ALPHA PARTICLE SPECTROMETRY WITH LR-115 POLYMERIC TRACK DETECTOR

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ABSTRACT

Spectrometric characteristic of a low alpha energy response polymeric detector have been obtained. The track etching kinematic theory of development of etched minor track diameter, has been applied. The kinematic parameters of the track trajectory have been calculated to standardize the detector for application in alpha-particle spectrometry.

KEY WORDS

Alpha-particles; alpha spectroscopy; dielectric track detectors; etching; particle tracks; sensitivity

INTRODUCTION

Solid state nuclear track detector (SSNTDs) possess a number of advantages over rival dosimeters. These include (i) cheapness of the plastic detecting-foils (ii) compact geometry (which under certain circumstances, gives them an overwhelming advantage over electronic devices) (iii) ease of development, (iv) permanence of record and (v) selectivity of response [1].

Alpha-particles form etchable tracks in a suitable plastic. The range of α energies over which this will occurs, however, is limited. To a first approximation, plastics show a threshold, $(dE/dx)_{th}$, in the rate of energy loss above which tracks are formed. Hence upper and lower limits on the energy of the α-particle are set by points at which the dE/dx versus E curve crosses the line $dE/dx = (dE/dx)_{th}$ [2].

The cellulose nitrate track detector (LR-115) has been investigated many times for detecting α-particles in the energy range from 0.2 to 4 MeV. In this energy range interval the detection efficiency is very close to 100 % due to the detection threshold $(dE/dx)\ th = 0.86$ MeV mg.cm^{-2} [3].

The efficiency of SSNTD as a function of particle energy and angle of incidence is a prerequisite for the design calculation and optimization of the use of this technique [4]. The etching properties of the detector can be characterized by the track and bulk etch-rate ratio (V_T/V_B) which depends on the range R of the particle and varies along the track trajectory. The dependence of V on the range of a particle is of prime importance in any application of SSNTD where spectrometry is involved.

In this work we aim to investigate the spectrometric characteristics of the LR-115 detector for empirically determined sensitivity function, using the kinematic parameters of the track trajectory.

TRACK ETCH KINETICS

It seems necessary to start with a survey of the historical background of the problem of evolution of etched track diameter. In view of simple model of track formation, two mechanisms of etching are involved. The bulk etch rate V_B and the track etch rate V_T along the particle track trajectory. The ratio $V = V_T/V_B$ is defining the degree of etch rate enhancement in the track. The track evolution has been treated analytically by a number of authors for the simplifying assumption of constant V along any given track [5-7]. According to this approach, the diameter, d, of a track at normal incidence is given by

$$d = 2h\sqrt{\frac{V-1}{V+1}} \qquad (1)$$

where h is the etched removal layer.

However V_T, in fact varies greatly along an particle track. To allow for this variation it has been suggested to introduce a factor e as shown in Figure (1), which is the vertical distance between the surface and the point of intersection of the vertical line and the normal to the etched cone at the surface, hence

$$e = \frac{d}{2}\tan(\theta) = h\frac{1}{V+1} \qquad (2)$$

It has been found that the value of V holds at a distance [8]

$$\frac{h-e}{2} = \frac{1}{2}h\frac{V}{V+1} \qquad (3)$$

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Hence V belongs t a residual range R′ given by

