Characterization of polyethylene terephthalate (PET) detector to search for rare events in cosmic rays.

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***Abstract*. Search for exotic particles (e.g. strangelets) in cosmic rays is an active field of research. An ideal choice of detectors to look for rare events in cosmic rays at very high mountain altitudes are solid state nuclear track detectors (SSNTDs). In our work we are using a commercially available polymer, polyethylene terephthalate (PET), as a SSNTD. It was found to have a higher detection threshold compared to many other widely used SSNTDs and hence is particularly suited for rare event search in cosmic rays as it eliminates the huge low Z background. A SSNTD has to be properly characterized before it can be used as charged particle detector. So systematic studies were carried out on PET to determine the ideal etching condition for it. Also the charge response of PET was studied using various ion beams from accelerators. The results of such studies and also the calibration curve obtained for PET is presented.**

***Keywords*: SSNTD, Calibration curve, Charge response.**

I. INTRODUCTION

According to many theorists, Strange Quark Matter (SQM) containing almost equal number of up, down and strange quarks constitute the true ground state of Quantum Chromodynamics [1], [2]. Search for nuggets of such SQM, called strangelets, with a highly unusual charge to mass ratio (Z/A$\ll 1/2$) in cosmic rays, is an active field of research [3]. According to one model of cosmic ray strangelet propagation within the earths atmosphere [4], an initially small strangelet will grow in size by preferentially absorbing neutrons over protons from atmospheric nuclei, as the protons are repelled by Coulomb force. At the same time it will lose energy by ionization, but will be left with enough energy for them to be detected at high mountain altitudes, albeit with a very low flux.

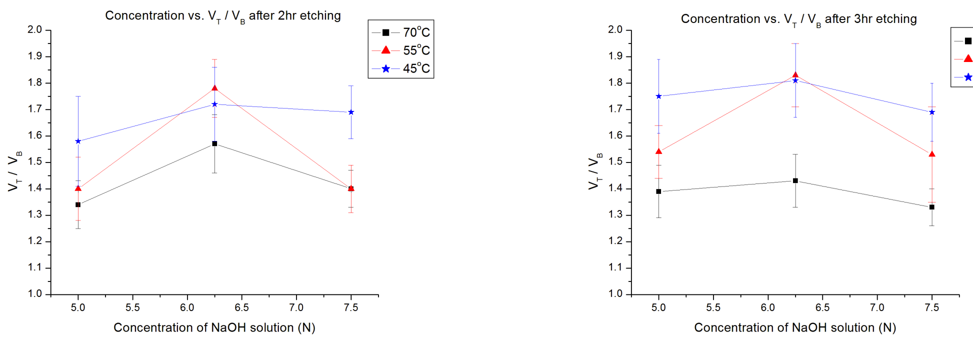
An ideal choice of detectors for setting up large area arrays to look for such rare events at very high mountain altitudes are solid state nuclear track detectors (SSNTDs). Use of SSNTDs for charged particle detection is a well established method [5], [6]. We are planning to set up passive detector arrays at high mountain altitudes to look for exotic particles in cosmic rays and for that purpose we propose to use a commercially available polymer called polyethylene terephthalate (PET) as a SSNTD. PET is found to have a much higher detection threshold (Z/$\beta > 140$) compared to many other widely used SSNTDs like CR-39, Lexan etc. [7], [8], [9] and so will be particularly suitable for rare event search in cosmic rays as it will eliminate the huge low Z background.

Before a detector can be used, it needs to be properly characterized and calibrated. With that aim, systematic studies were carried out to determine the ideal etching condition for PET and also to find out its charge response characteristics to various ions. In this paper the results of such studies are presented.

