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Mechanical Properties of Tungsten Implanted with Boron and Carbon Ions

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Abstract: Wear resistence and hardness of tungsten implanted sequntially with 60 keV ions of boron and carbon (fluences $\Phi = 1 \times 10^{15}$ - 3×10^{15} - 1×10^{16} - 3×10^{17}, ion × cm^{-2}) at 300-350 K tempertures has been studied. For testing hardness of samples modified by $\Phi = 1 \times 10^{15}$ - 3×10^{15} ion × cm^{-2} and 1×10^{16} - 3×10^{17} fluences ion × cm^{-2} nano-indentation and micro-indentation methods have been used, respectively. Determination of wear-resistance has been conducted by method of abrasive wear with dry friction. As a result, new composite materials with 1.3-4.5 times improved hardness and 2.0-6.7 times improved wear-resistance has been obtained with maintaining their rest properties. Influence of radiation processes and nano-physical phenomena on mechanical properties has been discussed.

Key words: Tungsten, boron, carbon, ion implantation, strength, wear resistance.

1. Introduction

A number of methods are used to create new construction materials with improved hardness and wear-resistance for the increased operational characteristics products. From the alternative methods should be noted: radiation-ion implantation technology. Operating of content, structure, physical-mechanical and other properties of materials by ion-implantation is implemented by accelerated ions irradiation. Radiation technology used for modification is based on common theory of interaction between accelerated particles and solid solution [1-3]. Therefore, parameters of the materials are mainly determined by radiation phenomena, nano-physical phenomena and rays condition. The advantage of ion implantation is in creation of modified materials. In recent years, differnet kinds of radiation modified materials have been created in equilibrium, non-equilibrium, metastable and nano-crystalline state [4-7]. In previous works, hardness and wear-resistance of refractory and heat resistant metals and their alloys were studied [4-6]. Present work deals with the creation and investigation of samples of composition construction materials with increased hardness and wear-resistanace by sequential implantation of boron and carbon ions on tungsten surface.

2. Materials and Methods

Polycrystalline grained tungsten samples with 99.99% purity obtained by zone melting have been used as initial materials.

Parallel cutting plates of 1 mm thick and 20 mm diameter initial samples (Machine for automatic cutting) is conducted on machine Saw EQ-SVY-200. After cutting, patterns mechanical grinding-polishing was conducted on machine for precisely automatic grinding and polishing UNIPOL-802 UNIPOL-802. For grinding-polishing, diamond large and grained emeries were used as well as a variety of sizes of diamond abrasives and polishing pads.

Metallographic microstructure of polycrystalline polished sample studied by NIKON Eclipse LV 150 microscope (× 2,000) is presented in Fig. 1.

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Structure and inter-grain boundaries, characteristic for grained-metals has been presented in Fig. 1. Testing of roughness of samples surfaces has been conducted on various stages of processing.

Roughness of surfaces was measured with non-contact Alpha-Step 200 TENCOR INSTRUMENTS profilometer. Roughness profile of tungsten made for implantation is shown in Fig. 2.

Initial roughness of polished patterns is 10.5 nm, which satisfies the requirements of their irradiation technology and mechanical properties of research methods. For the selection of ion implantation conditions radiation characteristics of bombarding ions is calculated. For parameters, range of ions, displacements of atoms, vacancies of the spatial distribution and sputtering yield ones are selected. Calculations are conducted by the method of Monte Carlo SRIM 2013 using computer programs TRIM [7]. Accelerated ions interaction with the containing target atoms are explained in binary collisions model. Evolution of the radiation point defects is not provided during the elastic collisions of ions in the calculations. In this approach, the estimated vacancies and values of displacements of atoms produce the ability of bombed bombarding ions' radiation defects. Results of calculations are shown in Figs. 3 and 4.

For the visualization, Table 1 contains average of projection range of bombarding ions (rang)-Rp, their standard leaning (straggle)-ΔRp, (displacements), (vacancies) and sputtering yield-Y values.

Sequential implantation of tungsten samples by 60 keV energy boron and carbon ions (fluences $\Phi = 1 \times 10^{15} - 3 \times 10^{15} - 1 \times 10^{16} - 3 \times 10^{17}$, ion × cm^{-2}, respectively) has been carried out at temperatures T = 300-350 K.

3. Results and Discussion

Indentation method was used for testing mechanical hardness of initial and modified layers [8]. Indentation methods allow investigation of physical-mechanical properties sand structural characteristics of materials. For testing samples' hardness, nano- and micro-indentation methods were used. Measurements of nano- microhardness and elastic modulus were conducted

Fig. 1 Tungsten microstructure.

