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Positron Lifetime Measurements on Electron Irradiation Damage in Amorphous $Pd_{80}Si_{20}$ and $Cu_{50}Ti_{50}$ Alloys

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Abstract. Positron lifetime measurements were performed on amorphous $Pd_{80}Si_{20}$ and $Cu_{50}Ti_{50}$ alloys irradiated with 3 MeV electrons at 20 K. The irradiation was found to increase the mean positron lifetime in both specimens indicating the presence of vacancy-like radiation damage. Isochronal annealing between 77 K and 300 K resulted in a continuous reduction of the positron lifetime, which suggests a gradual recovery of the irradiation induced defects.

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For the present, the only existing positron studies of electron irradiation amorphous metals are those performed by Chen [1] in Pd–Cu–Si and by Chuang et al. [2] in Pd–Ni–Si. Neither of these two works showed any considerable changes in positron parameters due to irradiations at room temperature. Further, annihilation characteristics in amorphous alloys have been observed to be rather unaffected by cold-working [3, 4]. Thus, there seems to be no evidence of positron localization in defects created in glassy metals by room temperature treatments. Instead, significant positron trapping by pre-existing vacancy-like defects has recently been seen in a variety of binary metallic glasses [5–8]. In this paper we report positron annihilation studies on amorphous alloys electron irradiated at low temperatures where at least a part of the induced damage should be frozen in. Consequently, a clear increase in the positron lifetime is seen due to positron localization in defects produced by irradiation.

The studied glassy metals were a metal-metalloid alloy of $Pd_{80}Si_{20}$ and a metal-metal alloy of $Cu_{50}Ti_{50}$ prepared by a melt-spinning technique. The amorphous structure of the ribbons of about 50 μm in thickness was verified by an x-ray diffractometer. The ribbons were then cut into pieces of dimensions 7 mm × 10 mm suitable for the positron examinations. The as-received specimens were irradiated with 3 MeV electrons under liquid hydrogen up to a total dose of about $2 \times 10^{19}\,e^-/cm^2$. For the positron studies three identical pieces were then placed on both side of a 10 μCi positron source made by evaporating carrier-free $^{22}NaCl$ solution onto a thin (1.1 mg/cm²) nickel foil. This set of six samples and a source was finally mounted into a holder which allowed heat treatments between 77 and 320 K and measurements at liquid nitrogen temperature. Isochronal annealing was performed under vacuum in steps of 20 K, each of which lasted 30 min. Positron lifetime was measured by using a conventional fast-slow coincidence system with a time resolution of 280 ps (FWHM). After source-background subtractions the obtained lifetime spectra were analyzed with both one and two exponential decay components in order to verify whether it is possible or not to separate a distinct lifetime for positrons localized by defects in glassy metals.

Positron lifetime spectra of the as-received samples proved to contain only one decay component, namely 155 ± 1 ps in $Pd_{80}Si_{20}$ and 159 ± 1 ps in $Cu_{50}Ti_{50}$. Recently, considerable positron trapping by quenched-in cavities has been reported to occur in many binary metallic glasses, including also $Pd_{80}Si_{20}$ [5–8]. We see this effect in our samples, too, since the measured

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Table 1. Positron lifetime values in the as-received and electron-irradiated $Pd_{80}Si_{20}$ and $Cu_{50}Ti_{50}$ alloys. For comparison, characteristic lifetime values in metallic components of the alloys are also shown

	τ [ps]	τ [ps]
Amorphous	as-received	as-irradiated
$Pd_{80}Si_{20}$	155±1	162±1
$Cu_{50}Ti_{50}$	159±1	176±
Crystal	Bulk	Vacancy
Pd[a]	118	–
Cu[b]	122	180
Ti	152	222

[a] Values are taken from [5]
[b] Values are taken from [10]

