining nanostructures is shown. It has been determined that: the value of the ion energy and the ion charge significantly affect the grain size with increasing energy and charge size; the grain size increases; an increase in the percentage composition of tungsten carbide leads to grain growth, and with an increase in the mass of the ion to an decrease in the grain size more significantly, which can be used to obtain the required grain size. The design of the chemical composition of the cutting tool material, taking into account the possibility of nanostructure formation, shows that not always an increase in the share of tungsten carbide increases the efficiency and efficiency of the tool, and often the grain size has a decisive influence. [dx.doi.org/10.29010/087.3]

Keywords: *nanostructures; design of chemical composition of the cutting tool; grain volume; hard alloy.*

Introduction

Back in the Soviet Union, the design of the cutting tool was carried out taking into account the processed material, which allowed to get rid of such effects as increased wear of the cutting tool (CT) on the front surface, since modern plates do not take into account the nature of the interaction of the chip with the front surface, which leads to the formation of one or two holes on the front surface of the CT, which was not on the plates created in the Soviet Union. Technological difficulties in obtaining plates with the necessary profile for the movement of chips have led to the fact that at present it is not usually taken into account the nature of the movement of chips on the front surface, and provides maximum bending strength of the plate in the cutting zone. All this leads to significant wear on the front surface, and further to the destruction of the cutting edge.

We have done research on the influence of the component share of different alloys on their capabilities, taking into account the formation of nanostructures and nanocoatings. Thus, the paper [1] shows the effect of the proportion of titanium carbide in a solid alloy based on titanium carbide and aluminum oxide (TiC, Al_2O_3). It turned out that in the formation of nanostructures the most successful would be their ratio of 50/50. Such hard alloys do not exist, this indicates that in each case it is necessary to take into account the possibility of obtaining nanostructures with a minimum grain size (but not less than 10 nm), when the maximum microhardness of the surface layer is realized. This makes it possible to predict the high wear resistance of such a cutting tool (nitrogen ions, zirconium, hafnium were considered), which allows to ensure minimal setting with many processed materials, including titanium alloys. Similar studies were carried out for single-carbide hard alloys, where the influence of the proportion of tungsten carbide on the grain volume was estimated. It turned out that using a hard alloy with 86 % tungsten carbide will be implemented minimum grain size. All this allows, using the same ions as in the previous case, to obtain a minimum amount of grain, which will provide the maximum possible microhardness, as well as the maximum wear resistance. In the papers [3-5] it is shown experimentally that the ratio 79.7% of tungsten carbide WC, of 9.5 percent cobalt, 6.3% of aluminum nitride, 1.2% of chromium nitride, 3% of titanium nitride obtained minimum grain size on the surface of the bombardment with ions of nitrogen, zirconium and hafnium. In this case, a minimum grain size is also formed [5], whereas in the processing of Sandvik Coromant plates, the grain size is realized, somewhat larger than in the first case. In this case, the resistance of the plates, and hence the removable volume of the material for the period of resistance in the first case will be in 1.3–1.5 times more than Sandvik Coromant. This indicates that it is possible, modifying the hard alloy VK10, to provide better performance and efficiency compared with Sandvik Coromant (leader in the production of cutting tools in the world) [6]. Therefore, when designing a cutting tool, it is necessary to take into account the possibility of its hardening by creating nanostructures and nanocoatings. This suggests the importance of creating scientific principles for the design of CT with nanostructures and nanocoatings, which will improve the performance (resistance CT) and efficiency (removable volume of material for the period of resistance).

The work was carried out within the framework of the program of the Ministry of education and science of Ukraine "New and resource-saving technologies in energy, industry and agriculture" (subsection 13 "Aerospace engineering and transport") and on the topics: "Creation of physical and technical bases for improving the quality of materials of aerospace structures" and "Development of technological bases of integrated technologies for plasma-ion processing of aerospace equipment parts" (subsection 6 "Physical and technical problems of materials science"), "Concept of creating nanostructures, nano- and traditional coatings, taking into account the influence of adhesion on the efficiency and performance of parts of CT", "Experimental and theoretical study of nanostructures under the action of ion and light-beam flows on structural materials and CT", contractual works and cooperation agreements.

Status of the problem

The results of theoretical studies, which are presented in [8-14], showed that it is possible to obtain nanostructures under the action of ions of different varieties, charges and energy. At the same time, there is a prospect of obtaining nanostructures under the action of laser radiation, especially under the action of femtosecond lasers, which provide high performance and low power in the processing of CT [10]. It was shown experimentally that it is possible to obtain high microhardness at a small grain size [9], as well as to increase the efficiency – resistance of CT and the volume of the material removed during the period of resistance of CT [5, 6]. Similar studies were carried out under the action of laser radiation, which showed the possibility of improving the efficiency and effectiveness of CT from high-speed steels, as well as single-carbide hard alloys [9].

We will analyze the processes that are implemented in the application of nanocoatings and the formation of nanostructures, and how to use them in the design of cutting tools and parts to ensure effective machining, reliability and high service life of parts. The design of CT and parts with nanostructures and nanocoatings requires three tasks:

- the first – the creation of theoretical models, allowing to estimate the influence of the base material CT for obtaining nanostructures (size of grain), and hence find the composition of the basic material of CT, in which the grain obtained in the range of 10-50 nm, to determine technological parameters of processing RI. By grain size to estimate the physical and mechanical characteristics of the surface layer;

- the second – carrying out experiments to determine the effect of the obtained (calculated) grain size on the physical and mechanical characteristics (microhardness, roughness, resistance of CT, the volume of material removed by it for the period of resistance, processing performance), the choice of the minimum adhesive interaction of the pair of the processed material – coating (the main material of CT), and for parts – their wear resistance, physical and mechanical characteristics of the material, the accuracy of the shape and size of the part, taking into account the adhesive interaction of the contacting parts;

- third – evaluation of the adequacy of the model for the calculation of grain size and regression models for the calculation of the resistance of CT, the removable volume of material for the period of resistance, processing performance and evaluation of the physical and mechanical characteristics of the cutting tool and parts (microhardness, wear resistance, oxidability, etc.).

For research, a system for measuring the cutting forces in real time, the assessment of the time to reach the maximum resistance was determined by the value of the maximum cutting force, calibrated according to the criteria of efficiency of CT (critical wear, critical change in shape or surface roughness of the part, the size of the part beyond the tolerances and others).

In the end, we obtain the modes of processing efficiency (maximum volume of material removed during the period of resistance), compliance with the details of the accuracy of size and shape, as well as parts with high resource and sufficient reliability.

All this shows that the study of the possibility of creating scientific principles for the design of CT with nanostructures and nanocoatings is an urgent and important task for engineering and other sectors of the economy that use CT.

Problem statement of the research

The study was carried out on the basis of solving the joint problem of thermal conductivity and thermoelasticity in the area of ion flows (or laser radiation) on a carbide and high-speed tool [9]. And the widely-ranged ion energy and their varieties, considered one-, two- and three-charge ions. For laser radiation for conventional lasers, studies were carried out in the range of the operating heat flux densities from 10^7 to 10^{11} W/m^2 and the operating time from 10^{-7} to 10^{-4} s. For Femto-second lasers, the range of effective heat flux densities from 10^{11} to 10^{16} W/m^2 was considered, and their action time was from 10^{-15} to 10^{-11} s. Such calculations were carried out for both carbide plates and high-speed steels. All this allows you to choose the type of processing that provides sufficient for the production of efficiency and effectiveness of CT, and ultimately makes it possible to create design principles CT with nanostructures and nanocoatings.

