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# THE EFFECT OF IRRADIATION WITH AN INTENSE PULSED ELECTRON BEAM ON MECHANICAL PROPERTIES OF TECHNIALLY PURE ALUMINUM

A. Klopotov A. Potekaev S. Kislitsyn Y. Kakushkin
O. Volokitin V. Kulagina

*Tomsky State University of Architecture and Building, Tomsk, Russia*

*The Institute of Nuclear Physics,* Almaty, Kazakhstan

[3]*National Research Tomsk State University, Tomsk, Russia*

- *Abstract* — The paper presents the results of studies of the effect of alpha-particle irradiation on the structural-phase composition of nitride coatings CrTiN, MoTiN and NbTiN on the surface of a steel substrate. The coatings were formed by vacuum-arc condensation in a gas medium with $N_2$ using ion bombardment with the use of Ti, Cr, and Mo cathodes. In addition, coatings in a $N_2$ gas medium on a steel substrate were produced by magnetron sputtering from Ti and Nb metals.

- Experimental data and the analysis of state diagrams of ternary systems of nitrides based on titanium and vanadium with transition metals of IVA-VIA groups have allowed deriving criteria for choosing materials for production of nitride coatings with a fairly high radiation stability.

- The paper presents the results of an analysis of the search for general laws of structural-phase states and the structure of ternary diagrams of nitride systems based on transition metals of IVA–VIA metal groups with titanium and vanadium in order to select the most promising ones for the use as protective coatings on structural reactor materials. The experimental data on the effect of ion irradiation $_4He^{2+}$ on structural-phase states of nitride coatings CrTiN, MoTiN and NbTiN are presented.

- *Structural phase states of the Ti-Mo-N system.*

- In these compounds, transition metal atoms Me are located in octahedral interstices of a face-centered cubic (FCC) (Fig. 1) or a hexagonal (HCP) metal sublattice. From the structural point of view, nitrides of transition metals are solid solutions of non-metal atoms in the FCC lattice, which is confirmed by a number of properties. We shall note some. The leading role of the size factor during formation of nitrides has been established (the possibility of placing nitrogen atoms in the octo-internodes of the FCC metal lattice (Fig. 1) is determined, with a few exceptions, by the famous Hagg rule: $0.41<R_X/R_{Me}<0.59$). Very wide areas of homogeneity exist. Metastability of nitrides based on transition metals under normal conditions is manifested (at temperatures below 1000 K, they undergo decay or ordering, as conventional solid solutions).

