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Characteristics of Track-Etch PN-3 Dosimeters for Alpha Particles

Yoo, Done-Sik*
Department of Physics, Queen Mary & Westfield College, University of London, London E1 4NS, U.K.

A method of detecting charged particles in an allyl diglycol carbonate material (PN-3) which is available, amorphous, optically clear and thermoset plastic in which nuclear particle tracks could be revealed by etching in hot NaOH solutions, has been investigated. It has been applied to the study of alpha particle tracks over an energy range of 3.17~5.49 MeV which has been obtained after having passed through several sheets of polycarbonate. The dose equivalent rate of the alpha source was calculated and the spark chamber was used in order to measure the range of alpha particles after having passed through different number of absorbers. The etching characteristics and the detection response of PN-3 have been studied as a funcion of lengths of etched tracks against the parameters of energies and of the track etching rate(V_T). The investigation of the etching process for alpha particles in the PN-3 provided the most interesting results.

1. Introduction

Dielectric solids applicable for the registration of charged nuclear particles have been more and more wodely used in many different branches of science in a variety of experiments in cosmic ray and solar physics, nuclear interactions, fusion research, earth science and radiation dosimetry.

The passage of heavily ionizing, nuclear particles through most insulating solids creates narrow paths of intense damage on an atomic scale. These damaged tracks may be revealed and made visible in an ordinary optical microscope by treatment with a properly chosen chemical reagent that attacks the damaged material. rapidly and preferntially The surrounding undamaged matrix is removed very slowly leaving the etched holes mark and characterize the sites of the original, individual, damaged regions. This simple technique of observing particles has been used in a wide variety of technical fields[1] that range from nuclear science and engineering to cosmic ray astrophysics, geology, archaeology, suboceanic geophysics, lunar science and meteoritics.

One of the useful features of plastics is the possibility of interrupting and then undertaking the development again. This allows the option of measuring the tracks during their formation, this obtaining useful information for the particle identification(charge, energy and mass).

Solid state materials, such as mica, glass and plastics are findig ever increasing use as track detectors of heavy, energetic particles.[2] Among the several kinds of plastic detectors[3]

allyl-diglycol-carbonate (PN-3 or CR-39, Vinten), cellulose-nitrate (Diacel. Kodak), cellulose-acetate, cellulose-acetate-butylrate, polycarbonate (Lexan, Makrolf), polyethylen-teraphtalate (Hostaphan, Melinex) etc., in this report only one has been studied in detail, PN-3.

Many researches[4-9] have used the same detrctor as used in this work for alpha particles. Although they have treated it under different etching conditions, a comparison of its properties will be useful in assessing its applicability.

2. Experimental Procedure

2.1 Characteristics of the Alpha Field

An ^{241}Am alpha source of the activity of 7.4×10^{4} Bq ($=2\ \mu Ci$) has been used and the density of PN-3 is 1.274×10^{3} kg/m^{3} The dose calculated in the PN-3 due to the alpha source is 2.194×10^{-7} Gy and the dose equivalent rate of the source is 81.17 mSv/s with the initial alpha particle energy of 5.49 MeV.

In order to irradiate the dosimeter with alpha particles of different energies, the attenuation characteristics of 2 μm sheets of polycarbonate were determined using the apparatus in Figure 2.1. In the measurement of alpha particle's range in air, water, oxygen etc., the energy of the alpha particle was reduced after having passed through 1~12 sheets of polycarbonate. The measurements have been done to determine the range of alpha particles with different energies as increasing the number of absorbers (2 μm-polycarbonate sheets) and were continued until the plateau region was appeared, and then the residual range was determined. Each value of the range was used to calculate each energy of alpha particles passing through several absorbers of polycarbonate sheets.

