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GIANT RADIATION-DYNAMIC EFFECTS DURING CORPUSCULAR IRRADIATION AND THEIR PRACTICAL USE FOR ION-BEAM MODIFICATION OF THE PROPERTIES OF METALS AND ALLOYS

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Nanoscale dynamic effects and processes in metals and alloys are considered for cascade-forming types of irradiations by heavy ions, neutrons, and fission fragments. The role of these processes is beyond the scope of classical radiation physics of condensed matter.

The sources of shock-wave effects studied and used in practice are the regions of passage of dense cascades of atomic displacements, r ~ 5 nm, thermalized over times of the order of one trillionth of a second (thermal spikes) with gigantic temperatures and thermal pressures in these regions (T = 3000-6000 K, P = 5-40 GPa), which are sources of powerful elastic and shock post-cascade waves. Shock-wave effects must be taken into account for cascade-forming types of irradiation, along with purely migration processes involving radiation defects, which are considered by classical radiation physics.

A theory of self-propagating (theoretically over unlimited distances) structural-phase transformations in metastable media initiated by ion bombardment has been developed.

In practice, this ensures: 1) an increase in the zone of action of penetrating radiation on materials by at least 3-5 orders of magnitude, in particular, the depth of action of accelerated ions (with energies of tens and hundreds of keV) up to several mm or more with projective ranges R_p of such ions in substance within only 0.01-1 μm; 2) lowering the temperature of initiated transformations by tens and hundreds of degrees compared to similar thermally activated processes; 3) an increase in the rate of migration of atoms by several orders of magnitude in comparison with thermally and radiation-stimulated processes.

The report considers examples of radiation-induced processes (structural-phase and intraphase transformations) in metals and alloys with changes in electrical, magnetic, mechanical, resource, and other characteristics.

Practical applications concern the modification of the properties of functional materials. Namely, the modes of ion-beam processing are proposed, providing: zero value of the TCR of high-resistance alloys for precision resistors of the Fe-Pd-Au system (in the range of T=300-700 K). As a result of joint work with scientific and technical organizations and industrial enterprises, a decrease in watt losses for magnetization reversal was achieved (from 5 to 35%) for strips of transformer steels and nanocrystalline tapes made of magnetically soft materials (a patent was received).

A technology has been developed for multiply accelerated cold radiation annealing of sheets and profiles of industrial aluminum alloys (together with Kamensk Uralsky Metallurgical Works (KUMZ)) by beams of accelerated Ar^+ ions (E = 20-40 keV) for 5-30 s at 150-200 K temperatures, providing a 2-3-fold reduction in labor intensity and energy intensity of the process, instead of a long 2-6 hours of standard intermediate furnace annealing. There is a patent for the method of ion-beam processing and an act of approbation at JSC KUMZ with a recommendation to use the process as a breakthrough industrial technology.

It has been established that the irradiation of hot-pressed and aged profiles from alloys D16 (Al-Cu-Mg) and B95 (Al-Zn-Mg-Cu) for several seconds with small (10^{15}-10^{16} cm^{-2}) fluences of Ar^+ ions (E = 20 keV) increases their plasticity. At the same time, the resource during standard tests at loads of the order of $0.3\sigma_u$ (measured by the number of cycles before failure) increases for these alloys, respectively, by 2.4 and 5 times (from several hundred thousand to a million cycles and more).

Rapid (within a few seconds) processes of formation in alloys of phases depleted and multiply enriched in chemical elements during ion bombardment at temperatures much lower than the activation threshold for thermal diffusion have been discovered, which are of fundamental interest. The emerging near-equilibrium states cannot be obtained by any other means. This makes it possible to detect theoretically predicted as well as unknown low-temperature phases (which are "things in themselves") with unknown properties.

Based on the analysis of the emission spectra of targets made of Al, Fe, W, Zr, and other metals, for the first time, measured the temperatures of the above-mentioned thermal peaks and estimated the thermal pressures. The substantiation of a unified fractal structure of cascades of atomic displacements in a given target is given, regardless of the nature and energy of cascade-forming radiation, which is the basis for the legitimacy of simulation studies of the radiation resistance of reactor materials.