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Identification of charged particles by etching the solid state nuclear track detectors in successive intervals

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The suitability of the method of charged particle identification by etching the samples in successive intervals developed by Grabez *et al.* [Nucl. Instrum Methods, B42(1989)286] has been checked in CR-39 exposed to heavy ions ^{238}U, ^{208}Pb, ^{197}Au and ^{132}Xe in the interval 11.0 to 17.0 MeV/u. A similar study has been made on soda glass detectors irradiated by ^{238}U, ^{132}Xe, ^{56}Fe and ^{48}Ti ions having energy 4.0 to 6.0 MeV/u. It is concluded that this method of particle identification can be used successfully in CR-39 and soda glass detectors.

1 Introduction

Solid state nuclear track detectors (SSNTDs) have been used to identify the charge and mass in cosmic rays and to investigate nuclear reactions produced by various projectiles. To identify particles detected in SSNTDs, it is necessary to establish a connection between the various parameters of the etched track and of the particle, i.e. mass, charge and energy[1]. These particle parameters can be determined by measuring the ratio of etching of the material along the track V_t (a quantity proportional to the energy loss) and the particle range R in the detector (a quantity proportional to the energy of the particle). However, the ionization curves of the dependence on the ion energies are rather complicated and as a result, it is not possible to propose a single principle of particle identification based on parameters of the observed track and valid for the complete range of energies. Therefore, the problem of the identification of charged particles in SSNTDs depends upon the energy range of the detected particles. There are a number of methods used to identify the particle in SSNTDs[2], viz., particle identification by measurement of track cone length versus residual range[3]; track profile method[4]; by measurement of track etch rate versus residual range[5]; by measurement of etch pit[6] and by measurement of maximum etchable track length[7]. These methods for the identification of ions in SSNTDs can be divided into two groups. One group of methods is based on the measurements of the track parameters in a single sheet of the detector. These methods can be used for ions which are stopped in the material of the detector and identification of particles is done using the local etch rate ratio (V_t/V_b) or mean etch rate (V_t/V_b) (Grabez *et al.*[8]). The second group of methods is based on measurements in many sheets of detector. In these methods if the ions are stopped in the stack of detectors, the etch rate ratio (V_t/V_b) and the range (R) are used for identification and if the ions are not stopped in the detector stack the etch rate ratio[9] (V_t/V_b) and its charge along the trajectory of the ion are used as parameters for identification. It is clear that single sheet methods are used for identification of low energy particles. Grabez *et al.*[10] developed a method for particle identification in a single sheet by etching the detector in successive intervals and used successfully for particle identification in CR-39. In this method the samples of CR-39 exposed to different heavy ions having energy between 10 to 20 MeV/u were etched for a time interval t_1 to determine the etched track length (L_1) and the corresponding track etch rate, V_t ($V_t=L_1/t_1$). As V_t is a function of Z^*/β ratio, where β is the velocity of the ion and Z^* its effective charge given by

$$Z^* = Z [1 - \exp (-130\beta/Z^{2/3})] \quad ...(1)$$

The data on V_t was fitted according to the usually used relation,

$$V_t = a(Z^*/\beta)^b \quad ...(2)$$

and the values of a and b are determined. Since the track etch rate V_t (or the etched track length, L_1) for the fixed etch conditions is a function of Z^* and β, the track length (L_2) of the etched track after the second etching can be expressed as a function of L_1 and Z^* and fit the data by the relation

$$L_2 = L_1 [1 + c(Z^*)^d] \quad ...(3)$$

From this relation, we obtain the relation

$$Z^* = (1/c)^{1/d}[L_2/L_1 - 1]^{1/d}$$

$$Z^* = k [(L_2/L_1) - 1]^{\xi} \quad ...(4)$$

where $k = (1/c)^{1/d}$ and $\xi = 1/d$. It follows that knowing the values of L_1 and L_2, and using the relations given in Eqs (1), (2) and (4), the atomic number Z of the particle and its velocity β can be determined. In the present paper, an attempt has been made to apply this method of particle identification in CR-39 exposed to ^{238}U (16.53 and 15.0 MeV/u), ^{208}Pb (13.6 MeV/u), ^{197}Au (11.4 MeV/u) and ^{132}Xe (14.5 MeV/u) ions from UNILAC heavy ion accelerator at GSI, Darmstadt, Germany. A similar study is carried out on soda glass detector irradiated by ^{238}U (5.9 MeV/u), ^{238}Xe (5.9 MeV/u), ^{56}Fe (4.0 MeV/u) and ^{48}Ti (4.0 MeV/u).

