Pramāṇa, Vol. 26, No. 5, May 1986, pp. 419–425. © Printed in India.

On the response of LR-115 plastic track detector to $^{20}_{10}$Ne-ion

S M FARID
Department of Physics, Rajshahi University, Rajshahi, Bangladesh

MS received 18 July 1985; revised 25 February 1986

Abstract. The track etch rates of $^{20}_{10}$Ne-ion in cellulose nitrate (LR-115) have been measured for different temperatures and the activation energy is determined. The experimental results show that both the track etch rate and the normalized track etch rate depend on the energy loss as well as on etching temperature. The maximum etched track length of $^{20}_{10}$Ne-ion agrees with the theoretically computed range. The experimental results show that there is no sharp threshold, at least in CN(LR-115).

Keywords. Solid state nuclear track detector; bulk etch rate; track etch rate; activation energy; energy loss.

PACS No. 29·40

1. Introduction

Dielectric detectors, in which nuclear particle tracks are made visible by preferential chemical etching, are useful for studies in nuclear physics, geophysics and astrophysics. Cellulose nitrate (CN) is generally accepted as one of the most sensitive plastic materials and is one of the few materials which can record low energy protons. The curve of the etching rate as a function of energy deposited along the trajectory of the particle is known as calibration curve or response curve. For particle identification with solid state nuclear track detectors (SSNTDS), it is necessary to have the response curves of different ions. The aim of the present study is to draw the response curve of LR-115 plastic detector using $^{20}_{10}$Ne-ions. The dependence of bulk etch rate, track etch rate and track registration sensitivity on etching temperature is also shown. The maximum etched track length is compared with the theoretical range obtained using range and stopping power equations of Mukherji and Nayak (1979).

2. Experimental procedure

Samples of cellulose nitrate detector (Kodak LR-115) have been irradiated with $^{20}_{10}$Ne-ions of energy 8·5 MeV/N at an angle of 30° (w.r.t. the detector surface) from cyclotron beam at JINR, Dubna (USSR). The samples are etched in NaOH $(6{\cdot}00 \pm 0{\cdot}05)$N solution kept at a constant temperature in a thermostatic bath. The etchant temperature is maintained constant at $\pm 0{\cdot}5$°C. The tracks were measured with an "Olympus" microscope (40 × objective and 15 × eyepiece). The least count of eyepiece micrometer is 0·215 μm at a magnification of 900 ×. The total error in track length measurements, arising from statistical errors, diffraction of light and microscope optical resolution is ± 0.5 μm. When the exposed samples are etched in NaOH solution conical tracks appeared. The true track length L (the length from the original surface to the terminal end of the tracks) is calculated by the relation (Dwivedi 1977; Dwivedi and Mukherji 1979; Farid and Sharma 1983a, b, c, 1984; Farid 1984),

$$L = \frac{l_p}{\cos\delta} + \frac{V_b t}{\sin\delta} - V_b(t - t_c), \tag{1}$$

where l_p is the corrected projection length, δ, the angle of incidence, V_b, the bulk etch rate, $V_b t/\sin\delta$ is the surface etching correction, $V_b(t - t_c)$ is the over-etching correction and t_c is the time required to etch the tracks upto the points where they stop (etched until the tracks ends become round).

V_t is calculated by the relation (Dwivedi and Mukherji 1979; Farid and Sharma 1983a, b, c, 1984; Farid 1984),

$$V_t = \Delta L/\Delta t \tag{2}$$

where ΔL is the track length increase in etching time Δt.

3. Results and discussion

3.1. *Effect of temperature on* V_b

V_b is determined following the procedure of Qaquish and Besant (1976). Figure 1 shows the variation of V_b as a function of etching time for 6 N NaOH at 60°C. The experiment is repeated at various etchant concentrations for different etchant temperatures, but not presented here. It is seen that V_b decreases with longer etching time to a limiting value. The limiting values are in good agreement with V_b reported earlier (Tanti-Wipawin 1975; Harris and Schlenker 1979). Since our values of V_b vary with etching time, we have used only the asymptotic values. The plot of $\ln V_b$ versus $1/T$ is a straight line which indicates that the dependence of V_b on etching temperature follows an Arrhenius relationship (Fleischer *et al* 1975) of the form,

$$V_b = A\exp(-E_b/kT) \tag{3}$$

where k is the Boltzmann constant, T is the temperature (in °K) of etchant and E_b is the activation energy for bulk etching. From the slope of the straight line the activation energy is calculated to be $E_b = (0.87 \pm 0.08)$ eV. This value is in good agreement with that reported by Somogyi *et al* (1978).

