TRACK RECORDING PROPERTIES OF CELLULOSE NITRATE (R) PLASTIC TRACK DETECTOR FOR ACCELERATED HEAVY IONS

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SUMMARY: Cellulose nitrate (Russian) plastic has been irradiated with Ne and $^{16}_{8}O$-ions from the Cyclotron at JINR, Dubna, USSR in order to investigate the track recording properties of the material. Etching in 6N NaOH solution is carried out at temperatures 30°, 40°, 50°, 60° and 70°C. The activation energy for bulk etching is (1.06±0.1) eV and that for track etching is (0.85±0.08) eV. We present the track etch rate, V_t vs range and V_t as a function of energy-loss, dE/dx, of $^{16}_{8}O$-ions. The response of the plastic can be be adjusted by altering the etch bath temperature. The maximum etched track length is compared with the theoretical range as well as with the range reported in literature. The effects of different annealing conditions on bulk etch rate of plastic detector and on diameters of $^{20}_{10}Ne$-ion tracks have been presented. Experimental results show that there is a decrease in track etch rate. The annealing of oblique tracks shows that the vertical tracks are stable for longer periods than oblique tracks.

Key Words: Cellulose nitrate, track recording, accelerated heavy ions.

INTRODUCTION

Cellulose nitrate, a member of the Solid State Nuclear Track Detectors (SSNTDs) family, is generally accepted as one of the most sensitive plastic (1, 2, 7). For all cases of particle identification with nuclear track detectors, it is necessary to know the relation between track etching rate and the energy deposited along the trajectory of the particle under a certain etching condition. The curve of the etching rate as a function of the deposited energy is often called a "Response curve" (1, 2, 5, 7). The heat treatment of latent tracks before etching brings about changes in the physical and chemical properties of the radiation-damaged region along the track Consequently, the etch pit diameter, the etchable track length, as well as the ratio of the track and bulk etch rates are reduced (2, 7, 9,16).

It is the goal of the present work to draw the response curve of CN (R) plastic track detector using accelerated $^{16}_{8}O$-ions The maximum etched track lengths of $^{16}_{8}O$-ions of different energies are compared with theoretically computed ranges as well as with those reported by earlier workers. The dependence of bulk etch rate, track etch rate, and track registration sensitivity on etching temperature is shown. The experimental results showing the effect of heat treatment on latent tracks before etching are also presented.

EXPERIMENTAL PROCEDURE

Cellulose nitrate (Russian) plastic detectors (1000 μm thick) exposed to $^{16}_{8}O$ and $^{20}_{10}Ne$-ions of different energies have been obtained from Cyclotron at JINR, Dusna, USSR. The exposure conditions are given in Table 1. All etching is carried out in NaOH (600±0.05) N stirred solution kept at a constant temperature in a thermostatic bath. The stability of temperature is ±0.5°C even for long etching time. The measurements are taken with an "Olympus" microscope with a 40x objective and 15x eyepiece. The least count of the eyepiece micrometer is 0.215 μm at a magnification of 900x. In figures the accuracy of the measurements is better than the size of the symbols, unless the error bases are specially shown. The exposed samples are annealed in air in an oven. The oven temperature is controlled to within ±3°C.

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Table 1: Ions and their energies used in the present study.

Detector	Ion	Energy	Angle of exposure (w.r.t. detector surface)
Cellulose nitrate (Russian) $C_6H_8O_9N_2$ σ= 1.45 g/cm^3	$^{16}_{8}O$	140 MeV	30^o
		113 MeV	30^o
	$^{20}_{10}N$	200 MeV	90^o, 30^o

RESULTS AND DISCUSSIONS

Effect of temperature on bulk etch rate, V_b

In the present experiment the bulk etch rate, V_b has been measured by two methods (3, 4, 6):

(i) Track diameter method

(ii) Thickness measurement method

The methods have been discussed elsewhere (5, 6).