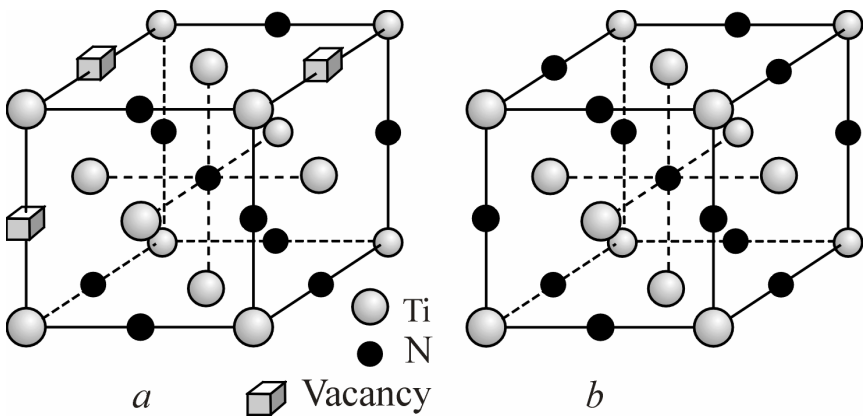
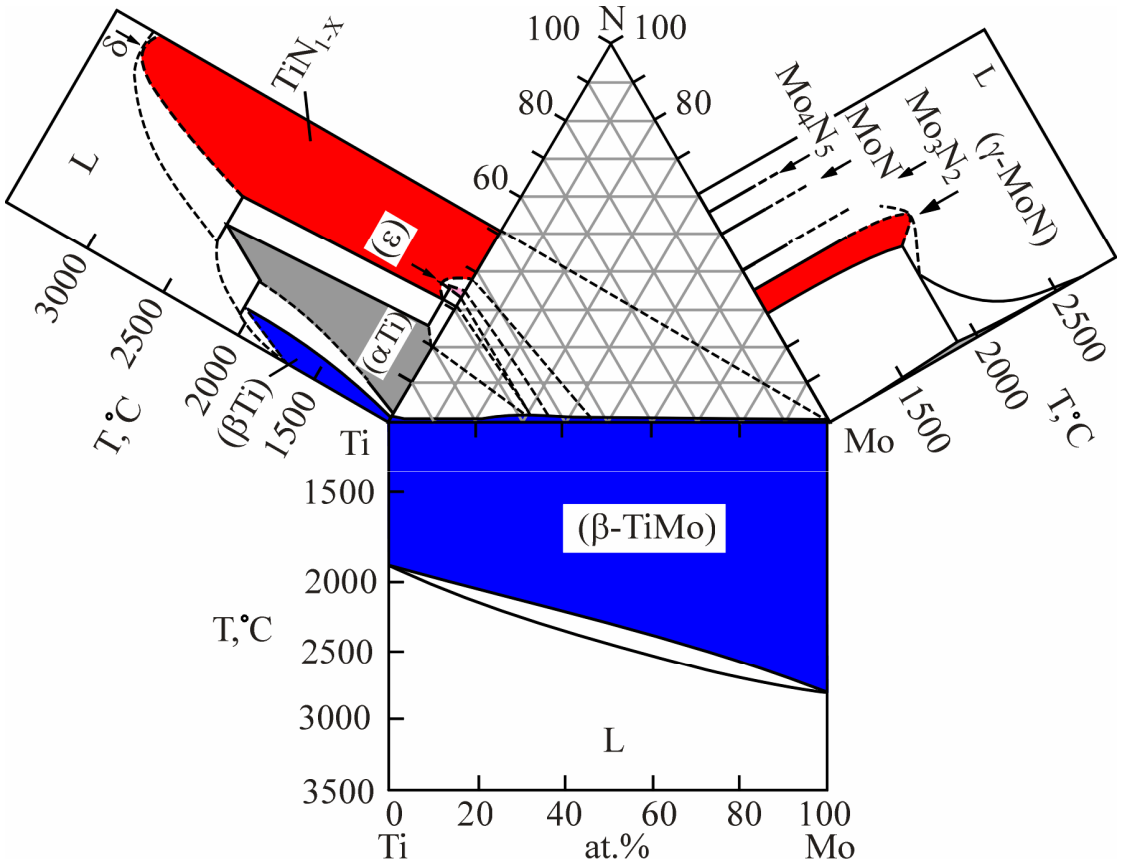


