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TECHNICAL NOTE

RESPONSE OF DIFFERENT PLASTIC TRACK DETECTORS TO α-PARTICLES

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Abstract—Samples of various plastic track detectors, namely CR-39, CR-39 (DOP) and SR-86, were exposed to α-particles from radioactive sources, ^{241}Am and ^{252}Cf. The exposed samples were etched in 6.25 N NaOH solution at a constant temperature of 70°C. In the present study, a comparison of the sensitivity of these detectors to α-particles has been made. Finally, an attempt has been made to determine the optimum conditions for the etching of SR-86 plastic track detector. © 1997 Elsevier Science Ltd

1. INTRODUCTION

Scientific and technological applications of solid state nuclear track detectors (SSNTDs) have stimulated efforts to develop better track recording solids. The sensitivity of these track detectors can be represented by the ratio of track etch rate, V_t and bulk etch rate, V_b, i.e. V_t/V_b, or the minimum detectable value of charge to velocity ratio $(Z/\beta)_{min}$. In the past few years, a number of new latent track recording materials, e.g. glasses, minerals, plastics, etc. have been reported in the literature (Cartwright *et al*., 1978; Price and Tarle, 1985; Price *et al*., 1987; Fujii *et al*., 1988; Wang *et al*., 1988). From the class of plastic track recorders, CR-39, discovered by Cartwright *et al*. (1978) is now used in many applications because of its high detection sensitivity and charge resolution. To record the particles having a minimum value of (Z/β), various attempts have been made to improve the sensitivity of CR-39. Tarle *et al*. (1981) have found that sensitivity and post-etch properties of CR-39 can be improved after doping it with 1% dioctyl phthalate; it is then known as CR-39 (DOP). Salamon *et al*. (1985) have recorded a charge resolution of $\sigma_z = n^{-1/2}(0.12 + 0.006Z^*/\beta)e$ by this detector, where n is the number of etch pits whose major axes are measured in a stack of thin sheets and Z^* and β are the effective charge and velocity, respectively.

Various research groups working on the same problem have reported a large number of plastic track detecting materials, namely Tuffak polycarbonate, CN-85 (manufactured by Kodak Pathe), CR-73 (Price and Tarle, 1985), (MA-ND)/α (made at ATOMKI, Debrecen, Hungary) and SR-86 (Fukuvi, Japan). The sensitivity of polymeric track detectors is known to be affected by various factors such as the purity of monomer, molecular structure of polymers (Stejny and Portwood, 1986), polymerization conditions (Henshaw *et al*., 1981; Somogyi *et al*., 1986), addition of antioxidants (Benton *et al*., 1986) and environmental conditions during irradiation and etching conditions (Amin and Henshaw, 1981; Green *et al*., 1982). The dependence of track response on registration temperature and oxygen environment has been studied by Thompson and O'Sullivan (1984) and Drach *et al*. (1987), respectively. In order to develop polymers of high sensitivity and good etching properties, Fujii *et al*. (1984) attempeted to add small quantities of chlorinated compounds to CR-39 and have achieved some improvements. Fujii (1985) has studied the relationship between the molecular structure and the sensitivity to charged particles by using commercially available thermosetting resins. Most recently, Fujii *et al*. (1988, 1991) have shown that the introduction of sulphonate groups into thermosetting resins with three-dimensional network structures increases both bulk and track etch rates. This new track detector, known as SR-86, is a copolymer of CR-39 with DEAS, diethylene glycol allyl sulphonate, and shows higher sensitivity than CR-39 for 6 MeV α-particles and relativistic iron nuclei. In the present work, a sensitivity comparison of various plastic track detectors, namely CR-39, CR-39 (DOP) and SR-86, to α-particles has been made.

Table 1. Various track etching parameters of CR-39 plastic track detector exposed to α-particles from ^{241}Am and ^{252}Cf radioactive sources

Etching time (h)	Track diameter (μm)	Sensitivity $S = V_t/V_b$	Etching efficiency $\eta = 1 - (V_b/V_t)$ (%)	Critical angle of etching $\theta_c = \sin^{-1}(V_b/V_t)$
(a) α-particles from ^{241}Am				
4.0	4.72 ± 0.14	2.00	50.00	30.00
6.0	7.23 ± 0.21	2.07	51.69	28.88
8.0	10.29 ± 0.34	2.32	56.82	25.58
10.0	13.29 ± 0.47	2.47	59.54	23.84
12.0	14.67 ± 0.24	2.12	52.89	28.10
14.0	16.11 ± 0.36	1.94	48.33	31.11
16.0	17.73 ± 0.35	1.84	45.56	32.98
18.0	19.01 ± 0.53	1.63	38.76	37.76
(b) α-particles from ^{252}Cf source				
10.0	12.47 ± 0.09	2.19	54.33	27.19
12.0	14.15 ± 0.28	2.00	50.00	30.00
14.0	15.20 ± 0.59	1.79	44.13	33.96
16.0	17.04 ± 0.76	1.75	42.82	34.87