The bulk etch rate, V_b is determined at 30°, 40°, 50°, 60° and 70°C for 6N NaOH solution. Both the methods give the same results within the limits of uncertainty. This shows the isotropic etching character of CN (R) detector. The results were reported in my earlier papers (5,6). The value of activation energy (E_b) for bulk etching was found to be $E_b = (1.06 \pm 0.1)$ eV. This value is in good agreement with that reported in literature (3, 8).

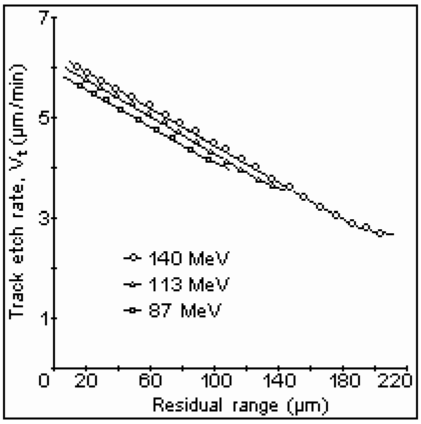
Effect of temperature on track etch rate, V_t

CN (R) detector simples exposed to $^{16}_{8}O$-ions at an angle of 30°C are etched in 6N NaOH. Following the procedure discussed in my earlier papers (5, 6) the track etch rate, V_t at different points on the track is determined. The V_t versus residual range curves of $^{16}_{8}O$-ions of different energies are shown in Figure 1 for 60°C. Clearly V_t increases with penetration depth.

In exactly the same way the plots of V_t vs residual range are also drawn for etching temperatures of 30°, 40°, and 50°C. These plots are similar in nature to those shown in Figure 1 but are not shown. Track etch rate, V_t corresponding to a particular range (50 μm in this case) is obtained from these curves for different temperatures for E = 140 MeV. The plot of ln V_t against 1/T is found to be straight line which shows the exponential dependence of V_t on 1/T. This can be expressed by a relation of the from: $V_t = B \exp(-E_t/kT)$ where B is a constant, E_t is the activation energy for track etching, k is the Boltzman constant and T is the etching temperature in absolute scale. The value of E_t is calculated from the slope of the straight line to be $E_t = (0.85 \pm 0.08)$ eV. It is noted that $E_t < E_b$.

The values of $V=V_t/V_b$ for different temperatures have been calculated from the experimentally determined V_t and V_b values. We found that with CN (R), there is a decrease of V i.e. track registration sensitivity) towards higher etching temperatures. Different authors (8, 14) have made similar conclusions after investigating heavy ion tracks in CN detectors.

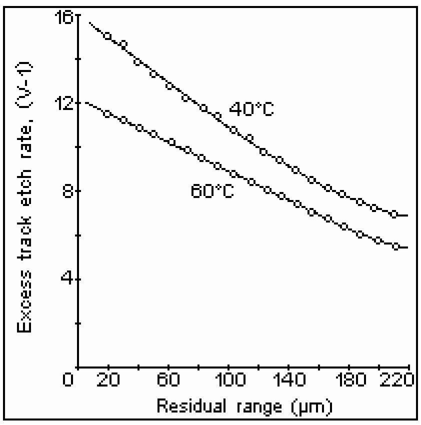
Figure 1: Plot of track etch rate, V_t versus residual range of $^{16}_{8}O$-ions of different energies in CN (R) for 6N NaOH solution at 60°C.



CN (R), $^{16}_{8}O$-ions, 6N NaOH, 60°C.

In Figure 2 data of excess track etch rate ratio, (V-1) are plotted vs the residual range of $^{16}_{8}O$-ion for 40°C and 60°C. It is observed that both track etch rate, Vt and normalized track etch rate, $V=V_t/V_b$ along the trajectory of the particle depends on the etching temperature .

Figure 2: Variation of excess track etch rate, (V-1) with residual range of $^{16}_{8}O$-ion tracks in CN (R) for two different etching temperatures.



CN (R), $^{16}_{8}O$-ion, E=140 MeV, 6N NaOH.