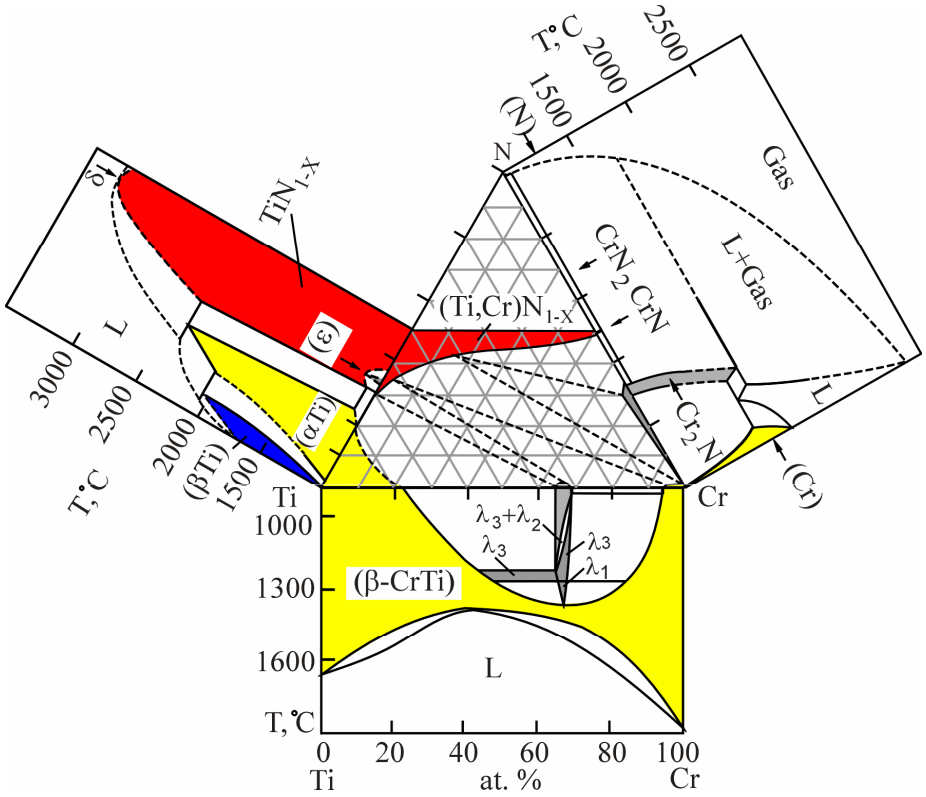

Fig. 1. Crystal structure of $TiN_X$ titanium nitride: *a* – B1 structure with vacancies; *b* – B1 structure without vacancies

# *Structural phase states of the Ti-Mo-N system*

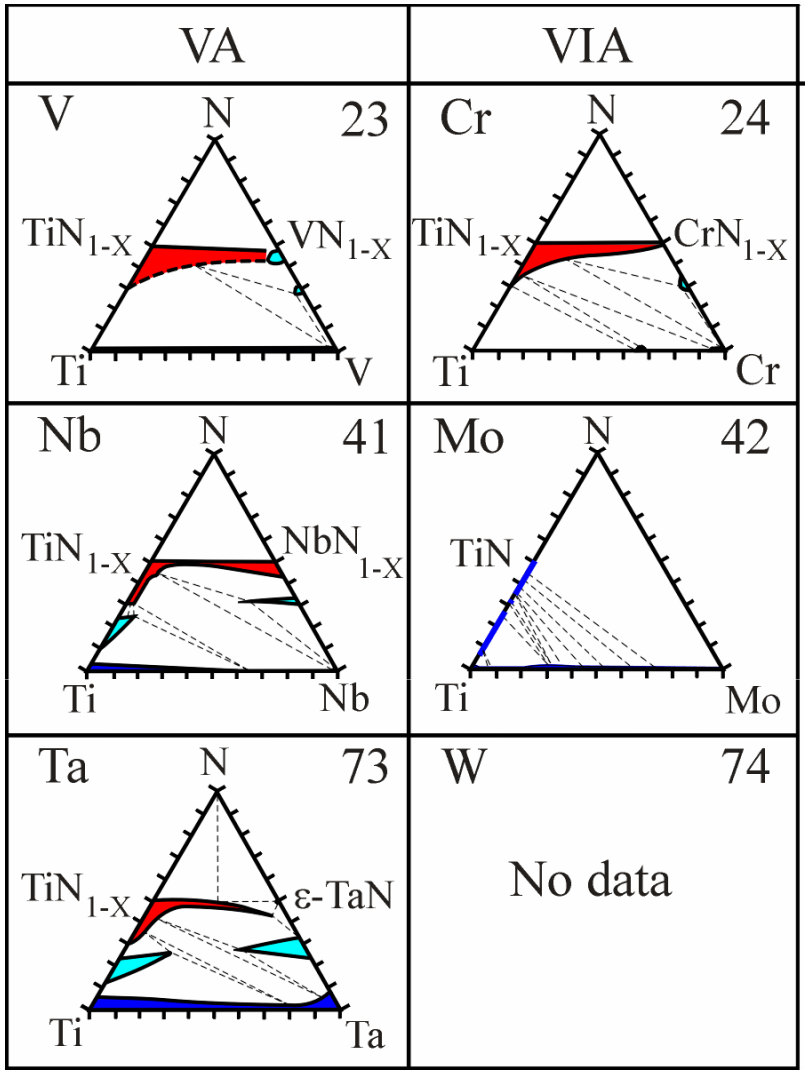



- Fig. 2. Binary diagrams of Mo-Ti, Mo-N, Ti-N systems and isothermal section of the Mo-Ti-N ternary system at 1000 °C.

