Positron Annihilation Doppler Broadening Spectroscopy as Convenient Method to Detect Radiation Effect on CR-39 Track Detector

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Positron Annihilation Doppler Broadening Spectroscopy (PADBS) is a characterization technique that is sensitive to damage of radiation in polymers. A damage zone or defect will be created due to the irradiation of Polyallyl diglycol carbonate (CR-39) with α-particles. It is convenient to study this defect caused by α-particle energies using both PADBS and track diameter measurements. An abrupt change in the S and W line-shape parameters has been observed at 3.75 Mev of α- particle energy, while the track diameter shows a continuous decrease for samples irradiated at more than 2.5 MeV of the α- particle energies.

1. Introduction

Solid state nuclear track detector (CR-39) or Polyallyl diglycol carbonate ($C_{12}H_{18}O_7$, ρ= 1310 kg/m^3) is widely used in the field of health physics, such as for radon monitoring [1-3] and has been used in many fields of science and technology (4-5). Basic operation of the CR-39 is based on the fact that charged particles such as alpha particle will cause ionization for almost all molecules close to its path through a medium. This primary ionizing process triggers a series of new chemical processes that result in the creation of a zone enriched with free chemical radicals and other chemical species [6]. This damaged zone is called a latent track. Alpha particles then form etchable tracks in the CR-39. The latent track of the particle after chemical etching is called etch pit [4]. The etch pit may be seen under an optical microscope.

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Positron annihilation spectroscopy (PAS) is a well-established technique to detect open volume defects in solids [7]. Two parameters (S&W) have been often used to characterize the annihilation peak in Doppler broadening spectroscopy [8, 9]. The S-parameter is the fraction of annihilation with low momentum valence and unbound electrons and is defined by Mackenzie et al. [8] as the ratio of the integration over the central part of the annihilation line to the total area of the line. The W-parameter is the fraction of annihilation with high momentum core electrons and it is defined as the ratio of counts in the wing regions of the peak to the total counts in the peak.

To study the effect of radiation on Polyallyl diglycol carbonate (CR-39), the Doppler broadening line-shape S- and W-Parameters of irradiated CR-39 samples with different α-particle energies at different flux were measured and reported in previous work [10]. In this paper, the measurements of the track diameter in addition to the Doppler broadening line-shape parameters as a function of α-particle energies at constant flux has been investigated.

2. Experimental techniques:

Various holder collimators with different heights are used to normally irradiate the INTERCAST CR-39 in air by α-particles of ^{241}Am [11]. The incident flux (ϕ) was calculated from the following equation:

$$\phi = \frac{A}{4\pi r^2} \qquad (1)$$

where A is the activity of the ^{241}Am- source in Bq and r is the source-detector distance in centimeter.

The total number of α- particles (Φ) emitted from the collimator and incident on CR-39 per unit area in a certain irradiation time (t) is:

$$\Phi = \varphi t \qquad (2)$$

The value of Φ was kept constant (8547.25 ± 13.46 incident α-particles per cm^2) for all CR-39 samples.

The heights of the holders are kept at 12.47, 17.55, 21.58, 24.93, 28.7 and 31.55 mm, which would reduce the energy of 5.486 MeV α-particles from ^{241}Am to 4.33, 3.75, 3.30, 2.86, 2.30 and 1.78 MeV, respectively. After irradiations, the detectors are etched chemically in 6.25 M NaOH solution at 70 ^{0}C for 6 hr. The diameter of the etch pit opening (track diameter) is measured with an optical microscope magnifying 1000 times and eyepiece micrometer.

The positron source of 1mCi free carrier ^{22}NaCl is evaporated from an aqueous solution of sodium chloride and deposited on a thin kapton foil of 7.5 µm in thickness. The source has to be very thin so that only small fractions of the positron annihilate in the source. A sandwich configuration has been used to guide the positron into the CR-39 samples. The system, which has been used in the present work to determine the Doppler broadening S- and W- parameters consists of an Ortec HPGe detector with an energy resolution of 1.95 keV for 1.33 MeV line of ^{60}Co, an Ortec 5 kV bias supply 659, Ortec amplifier 575 and trump 8 K MCA. Fig. (1) shows a schematic diagram of the experimental setup. The signal coming from the detector enters the input of the preamplifier and the output from the preamplifier is fed to the amplifier. The input signal is a negative signal. The output signal from the amplifier is fed to a computerized MCA. All samples spectra are collected for 30 min.

