

## Article

# Effect of Irradiation with Si<sup>+</sup> Ions on Phase Transformations in Ti–Al System during Thermal Annealing

Zhuldyz Sagdoldina <sup>1</sup>, Baurzhan Rakhadilov <sup>1,2,\*</sup>, Sherzod Kurbanbekov <sup>2</sup> and Rauan Kozhanova <sup>2</sup>  
and Aidar Kengesbekov <sup>1</sup>

- <sup>1</sup> Research Center «Surface Engineering and Tribology», Sarsen Amanzholov East Kazakhstan University, Ust-Kamenogorsk 070000, Kazakhstan; sagdoldina@mail.ru (Z.S.); aidar.94.01@mail.ru (A.K.)
- <sup>2</sup> PlasmaScience LLP, Ust-Kamenogorsk 070000, Kazakhstan; kozhanova@mail.ru (R.K.)
- <sup>3</sup> Department of Physics, Kocaeli Ahi Evran International Turkish-Turkish University, Turkestan 161200, Kazakhstan; sherzod.kurbanbekov@ayyu.edu.tr
- \* Correspondence: rakhadilov@mail.ru; Tel.: +7-775-668-6239

**Abstract:** The article deals with the effect of irradiation with Si<sup>+</sup> ions on phase transformations in the Ti–Al system during thermal annealing. An aluminum film with a thickness of 500 nm was deposited on VT1-00 titanium samples by magnetron sputtering, followed by ion implantation. Samples before and after irradiation with Si ions were annealed in a vacuum of 10<sup>−4</sup> Pa in the temperature range 600–1000 °C. It was established that ion implantation reduces the dissolution of Al in α-Ti with the formation of titanium silicides (TiSi<sub>2</sub>, TiSi<sub>3</sub>) and stabilizes aluminide phases Ti<sub>3</sub>Al rich in aluminum. As a result, a composite structure based on titanium silicide/aluminide was obtained on the surface of the sample synthesized by complex treatment: deposition, irradiation with Si<sup>+</sup>, and thermal annealing at the near-surface layers. The formation of the phase-structural state of the implanted layers is associated with the displacement of atoms of the crystal lattice, a result that is reflected in an increase in the size of the crystal lattice and a decrease in microdistortion of the lattice. The opposite effect is observed with increasing temperature. This fact is explained by the relaxation of unstable large grains with an excess of internal energies. At the annealing temperature of 900–1000 °C, a significant increase in microhardness was observed due to silicide phases.

**Keywords:** Ti–Al system; magnetron sputtering; ion implantation; coating; structure

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## 1. Introduction

Intermetallic compounds of the Ti–Al system have high melting point, low density, high modulus of elasticity, resistance to oxidation and fire, and high specific heat resistance [1]. Intermetallic alloys of the Ti–Al system are distinguished by unique structural properties and are considered very promising for aerospace engineering products. The main disadvantages of these alloys are low plasticity at low temperatures and low fracture toughness, which complicate their technological processing and industrial use [2–4]. Consequently, methods of increasing their ductility while maintaining their strength remain serious problems.

In recent years, composite coatings based on the Ti–Al–Si system, obtained by combined methods, have become attractive for many industrial applications due to their properties, such as low friction coefficient, increased hardness, and heat and oxidation resistance, which significantly increase the service life of the products [5–7]. The combination of ion-plasma and ion-beam technologies opens up new possibilities in the formation of effective composite nanostructured and nanolayer films. The prospects of such technologies are due to the possibility of creating various new surface structures with improved physical and mechanical properties [8]. At the same time, the study of the

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**Frank V. Nolfi**



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**Fundamentals of Radiation Materials Science** Gary S. Was, 2007-07-16 This book is an eye opening treatise on the fundamentals of the effects of radiation on metals and alloys When energetic particles strike a solid numerous processes occur that can change the physical and mechanical properties of the material Metals and alloys represent an important class of materials that are subject to intense radiation fields Radiation causes metals and alloys to swell distort blister harden soften and deform This textbook and reference covers the basics of particle atom interaction for a range of particle types the amount and spatial extent of the resulting radiation damage the physical effects of irradiation and the changes in mechanical behavior of irradiated metals and alloys

