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Stopping Power of Aluminium for Energetic ^{238}U IONS Using Nuclear-Track Technique

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(**Note:** Please refer the Table.1 at end of the articles)

Abstract

Using a versatile nuclear-track technique proposed by Saxena et al, we have determined experimental ranges and stopping powers for the passage of energetic ^{238}U ions through Aluminium. CR-39, a very sensitive polymer Solid State Nuclear Track Detector, is used in the present study. The experimental data are compared with the corresponding theoretical values from SRIM, Mukherji et al, the data tables of Hubert et al and of Northcliff and Schilling.

Keywords: Stopping power, range, ^{238}U, Aluminium, CR-39

1. Introduction

Studies on physical and biological effects produced by the penetration of charged particles through matter invariably require stopping power and range information. Ion implantations in semiconductors, which are essential in the manufacture of modern integrated circuits, require accurate range data (Rose & Ryding,2006). Due to limited availability of experimental range and stopping power data, it is customary to use the values derived from different theoretical models, which have been known to have significant discrepancies between themselves (Paul & Schinner,2003; ICRU,2005) and with experimental data, as high as 30% in some cases (Bimbot et al.,1978). Nuclear tracks in solids have found many applications in diverse fields (Fleischer et al.,1975, Nikezic & Yu,2004). The Nuclear track technique (Saxena,1987, Saxena et al.,1989), a relatively simple method, is used in the present study for the experimental determination of ranges and stopping powers.

2. Materials and Methods

a) Nuclear track technique (Saxena et al)

The Solid State Nuclear Track Detector (SSNTD) is calibrated for the given ions in terms of maximum etchable track length as a function of ion energy. Stacks of target foils of precise known thicknesses are prepared and then placed in front of the SSNTD and exposed to a collimated beam of the given ions. Subsequently, these exposed detectors are etched in suitable etchants until the nuclear tracks are completely developed which are then measured through an optical microscope. The energy-loss of transmitted ions is obtained directly from the values of the measured track lengths in the SSNTD and calibration curve. The plot of the transmitted ion energy as a function of target thickness gives the energy-loss curve. By extrapolation of the energy-loss curve down to ion energy zero, one may obtain the mean range (R_i) of the heavy ion at the given maximum ion energy (E_i) in the given target. Once R_i is known, the mean range $R(E)$ at any intermediate energy E may simply be obtained from the following relation:

$$R(E) = R_i - x(E)$$

where $x(E)$ is the target thickness that reduces ion energy from E_i to E and is obtained from the energy-loss curve. The stopping power of the target material is related to the range by

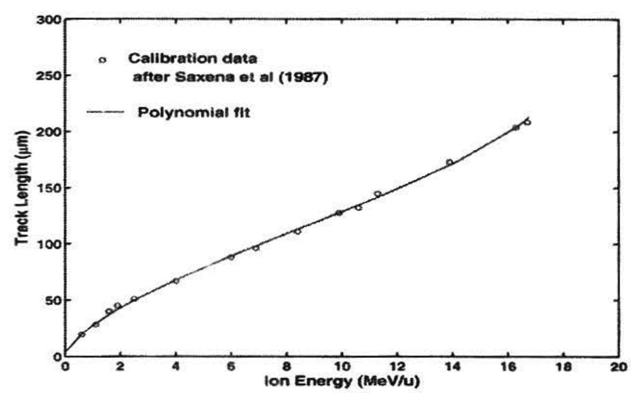
$$\int_0^{E_0} S^{-1} dE = R(E_0) \Rightarrow \quad S = \frac{dE}{dR}$$

and is obtained from the slope of the range-energy curve.

