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METAL IONS IMPLANTATION IN RAPIDLY SOLIDIFIED ALUMINIUM ALLOYS

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Abstract. The influence of heavy ions (zinc, iron) implantation on the structure of two rapidly solidified aluminium alloys — Al-1 wt. % Cu and Al-1 wt. % Zn was investigated by means of transmission electron microscopy, X-ray analysis and magnetic thermoanalysis. All implantations were carried out with 60 keV ions at doses ranging from 1×10^{17} to 1×10^{18} cm^{-2}. Bombardment with Zn ions endamages mainly the θ-phase precipitate in Al-4 wt. % Cu alloy. Amassing of implanted Fe ions is observed in the near-to-surface region in the two examined alloys and an amorphous layer weakly transparent for the electron beam forms at doses greater than 8×10^{17} cm^{-2}.

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1. Introduction

Rapid quenching at rates of 10^5—10^7 K/s has generated different new materials ranging from metal glasses to microcrystalline alloys. These materials exhibit specific characteristics which cannot be obtained by conventional casting methods. One of these characteristics is the increased solubility of alloying elements and impurities. The implantation of metal ions which form substitutional solid solutions with the material of the target is another method for producing supersaturated solid solutions and new phases. The aim of the present work is to study the influence of metal ions implantation on the structure and phase-forming of rapidly solidified aluminium alloys. As far as we know there is no information concerning the ion implantation in rapidly solidified materials. Aluminium alloys were chosen because of their good radiation resistance and wide application in practice.

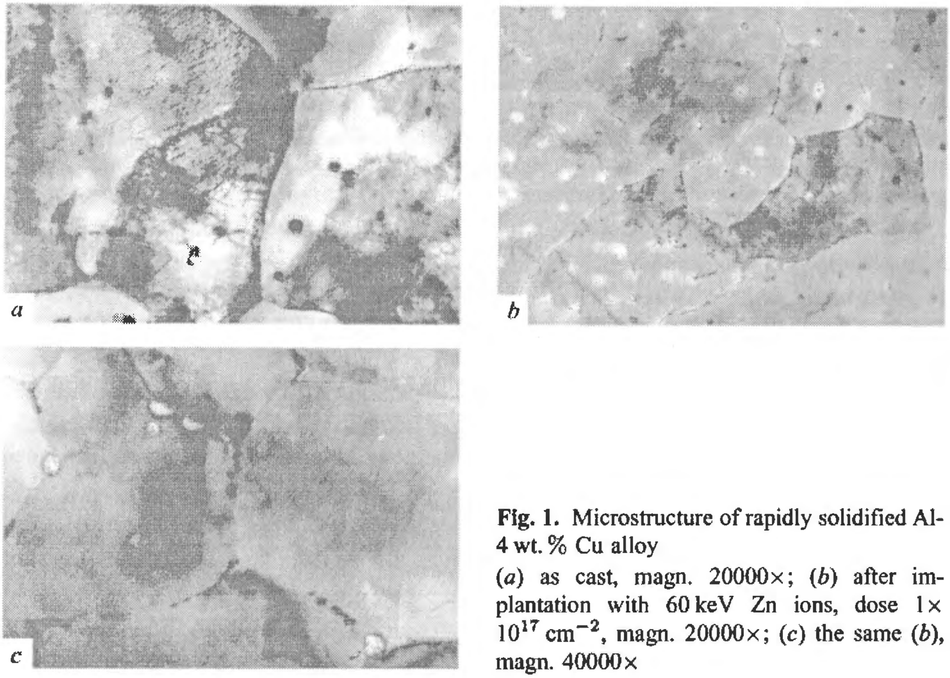

Fig. 1. Microstructure of rapidly solidified Al-4 wt. % Cu alloy
(*a*) as cast, magn. 20000×; (*b*) after implantation with 60 keV Zn ions, dose 1×10^{17} cm^{-2}, magn. 20000×; (*c*) the same (*b*), magn. 40000×