3.2 *Effect of temperature on* V_t *and* θ

Irradiated samples are etched in NaOH solution at 60°C. At least 50 tracks are measured for each set of observations. The variations of l_p and L with etching time are shown in figures 2a, b. The projected length starts decreasing after t_c because the bulk etching shortens the completely developed tracks. The track tips (which are round) increase at the same rate of bulk etching. When the bulk etching and over-etching corrections are made, L remains constant beyond t_c as can be seen from figure 2b.

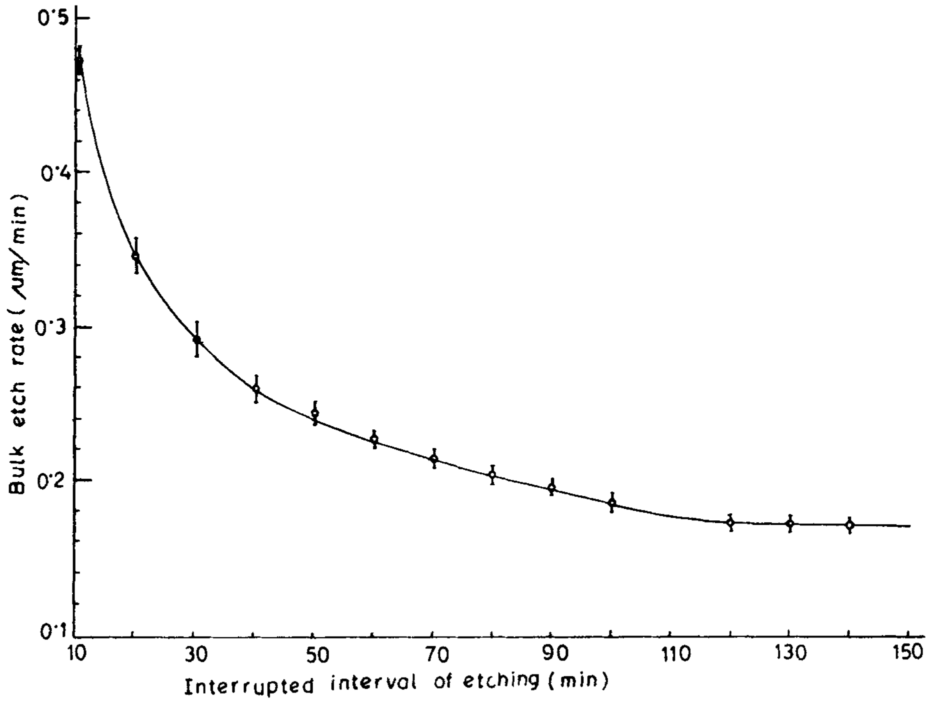

Figure 1. Dependence of V_b on the time interval of interrupted etching of LR-115 detector in 6 N NaOH solution at 60°C.