B) Experimental Procedure

Polyallyl Diglycol Carbonate (composition: $C_{12}H_{18}O_7$; molecular weight: 274.0; density: 1.32 g/ml) commercially known as CR-39, is a very sensitive SSNTD (Cartwright et al.,1978) which make it quite suitable for the present study. The calibration curve (Fig.1.) is drawn between the track lengths of ^{238}U ions in CR-39 at various energies for which data is reported elsewhere (Saxena et al.,1987). Aluminium targets of various thicknesses 7.2–156.2 μm with a uniformity of 1–5% are prepared and placed before CR-39 detectors of dimensions 2x2x0.15 cm^3. These target-detector assemblies are then exposed to a well-collimated beam of 16.3 MeV/u ^{238}U at XO port of UNILAC, GSI, Darmstadt. All irradiations were done at an incident angle of 45° with respect to the detector surface, using an optimum flux of $\sim 10^4$ ions per cm^2. The irradiated CR-39 detectors are then etched in 6N NaOH at 55° for 2–4 hours, until the nuclear tracks are completely etched. Track parameters (projected track lengths and track diameters) are measured by an optical microscope (magnifications 675X and 1500X with measuring accuracy ±1.0 μm and ±0.5 μm respectively) at random all over the detector area to minimize the error due to non-uniformity in target. The true track lengths are then calculated from the projected track lengths (Dwivedi & Mukherji,1979).

Fig.1 *Calibration curve between the measured track length in CR-39 and corresponding energy of ^{238}U ion*

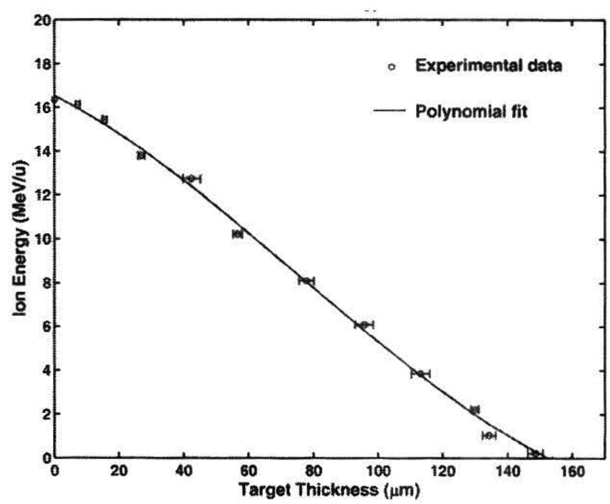


3. Results and Discussion

The experimental ranges and stopping power results are compared with various theoretical predictions viz. Hubert et al (1990) and Northcliff and Schilling (1970) data tables, SRIM (Ziegler et al.,2010), the computed range and stopping power values from stopping-power equations of M ukherji and coworkers (Mukherji & Nayak,1979; Dwivedi,1988).

The target thicknesses of Aluminium, the corresponding track lengths in CR-39 and the transmitted ion energy are presented in Table 1. The plot (Fig.2.) of the transmitted ion energy versus the target thickness gives the energy-loss curve of ^{238}U ion in Aluminium.

Fig.2. *The energy-loss curve for 16.3 MeV/u ^{238}U ions in Aluminum.*



Extrapolation of the energy-loss curve to ion energy zero suggests that 1 52.3± 4 μm of Aluminium is j ust sufficient to absorb ^{238}U ions of 16.3 MeV/u.. The mean ranges of ^{238}U at several lower energies are determined using equation 1 and tabulated in Table 1. Fi g.3 shows the plots of e xperimental mean ranges of ^{238}U in Aluminium as a function of ion energy along with various theoretical results. The experimental range data, within error li mits, agrees fairly well with the theoretical predictions. Around 2 Mev/u, theoretical values are overestimated by about 15%. However, at higher energies the experimental data are cl oser to those predicted by SRIM and Hubert et al. Th e range-energy data is fitted with a th ird order polynomial fit. The stopping power of Aluminium for ^{238}U ions at various ion energies are then obtained from the slope of the fitted curve.

