1st International & 28th National Conference on Nuclear Science & Technology 2022 (ICNST22)
Nuclear Science & Technology Research Institute

Experimental investigation of the oxygen sensing ability of positron annihilation spectroscopy for tumor imaging

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Abstract
The potential biomedical application of Positron Annihilation Spectroscopy (PAS) for nonstructural characterization of normal and cancer cells was not thoroughly employed and researched. In this paper, the experimental investigation of the oxygen sensing ability of the PAS technique for tumor imaging is presented and discussed. This research is based on the validated hypothesis that tumor cells differ from the normal tissues in their value of oxygen concentrations. The components of Doppler Broadening and positron annihilation lifetime spectra are measured with our homemade spectrometer to determine the mechanism behind the positron annihilation in oxygen content tissue-equivalent samples. The analysis of PAS data shows that the Orbital Momentum Spectrum (OEMS) of the Coincidence Doppler Broadening Spectroscopy (CDBS) and the positronium lifetime components of Positron Annihilation Lifetime Spectroscopy (PALS) are sensitive to the presence of oxygen. The results are applicable in the development of a tumor imaging system based on the PAS technique.

Keywords: Positron Annihilation Spectroscopy, Tumor imaging, Positronium, Oxygen.

Introduction
PAS is a well-established technique for defect assay and their chemical environments in solids and liquids [1]. PAS includes the PALS technique to obtain the size and concentration of defects and CDBS analysis to explore the chemical environment of positron annihilation sites. Although the PAS analysis have been extensively used for defect characterization in metals and semiconductors, the possible biomedical application of PAS has not been thoroughly researched [2]. In low-electron density materials such as tissues and polymers, Positronium atom (Ps) significantly forms during the PAS analysis. Due to its charge neutrality, Ps is a suitable probe for the characterization of annihilation sites. Since the carcinogenic and healthy tissues differ significantly by the concentration of oxygen in their contents, the development of a tumor imaging system based on the PAS technique is the subject of study. Stepanov et al. have been shown the sensitvity of PALS to dissolved oxygen in tissue equivalent liquids [3]. In this paper, the sensitivity of the CDBS and PALS technique for the identification of annihilation sites are explored and discussed for some tissue-equivalent polymers.

Experimental
PALS and CDBS techniques are executed for four samples including PP, LDPE, PTFE, and PMMA to explore the sensitivity of PAS parameters to positron annihilation sites. The selected polymers have similar electronic structure (2s2p) of characteristic atom and carbon is present at the backbone of all. All the experiments are carried out at Nuclear Science and Technology Research Institute (NSTRI). The details of set-up, calibration, long-term stability, and resolution of the 2d-CDBS and PALS spectrometer are presented in our previous works [4, 5].

Results and discussion
Figure1 shows the Orbital Electron Momentum Spectrum (OEMS) of the samples. The OEMS is the weighted counts $n(p_l)p_l^2$ versus the longitudinal momentum of annihilated electrons (p_l) and describes the competition between valence and core electrons for annihilation with positrons. As shown in OEMS, the contribution of positron annihilation for low-momentum electrons is despised and this contribution for core electrons is magnified. So the OEMS peak is a signature of positron annihilation sites [6]. For the PP and LDPE samples the OEMS peaks show the positron annihilation with carbon atoms because the hydrogen atom has no core electrons. The position of OEMS peaks for PMMA and PTFE are mainly attributed to the positron annihilation with core electrons at polar groups (see the chemical bonds in Table.1). Compared to LDPE and PP samples the peak intensity for PMMA and PTFE is much higher because the polar groups (with higher positron affinity) trap positrons and force them to annihilate near the polar bonds. The OEMS peak position is a characteristic of each group of polymers and its intensity is attributed to the probability of positronium annihilation with core electrons. So it is expected that the intensity of the OEMS peak increases by an increase in the concentration of oxygen in the content because this peak is a characteristic of positron annihilation near oxygen and fluorine sites. This provides a systematic approach for relative measurement of oxygen concentration in carcinogenic tissues by CDBS

Table.1. The results of the PALS technique for the investigated samples.