Range of $^{16}_{8}O$-ion in CN (R)

Samples of CN (R) exposed to $^{16}_{8}O$-ions of different energies are etched in 6N NaOH solution at 60°C. Following the procedure discussed in Refs 1, 5 and 6, the average length of maximum etched tracks is calculated. The results are tabulated in Table 2.

Table 2: Range of $^{16}_{8}O$-ion in CN (R) plastic detector.

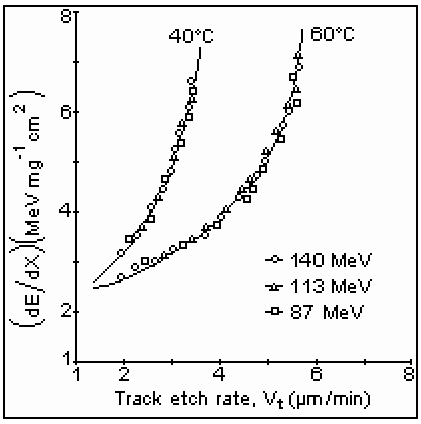
Ion	Energy (MeV)	Maximum etched track length (μm)	Theoretical range (μm)
$^{16}_{8}O$	140	208.74±2.80	212.26
	113	147.40±2.34	149.82
	87	100.58±1.86	102.44

To calculate the theoretical range of the ion we have used the range and stopping power equations of Mukherji and Najak (12). Using these equations a computer program is made and with the help of the computer the ranges of $^{16}_{8}O$-ions having different energies in CN (R) are computed. 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 E(=0.01MeV). The computed ranges are also presented in Table 2. The maximum etched track lengths agree with the calculated ranges to better than 2% as well as with those reported by different authors (1,13,15). The maximum etched track length can be regarded in good approximation as the range of the particle in plastic. Hence track lengths can be used for determination of particle energy.

The "Response Curve"

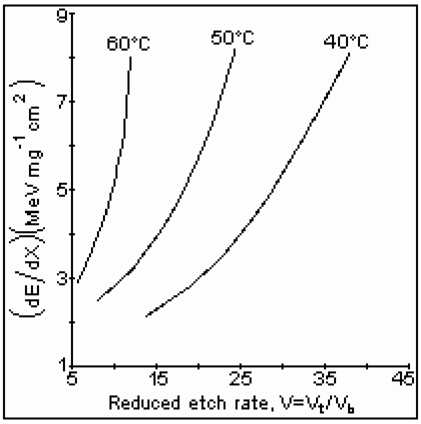
From the computer output, the plot of energy-loss, dE/dx vs residual range has been drawn for $^{16}_{8}O$-ion (not shown). The variation of track etch rate, V_t with residual range is shown in Figure 1. Combining these two figures, the "response curve" [(dE/dx) vs V_t] for two different temperatures is shown in Figure 3. For large values of dE/dx, the track etch rate, V_t approaches a constant value. Thus the detector appears to saturate at high values of dE/dx. In Figure 4, the normalized track etch rates are plotted against (dE/dx) for different temperatures. The solid curve is the best fit to the experimental points. It is evident that the ratio V_t/V_b depends on dE/dx as well as on etching temperature. The response of this detector depends strongly upon the etch bath temperature. Hence the response of this detector can be adjusted by altering the etching temperature.

Figure 3: Dependence of track etch rate, V_t on the energy-loss, dE/dx of $^{16}_{8}O$-ions in CN (R) for two different etching temperatures.



CN (R), $^{16}_{8}O$-ions, 6N NaOH.

Figure 4: Dependence of normalized track etch rate, $V=V_t / V_b$ on the energy-loss, dE/dx of $^{16}_{8}O$-ions in CN (R) for different temperatures of etching.