**Radiation-induced Changes in Microstructure** F. A. Garner, 1987 Physics of Radiation Effects in Crystals R.A. Johnson, A.N. Orlov, 2012-12-02 Physics of Radiation Effects in Crystals is presented in two parts The first part covers the general background and theory of radiation effects in crystals including the theory describing the generation of crystal lattice defects by radiation the kinetic approach to the study of the disposition of these defects and the effects of the diffusion of these defects on alloy compositions and phases Specific problems of current interest are treated in the second part and include anisotropic dimensional changes in x uranium zirconium and graphite acceleration of thermal creep in reactor materials and radiation damage of semiconductors and superconductors

**The Effects of Irradiation on Phase-transformations in the Al Rich-Cu System** Lewis Emanuel Katz, 1967 **Effects of Radiation on Materials** F. A. Garner, J. S. Perrin, 1985 Radiation Physics of Metals and Its Applications L. I Ivanov, Yu M. Platov, 2004 Annotation Examination of problems of radiation materials science behaviour of solid in conditions of reactor and space irradiation development of radiation resistant materials for atomic power engineering Computer Modelling of Structural Transformations of Nanopores in Fcc Metals M.D. Starostenkov, A.V. Markidonov, P.V. Zakharov, P.Y.

Tabakov, 2019-11-25 The book focuses on the effects of shock waves on vacancies and their clusters in fcc crystals It is shown that high speed cooperative atomic displacements represent a powerful tool for the purposeful modification of defect structures in crystalline bodies The results are important for radiation material science nano engineering the study of shock wave effects and the ultrasonic treatment of materials Keywords Computer Modelling of Nanopores Molecular Dynamics Fcc Metals Defect Structures in Crystals Radiation Material Science Nano Engineering of Materials Ultrasonic Treatment of Materials Radiation Induced Defects Vacancy Clusters Shock Wave Effects Radiation Resistant Materials Thermomechanical Processing Energy Transfer Mechanism Nanopore Nucleation Nanopore Based Filters Nanopore Based Detectors Cooling Elements in Nano Electronics

*Nuclear Science Abstracts* , 1975 **Technical Progress Report, Pressurized Water Reactor (PWR) Project for the Period ...** , 1958-02 Energy Research Abstracts , 1993 **Zirconium in the Nuclear**

**Industry** George P. Sabol,2000     *TID.* ,1958     **Materials sciences overview** ,1977     *ERDA.* ,1977     Comprehensive Nuclear Materials ,2020-07-22

Materials in a nuclear environment are exposed to extreme conditions of radiation temperature and or corrosion and in many cases the combination of these makes the material behavior very different from conventional materials This is evident for the four major technological challenges the nuclear technology domain is facing currently i long term operation of existing Generation II nuclear power plants ii the design of the next generation reactors Generation IV iii the construction of the ITER fusion reactor in Cadarache France iv and the intermediate and final disposal of nuclear waste In order to address these challenges engineers and designers need to know the properties of a wide variety of materials under these conditions and to understand the underlying processes affecting changes in their behavior in order to assess their performance and to determine the limits of operation Comprehensive Nuclear Materials Second Edition Seven Volume Set provides broad ranging validated summaries of all the major topics in the field of nuclear material research for fission as well as fusion reactor systems Attention is given to the fundamental scientific aspects of nuclear materials fuel and structural materials for fission reactors waste materials and materials for fusion reactors The articles are written at a level that allows undergraduate students to understand the material while providing active researchers with a ready reference resource of information Most of the chapters from the first Edition have been revised and updated and a significant number of new topics are covered in completely new material During the ten years between the two editions the challenge for applications of nuclear materials has been significantly impacted by world events public awareness and technological innovation Materials play a key role as enablers of new technologies and we trust that this new edition of Comprehensive Nuclear Materials has captured the key recent developments Critically reviews the major classes and functions of materials supporting the selection assessment validation and engineering of materials in extreme nuclear environments Comprehensive resource for up to date and authoritative information which is not always available elsewhere even in journals Provides an in depth treatment of materials modeling and simulation with a specific focus on nuclear issues Serves as an excellent entry point for students and researchers new to the field     Handbook of Generation IV Nuclear Reactors Igor Pioro,2022-12-07 Handbook of Generation IV Nuclear Reactors Second Edition is a fully revised and updated comprehensive resource on the latest research and advances in generation IV nuclear reactor concepts Editor Igor Pioro and his team of expert contributors have updated every chapter to reflect advances in the field since the first edition published in 2016 The book teaches the reader about available technologies future prospects and the feasibility of each concept presented equipping them users with a strong skillset which they can apply to their own work and research Provides a fully updated revised and comprehensive handbook dedicated entirely to generation IV nuclear reactors Includes new trends and developments since the first publication as well as brand new case studies and appendices Covers the latest research developments and design information surrounding generation IV nuclear reactors     **Decomposition of Alloys: The Early**