Sample	Characteristic bond	Density (g/cm^3)	τ_1(ns)	I_1(%)	τ_2(ns)	I_2(%)	τ_3(ns)	I_3(%)
PMMA	C=O	1.159	208±0.014	49.81±0.01	0.431±0.016	33.24±1.07	3.22±0.029	16.95±1.08
PTFE	C-F	2.2	0.231±0.005	59.43±1.01	0.521±0.047	28.41±1.28	3.85±0.018	12.16±1.17
PP	C-H	0.861	0.241±0.005	50.98±1.09	0.475±0.011	27.41±1.03	2.40±0.031	21.61±1.13
LDPE	C-H	0.930	0.217±0.003	46.07±1.05	0.496±0.019	24.51±1.24	2.61±0.015	29.42±1.11

technique. The other approach can be explored by the PALS technique. Figure 2 shows the positron lifetime spectrum for the PMMA sample. The positron lifetime spectrum of each sample is decomposed to the positron annihilation lifetime τ_i (ns) and its related intensity I_1(%) using LT-10 software [7]. The results of the data analysis are listed in Table1. The τ_1 component is related to P-Ps self-annihilation and does not make sense in our study. The intermediate component (τ_2) causes by the positron annihilation at the sites of lattice flow. The τ_3 parameter and its relative intensity with a lifetime greater than 2 ns is directly related to the O-Ps annihilation [8]. As listed in Table1, the I_3 parameter for PTFE and PMMA samples is much lower than PP and LDPE because the high electron density at polar groups sites reduces the probability for positronium formation. In brief, for samples with different concentrations of oxygen, we expect that I_3 decreases as the oxygen concentration increases in the content. So, with the hypothesis that PAS is sensitive to oxygen annihilation sites, we can examine the possibility to use positronium as a novel biomarker in cancer diagnosis systems.

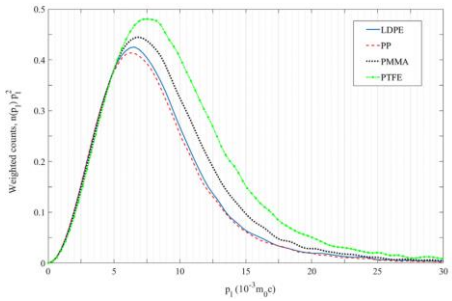

Figure 1. The OEMS of the investigated samples.

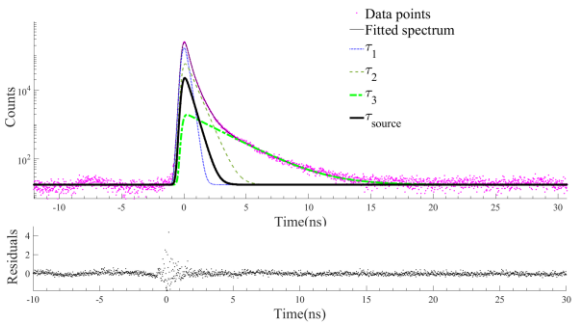

Figure 2. Positron lifetime spectrum of the PMMA sample fitted by LT-10 code.

Conclusions

In this paper, the capability of Positronium atoms for the identification of polar-bond positron annihilation sites is studied. The results of PAS analysis confirm that OEMS and the probability of positronium formation are sensitive to the presence of oxygen in the samples. Further to this work, we are going to initiate a systematic investigation of the tissue-equivalent samples with different concentrations of oxygen by the PALS technique. The potential application of such an investigation is to identify the carcinogenic tissues that suffer from the lack of oxygen by the PALS technique. If the PALS analysis shows the required sensitivity to distinguish between healthy and tumor tissues, PALS and PET techniques can combine in one clinical tomography system to provide data with a higher degree of precision to support the cancer diagnostic tests.

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