Experimental results are shown in Table 2.1. The first column shows the number of polycarbonate sheets and the second column is the range of alpha particles in the air. Energy

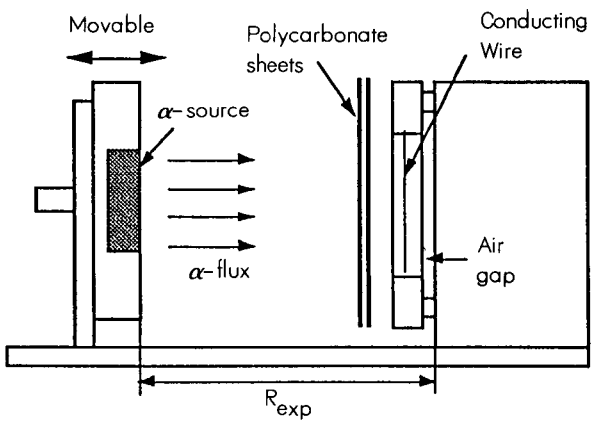

Figure 2.1 The Geometry of the Alpha Source and Spark Chamber.

Table 2.1 Average Energy loss in polycarbonate Sheets

Number of Absorbers	R_{exp} (cm)	E_{exp} (MeV)	E_{cal} (MeV)	E_{mean} (MeV)	*SD*
0	4.26	5.49	5.49	5.49	0.00
1	3.89	5.15	5.29	5.22	0.07
2	3.67	4.98	5.06	5.01	0.06
3	3.43	4.75	4.84	4.80	0.05
4	3.19	4.57	4.62	4.60	0.03
5	2.98	4.43	4.38	4.41	0.03
6	2.73	4.23	4.14	4.19	0.05
7	2.55	4.05	3.91	3.98	0.07
8	2.41	3.98	3.65	3.79	0.14
9	2.05	3.57	3.37	3.47	0.10
10	1.77	3.25	3.08	3.17	0.09
11	1.57	2.97	2.76	2.87	0.11
12	1.35	2.70	2.42	2.56	0.14

values in the third and fourth column are calculated using the experinental range of alpha particles and LET (Linear Energy Transfer) values in ICRU report 16.[10] Energy values used in this article are shown in the fifth column in the table. SD in sixth column means standard deviation of each alpha particle's energy.

2.2 Chemical Etching Procedure

Using the results of alpha particle's energy against the number of absorbers, the PN-3 dosimeter was irradiated with various alpha particle energies (3.17~5.49 MeV). In order to visualize the tracks, the alpha particles were arranged to hit the PN-3 dosimeter's surface at an angle of about 27°using the arrangement illustrated in Figure 2.2.

Each PN-3 dosimeter was marked off into 11 approximately equal areas which were exposed to alpha particles of different energies and each area was irradiated for three minutes. Figure 2.3 shows the areas irradiated by alpha particles of differnt energies. Figure 2.3(*C*)

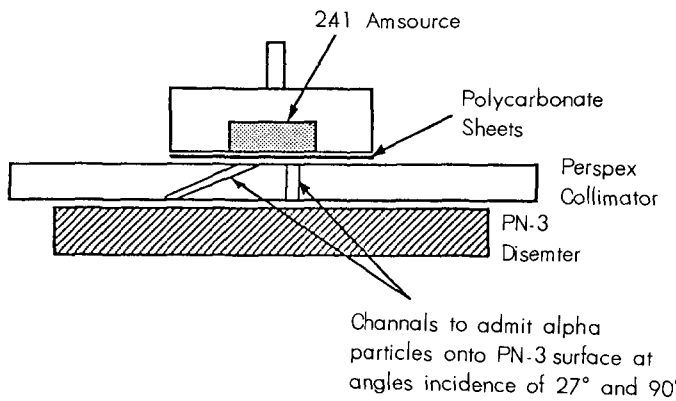

Figure 2.2 Schematic Diagram of the Geometry of the Source and PN-3 Dosimeter with a Collimator. 2μm thick polycarbonate sheets were placed between the source and the collimator.

