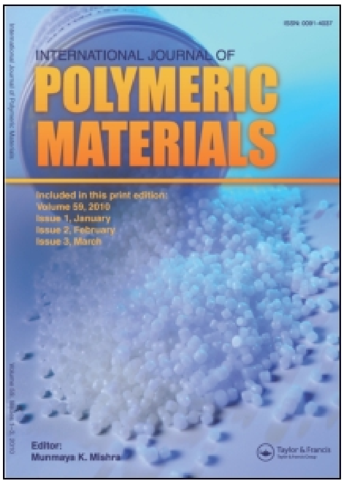

International Journal of Polymeric Materials
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713647664

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To cite this Article Eissa, M. F.(2008) 'Chemical Etching Phases of Irradiated CR-39 Track Detector by Positron Annihilation Doppler Broadening Spectroscopy', International Journal of Polymeric Materials, 57: 3, 288 — 293
To link to this Article: DOI: 10.1080/00914030701555668
URL: http://dx.doi.org/10.1080/00914030701555668

International Journal of Polymeric Materials, 57:288–293, 2008

ISSN: 0091-4037 print/1563-535X online
DOI: 10.1080/00914030701555668

Chemical Etching Phases of Irradiated CR-39 Track Detector by Positron Annihilation Doppler Broadening Spectroscopy

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Positron annihilation Doppler broadening (DB) spectroscopy is a characterization technique that is sensitive to radiation damage in polymers. Passage of α-particles radiation through the CR-39 polymer detector produces damage or defect. It is convenient to study this defect by Doppler broadening spectroscopy. This study found that the fraction of positrons trapped depends on α-particle energies.

Keywords: α-particle irradiation, Doppler broadening (DB) spectroscopy, fraction of positrons trapped, poly(allyl-diglycol carbonate) CR-39 polymer samples, S- and W-parameters

INTRODUCTION

In recent years, etch-track detectors, poly(allyl diglycol carbonate) ($C_{12}H_{18}O_7$), (CR-39) have been used increasingly for studies in astrophysics, nuclear physics and geophysics [1] as well as environmental studies [2–4]. Operation of the CR-39 track detection is based on the fact that when a charged particle passes through a medium, it will cause extensive ionization. A large number of damaged molecules are created close to the path of ionized-charged particles (latent track). The track in the detector is revealed by a suitable chemical etching. In the track development, two main parameters are of interest [5–6], the track etch rate (the latent track) along the damaged zone and the etch rate of the undamaged zone (detector surface material).

Received 16 June 2007; in final form 26 June 2007.
The author is extremely thankful to Prof. Dr. E. Badawi, Physics Department, Faculty of Science, Minia University, Egypt, for their valuable support.
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The track profile in the CR-39 samples with prolonged etching goes through three phases [1]: conical, transition and spherical phase. In the conical phase, the etching doesn't reach the end of α-particle range. The etch pit begins to grow increasingly round in the transition phase. In the spherical phase, the whole track profile becomes completely spherical.

The track diameter can be measured using an eyepiece micrometer attached to a microscope in the conical phase. In the spherical phase, the track diameter can be determined using mathematical analysis [7] and then the average track etching rate may be determined.

At optimum etching conditions, the phases in CR-39 depend on the range (energy) of the incident α-particles.

Positron annihilation Doppler broadening spectroscopy is a well-established tool to probe and characterize defects. The 511 keV annihilation peak was characterized by the line shape parameters S and W. S is the fraction of annihilation with low-momentum valence and unbound electrons having a longitudinal momentum $p_L < 3.0 \times 10^{-3}$ m_0c, where m_0 is the electron rest mass and c is the speed of light. W is the fraction of annihilation with high-momentum core electrons with $6.20 \times 10^{-3}\, m_0c < p_L < 15.5 \times 10^{-3}\, m_0c$. The dependence of S- and W-parameters on the irradiation time for the CR-39 samples irradiated at 0.5, 2 and 3 min for different α-particle energies has been studied [8]. The S- and W-parameter at 1 min irradiation time on CR-39 due to the effect of α-particle energies (1.13–4.95 MeV) has been previously investigated [9]. The fraction of positrons trapped in the open volume defect (etch pit) depends on the shape parameters of positron annihilation. In this article, the dependence of the fraction of positrons trapped in the open volume defect on α-particle energies at irradiation time of 4.5 min has been investigated.

CALCULATIONS

From the trapping model [10], the fraction of positrons trapped in open volume defect (F) for only one defect state is:

$$F = \frac{k}{k + \lambda_b} \tag{1}$$

where k is the trapping rate and λ_b is the annihilation rate in the bulk state.

The measured values of S- and W-parameters can be determined as:

$$S = FS_d + (1 - F)S_b \tag{2}$$

$$W = FW_d + (1 - F)W_b \tag{3}$$

where S_d and W_d are the S- and W-parameters for the defect in CR-39 sample and S_b and W_b are the parameters for bulk (background) sample.

From Equations 2 and 3 we obtain

$$F = \frac{S - S_b}{S_d - S_b} \tag{4}$$

$$F = \frac{W - W_b}{W_d - W_b} \tag{5}$$

Also

$$S = \left(\frac{S_d - S_b}{W_d - W_b}\right) W + \frac{S_b W_d - W_b S_d}{W_d - W_b} \tag{6}$$

EXPERIMENTAL TECHNIQUE

Various holder collimators with different heights are normally used to irradiate the INTERCAST CR-39 in air by α-particles [11]. The heights of the holders are 12.47, 17.55, 21.58, 24.93, 28.7, 31.55 and 34.6 mm. They would reduce the energy of 5.486 MeV α-particles from ^{241}Am to 4.33, 3.75, 3.30, 2.86, 2.30, 1.78 and 1.13 MeV, respectively. The irradiations were continued for 4.5 min. After irradiations, the detectors were etched chemically in 6.25 M NaOH solution at 70°C for 6 h.

