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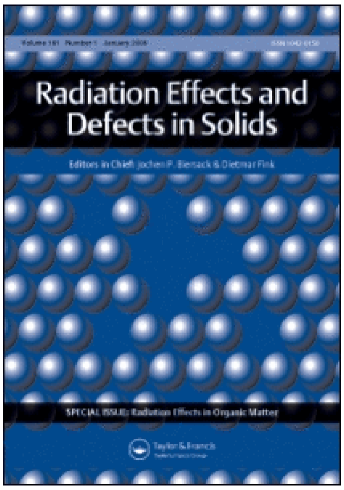

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Ranges and energy-loss measurement of 1.0-4.7 MeV/u ^{28}Si ions in Makrofol-G using padc as detector

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RANGES AND ENERGY-LOSS MEASUREMENT OF 1.0–4.7 MeV/u ^{28}Si IONS IN MAKROFOL-G USING PADC AS DETECTOR*

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Ranges and energy-loss up to 4.7 MeV/u ^{28}Si ions in Makrofol-G polymer have been determined using a nuclear track technique. Polyallyldiglycol carbonate (CR-39) detectors were calibrated using Al degraders to determine the degraded energy of ^{28}Si ions after passing through the different stacks of Makrofol-G placed in the staircase configuration. The mean ranges of ^{28}Si in Makrofol-G have also been determined at different energies between 1.0 MeV/u and 4.7 MeV/u. The experimental results are discussed and compared with the theoretical values obtained from four different computer codes.

Keywords: Range; Energy loss; Makrofol; CR-39; Ion implantation; Theory

1 INTRODUCTION

The interaction of heavy ions with matter, particularly with solid state nuclear track detectors (SSNTDs), provides valuable information

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regarding the ranges and energy-loss of the ions in these detectors. In the last few years lot of work has been done to characterize and improve track detectors for better detection sensitivity as well as charge and energy resolutions. The SSNTDs have found many applications in diverse fields viz., particle identification [1,2], lifetimes of heavy unstable nuclear particles [3], development of microfilters [4,5], single pore membranes [6], multifragmentation reactions [7,8], biomedical science [9,10] and environmental science [11,12]. The widespread applications of SSNTDs in these fields require reliable and accurate data on heavy ion ranges and energy-loss in several commonly used elemental and composite materials. Also the rate of energy-loss or the way the impinging ion looses its energy as it passes through succeeding layers of the material gives information regarding the nature of the material itself. It is desirable to have a reliable and accurate data on heavy ion ranges and energy-loss in different materials to ascertain their use as a track detector.

Polycarbonates have found their use in producing microfilters and single-pore membranes which in turn find their applications in a number of fields [13–15] and technical devices [6]. Experimental ranges and energy-loss data for Makrofol-G are scanty in the literature [28]. It prompted the present measurement of ranges and energy-loss of ^{28}Si ion in Makrofol-G to facilitate the application of this polymer in the different fields. The nuclear track technique [16] is quite versatile, simple and accurate. It does not require costly equipments, such as time of flight (TOF) [17], double time of flight (DTOF) [18], a magnetic or recoil proton spectrometer [19]. For measurement of ranges and energy-loss, a sensitive track detector only requires calibration for a desired heavy ion species in terms of maximum etchable track length as a function of ion energy. In the present study, Polyallyldiglycol carbonate (PADC) track detectors have been calibrated for energy measurement of ^{28}Si ions in terms of maximum etchable track length. The ranges and energy-loss of ^{28}Si ion in Makrofol-G foils are then determined for an energy range of 1.0–4.7 MeV/u. The experimental data are compared with theoretical values computed from codes (a) RANGE [20], (b) TRIM [21], (c) Henke and Benton (BENTON) [22] and (d) Hubert *et al.* (HUBERT) [23] in order to assess their validity.

