Investigation of Structure and Phase Composition under Intense Pulsed Ion Beam Mixing of Film /Substrate Systems

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Abstract – The structural phase states, surface morphology and mechanical characteristic of the system film (Ti) – a substrate (Ni), irradiated by power ion beam has been investigated. High power ion beam (HPBI) was generated by the "Temp" accelerators. The compositions of beam were 70% C and 30% H. HPBI irradiation allows to form intermetallic phases Ni_3Ti, NiTi, $NiTi_2$ and solid solution Ti in Ni surface layers. Irradiated nickel samples have higher mechanical properties than unimplanted material.

1. Introduction

Results of an experimental research of a structural phase states, elemental composition and formation intermetallic phases of nickel formed in conditions of high-intensity titanium ion implantation are presented in work [1–2].

The high intensity ion implantation was carried out using the "Raduga-5" source generating continuous or pulse-periodical beam charged particle energy of up to 120 keV. It is established, that ion implantation of nickel adduce to formation intermetallic phases (Ni_3Ti, NiTi, and $NiTi_2$) and solid solution Ti in Ni surface layers thickness up to 1600 nm. The surface layers have higher mechanical characteristics in comparison with an initial material of a target. In this work, the results are presented on a study of structural phase states and changing of surface morphology of the system film (Ti)-a substance (Ni) irradiated by HPIB. HPIB was generated by the "Temp" accelerators. The ion accelerating voltage was 300 kV, averaged ion current densities were 50–150 A/cm^2 and pulse duration 60 ns.

2. Experimental results and discussion

The substrate polycrystalline nickel was buffing and mechanical polished. After that coated film by thermal vacuum evaporation method thickness 0.32 μm. The average grain size of unirradiated polycrystalline nickel was equal to 20–23 μm. In experiments the averaged ion current density and the number of HPIB pulses was varied. Table 1 presents regimes of irradiations.

Surface morphology of samples before and after HPIB irradiation was observed by atomic-force microscope "Solver Pro" and optical microscope "Neophot-2".

The structural phase states modified layers were investigated by X-ray diffraction (XRD) method.

Table 1. Regimes irradiation of samples

Regime	Current density, A/cm^2	Number pulse
1	50	1
2	50	3
3	100	1
4	100	3

XRD spectra were recorded on a difractometer "Dron-3M" using CuKα radiation. The microhardness of the samples was investigated with "PMT-3" use Vickers indenters.

Figure 1 shows surface morphology irradiated samples with regimes 1 and 4 received by atomic force microscope (AFM).

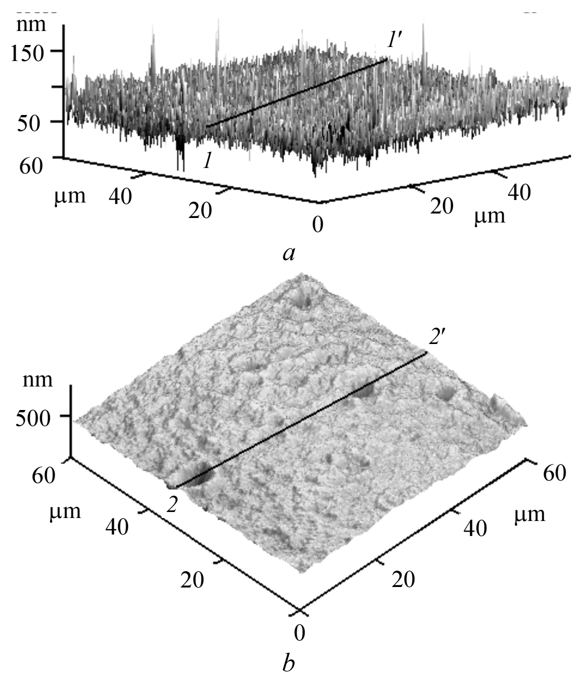

Fig. 1. Image of surface samples after irradiation by HPIB: *a* – regime 3; *b* – regime 4

The formation of craters for all regimes of HPBI irradiation was registered. The form, dimensions and surface concentration of craters depend on current density of beam and impulses quantity. Figure 2 shows scale craters distribution.

Part of the craters average size 1–5 μm changes from 60 (regime 1) up to 82% (regime 4). Maximum diameter of craters reaches order 25 μm for 4 regime of irradiation with percentage not exceed 2%.

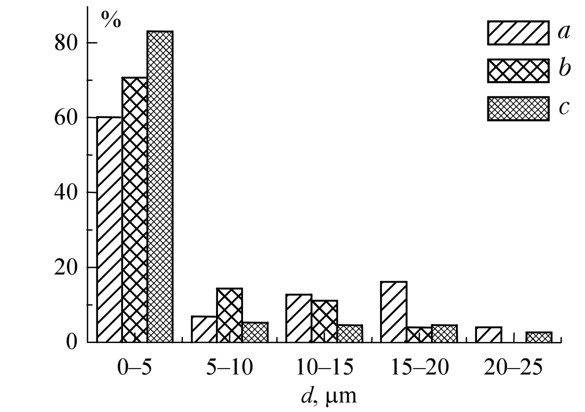

Fig. 2. Scale craters distribution: *a* – regime 1; *b* – regime 2; *c* – regime 4

In Fig. 3 are presented univariate profiles in the line *1–1*' and *2–2*' (see Fig. 1) of surface subject to regimes of influences.

