Positron Annihilation Line Shape Parameters for CR-39 Irradiated by Different Alpha-Particle Doses

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Doppler broadening positron annihilation technique (DBPAT) provides direct information about the change of core and valance electrons in Polyallyl diglycol carbonate (CR-39). CR-39 is widely used as etched track type particle detector. This work aims to study the variation of line-shape parameters (S- and W-parameters) with different α-particle doses of ^{241}Am (5.486 MeV) on CR-39 samples at different energies. The relation between both line-shape parameters was also reported. The behavior of the line-shape S- and W-parameters can be related to the different phases.

1 Introduction

Positron Annihilation Technique (PAT) has been used to probe a variety of material properties as well as carry out research in solid state physics. Recently this technique has become established as a useful tool in material science and is successfully applied for investigation of defect structures present in metal alloys. PAT has been employed for the investigating Polymorphism in several organic materials [1] and it has emerged as a unique and potent probe for characterizing the properties of polymers [2].

Positron Annihilation Doppler Broadening Spectroscopy (PADBS) is a well established tool to characterize defects [3]. The 511 keV peak is Doppler broadened by the longitudinal momentum of the annihilating pairs. Since the positrons are thermalized, the Doppler broadening measurements provide information about the momentum distributions of electrons at the annihilation site.

Two parameters S (for shape), and W (for wings) [4] are usually used to characterize the annihilation peak. The S-parameter is more sensitive to the annihilation with low momentum valence and unbound electrons. The S-parameter defined by Mackenzie et al. [5] as the ratio of the integration over the central part of the annihilation line to the total integration. The W-parameter is more sensitive to the annihilation with high momentum core electrons and is defined as the ratio of counts in the wing regions of the peak to the total counts in the peak.

CR-39 is a polymer of Polyallyl diglycol carbonate (PADC) has been used in heavy ion research such as composition of cosmic rays, heavy ion nuclear reactions, radiation dose due to heavy ions and exploration of extra heavy elements. Some applications include studies of exhalation rates of radon from soil and building materials [6, 7] and neutron radiology [8]. When a charged particle passes through a polyallyl diglycol carbonate, $C_{12}H_{18}O_7$ (CR-39) a damage zone are created, this zone is called latent track. The latent track of the particle after chemical etching is called "etch pit" [9]. The etch pit may be seen under an optical microscope. 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 is increased at vacancies.

2 Experimental technique

Various holder collimators with different heights are used to normally irradiate the INTERCAST CR-39 in air by α-particles [10]. Track detectors "CR-39" were normally irradiated in air by different α-particle energies from 0.1 μCi ^{241}Am source.

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 4.34, 3.75, 3.3, 2.86, 2.3, 1.78 and 1.13 MeV, respectively. The irradiations were verified at 0.5, 2, 3, 4.5 min. After exposures, the detectors were etched chemically in 6.25 M NaOH solution at 70°C for 6 h. The simplest way to guide the positrons into the samples is to use a sandwich configuration. ^{22}Na is the radioactive isotope used in our experiment.

The positron source of 1 mCi 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 ^{22}Na decays by positron emission and electron capture (E. C.) to the first excited state (at 1.274 MeV) of ^{22}Na. This excited state de-excites to the ground state by the emission of a 1.274 MeV gamma ray with half life $T_{1/2}$ of $3{\times}10^{-12}$ sec. The positron emission is almost simultaneous with the emission of the 1.274 MeV gamma ray while the positron annihilation is accompanied by two 0.511 MeV gamma rays. The measurements of the time interval between the emission of 1.274 MeV and 0.511 MeV gamma rays can

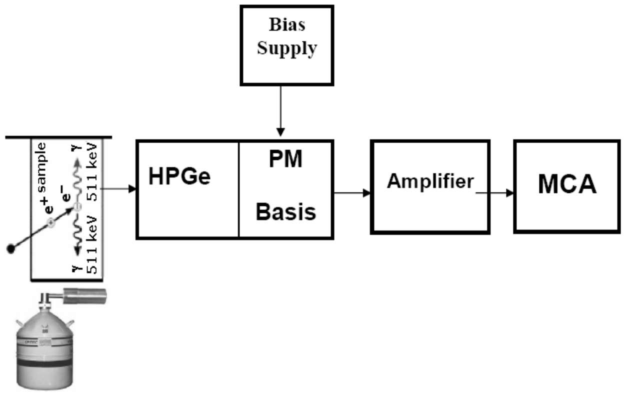

Fig. 1: Block diagram of HPGe-detector and electronics for Doppler broadening line shape measurements.