2. EXPERIMENTAL DETAILS

The different types of plastic track detectors, i.e. CR-39, CR-39 (DOP) and SR-86 were exposed to α-particles from the radioactive sources ^{241}Am (5.4 MeV) and ^{252}Cf (6.1 MeV). After creating a vacuum in the glass chamber, the samples of different types of plastics were exposed at an angle of 90° for half an hour. After irradiation these samples were cut into small pieces and etched in 6.25 N NaOH at a constant temperature of 70°C. In order to compare the sensitivity of these detectors, the irradiations and etching conditions were kept the same. The etched samples were washed in running water and dried in folds of tissue paper. The washed and dried samples were scanned under the Carl Zeiss optical microscope. The track diameter in each case was measured by a Filler Eye Piece having a least count of 0.23 μm.

The bulk etch rate, V_b, is determined by using two different techniques: (1) the thickness measurement technique, and (2) the diameter measurement technique.

The thickness measurement technique was applied by measuring the thickness of each sample before and after etching for 18 h. For determining the bulk etch rate by diameter measurement, the samples of the various plastics, CR-39, CR-39 (DOP) and SR-86, were exposed to fission fragments of ^{252}Cf. The bulk etch rate was determined by measuring the diameter of fission fragment tracks after etching in 6.25 N NaOH solution at a temperature of 70°C for 2 h. The track etch rate, V_t, is determined by using the relationship:

$$V_t = \frac{4V_b^3t^2 + V_bD^2}{4V_b^2t^2 - D^2} \quad (1)$$

The track etching parameters, i.e. the sensitivity, the etching efficiency and the critical angle of etching, have been determined using the following relationships (Durrani and Bull, 1987):

$$\text{Sensitivity, } S = V_t/V_b\,, \quad (2)$$

$$\text{Track etching efficiency, } \eta = 1 - (V_b/V_t), \quad (3)$$

$$\text{Critical angle of etching, } \theta_c = \sin^{-1}(V_b/V_t) \quad (4)$$

3. RESULTS AND DISCUSSION

Tables 1–3 present the values of various track etching parameters such as sensitivity (S), etching efficiency (η) and critical angle of etching (θ_c) for CR-39, CR-39 (DOP) and SR-86 exposed to α-particles from ^{241}Am and ^{252}Cf. The variation in track diameter with etching time for these three detectors is shown in Fig. 1. In the field of SSNTDs, the sensitivity, S, given by the ratio of the rate of etching along the path of the damaged trail to the rate of etching of the undamaged material, is the most important parameter. From these tables it is clear that the S value for SR-86 is higher than that of

Table 2. Various track etching parameters of CR-39 (DOP) plastic track detector exposed to α-particles from ^{241}Am radioactive sources

Etching time (h)	Track diameter (μm)	Sensitivity $S = V_t/V_b$	Etching efficiency $\eta = 1 - (V_b/V_t)$ (%)	Critical angle of etching $\theta_c = \sin^{-1}(V_b/V_t)$
4.0	4.00 ± 0.26	1.75	42.86	34.84
8.0	9.86 ± 0.99	2.40	58.33	24.62
10.0	12.62 ± 0.35	2.53	60.47	23.28
12.0	14.18 ± 0.43	2.22	54.95	26.77
14.0	16.26 ± 0.33	2.15	53.48	27.72
16.0	18.22 ± 0.33	2.08	51.92	28.74
18.0	19.99 ± 0.50	2.00	50.00	30.00

Table 3. Various track etching parameters of SR-86 plastic track detector exposed to α-particles from ^{241}Am and ^{252}Cf radioactive sources