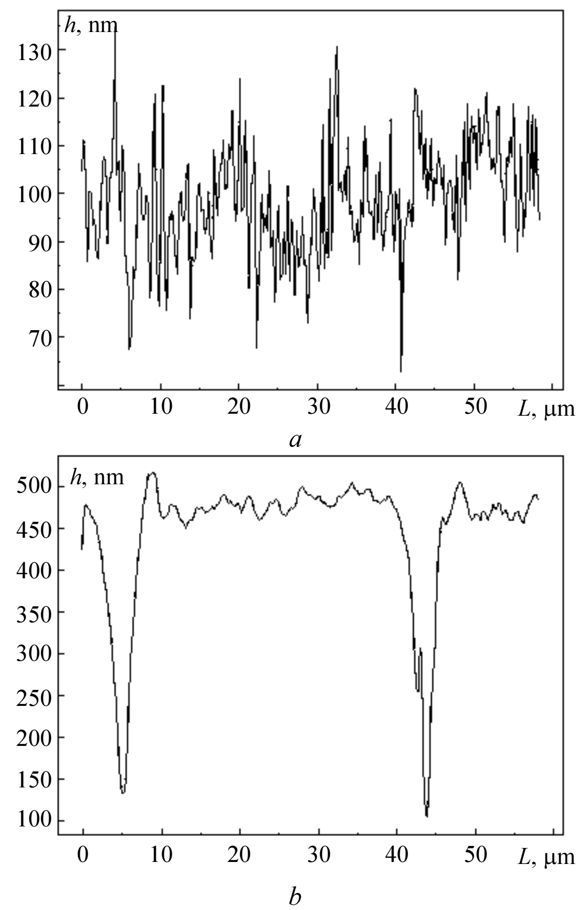

Fig. 3. Univariate profile of surface system after influences by HPIB: *a* – regime 3; *b* – regime 4

Average depth of formed craters exchanges from 150 (regime 1) up to 500 nm (regime 4). A maximal roughness of a surface with mean height of peaks 45 nm observed by three influences with ion current density 50 A/cm^2 and single influence with ion current density 100 A/cm^2. Surface of the system become comparative smooth, rather fritted with occurrence infrequent but rather deep craters at regime 4 irradiation. Intensive formation of intermetallic compounds Ni_3Ti, NiTi, $NiTi_2$ in sufficiently major depths was registered under such regime of irradiation. The peaks of intermetallic phases of Ti–Ni system are presented on XRD patterns in Fig. 4 (the peaks of pure nickel are not shown in Fig. 4 due to their high intensity compare to formed phases).

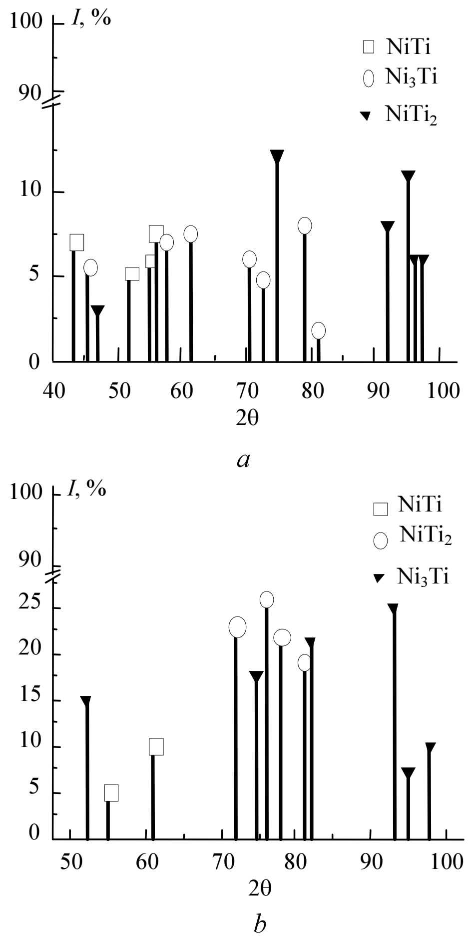

Fig. 4. X-ray diffraction patterns of Ni implanted with Ti ions (*a*) and after irradiation (*b*) in regime 4

According to XRD investigation formation of solid solution Ti in Ni are ascertained. Concentration of solid solution increase by increase of beam current density. Comparison intensity formation of recent compounds at high intensity ion implantation [1–2] and ion-radial mixing after HPIB impact are transacted. Maximal concentration of $NiTi_2$ (42.6%) phase formed at high intensity ion implantation Ti in Ni while HPIB irradiation just 32.2%.

Dominant compound Ni_3Ti (40.6%) after ion-radial mixing was registered. Very subambient concentration NiTi phase registered such as regime ion implantation (17.02%) as HPIB impact (26.56%). Besides the aforementioned intermetallic phases, we also observed the formation of the titanium oxide TiO_2 and the carbide (NiC, TiC) in near-surface layers after irradiation by HPIB with ion current density 100 A/cm^2.

According to the investigation of mechanical properties, the microhardness of all implanted and irradiated samples approximately two times higher then of initial materials. At the depths to 2 μm in regime ion implantation [1] and at the depths to 8 μm after HPIB impact registered of increasing the microhardness.

3. Conclusion

The HPIB regime generated by the “Temp” makes it possible to produce modify layers whole thickness up to 8 μm. The implantation of recoil titanium atoms into nickel results in the formation of nanocrystalline phases of intermetallic compounds, titanium oxide and carbide and also a nickel-titanium solid solution of variable composition. The formation of modify layers to improve substantially the mechanical properties of nickel. It was established that irradiated nickel samples have higher mechanical properties than unimplanted material.

References

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[2] E.V. Kozlov, I.A. Kurzina, and Yu.P. Sharkeev, Rus. Fiz. Zh. **8**, 517 (2006).