2. Experimental Procedures

Two aluminium alloys were studied; Al-4 wt. % Cu, 0.18 wt. % Fe, 0.09 wt. % Si and 0.02 wt. % Zn; and Al-1.05 wt. % Zn, 0.004 wt. % Fe. Rapidly solidified ribbons (with thickness 50 μm approx.) were prepared from the alloys using a melt-spinning apparatus described in [1]. Thin foils were cut mechanically from the ribbons and polished electrolytically for the transmission electron microscope (TEM) examination. Both the ribbons and the thin foils were implanted with 60 keV Fe ions at doses from 1×10^{17} cm^{-2} to 1×10^{18} cm^{-2} in ionic accelerator ILU-4 in the Institute of Nuclear Research and Nuclear Energy, Bulgarian Academy of Sciences under the conditions of mass separation. Samples from the Al-4 wt. % Cu alloy were implanted also with 60 keV Zn ions at a dose of 1×10^{17} cm^{-2}.

Transmission electron microscopy (JEOL-7A), X-ray analysis and thermomagnetic analysis were used for the examination of the structure of implanted materials.

3. Experimental Results and Discussion

Electron microscope observation of thin foils implanted with metal ions reveals a number of structural changes essentially different from those in the case of nitrogen ions implantation in which interstitial solid solutions are formed.

3.1. Implantation of Accelerated Zinc Ions

Typical structures of thin foils of Al-4 wt. % Cu alloy after implantation of zinc ions are shown in Fig. 1*b, c*. The structure prior to implantation of zinc ions is shown in Fig. 1*a*. The highest rate of erosion in result of the implantation is observed in areas containing θ-phase precipitate (Fig. 1*b*). At the applied close of implantation (1×10^{17} cm^{-2}) a beginning of β-phase (Zn-Al) formation occurs (see the grain in the right side of Fig. 1*c*).

From the ternary diagram Al-Cu-Zn [2] at temperature 350 °C one sees that the solubility of Cu in Al increases with increasing the Zn content, i. e. the solid solution range in binary Al-Cu system is extended. This fact partly explains the observed decomposition in θ-phase containing areas. On the other hand the θ-phase is expected to be strongly vulnerable to the accelerated heavy ions ($^{30}Zn_{65}$ in our case) impact due to its incoherent interface with the matrix. It could be supposed that a preliminary treatment including homogenization, quenching and initial ageing, aiming segregations of Guinier- Preston zones or θ-phase to be formed would enhance the erosion resistance of the examined alloy.

3.2. Implantation of Accelerated Iron Ions

3.2.1. *Al-4 wt. % Cu Alloy*

Figure 2 illustrates typical structures of implanted with 60 keV Fe ions Al-4 wt. % Cu alloy. Because of the very low solubility of iron in aluminium the implanted ions amass in the near-to-surface region. Erosion of implanted material in the grain boundary zone is observed after bombardment with accellerated ions at a dose of 8×10^{17} cm^{-2} (Fig. 2*a*). The θ-phase is undamaged in the major part and traces of erosion as well as amassing of iron ions are observed.

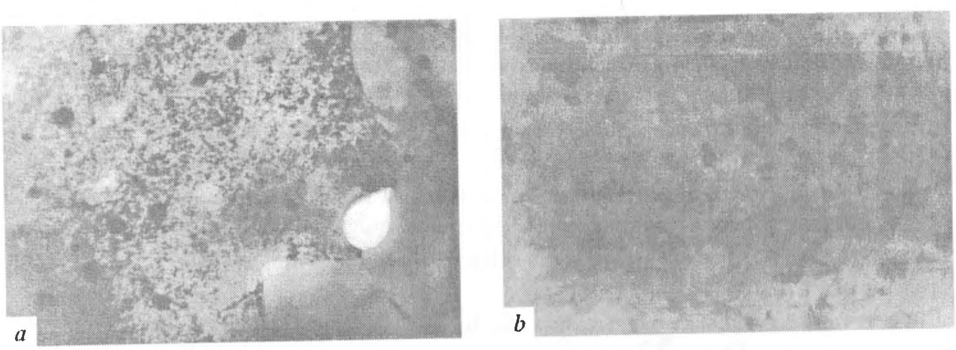

Fig. 2. Microstructure of rapidly solidified Al-4 wt. % Cu alloy after implantation with 60 keV Fe ions

(*a*) dose 1×10^{18} cm^{-2}, magn. 40000×; (*b*) dose 1×10^{18} cm^{-2}, magn. 100000×

In Fig. 2*b* the structure after implantation at a dose of 1×10^{18} cm^{-2} is shown. A layer which is weakly transparent for the electron beam is formed. The diffraction pattern indicates the presence of microcrystalline areas of α-Fe. However no diffraction maxima of iron were detected by the X-ray analysis carried out with Fe-K_α emission. The reason probably is the very small quantity of the crystalline phase — it is known that the X-ray analysis provides a possibility to identificate some phases only if the amount exceeds 5 %.

