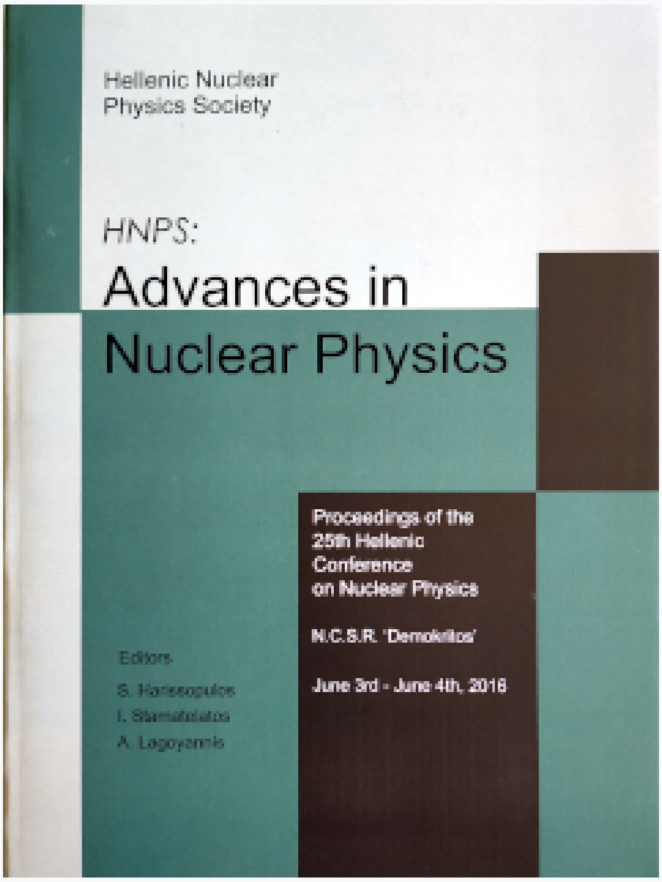
HNPS Advances in Nuclear Physics

Vol 24 (2016)

HNPS2016



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doi: 10.12681/hnps.1872

To cite this article:

Triantou, K., Mergia, K., & Stamatelatos, I. E. (2019). Positron Annihilation Lifetime Spectroscopy in the study of defects in materials. *HNPS Advances in Nuclear Physics*, *24*, 235–238. https://doi.org/10.12681/hnps.1872

Positron Annihilation Lifetime Spectroscopy in the study of defects in materials

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Abstract The Positron Annihilation Lifetime Spectroscopy (PALS) is a valuable method for the study of the open volume defects in materials. The reduced electron density at the vacant/defect site increases the positron lifetime, and positron lifetime increases as the size of defect increases. In the current paper the experimental apparatus for the measurement of the positron lifetime in materials is described and the spectra from W and Cd specimens are analyzed. The presence of dislocations and vacancy defects is found, since the positron lifetimes of specimens are higher than the defect-free (bulk) values.

Keywords Positron Annihilation Lifetime Spectroscopy, vacancy defects

INTRODUCTION

The lifetime of a positron in matter will depend on the electron environment in which it finds itself, and this in turn gives information about the submicroscopic nature of the material [1]. Positron Annihilation Lifetime Spectroscopy (PALS) is used to investigate open volume defects in materials. In this technique, positrons are created from a radioactive source and injected into a material. The positrons thermalize, i.e. lose kinetic energy, through scattering events. 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. As a result of the reduced electron density at these sites, the positron annihilation lifetime is increased for these trapped positrons, and can be related to the size/type of defect. Annihilation is detected as a function of time through observation of the resultant 511 keV gamma rays. The timing spectrum obtained is deconvoluted to determine the lifetimes present [2]. Average lifetime differs according to the material and is proportional to its electronic density. In the presence of defects, the spectrum is the result of a superposition of exponentials decreasing over time, characterized by different intensities and different lifetimes. The duration of the lifetime is related to the nature of the defect and the intensity of the defect specimen component is related to spatial concentration of defects [3]. In this work, two metals are studied using PALS: tungsten (W) and cadmium (Cd). W is investigated in view of its use as a plasma facing material in fusion energy applications.

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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 [1].

The ^{22}Na isotope (from evaporated metallic salt) wrapped in kapton foil was used as the positron source. The source is placed in contact with two pieces of material in a “sandwich” configuration (Fig. 1a). 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 sandwich of specimen-source-specimen was placed between the two detectors at a distance of 1 to 3 mm from their outer surface. Each specimen piece has a thickness of 1 mm. 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 [4]. The spectra were fitted to a sum of exponential lifetime components, $\tau_{i,}$ weighted to the intensities, I_i.

Commercial high purity cold rolled tungsten (W) and cadmium (Cd) specimens are measured using the geometry depicted in Fig.1a.

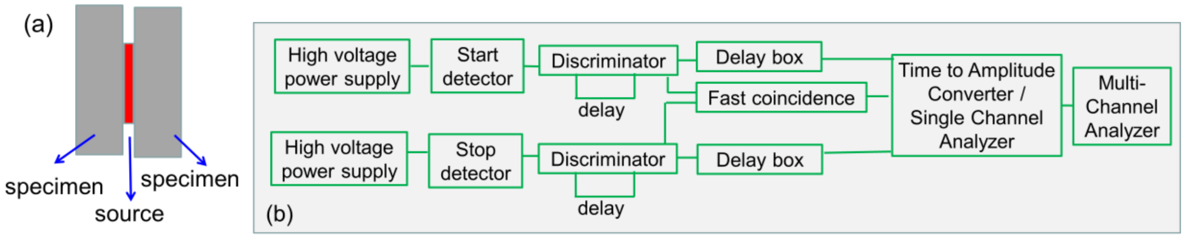

Fig. 1. Sandwich configuration of specimens and source (a) and block diagram of the Positron Annihilation Lifetime Spectrometer (b).

