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Analytical Method of Positron Annihilation Lifetime Spectrum for Single-piece Samples

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1. Introduction

Positron annihilation lifetime spectroscopy (PALS) is a technique used to examine the defect characteristics of materials, particularly metal alloys, compounds, polymers, and semiconductors. It is a non-destructive method that can be used to study the properties of materials without damaging them. The positron lifetime is related to the size of defects or free volume in the material, which can provide information such as the presence of defects or voids, chain mobility, and molecular weight. PALS typically uses a Na-22 positron-emitting radioisotope source, covered by two identical samples to block the positrons. However, in some cases, such as cultural heritage or naturally occurring materials, two identical samples cannot be prepared. With a single-piece sample, the positrons emitted from the Na-22 radioisotope source in the opposite direction of the samples can annihilate with the atmosphere of the detectors, such as air, table, sample holder, and detector modules. In this case, the positron annihilation lifetime (PAL) spectrum may not give correct information about the sample, and may contain unwanted components in the PAL spectrum. In this study, we propose an analytical method for PAL spectrum analysis for single-piece samples.

2. Materials and Methods

A Na-22 positron source encapsulated with a 5-µm titanium window (POSN-22, Eckert & Ziegler) was attached to the artificial pottery sample. Two photomultiplier tubes (PMT) (R329-02, Hamamatsu Photonics K.K.) and PMT bases (265A, Ortec) were assembled with fast timing plastic scintillation crystals (BC-422Q, Saint Gobain Crystals). Each PMT was supplied with a high voltage of 2.1 kV (556, Ortec). Two constant fractional differential discriminators (CFDDs) (418, Ortec) were used to selectively process gamma rays of 1.27-MeV from the beta decay of Na-22 and 0.511-MeV from positron annihilation. A time-to-amplitude converter (TAC) (566, Ortec) generated time-different logic signals from the two CFDD output signals, within a 50 ns window. An analog-to-digital converter/multi-channel analyzer (927, Ortec) digitized the output signals from the TAC and sent them to a personal computer. Finally, PALSfit3 software was used to analyze the PAL spectra.

There were two PALS setups (Fig. 1). For the conventional PALS setup, two identical samples were attached to the positron source. In the single-piece PALS setup, the opposite direction of the source was not blocked, and unwanted positron-annihilated gamma-rays could be collected, resulting in the longest positron lifetime (τ_3). The τ_3 and the intensity of τ_3 (I_3) could be eliminated by the source correction process, considering the background of the PAL spectra. In this study, we compared the PALs with and without single-piece sample correction.

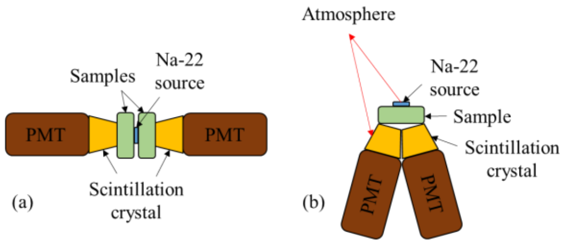

Fig. 1. Setup for positron annihilation lifetime spectroscopy (PALS): (a) conventional sample setup, (b) single-piece sample setup.

3. Results and Discussion

Fig. 2 shows the PAL spectra of the artificial pottery sample. With the single-piece correction, the longest positron lifetime was eliminated. Table 2 shows the PALs with and without the correction.

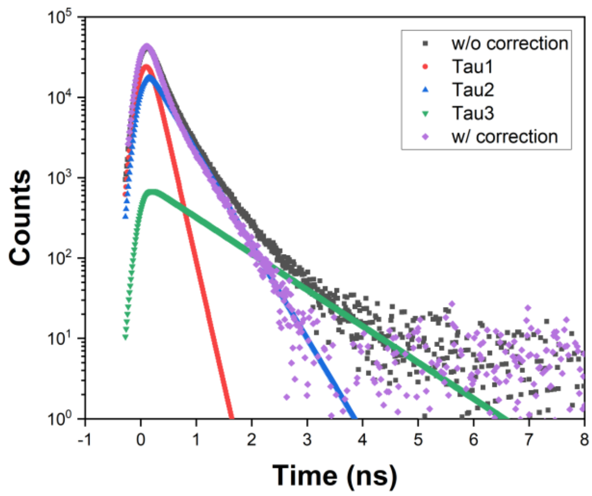

Fig. 2. Positron annihilation lifetime (PAL) spectra: uncorrected PAL spectrum (black), positron lifetime components (red, blue and green) and corrected PAL spectrum (purple).

Table 1. Positron annihilation lifetimes of the artificial pottery sample without and with single-piece correction

	w/o correction	**w/ correction**
τ_1 (ns)	0.128 ± 0.001	0.124 ± 0.001
τ_2 (ns)	0.392 ± 0.004	0.381 ± 0.002
τ_3 (ns)	1.88 ± 0.04	-
Mean lifetime (ns)	0.307 ± 0.001	0.240 ± 0.001
χ^2	1.04	1.05

Recent studies have suggested the use of an additional anti-coincidence detector to eliminate the longest positron lifetime for the analysis of single-piece samples [1-3]. The anti-coincidence detector rejects the positron-annihilated gamma-ray signals from the atmosphere of the PALS system. This method could be compared to the analytical method presented in this study, and a portable PALS system could be suggested.

4. Conclusions

For non-destructive studies using PALS, it is important to handle the positron lifetime spectra by eliminating any unwanted signals that may arise from the detector's atmosphere. Alternatively, an anti-coincidence detector can be assembled in the PALS system to eliminate gamma rays that may arise from positron annihilation outside of the sample.

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