Another result from the X-ray analysis was that the intensities of aluminium lines of implanted material were weaker as compared with those prior to implantation, i. e. an absorption layer containing elements with an atomic number greater than Al does exist.

The intensities of 5 of the most intensive lines of X-ray phase diagram of aluminium are shown in Table 1.

Table 1. Intensities of 5 Al lines; I_0 — ptior to implantation, I — after implantation of 60 keV Fe ions at a dose of 1×10^{18} cm^{-2}

hkl	d (Å)	I_0 (rel. units)	I (rel. units)
111	2.33	190	90
200	2.02	98	45
220	1.43	76	50
311	1.219	108	65
222	1.168	30	15

Table 2. Calculared values of R_p, ΔR_p and C_i

Type of ions	R_p (nm)	ΔR_p (nm)	Dose (cm^{-2})	C_i
Fe	48	11	8×10^{17}	280
			1×10^{18}	350
Zn	44	10	1×10^{17}	38

By computer calculating using the TRIM programme [3] the projected range R_p and the standard deviation from the projected range ΔR_p were evaluated for the two kinds of implanted ions. Since both erosion of material and reflection of ions from the target occur, the real distribution curve differs from the Gaussian's in the region close to the implanted surface.

The values obtained for R_p and ΔR_p are listed in Table 2. These values are almost the same for the two kinds of ions implanted and are three times lower than those obtained for implantation of N ions [4]. In the same table the values of ratio C_i representing the number of implanted ions/100 Al atoms, calculated for a layer close to the implanted surface with a thickness equal to the projected range are also shown.

The calculations show that when the dose of implantation is greater than 3×10^{17} cm^{-2} the ratio C_i surpasses 1:1. Taking into account the TEM micrographs and the calculated values of C_i it seems very likely that the predominating part of the implanted at a dose of 8×10^{17} cm^{-2} Fe ions form clusters of Fe_3Al (the particles with a diameter of 25 nm approx., Fig. 2*a*). At a dose of 1×10^{18} cm^{-2} C_i surpasses 3:1 and a formation of α-Fe crystallites with diameter 100 nm approx. begins (Fig. 2*b*).

3.2.2. *Al-1 wt. % Zn Alloy*

The Al-1 wt. % Zn alloy may be considered as a model of a homogenous solid solution which does not differ from pure aluminium by its structure. Typical structures of implanted with 60 keV Fe ions foils are shown in Fig. 3*b, c*. The as-cast structure is shown in Fig. 3*a*. Micrograins (with size 2.5 μm and traces of dislocations exits are observed prior to implantation. After implantation at a dose of 8×10^{17} cm^{-2} traces of erosion as well as amassing of iron ions are observed (Fig. 3*b*). After implantation at a dose of 1×10^{18} cm^{-2} the layer of implanted iron ions strongly masks the structure of the aluminium target; nevertheless a lot of particles with a size of 100–200 nm are observed, probably α-Fe crystallites (Fig. 3*c*).