Calculation results and discussion

Were calculated for the CT options: 1) ВК10(90% WC and 10% Co); 2) modified ВК10 (79.7% of WC and 9.5% Co1,3% CrN; AlN of 6.5%, TiN 3%) and ВК20 (80% WC and 20% Co).

The volumes of nanostructures (*V*), minimum (h_{min}) and maximum (h_{max}) depths, as well as grain sizes (*a*) were calculated. The criterion for the formation of a nanostructure in the volume was considered to be the achievement of the required temperature range (500-1500 K) of the temperature rise rate of more than 10^7 K/s. The dependences of these values on the energy of ions (200, 2000, 20000 eV) under the action of one-, two - and three-charge ions were determined. These values were calculated for the case of action of ions: boron, carbon, nitrogen, aluminum, vanadium, chromium, oxygen, iron, Nickel, cobalt, yttrium, zirconium, molybdenum, hafnium, tantalum, tungsten and platinum. Comparisons of these values were made for the three cutting tools considered.

For example, in the case of boron ions (Fig. 1-4) classical ВК10 (90 % WC and 10 % Co) have values of volume $8{\cdot}10^{-27}$ m^3, $h_{min} = 1.06{\cdot}10^{-9}$ m, $h_{max} = 3.29{\cdot}10^{-9}$ m, and the grain size $a = 2.48{\cdot}10^{-9}$, whereas at the transition to the modified VK10 have a volume of $4.36{\cdot}10^{-27}$ m, $h_{min} = 0$, $h_{max} = 3.29{\cdot}10^{-9}$ and grain size of $2.03{\cdot}10^{-9}$ m. For VK20 matter of amount of $4.11{\cdot}10^{-27}$ ... $2.77{\cdot}10^{-23}$ m^3, $h_{min} = 0$, $h_{max} = 6.83{\cdot}10^{-8}$ m, and grain size $a = 3.75{\cdot}10^{-8}$ m. In this case, the transition to a modified VK10 leads to a decrease in grain volume to $6.68{\cdot}10^{-24}$ m depth $h_{min} = 3.11{\cdot}10^{-8}$ m, $h_{max} = 4.08{\cdot}10^{-8}$ m, and the grain size increases to $3.01{\cdot}10^{-8}$ m. For VK20 have a value of volume of grain from $3.13{\cdot}10^{-24}$ m^3 to $2.7{\cdot}10^{-23}$ m^3, depth, $h_{min} = 0$, $h_{max} = 2.48{\cdot}10^{-8}$ m, and the grain size increases to $3.75{\cdot}10^{-8}$ m.

In case of nitrogen ions (200 eV) for VK10 have a volume of $5.8{\cdot}10^{-27}$ m^3, $h_{min} = 7.97{\cdot}10^{-10}$ m, $h_{max} = 3.02{\cdot}10^{-9}$ m and a grain size of $2.23{\cdot}10^{-9}$ m. For the modified VK10 get the volume of $2.91{\cdot}10^{-27}$ m^3, $h_{min} = 0$, $h_{max} = 2.88{\cdot}10^{-9}$ m and the grain size is $1.77{\cdot}10^{-9}$ m. In the case of the action of nitrogen for VK20 have a volume of $7.42\ {\cdot}10^{-26}$ m^3, $h_{min} = 0$, $h_{max} = 8.46{\cdot}10^{-9}$ m, and the grain size is $5.21{\cdot}10^{-9}$ m.

The increase of energy up to 20 KeV leads to a significant increase of NS and he is set to $4.46{\cdot}10^{-24}$ m^3, depth also increase somewhat $h_{min} = 2.33{\cdot}10^{-9}$ m, $h_{max} = 2.69{\cdot}10^{-8}$ m, and the grain size is $2.04{\cdot}10^{-8}$ m. For VK20 the volume of $2.63{\cdot}10^{-23}$ m^3, $h_{min} = 1.24{\cdot}10^{-8}$ m, $h_{max} = 5.73{\cdot}10^{-8}$ m, and the grain size is $3.69{\cdot}10^{-8}$ m.

For the case of action of yttrium ions at 200 eV energy we have a volume of $3.98{\cdot}10^{7}$ m^3, $h_{min} = 5.18{\cdot}10^{-10}$ m, $h_{max} = 2.72{\cdot}10^{-9}$ m, grain size is $1.97{\cdot}10^{-9}$ m. For the modified VK10 get the volume of $4.06{\cdot}10^{-8}$ m^3, $h_{min} = 0$, $h_{max} = 1.49{\cdot}10^{-9}$ m, the grain size is of $9.19{\cdot}10^{-10}$ m. For VK20 volume $3.07{\cdot}10^{-27}$ m^3, $h_{min} = 0$, $h_{max} = 4.32{\cdot}10^{-9}$ m, and the grain size is $2.7{\cdot}10^{-9}$ m.

Increasing energy to 20 kV leads to an increase in grain size VK10 to $1.92{\cdot}10^{-24}$ m^3, $h_{min} = 1.3{\cdot}10^{-8}$ m, $h_{max} = 1.99{\cdot}10^{-8}$ m, and the grain size is $1.54{\cdot}10^{-8}$ m. For VK20 to $6.8{\cdot}10^{-24}$ m^3, $h_{min} = 1.54{\cdot}10^{-8}$ m, $h_{max} = 2.99{\cdot}10^{-8}$ m, and the grain size is $2.35{\cdot}10^{-8}$ m.

For the case of the action of ions of hafnium on VK10 (200 eV) have a volume $1.18{\cdot}10^{-25}$ m^3, $h_{min} = = 3.94{\cdot}10^{-9}$ m, $h_{max} = 7.76{\cdot}10^{-9}$ m, grain size is $60.9{\cdot}10^{-9}$ m. The transition to greater energy leads to an increase in volume to $2.6{\cdot}10^{-24}$ m^3, hmin = $1.5{\cdot}10^{-8}$ m, $h_{max} = 2.21{\cdot}10^{-8}$ m, the grain size is $1.71{\cdot}10^{-8}$ m. For the modified VK10 have a volume of $2.54{\cdot}10^{28}$ m^3, $h_{min} = 0$, $h_{max} = 2.2{\cdot}10^{-9}$ m, the grain size is of $7.86{\cdot}10^{-10}$ m. For VK20 amount of grain is up to $6.41{\cdot}10^{-27}$ m^3, $h_{min} = 0$, $h_{max} = 3.74{\cdot}10^{-9}$ m, and the grain size is $2.3{\cdot}10^{-9}$ m.

The transition to greater energy leads to an increase in the volume of grain to $2.64{\cdot}10^{-25}$ m^3, $h_{min} = 0$, $h_{max} = 1.29{\cdot}10^{-8}$ m, and the grain size is $7.96{\cdot}10^{-9}$ m.

For VK20 the grain volume increases to $4.6 \cdot 10^{-24}$ m^3, $h_{min} = 6.01 \cdot 10^{-9}$ m, $h_{max} = 2.67 \cdot 10^{-8}$ m, and the grain size is $2.06 \cdot 10^{-8}$ m.