Etching time (h)	Track diameter (μm)	Sensitivity $S = V_t/V_b$	Etching efficiency $\eta = 1 - (V_b/V_t)$ (%)	Critical angle of etching $\theta_c = \sin^{-1}(V_b/V_t)$
(a) α-particles from ^{241}Am				
4.0	5.32 ± 0.36	2.34	57.26	25.29
8.0	11.85 ± 0.38	2.98	66.44	19.60
10.0	14.62 ± 0.35	2.99	66.55	19.54
12.0	17.04 ± 0.31	2.69	62.82	21.82
14.0	19.83 ± 0.40	2.66	62.40	22.08
16.0	22.77 ± 0.34	2.65	62.26	22.17
18.0	24.73 ± 0.35	2.50	60.00	23.58
(b) α-particles from ^{252}Cf				
8.0	11.19 ± 0.32	2.59	61.38	22.71
10.0	14.54 ± 0.41	2.82	64.61	20.72
12.0	16.44 ± 0.61	2.48	59.71	23.75
14.0	18.86 ± 0.23	2.40	58.35	24.61
16.0	21.39 ± 0.62	2.36	57.71	25.01
18.0	23.65 ± 0.32	2.29	56.27	23.93

CR-39 and CR-39 (DOP) plastic track detectors. Such evidence is also available from Fig. 2 which gives the variation in sensitivity of CR-39, CR-39 (DOP) and SR-86 to α-particles from ^{241}Am with etching time. At the start, the sensitivity (S), of all three types of plastic detectors increases with the increase in etching time and attains a maximum value, then it starts decreasing with time. It has been observed that the maximum value of S is attained for 10 h of etching time for all the detectors. The maximum value of S to α-particles is 2.47, 2.53 and 2.99 for CR-39, CR-39 (DOP) and SR-86, respectively. It is evident that the sensitivity (S) (after etching for 10 h in 6.25 N NaOH) of SR-86 is about 18% and 21% greater than that of CR-39 (DOP) and CR-39, respectively. Similar evidence was obtained by Ansari *et al.* (1991) i.e. that the sensitivity (S) of SR-86 is 15% and 20% more than that of American Acrylic, CR-39 and Pershore Moulding CR-39, respectively.

The track etching efficiency is one of the most important criteria in the choice of a detector. As the etching efficiency (η) depends upon the ratio V_b/V_t it is clear from the tables that it shows the same sensitivity behaviour for all three detectors and has a

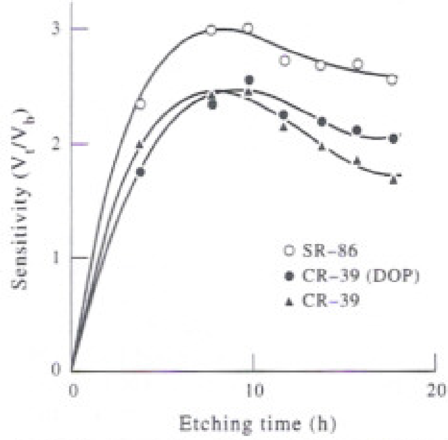

Fig. 2. Variation of sensitivity (S) of CR-39, CR-39 (DOP) and SR-86 to α-particles from a ^{241}Am radioactive source.

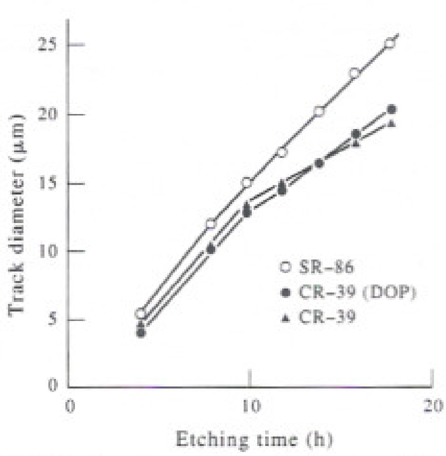

Fig. 1. Variation of α-particle track diameter with etching time in SR-86, CR-39 and CR-39 (DOP).

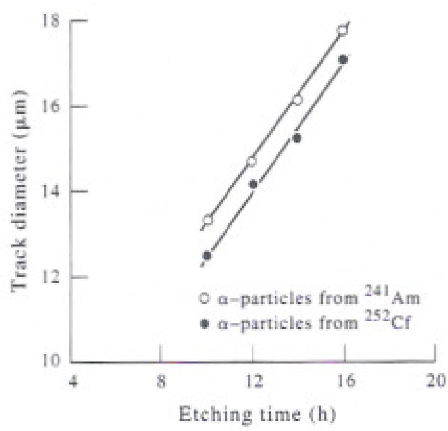

Fig. 3. Variation of track diameter with etching time in CR-39 for two types of α-particles from ^{241}Am and ^{252}Cf radioactive sources.