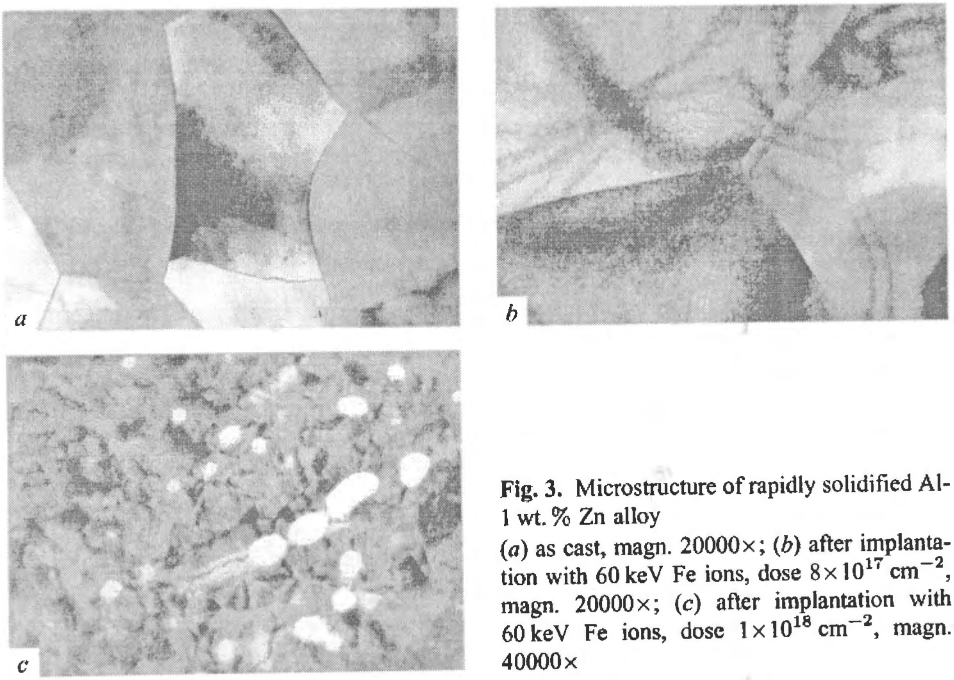

Fig. 3. Microstructure of rapidly solidified Al-1 wt. % Zn alloy
(*a*) as cast, magn. 20000×; (*b*) after implantation with 60 keV Fe ions, dose 8×10^{17} cm^{-2}, magn. 20000×; (*c*) after implantation with 60 keV Fe ions, dose 1×10^{18} cm^{-2}, magn. 40000×

Thermomagnetic analysis was carried out in order to determine the temperature dependence of magnetization of rapidly solidified Al-1 wt. % Zn alloy prior to and after implantation of Fe ions. Magnetic characteristics provide useful information in the case of dilute solid solutions with very small concentration of magnetic atoms. Experimental results are shown in Fig. 4. Although the implantation affects mainly about 5 μm of the thickness of the ribbon (thick about 50 μm), a large increase of magnetization is observed after implantation.

While the non-implanted sample exhibits a temperature dependence typical for paramagnetic, a quasi ferromagnetic state (due to indirect exchange mechanism involving conductivity electrons of matrix rather than direct exchange between long distant magnetic atoms [5] with a Curie temperature about 540 °C arises after implantation of Fe ions at a dose of 8×10^{17} cm^{-2}. The temperature of magnetic change is corresponding to the composition of Fe_3Al [6].

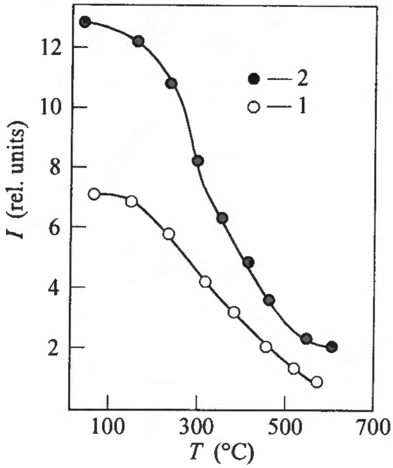

Fig. 4. Temperature dependence of magnetization of rapidly solidified Al-1 wt. % Zn alloy
(*1*) as cast; (*2*) after implantation with 60 keV Fe ions, dose 8×10^{17} cm^{-2}

4. Conclusions

Implantation of accelerated ions of Zn (with good solubility in Al) in rapidly solidified Al-4 wt. % Cu alloy provokes erosion of implanted material and decomposition of yet existing phase Al_2Cu.

Implantation of Fe ions at doses of 8×10^{17} cm^{-2} and 1×10^{18} cm^{-2} gives rise to formation of an amorphous layer to the surface in the two examined rapidly solidified aluminium alloys. On the basis of thermomagnetic analysis it can be assumed that, most likely, a solid solution zone with approximative composition Fe_3Al is the formed in interface of this layer and the aluminium matrix.

Acknowledgements

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