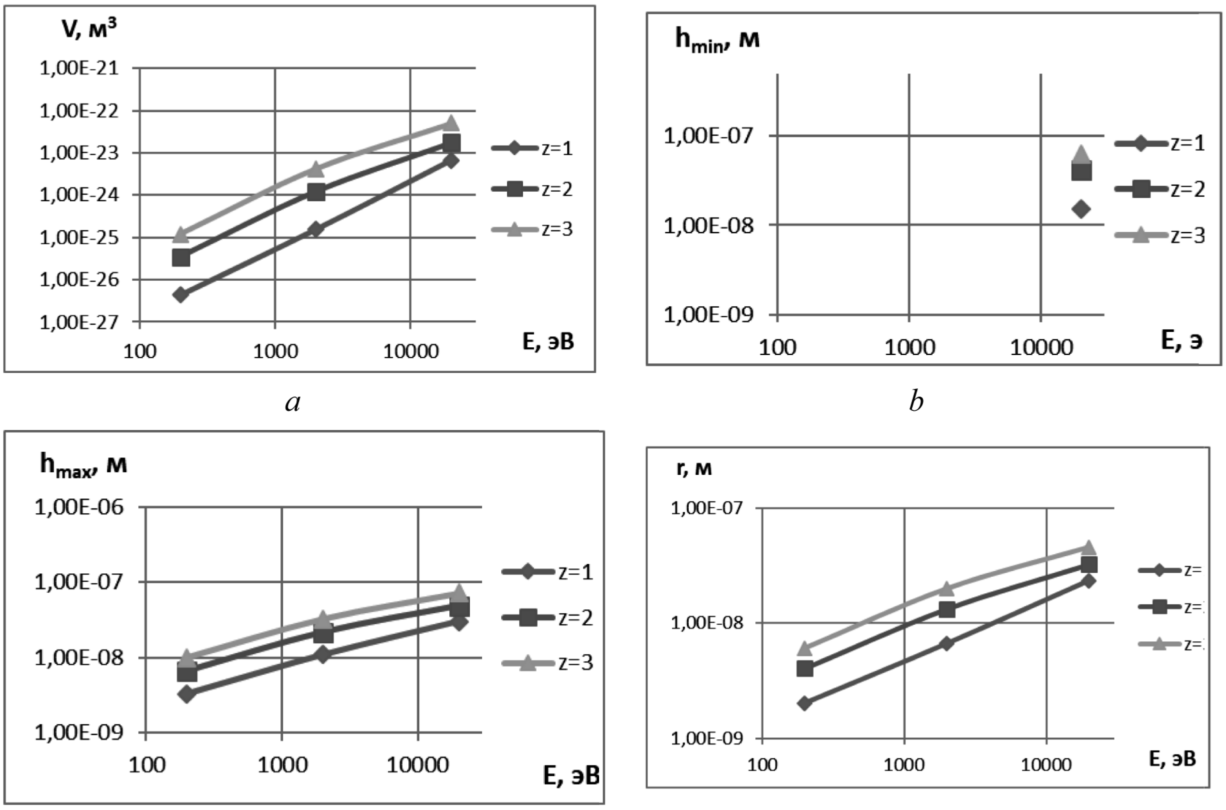
The study was carried out for single-charge ions, the increase in charge leads to an increase in all values is particularly significant at 20 kV and z = 3.

The action of boron (B^+), nitrogen (N^+), yttrium (Y^+) and hafnium (Hf^+) ions on the modified VK10 (79.7% WC) was considered. VK20 (80 % WC) and VK10 (90 % WC), as shown in Fig. 2-5 shows the dependence of the volume of grain (a) minimum (b) maximum and (c) the depth of the NS and the radius of the grain on the energy of the B^+ ions (Fig. 1), N^+ ions (Fig. 2), ions Y^+ (Fig. 3) and Hf^+ ions (Fig. 4) for the case of their action on the modified VK10.

For Fig. 5-8 dependences of grain volume (a), maximum (b) and depths of NS and radius (c) on the energy of boron B^+ ions are given (Fig. 5), nitrogen (Fig. 6), yttrium (Fig. 7) and hafnium (Fig. 8).

To estimate the influence of the composition of the hard alloy (WC percentage in the material) on the efficiency of production of nanostructures of these ions was built based on the grain volume of the portion of the tungsten carbide in the material of RI for the case of the action of boron ions (B^+), nitrogen (N^+), yttrium (Y^+) and hafnium (Hf^+) (Fig. 13-14). Analysis of the results shows that for low-mass ions of boron and nitrogen, the percentage composition of tungsten carbide affects slightly (Fig. 13), whereas with the growth of ion mass this difference becomes significant (especially for hafnium ions it changes by more than an order of magnitude). All this indicates that the ion mass significantly affects the volume, and hence the grain size.

It is seen that for all ions the minimum value of grain size is realized for VK20 several large sizes for modified VK10 and significantly higher for VK10 (classical). The results suggest the possibility of using a modified VK10, which has higher physical and mechanical characteristics than VK20 and VK10, although the grain size is almost the same as that of VK20.



a *b*

c *d*

Fig. 1. Dependences of nanocluster volume (NC) (*a*), minimum (*b*) and the maximum (*c*) depth and radius of NC (*d*), from the energy of boron ions (B^+) with different charge (z = 1, z = 2, z = 3) for VK10 modified

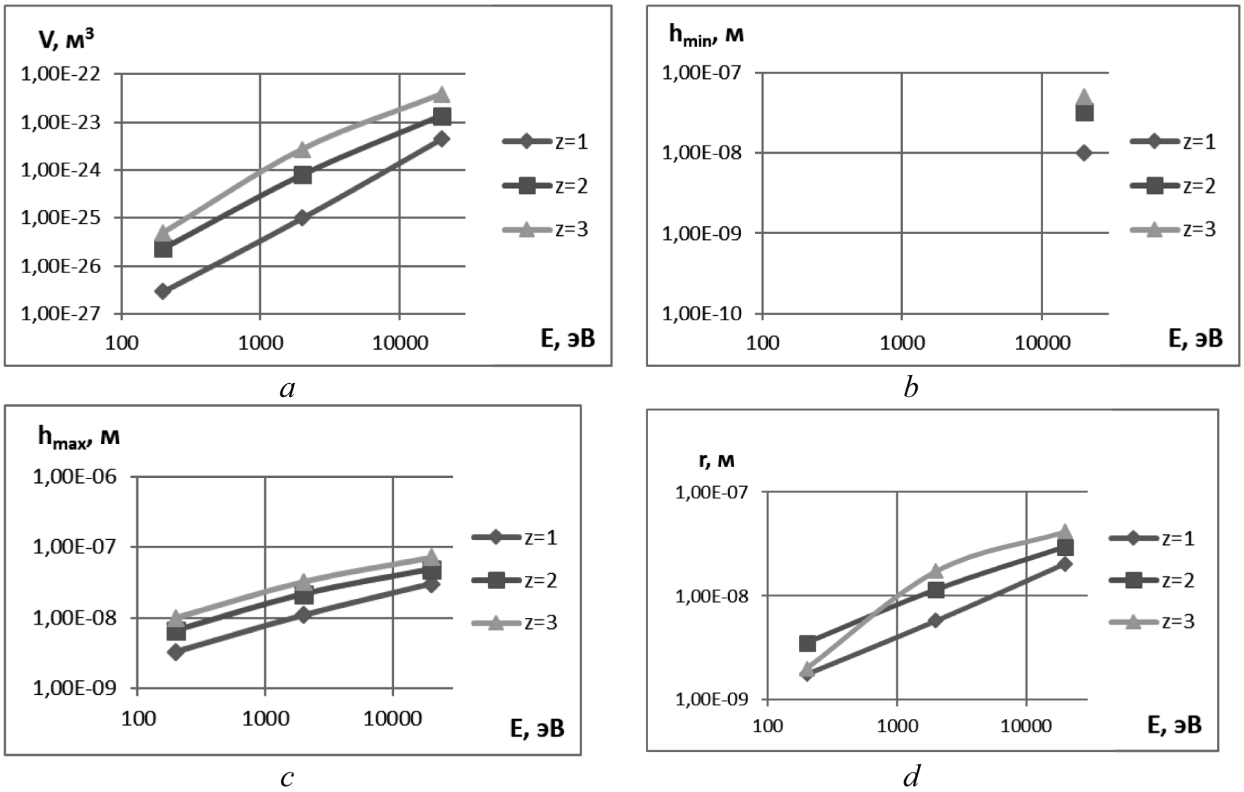


Fig. 2. Dependences of nanocluster volume (NC) (*a*), minimum (*b*) and the maximum (*c*) depth and radius of NC (*d*), from the energy of nitrogen ions (N^+) with different charge (z = 1, z = 2, z = 3) for VK10 modified