2 Experimental Details

The samples of CR-39 plastic were exposed to different heavy ions, viz., ^{238}U (16.53 and 15.0 MeV/u), ^{208}Pb (13.6 MeV/u), ^{197}Au (11.4 MeV/u) and ^{132}Xe (14.5 MeV/u) from the heavy ion accelerator UNILAC at GSI, Darmstadt, Germany. The exposed samples were cut into small pieces and etched in 6.25N NaOH solution at a constant temperature of 70°C. At first interval the samples were etched for 10 minutes. The etched samples were washed in running water and dried in folds of a tissue paper. The etched and dried samples were scanned under the Carl Zeiss optical microscope to determine the track length L_1 corresponding to the first interval of etching. After the first observation corresponding to 10 minutes of etching, the same samples were etched for 10 minutes more under the same etching conditions and the value of track length L_2 corresponding to etching time 20 minutes is determined in a similar way.

A similar investigation is carried on the soda glass irradiated by ^{238}U and ^{132}Xe ions having energy 5.9 MeV/u from the same source and ^{56}Fe (4.0 MeV/u) and ^{48}Ti (4.0 MeV/u) from the heavy ion accelerator at JINR, Dubna. All these irradiations were done at an angle of 90° with respect to the surface of the glass. The irradiated samples were cut into small pieces and etched in a solution of HF (48 Vol%), H_2SO_4 (98 Vol%) and distilled water in the ratio 6:1:18 at a constant temperature of 40°C for 2 min. After washing and drying, the samples were scanned under an optical microscope. The etched tracks were circular in shape. The depths of the tracks are measured by using the Z-motion of the microscope. The values of depth d_1 have been determined for a time of 2 minutes. After making all observations corresponding to 2 minutes, the samples were etched for 2 minutes more under the same conditions. The value of depth d_2 corresponding to 4 minutes etching is measured using the same procedure.

Table 1 — The track lengths L_1 and L_2 (average of 50-60 tracks) after etching in 6.25N NaOH for 10 and 20 minutes with theoretical ranges corresponding to different heavy ions in CR- 39

Ion	Energy (MeV/u)	Track length L_1 (μm)	Track length L_2 (μm)	Range (μ m)
^{238}U	16.53	128.20 ± 1.43	147.4 ± 1.46	209.22
^{238}U	15.00	136.39 ± 1.49	161.05 ± 1.70	191.96
^{208}Pb	13.60	112.4 ± 1.42	137.62 ± 2.16	171.23
^{197}Au	11.40	118.92 ± 1.39	140.42 ± 1.87	144.00
^{132}Xe	14.50	84.13 ± 1.89	124.48 ± 1.71	195.00

3 Results and Discussion

Table 1 presents the data for different heavy ions in CR-39. The L_1 and L_2 are the values of track lengths after etching the samples for 10 and 20 minutes, respectively, and R is the theoretical range of different heavy ions in CR-39 calculated by Mukherjee and Nayak stopping power and range equations[11] (most suitable equations for this combination of heavy ion and light target in the given energy range[12]). The value of track etch rate, V_t, is calculated by using the relation $V_t = L_1/t_1$, where t_1 is the time of etching, 10 minutes. Our data on CR-39 fit the following relationship between V_t and Z^*/β

$$V_t = 0.016\ (Z^*/\beta)^{1.139} \qquad ...(5)$$

Fig. 1 shows the variation of V_t with (Z^*/β) in CR-39. Assuming the validity of the relation given in Eq. (3), the relation in Eq. (4) gets the following form

$$Z^* = 34.47\ [L_2/L_1 - 1]^{-0.313} \qquad ...(6)$$

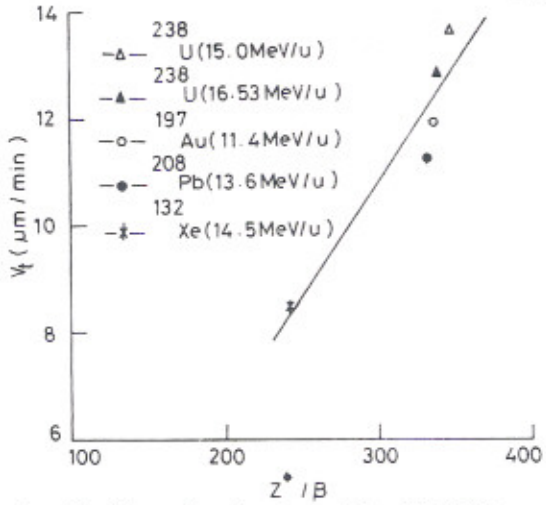

Fig. 1 — Variation of track etch rate (V_t) with Z^*/β in CR-39.