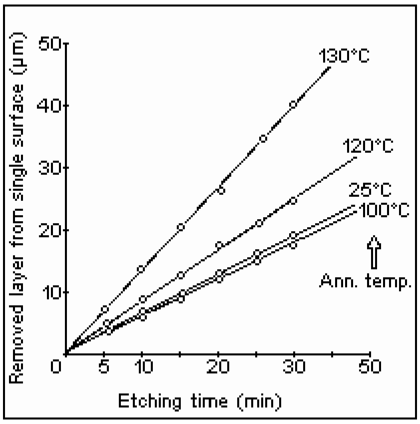
CN (R), $^{16}_{8}O$-ions, 6N NaOH.

ANNEALING OF $^{20}_{10}NE$ ION TRACKS IN CN (R)

Effect of annealing temperature on the bulk etch rate, V_b

Unexposed samples of CN (R) are annealed at different temperatures for 10 min. The samples are then etched simultaneously in 6N NaOH at 60°C. The removed layers of the sheets are measured with a micro thickness gauge having e least count of 0.5 μm. The effected of heat treatment on the bulk etch rate of CN (R) plastic is present in Figure 5 which shows the removed layer from a single surface of the detector as a function of etching time for the samples annealed at different temperatures. It can be observed that above 100°C the bulk etch rate of CN (R) sheet increases rapidly indicating the ever-growing degree of thermal degradation. Above 140°C, the mechanical l properties strongly deteriorate, the sheet becomes glassy and brittle, and the measurement of the removed layer becomes unreliable.

Figure 5: Thickness of removed layer versus etching time curves for CN (R), annealed at various temperatures.



CN(R), 6N NaOH, 60°C, Ann. temp.=10 min.

Effect of annealing temperature on track diameter

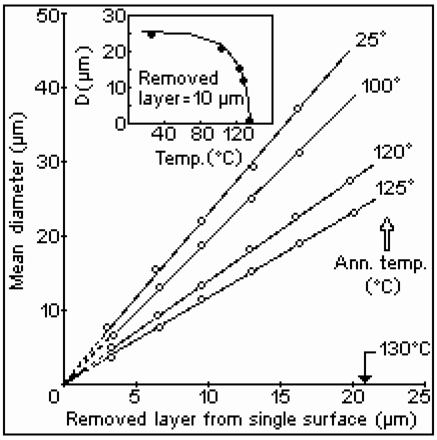
CN (R) detector samples exposed vertically to $^{20}_{10}$Ne-ions are etched in 6N NaOH at a particular temperature. The track diameters are measured for different etching times. A linear relationship exists between track diameter and etching time for different etching temperatures. Different authors (10,11) also observed similar linear relationship.

Detector samples exposed vertically to $^{20}_{10}$Ne-ions are annealed for 10 minutes at various temperatures. The choice of annealing time of 10 min is accounted for by our experience with plastic annealed for a longer period. After etching the samples simultaneously in 6N NaOH at 60°C the etch pit diameters are measured as a function of the removed layer. The results are presented in Figure 6. In the left hand corner of Figure 6 (inset) the track diameter is plotted after removing a 10 μm thicket surface layer as a function of annealing temperature. Thus to eradicate $^{20}_{10}$Ne-ion tracks in CN (R) completely, an annealing period of 10 min must be applied at 130°C.

Effect of annealing time on track diameter

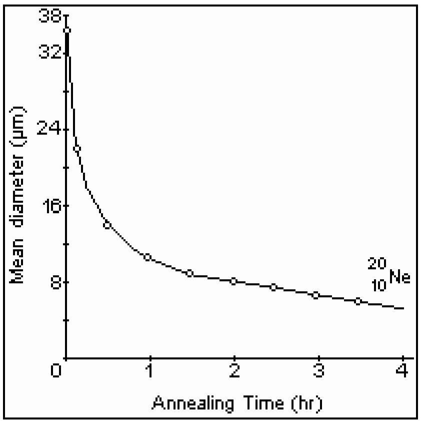
Detector samples exposed vertically to $^{20}_{10}$Ne-ions are annealed at 120°C for different lengths of time. After etching the track diameters are measured. Figure 7 shows the effects of annealing time on etch pit diameter after removing a 15 μm thick surface layer of the detector sample. It is observed that the curve consists of a steeply and a slowly falling complement. It is apparent that a part of the radiation-damaged region produced by the ions is already eradication at the given temperature by short annealing; however in the more stable region persistent after the treatment, no considerable change is brought about even by a significant extension of annealing time.

