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Track Registration Characteristics of Low-Energy Protons in Cellulose Nitrate (CN-85)

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Abstract

We describe our efforts to determine the most important track registration parameters for the suitable use of CN-85 track detectors in the registration of low energy protons.

1. Introduction

Cellulose Nitrate CN-85 track detectors have been extensively used in a variety of studies [1–2] and are considered suitable for the detection of particles involved in radon studies [3–5]. However, it has been speculated that CN-85 is insensitive for the detection of protons [6–8], and a number of investigators in their numerous studies have shown different reasons for the non-detection of proton tracks in these detectors [9–10]. In order to study the suitability of CN-85 for low energy protons, various track registration parameters—such as etching conditions, critical angle of etching, etching velocities and variation of the etch rate ratio (ERR) as a function of restricted energy loss (REL) and effective charge number Z_{eff}—are of immense importance [11–14]. In the present work, we describe our efforts to determine the most important track registration parameters, i.e. critical angle of etching, etch rate ratio (ERR) and etching efficiencies for application over the proton energy range 200–400 KeV. Effects of prolonged etching and energy of protons on track diameter were also studied.

2. Experimental Work

2.1. Irradiation of the detectors

A multi-target brass chamber was designed and constructed for exposing several solid state nuclear track detectors to different energy protons supplied by a continuously running 1.2 MeV Cockroft & Walton Accelerator, installed in the Center for Advanced Studies in Physics, Government College, University Lahore, Pakistan. This facilitates the study of several CN-85 detectors without dismantling and disturbing the vacuum-tight target chamber. These detectors were exposed at 90° to protons in the energy range 200–400 KeV with the lowest possible current, on the order of 10^{-9} amperes.

2.2. Etching

The exposed CN-85 detectors were etched in freshly prepared 6N NaOH at a temperature of 70 °C. All etching was carried out over 10–20 minutes in order to see the effect of prolonged etching on track diameter, with special reference to energy of incident protons. After etching, well rounded circular tracks of normally incident protons on the CN-85 detectors were observed.

2.3. Scanning and measurements

An optical microscope loaded with a calibrated foil eyepiece micrometer was used for measuring the proton induced track diameter. Measurements were carried out under magnification of 12.5× for a total scanned area of the detector equal to 76 × 10^{-4} cm^2. The observed results regarding the track diameter corresponding to etching time and energy of incident protons are given in Figures 1–2.

The following equation (3) has been derived [11] to estimate the etch rate ration (ERR), also called sensitivity, $V = \frac{V_T}{V_B}$, of the etchable track detectors due to normal incidence of charged particles.

$$D = 2\,V_B T \sqrt{\frac{V_T - V_B}{V_T + V_B}} \tag{1}$$

On squaring both sides and simplifying, we get

$$V_B \left[1 + \left(\frac{D}{2V_B T}\right)^2\right] = V_T \left[1 - \left(\frac{D}{2V_B T}\right)^2\right] \tag{2}$$

This leads to

$$V = \frac{V_T}{V_B} = \frac{1 + \left(\frac{D}{2V_B T}\right)^2}{1 - \left(\frac{D}{2V_B T}\right)^2} \text{ or } V = \frac{1 + \left(\frac{D}{2h}\right)^2}{1 - \left(\frac{D}{2h}\right)^2} \tag{3}$$

Here, D is the surface diameter of the track and $h = V_B T$ is the amount of the bulk material removed from the surface of the sheet during the etching. Diameter is measured by using a micrometer attached to the eyepiece of microscope and V_B is measured by the change in the thickness of the detector using the relation $V_B = h/T$ [15]. Thickness of the detectors was measured before and after etching for 120 minutes, from different five corners of the detector sheet. We measured V_B for each detector. The reduced thickness and the corresponding value of V_B as a function of energy of incident protons is given in Table 1. The measured values of V_B for proton energy ranging from 200–400 KeV varies slightly; therefore the mean value of V_B is taken as the best suitable choice.