- *Structural phase states of the Ti-Cr-N system*




- Fig. 3. Binary diagrams of Cr-Ti, Cr-N, Ti-N systems and the isothermal section of the ternary Cr-Ti-N system at 1000 °C.




- Fig. 4 shows a schematic view of ternary diagrams of titanium-based nitrides with transition metals from VA and VIA groups [9, 10]. Nitrides $(Ti,V)N_{1-X}$, $(Ti,Cr)N_{1-X}$, $(Ti,Nb)N_{1-X}$, $(Ti,Ta)N_{1-X}$ with extended homogeneity regions are formed in ternary systems Ti–Me–N (Me=V, Nb, Ta) based on titanium with transition metals from VA and VIA groups. Only one system Ti-Mo-N has no ternary nitrides with extended homogeneity regions. There is no data in literature on the state diagram for the Ti-W-N ternary system. The structure of the state diagram for this system is likely to be similar to that for the Mo–Ti–N system (Fig. 4).

- Fig. 4. Representation of ternary diagrams of titanium-based nitrides with transition metals from VA and VIA groups in a fragment of D. I. Mendeleev table. The numbers in the cells in the upper right corner correspond to the element number of the periodic table.

- *Ternary diagrams of vanadium-based nitrides with transition metals from IIIA, IVA and VIA groups*