Table 4. Various track etching parameters of SR-86 plastic track detector exposed to α-particles from ^{241}Am radioactive source (etchant 6.5 N KOH:6.25 N NaOH)

Etchant ratio	Track diameter(μm)	Sensitivity $S = V_t/V_b$	Etching efficiency $\eta = 1 - (V_b/V_t)$ (%)	Critical angle of etching $\theta_c = \sin^{-1}(V_b/V_t)$
1:0	19.73 ± 0.57	2.57	61.05	22.91
3:1	18.72 ± 0.52	2.62	61.68	22.52
2:1	17.44 ± 0.73	2.83	64.66	20.69
1:1	15.92 ± 0.27	2.57	61.11	22.88
0:1	11.85 ± 0.85	2.98	66.44	19.60
1:3	14.84 ± 0.66	2.41	58.50	24.51

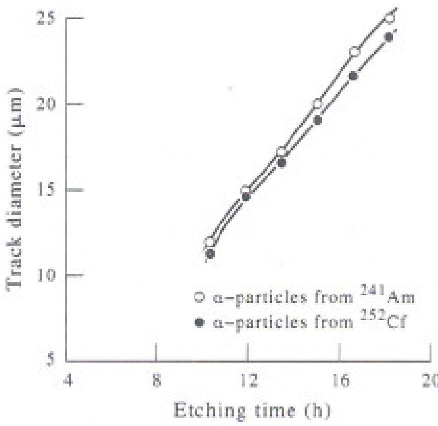

Fig. 4. Variation of track diameter with etching time in SR-86 for two types of α-particles from ^{241}Am and ^{252}Cf radioactive sources.

higher value for SR-86. The maximum value of η is found to be 59.54 for CR-39, 60.47 for CR-39 (DOP) and 66.55 for SR-86. The latent tracks with inclination less than cone angle, θ_c (critical angle of etching) to a surface are not etched out, so in order to make the tracks visible by etching in a suitable etchant, the angle of incidence of the particle to the detector surface should be greater than θ_c. The minimum values of θ_c for CR-39, CR-39 (DOP) and SR-86 detector are 23.84, 23.28 and 19.54°, respectively. Figures 3 and 4 show the variation of track diameter with etching time for α-particles from ^{241}Am and ^{252}Cf radioactive sources in CR-39 and SR-86 plastic track detectors. It is evident from these figures that both these detectors can be used successfully to resolve the α-particles of different energies.

From the above study it may be concluded that the SR-86 is the most sensitive track detector (for α-particles) amongst the class of plastic track recorders having higher sensitivity, better etching efficiency and lower critical angle of etching. Due to the higher sensitivity of SR-86, there is a need to determine the optimum etching conditions for this detector. Like CR-39, SR-86 is also etchable in KOH solution. Waheed *et al*. (1990) reported that the sensitivity of CR-39 to protons in the energy range 0.41–1.17 MeV can be significantly increased by etching in a mixed solution of 6.5 N KOH and 6.25 N NaOH at a ratio of 2:1 at 60°C. He and Solarz (1995) carried out a similar study on CR-39 exposed to 200A GeV ^{32}S and pointed out that 6.5 N KOH:6.25 N NaOH in the ratio 1:3 gives better results. We have carried out a similar study on SR-86 in order to find the optimum etching conditions, by etching in different proportions of 6.5 N KOH and 6.25 N NaOH solution at 70°C. Table 4 presents the track diameter, sensitivity, etching efficiency and critical angle of etching for SR-86 exposed to α-particles (^{241}Am source) etched in various mixing ratios of 6.5 N KOH and 6.25 N NaOH solution at 70°C after an etching interval of 8 h. From this table it is clear that for the same etching time and temperature, the track diameter of α-particles etched in 6.5 N KOH solution is greater than that of its value in 6.25 N NaOH solution. Hence, the bulk etch rate of SR-86 at 70°C in 6.5 N KOH is higher than that in 6.25 N NaOH solution. It is also evident from the table that any mixture of 6.5 N KOH and 6.25 N NaOH solution does not give better sensitivity than 6.25 N NaOH solution. In comparison to pure 6.5 N KOH, 6.25 N NaOH solution gives better results. The mixture of 6.5 N KOH and 6.25 N NaOH in the ratio 2:1 results in lower sensitivity in comparison to 6.25 N NaOH solution.

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