Nuclear Instruments and Methods in Physics Research A 813 (2016) 96–101

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Response of CR-39 to 0.9–2.5 MeV protons for KOH and NaOH etching solutions

F. Bahrami [a], F. Mianji [b,c,*], R. Faghihi [a], M. Taheri [c], A. Ansarinejad [b]

[a] Department of Medical Radiation Engineering, Shiraz University, Shiraz, Iran
[b] Nuclear Science & Technology Research Institute, Tehran, Iran
[c] Iran Nuclear Regulatory Authority, Tehran, Iran

ARTICLE INFO

Article history:
Received 8 January 2015
Received in revised form
3 January 2016
Accepted 3 January 2016
Available online 12 January 2016

Keywords:
Chemical etching
CR-39
Dynamic range
Proton spectrometry
Track detection
Van de Graaff

ABSTRACT

In some circumstances passive detecting methods are the only or preferable measuring approaches. For instance, defining particles' energy profile inside the objects being irradiated with heavy ions and measuring fluence of neutrons or heavy particles in space missions are the cases covered by these methods. In this paper the ability of polyallyl diglycol carbonate (PADC) track detector (commercially known as CR-39) for passive spectrometry of proton particles is studied. Furthermore, the effect of KOH and NaOH as commonly used chemical etching solutions on the response of the detector is investigated. The experiments were carried out with protons in the energy range of 0.94–2.5 MeV generated by a Van de Graaff accelerator. Then, the exposed track dosimeters were etched in the two aforementioned etchants through similar procedure with the same normality of 6.25 N and the same temperature of 85 °C. Formation of the tracks was precisely investigated and the track diameters were recorded following every etching step for each solution using a multistage etching process. The results showed that the proposed method can be efficiently used for the spectrometry of protons over a wider dynamic range and with a reasonable accuracy. Moreover, NaOH and KOH outperformed each other over different regions of the proton energy range. The detection efficiency of both etchants was approximately 100%.

1. Introduction

Polyallyl diglycol carbonate (PADC) monomer is a damage track detector (a Solid State Nuclear Track Detector (SSNTD)) that was introduced by Cartwright and Shirk in 1978 [1]. This passive detector has desirable properties like high optical transparency, isotropy, and uniformity. It is extremely sensitive to the high LET particles such as alphas, protons, fast neutrons and immune to low LET radiations like photons and electrons [2]. Its operation is based on breaking the chain of monomers by the high LET passing particles that leave latent tracks in their trajectories. By putting the exposed PADC track detectors (commercially known as CR-39) in the etching solution, the tracks could be seen by an optical microscope [3]. CR-39 is widely utilized in several fields such as neutron personnel monitoring, indoor radon measurements, and space radiation dosimetry [4–6]. Several researches have been carried out for neutron spectrometry using CR-39 foils coupled with the polyethylene radiators and aluminum degraders [7–9]. These studies have shown that CR-39 could be used for neutron spectrometry in the energy range of 100 keV to more than 10 MeV. In contrast, no specific research has been committed to studying the applicability of CR-39 for proton passive spectrometry. Only a few studies have been done to compare the response of CR-39 (track diameter) to protons in different chemical etching solutions [10–13]. For instance, Amin and Henshaw studied the effect of the etching solution concentration on the bulk etch rate in CR-39 [12].

In this paper a method for application of CR-39 for proton spectrometry based on employing a multistage etching process is investigated. Furthermore, the performance of the proposed method for two commonly used etching solutions (NaOH and KOH) is compared under the same etching conditions. The studied parameters included the required developing time for various proton energies, the normalized (to bulk etch rate) track diameter, and the track to bulk etch rate ratio (V function$=V_t/V_b$). For our experiments, the full energy range (0.94–2.5 MeV) of the only available proton accelerator in Iran that is suitable for irradiating the CR-39 foils was used.

It is worth mentioning that due to lesser weight and charge of protons compared to alpha particles, protons have longer range in materials (i.e., deeper penetration) and hence exhibit different behavior in contrast to alpha particles in CR-39. Projected ranges

* Correspondoing author at: Nuclear Science & Technology Research Institute, Tehran, Iran. Tel.: +98 2182067346.
E-mail address: fmianji@aeoi.org.ir (F. Mianji).

http://dx.doi.org/10.1016/j.nima.2016.01.015
0168-9002/

for various energies of protons, calculated by the TRIM software [14], are illustrated in Table 1.

2. Materials and methods

2.1. Exposing the samples

The samples were cut from a CR-39 sheet 750 μm thick (Tas-Trak produced by Track Analysis Systems Ltd.: www.tasl.co.uk) in 1 cm × 1 cm pieces. Owing to the very high output of the Van de Graaff accelerator, direct exposure of the films to the proton beam was not applicable. Therefore, employing a uniform pure Au foil 800 nm thick and 7mm diameter, the backscattered protons were used for the experiments (the elastic collision of the primary protons with the Au foil results in 4π scattering). The protons that reached the samples, known as Rutherford backscattering protons, were monoenergetic. Calculations by SIMNRA software [15] showed that the energy loss of the backscattered protons for all energies of the accelerator was less than 40 keV; so the energy of the backscattered protons was assumed to be equal to the primary beam. For generating the specific proton energies that were not accessible through the device direct adjustment, one or more Kapton ($C_{22}H_{10}N_2O_5$) layer(s) (polymide film) 7.5 μm thick was/were placed on the CR-39 films. The layer(s) reduced the proton energies to the specific amounts calculated by the TRIM software.