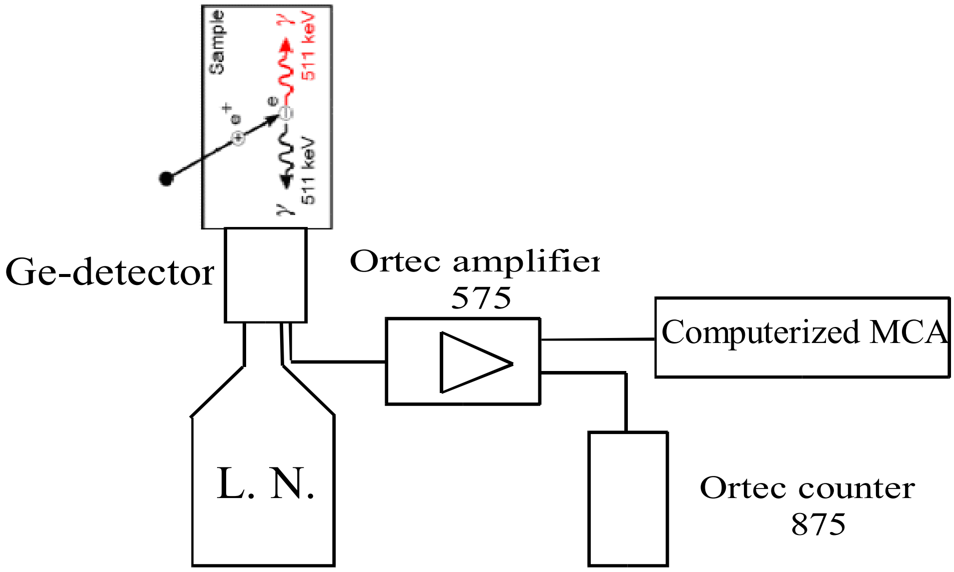


Fig. (1): Experimental setup for Doppler broadening line-shape measurements.

3. Results and discussion:

The CR-39 samples are irradiated with different α- particle energies ranging from 1.78 to 4.34 MeV at constant flux (8547.25±13.46 α-particles per cm^2). Fig. (2) reveals the relation between the measured track diameters at different α-particle energies. The track diameter is almost constant for lower α-particle energies, while a continuous decrease of the track diameter is observed for samples irradiated at more than 2.5 MeV of the α-particle energies. The track diameter has avalue of about 13 µm at lower α-particle energies, while value of about 11.3 µm is observed for samples irradiated at the highest α-particle energy (4.34 MeV). These can be explained by the fact that, at low α-particle energies a high linear energy transfer (LET) to the CR-39 samples occurs. So, an advanced damage zone is created. This zone is characterized by higher track diameter. As α-particle energies increase, the LET is decreased and then a decrease in the track diameter is observed.

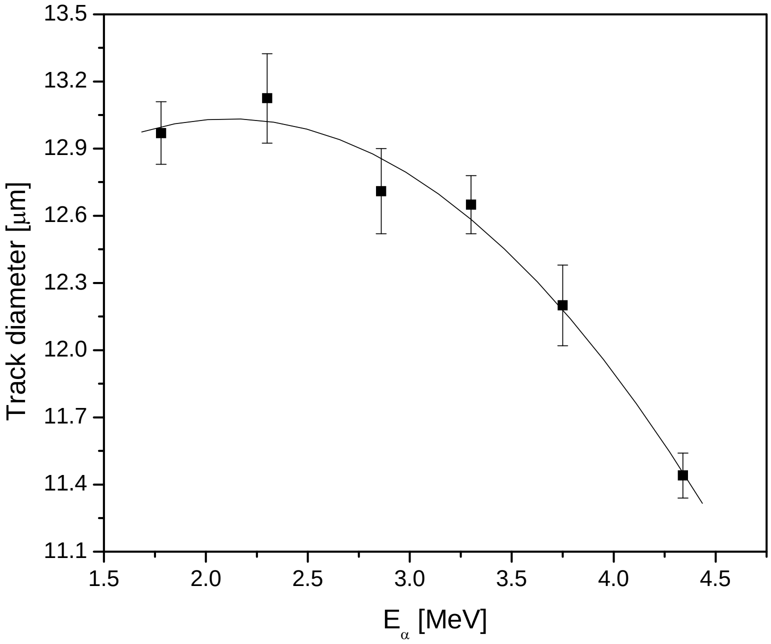


Fig. (2): The variations of the track diameter as a function of α-particle energies at constant flux.

The Doppler broadening line-shape for all samples are measured for unirradiated and irradiated CR-39 samples at different α-particle energies. The obtained spectra show a 511 keV annihilation line for unirradiated and irradiated samples at 2.3 and 3.75 MeV (see Fig. 3). Similar line-shape profiles are obtained for all samples.