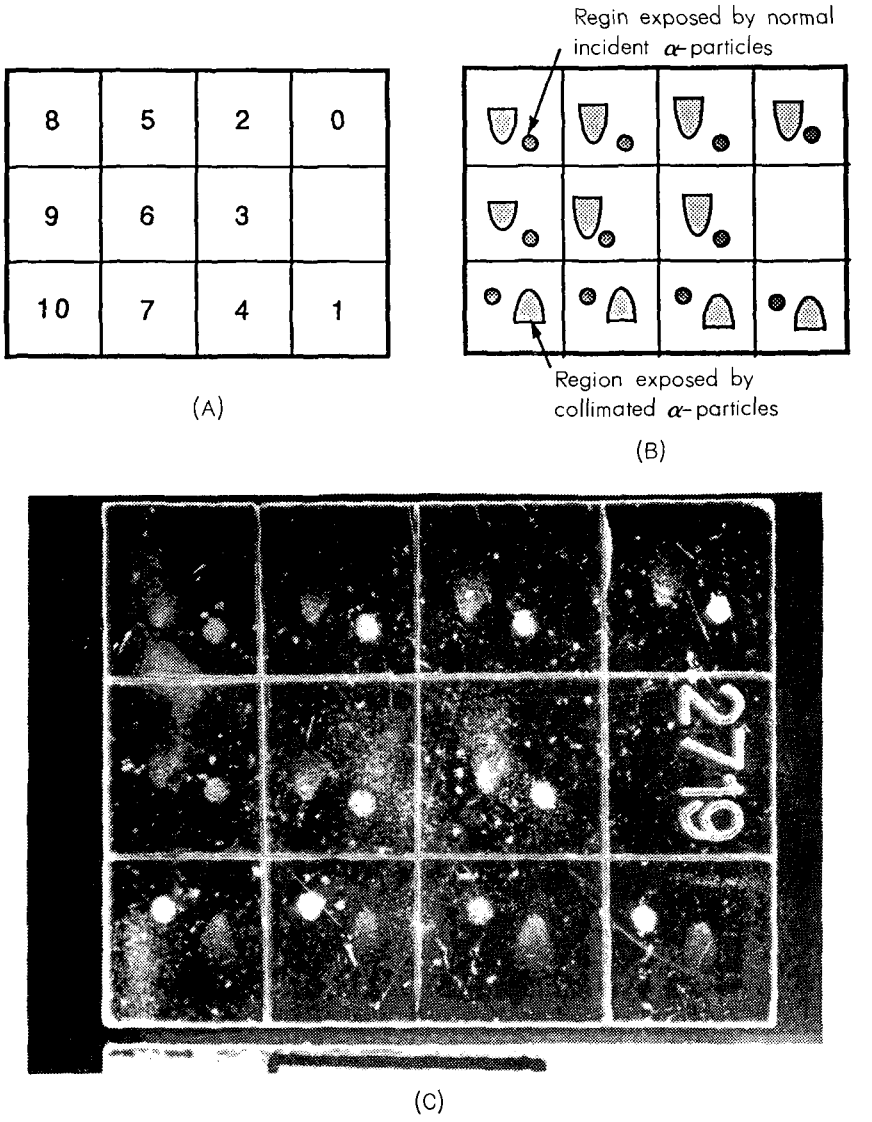

Figure 2.3 The Regions of Exposure on a Typical PN-3 dosimeter. The number corresponds to the number of absorbers (polycarbonate sheets). The scale is 1cm.

shows the picture of the exposed PN-3 with the region divided into the different energies of alpha particles. In order to avoid exposing other regions of the PN-3 dosimeter, sellotape was used to cover those areas not being irradiated. Each PN-3 dosimeter was etched using 6.25 N (Normal) NaOH at 70 ℃[11] but not pre-etched in order not to remove the approximately 60 μm[12] from the etch face which contains much of the low energy alpha particle thracks. The same PN-3 dosimeter was then etched for further etching time so that track structure data could be obtained following 3, 4, and 5 hours etching periods.

The greatest difficulty encountered in the process was the achievement of a constant

temperature over the five-hour period. An electrically heated sand bath was used to heat a beaker of the solution which was magnetically stirred during the etching process. Even though the heater was thermostatically controlled, a problem was experienced in the control of the solution temperature. Without a cover on the top of the beaker, the evaporation of water vapor during the etching process resulted in the etching solution beconimg more concentrated. This problem was partly overcome by covering the beaker and only heating the sand bath to the minimum temperature necessary. After the end of the etching process, the etched PN-3 was rinsed using hot deionized water[11] at temperature of about 80℃.

3. Experimental Results

After etching the dosimeters, the length of tracks was measured using a total magnification of $\times 1000$(a $\times 10$ eyepiece lens and a$\times 100$ objective lens). A higher magnification was now needed because the alpha tracks were shorter than those due to the recoil protons.

