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Particle Identification by Measurement of Track Cone Length as a Function of the Residual Range of Heavy Ions in CR-39 and Lexan Polycarbonate

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The maximum etchable ranges of heavy ions such as ^{238}U, ^{208}Pb, ^{197}Au, ^{132}Xe and ^{93}Nb in CR-39 and ^{238}U, ^{197}Au and ^{132}Xe in Lexan polycarbonate have been determined. An attempt has been made to examine the suitability of the single-sheet particle identification technique in CR-39 and Lexan polycarbonate by plotting track cone length vs residual range for different heavy ions. A comparison has been made between experimental and theoretical values of ranges for different heavy ions in these detectors. A reasonably good agreement has been observed between the experimental and the theoretically computed values.

Introduction

The passage of heavy charged particles through most insulators leads to the formation (at the micro-structural level) of narrow regions of radiation damaged matter; referred to as latent tracks (Silk and Barnes, 1959). The insulator materials used to store the tracks are solid state nuclear track detectors (SSNTDs). Price and Walker (1962) successfully proposed that the tracks of charged particles in minerals and polymers should be preserved by the selective etching of the damaged material along the particle trajectories. The establishment of a relationship between the rate of etching of the material along the track of an ion and its ionization losses stimulated the development of methods of identifying the charge, mass, energy, and orientation of particles. These particle parameters can be determined by measuring the rate of etching of the material along the track, V_t (a quantity proportional to energy loss) and the particle range R in the SSNTDs (a quantity proportional to the energy of the particle). However, the dependence of the ionization on the ion energy is rather complicated and as a result, it is not possible to propose a single principle of particle identification based on the parameters of the observed tracks and valid for the complete range of energies of the incident particle. Therefore, the problem of the identification of charged particles in the SSNTDs depends on the energy range of the detected particles. There are a number of methods used to identify the particle in SSNTDs (Fleischer *et al.*, 1975) viz. particle identification by measurement of track cone length vs residual range (Price *et al.*, 1967); track profile method (Fleischer *et al.*, 1970); by measurement of etch rate vs residual range (Price and Fleischer, 1973); by measurement of etch pit diameters (Somogyi and Szalay, 1973) and by measurement of maximum etchable track length (Price and Shirk, 1973).

In our present work, we have used the track cone length vs residual range method of identification using CR-39 and Lexan polycarbonate detector irradiated by different heavy ions at different energies. This technique is also called the single sheet identification or LR-plot method of particle identification using SSNTDs. This is one of the highly developed methods, and one that has been applied to all classes of dielectric solids. It involves measuring track length L at several values of the residual range (RR).

Experimental Details

(a) Irradiation

The samples of CR-39 (composition $C_{12}H_{18}O_7$, molecular weight 274 a.m.u., density 1.32 g/cm^3) have been irradiated by heavy ions such as ^{238}U (16.53 and 15.0 MeV/u), ^{208}Pb (13.6 MeV/u), ^{197}Au (11.4 MeV/u), ^{132}Xe (14.5 and 13.02 MeV/u) and ^{93}Nb (18.0 MeV/u) available from the UNILAC accelerator at GSI, Darmstadt, Germany. Similarly, the samples of Lexan (composition $C_{16}H_{14}O_3$, molecular weight 254 a.m.u., density 1.23 g/cm^3 have been irradiated by heavy ions such as ^{238}U (16.53, 15.0 and 5.9 MeV/u), ^{197}Au (13.42 MeV/u) and ^{132}Xe (14.5 and

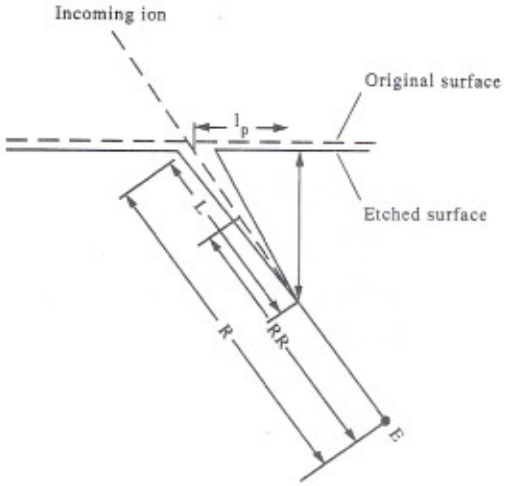


Fig. 1. Etched track geometry.

5.9 MeV/u) available from the same source. All the irradiations were carried out at 45° with respect to the surface of the detector with well collimated beams of different heavy ions using the same fluence of 10^4 ions/cm^2.