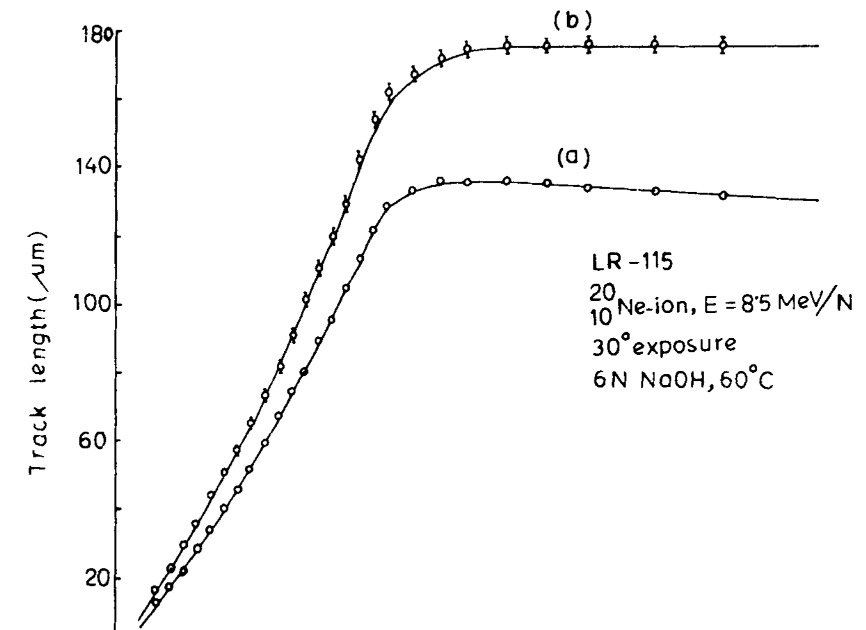

Figure 2. Variation of (**a**) corrected projection length and (**b**) true track length of $^{20}_{10}$Ne-ions in LR-115 with etching time.

Using (2), the values of V_t at different points on the track are obtained from figure 2b. Similarly the values of V_t at different points on the tracks are also determined for etching temperatures of 30°, 40° and 50°C. Figure 3 shows the variation of V_t with residual range of $^{20}_{10}$Ne-ion for 40° and 60°C. The value of V_t corresponding to a particular residual range (55 μm in this case) is determined from V_t vs residual range curves for different etching temperatures. The plot of ln V_t versus $1/T$ is a straight line which indicates that the increase of V_t with etching temperature, T (in °K) is exponential and this can be expressed by

$$V_t = B \exp(-E_t/kT), \tag{4}$$

where B is a constant and E_t is the activation energy for track etching. The value of E_t is calculated to be $E_t = (0{\cdot}67 \pm 0{\cdot}07)$ eV. It is noted that $E_b > E_t$ for LR-115 detector.

From the experimentally determined V_t and V_b values it is observed that there is a decrease of $V(= V_t/V_b)$ (i.e. track registration sensitivity) towards higher etching temperatures. Similar conclusions have earlier been arrived at in heavy ion tracks in CN detectors (Benton 1968; Schlenk *et al* 1972). In figure 4a, ln V is plotted as a function of $1/T$ and hence we can write,

$$V = V_t/V_b = \frac{B}{A} \exp[-(E_t - E_b)/kT]. \tag{5}$$

It is observed that the cone angle, $\theta[= \sin^{-1}(V_b/V_t)]$ of $^{20}_{10}$Ne-ion tracks in LR-115 increases towards higher etching temperatures. Substituting $\sin\theta = V_b/V_t$ in (5), we can write,

$$\ln(1/\sin\theta) = \frac{-(E_t - E_b)}{kT} + \ln(B/A). \tag{6}$$

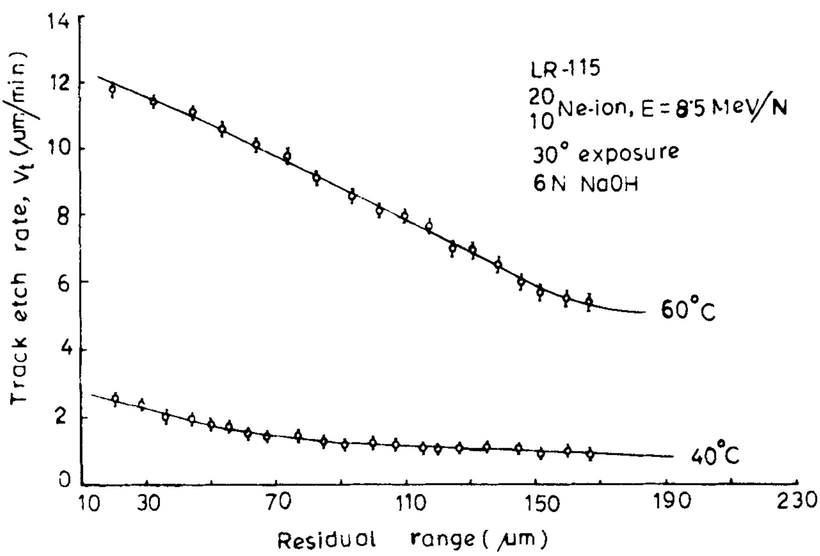

Figure 3. Variation of V_t with residual range of $^{20}_{10}$Ne-ion in LR-115 for 40°C and 60°C.