As in the case of the neutron irradiated dosimeters, there was not a large variation in the lengths of the tracks for each different energy used. Initially the lengths of up to about 30 tracks were measured for each region, the measurement of each track being made by reference against the calibrated eyepiece graticule. The major graticule area using the $\times 1000$ magnification was 0.75 μm$\times$0.75 μm.

The length of each track was determined from the center of the elliptical entrance to the end of the tail (see Figure 3.1). Because there was a distribution of alpha particle trajectories onto the top surface of the PN-3 dosimeter due to the finite size of the collimator hole, the observed tracks had a distribution both in projected length and in angle. In scanning the projected track lengths, an attempt was made to measure the mean of these distributions by ignoring the very smallest and the very largest features

3.1 Results of Alpha Particle Irradiation

Figure 3.2 shows the shape of alpha particle tracks with differnt energies. It can be seen in Figure 3.2 that the several stages of the develpment of track profiles, i.e., the conical phase (A), the transition phase(B), and the spherical phase(C).

Figure 3.3 shows the distribution of alpha particle's tracks with various etching time as

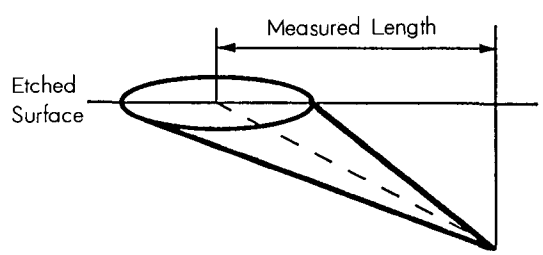

Figure 3.1 Determination of the Track Length.