Table 1. Estimation of bulk etching rate for various proton energies in CN-85 detector.

Energy of Protons (keV)	Reduction in the Detector Surface (μm)	Bulk Etching Rate, V_B (μm min^{-1})
200	22.2	0.0925
250	23.38	0.097
300	23.76	0.098
350	22.75	0.0948
400	26.92	0.112
Average Value of V_B = 0.099 (μm min $^{-1}$)		

The track registration efficiency of CN-85 for different energy protons can be calculated by using θ_c from the following equation [12–14]:

$$\eta = 1 - Sin\,\theta_c, \tag{4}$$

where θ_c, the critical angle of etching, represents the minimum angles to the surface that a track can make in order to be revealed by etching.

We have estimated some important etching parameters as regards CN Detectors by low energy protons (see Table 2) along with a comparison of CN-85 & CR-39 by high energy protons (see Table 3).

Table 2. Estimation of some important etching parameters for detection of low energy protons. Detectors were etched in 6N NaOH solution at 70 °C for 120 minutes.

Energy of Protons keV	Etching Velocity V	Cone Angle of Etching $(\Psi)^\circ$	Critical Angle of Etching $(\theta_c)^\circ$	Detection Efficiency $(\eta)\%$
200	5.0	23.2	11.6	79.9
250	4.6	25.4	12.7	78.0
300	4.1	28.0	14.0	75.8
350	3.4	30.8	15.4	73.4
400	3.6	32.7	16.4	71.8

Table 3. Comparison of some important etching parameters for detection of different energy protons in CN-85 and CR-39 detectors.

Energy of Protons	Critical Angle of Etching θ_c (degrees)	Detection Efficiency η(%)	Detector & Etching Conditions	Reference
200 KeV	11.6	79.9	Cellulose Nitrate (CN-85) 6N NaOH 70 °C, 120 min.	Present Work
250 KeV	12.7	78.0		
300 KeV	14.0	75.8		
350 KeV	15.4	73.4		
400 KeV	16.4	71.8		
1 MeV	35.6	41.8	Cellulose Nitrate (CN-85) 6M NaOH 70 °C 30 min	Faghih-Habibi (1994) [18]
1.2 MeV	36.5	40.5		
1.55 MeV	38.2	38.1		
1.85 MeV	41.3	34.0		
2 MeV	45.0	29.3		
1.2 MeV	27	54.6	Allyll Diglycol Carbonate (CR-39) 6N NaOH 70 °C 12 h	Khan et. al (1984) [17]
1.8 MeV	36	41.2		
3.9 MeV	48	25.7		
5.1 MeV	52	21.2		
7.6 MeV	57	16.1		
10 MeV	61	12.5		

3. Results and Discussion

The variation of track diameter as a function of proton energy (200–400) KeV for 120 minutes etching in different intervals of time is given in Figure 1. Track diameter increases linearly with etching time and this behavior is common for all exposed detectors with the protons of different energy. A decrease in the track diameter with increase of energy is quite evident following the energy loss rate, $\frac{dE}{dX}$ for given media [15-16] as shown in Figure 2. This variation, however, is small due to the small energy range of protons for which tracks have been revealed.