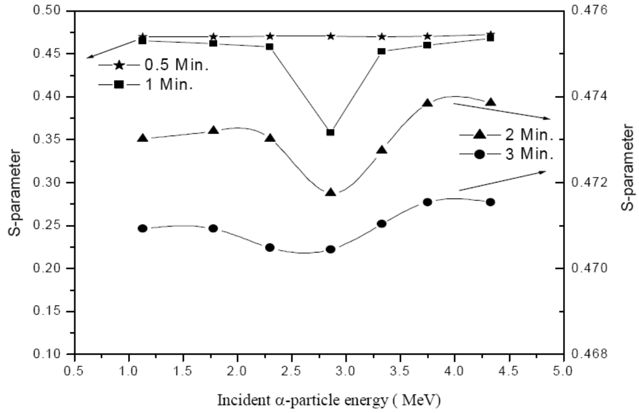

Fig. 2: The variation of S-parameter as a function of irradiation energy for 0.5, 1, 2 and 3 min. irradiation time.

yield the lifetime τ of positrons. The source has to be very thin so that only small fractions of the positron annihilate in the source.

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 bais supply 659, Ortec amplifier 575 and trump 8 k MCA. Figure 1, shows a schematic diagram of the experimental setup. Doppler broadening is caused by the distribution of the velocity of the annihilating electrons in the directions of gamma ray emission. 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 spectrum are collected for 30 min.

3 Results and discussion

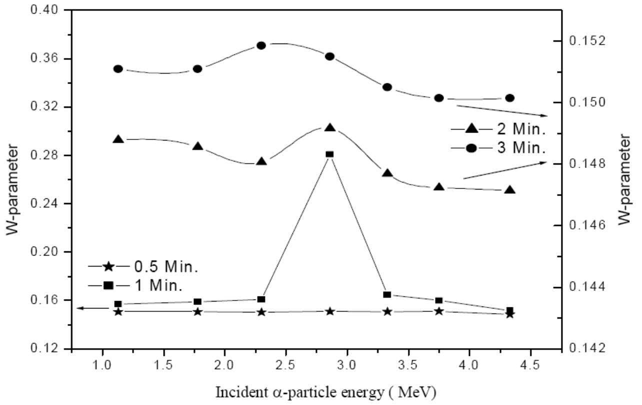

Fig. 3: The variation of W-parameter as a function of irradiation energy for 0.5, 1, 2 and 3 min irradiation time.

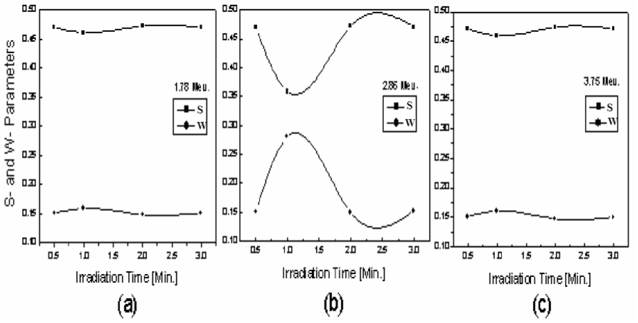

Fig. 4: The variation of S and W parameters as a function of irradiation time for CR-39 samples.

The Doppler broadening line-shape parameters were measured for irradiated CR-39 samples of different α-particle energies at different doses (0.5, 1, 2 and 3 min). The data of S-and W-parameters at 1 min were calculated by Abdel-Rahman et. al. [11]. The Doppler broadening line-shape S- and W-parameters are calculated using SP ver. 1.0 program [12] which designed to automatically analyze of the positron annihilation line in a fully automated fashion but the manual control is also available. The most important is to determine the channel with the maximum 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 results of S- and W-parameters as a function of α-particle energy at different irradiation doses into CR-39 polymer are shown in Figures 2 and 3. From these figures one notice a linear behavior of S- and W-parameters obtained at minimum irradiation time of 0.5 min. The effect of such small irradiation time is very weak to make any variation in line-shape parameters. The values of S- and W-parameters are 47% and 15% respectively at 0.5 min. At longer time (1 min) the S-parameter has values around 46% while values of about 15% are obtained for W-parameter. An abrupt change at 1 min definitely observed at irradiation energy of 2.86 MeV of α-particles for both S- and W-parameters. At this energy a drastically decrease in the S-parameter with deviation of about $\Delta S = 11\%$ comparable with a drastically increase in the W-parameter with deviation of about $\Delta W = 13\%$ [11].