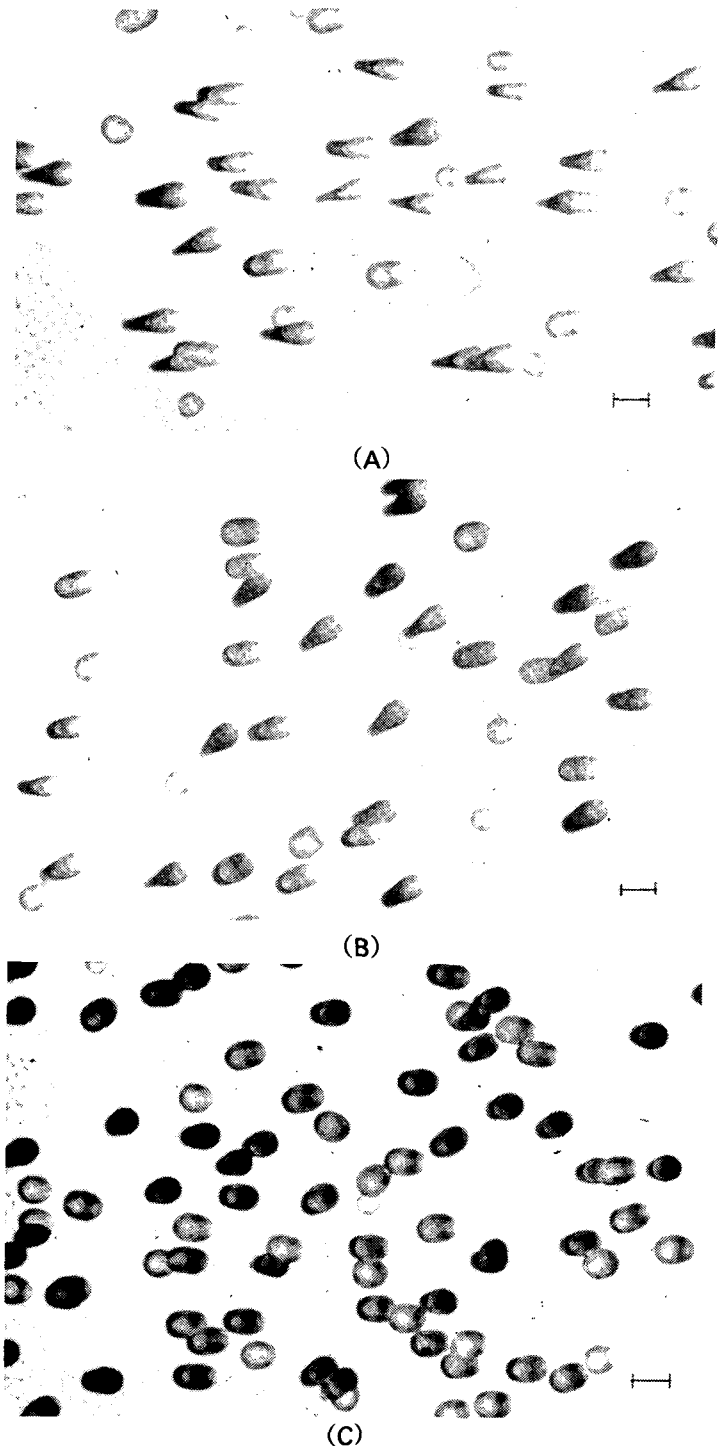

Figure 3.2 Pictures of Alpha Particle Tracks with Different Energies. (A) Alpha particle tracks after having passed through 3 absorbers under the $\times 400$ magnification. (B) 4 Absorbers (C) 5 Absorbers. The scale is 0.1 μm.

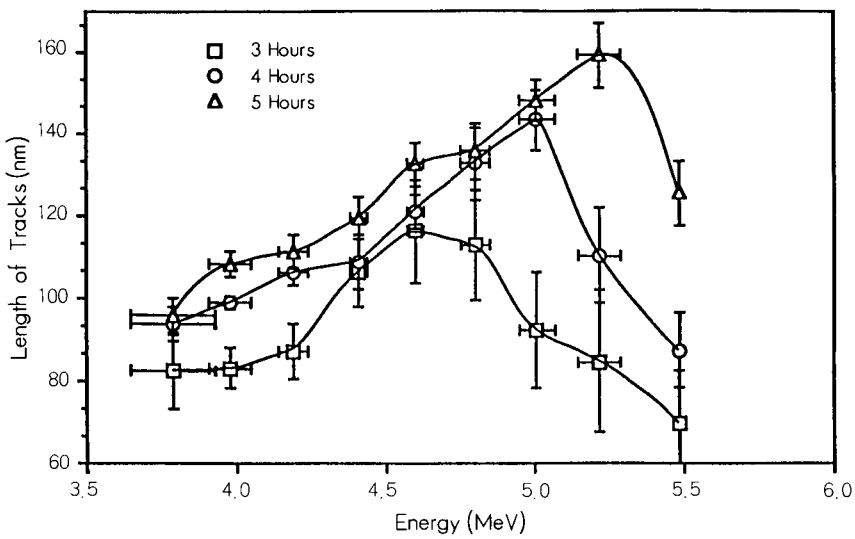

Figure 3.3 Distribution of Alpha Particle Tracks with Different Etching Time.

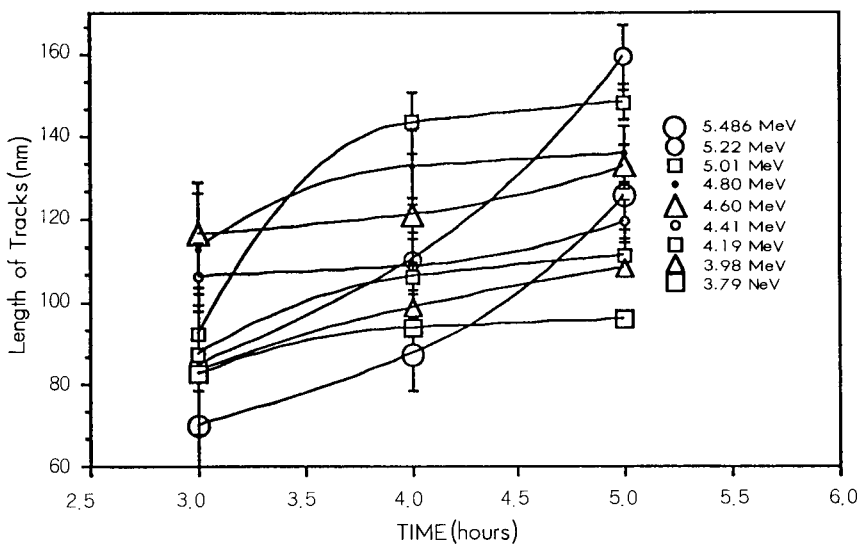

Figure 3.4 Distribution of Alpha Particle Tracks with Differnt Energies.

a function of length of tracks against the incident alpha particle energies. It can be seen that every curve has a peak which shifts to the higher energy and to the longer length as the etching time increased.

