Positron Annihilation Measurements In Deformed Iron

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SUMMARY

Positron annihilation lineshape measurements are performed on deformed iron. The samples used are pure iron (MARZ grade from MRC) and commercial ARMCO iron. Samples from both lots were deformed to thickness reductions of 60 % and 5 %. Isothermal annealing at room temperature showed that in pure iron the lineshape parameter remained constant, while in the commercial ARMCO iron an annealing effect was measured. This indicates that positron traps become inefficient when enough impurities are present.

ÖZET

Deforme demirde pozitron annihilasyon hat şekli ölçümleri yapıldı. (MRC den MARZ derecesi) saf demiri ve ticari ARMCO demiri nümuneleri kulanıldı. Her iki çeşitten parçalar % 60 ve % 5 nisbetinde kalınlık azaltılmakla deforme edildi. Oda sıcaklığında izotermal tavlama sonucu, ticari ARMCO demirinde bir tavlama tesiri ölçülürken saf demirde hat şekli parametresi sabit kaldı. Bu gösteriyor ki yeterli impurite bulunması halinde pozitron tuzakları yetersiz hale gelir.

INTRODUCTION

When positrons from a radioactive source such as ^{22}Na are injected into a material, they are very quickly slowed down to thermal velocities. The thermalized positron diffuses through the lattice until it annihilates with an electron of the material, emitting two 511 keV gamma rays. The thermalization time is of the order of a few picoseconds and is much smaller than the lifetime of the positron in a solid which is of the order of a few hundred picoseconds. There are three basic techniques for doing positron annihilation research, i.e. lifetime measurements, angular cor-

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relation measurements and Dopplerbroadening measurements. The lifetime of the positron is determined by the electron density at the position of the positron. Angular correlation curves and lineshape measurements are determined by the distribution of linear momenta of the electron with which the positron annihilates. Since the positron itself is thermalized, the linear momentum of the positron-electron pair at the instant of annihilation is determined by the momentum of the electron.

EXPERIMENTAL PROCEDURE

The principle for performing Doppler broadening measurements (1) is given in figure 1. The component of the linear momentum in the direction source-detector causes a Doppler shift of the measured energy of the annihilation gamma's. The energy of the two annihilation quanta is given by:

$$E_{1,2} = m_0c^2 \pm p_x c/2$$

In order to characterize the lineshape, a lineshape parameter or so called

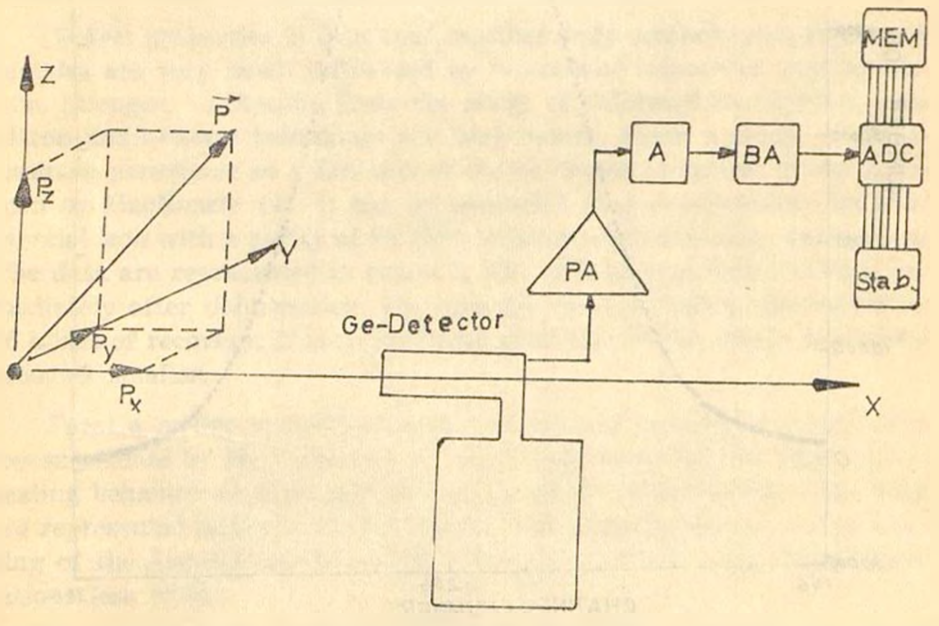

Figure 1. The principle for performing Doppler broadening measurements of the 511 keV annihilation line.
(PA: preamplifier, A: amplifier, BA: bias-amplifier, MEM: memory, ADC: analog-to-digital convertor, Stab: stabilizator).