$$R' = R_o - \frac{V}{V+1} \cdot \frac{h}{2} \tag{4}$$

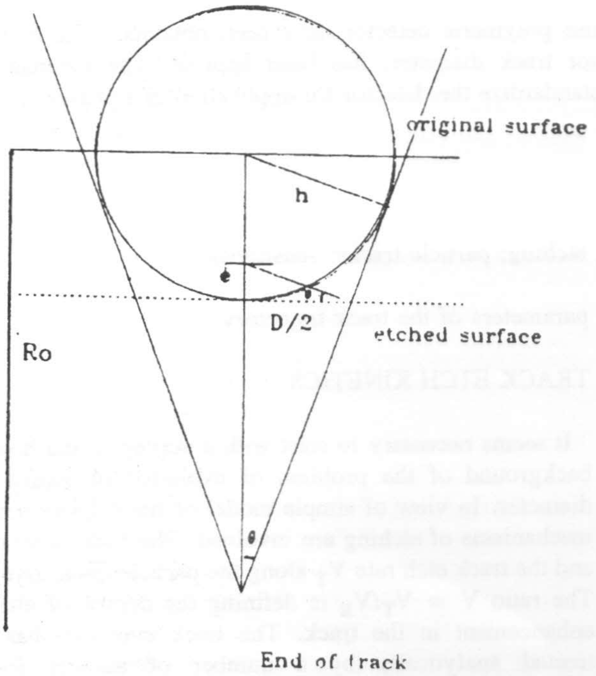


Figure 1. The corrected model of etched track formation.

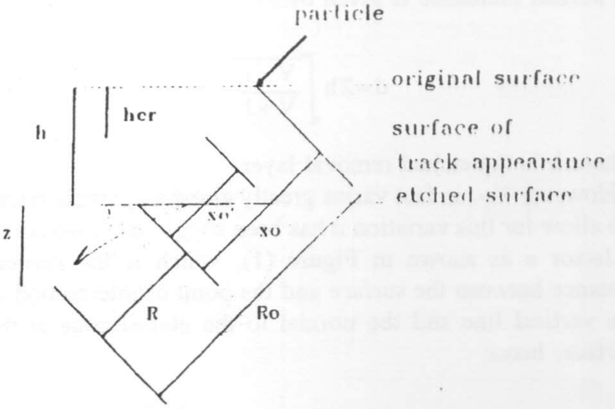


Figure 2. The general model for etched track formation.

Knowledge of the variation of V with particle range allows prediction of track shapes for any value of layer removal, h. It has been found that for LR-115 II the V function for 2N NaOH data is best fitted to the relation due to Durrani et al, [9].

$$V(R') = 1 + (100_e^{-0.446R'} + 5.0_e^{-0.107R'})(1 - e^{-R'}) \tag{5}$$

In other literature however a more simple expression has been used, namely [10-11]:

$$V(R') = 1 + \exp(a R' + b) \tag{6}$$

where a and b are fitting parameters.

For the general case of inclined incidence at an angle θ, as shown in Figure (3), a number of parameters concerning the track-etch kinetics have to be taken care of. Among these parameters is the critical layer thickness (h_{cr}) given by solving the equality

$$\sin(\theta) \left[\frac{1}{V(R')}\right]_{R' = Ro - \frac{h_{cr}}{\sin(\theta)}} \tag{7}$$

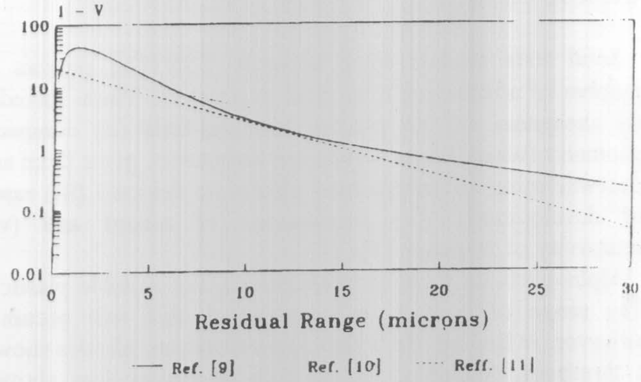


Figure 3. Etch-ratio function LR-115 type II.