where $k = 34.47$ and $\xi = -0.313$. Our experimental data on CR-39 for different heavy ions fitted this relation within a maximum deviation of 9%. Grabez *et al.*[10] have developed this method of particle identification for heavy ions, viz., ^{40}Ar (18.6 MeV/u), ^{56}Fe (16.3 MeV/u), ^{86}Kr (17.7 MeV/u), ^{93}Nb (18.0 MeV/u) and ^{132}Xe (14.0 MeV/u). The present investigation has been done on ^{238}U (16.53 and 15.0 MeV/u), ^{208}Pb (13.6 MeV/u), ^{197}Au (11.4 MeV/u) and ^{132}Xe (14.5 MeV/u) ions successfully. It means that the method of particle identification by etching the detector in successive intervals has its validity and that the relations given in Eqs (4), (2) and (1) can be used successfully for the determination of charge and velocity of the heavy ions in CR-39.

Table 2 presents the data on soda glass irradiated by ^{238}U(5.9 MeV/u), ^{132}Xe(5.9 MeV/u), ^{56}Fe (4.0 MeV/u) and ^{48}Ti (4.0 MeV/u) ions. The d_1 and d_2 are the track depth values for different heavy ions in soda glass after etching for 2 and 4 minutes, respectively, and R is the theoretical range values of these heavy ions in the detector computed by TRIM-95[13,14]. The value of V_t is determined by $V_t = d_1/t_1$, where t_1 is the time of etching, 2 minutes. The variation of V_t with Z^*/β is shown in Fig. 2 and fit the following relation

$$V_t = 0.124\ (Z^*/\beta)^{0.733} \qquad ...(7)$$

In place of L_1 and L_2, the validity of d_1 and d_2 is assumed in the relation given in Eq. (3); here d_1 and d_2 are the depths of the tracks in soda glass after etching for 2 and 4 minutes, respectively.

$$d_2 = d_1\ [\ 1 + k_1\ (Z^*)]^{\xi}_1 \qquad ...(8)$$

From the relation given in Eq. 8, relation for Z^* is derived as

$$Z^* = k_1\ [\ d_2/d_1 - 1\ ]^{\xi}_1 \qquad ...(9)$$

Table 2 — The track depths d_1 and d_2 (average of 50-60 tracks) after etching in HF + H_2SO_4 + H_2O in the ratio 6:1:18 for 2 and 4 minutes with theoretical ranges corresponding to different heavy ions in soda glass

Ion	Energy (MeV/u)	Track depth d_1 (μm)	Track depth d_2 (μm)	Range (μ m)
^{238}U	5.9	20.44 ± 1.83	27.05± 1.46	54.42
^{132}Xe	5.9	15.71 ± 1.48	22.0 ± 1.06	51.97
^{56}Fe	4.0	12.50 ± 0.86	18.16 ± 1.28	30.57
^{48}Ti	4.0	11.07 ± 0.99	16.4 ± 0.80	31.82

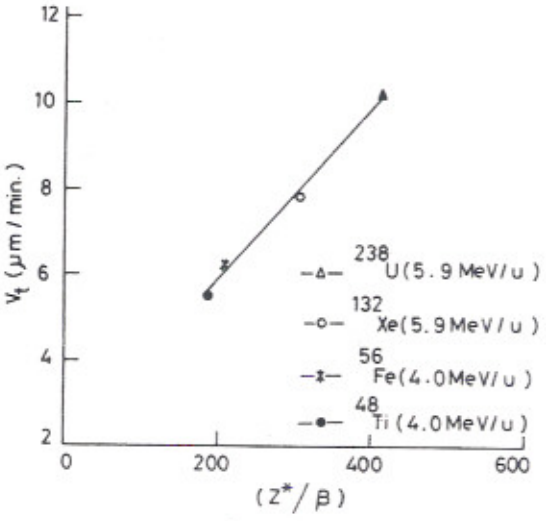

Fig. 2 — Variation of track etch rate (V_t) with Z^*/β in soda glass.

Our data on soda glass follows this relation with $k_1 = 2.58$ and $\xi_1 = -2.613$. The experimental data in the present investigation have maximum deviation of 6% from this relation. Knowing the values of d_1 and d_2, the atomic number, Z of the particle and its velocity β can be determined. Hence it is concluded that along with CR-39, soda glass detector can also be used for particle identification by using this method of etching in successive intervals.

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