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2 EXPERIMENTAL DETAILS

Energy calibration of PADC detector In order to calibrate PADC detectors for different energies (E) of ^{28}Si ions in terms of maximum etchable track length (L) Al degraders were used. Thin foils of pure Al were procured and their thickness were measured by Heidenhain depth measuring device. These foils with a thickness ranging from 5 to 80 μm were arranged on a PADC detector in a staircase configuration to prepare the degraders. The assembly was then mounted on a target holder for irradiation. The PADC detector was then etched, and the maximum etchable track lengths were measured for different energies of the ion. The values of transmitted energies after passing through different foils of Al were then plotted against the experimental track lengths in PADC corresponding to different foils of Al, to obtain the calibration of energy of ^{28}Si ion versus track lengths in PADC.

Target preparation Rectangular pieces of different sizes were cut from 15 μm thin sheets of Makrofol-G (composition: $C_{16}H_{14}O_3$, density: 1.2 g cm^{-3}) to prepare the target for irradiation. The thickness of Makrofol-G sheet was measured by a sensitive Heidenhain device within an accuracy of ±1 μm. The target was prepared on PADC backing in the form of a staircase. The effective thickness of the target ranges from 15.7 to 109.8 μm. The PADC detector was then fixed on the target holder for irradiation.

Irradiation of Makrofol-G The staircase of Makrofol-G on PADC was irradiated with a well-collimated beam of 4.7 MeV/u ^{28}Si ions in the general purpose scattering chamber (GPSC) at the Nuclear Science Centre New Delhi. Irradiations were done at an incident angle of 70° with respect to the detector surface using an optimum fluence of 2×10^4 ions/cm^2. Figure 1 shows the irradiation geometry.

Etching and measurement of tracks After irradiation, both Al and Makrofol-G foils were removed from the PADC detectors. The detectors were washed thoroughly and etched in 6 N NaOH at 55°C for a period of 2 h. After etching the detectors were washed in running water and dried in air. Etchable track lengths were then measured at a magnification of 625× in different regions of the staircase at random all over the detector surface. The true track lengths were

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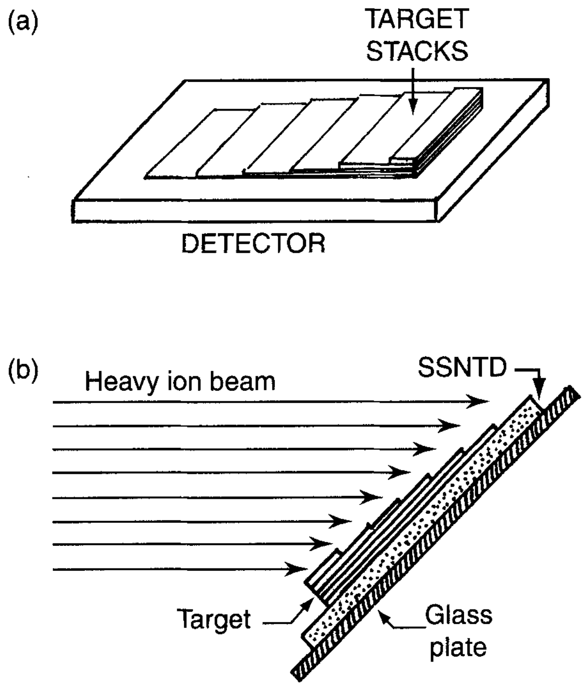

FIGURE 1 Schematic diagram showing (a) the target stacks on detector and (b) heavy ion irradiation geometry for targets in stair-case configuration.

then obtained from the measured projected track length using the relation given by Dwivedi and Mukherji [24].

Determination of mean ranges and energy-loss rate The maximum etchable track lengths in PADC detectors were measured for ^{28}Si ions transmitting through different thickness of Makrofol-G foils. The energies of the degraded ions were obtained from the calibration curve (Fig. 2) using these values of track lengths. An energy-loss curve (Fig. 3) of the ion has been constructed from the data of target thickness and the ion energies. The experimental data were fitted by a third order polynomial. By extrapolating the energy-loss curve down to energy $E_i = 0$, the mean range of 4.7 MeV/u ^{28}Si ion in Makrofol-G was then obtained. With the help of this curve mean ranges of ^{28}Si ion in Makrofol-G for different energies have also been determined.