The Doppler broadening line-shape S (for shape) and W (for wings) parameters are calculated using SP ver. 1.0 program [12]. The width's definitions of the line-shape S- and W-parameters of the 511 keV annihilation line can be chosen either manually or automatically. The most important is to determine the channel with maximum counts, which is associated with the energy 511 keV. The maximum is necessary because it is a base for definition of the regions for calculations of S- and W- parameters. The channel numbers (input data) for this program are fixed for all measurements.

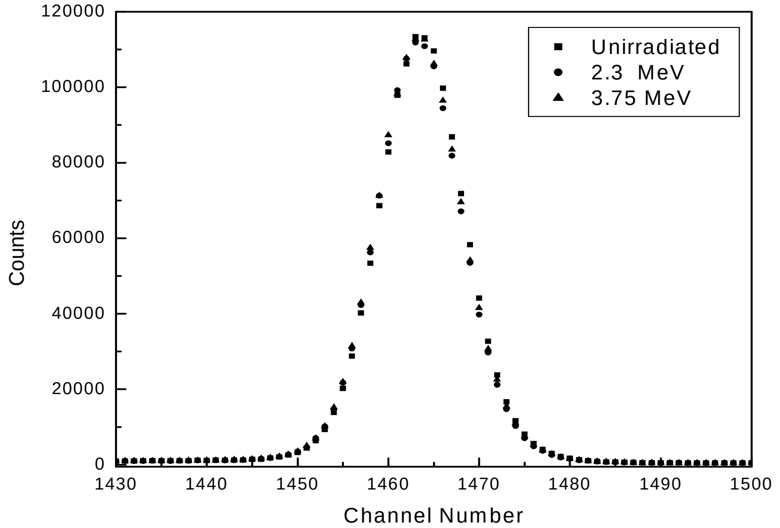
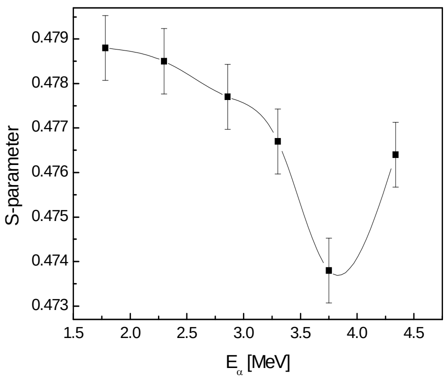


Fig. (3): The line shape spectra of the unirradiated sample and those irradiated with α-particle energies of 2.3 and 3.75 MeV at constant flux.

The S- and W-parameters calculated using the mentioned program has been correlated as a function of α-particle energies at constant flux as illustrated in Fig. 4 (a and b). A steep decrease comparable with a steep increase in the behavior of S- and W-parameters respectively observed with increasing of α-particle energies. An abrupt change definitely observed at 3.75 Mev of α-particles for both S- and W-parameters. At this energy a rapid decrease in the S-parameter comparable with a rapid increase in the W-parameter occurred. An increase and decrease in the values of S- and W-parameters respectively observed at higher α-particle energy (4.34 MeV). Positron trapping in vacancies (the size of the etch pit in the CR-39 sample) results in an increase (decrease) in S (W), since annihilation with low momentum valence electrons increased at vacancies. A high concentration of defects, or an increase in the mean size of defects, leads to a larger contribution of annihilation photons from low momentum electrons because positrons are trapped at defects [13]. This is reflected in Doppler broadening measurements by an increase in S-parameter and a decrease in W-parameter as energy is reduced. May be the irradiation with α-particle induces a phase transition in the Polyallyl diglycol carbonate [10]. The behavior of S- and W-parameters reveals an abrupt change at the position of the transition. Like many others molecular materials, the use of Positron Annihilation Spectroscopy (PAS) has proven very valuable in the study of phase transition in polymers [14, 15].



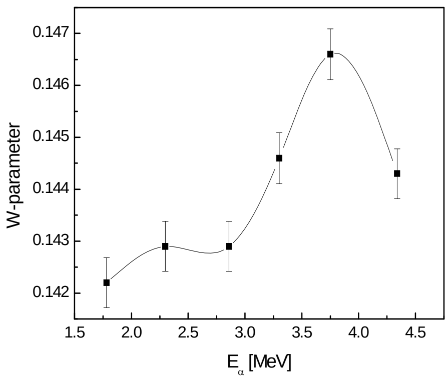


Fig. (4): The behavior of the S-parameter (a) and W-parameter (b) as a function of α-particle energies at constant flux.

4. Conclusion:

CR-39 polymer detectors are irradiated by α-particle with different energies at constant flux. Positron annihilation Doppler broadening spectroscopy (PADBS) and track diameter measurements for these samples have been investigated. PADBS could probe the defect occurred in CR-39 at different α-particle energies. Track diameter measurements gives a drastically decrease with increasing of α-particle energies.

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