The positron source of 1mCi free carrier ^{22}NaCl was evaporated from an aqueous solution of sodium chloride and deposited on a thin kapton foil of 7.5 μm in thickness. The positron source was sandwiched between two identical $1.00 \times 1.00\,\text{cm}^2$ CR-39 specimens. The Doppler broadening (DB) spectra of the positron annihilation were satisfied by a High Purity Germanium (HPGe) detector with an energy resolution of 1.95 keV for 1.33 MeV line of ^{60}Co. The spectra were analyzed in terms of the conventional S and W shape parameters.

RESULTS AND DISCUSSION

Doppler broadening of the 511 keV annihilation peak measurements provides information about the momentum distribution of electrons at the annihilation site. Two parameters, S (for shape) and W (for wings), are usually used to characterize the annihilation peak. The measurements of S- and W-parameters were estimated using SP version 1.0 program [12] for the CR-39 samples irradiated with α-particle energies from 1.13 to 4.34 MeV at 4.5 min. This program was designed to automatically analyze the 511 keV line of the positron annihilation.

The analysis of this line extracts the S-parameter, which is defined as the ratio of central part to the total surface of annihilation line. The wing parameter (W-parameter) is defined as the ratio of central of part to the total surface. The channel numbers (input data) for this program are fixed for all measurements. These numbers are chosen such that the values of S- and W-parameters must not exceed 0.50 and 0.20, respectively.

The values of W-parameter as a function of S-parameter at 4.5 min are plotted in Figure 1. It is clear from Figure 1 that the W-parameter increases as the S-parameter decreases.

By applying Equation 6 to Figure 1 and substituting from S_b and W_b the values of 0.4748 and 0.1463, respectively [13], we can determine the values of S_d and W_d. The values of S_d and W_d were calculated to be 0.4747 and 0.1464, respectively.

The dependence of F-values, which can be calculated from Equation 4 on the alpha particle energies at irradiation time of 4.5 min, is represented in Figure 2. Two regions appear in Figure 2; the first region has low average value of $F = 31.69 \pm 2.68$ and the second has high average value of $F = 53.21 \pm 2.77$. The low α-particle energies show low F-values and vice versa. It can be concluded that the two regions are equivalent to two phases in CR-39 samples due to the effect of chemical etching.

The first phase containing α-particle energies of 1.13, 1.78 and 2.30 MeV, may be called the spherical phase. That is in agreement with previous literature [7]. This phase is formed around the end point of the track and has advanced damage in the CR-39 sample. The

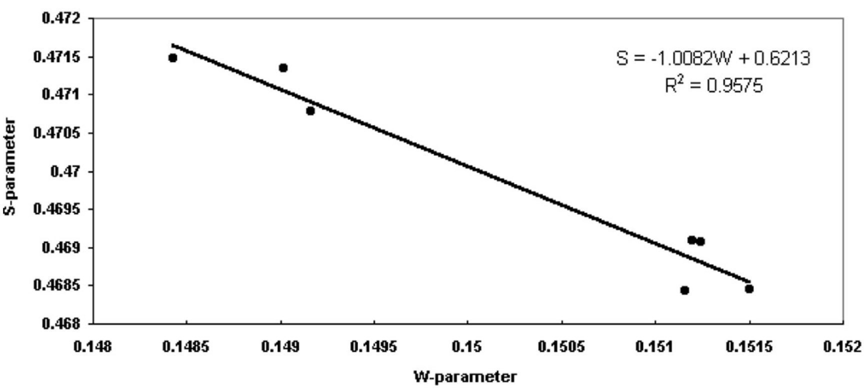

FIGURE 1 The S- and W-parameters in the CR-39 samples at various α-particle energies.

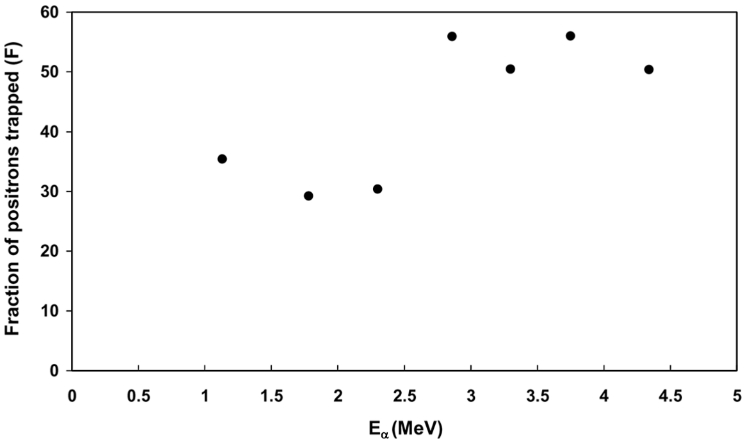

FIGURE 2 Fraction of positrons trapped as a function on the α-particle energies.

etching progresses in all directions with the same rate after the end of the range of α-particles.

The second phase contains α-particle energies of 2.86, 3.30, 3.75 and 4.34 MeV, and may be called the conical phase. This phase was observed in the CR-39 sample where the etching doesn't reach the end of α-particle range with lower damage.

CONCLUSIONS

Positron annihilation Doppler broadening for the CR-39 polymer sample irradiated by α-particles with different energies at 4.5 min irradiation time have been investigated. A good behavior of the fraction of trapped positrons may differentiate between the etching phases for α-particle energies (1.13–4.34 MeV) in CR-39 samples at 4.5 min irradiation time.

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