S-parameter is defined. This is the ratio of the content of a central integration window, to the total number of counts ($S=n_1/N$). When the annihilation line becomes narrower, the S-parameter increases (3).

Positrons can be localized by defects with a suitable attractive potential. Defects with which the positron can form a bound state are va-

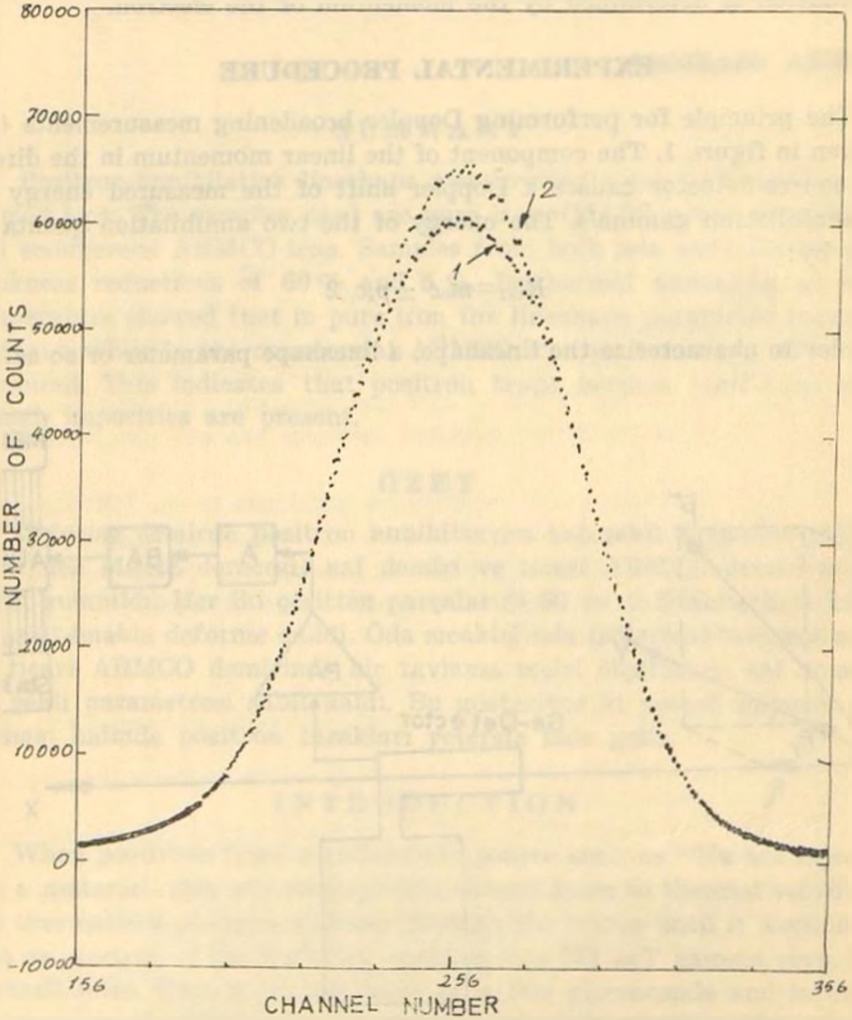

Figure 2. The positron annihilation lineshape for aluminium.
(1) Lineshape for the annealed aluminium.
(2) Lineshape for the strongly deformed (%64) aluminium.

cancies, vacancy-agglomerates and dislocations. Since the electron density and the momentum distribution of the electrons seen by a localized positron, is different from the electron density and the momentum distribution seen by a delocalized or free positron, effects of trapping on the lifetime, on the angular correlation curve and on the lineshape of the 511 keV annihilation line can be seen.

When a metal is deformed, mainly dislocations are introduced. Beside those defects, also vacancies and interstitials are formed.

The effect of deformation on the lineshape of the 511 keV line for aluminium is illustrated in figure 2. The two 511 keV lines are normalized to the same area. Lineshape 1 is for the annealed aluminium and lineshape 2 is for the strongly deformed ($D/D_0 = 64\ \%$) aluminium. As can be seen for deformed metals, a narrower lineshape is measured This means that the lineshape parameter for deformed materials (with defects) is higher than for annealed materials (5).