**Stages** P. Haasen, V. Gerold, R. Wagner, 2013-10-22 Decomposition of Alloys The Early Stages contains the proceedings of the 2nd Acta Scripta Metallurgica Conference held in Sonnenberg Germany on September 19-23 1983 Contributors discuss the early stages of decomposition in alloys placing emphasis on the unsolved problems of the field rather than on the solved ones This book has 36 chapters and opens with a discussion on developments in the theory of the kinetics of first order phase transitions followed by an analysis of metastability and spinodal nucleation neutron scattering during decomposition of aluminum alloys Ostwald ripening of precipitates and phase stability under irradiation The next chapters explore decomposition processes in Al-Zn alloys thermal decomposition in Cu-Ni-Fe alloys and the initial stages of discontinuous precipitation reactions Other papers focus on the mechanisms of plate precipitate growth spinodal decomposition and continuous ordering and early stages of decomposition in Ni-Al single crystals This monograph will be of interest to students and practitioners of physics and metallurgy     Zirconium in the Nuclear Industry E. R. Bradley, 1996     **Effects of Radiation on Materials** Roger E. Stoller, 1992 Symposium held in Nashville Tennessee June 1990 Almost two thirds of these 91 papers are authored by researchers outside of the US including information on research in the former USSR Japan and Europe Topics include current commercial power reactor systems microstructural characterization

## The Enigmatic Realm of **Phase Transformations During Irradiation**: Unleashing the Language is Inner Magic

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### **Table of Contents Phase Transformations During Irradiation**

1. Understanding the eBook Phase Transformations During Irradiation
  - The Rise of Digital Reading Phase Transformations During Irradiation
  - Advantages of eBooks Over Traditional Books
2. Identifying Phase Transformations During Irradiation
  - Exploring Different Genres
  - Considering Fiction vs. Non-Fiction
  - Determining Your Reading Goals
3. Choosing the Right eBook Platform
  - Popular eBook Platforms
  - Features to Look for in an Phase Transformations During Irradiation
  - User-Friendly Interface
4. Exploring eBook Recommendations from Phase Transformations During Irradiation
  - Personalized Recommendations
  - Phase Transformations During Irradiation User Reviews and Ratings
  - Phase Transformations During Irradiation and Bestseller Lists

5. Accessing Phase Transformations During Irradiation Free and Paid eBooks
  - Phase Transformations During Irradiation Public Domain eBooks
  - Phase Transformations During Irradiation eBook Subscription Services
  - Phase Transformations During Irradiation Budget-Friendly Options
6. Navigating Phase Transformations During Irradiation eBook Formats
  - ePub, PDF, MOBI, and More
  - Phase Transformations During Irradiation Compatibility with Devices
  - Phase Transformations During Irradiation Enhanced eBook Features
7. Enhancing Your Reading Experience
  - Adjustable Fonts and Text Sizes of Phase Transformations During Irradiation
  - Highlighting and Note-Taking Phase Transformations During Irradiation
  - Interactive Elements Phase Transformations During Irradiation
8. Staying Engaged with Phase Transformations During Irradiation
  - Joining Online Reading Communities
  - Participating in Virtual Book Clubs
  - Following Authors and Publishers Phase Transformations During Irradiation
9. Balancing eBooks and Physical Books Phase Transformations During Irradiation
  - Benefits of a Digital Library
  - Creating a Diverse Reading Collection Phase Transformations During Irradiation
10. Overcoming Reading Challenges
  - Dealing with Digital Eye Strain
  - Minimizing Distractions
  - Managing Screen Time
11. Cultivating a Reading Routine Phase Transformations During Irradiation
  - Setting Reading Goals Phase Transformations During Irradiation
  - Carving Out Dedicated Reading Time
12. Sourcing Reliable Information of Phase Transformations During Irradiation
  - Fact-Checking eBook Content of Phase Transformations During Irradiation
  - Distinguishing Credible Sources
13. Promoting Lifelong Learning

- Utilizing eBooks for Skill Development
- Exploring Educational eBooks

### 14. Embracing eBook Trends

- Integration of Multimedia Elements
- Interactive and Gamified eBooks

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