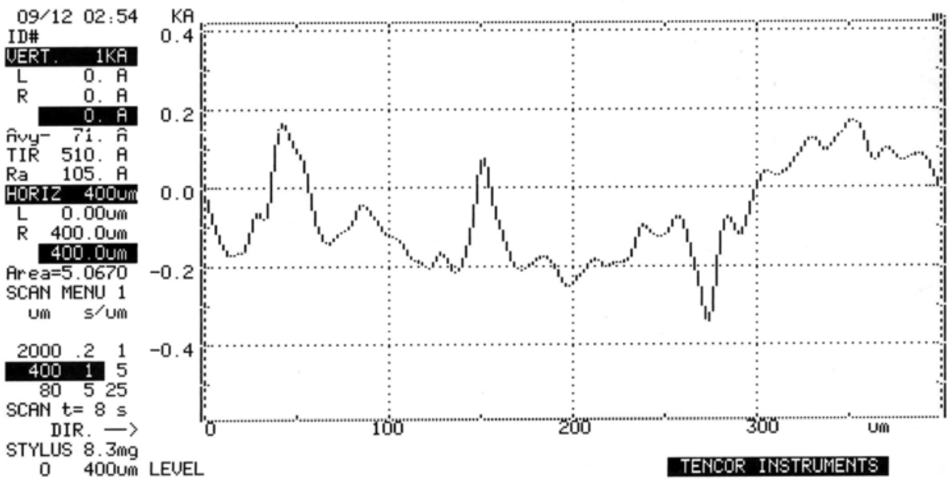
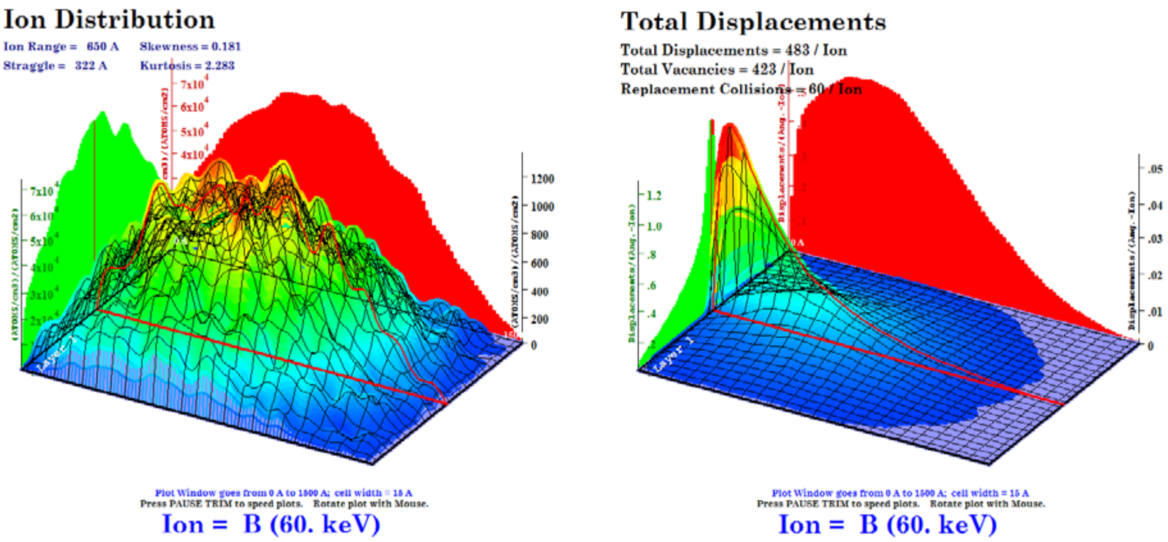
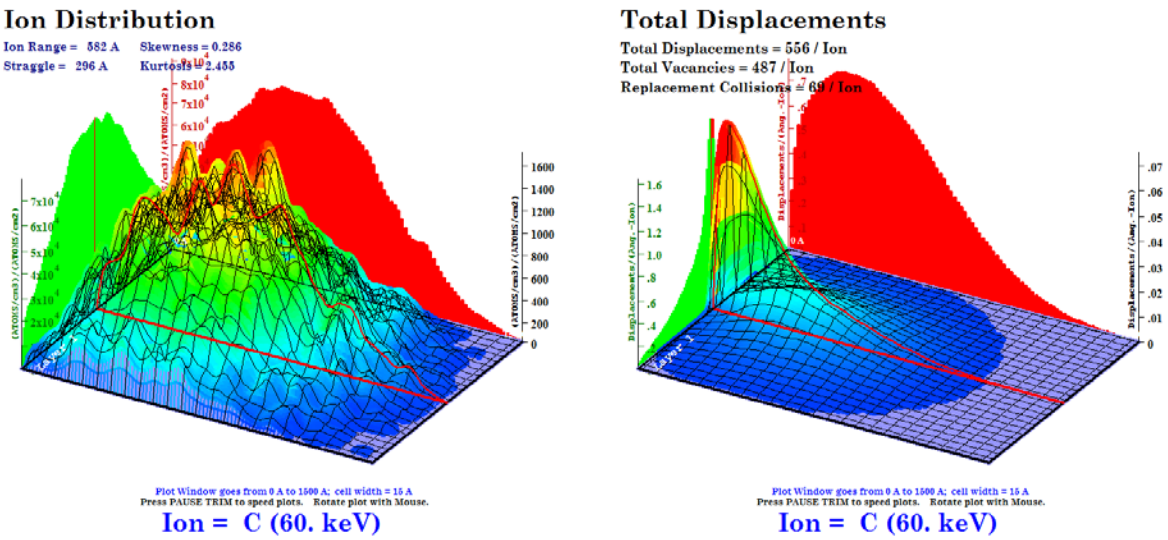