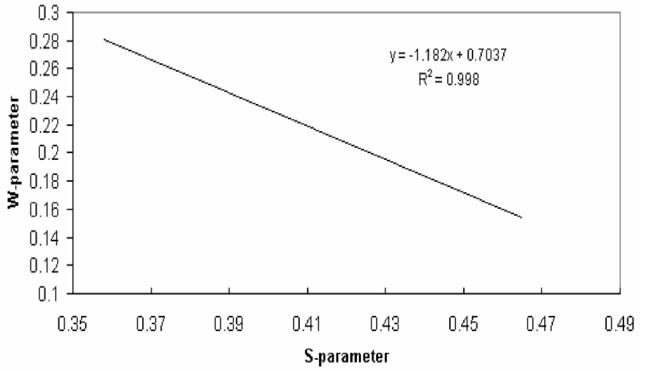

Fig. 5: The correlation between the W-parameter and S-parameter at irradiation time of 1 min.

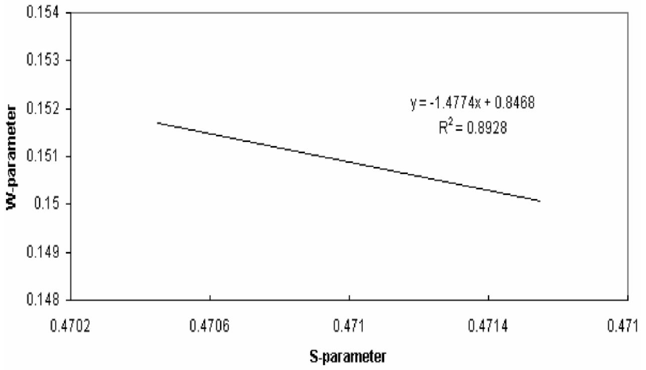

Fig. 6: The correlation between the W-parameter and S-parameter at irradiation time of 3 min.

The S-parameter decreases while W-parameter increases with increasing of irradiation time. Values of about 35% and 25% for S-parameter are obtained at 2 and 3 min respectively for lower energies. The deviation of both S- and W-parameters at 2.86 MeV become very small at longer time as measured at 2 and 3 min. The deviations of $\triangle$S and $\triangle$W reach values less than 0.1% at 3 min (notice different scale on Figures 2 and 3). The behavior of S- and W-parameters reveal an abrupt change at the position of the transition (1 min at 2.86 MeV). The behavior of the line-shape S- and W-parameters can be related to the different phases. Like many others molecular materials, the use of PAT also proven a very valuable in the study of phase transition in polymers.

To recognize more clear the effect of both irradiation time and energy, we take 3 values of energies from presented figures and draw them as a function of irradiation time. Figure 4 (a, b, and c) represent the S- and W-parameters as a function irradiation time for samples irradiated at energies of 1.78, 2.86 and 3.75 MeV respectively. It is much more clear from these figures a slightly change of S- and W-parameters are obtained only at 1 min at irradiation energies of 1.78 and 3.75 MeV. Much more pronounced change in both S- and W-parameters are obtained at the same irradiation time at energy of 2.86 MeV.

The values of W-parameter as a function of S-parameter at 1 and 3 min are plotted in Figs. 5 and 6. It is obvious from these Figures that W-parameter increases as S-parameter decreases for all irradiation times. In addition there are a good correlation with $r^2 = 0.998$ and 0.8928 between S-parameter and W-parameter for 1 and 3 min respectively.

4 Conclusion

The variation of line-shape parameters (S- and W-parameters) at different α-particle doses of ^{241}Am on CR-39 samples for different energies have been studied. The behavior of line-shape parameters at different α-particle doses reveals a pronounced decrease and increase in both S- and W-parameters respectively. A linear behavior of S- and W-parameters are obtained at minimum irradiation time of 0.5 min. An abrupt change of both line-shape parameters, obtained at 2.86 MeV and irradiation dose of 1 min. The W-parameter increases as S-parameter decreases for all irradiation times.

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