As for the track depth it can be easily expressed for the cone phase by the parametric relation

$$z = x_o \sin\theta - h_{cr} - H_{co}(x_o); \; h = h_{cr} + H_{co}(x_o) \tag{8}$$

where $c_{cr} < x_o < R_o$

$$h_{co}(x) = \int^{x} x_{cr} V^{-1}(x)\,dx \tag{9}$$

and the maximum track depth Z_m is given by

$$Z_m = R_o \sin(\theta) - h_c - H_g \tag{10}$$

After a removal layer thickness $h = R_o \sin i$, there is no more preferable etching zone along the track cone axis. The end of the track cone, in this phase, become spherical and the track etch depth of the spherical phase is given by

$$z_g = R_o \sin\theta - h_{cr} - H_g \tag{11}$$

where $h_g(x) = \text{const} = H_{co}(R_o)$.

Using the above equations one can quantitatively predict the evolution of minor track diameter at varying etch-rate. The common solution of the equations of "moving planes" and "travelling balls" can be expressed in parametric form and their actual computation can be performed with successive iteration procedures [5,12]. The minor axis of the track in the cone phase d_{co} is given by the parametric formula

$$d_{co} = 2\,(h' - h_{co})\,\sqrt{(1-(V x'_{o})\sin(\theta))^{-2})} \qquad (11.a)$$

$$h' = x'_{o} + \frac{x'_{o}\sin(\theta) - H_{co}}{V(x'_{o})\sin(\theta) - 1} \qquad (11.b)$$

where $x'_o = x_o - x_{cr}$ and $0 < x'_o < R_o - x_c$

Finally in the "sphere phase" of track evolution the minor track axis can be expressed in a non-parametric form given by

$$d_s = 2\sqrt{((h' - h_s)^2 - [h' - (R_o - x_{cr})\sin\theta\,]^2)}$$

$$= 2\sqrt{(h - h_{cr} - h_g)^2 - (h - R_o\sin(\theta))^2)}$$

where $h = h' + h_{cr}$ and $x'_o = R_o - x_{cr}$

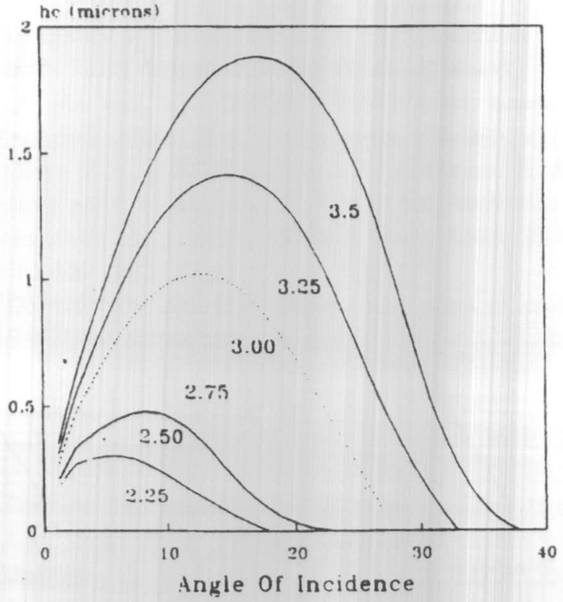
Figures (8)-(11) shows the variations of the track minor diameter versus energy of particles at constant etched removal layer and for incident angle 20-45°.

RESULTS AND DISCUSSION

The detector material selected for this analysis is a cellulose nitrate type LR-115 II ($C_6H_8O_9N_2$) with a density of 1.4 g cm^{-3}. It is a composite plastic, consisting of a thin (12-13) microns) layer of cellulose nitrate, incorporating a red dye, on a thicker (~ 100 microns), backing of inert polyester.

The above expressions for the etched alpha-particle tracks have been used to obtain the spectrometric characteristics for this low energy response detector. The etch rate ratio function V have been given by the empirical relations 5 and 6. The fitting parameters are given by b=3 and a = - 0.15 micron^{-1} according to Palfalvi [10], or a = 0.205 micron^{-1} according to Somogyi [11]. Figure (3) shows the behaviour of the above mentioned expressions. From the figure we may assume that expression used by Palfalvi reproduce the gross structure of the more elaborate expression of Ref [9]. In this work we adopted the simpler expression to conserve computing time.