Fig. 2 Roughness of tungsten treated surfaces before ions irradiation.



(a) (b)

Fig. 3 Spatial distribution parameters of 60 keV energy boron ions implanted atoms (a), displaced atoms and vacancies (b).



(a) (b)

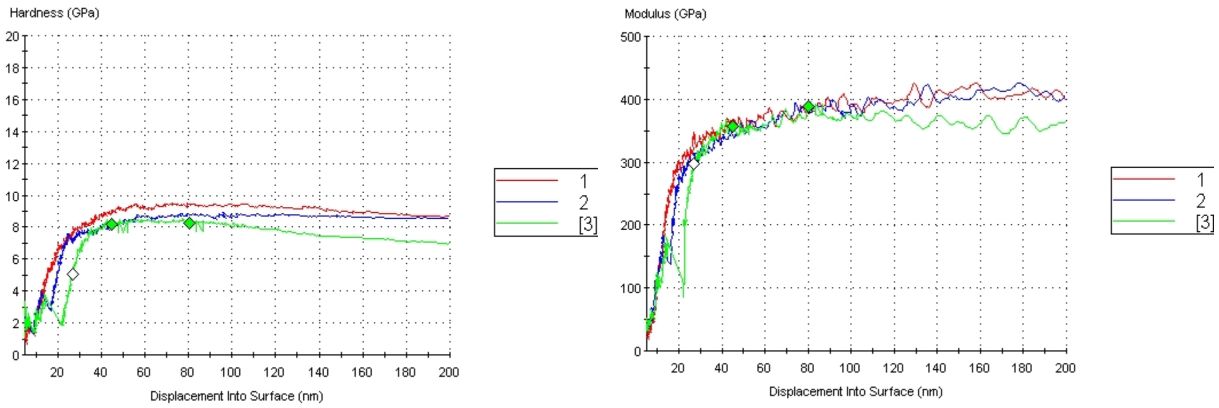
Fig. 4 Spatial distribution parameters of 60 keV energy carbon ions implanted atoms (a), displaced atoms and vacancies (b).

Table 1 Ions radiation parameters of the bombarding ions.

Targe	Ion	Rp, nm	ΔRp, nm	Displacements/ion	Vacancies/ion	Y, atoms/ion
W	B	65.0	32.2	483	423	0.36
	C	58.2	29.6	556	487	0.53

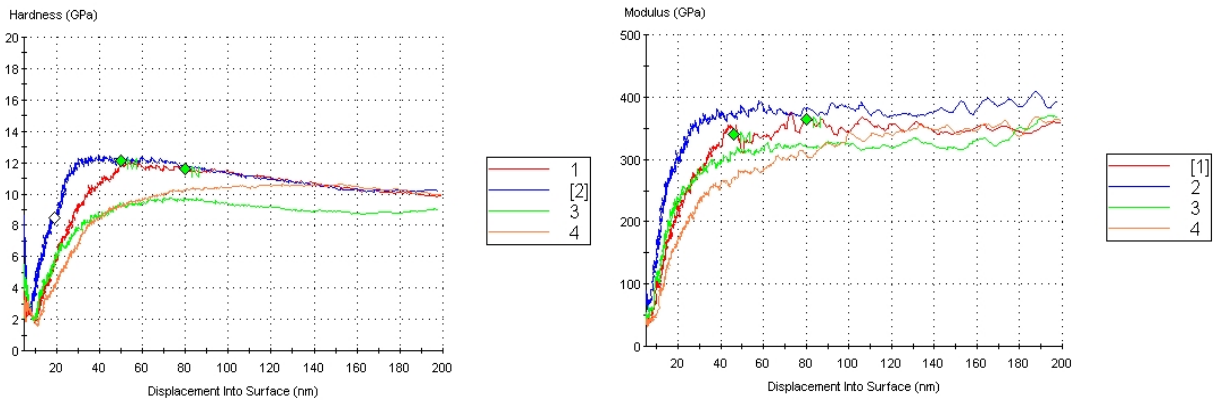
on Nano Indenter G200 and DUN-213S devices. Indentation process was carried out under different loadings and delaying and at constant velocity of deformation. Investigation results are presented in Fig. 5.