Fig.3. *Plot of the experimental range-energy data for 238U in Aluminium along with theoretical values.*

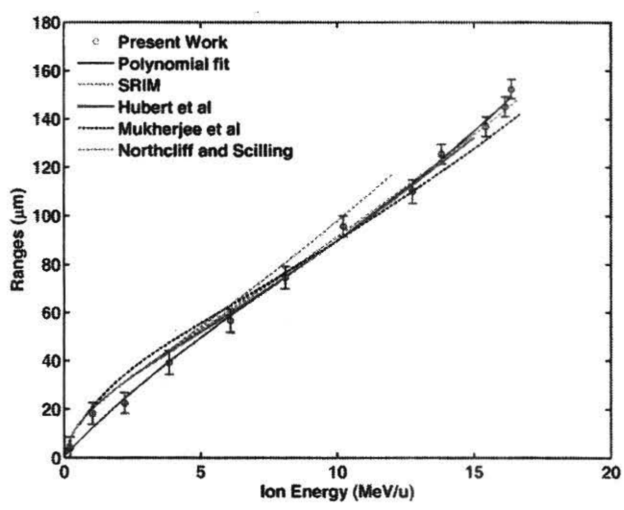
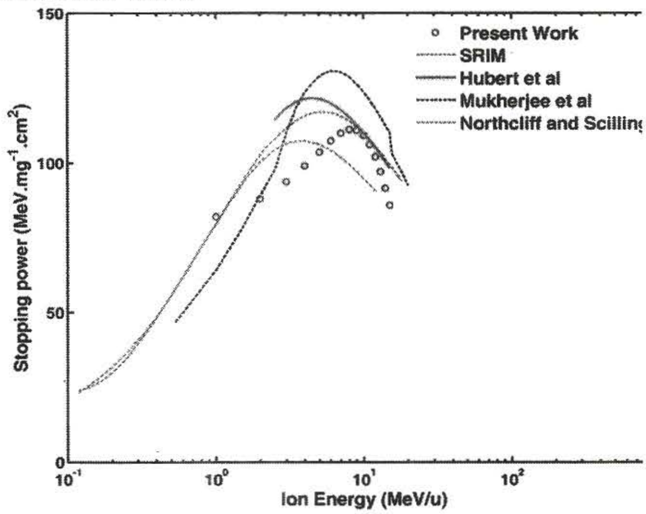


Fig.4. *Plot of experimental stopping power data of Aluminium at various energies of ^{238}U, along with theoretical values.*



4. Conclusions

Here we pre sent the experimental stopping power values for energies upto 16.3 MeV/ u whereas a vailable results are generally found below 11 MeV/u, which are not available earlier. The validity of all considered theoretical ranges are broadly found in good agreement with our experimental results. Our experimental stopping power results are i n between the values obtained from Hubert et al and SRIM and the data tables of Northcliff and Schilling.

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Table.1. *Values of Aluminium thickness, maximum etchable track length of ^{238}U in CR-39 detector, energy of the transmitted ^{238}U ions and the ranges obtained in Aluminium.*

Target Thickness (µm)	Track length (µm)	Transmitted ion energy (MeV/u)	Experimental ranges (µm)
Without target	205 ± 2	16.34 ± 0.1	152.3± 4
7.2 ± 0.7	201 ± 2	16.1 ± 0.1	145.1 ± 4.1
15.5 ± 0.7	190 ± 2	15.33 ± 0.1	136.8 ± 4.1
26.9 ± 1	169 ± 3	13.66 ± 0.2	125.4 ± 4.1
42.4 ± 2.7	157 ± 4	12.62 ± 0.3	109.9 ± 4.8
56.6 ± 1.4	131 ± 3	10.4 ± 0.2	95.7 ± 4.3
77.8 ± 2.3	110 ± 4	8.3 ± 0.3	74.5 ± 4.6
95.7 ± 2.8	90 ± 4	6.37 ± 0.3	56.6 ± 4.9
113.1 ± 2.8	66 ± 4	3.96 ± 0.4	39.2 ± 4.9
129.8 ± 1.2	46 ± 3	2.02 ± 0.3	22.5 ± 4.2

134.2 ± 2	28 ± 3	0.9 ± 0.3	18.1 ± 4.5
148.5 ± 2.4	11 ± 3	0.25 ± 0.2	3.8 ± 4.7
156.6± 2.8	No tracks	-	-

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