II. DETERMINATION OF IDEAL ETCHING CONDITION

Passage of charged particles through SSNTDs leave behind narrow damage trails which can then be enlarged by a suitable chemical etching process to form etch pits. Such etch pits can be approximated by geometrical cones with their axes lying along the damage trails. This happens as the damaged regions are etched out at a faster rate (called track etch rate V_T) compared to the rate of etching (called bulk etch rate V_B) of the undamaged bulk material. By studying the geometry of such etch pits one can determine the ratio of the track etch rate to the bulk etch rate (V_T/V_B). This ratio, called the charge response, is the most important parameter for SSNTDs, as it helps in identifying the particles forming tracks and it depends very sensitively on the etching condition. For etching one should choose a particular concentration and temperature of a suitable chemical reagent so that etch pits formed are well defined and are of maximum possible size so that the ratio V_T/V_B is maximized. This is done to minimize the errors in track parameter measurements and also to make the task of finding tracks easier.

In order to determine the ideal etching condition for PET detector, PET samples exposed to cosmic rays were etched in NaOH solution (which is found most suitable for our purpose) of three different concentrations(5 N, 6.25 N, 7.5 N). For each concentration three different temperatures (45 °C, 55 °C, 70 °C) were tried (the



(a) After 2hr etching (b) After 3hr etching

Fig. 1. Variation of V_T/V_B with concentration and temperature. Lines are drawn to guide the eye.

Fig. 2. Inside of the scattering chamber showing PET detectors mounted on aluminum holders and placed on the two movable arms. The target ladder with the gold foil (used as a scatterer) mounted on it can also be seen.

temperatures were maintained to within $\pm 0.5\,^\circ$C) For every combination of temperature and concentration the PET samples were etched for two different durations (2hr, 3hr). The bulk etch rate (V_B) was determined by measuring the thickness of the PET samples before and after the etching process with a micrometer screw gauge. The track parameters (minor and major axes of etch pit openings and cone depths) were measured under the $\times 100$ dry objective of a Leica DMR microscope, interfaced with a computer preloaded with an image analysis software. The results of such studies are shown in Fig. 1.

As can be seen from the figures, the ratio V_T/V_B is showing a tendency of getting maximized when the concentration of NaOH solution is 6.25 N and the temperature is $55\,^\circ$C. So we have used 6.25 N NaOH solution at $55\,^\circ$C for all subsequent etching processes of the PET detector.

III. Study of Charge Response of PET

Previously we had studied the charge response of the PET detector with exposure to ^{16}O and ^{238}U ions[7]. With the aim of gaining a better understanding of the charge response characteristic of PET and of obtaining a calibration curve for PET, further studies were conducted by irradiating those detectors with 2.7 MeV/n ^{56}Fe and 3.9 MeV/n ^{32}S beams using the pelletron accelerator at IUAC, New Delhi.

For the experiment, small (5 cm $\times$ 5 cm) pieces of PET were placed in aluminum holders which in turn were mounted on two movable arms inside a scattering chamber as shown in Fig. 2. A 250 μg/cm^2 gold foil was used as a scatterer. By moving the two arms inside the scattering chamber one could vary the angles and hence the energies with which the ions will impinge on the PET films after being scattered by the gold foil. For one set of aluminum holders placed on one of the arms, the frames holding the films were turned by an angle of $30\,^\circ$ so that the ions are incident on them at a $30\,^\circ$angle. This was done so that the conical profile of the tracks become clearly visible after etching, thereby enabling a more accurate determination of the track parameters.