RESULTS AND DISCUSSION

Defect properties in iron (and in other body centred cubic refractory metals) are very much influenced by interstitial impurities such as carbon, nitrogen, ... Results from the study of deformed iron with the positron annihilation techniques are very scarce. From a study of the lineshape parameter as a function of the thickness reduction of the specimen by MacKenzie (4), it can be concluded that in «Ferrovac E» commercial iron with a purity of 99.97 % an isothermal annealing takes place. The data are represented in figure 3. The dots are the data obtained immediately after deformation. The squares are the results obtained after 36 hours of recovery. It is noticed that after 36h the lineshape parameter becomes smaller.

From a recovery study of deformed iron with positron annihilation measurements by Hautojärvi et al. (2), it can be concluded that the annealing behavior depends slightly on the purity of the sample. The data are represented in figure 4. The results can be explained by partial blocking of the dislocations by carbon impurities, which makes those dislocations less mobile.

In order to have a clearer insight into the influence of the purity of the iron samples on positron annihilation results, iron specimens of different purity were investigated. The iron used was on the one hand commercial Armco iron with a purity of 99.86 % and on the other hand MARZ grade iron (this is iron characterized by Masspectrometer Analysis, Residual resistivity ratio measurements = $R(298°K)/R(4.2°K)$, and Zone refined in high vacuum) with a purity of 99.995 % from MRC

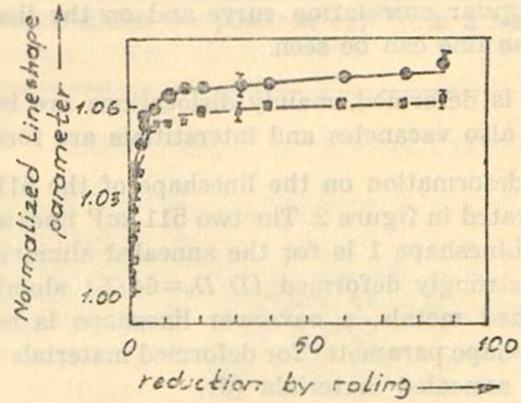

Figure 3. The dependence of annihilation lineshape in «Ferrovac E» iron of 99.97 % purity on the degree of deformation and on the time elapsed after deformation. The upper set of data applies to freshly deformed material and the lower set after 36 h of recorvery.

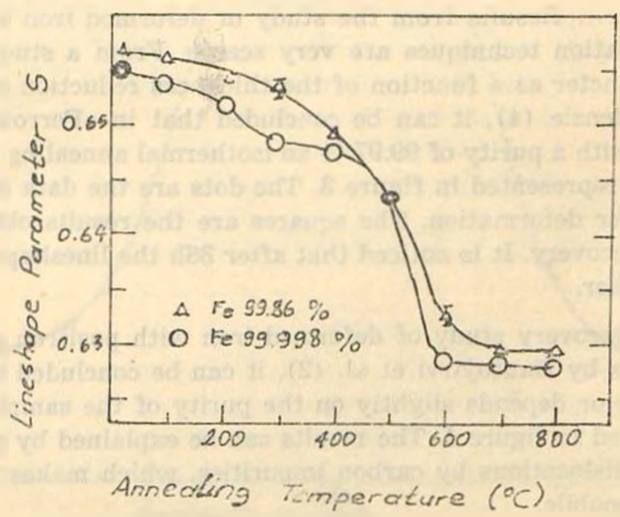

Figure 4. The recovery of annihilation lineshape in two deformed irons as a function of isochronal (1h) annealing temperature. The size of the points denotes the statistical standard.