This equation shows a linear relationship between $(1/\sin\theta)$ and $1/T$. The experimental results are shown in figure 4b which is indeed a straight line.

3.3 *Range of Ne-ion in LR-115 detector*

The irradiated samples of LR-115 are etched in NaOH at 60°C. The average length of maximum etched tracks (etched until the tips of the tracks become round) is calculated to be $L = (175{\cdot}55 \pm 2{\cdot}90)$ μm. To compare this maximum etched track length with the theoretical range, we have used the stopping power and range equations of Mukherji and Nayak (1979). By making use of these equations and a computer program the range of $^{20}_{10}$Ne-ion in LR-115 ($C_6H_8O_9N_2$ and $\rho = 1{\cdot}45$ g/cm^3) is determined. The computer lists the energy loss dE/dx and the penetration depth (i.e. range) starting from the initial ion energy down to zero at intervals of $\delta E (= 0{\cdot}01$ MeV). The theoretical range is found to be $L = 178{\cdot}45$ μm. The maximum etched track length agrees with the calculated range and is better than 2%. The present value agrees closely with that reported by Benton (1968) and Tripier *et al* (1974).

3.4 *The response curve*

From the computer output, the plot of energy-loss, (dE/dx) vs residual range has been drawn (not shown). The variation of V_t with residual range is shown in figure 3. From these two figures, the plot of V_t versus (dE/dx) has been obtained as shown in figure 5. For large values of (dE/dx), V_t approaches a constant value. Thus the detector appears to saturate at high values of dE/dx. In figure 6 the normalized track etch rates are plotted against (dE/dx) for two different etching temperatures. It is seen that the ratio V_t/V_b depends on dE/dx as well as on etch bath temperature.

Our investigation depicts clearly an asymptotical behaviour of the response curve at

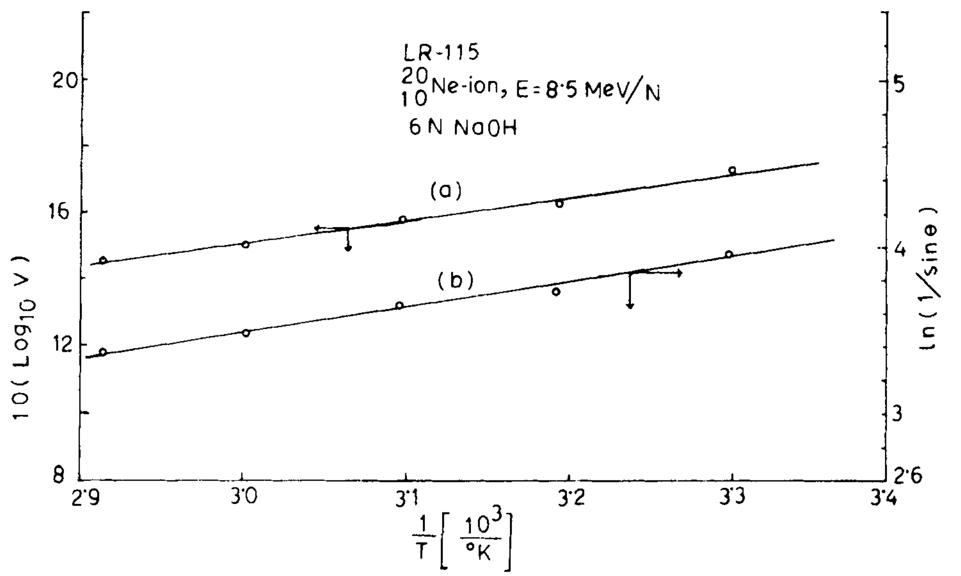

Figure 4. Dependence of $V = V_t/V_b$ and $\sin\theta$ on etching temperature for $^{20}_{10}$Ne-ion in LR-115 plastic detector.

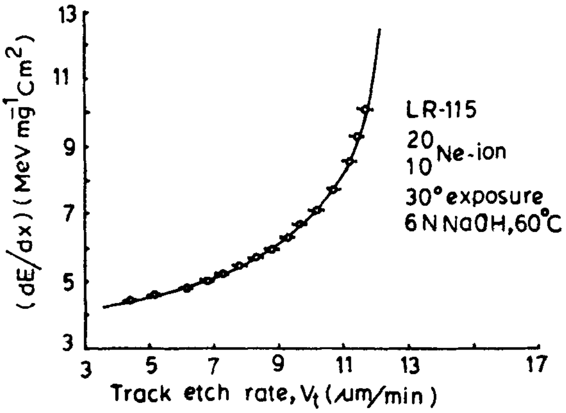

Figure 5. Dependence of V_t on the energy-loss, dE/dx of $^{20}_{10}$Ne-ion in LR-115 plastic detector.