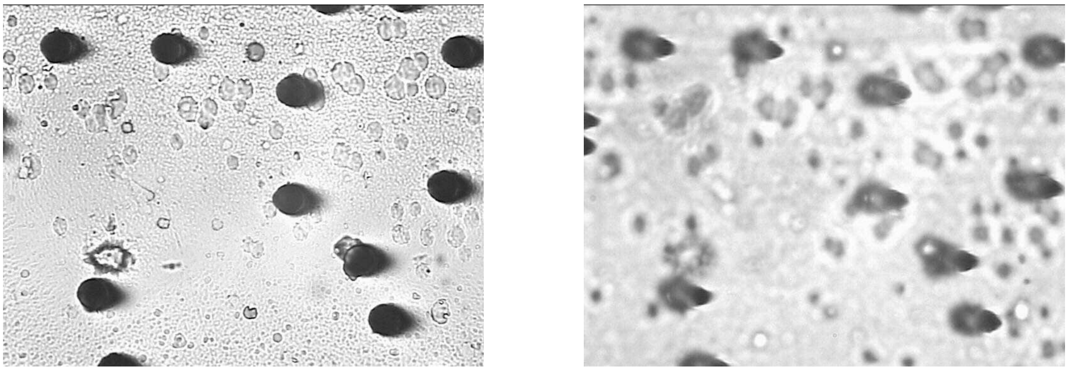
To enable us to develop a plan for the placement of the detectors, a software code was written which gives the energy values and also the flux of Fe and S ions at various angles after they scatter from a gold foil used as a target. The code also takes into account the loss of energy of ions inside the gold target and also their effective charges. It gives the energies and fluxes for the scattered gold ions also.

The exposed PET samples were etched in 6.25 N NaOH solution at $55.0 \pm 0.5\,^\circ$C for durations ranging from 1 to 3hrs. Fig. 3 show some track images.

IV. Results and Discussions

Fig. 4 and Fig. 5 show the charge response (V_T/V_B) obtained from track parameter measurements plotted as a function of Z/β values for ^{56}Fe and ^{32}S ions respectively. By combining the data for ^{56}Fe and ^{32}S ions with that of ^{16}O and ^{238}U ions obtained previously [7], we can get a calibration curve for PET as shown in Fig. 6. The specific energy losses (dE/dx) of the incident ions at different energies were obtained using the code SRIM [10].

Our work clearly demonstrates that PET can be effectively used as a charged particle detector with a high



(a) (b)

Fig. 3. Fe- tracks on PET after 3hr etching with the microscope focused (a) on the surface and (b) at a depth of 9μm showing the conical profile of the tracks. Incident energy is 2.3 MeV/u and incident angle is 30°.

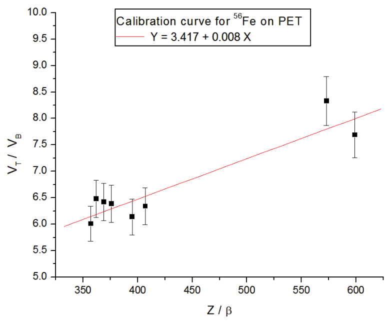


Fig. 4. Charge response characteristic of PET for ^{56}Fe ions.

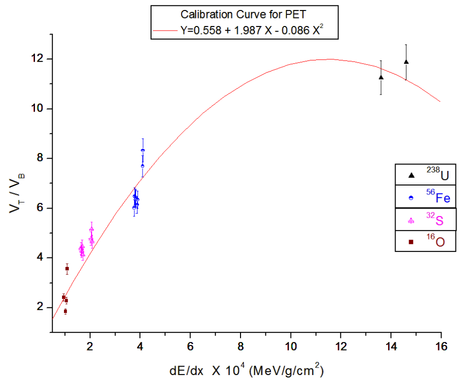


Fig. 6. Calibration curve for PET.

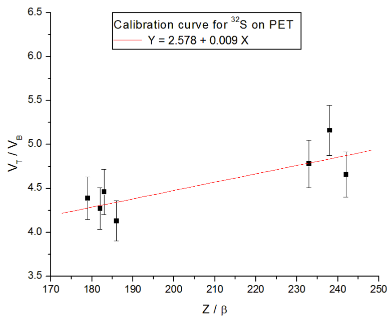


Fig. 5. Charge response characteristic of PET for ^{32}S ions.

detection threshold and can be particularly useful in cases where there is a requirement for detecting high Z particles against a low Z background.

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