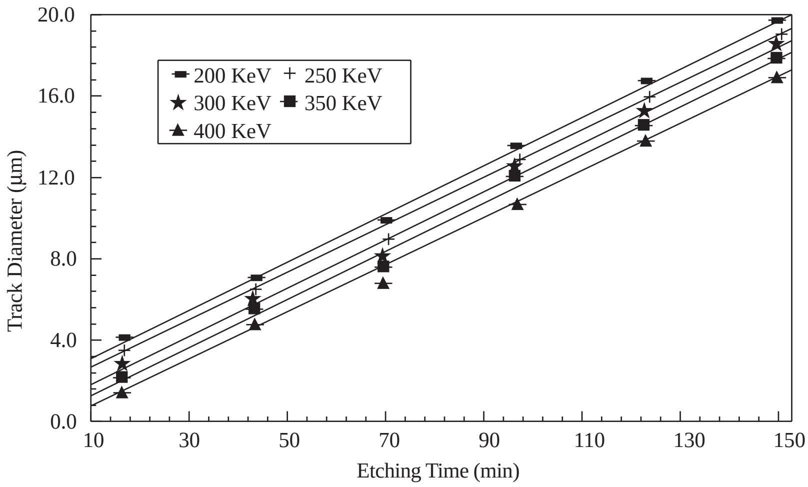

Figure 1. Variation of track diameter in CN-85 track detectors for different etching times at different energies of protons.

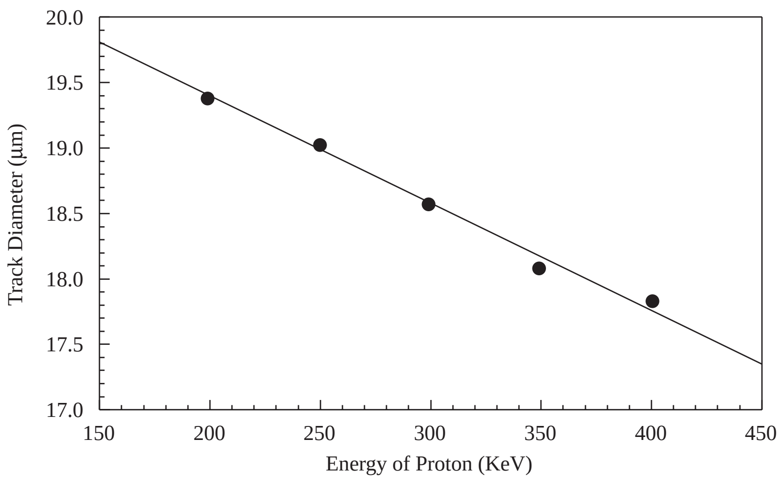

Figure 2. Variation of track diameter as a function of different proton energies with etching time. The detectors were etched upto 120 minutes.

The results of the cone angle, critical angle of etching and etching efficiencies for various proton energies are given in the Table 2. Cone angle is observed to increase with proton energy. Maximum track registration efficiency of 79.87% has been found for protons having 200 KeV energy, monotonically decreasing with the increase in proton energy.

The observed track registration characteristics resembles those observed by Khan [17], for investigation of critical angle of etching and etching efficiencies of protons in CR-39 track detectors, and by Faghih-Habibi [18], in his work for detection of high energy protons in CN-85. The results of both workers, along with the present study, are summarized in Table 3. For completing the table values of θ_c are deduced from graph, given by Faghih-Habibi [18] and have been used in equation 4 for determination of efficiency. In CR-39 the maximum efficiency in 2π geometry for 1.2 MeV protons is 54%, but for energy of 10 MeV protons the efficiency is reduced to about 12% and the detection efficiency of CN-85 for protons having energy range 200 KeV–2 MeV fluctuates between 79.9–29.3%.

This fluctuation means that the detection efficiency of the detectors very much depends on the proton energy and it is expected that no tracks are likely to be revealed in CN-85 for protons of roughly 4 MeV and above. However, there needs to be further investigation to set a practical limit on detection efficiency for protons of higher energies.

4. Conclusions

Very limited work has been reported on the detection of protons with CN-85 track detector, as this detector has been considered to be least efficient detector of low energy protons. Proton tracks in the energy range 200–400 KeV in etched CN-85 track detector have been observed. The track registration efficiency in CN-85 has been estimated and this detector has been found appreciably good for detection of low energy protons. Etching characteristics, which have been studied in the present work, have a good agreement with the results of other investigators in similar type of work. However, much more work is needed for investigation of different characteristics for the detection of proton tracks in etched CN-85 detectors.

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