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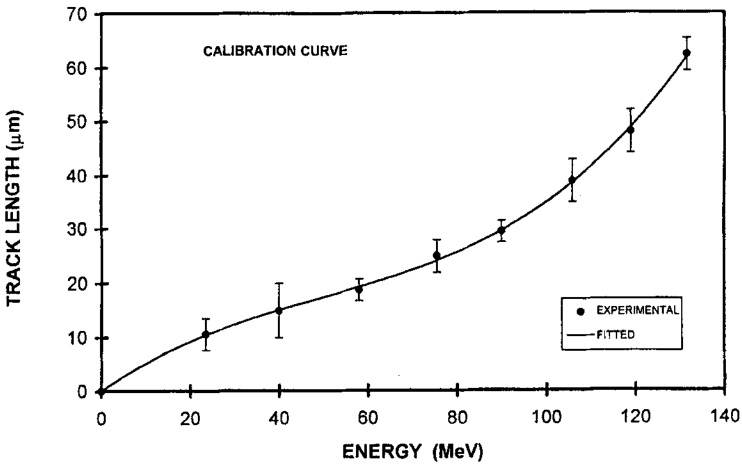

FIGURE 2 A plot showing the calibration curve between track length and energy of ^{28}Si ion in PADC track detector.

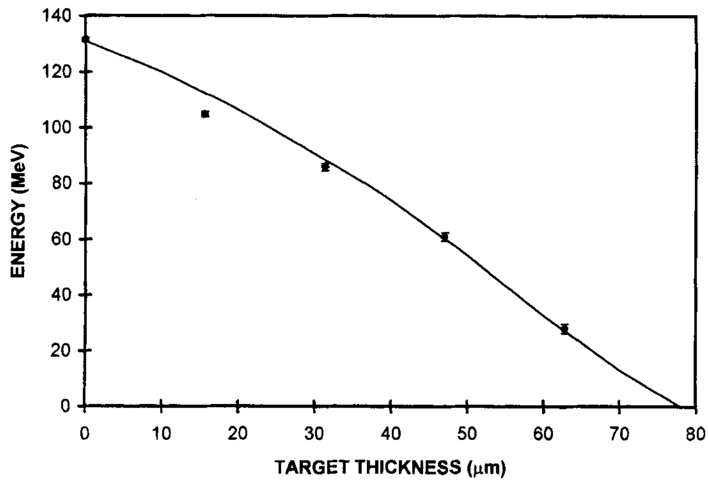

FIGURE 3 A curve showing the energy-loss data for ^{28}Si in Makrofol-G.

Experimental errors The error involved in the determination of initial energy was within 0.5%. The error in the measurement of thickness of the foils is of the order of ±2 μm. The standard deviations obtained from the track length distribution curves vary between 1.7 and 3.5 μm. The variations in the mean ranges on account of the above mentioned uncertainties were found to vary between 2 and 4 μm.

3 RESULTS AND DISCUSSION

The experimental data for maximum etchable track length (L) corresponding to different energies of ^{28}Si ions in PADC are given in Table I. Figure 2 shows the track length–energy calibration curve for the ^{28}Si ions in PADC. With the help of this calibration curve and the values of maximum etchable track lengths of ^{28}Si ions in PADC, the energies lost by ^{28}Si ions while passing through different thickness of Makrofol-G foils were obtained. An energy loss curve for ^{28}Si in Makrofol-G is shown in Fig. 3. The range (R_i) of 4.7 MeV/u ^{28}Si in Makrofol-G has been obtained by extrapolating the energy-loss data down to zero energy and is found to be 78 ± 3 μm. Taking this value of R_i, the mean ranges of ^{28}Si in Makrofol-G at different energies have been determined using the energy-loss curve. The target thickness, maximum etchable track length of ^{28}Si in PADC, energy of the transmitted ion and the total energy lost by the ion have been listed in Table II.