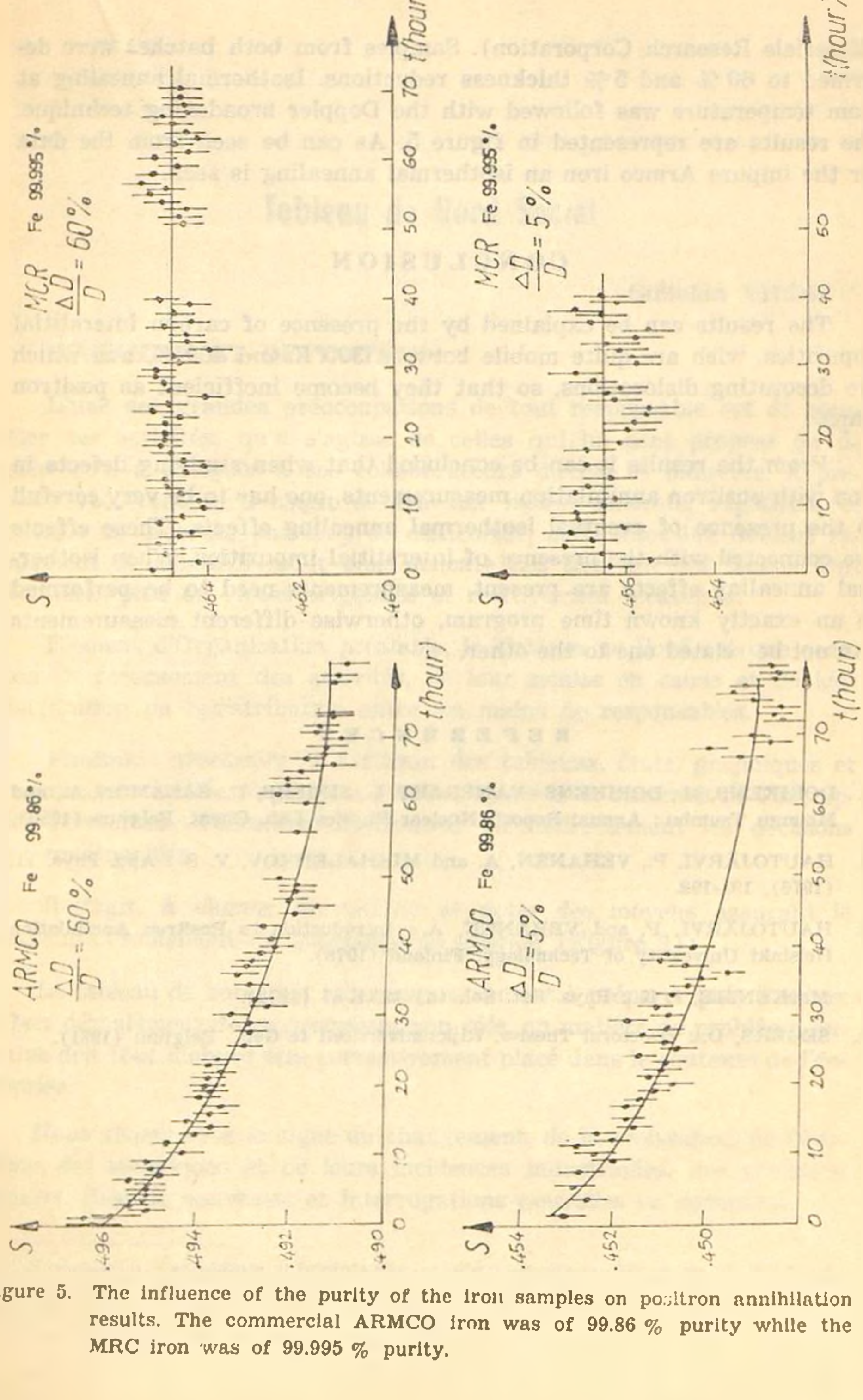

Figure 5. The influence of the purity of the iron samples on positron annihilation results. The commercial ARMCO iron was of 99.86 % purity while the MRC iron was of 99.995 % purity.

(Materials Research Corporation). Samples from both batches were deformed to 60 % and 5 % thickness reductions. Isothermal annealing at room temperature was followed with the Doppler broadening technique. The results are represented in figure 5. As can be seen from the data for the impure Armco iron an isothermal annealing is seen.

CONCLUSION

The results can be explained by the presence of carbon interstitial impurities, wich are quite mobile between 300°K and 400°K, and which are decorating dislocations, so that they become inefficient as positron traps.

From the results it can be concluded that when studying defects in iron with positron annihilation measurements, one has to be very cercfull to the presence of eventual isothermal annealing effects. These effects are connected with the presence of interstitial impurities. When isothermal annealing effects are present, measurements need to be performed in an exactly known time program, otherwise different measurements can not be related one to the other.

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