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POSITRON LIFETIME MEASUREMENTS ON ELECTRON IRRADIATED AMORPHOUS ALLOYS

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INTRODUCTION

Great advance in understanding the nature of point defects in crystalline metals has been achieved by employing positron annihilation technique. Positrons detect vacancy-type defects already at the concentrations of a few ppm and the lifetime value of trapped positrons gives information on the size of submicroscopic vacancy agglomerates and microvoids (1). However, annihilation characteristics in various amorphous alloys have been observed to be rather insensitive to the physical state of the alloys. Room temperature electron irradiations (2,3) and deformations (4,5) have been reported to cause almost no changes in the positron parameters. Even the crystallization seems to reduce only slightly the positron lifetime values in the alloys (3,9). In this paper we show that low-temperature electron irradiations can result in a considerable increase in the positron lifetimes in various amorphous alloys because of the formation of vacancy-like defects which, in addition of the pre-existing holes, are able to trap positrons.

EXPERIMENTAL

Studied amorphous alloys were $Fe_{80}B_{20}$, $Pd_{80}Si_{20}$ and $Cu_{50}Ti_{50}$ prepared by melt-spinning technique, and $Fe_{40}Ni_{40}P_{14}B_6$ obtained from Allied Chemical Company. Before experiments the amorphous structure of the specimens was verified by X-ray measurements. Electron irradiations were performed with 3 MeV electrons at 20 K under liquid hydrogen to doses around 10^{19} e^-/cm^2. For positron studies three identical pieces of the irradiated specimens with dimensions 50 μm x 7 mm x 10 mm were put on both side of a 10 μCi Na^{22} positron source. Isochronal annealings of 30 minutes between 77 K and 300 K were made under vacuum. After each heat treatment positron lifetime spectra were measured at 77 K by using an ordinary fast-slow coincidence system with a time resolution of 280 psec (FWHM) in experimental conditions. After source-background substractions the spectra were analyzed with one exponential decay component.

RESULTS AND DISCUSSION

Positron lifetime results in non-irradiated specimens are seen in Table 1. In all cases the measured spectra were characterized by using only one exponential decay component and attempts to fit them with two lifetimes were unsuccessful. However, we want to point out that this does not strictly mean the existence of only one specific positron lifetime in an amorphous alloy. As well there might be several of them which are so close (typically ± 20 ps) to each other that they can not be separated in computer analysis. In this case, the measured positron lifetime values represent the average of the different components. Anyhow, Table 1 shows that in the as-recieved state of the alloys the obtained positron life-

Table 1 : Positron lifetimes in as-recieved and electron irradiated $Fe_{80}B_{20}$, $Pd_{80}Si_{20}$, $Cu_{50}Ti_{50}$ and $Fe_{40}Ni_{40}P_{14}B_6$ alloys. For comparison, characteristic lifetime values in metallic components of the alloys are also shown.

	τ(psec)	τ(psec)
Amorphous	as-recieved	as-irradiated
$Fe_{80}B_{20}$	142 ± 1	157 ± 1
$Pd_{80}Si_{20}$	155 ± 1	162 ± 1
$Cu_{50}Ti_{50}$	159 ± 1	176 ± 1
$Fe_{40}Ni_{40}P_{14}B_6$	147 ± 2	157 ± 2
Crystal	bulk	vacancy
Fe (ref. 10)	110	171
Ni (ref. 11)	110	180
Pd (ref. 12)	118	-
Cu (ref. 13)	122	180
Ti (present work)	152	222

time values are clearly higher than the bulk values for the crystalline metallic constituents of the alloys, but still lower than the lifetimes at monovacancies of these metals. In the case of $Fe_{80}B_{20}$ and $Fe_{40}Ni_{40}P_{14}B_6$ it further turned out that heat treatments of the alloys below the crystallization temperature change the lifetime values less than 2 psec. When the specimens were crystallized (30 min at T_c + 20°C) we saw a small decrease of about 5 psec, but even after the crystallization the lifetime level seemed to be still well above the values measured in carefully annealed pure metals. These observations are in a good agreement with e.g. the earlier positron lifetime results on $Fe_{40}Ni_{40}P_{14}B_6$ reported by Howell and Hopper (5) and Mihara et al (9). In fact, the high positron lifetime level in the as-crystallized states of the alloys is not surprising since these states are strongly heterogeneous containing high concentration of defects like dislocations, grain boundaries, structural vacancies etc., which are known to be effective traps for positrons and cause an increase in the positron lifetime. Altogether, the obtained results suggest that in the amorphous state all positrons are trapped by some quenched in cavities the effective size of which is less than one atomic volume. This kind of ideas have been previously presented also by Kajcsos et al (14) and by Cartier et al (15).

