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POSITRON ANNIHILATION IN γ-IRRADIATED AMORPHOUS IRON ALLOYS

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One-dimensional angular correlation of annihilation radiation was measured in a series of amorphous $(Fe_{100-x}Cr_x)_{85}B_{15}$ alloys ($x = 0$–32) exposed to γ-irradiation from intensive ^{60}Co source. The relevant shape parameters were compared with those in non-irradiated alloys. Irradiation-induced changes of those parameters were found to depend on Cr contents x. The opposite signs of these changes were observed in $x < 4$ and $x > 4$ ranges, while near $x = 4$ the parameters stayed unchanged. We try to interpret the results assuming that γ-quanta are able to knock out boron atoms from their positions into large cavities, thus preventing positron trapping. The crystalline embryos model of amorphous alloys suggested by Hamada and Fujita is also used for explanation of the observed effects.

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1. Introduction

One of the main applications of positron spectroscopy in solid state physics is the diagnostics of structural imperfections, which is based on the phenomenon of positron trapping at the open volume defects [1]. In crystalline solids the positrons are trapped by such defects as vacancies, their agglomerations and dislocation cores [1]. The nature of positron traps in amorphous alloys (AA) remains still questionable. Nevertheless, the positrons in AAs are established to annihilate from the trapped state [2], the trap sizes being less than in respective crystalline materials. For instance, Bernal holes in the close packed hard spheres model might serve as positron traps [3]. As the positron binding energy with a trap in AA does not exceed 0.4 eV, the traps are considered to be shallow. The motion of the thermalised positron is then represented by a sequence of jumps between the traps. Such mechanism leads to a considerable shortening of positron diffusion length [4].

Electron irradiation of AAs at low temperatures results in creation of vacancy-like defects giving rise to positron lifetime [2]. However, these defects are unstable and disappear completely even below room temperature.

In the previous paper [5] we observed the changes of annihilation parameters in consequence of alloying of $Fe_{85}B_{15}$ AA with Cr, which were attributed to the variation of positron traps characteristics. This paper aims at elucidating whether γ-irradiation has any influence on the positron traps in $Fe_{85}B_{15}$ AA and whether this effect, if any, depends on the Cr contents.

2. Experimental

The strips of $(Fe_{100-x}Cr_x)_{85}B_{15}$ AAs ($x = 0, 1, 2, 4, 10, 21, 32$), 30 μm thick, were prepared by melt-quenching onto the cooled rotating copper disc. γ-irradiation was carried out at 325 K by means of ^{60}Co source up to 2.58×10^5 C/kg exposure dose. The samples were composed of 5 layers in order to provide full absorption of positrons.

Using conventional long-slit device with 0.7 mrad angular resolution, the angular correlations of annihilation radiation (ACAR) were measured at room temperature in a range of angles -25 to $+35$ mrad. Accumulation of coincident events exceeded 10^4 in the peak of ACAR.

After subtracting background ACARs are decomposed into inverted parabolic and Gaussian components resulting from positron annihilation with conduction and core electrons, respectively. For analysis of ACAR shape two parameters are taken. One of them, W_p, is a relative contribution of parabolic component to the full ACAR. If positrons are trapped at defects, W_p is known to increase [6]. The larger is the defect size, the greater is an increase in W_p. Another analysed parameter, r_m, stands for a distance from ion position, at which the product of positron and core electrons wave functions is maximum. This parameter is determined from a standard deviation of Gaussian σ, by means of relation $r_m = 0.47/\sigma$, where r_m is obtained in nm if σ is expressed in mrad. In crystalline metals and alloys r_m was found to rise if positron got trapped at defect [7].

3. Results

In Fig. 1 the reduced changes, $\Delta W_p/W_p$ and $\Delta r_m/r_m$, of W_p and r_m parameters due to γ-irradiation of the studied AAs are shown as a function of Cr contents. One can see that both $\Delta W_p/W_p$ and $\Delta r_m/r_m$ vanish near $x = 4$, i.e., in this concentration region γ-irradiation does not cause any effect on the ACAR shape. At lower x, $\Delta W_p/W_p$ becomes negative while $\Delta r_m/r_m$ is getting positive. In AAs with $x > 4$ the opposite effects are revealed.

The obtained results seem to be somewhat unexpected, at least, in two respects. Firstly, so large changes of the ACAR parameters after γ-irradiation at room temperature are inconsistent with the results on electron and neutron irradiation of the AAs [2]. Secondly, the opposite changes of W_p and r_m are uncommon in crystalline materials, in which positron localization at defects results in an increase in both W_p and r_m.

Another feature of the obtained results is the change of the sign of γ-irradiation effect on the annihilation parameters near $x = 4$. Such behaviour could be expected if it is caused by, at least, two different processes which alter the characteristics of positron traps and compete one another.