Figure 3.4 shows a different view from the same data of Figure 3.3. It shows the relation between various energies as a function of the length of tracks against etching time. It can

be seen that the length of tracks increases with increasing etching time[1],[3],[6],[13~14] and that the track etching rate (V_T) at each energy is different.

It is interesting to compare the length of rtacks for different energies at the same etching time in Figure 3.4. The shortest track, at three hours etch time, corresponds to the highest energy of 5.49 MeV and even at four-hour etch time the highest energy corresponds to the shortest track length. However, when the etching time is increased still further, the tendency is to produce the largest tracks for highest energies as expected.

Similar track length distrlbutions against etching time have been previously reported by other workers although they used different track detector material:CA 80-15[5] or cellulose nitrate.[8] Baroni *et al.* used a 50℃ etch temperature in 6 N NaOH solution and to 70 minutes etch time and Ruddy *et al.* used a continuous method in the same etchant (6.25 N NaOH) but different etching temperature (30℃) for 120 minutes. However, both of them showed the plateau region after the longest etching times.

Our results show the plateau region for several energies, but for high energies (5.22 MeV and 5.49 MeV) and for medium energies (4.41 MeV and 4.60 MeV), the curves tend to go up with increasing etching time. For the high enegies, the tendency to increase is seen more clearly than at the medium energies.

Figure 3.5 shows that the relation between the energies and the track etching rate (V_T) derived from the gradient[3] of each curve in Figure 3.4. It can be seen in Figure 3.5 that there are two maximum values at 3.98 MeV and at 5.22 MeV.

3.2 Etching Process for Different Energies with Various Etching Time

The phenomenon of the shift of the energy peak in Figure 3.3 can be explained by the

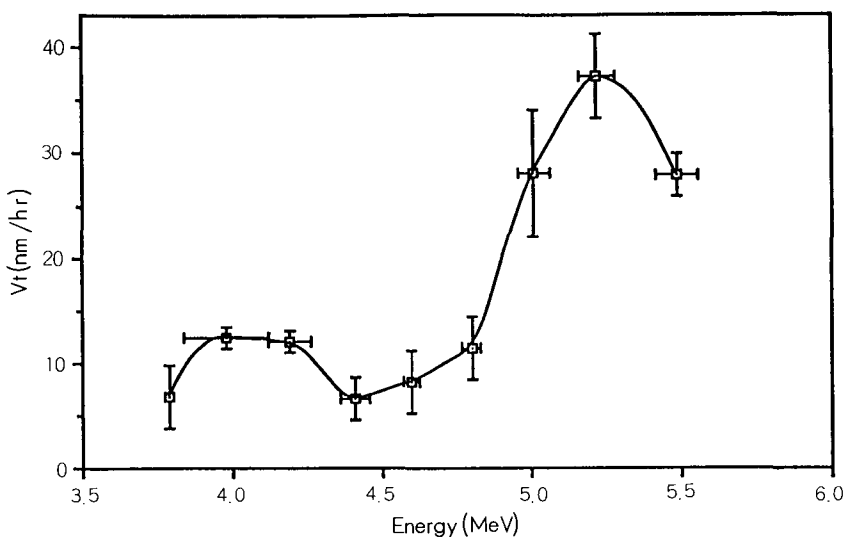

Figure 3.5 Distribution of the Alpha Particle Energy vs. Track Etching Rate.