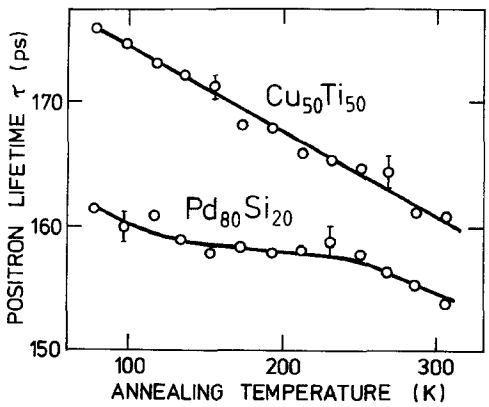

Fig. 1. Positron lifetime τ as a function of isochronal annealing temperature in electron irradiated amorphous alloys of $Pd_{80}Si_{20}$ and $Cu_{50}Ti_{50}$

lifetime values are somewhat larger than expected on the basis of positron lifetimes in the pure constituents of the alloys (Table 1). This increase of τ being of the order of 30 ps cannot originate from the density differences between the amorphous and crystalline materials. The existence of only one positron lifetime component, which is shorter than typically measured in metal vacancies, thus leads to the conclusion that in the as-received state of the studied amorphous alloys all positrons are trapped by holes which, on the average, are smaller than vacancies in crystalline metals. It is also interesting that hydrogen absorption seems to have no effect on the positron lifetime in amorphous $Pd_{80}Si_{80}$. Practically the same lifetime values were detected whether the measurements at room temperature were performed either under vacuum or under hydrogen atmosphere. Instead, a clear difference in the resistivity of the samples can be seen [9].

Clear changes in positron lifetime spectra were found due to the electron irradiation in both amorphous specimens. However, the measured spectra were again well characterized by only one exponential decay component; no separate lifetimes could be distinguished. Table 1 shows the results of our one-component analysis both in the as-received and as-irradiated state of the alloys. It is seen that the increase of the mean positron lifetime τ is unambiguous being 7 ps in $Pd_{80}Si_{20}$ and 17 ps in $Cu_{50}Ti_{50}$. Isochronal annealing between 77 and 300 K gradually restored the positron lifetime. Values very near those measured in the unirradiated samples were detected after room temperature treatments, as seen in Fig. 1 where the two recovery curves are presented.

These observations indicate that low-temperature electron irradiations can produce such defects in amorphous alloys, which are able to localize positrons. The increase of the positron lifetime τ suggests that the average size of these vacancy-like defects is larger than that of the pre-existing holes. However, the change in τ is not as pronounced as in crystalline metals after identical electron irradiations. Two factors can be given. Firstly, the lack of the channeling and focusing effects in amorphous materials results in the fact that atoms deplaced by electron collisions can not move far from their original sites. Thus the structure can easily be restored by thermal activation. Therefore the number of defects still existing at 77 K is less than in corresponding crystalline metals. This idea is supported by the observed recovery behaviour: τ decreases continuously starting already after the first heat treatments. The second factor is that, all the time, considerable amount of positrons are trapped by the pre-existing holes, and defects induced by irradiation fail to be noticed.

The gradual recovery of the positron lifetime between 77 and 300 K agrees well with previous resistivity studies of damaged amorphous alloys. Recently, for example, Schumacher et al. [11] have studied $Pd_{80}Si_{20}$ after high-energy Ag-ion irradiation. They found a smooth recovery throughout the examined temperature range up to 400 K. A continuous change of the resistivity has also been observed in electron-irradiated $Cu_{50}Ti_{50}$ but this effect seems to be sample dependent [9]. Further, a similar gradual annealing behaviour of the positron lifetime was also observed in our more recent studies of electron-irradiated amorphous $Fe_{80}B_{20}$ and $Fe_{40}Ni_{40}P_{14}B_6$ alloys [8]. The results thus indicate that the stability of the open cavities created by radiation is widely dispersed in metallic glasses. It is also seen that practically all irradiation-induced vacancy-like defects seem to anneal out below room temperature. This explains why only negligible changes in positron parameters have been seen in previous studies of electron-irradiated amorphous alloys [1, 2].

If the behaviours of the positron lifetime in the two alloys are compared with each other, the principal features are found to be the same. The only remarkable difference is that, in spite of the same electron dose, the irradiation-induced lifetime increase in $Cu_{50}Ti_{50}$ seems to be clearly larger than that in $Pd_{80}Si_{20}$. However, further experiments would be needed to answer the question whether this is a characteristic difference between metal-metal and metal-metalloid systems.

In conclusion, we have shown that low-temperature electron irradiation produces vacancy-like defects capable to localize positrons in amorphous $Pd_{80}Si_{20}$ and $Cu_{50}Ti_{50}$. The defects anneal out gradually between 77 and 300 K, and above room temperature practically no marks of radiation damage are observed.

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