Figure 6: Relationship between track diameter and thickness of removed layer for $^{20}_{10}$Ne-ion tracks in CN (R) annealed for 10 min at different temperatures.



CN (R), $^{20}_{10}$Ne-ion, E=10 MeV/N, Ann. time=10 min, 6N NaOH, 60°C.

Figure 7: Relationship between track diameter and annealing time for $^{20}_{10}$Ne-ion in CN (R) annealed at 120°C.



CN (R), Ann. temp.=120°C, Ann. time=10 min, Removed layer =15 μm, 6N NaOH, 60°C.

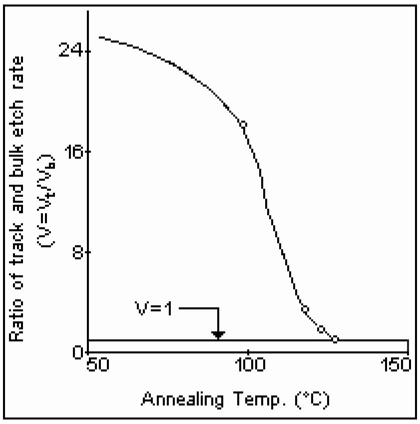
Effect of annealing temperature on V_t

Experiments are conducted to show the decrease in V_t of ${}^{20}_{10}$Ne-ions. The ratio of track and bulk etch rates, $V=V_t/V_b$ is evaluated for different temperatures from the initial slopes, S of the curves shows in Figure 6 using the relation (13),

$$V= (1=0.25 S^2) / (1-0.25 S^2)$$

This etch rate ratio is plotted against annealing temperature as shown in Figure 8. It is observed that V_t decrease with annealing temperature.

Figure 8: Etch rate ratio ($V=V_t/V_b$) as a function of annealing temperature for ${}^{20}_{10}$Ne-ion in CN (R) detector.

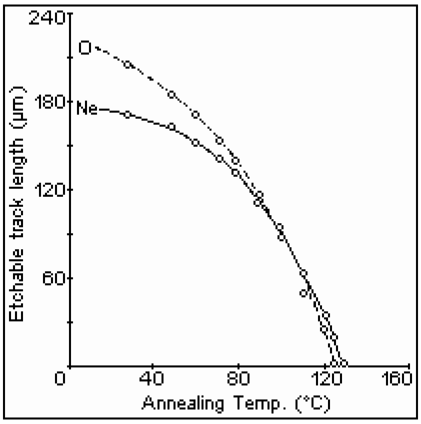


CN (R), ${}^{20}_{10}$Ne-ion, 6N NaOH, 60°C

Effect of temperature on maximum etchable track length

The detector samples exposed to ${}^{20}_{10}$Ne and ${}^{16}_{8}$O-ions at an angle of 30° are cut into small pieces. They are then annealed for 10 min at different temperatures. The annealed samples are etched until the tips of the tracks become round. The maximum etched track lengths are determined. The effect of annealing temperature on the maximum etchable lengths (i.e. range) of the ions in the plastic detector is shown in Figure 9. It is observed that the track lengths are decreased by the application of heat. Again, it is noted that the thermal stabilities of tracks of different ions are different. Thus, the process of discrimination of ion tracks by following different annealing procedures will help in particle identification and background eradication. From a comparison of the curves in Figures 9 and 6 for ${}^{20}_{10}$Ne-ions it is evident that oblique tracks are less stable than vertical tracks.

Figure 9: Variation of maximum etchable track length of ${}^{20}_{10}$Ne and ${}^{16}_{8}$O-ions in CN (R) with annealing temperatures.



CN (R), ${}^{20}_{10}$Ne-ion and ${}^{16}_{8}$O-ion,
Ann. time=10 min, 6N NaOH, 60°C.

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