Hardness of modified materials increases with raising irradiation fluencies. Analysis of investigation results shows significant hardening of initial material. Therefore, new class of ion-implanted construction materials with 1.3-4.5 times improved hardness have been obtained by sequential implantation. Hardening of samples is stipulated by increasing radiation hardening, saturated impurity atoms, nano-sized inclusions and synthesized high strengthening compounds



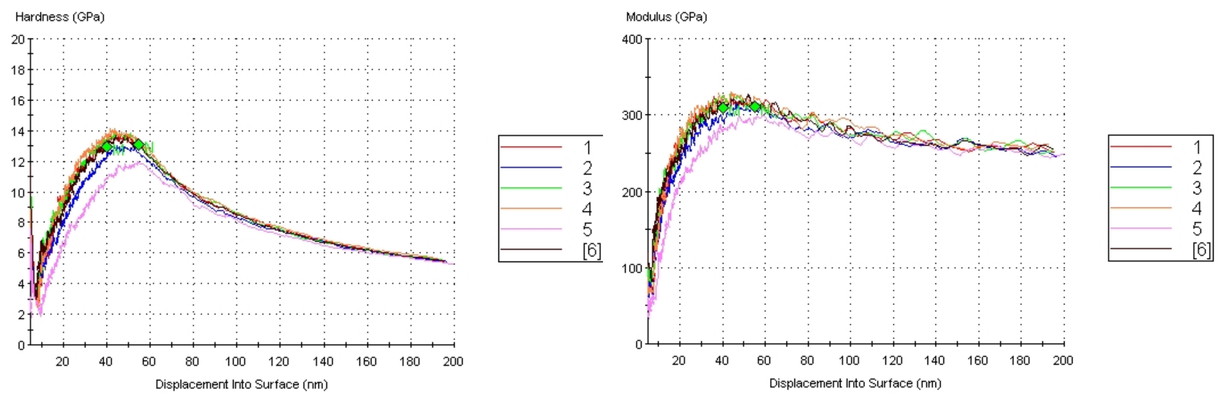
A	B	C
Test	E Average Over Defined Range	H Average Over Defined Range
	GPa	GPa
1	369.493	9.263
2	363.712	8.524
3	360.524	8.343
Mean	364.576	8.71
Std. Dev.	4.547	0.487
% COV	1.25	5.59

(a)



A	B	C
Test	E Average Over Defined Range	H Average Over Defined Range
	GPa	GPa
1	341.047	11.695
2	378.097	12.083
3	317.807	9.491
4	292.615	9.766
Mean	332.392	10.759
Std. Dev.	36.326	1.319
% COV	10.93	12.26

(b)



A	B	C
Test	E Average Over Defined Range	H Average Over Defined Range
	GPa	GPa
1	314.415	13.449
2	304.466	12.723
3	319.407	13.603
4	321.125	13.728
5	287.998	11.446
6	315.65	13.27
Mean	310.51	13.037
Std. Dev.	12.464	0.854
% COV	4.01	6.55

(c)

Fig. 5 Hardness and elastic modulus of initial tungsten (a), and tungsten implanted with B + C ions of 1 × 10^{15} ion/cm^2 fluencies (b) and 3 × 10^{15} fluencies (c).

[9, 10]. Radiation hardening of metals during irradiation is being implemented as a result of accumulation of dislocations, vacancies and complex defects in various traps. Surface of target samples is saturated trap for radiation defects. Contribution of deformation hardening, which is stipulated by compression-tension fields of elastic deformation, is notable. These effects largely determine physical-mechanical and exploitation properties of materials. Dependence of physical-mechanical properties on roughness of experimental sample has been studied in a process of obtaining modified construction materials. Investigation results are given in Fig. 6.