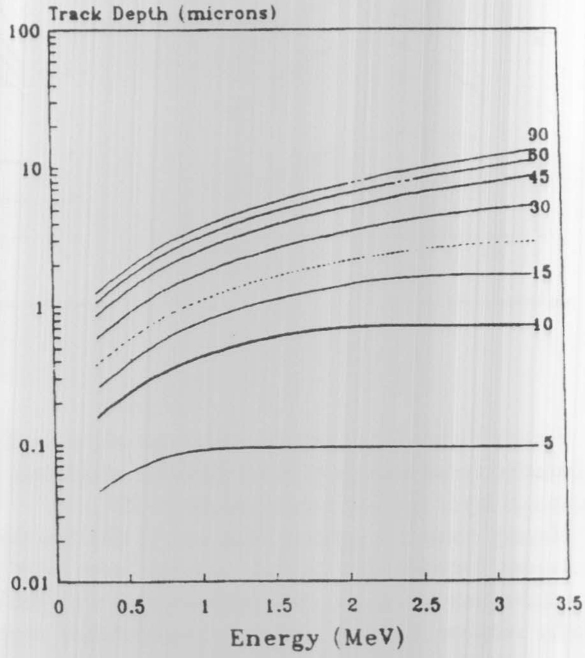
Figure (4) shows the variation of h_{cr} with incidence angle for different alpha-particle energies.



Energy is indicated on each curve in MeV

Figure 4. Critical layer distance LR-115 type II.

Figure (5) shows the maximum track depth in the cone phase versus the alpha-particles energy at different incident angles. Figure (6) show the relation between the track etch depth with different layer removal thickness at constant incident angle for alpha-particles energies of 0.5,1 and 2 MeV respectively.



Angle of incidence on each curve.

Figure 5. Maximum track depth LR-115 type II.

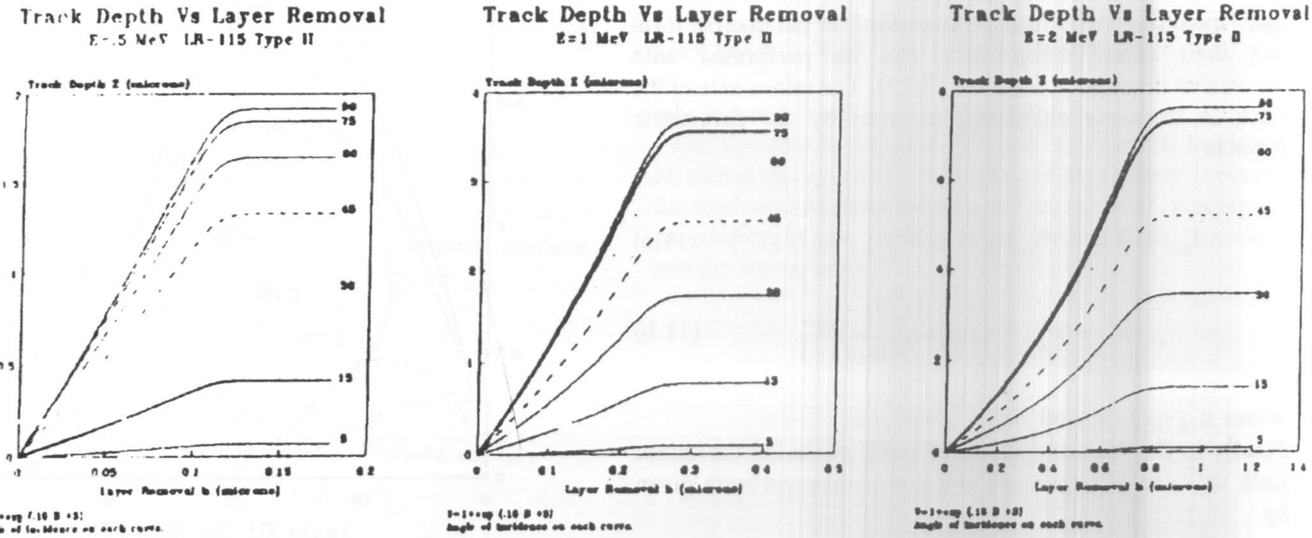


Figure 6.

