

MANIFESTATION OF FOUR BASIC FEATURES OF HIGH-ENTROPY MATERIALS UNDER EXPOSURE TO RADIATION

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Abstract

The article discusses the manifestations of key properties of high entropy materials (High Entropy The study examines the effects of high-energy multiply charged particles (HEM) on the radiation hardness of high-energy metals (HEMs). Four fundamental HEM characteristics—elastic lattice deformation, cocktail effect, slow diffusion, and thermodynamic stabilization—and their influence on the formation of radiation damage are analyzed. A physical model of the initial stage of ion track formation is proposed, taking into account the nonequilibrium dynamics of electrons and ions, the underlying Coulomb explosion mechanism, and the probability of its occurrence. It is shown that HEM properties can both enhance primary radiation damage and influence its subsequent relaxation processes, including radiation-induced self-annealing. This study emphasizes the need for a comprehensive study of the radiation hardness of HEMs, taking into account their unique properties.

Keywords: High-entropy materials, radiation damage, Coulomb explosion, ion track, electron-ion relaxation.

Introduction

Over the past 25 years, there has been an increasing interest in the properties and applications of high entropy materials (High Entropy Materials , HEM). Today, it is believed that the key physical, chemical and technological properties of these materials can be explained on the basis of four basic characteristics: elastic lattice deformation, cocktail effect, slow diffusion and thermodynamic stabilization due to high entropy [1].

Despite the development of these concepts, they still do not fully explain the effects of radiation exposure on HEM. This is due to the diversity of factors influencing the interaction of radiation with matter, including the energy and charge of particles, microstructure, and local chemical inhomogeneities [2].

The aim of this work is to analyze the manifestations of four basic features of HEM under radiation exposure and to propose a model of the initial stage of ion track formation taking into account the nonequilibrium dynamics of electrons and ions.

Physical model of interaction of multiply charged ions with HEM

Consider the passage of a high-energy, multiply charged particle of large mass (e.g., a nuclear fission fragment) through matter. Along the particle's trajectory, a cylindrical region of ionization—an "ion track"—forms. Initially, the equilibrium between the electron and ion subsystems is disrupted, creating a local positive charge density and repulsive potential energy.

Fast electrons leave the track within a time (τ_e), while heavy ions remain in a local region. Under these conditions, the "Coulomb explosion mechanism" becomes possible, in which the accumulated repulsive energy of the ions is released in the form of rapid expansion.

The features of HEM significantly modify this process:

"Elastic lattice deformation" redistributes local stresses;

The "cocktail effect" changes the local energy of ions;

"Slow diffusion" prolongs the life of local charge fluctuations;

"High entropy" affects thermodynamic stability and energy balancing .

Probability of a Coulomb explosion

The probability of the Coulomb explosion occurring in a local region of the track can be expressed through the cross-section:

$$\sigma_D = \sigma_i * P(Z) * e^{(-\tau_*/\tau_e)}$$

Where:

Here σ_i is the cross section of the primary ionization of an ion (caused by the passage of a multiply charged particle); $P(Z)$ is the probability of the formation of a positive charge Z (as a result of intracascade electron transitions); τ_* is the time required for the irreversible scattering of ions from a local region; τ_e is the

time for the primary ion instability to be filled with electrons from the surrounding medium.

The evolution of the resulting ion track depends on the ratio of characteristic times: this parameter can vary by an $\gamma = \tau_*/\tau_e$ order of magnitude depending on the original substance (in metals, it is significantly smaller than in non-metals). This circumstance has previously been virtually undiscussed for HEM materials, although it is of fundamental importance. In particular, according to our model, radiation damage is less pronounced in metallic objects, while it is significantly more severe in non-metals [3].

Let us note an important circumstance that is characteristic specifically of HEM materials: their high entropy apparently contributes to increased radiation damage (in particular, due to the lower γ).

At the same time, the situation is not hopeless if we correctly take into account the processes of radiation self-annealing, which is an independent and rather complex problem (however, it is already possible to highlight the special significance of shock waves for metals and recombination charge exchanges for non-metals [5]).

In metals, free electrons quickly shield the positive charge, which reduces the likelihood of a Coulomb explosion.

In non-metals, the delay in electron shielding increases the destructive effect.

In HEM, the structure and composition create a complex local distribution of electrons, which can either enhance or mitigate damage.

Elastic deformation of the lattice promotes the redistribution of local stresses, the cocktail effect influences the local energy of ions, slow diffusion prolongs the lifetime of local charge fluctuations, and high entropy changes the thermodynamic stability of the track.

The influence of radiation self-annealing

self-annealing processes can reduce accumulated damage. In HEM, this process is more complex due to the heterogeneous structure:

- recombination of vacancies and interstitial atoms,
- local lattice restructuring,
- relaxation of internal stresses.

The efficiency of self-annealing depends on the temperature, structure, and irradiation rate, which opens up ways to control the radiation resistance of HEM.

Conclusion

The paper demonstrates that four fundamental features of HEM—elastic lattice deformation, the cocktail effect, slow diffusion, and thermodynamic stabilization—significantly influence the formation of ion tracks and Coulomb explosions. Track evolution is determined by the ratio of electron screening and ion expansion times. Radiation-induced self-annealing processes can partially compensate for the damage.

The results highlight the need for a detailed study of radiation effects in HEM to assess their applicability in extreme conditions.

References

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