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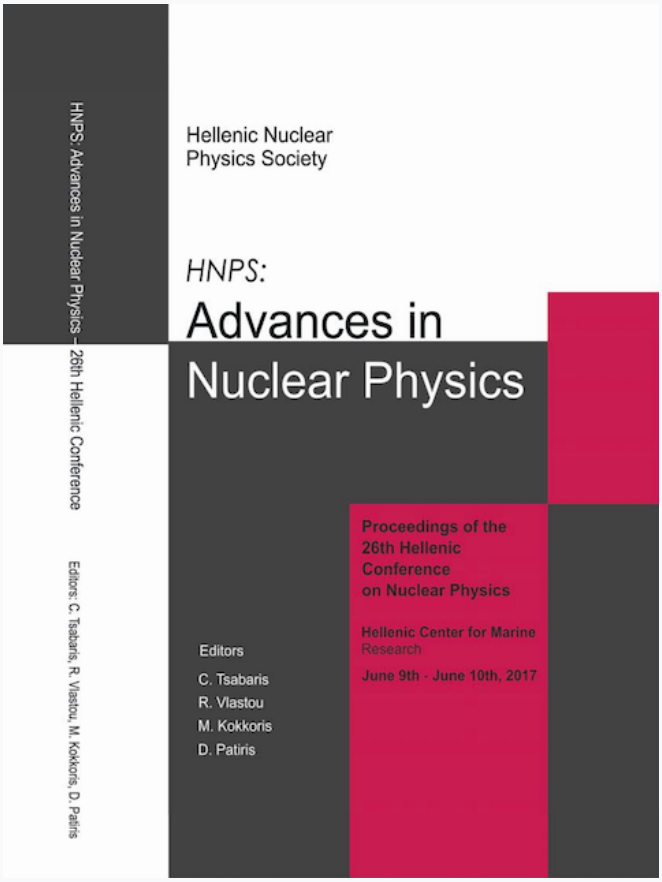

Determining the positron lifetime of a material using Positron Annihilation Lifetime Spectroscopy

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Determining the positron lifetime of a material using Positron Annihilation Lifetime Spectroscopy

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Abstract

Positron Annihilation Lifetime Spectroscopy (PALS) is a non-destructive technique, used to investigate open volume defects in materials. The usual sandwich configuration for Positron Annihilation Lifetime Spectroscopy measurements includes two similar pieces of material. In this study, the proposed configuration consisted of two different materials with one of them being of known lifetime. Specifically, the lifetime of a lead (Pb) specimen, measured together with a tungsten (W) specimen of known positron lifetime, was determined using this methodology. This methodology can be useful in the cases that two pieces of the same material are not available.

Keywords: Positron Annihilation Lifetime Spectroscopy; vacancy defects

1. Introduction

Positron Annihilation Lifetime Spectroscopy (PALS) is used to investigate open volume defects in materials [1-3]. Positron after being implanted into a solid sample gets thermalized up to depths around 100 μm very fast (within few ps) through the interaction with the surrounding medium. After that, it gets trapped into an open void defect before annihilating with an electron. Defects, such as vacancies, voids and dislocations, act as traps for the thermalized positrons (or ortho-positronium- instable bound state of positron-electron), due to the absence of positively charged nuclei at these sites. In PALS the time from the birth of the positron until the positron annihilates with one of the material's electrons producing gamma rays is measured. The lower the electron density at the vacant/defect site the higher the positron lifetime is; also the positron lifetime increases as the size of defect increases [3-4].
In the standard PALS experiments the positron source is placed in contact between two identical pieces of the material under investigation in a "sandwich" configuration (Fig. 1a). In the present study, the feasibility to determine the positron annihilation lifetime of an unknown material specimen, when it is measured together with a material specimen with a known

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positron lifetime, is investigated. Specifically, the lifetime of a lead (Pb) specimen, measured together with a tungsten (W) specimen of known positron lifetime was determined using this methodology. This can be useful in the cases when two identical samples of the same material are not available.

2. Experimental details

The principle of operation of the lifetime spectrometer is to measure the spectrum of time intervals between start signals, generated by detecting prompt gamma rays following the emission of positrons, and stop signals from one of the annihilation gamma photons [5].
The ^{22}Na isotope (from evaporated metallic salt) enclosed in kapton foils was used as the positron source. The source is placed in contact with two specimens of a material in a "sandwich" configuration (Fig. 1a). Commercial high purity specimens of cadmium (Cd), lead (Pb), W polycrystal (as rolled), W single crystal and nickel (Ni) (annealed) supplied from Goodfellow Cambridge Ltd and Ortec, were used. Positron annihilation lifetime measurements were carried out using Ortec PLS-system, which included two plastic scintillation detectors (block diagram of the system is shown in Fig. 1b). The time resolution of the lifetime spectrometer is 260 ps and corresponds to the FWHM of the spectrum of a ^{60}Co source which emits simultaneously two γ-rays. The data analysis was performed using LT10 software [6]. The experimental spectra were fitted to the expression in eq.1 [2], which involves a sum of i exponential components and background B, convoluted by the resolution function R (Gaussian function). Each exponential component is a simple exponential function, characterized by two parameters: intensity I and lifetime τ, and characterizes the various positron annihilation types.