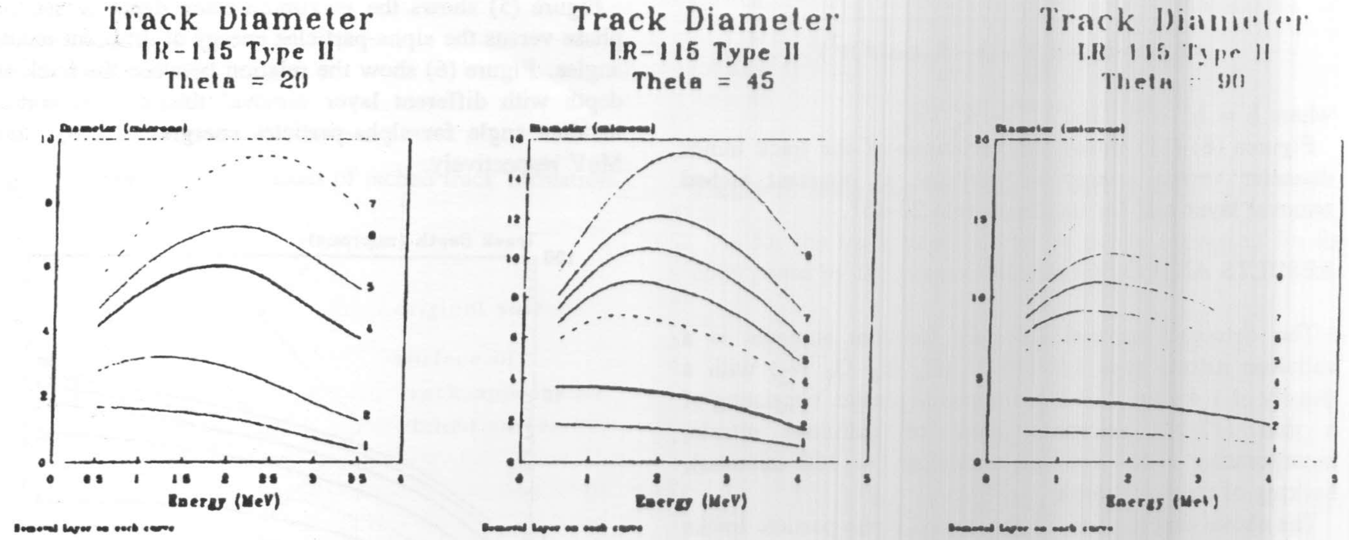


Figure 7.

Finally Figure (7) shows the variations of the track minor diameter versus energy of alpha-particles at constant etched removal layer and for incident angle 20-90°.

Having chosen a proper form for V (R) function, the relations between the critical removal layer with alpha-particles incident angle, track etched depth with the etched layer removal and the maximum track etched depth and minor track diameter with the alpha-particles energy have been obtained. From these results for LR-115 II detector we can conclude that:

1- It appears that the critical removal layer is small and widely varies with the incident angle, especially for energies above 3 MeV. In all cases it vanishes for particles incident angles above 30°.
2- It appears that the maximum etched track depth is nearly flat for small angles of incidence.
3- The differential variation of track depth with incident angle is poor for angles above 75°.
4- The energy dependence of the minor track diameter is

linear for small etched removal layer. The energy resolution gets better for higher etched removal layer.

In conclusion it appears that LR-115 II has fair sensitivity for alpha-particles spectroscopic applications. In the energy ranges 0.5 to 4 MeV. The present treatment needs to be extended to include mixed pit shapes.

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