Clear changes in position lifetime spectra were found due to the low-temperature electron irradiations in all studied amorphous alloys. However, the spectra were again well-characterized by using only one decay component, but again, as discussed earlier in the case of the as-recieved state, one must keep in mind the limitations of the computer analysis to separate close lifetimes from each other. The obtained positron lifetime values are shown in Table 1. A clear increase in τ is seen. In fact, the positron lifetimes in the as-irradiated alloys are rather close to the monovacancy values also shown in Table 1. The observed increase of the positron lifetime directly indicates that low temperature electron irradiations produce such defects in amorphous alloys which can trap positrons. Further, the average size of these vacancy-type defects seems to be near one atomic volume, i.e. they are bigger than the pre-existing holes. Anyhow, the total change in τ is not as pronounced as observed in crystalline metals after identical electron irradiations. It has also been shown that, compared to crystalline metals, electron doses which are one order of magnitude higher are needed to saturate the position lifetime in amorphous metals (16). Two factors can be given. Firstly a considerable amount of positrons is always trapped by the pre-existing holes so that there exists a competition between positron trapping into these holes and into the irradiation induced defects. This results in the fact that only a part of the defects are detected by positrons. The second factor is the lack of channeling and focussing phenomena in amorphous materials. The atoms deplaced by electron collisions can not move far from their original sites. Therefore it can be imagined that the damage structure is very unstable and thus the number of defects still exis-

ting at 77 K is smaller than in crystalline metals.

Fig. 1 represents the recovery behaviour of the positron lifetime in the four electron irradiated alloys. It is seen that τ decreases continuously between 77 K and 300 K. No clear stages typical for crystalline metals are observed. This means that the stability of the vacancy-like defects created by irradiation is widely dispersed in metallic glasses. Fig. 1 shows that values very near those measured in the non-irradiated specimens were detected after heat treatments at about 300 K. It indicates that practically all vacancy-type defects anneal out below room temperature and also explains why only faint changes in positron parameters have been detected in previous studies of electron irradiated amorphous metals (2,3). It is also interesting to notice that, on the contrary to pure iron where positron annihilation studies have revealed the clustering of vacancies at around 220 K (10), no sign of the formation of any big cavities could be seen during the recovery of the irradiation induced defects in any studied amorphous alloys.

Additional information on the recovery behaviour of the radiation damage in iron based amorphous alloys has been recently obtained by magnetic after-effect measurements (16). It has been shown that the defects anneal out very quickly. Between 77 K and 300 K the mean number of reorientation jumps before defect annealing was never detected to higher than ten. This means that no long range migration of the irradiation induced defects can take place in amorphous alloys.

A possible model which explains all observed irradiation effects in metallic glasses is the following. The colliding particle opens a new cavity, the size of which is distributed from zero to one atomic volume. For this cavity ("vacancy") we have to assume an antidefect ("interstitial") which is made of a compressed zone in the neighbourhood of the cavity. This induces a high local stress making the defect unstable and, when the temperature is

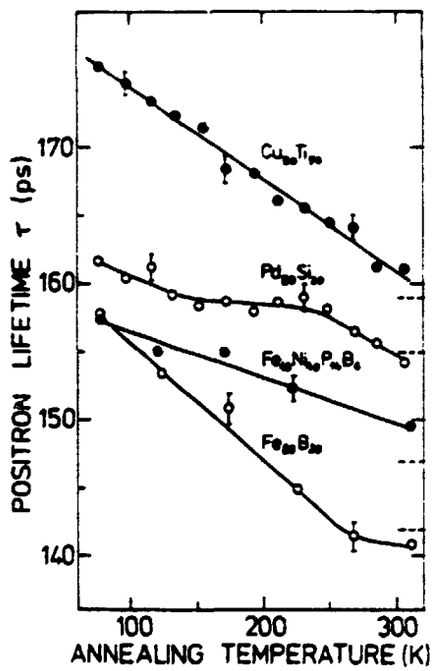

Fig. 1. Positron lifetime as a function of isochronal annealing temperature in various amorphous alloys electron irradiated at 20 K. Dotted lines in the right margin of the figure represent positron lifetime values in the as-recieved state of the corresponding alloys.

high enough, after a few oscillations the cavity collapses. The continuous decrease in the positron lifetime between 77-300 K can be understood e.g. so that the biggest cavities are most unstable and thus anneal out first. It will be interesting to see by further experiments, whether it is possible to observe below 77 K still longer positron lifetimes indicating bigger irradiation-induced cavities. Some hints to this direction are given by the recovery behaviour observed in the present work : in all studied alloys the positron lifetime seems to decrease already after the first heat treatments.

CONCLUSIONS

We conclude that in the as-recieved specimens all positrons are trapped by some quenched-in cavities, the average size of which is less than one atomic volume. Additional vacancy-like defects are created by low-temperature electron irradiations. These defects being of one atomic size are bigger than the pre-existing holes. They recover continuously between 77 K and 300 K so that above room temperature there exist practically no radiation induced vacancy-like defects.

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