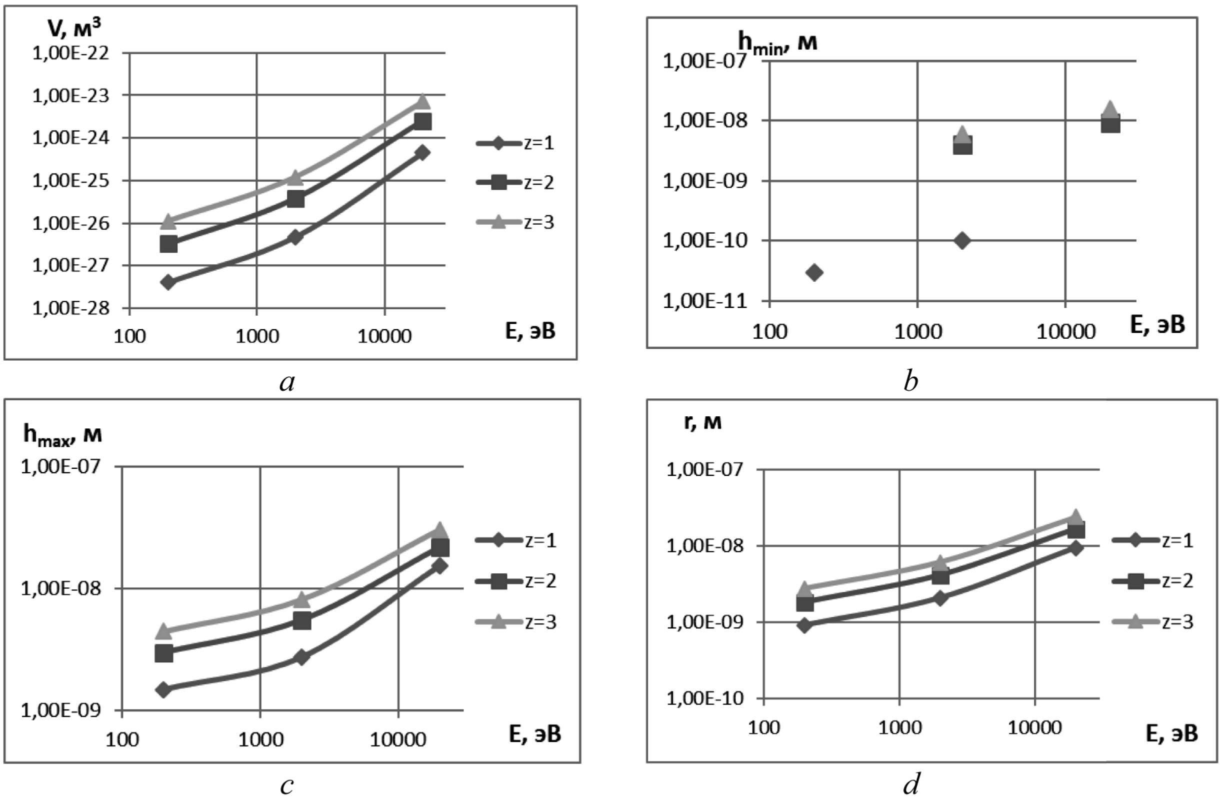
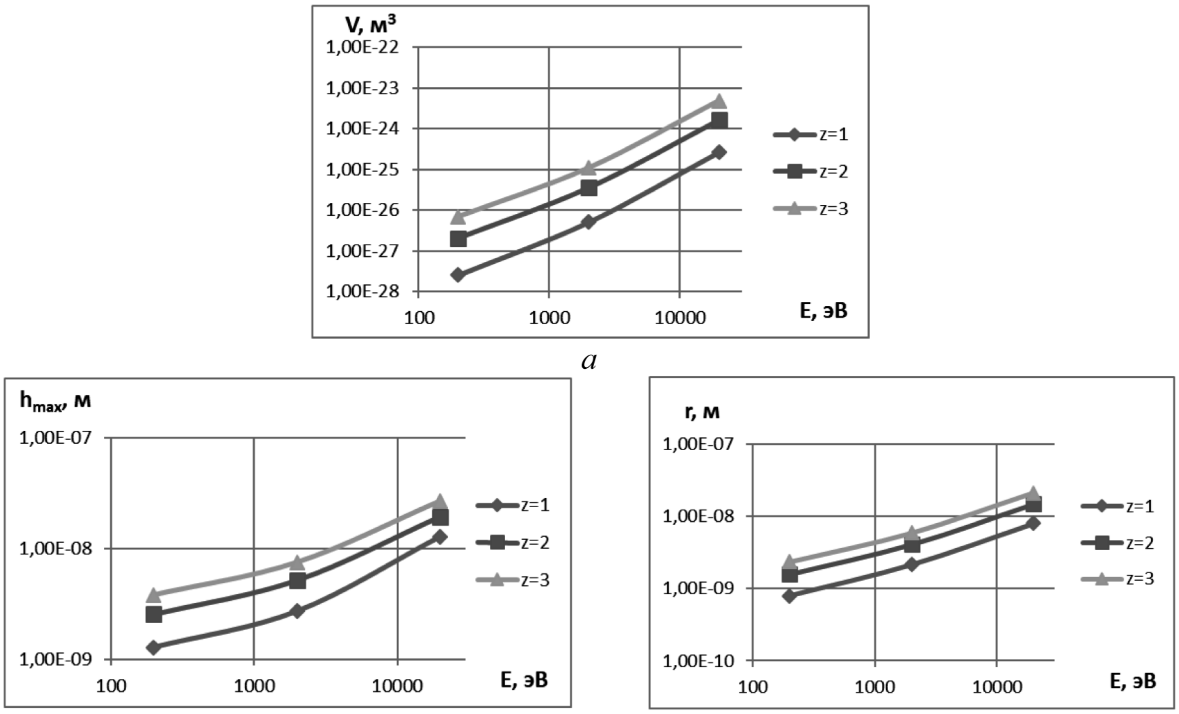