(b) Chemical etching and other measurements

After irradiation, the samples of CR-39 and Lexan were cut into small pieces and etched for a sufficient time to yield a measurable track length (not to the very end of the range) in 6.25 N NaOH solution at a constant temperature of 60°C with a control accuracy of ±1°C. The etched samples were washed under running tap water for about 10 min. After washing, the samples were dried in the folds of a tissue paper. The washed and etched samples were scanned using a binocular Carl Zeiss microscope having a magnification of 1000×. After measuring the projected track length, the total etchable range was determined by applying the corrections due to the angle of incidence, bulk etching and over-etching (Dwivedi, 1979). Knowing the total etchable range, it is possible to determine the residual range of the different heavy ions (different measurable parameters shown in Fig. 1):

$$\text{Residual range} = \text{total etchable range} - 1/2 \text{ track length},$$

$$RR = R - L/2.$$

Thus the track cone length and residual range, RR gives a (L, RR) pair which forms the basis of the single sheet identification technique. Finally, a comparison was made between experimental and theoretical values of ranges computed by using the program "TRIM92" (Ziegler *et al.*, 1985).

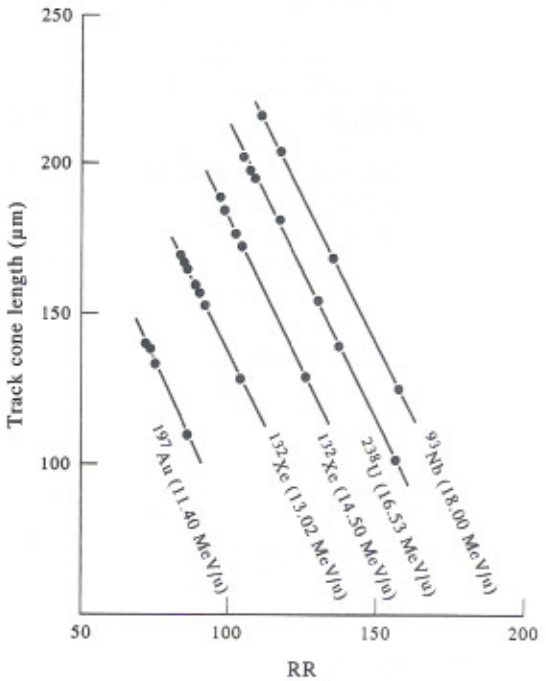


Fig. 2. Variation of track cone length with residual range for different heavy ions in CR-39.

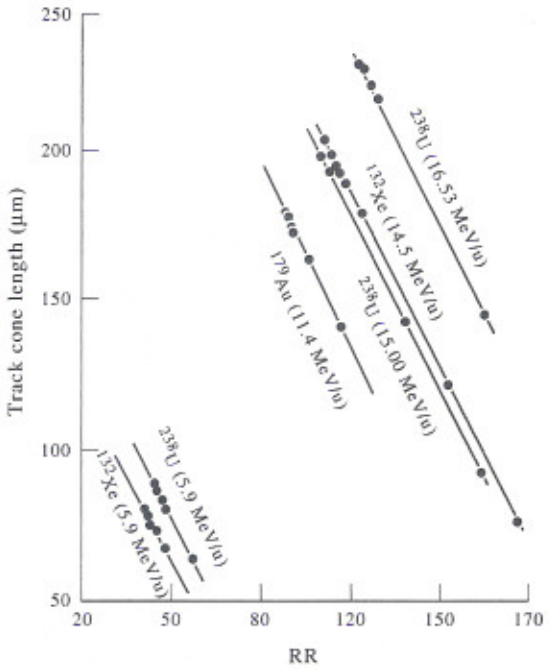
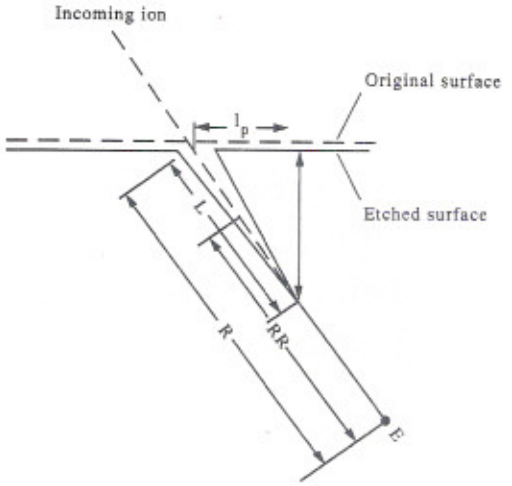


Fig. 3. Variation of track cone length with residual range for different heavy ions in Lexan polycarbonate.

