Measurement of total charge changing cross-section for 5 A GeV Si^{14+} ions in polyethylene and CR39 combined medium

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Introduction

Interaction of high energy heavy ions (HZE) in various media is a field of great interest in many aspects of fundamental and applied sciences, detection of cosmic rays, shielding design for space-vehicles and hadrontherapy for cancer treatment etc. [1,2]. Nuclear fragmentation in shielding materials generates secondary particles and substantially modifies the radiation field inside the spacecraft. HZE interactions with interstellar gas and fragmentation in interstellar space change the chemical composition of GCR [3]. These radiations may cause health risk to the astronauts. Therefore a good shielding design [4] is required to minimize the radiation risks.

In this paper, the total charge changing cross-section of 5 A GeV Si^{14+} ion beam on CR39 $(C_{12}H_{18}O_7)_n$ and polyethylene (CH_2) combined medium has been calculated using CR39 nuclear track etch detectors by cone-height measurements.

Experimental

A stack composed of CR39 foils of 11.5 cm × 11.5 cm × 0.15 cm in size; two foils upstream and six downstream of 0.6 cm CH_2 target (as shown in Fig.1) was exposed to Si^{14+} ion beam of energy 5 A GeV at Brookhaven National Laboratory (BNL), USA in 2005 using Alternating Gradient Synchrotron at normal incidence with total ion density of ~2040/cm^2. The used CR39 detectors were manufactured by Intercast Europe Co., Parma, Italy using a specially designed line of production [5]. These detectors were covered by a 45 µm plastic film to protect them from exposures to ambient radon and its progeny; these protective layers were removed before etching. From the previous experience of cone-height measurements [6], the chemical etching was performed on one side of the detector in 6N NaOH solution + 1% ethyl alcohol at 70 ˚C for 167 hours in several steps by applying araldite on back surface of the detector to avoid the shadow effects.

After etching, the detector was washed in deionized water and then washed for at least one hour in an ultrasonic water-bath to clean up the etchants from inside the pores. After cleaning and drying, the detector was used for scanning under Leica DM6000 M optical microscope. The microscope consists of a CCD camera, a frame grabber and a personal computer (PC) consisting of hardware and software interface. The microscope is equipped with a motorized X/Y stage with an accuracy of better than 1 µm.

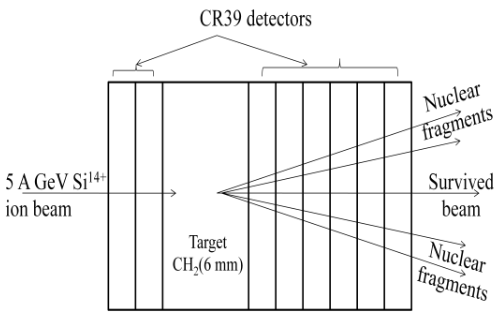

Fig. 1 Sketch of the stack configuration used for the exposures to 5 A GeV Si^{14+} ion beam.

Results and Discussion

Fig. 2 shows the distribution of cone-height of the etched tracks for Si^{14+} ions and their fragments. An area of ~ 4 cm^2 on front face of the CR39 detector was scanned manually by the microscope and the cone-height of each track was measured. The peaks are well separated for the incident beam ions and for the fragments and a charge was assigned to each of these peaks from Z/β = 14.1 down to 6.0 as shown in Fig. 2.

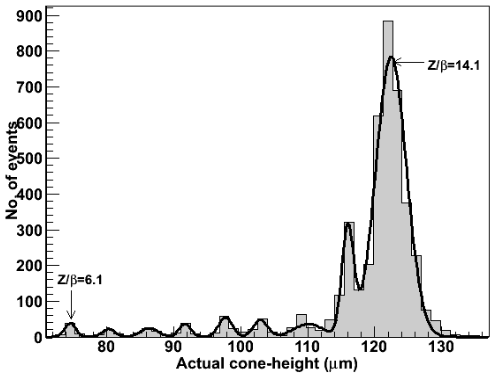

Fig. 2 Cone height distribution of etched tracks in the last sheet of CR39 detector in the stack due to 5 A GeV Si^{14+} ions and their fragments.

Measurement of Total Charge Changing Cross-Section

The total charge changing cross-section of 5 A GeV Si^{14+} ions in polyethylene and CR39 as a combined medium was computed using the relation as given in ref. [7]. Average atomic mass number and density of CH_2 and CR39 are 6.4 and 1.181 g cm^{-3}, respectively. For calculating the total charge changing cross-section, the number of survived beam ions after the target was determined by Gaussian fitting of the height distribution as shown in Fig. 2. The number of survived ions was determined to be 1783 cm^{-2} with a confidence level of 99.7% (± 3σ). Using formula in ref. [7], the value of the total charge changing cross-section was calculated to be $\sigma_{tot} = (734 \pm 128)mb$. The uncertainty in the measurement is statistical only; a systematic error of around 8% was estimated. The measured cross-section was compared with the results in [8] for CH_2 target at same energy; there is a good agreement within the experimental errors. The measured cross-section was fitted by the Bradt-Peters geometrical cross-section for a projectile of mass number A_p on a target of mass number A_T using the relation [7]:

$$\sigma = \pi r_0^2 \left(A_p^{1/3} + A_T^{1/3} - b\right)^2 \quad (1)$$

where r_0 and b were 1.31 fm and 1.2 respectively. Various authors used different values for the overlap parameter b within the interval 0.74-1.3. By taking A_p (= 28) for Si as projectile and A_T (= 6.4) for CH_2 and CR39 as the combined medium, the geometrical cross-section is 734 mb.

Conclusions

The method of one-side etching was used to avoid shadow effects occurring in cone-height measurements. This technique of one side etching for cone-height measurements is better as compared to both sides etching for increasing the track cone height for better charge resolution. The total charge changing cross-section calculated by this method is in good agreement with the result of others.

Acknowledgments

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