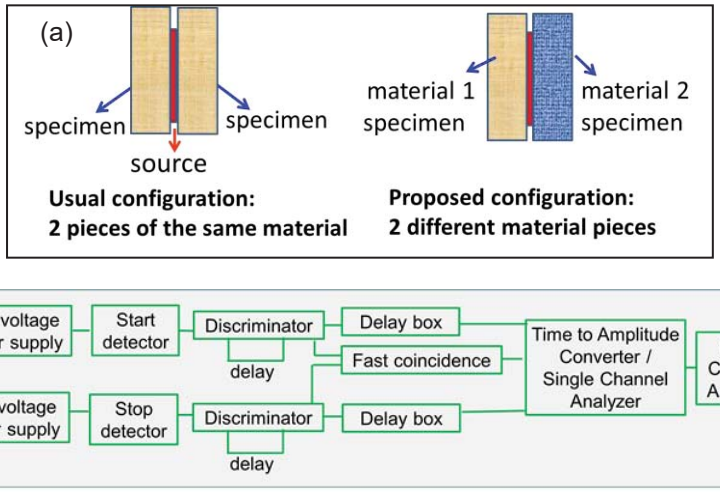

Fig. 1. (a) Specimen-source-specimen sandwich configuration (usual and proposed) and (b) schematic diagram of the Positron Annihilation Lifetime Spectroscopy system.

$$S(t)=R(t) \otimes \left(B+\sum_i \frac{I_i}{\tau_i} e^{-t/\tau_i}\right) \qquad \text{(eq. 1)}$$

3. Results and Discussion

3.1. Determination of source parameters using simultaneous analysis of various specimens

Various specimens (Ni, Pb, W polycrystal, W single crystal and Cd) were analyzed simultaneously for the determination of the source parameters. Two source components were taken into account: one for the positron annihilations in the kapton foil and in the source and a second one for the annihilations in the air between the source and the specimen. In the analysis of the spectra, the lifetimes of the source components are set as common variables. The results from the simultaneous analysis of the specimens as well as the source parameters are presented in Table 1. Also, the positron lifetime spectrum of the W polycrystal specimens resulting from the simultaneous analysis is presented in Fig.2a, indicatively. All the specimens measured exhibited a lifetime between that of a defect-free material and a material with single vacancy, which is what it would be expected from not well annealed specimens.

Table 1

Lifetimes of specimens and source components resulting from the simultaneous analysis.

Specimen parameters		Source parameters	
Specimen	τ specimen (ns)	τ source1 (ns) (kapton foil and source)	τ source2 (ns) (air between source and specimen)
Ni	0.171		
Pb	0.260		
W polycrystal	0.185	0.390	1.64
W single crystal	0.159		
Cd	0.212		

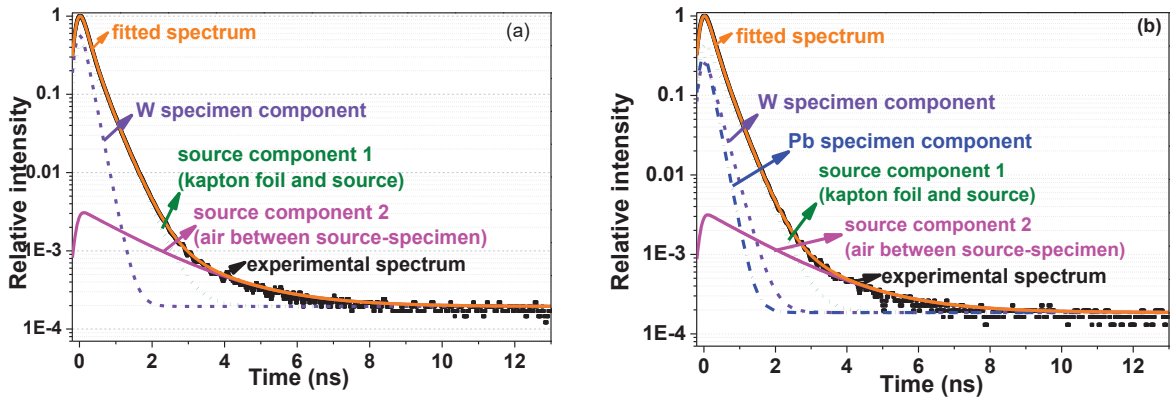

Fig. 2. Positron lifetime spectrum of: (a) W polycrystal sandwiched specimen and its fitted curve with the various components and (b) Pb+W specimen (with W polycrystal considered of known lifetime) and its fitted curve with its various components.

3.2. Use of the determined positron lifetime of one standard material in combination with the material of unknown positron lifetime

The proposed sandwich specimen configuration (Fig. 1a) consisted of two different materials: W (polycrystal) specimen considered of known lifetime and Pb specimen considered of unknown lifetime. The known parameters included the source parameters determined from the simultaneous analysis of various specimens (§3.1) and the lifetime of one material (W polycrystal, as determined from the simultaneous analysis). In the analysis, it is assumed that the two different materials contribute equally to the sandwich specimen. The experimental spectrum of Pb+W sandwich specimen as well as the fitted spectrum with its components are presented in Fig. 2b. The resulting parameter from the least square fit of the experimental spectrum is the positron lifetime of the second material (Pb in this case). The lifetime value obtained for Pb is 0.260 ns and it is equal with the value (0.260 ns) determined from the simultaneous analysis of the various materials.

4. Conclusions

The usual sandwich configuration for Positron Annihilation Lifetime Spectroscopy measurements includes two pieces of the same material. In this study, the proposed configuration consisted of two different materials, with one of them being of known lifetime. It was shown that the unknown lifetime of the other material can be determined when the source parameters and the lifetime of the standard material are known. This methodology is useful in the cases that two identical samples of the material are not available.

Acknowledgments

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