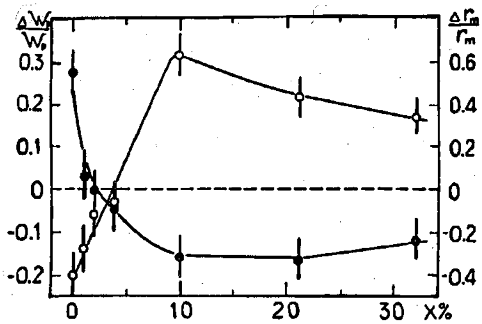

Fig. 1. The reduced changes of ACAR parameters, W_p (open circles) and r_m (full circles), in γ-irradiated amorphous alloys $(Fe_{100-x}Cr_x)_{85}B_{15}$ as a function of Cr contents x. The curves are guides to an eye.

4. Discussion

Attempting to interpret these surprising results we accept the following assumptions. According to [2], all positrons are suggested to annihilate from the trapped state. The size and environment of a trap depend on both the Cr content and the irradiation.

The structure of AA is adopted to be described by a version of quasi-crystalline model formulated by T. Hamada and F. Fujita [8]. In this version the AA is suggested to consist of randomly oriented crystalline "embryos" embedded into an amorphous matrix through the boundary layers between "embryos" and matrix. In this structure such cavities as Bernal holes in amorphous matrix, dilated regions in boundary layers, as well as the defects in crystalline "embryos", can serve as positron traps. Trapping of positrons by fluctuations enriched with Cr atoms is hardly expected, as the positron affinity to the Cr atoms is less than to Fe ones [9].

Since we are interested in the influence of irradiation on the ACAR parameters, let us consider how the traps configuration can be affected by γ-quanta.

There is a set of positron traps having different configuration in AAs. Their efficiency depends on the size. During γ-irradiation some atoms in AA may be knocked out of their positions and occupy one of the neighbouring cavities. The most probable candidates for such transfer are light boron atoms. The migration of B atoms under the action of γ-irradiation was really detected in amorphous $(FeCo)_{85}B_{15}$ by means of NMR technique [10]. This forces us to think that lowering of W_p in $Fe_{85}B_{15}$ after γ-irradiation may be caused by partial passivation of positron traps in amorphous phase owing to their filling up with B atoms.

Addition of Cr to $Fe_{85}B_{15}$ results in a decrease in passivation effect (see Fig. 1). In order to explain this behaviour one may take into account that if AA of metal–metalloid type is doped with another transition metal having atomic number less than that of basic metal, the amorphous state turns out to become more stable. This stabilization is suggested to be caused by strengthening of metal–metalloid bonds formed by overlapping of *sp* hybrid orbitals of metalloid atoms with *sd* orbitals of transition element owing to the reduction of *d*-electron concentration [11]. More tight binding of B atoms, originating from addition of Cr, should decrease the probability of knocking out B atoms into cavities and, consequently, bring down the passivation effect observed in $Fe_{85}B_{15}$. Obviously, the change of W_p initiated by irradiation approaches zero, if the passivation effect is completely suppressed.

At the same time one must assume the existence of another mechanism, which provides the creation of new positron traps and is responsible for the rise of W_p and, consequently, for the positive sign of $\Delta W_p/W_p$ at $x > 4$. One of such mechanisms might be irradiation-initiated disordering. However, amorphous matrix is initially extremely disordered. Therefore, disordering effect could be expected in crystalline "embryos" and, partially, in boundary layers. Disordering creates the dilated regions, which can be considered to trap positrons. Strengthening of interatomic bonds due to alloying with Cr must diminish the irradiation-initiated disordering, thus reducing the concentration of traps. This may be the reason for reduction of $\Delta W_p/W_p$ at $x > 10$.

The combined action of two above mentioned mechanisms makes it possible to explain qualitatively the behaviour of $\Delta W_p/W_p$ shown in Fig. 1. Stabilising effect of Cr impedes both the passivation of traps in amorphous phase and the formation of new ones in crystalline "embryos".

Turning to the behaviour of $\Delta r_m/r_m$ in Fig. 1, let us recall that r_m parameter depends on the size and elemental environment of positron traps, but is not affected by their concentration. According to [8], r_m in Fe is less than that in Cr. Extrapolation of the data of Ref. [8] shows that r_m for boron ions should also be larger than that in Fe. If the traps in amorphous matrix of $Fe_{85}B_{15}$ are enriched with B atoms due to irradiation-initiated motion of the last, r_m is expected to increase and $\Delta r_m/r_m$ turns out to be positive. An assumption that alloying with Cr leads to a decrease in irradiation-initiated motion of B atoms allows to explain the reduction of r_m with increase in x.

In order to interpret the negative sign of $\Delta r_m/r_m$ at large x we have to suppose that the new traps formed in crystalline "embryos" of $Fe_{85}B_{15}$ by irradiation are surrounded mainly with iron atoms having small r_m. An increase in x may result in slight rise of r_m because of appearance of Cr atoms with higher r_m in the neighbourhood of traps. The competition of processes in amorphous matrix and "embryos" may explain qualitatively both the positive and negative signs of r_m.

In conclusion we tried to consider the observed changes in the ACAR shape of AAs $(FeCr)_{85}B_{15}$ after γ-irradiation in terms of evolution of positron traps configuration. We realise that the explanations involved are not the only ones and, perhaps, not the best ones, since the nature of suggested processes remains unclear. Further experiments are needed to ascertain if these explanations are valid and to avoid some contradictions in the scheme drawn.

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