Table 1. Comparison between experimental and theoretical values of the ranges for different heavy ions in CR-39

Ion	Energy (MeV/u)	Experimental range (μm)	Theoretical range (μm)
^{238}U	16.53	207.22	229.88
^{238}U	15.0	190.33	210.20
^{208}Pb	13.6	166.00	190.17
^{197}Au	11.4	142.68	160.33
^{132}Xe	14.5	191.45	199.82
^{132}Xe	13.02	169.29	178.43
^{93}Nb	18.0	263.00	273.83



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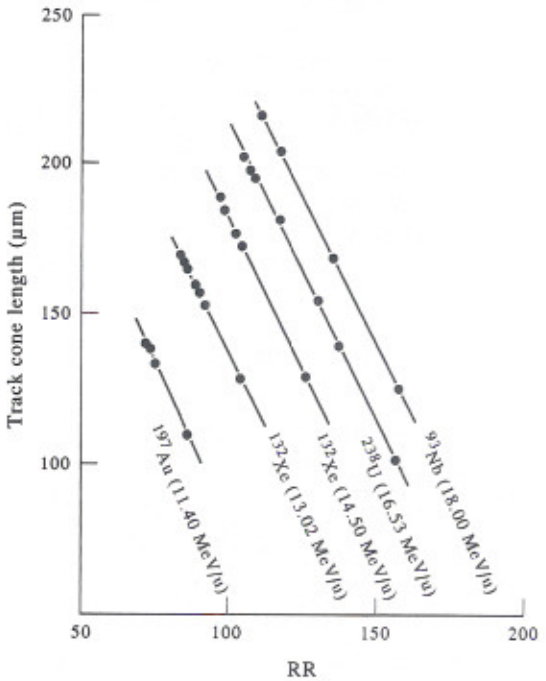

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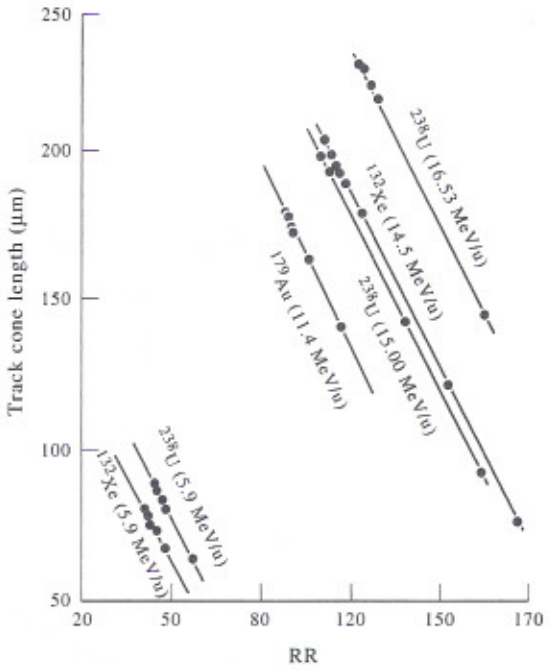

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^{132}Xe	13.02	169.29	178.43
^{93}Nb	18.0	263.00	273.83

Table 2. Comparison between experimental and theoretical values of ranges for different heavy ions Lexan polycarbonate

Ion	Energy (MeV/u)	Experimental range (μm)	Theoretical range (μm)
^{238}U	16.53	226.82	247.75
^{238}U	15.0	202.85	226.85
^{238}U	5.9	91.72	98.75
^{197}Au	13.42	181.43	202.61
^{132}Xe	14.5	205.94	214.65
^{132}Xe	5.9	83.10	86.14

Results and Discussion

Figure 2 shows the plot of track cone length (L) vs residual range (RR) for different heavy ions in CR-39. From the figure it is clear that the points corresponding to the different heavy ions lie on the different lines. It is also observed that the points corresponding to the plot between track cone length and residual range for the ^{132}Xe ion with two different energies (14.5 and 13.02 MeV/u) lie on two different lines. Hence, it is concluded that the single-sheet identification method is successful for the energy resolution of heavy ions in CR-39. Similarly, Fig. 3 shows the plot between track cone length and the residual range (RR) for different heavy ions in Lexan polycarbonate. The points corresponding to the graph between track cone length and the residual range for the ^{238}U ion with three different energies lie on the three different lines. Thus, it is concluded that the single sheet particle identification is also successful for the energy resolution in Lexan polycarbonate. To consider its response to the charge resolution, the points corresponding to the ^{132}Xe and ^{238}U ions with the same energy (5.9 MeV/u) lie on the different lines as shown in Fig. 3. Hence, this method can be used successfully for the identification of low-energy particles, such as solar cosmic ray particles from solar flares, which cannot penetrate more than one sheet.

A comparison between experimental and theoretically computed values of ranges for different heavy ions in CR-39 and Lexan have been shown in Tables 1 and 2, respectively. It is evident that the experimental values are less than the corresponding theoretical values of range. This is so because each detector material fails to record the last few microns of length of the track where the energy loss rate, (dE/dX), of the ion becomes less than the critical energy loss rate, $(dE/dX)_c$ for that detector (Fleischer *et al.*, 1975). Thus, it is clear that the values of range computed theoretically are in reasonable agreement with the corresponding experimental values.

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