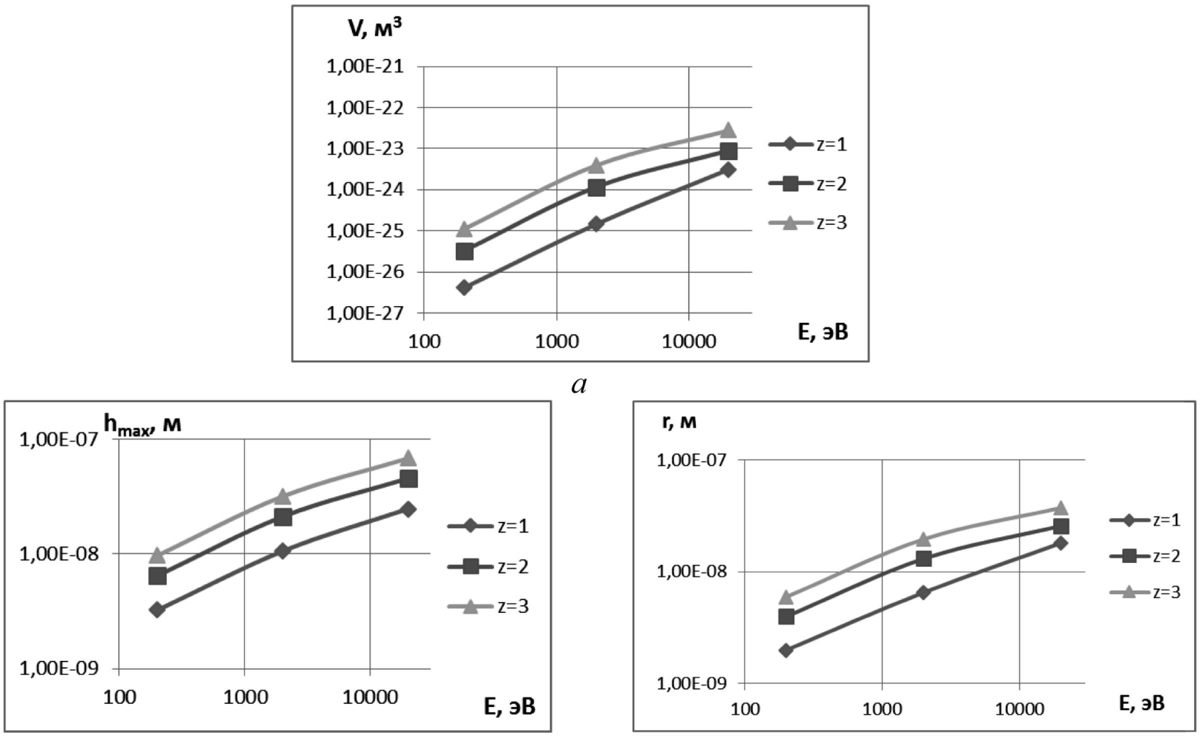
Fig. 3. Dependences of nanocluster volume (NC) (*a*), minimum (*b*) and the maximum (*c*) depth and radius of NC (*d*), from the energy of yttrium ions (Y^+) with different charge (z = 1, z = 2, z = 3) for VK10 modified



a

b *c*

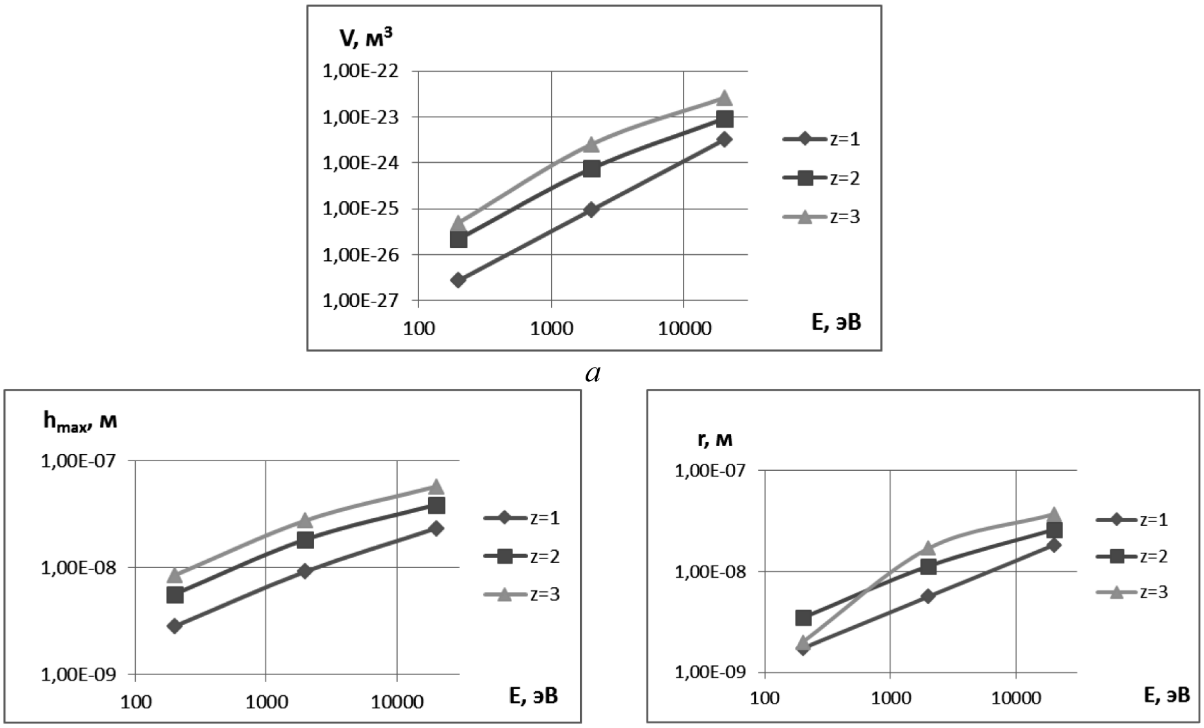
Fig. 4. Dependences of nanocluster volume (NC) (*a*), maximum (*b*) depth and radius of NC (*c*), from the energy of hafnium ions (Hf$^+$) with different charge (z = 1, z = 2, z = 3) for VK10 modified



a

b *c*

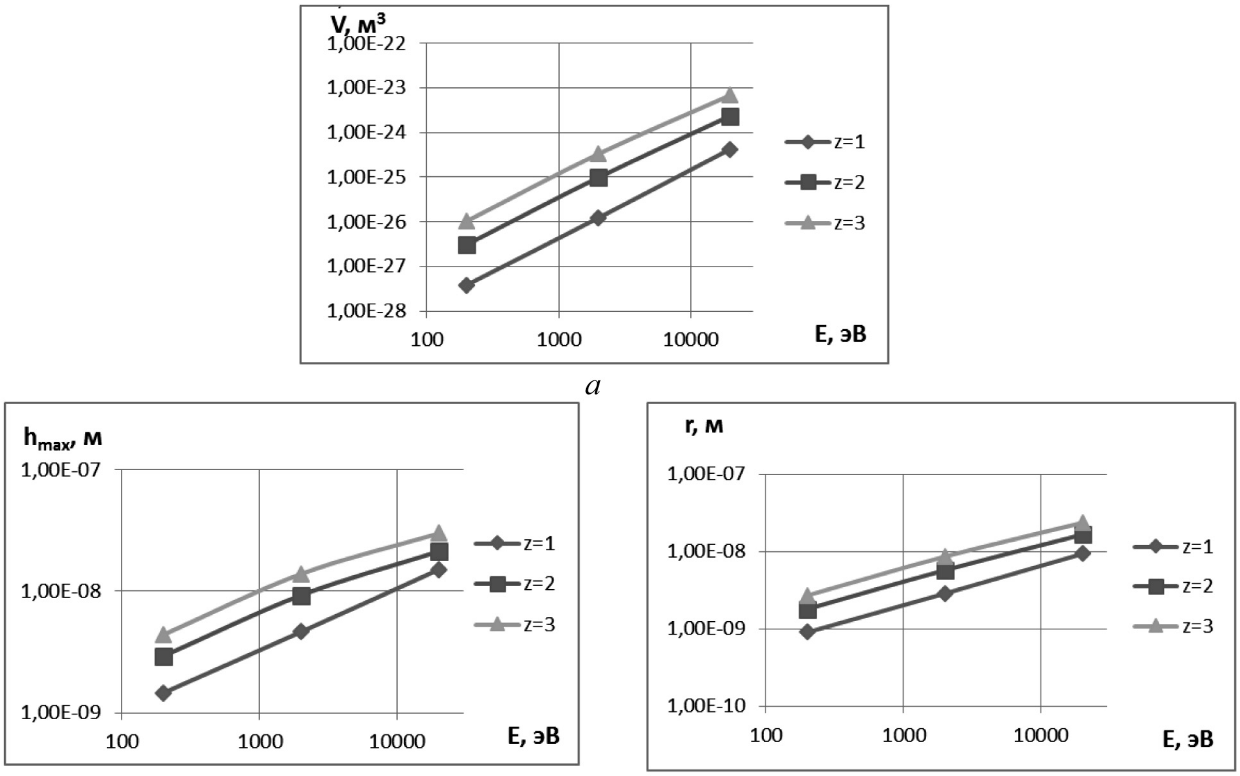
Fig. 5. Dependences of nanocluster volume (NC) (*a*), maximum (*b*) depth and radius of NC (*c*), from the energy of boron ions (B$^+$) with different charge (z = 1, z = 2, z = 3) for VK20