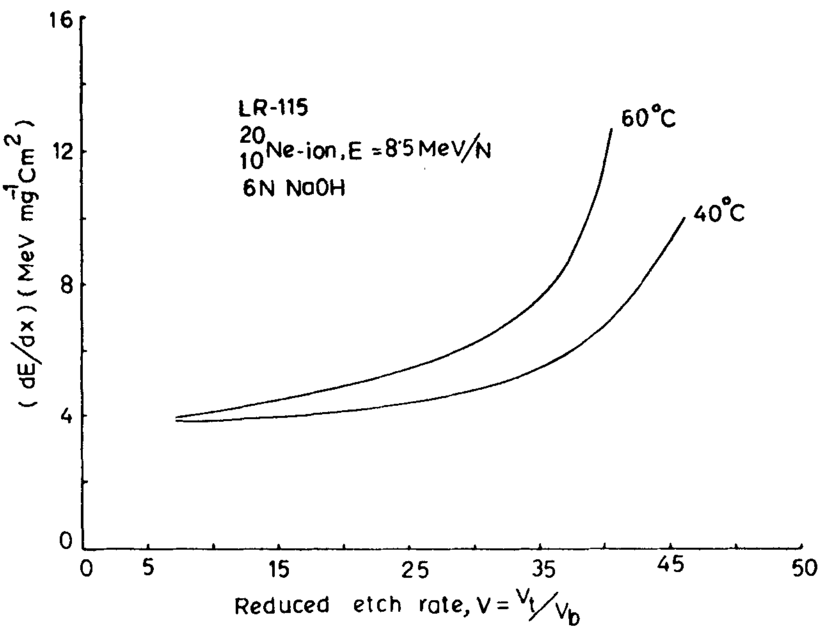

Figure 6. Dependence of normalized track etch rate, $V (= V_t/V_b)$ on the energy-loss, dE/dx of $^{20}_{10}$Ne-ion in LR-115 for two different temperatures of etching.

very low values of V. We make no attempt to extrapolate the response curve to threshold ($V = 1$) because of the observed flattening of V_t vs R curves at the highest ranges. Thus our investigations indicate that there is no sharp threshold in LR-115 cellulose nitrate for $^{20}_{10}$Ne-ions, with the etching conditions used by us.

References

Benton E V 1968 *Study of charged particle tracks in cellulose nitrate*, USNRDL-TR-68-14.
Dwivedi K K 1977 *Studies of heavy ion tracks in solid dielectrics*, Ph.D. Thesis, IIT, Kanpur
Dwivedi K K and Mukherji S 1979 *Nucl. Instrum. Methods* **159** 443
Fleischer R L, Price P B and Walker R M 1975 *Nuclear tracks in solids* (California: University Press)
Farid S M and Sharma A P 1983a *Pramana (J. Phys.)* **21** 339
Farid S M and Sharma A P 1983b *Rad. Eff.* **80** 121
Farid S M and Sharma A P 1983c *Nucl. Instrum. Methods* **213** 513
Farid S M 1984 *Pramana (J. Phys.)* **23** 187
Farid S M and Sharma A P 1984 *Int. J. Appl. Rad. Isot.* **35** 181
Harris M J and Schlenker R A 1979 *Nucl. Instrum. Methods* **160** 159
Mukherji S and Nayak A K 1979 *Nucl. Instrum. Methods* **159** 421
Qaquish A Y and Besant C B 1976 *Nucl. Instrum. Methods* **138** 493
Schlenk B, Somogyi G and Valek A 1972 *Rad. Eff.* **24** 247
Somogyi G, Bunyadi I and Varga Zs 1978 *Nucl. Tracks* **2** 191
Tripier J, Remy G, Ralarosy J, Debeauvais M, Stein R and Huss D 1974 *Nucl. Instrum. Methods* **115** 29
Tanti-Wipawin W 1975 *Nucl. Instrum. Methods* **126** 597