Roughness (14 nm) of irradiated sample exceeds roughness of initial sample (10.5 nm). Increase of roughness is caused by selective ion dispersion, which is one of the accompanying process of ion irradiation. It is characterized by ions' emission coefficient Y. Ions emission coefficient Y of tungsten implanted with 60 keV energy B and C ions with 3 × 10^{17}, ion × cm^{-2} fluence at temperatures 300-350 K is less than 1. For determination of wear-resistance of ion-implanted layers, method of abrasive wear with dry friction has been used [11]. Wear-resistance was determined by ration of wear of initial nonimplanted—H_0 and implanted—H samples. Diamond powderds with ≈ 1 µm size were used as abrasives. Studying of wear-resistance of the materials was conducted on machine for grinding and polishing M-PREP 3. Worn-out layers' thickness was defined by variations of prints sizes during microindentation. Increment of wear-resistance is proportional to the increment of hardness, with constant coefficient of linearity. It is established that wear resistance of implanted samples is increased in every case. Materials with 2.0-6.7 times improved wear-resistance have been obtained by ions sequential implantation. Experimental results of

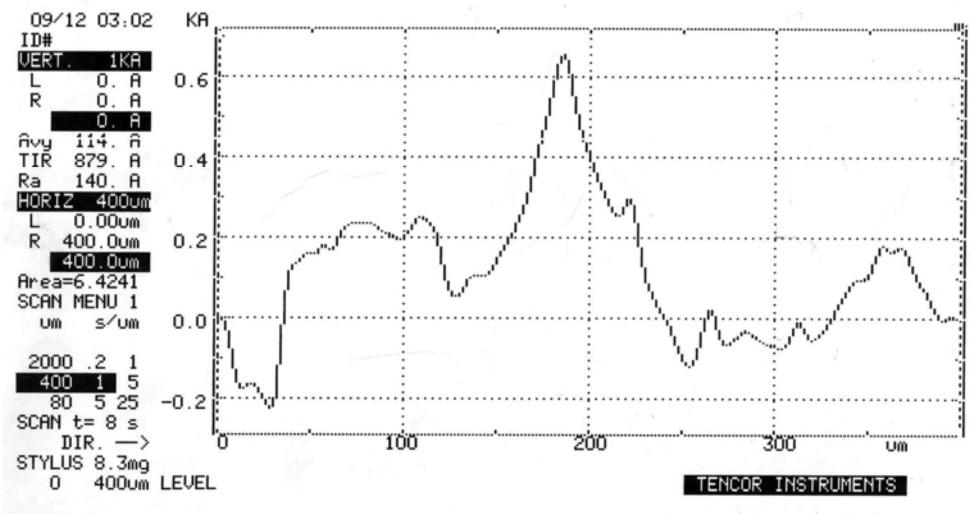


Fig. 6 Roughness of tungsten implanted with 3×10^{17} ion × cm $^{-2}$ fluencies B and C ions.

Table 2 Increment of relative hardness and wear resistance of tungsten implanted with different fluences ions.

Target	Ion	Φ, ion/cm^2	H/H_0	W/W_0
		1×10^{15}	1.3	2.0
		3×10^{15}	1.5	2.3
W	B + C	1×10^{16}	2.0	3.0
		1×10^{17}	2.9	4.35
		3×10^{17}	4.5	6.7

relative hardening H/H_0 and wear-resistance W/W_0 of ion-implanted tungsten are presented in Table 2.

According to the results analysis, increment of relative wear-resistance is more than increment of microhardness. Improvement of relative wear-resistence of ionimplanted metals is related to the increase of nanometric-sized layers microhardness of modified materials. As it was above mentioned, strengthening of ion-implanted metals is stipulated by oversaturating radiation defects, implanting atoms and synthesizing high-strength compounds. Therefore, a new class of composite construction materials with 1.3-4.5 times improved hardness and 2.0-6.7 times improved wear-resistance has been obtained by ion implantation at temperatures T = 300-350 K. Radiation modification process at the last stage of nano-sized construction materials formation is conducted with maintaining their rest properties. Manufacturing of devices based on ionimplanted materials is implemented with maintaining their construction and existing technology.

4. Conclusions

Modified nanosized metals with the rest maintained properties have been obtained by sequential irradiation with 60 keV tungsten, boron and carbon ions at temperatures 300-350 K.

As a result, new class of ion-implanted composite construction materials with 1.3-4.5 times improved hardness and 2.0-6.7 times improved wear-resistance has been obtained.

Influence of ongoing radiation processes and nano-phenomena on mechanical properties of materials has been reviewed in various models of target content changes and generation of bombarding ions defects.

Acknowledgements

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