a

b *c*

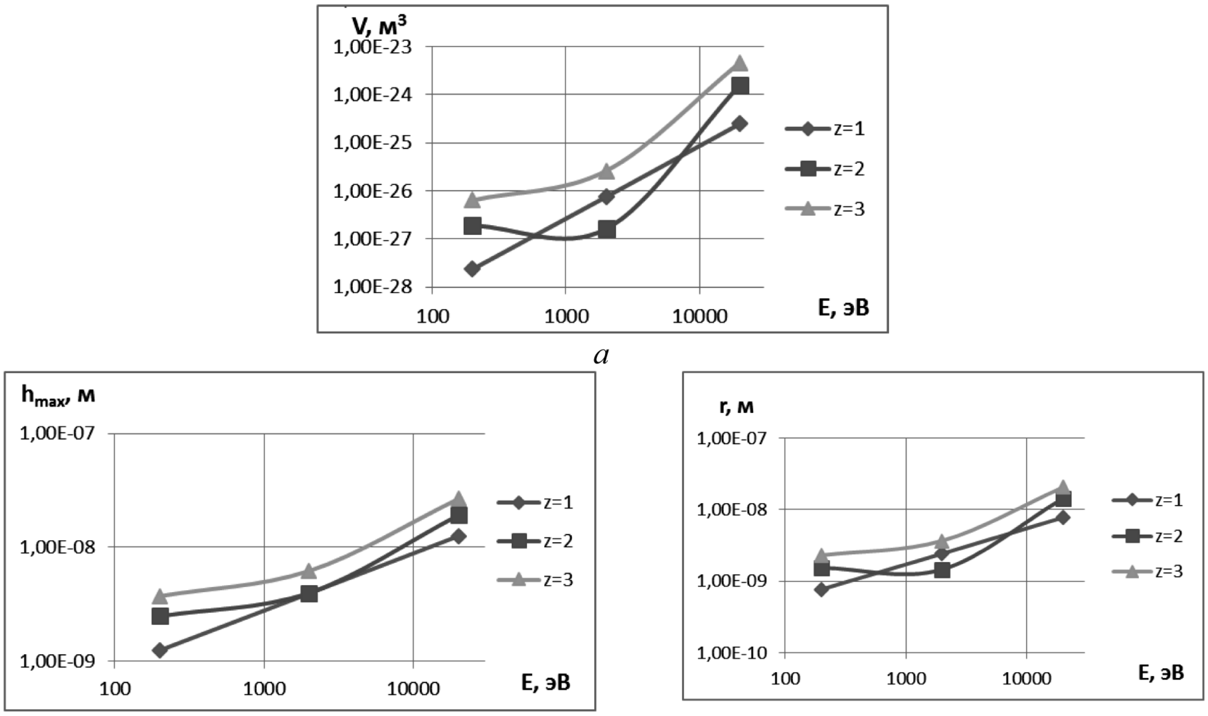
Fig. 6. Dependences of nanocluster volume (NC) (*a*), maximum (*b*) depth and radius of NC (*c*), from the energy of nitrogen ions (N^+) with different charge (z = 1, z = 2, z = 3) for VK20



a

b *c*

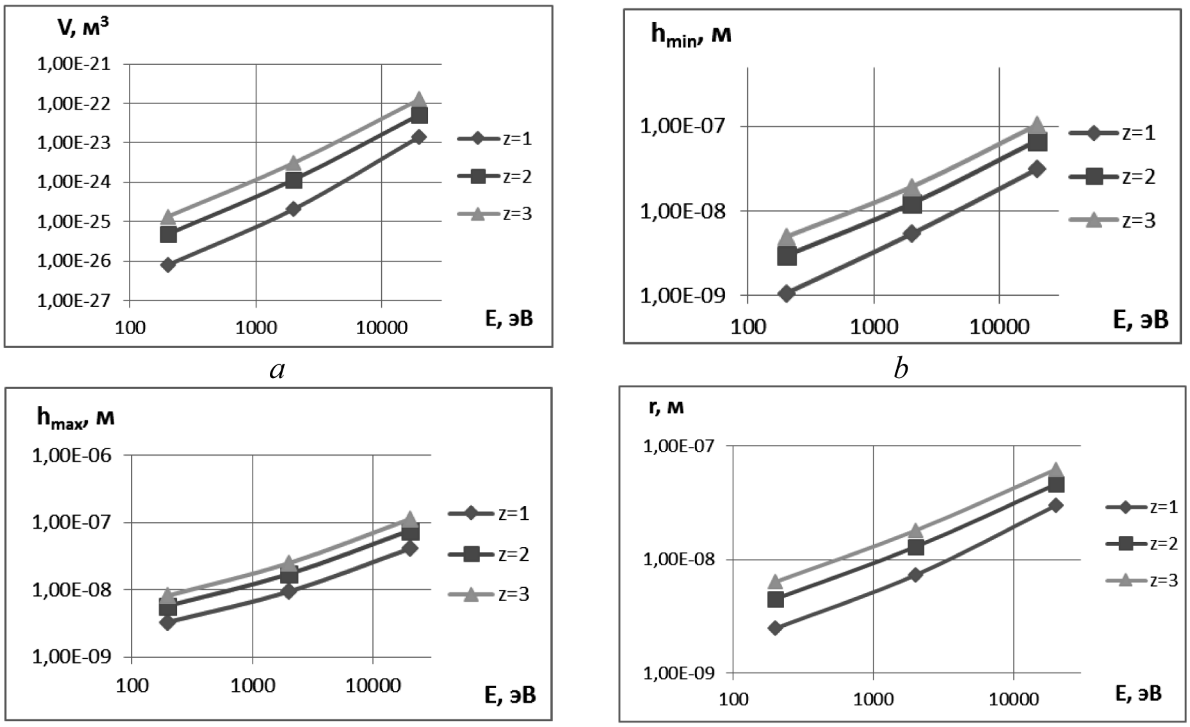
Fig. 7. Dependences of nanocluster volume (NC) (*a*), maximum (*b*) depth and radius of NC (*c*), from the energy of yttrium ions (Y^+) with different charge (z = 1, z = 2, z = 3) for VK20