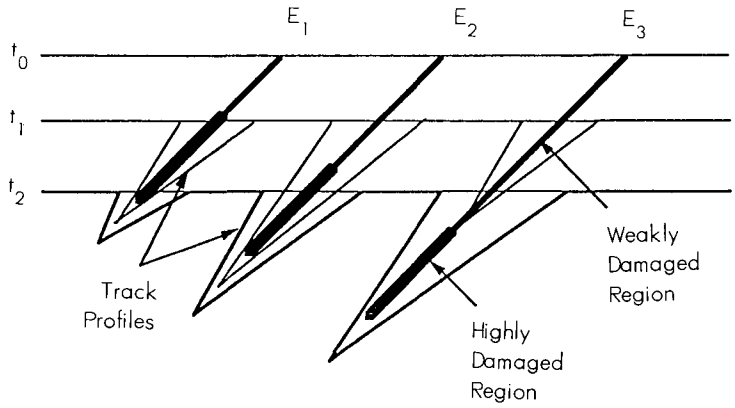

Figure 3.6 The Profile of Tracks with Differnt Incident Energies ($E_1<E_2<E_3$) and Several Etching Time ($t_0<t_1<t_2$).

fact that the higher energy alpha particle will penetrate further into the PN-3 plastic so that the region of highest LET (Linear Energy Transfer), or REL (Restricted Energy Loss), and therefore the greatest damage, will be at a greater depth than for low energy alpha particles (see Figure 3.6). If the etching process is more effective in the region of the greatest damage, then the low energy particles will produce larger pits than high energy particles for short etch times.

Figure 3.6 shows the schematic diagram of the etching process for different energies ($E_1<E_2<E_3$) of alpha particles with various etching times ($t_0<t_1<t_2$) based on our results. After etching time t_1, the track length of E_2 is larger than that of E_3 because the etchant has reached the highly damaged region (HDR), in which the etchant can attack the track more rapidly than (relatively) weakly damaged region (WDR) (i.e. lower V_T region), of E_2 track but reached only WDR of E_3 track.

In other words, the track etching rate of HDR is higher than normal latent track (WDR). Also the depth of HDR of each track seemed to depend on the incident energy of alpha particles, i.e., the higher energy particle produces a longer track in the PN-3 so that the HDR is located deeper than for the lower energy particle track. However, the size of HDR of each energy might be the same because the incident source of alpha particles is the same (only difference is that they pass through a different number of polycarbonate sheets). After raching the end of the HDR, the etching velocity will follow the bulk etching rate of the dosimeter.

4. Conclusions

The method of etching tracks of PN-3 dosimeter has been applied to tracks of alpha particles with various energies (3.17~5.49 MeV). Both the etch and the detection response of PN-3 has been studied as a function of etched-track lengths against various parameters. However, here further studies are needed.

For the alpha particle detection in the PN-3, the distribution curves were plotted as a function of the track sizes against the incident alpha particle energies with various etching time (3~5 hours). Every curve has a peak which shifts to the higher energy and to the longer track length as the etching time increased (see Figure 3.3). It can be explained that the higher energy alpha particle would make the deeper latent region which is more damaged at the end of the track but the size of the region is the same. Also the higher energy alpha particle is likely to have the higher value of LET (Linear Energy Thransfer), or REL (Restricted Energy Loss) in the PN-3 dosimeter.

The higher energy alpha particle will penetrate the PN-3 plastic that the region of highest LET (or REL), and therefore, the greatest damage will be at a greater depth than for low energy alpha particles (see Figure 3.6). If the etching process is more effective in the region of the greatest damage, then the low energy particles will produce larger pits than high energy particles for short times. The etchant seemed to be able to more easily attack the highly damaged region than the normal latent damaged track.

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알파입자 부식-새김을 이용한 PN-3 선량측정기의 특성

유 돈 식
런던대학교 물리학과 의학물리학 전공

본 논문에서는 플라스틱 검출기의 일종인 알릴 다이글리콜 카보네이트 물질 (PN-3)에서의 하전입자의 검출 방법과 여러장의 흡수체를 통과하여 얻어진 알파 입자의 에너지(3.17~5.49 MeV)에 대한 알파입자 궤적의 특성을 논의하였다. 또한 등가흡수선량율을 계산하였고, 알파입자의 도달거리를 특정하기위해 섬광계수기를 사용하였다. PN-3의 에칭특성과 검출특성등이 여러가지 변수들로 표현되었다. 즉, 부식당한 입자궤적의 길이가 갖는 각각의 알파입자 에너지에대한 연관성등을 논의하였다. PN-3 플라스틱 선량 검출기에 기록된 알파입자의 에칭과정에서 매우 흥미있는 결과를 얻었다.

* Present Address : Nuclear Physics Laboratory, Department of Physics; Korea Vniversity, Seoul 136~701.