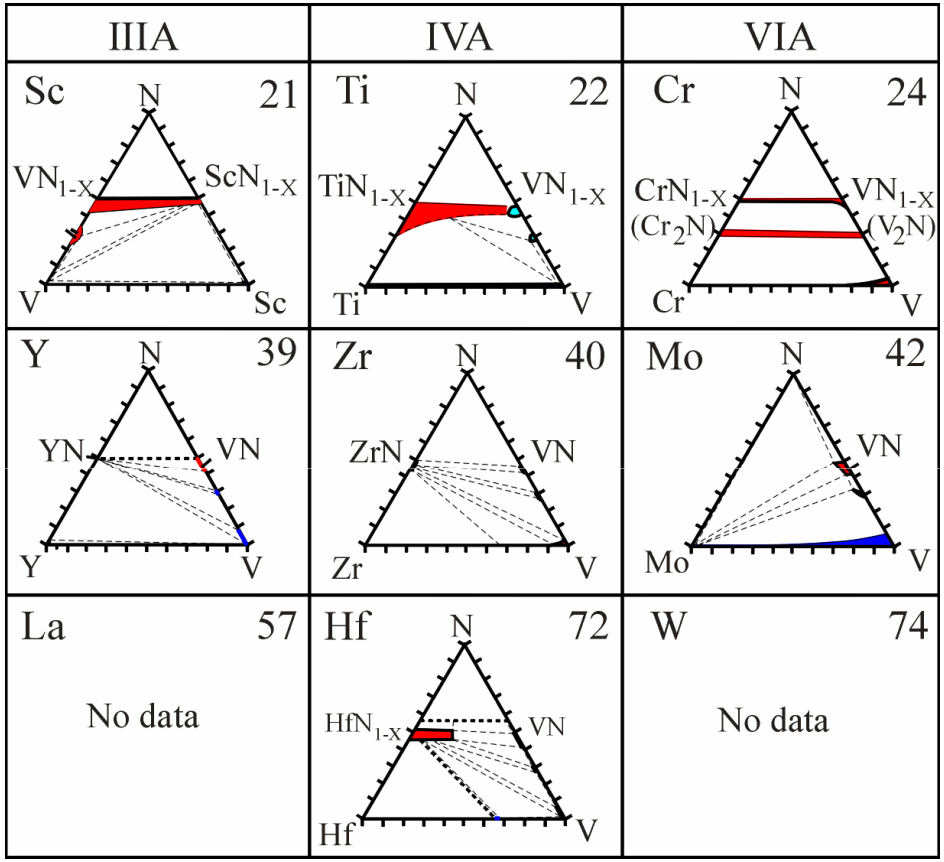



Fig. 5 shows a schematic of ternary diagrams of vanadium-based nitrides with transition metals from IIIA, IVA, and VIA groups. It can be seen that formation of nitrides $(Sc,V)N_{1-X}$, $(Ti,V)N_{1-X}$, $(Cr,V)N_{1-X}$ with extended homogeneity regions is observed in these ternary systems. There is no data in literature on the state diagram for V-W-N and La-V-N ternary systems. An assumption can be made that these systems will have a similar in structure state diagram as for the Y-V-N, V-Zr-N, Mo-V-N systems (Fig. 5).

Fig. 5. Representation of ternary diagrams of vanadium-based nitrides with transition metals from IIIA, IVA and VIA groups in a fragment of the D.I. Mendeleev table. The numbers in the cells in the upper right corner correspond to the element number of the periodic table.

# RESULTS AND DISCUSSION

- Coatings based on CrTiN were formed on the surface of a carbon steel substrate (<0.2 wt.% C) using the method of vacuum-arc condensation with ion bombardment. To produce a coating, metal ions were simulated from Ti and Cr cathodes in a nitrogen medium at a residual pressure $P_N = 10^{-1}$ Pa. The cathodes had a voltage of 60 V with a cathode current of 100 A. Coatings with different thicknesses based on $(Ti,Cr)N_{1-X}$ with a thickness from 50 to 150 nm were produced during deposition of 60 ÷ 120 sec. The technique for producing a coating using this method is given in more detail in.

- A similar technique was used to form coatings based on MoTiN nitrides on a plate made of Cr18Ni10Ti steel. The coating modes were as follows: the burning current of cathode arcs from Ti and Mo was 100 A and 180 A at a potential on the substrate of 120 V. The cathodes of Ti and Mo were located at an angle of 60° to each other at a distance of 120 mm from the substrate. The thickness of the MoTiN-based coating obtained under these conditions has reached 2 μm.

## RESULTS AND DISCUSSION

An X-ray study of the MoTiN coating has been carried out. As a result, it has been found that the surface layer of the coating mainly contains titanium nitride δTiN with the B1 structure and a small amount of a solid solution (β-Ti,Mo) based on the BCC lattice. This is in good agreement with the state diagram of the ternary system Mo-Ti-N (Fig. 2). It has been found that the content of the solid solution (β-Ti,Mo) is nonuniform in thickness of the coating and increases with distance from the surface of the coating [4]. Irradiation with low-energy alpha particles to a fluence of $1 \cdot 10^{17}$ ion/cm$^2$ has not lead to a significant change in the diffraction patterns.

The X-ray diffraction study of the NbTiN nitride coating has shown formation of two compounds: TiN with dissolved Nb (lattice parameter $a_{TiN(Nb)}$=0.4344 nm) and a compound NbN with dissolved titanium ($a_{NbN(Ti)}$=0.4370 nm). It has been found that the dissolution process of Nb in TiN proceeds 4 times faster than the dissolution process of Ti in NbN. It has been found that $_4He^{+2}$ irradiation leads to a decrease in the size and the number of small inclusions from particles of the NbN phase with dissolved Ti.

# CONCLUSION

- It is possible to produce homogeneous coatings as protective coatings based on transition metal nitrides from groups IIIA–VIA on structural materials if ternary state diagrams Ti-Me-N and V-Me-N contain extended homogeneity regions of compounds $(TiMe)N_{1-X}$ and $(VMe)N_{1-X}$ with the structure B1. Thus, production of coatings based on transition metal nitrides $(TiMe)N_{1-X}$ and $(VMe)N_{1-X}$ (Me = Sc, Cr, Nb, Ta, Hf) with extended homogeneity regions can have a fairly high radiation stability.

- It has been found that the spraying conditions used has not allowed producing uniform NbTiN and MoTiN coatings on a steel substrate. Whereas using the method of vacuum-arc condensation with ion bombardment, a uniform coating was formed on the surface of a steel substrate based on the three-component nitride $(Ti,Cr)N_{1-X}$.

The end