a

b *c*

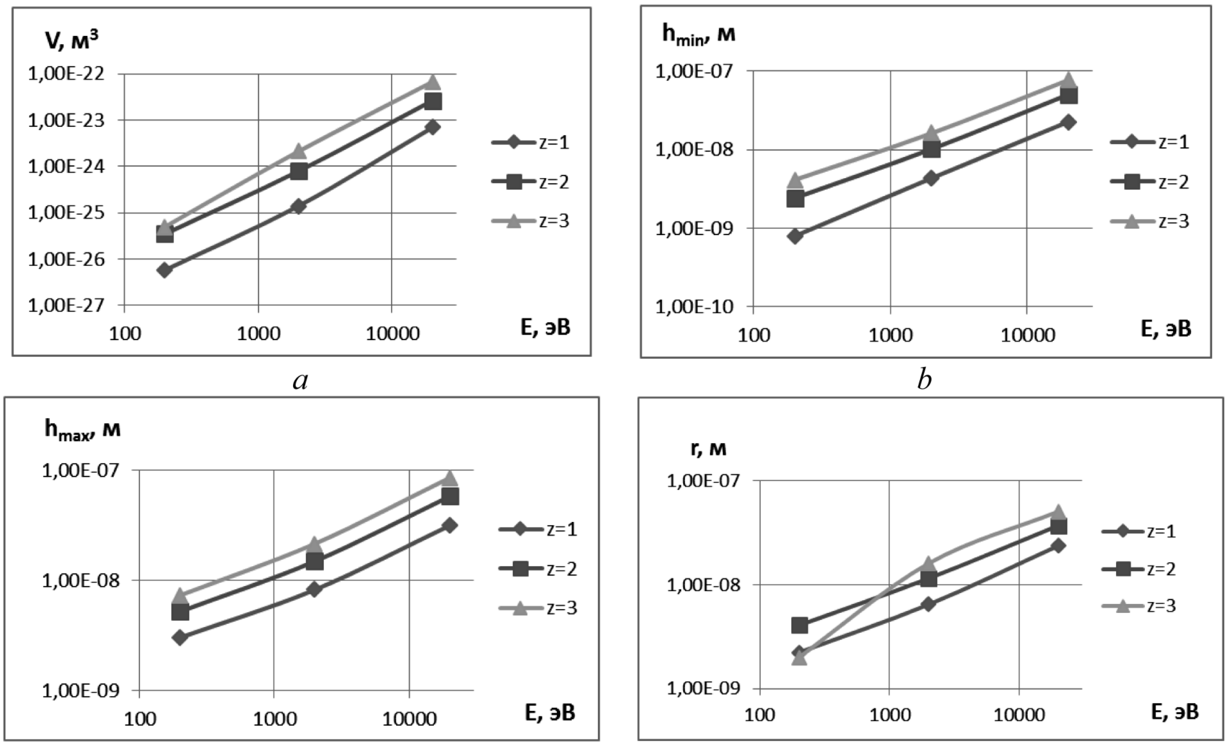
Fig. 8. Dependences of nanocluster volume (NC) (*a*), maximum (*b*) depth and radius of NC (*c*), from the energy of hafnium ions (Hf^+) with different charge (z = 1, z = 2, z = 3) for VK20



a *b*

c *d*

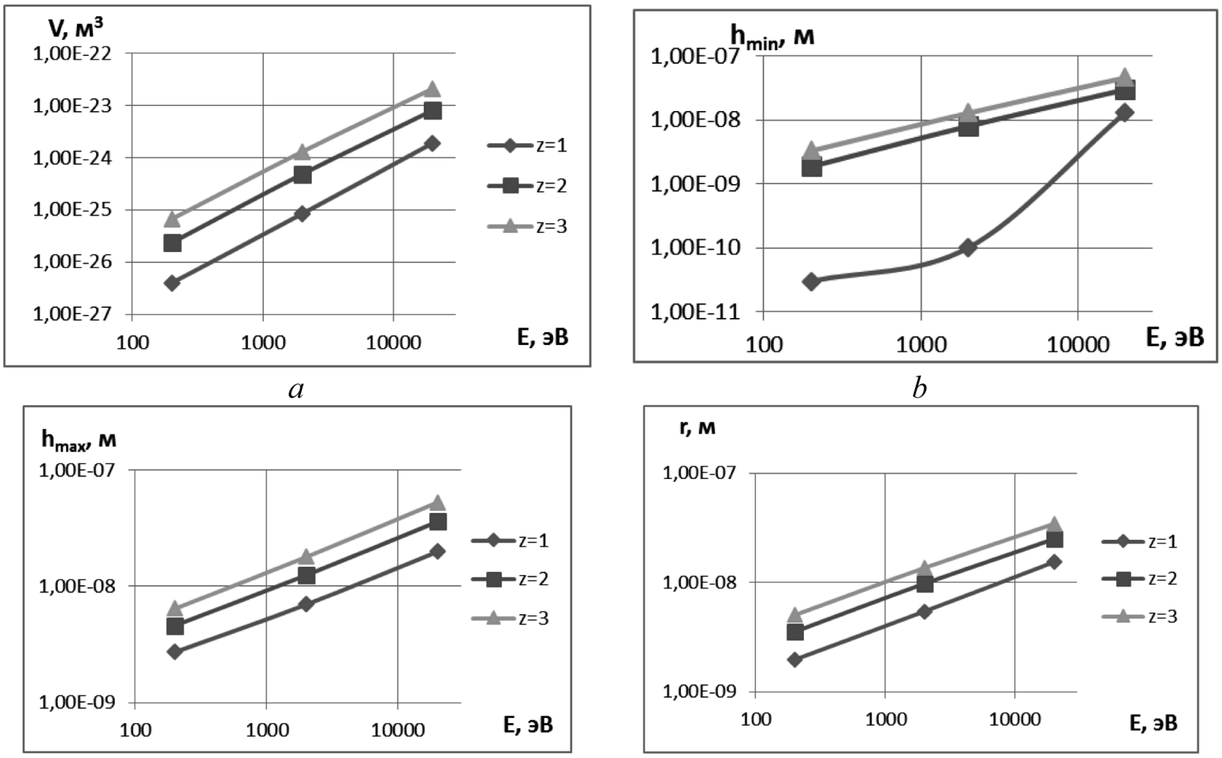
Fig. 9. Dependences of nanocluster volume (NC) (*a*), minimum (*b*) and the maximum (*c*) depth and radius of NC (*d*), from the energy of boron ions (B^+) with different charge (z = 1, z = 2, z = 3) for VK10