In order to minimize the statistical uncertainty, five samples (the geometry of the experiments limited the number of samples) were placed in the device for each proton's energy. The Van de Graaff current was set on 4 nA and the pressure was reduced to 10^{-4}torr in all experiments. A surface barrier detector was used to control each step of exposure to ensure the correctness and stability of the proton flux. The detector was placed exactly under the samples at the angle of 165° with respect to the primary beam. To eliminate the environmental noise, the surface of barrier detector was protected (covered) against the light by a tube.

The employed proton energies were 0.94, 1.1, 1.5, 1.7, 1.85, 2, and 2.5 MeV (35 samples total). The upper energy limit was imposed by the Van de Graaff accelerator's operating range. All samples were exposed to the proton fluence of $\frac{25000}{cm^2}$, a value that did not cause a too high track overlapping. Using much higher fluence would saturate the PADC detectors and make them unreadable. After exposing samples, they were transferred to the laboratory for etching and track evaluation.

2.2. Chemical etching of the samples

Formation of the tracks through chemical etching is a function of two variables: (1) the etch rate along the track (V_t); and (2) the etch rate of the bulk detector (V_b). These variables are related to the etching parameters through the formulas (1) and (2) proposed for tracks of alpha particles in CR-39 [16]. The relations are employed here for protons (V_b is in fact independent of the particle type).

$$V_b = \frac{h}{t} \tag{1}$$

$$V = \frac{(1+r^2)}{(1-r^2)}, r = \frac{d}{2h}, V_t = \frac{V}{V_b} \tag{2}$$

where h is thickness of the removed surface of the detector during the etching period, t is the etching time, and d is the particle track diameter at normal incidence.

In order to compare the performance of different etching solutions, two commonly used chemical etching solutions, NaOH

Table 1
Projected ranges of 0.9–2.5 MeV protons in PADC (CR-39) track detector calculated by the TRIM software.

Proton energy (MeV)	0.94	1.1	1.5	1.7	1.85	2	2.5
Projected range (μm)	16.79	23	37.49	45.85	50.3	59.75	86.52

Table 2
Minimum required etching time (h) for formation of clear tracks on CR-39 foils for different proton energies in NaOH (6.25N and 85 ± 1 °C).

Energy (MeV)	0.94	1.1	1.5	1.7	1.85	2	2.5
Required time (h)	4.5	4.5	4.5	6	7.5	9	10.5

Table 3
Minimum required etching time (h) for formation of clear tracks on CR-39 foils for different proton energies in KOH (6.25N and 85 ± 1 °C).

Energy (MeV)	0.94	1.1	1.5	1.7	1.85	2	2.5
Required time (hr)	4.5	4.5	4.5	4.5	6	7.5	9

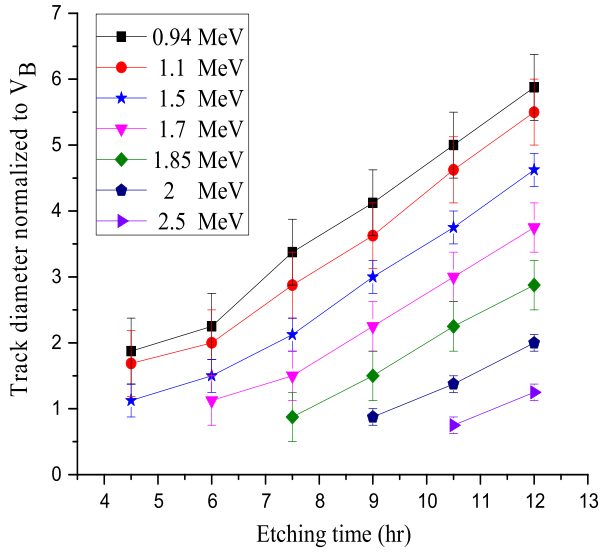

Fig. 1. Response of the CR-39 detectors to different proton energies at various etching times in NaOH (6.25 N and 85 ± 1 °C).

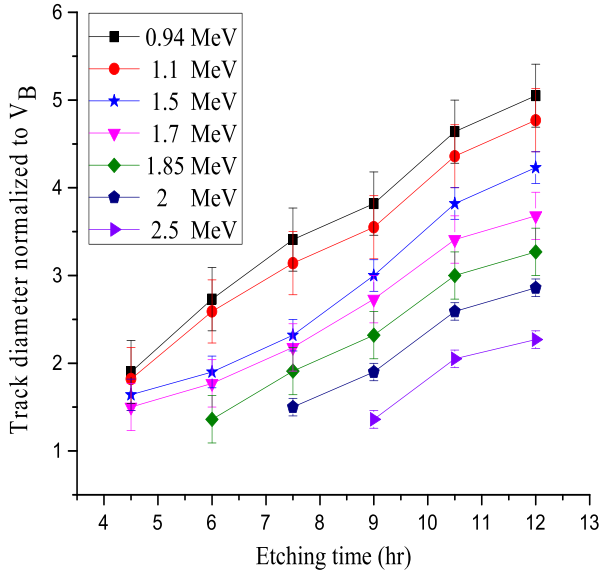

Fig. 2. Response of the CR-39 detectors to different proton energies at various. etching times in KOH (6.25 N and 85 ± 1 °C).