Figure 4 represents the experimental range data plotted with the corresponding theoretical values at different energies as calculated from the computer codes BENTON, HUBERT, RANGE and TRIM. The theoretical ranges from different codes are tabulated in Table III along with the experimental values of ranges at different energies.

The experimental mean ranges are in good agreement with the calculated values from the computer codes TRIM and HUBERT.

TABLE I Range energy calibration of PADC detector for 4.7 MeV ^{28}Si ion

Energy of the ion (MeV)	*Maximum etchable track length* (μm)
131.6	62 ± 3
119.0	48 ± 4
106.0	39 ± 4
90.0	29 ± 2
75.5	25 ± 3
58.0	19 ± 2
40.0	15 ± 5
23.5	11 ± 3

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TABLE II Values of Makrofol-G target thickness, maximum etchable track length of ^{28}Si in PADC, energy of the transmitted ^{28}Si ions and total energy lost by the ions after passing through Makrofol-G foils

Effective target thickness X (μm)	*Maximum etchable track length L* (μm)	*Ion energy* (MeV)	*Total energy loss* (MeV)
0	61 ± 3	131.6 ± 0.7	0
15.7	37 ± 5	102.0 ± 1.0	29.6 ± 1.2
31.4	28 ± 5	86.0 ± 1.3	45.6 ± 1.5
47.0	19 ± 2	61.0 ± 1.5	70.6 ± 1.7
62.7	12 ± 2	28.0 ± 1.7	103.6 ± 1.8
78.4	No tracks	—	—

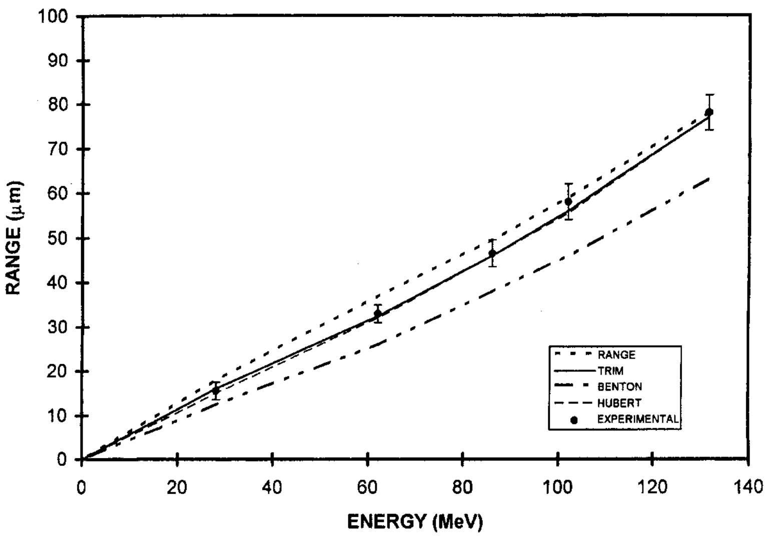

FIGURE 4 Experimental and theoretical range–energy plots for ^{28}Si in Makrofol-G.

TABLE III Values of experimental and theoretical mean ranges of ^{28}Si in Makrofol-G

Energy of the ion (MeV)	*Experimental range* (μm)	*Theoretical range* (μm)			
		RANGE[20]	*TRIM*[21]	*BENTON*[22]	*HUBERT*[23]
131.6 ± 0.7	78 ± 4	78	77	63	77
102.0 ± 1.0	58 ± 4	59	56	46	56
86.0 ± 1.3	47 ± 3	49	46	38	46
61.0 ± 1.5	33 ± 2	37	33	26	32
28.0 ± 1.7	16 ± 2	20	16	13	15

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The ranges obtained from code RANGE seem to be 6–10% over-estimated below 90 MeV, however, above this energy they agree fairly well. The ranges calculated by the code BENTON are underestimated by 6–20% and the discrepancies are larger at higher energies. These results along with some earlier reported work [25–28] provide valuable information on the reliability of the theoretical range data in complex media. This work should be extended by using a number of heavier ions at higher energies in order to obtain a more realistic comparison.

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