a *b*

c *d*

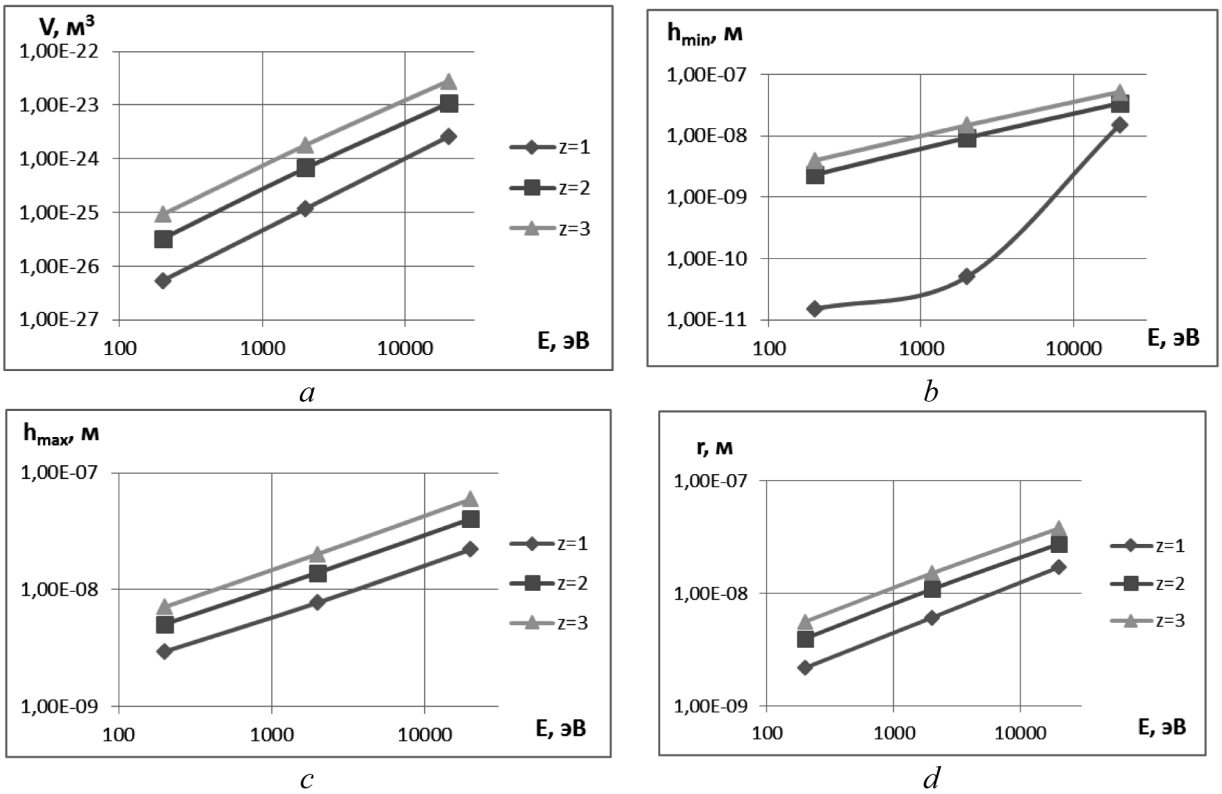
Fig. 10. Dependences of nanocluster volume (NC) (*a*), minimum (*b*) and the maximum (*c*) depth and radius of NC (*d*), from the energy of nitrogen ions (N^+) with different charge (z = 1, z = 2, z = 3) for VK10



a *b*

c *d*

Fig. 11. Dependences of nanocluster volume (NC) (*a*), minimum (*b*) and the maximum (*c*) depth and radius of NC (*d*), from the energy of yttrium ions (Y^+) with different charge (z = 1, z = 2, z = 3) for VK10



a *b*

c *d*

Fig. 12. Dependences of nanocluster volume (NC) (*a*), minimum (*b*) and the maximum (*c*) depth and radius of NC (*d*), from the energy of hafnium ions (Hf^+) with different charge (z = 1, z = 2, z = 3) for VK10

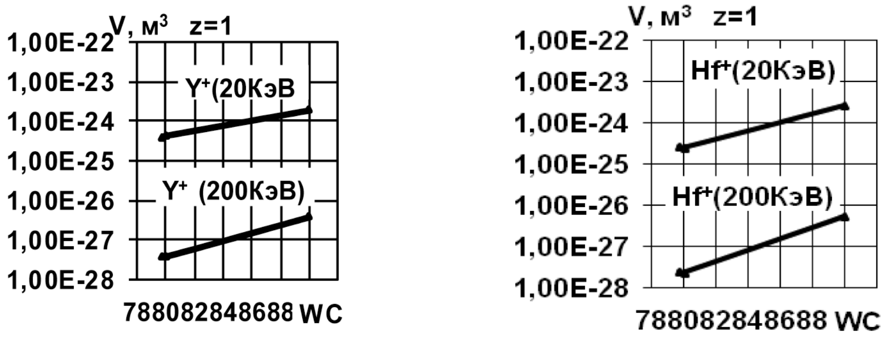
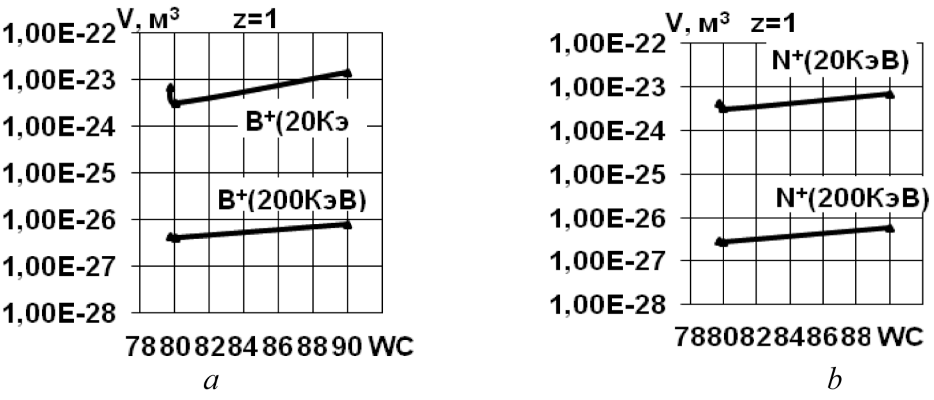


Fig. 13. Depending on the volume of the NC from the percentage composition of tungsten carbide for VK10 modified (WC – 79.7 %), VK20 (WC – 80.00 %) and VK10 (WC – 90.00 %)



a *b*

Fig. 14. Depending on the volume of the VAT from the percentage composition of tungsten carbide for VK10 modified (W – 79.7 %), VK20 (WC – 80.00 %) and VK10 (WC – 90.00 %) under the action of yttrium (*a*) and hafnium (*b*) ions

Conclusions

Consideration of boron, nitrogen, yttrium and hafnium for the modified VK10 (WC – 79.7 %), VK20 (WC – 80.00 %) and VK10 (WC – 90.00 %) showed:

- the value of ion energy and charge capacity of the ion significantly affects the grain size (with the growth of energy and the size of the charge, the grain size increases);

- the increase in the percentage composition of tungsten carbide leads to grain growth, and with the increase in the ion mass, the grain size reduction is more significant, which can be used to obtain the required grain size;

- design of the cutting tool material taking into account the possibility of formation of nanostructures shows that not always an increase in the proportion of tungsten carbide increases the efficiency and effectiveness of the tool, and often the grain size has a decisive influence.

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Костюк Г. И.[1]*, Попов В. В.*[2]*, Костик Е.А.*[3]

[1]Национальный аэрокосмический университет им. Н. Е. Жуковского «Харьковский авиационный институт». Украина, г. Харьков
[2]АО «ФЭД». Украина, г. Харьков
[3]Национальный технический университет «Харьковский политехнический институт». Украина, г. Харьков

КОНСТРУИРОВАНИЕ МАТЕРИАЛА РЕЖУЩЕГО ИНСТРУМЕНТА С УЧЕТОМ ТИПА УПРОЧНЕНИЯ НАНОПОКРЫТИЙ

Рассмотрено действие ионов бора, азота, иттрия и гафния на модифицированный ВК10 (WC – 79.7 % Co – 9,5 % + CrN – 1,3 % + AlN – 6.5 % + TiN – 3 %), ВК20 (WC – 80.00 %) и ВК10 (WC – 90.00 %). Показана возможность получения наноструктур. Определено, что величина энергии ионов и зарядность иона существенно влияют на размер зерна. С ростом энергии и величины заряда размер зерна растет; рост процентного состава карбида вольфрама приводит к росту зерна, причем с увеличением массы иона уменьшению размера зерна более существенно, что может быть использовано для получения необходимого размера зерна. Проектирование химического состава материала режущего инструмента с учетом возможности образования наноструктур показывает, что далеко не всегда увеличение доли карбида вольфрама увеличивает работоспособность и эффективность инструмента, а часто размер зерна оказывает определяющее воздействие..
[dx.doi.org/10.29010/087.3]

Ключевые слова: *наноструктуры; проектирование химического состава режущего инструмента; объем зерна; твердый сплав.*

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