RESULTS AND DISCUSSION

The experimental PALS spectra from W and Cd are shown in Figs. 2 and 3, respectively. For the analysis of these spectra one specimen lifetime component, as an average of the annhilations at the various sites, is considered. Regarding the contribution of the source two components are taken into account: one for the positron annihilations in the kapton foil and in the source (radioactive metallic salt) and a second one for the annihilations in the air between the source and the specimen. In the analysis of the spectra of the two materials, the lifetimes of the source components are set as common variables. The spectrometer resolution (prompt response) is fixed at the value of 260 ps found from measuring the ^{60}Co spectrum.

For tungsten the average positron lifetime specimen component along with its respective percentage integrated intensity are determined (Fig. 2, Table 1). The average positron lifetime (0.209 ns) determined for tungsten is much higher than its bulk value. The specimen lifetime value is the result of a mixture of annihilations in the dislocation loops, monovacancies and maybe a small contribution from di-vacancy like defects. In literature, the positron lifetime in defect-free tungsten is in the range of 0.105-0.108 ns [5-7]. Values of about 0.136 ns, but mainly in the range of 0.15-0.20 ns have been reported by different authors as the positron lifetime in mono-vacancies or dislocation loops in tungsten [5-6, 8]. Also, for di-vacancies the positron lifetime has been estimated about 0.157 ns whereas the theoretically calculated lifetime is 0.23 ns [5-6]. Positron lifetime calculations for different number of vacancies in tungsten lattice have been reported in [6]. For instance, for nano voids having 13-37 vacancies the lifetimes have been calculated to be 0.41-0.44 ns [6]. Taking into account that the specimen measured is cold rolled a very large number of dislocations are expected and the determined average lifetime value is accordance with the literature values.

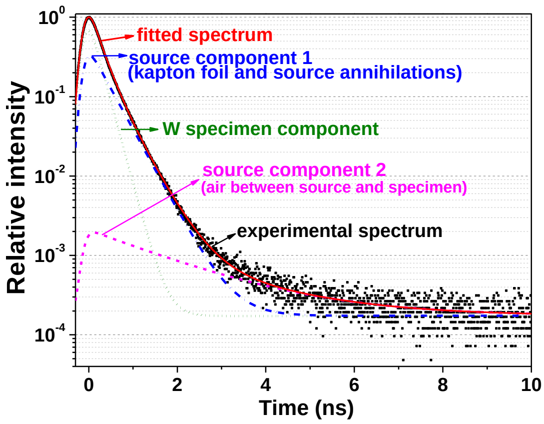

Fig. 2. Positron lifetime spectrum of W specimen and its fitted curve (solid line) with the various components.

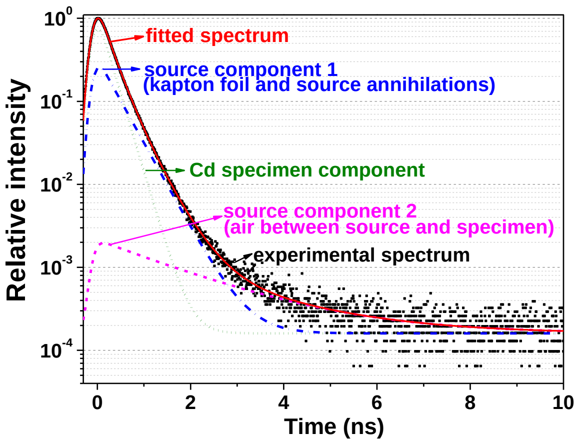

Fig. 3. Positron lifetime spectrum of Cd specimen and its fitted curve (solid line) with the various components.

Component	**Lifetime τ (ns)**		**Integrated Intensity (%)**	
	W	**Cd**	**W**	**Cd**
specimen component	0.209	0.230	58	66
source component 1 (kapton foil and source annihilations)	0.424	0.424	42	33
source component 2 (air between source and specimen)	1.93	1.93	0.7	0.8

Table 1. Positron lifetime and the percentage of the integrated intensity of the various components for W and Cd spectra.

Regarding the cadmium specimen, its experimental spectrum with the fitted spectrum and its components are shown in Fig. 3 and the results in Table 1. The average positron lifetime in cadmium specimen is 0.230 ns. This value shows that the cadmium specimen is not defect-free, as in that case the positron lifetime should be around 0.184 ns. In literature, mean positron lifetimes in Cd specimens in the range from 0.16 to 0.25 ns have been reported at temperatures from 100 to 600 K [9-12].

For both W and Cd materials, a source component of 0.42 ns is obtained (Table 1), which is attributed to kapton film and source annihilations [9, 13-14]. Besides, a second source component of 1.93 ns, but with a very low integrated intensity (<1 %) is found and this is attributed to annihilations in air between the specimen and the source [13].

CONCLUSIONS

The technique of Positron Annihilation Lifetime Spectroscopy has been used for the characterization of W and Cd materials and the determined average positron lifetimes are 0.209 and 0.230 ns, respectively. The inceased positron lifetime of W with respect to its defect-free value (106 ns) is attributed mainly to the presence of dislocation loops as expected for a cold rolled specimen and the presence of vacancies. The average positron lifetime value found for Cd specimen is attributed to the presence of mono-vacancies. A significant contribution of two source components in the spectra has been determined which originates from the kapton foil encapsulating the source and the source itself.

Acknowledgments

This work has received funding from the project “SIEMENS-Establishing a Multidisciplinary and Effective Innovation and Entrepreneurship Hub”. Also, it has been carried out partly within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement number No 633053.

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