

Study of Ion Implantation Effects on 316 Stainless Steels with Positron Annihilation Spectroscopy

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1. Introduction

Positron annihilation is a powerful tool for the analysis of defects such as vacancies, small vacancy clusters, and dislocations [1]. Positron annihilation lifetime spectroscopy (PALS) allows the determination of the open-volume size and concentration of the defect. The PALS technique based on ^{22}Na positron source is usually applied for study of the defects in the bulk specimen. And also the PALS technique is suitable for measuring changes in the vacancy type defect density. In addition, Doppler broadening coincidence spectroscopy (DBCS) provides information on the chemical environment of the defect.

The number of positrons trapped by the defects rises as the defect concentration increases, therefore the trapping rate (κ) increases. This trapping rate is determined from positron lifetime measurements provided. The trapping rate (κ) is directly linked to the defect concentration (ρ_d). In many cases, for vacancies and dislocations, κ is proportional to ρ_d .

This work discusses our recent positron annihilation lifetime experiments focused on the ion implantation treated on 316 stainless steels. This will enable to create material damage similar to the real radiation damage, without problem with induced activity of the specimens. To simulate high neutron fluencies in these materials, the proton implantation has been used. The interpretation of the measured data has been based on previous paper for pure iron and chromium [2].

2. Methods and Results

2.1 Sample preparation

To study the influence of dose of ion implantation, the 316 stainless steels with different dose have been prepared. The chemical composition of the alloy can be seen in table 1. All specimens were heat-treated by solid solution treatment.

Table 1. Chemical composition of the specimens [wt%]

Fe	Cr	Ni	Mo	Mn	Si	C	P	S
Bal.	16	12	2.5	2.0	1.0	0.08	0.045	0.03

The as-received materials have been grinded and carefully polished to mirror like surfaces (up to $1\mu\text{m}$) and then electrochemically polished with 70% HClO_4 +

30% CH_3COOH electrolyte at about 8.0 voltage and room temperature before exposure to proton implantation. Subsequently, an unimplanted sample and the implanted samples were investigated with PALS techniques.

2.2 Ion implantation

To create material damage similar to the neutron radiation damage without neutron activation, accelerated proton ions have been used. Implantations of 3.0 MeV proton ions at two different dose levels (1.85×10^{16} , 1.85×10^{17} ions/cm 2) have been performed at the linear accelerator of the KIGAM (Korea Institute of Geoscience and Mineral Resources). The DPA (displacement per atom) of these specimens is 0.01 and 0.1, respectively. The depth profile of collision events can be seen in figure 1. In this case, the ion ranges was about 35.6 μm .

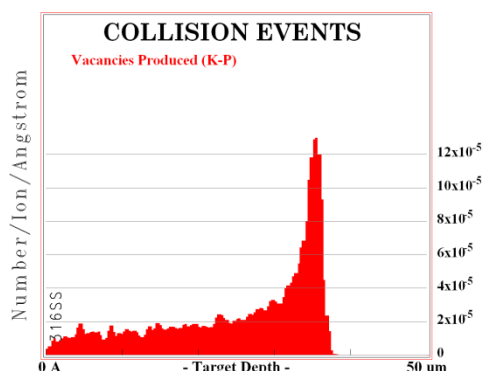


Figure 1. Depth profile of the proton implantation, $E = 3.0$ MeV (SRIM simulation of 10^5 ions).

2.3 PALS technique

Positron lifetime measurements have been performed on the fast-fast coincidence system. The instrumental time resolution of the apparatus was determined to be about 250ps. The experimental data have been evaluated with the PALSfit program using the three component decomposition. This spectra fitting was sufficient and moreover the fourth component cannot be found in any spectra. However these components mean that only one describes the lattice defects (τ_2) and the others correspond to both material bulk (τ_1) and PALS source-sample setup (τ_3) which is the long component with small intensity [3]. Therefore the τ_2 component

may differ from known positron lifetimes of particular lattice defects and combination of several types of defects must be considered by this data interpretation.

To investigate the thickness and dose effects, we reduced the thickness of specimens from 500 μm up to 150 μm by 50 μm . Then we obtained the PALS data at every thickness.

3. Results

3.1 Thickness effects

The PALS results of the thickness effects in unimplanted specimens show that positron lifetime in the defects (τ_2) which correspond to the size of the vacancy type defects (vacancy clusters) is almost fixed with decreasing the thickness (figure 2). Positron lifetime in the bulk (τ_1) which related to the matrix also did not change. These average values are $\tau_1 = 0.1426$ (± 0.0024) and $\tau_2 = 0.2308$ (± 0.0110) whose value corresponds to di-vacancy in pure Cr matrix [4, 5].

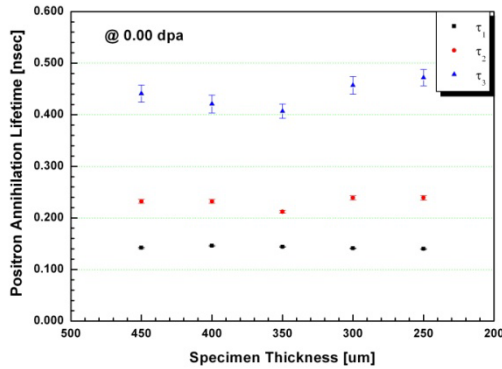


Figure 2. Positron annihilation lifetimes of the unirradiated specimen

3.2 Dose effects

The PALS results of the dose effects on 400 μm specimens show that positron lifetimes in the defects (τ_1 , τ_2) have a linear relationship with dose (figure 3). Their relations are below:

$$\tau_1 = 0.14639 + 0.13717 \times \text{dose},$$

$$\tau_2 = 0.22234 + 0.32878 \times \text{dose}$$

At 0.10 dpa $\tau_2 \approx 0.255$ which corresponds to three vacancy-clusters in pure Cr matrix [4, 5].

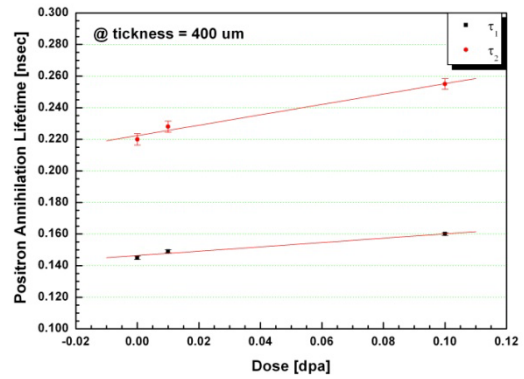


Figure 3. Positron annihilation lifetime of the irradiated specimens

4. Conclusions

Our study showed that positron lifetime technique can be used. Prior to ion implantation lattice defects have had 2-vacancy clusters which corresponded to the defect in pure Cr matrix. Moreover, posterior to ion implantation lattice defects have had 3-vacancy clusters which related to the defect in pure Cr matrix.

The value of τ_2 measured in the thickness and dose effects showed that chromium plays an important role in the formation of the microstructure under radiation treatment.

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