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Control of the detection threshold of CR-39 PNTD for measuring ultra heavy nuclei in galactic cosmic rays

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ABSTRACT

It is necessary to develop a track detector with higher detection threshold and high charge resolution for ultra heavy cosmic ray observation. The track registration sensitivity in CR-39 track detector etched by PEW (Potassium–Ethanol–Water) solution was verified using heavy ion beams at the HIMAC accelerator. It was found that PEW solution makes effectively to desensitize the track registration sensitivity in CR-39 detector. Its detection threshold of Z^*/β is successfully raised to be $Z^*/\beta = 39$ by using PEW solution with the concentration of ethanol of 45 wt%. However this produces a "fuzzy track". A two-step process of etching involving a post-etch with 7 mol/*l* sodium hydroxide solution produced very clear track edges and remarkably improves the charge resolution for heavy ions.

1. Introduction

The chemical composition of ultra heavy (UH; $Z \geq 30$) nuclei in galactic cosmic rays (GCRs) could illuminate the nucleosynthesis processes leading to the genesis of cosmic ray matter and governing the evolution of galaxies, and could lead to improved understanding of the structure and properties of the interstellar medium (Hasebe et al., 2006; Kodaira et al., 2009). The observation of UH nuclei in GCRs requires a detector with a large exposure area and excellent charge and mass resolutions because such particles have extremely low fluxes and it is difficult to differentiate and identify charge and mass in such massive particles. Solid-state track detectors such as CR-39 Passive Nuclear Track Detector (PNTD) have an advantage in that it is easy to extend the exposure area. Moreover, CR-39 PNTD can identify heavy ion isotopes with excellent mass resolution (Kodaira et al., 2004, 2007). In using CR-39 PNTD for the observation of UH nuclei, it is important to 1) raise the detection threshold of heavy ions in order to suppress background tracks produced by lighter ions with $Z/\beta < 30$ and 2) achieve excellent charge resolution. CR-39 PNTD is superior in detection of rather lower Z/β ion. The typical thresholds of CR-39 detectors manufactured by Fukuvi Chemical Industry in Japan are $Z/\beta \sim 13$ (LET $\sim$ 38 keV/μm in water; LET is Linear Energy Transfer) for BARYOTRAK (Yasuda et al., 2008), $Z/\beta \sim 5$ (LET $\sim$ 3 keV/μm) for HARZLAS TD-1 (Ogura et al., 2001a) and $Z/\beta \sim 4$ (LET $\sim$ 2 keV/μm) for HARZLAS TNF-1 (Ogura et al., 2001a), respectively.

One approach to raising the detection threshold of CR-39 PNTD is to use a copolymer resin of CR-39 and DAP (diallyl phthalate). This approach was recently studied (Tsuruta, 1999, 2000; Kodaira et al., 2008a, 2008b). Although the CR-39-DAP-copolymer detector is a candidate for the detection of UH nuclei, the surface conditions after chemical etching becomes very rough which leads to charge resolution deterioration with high concentration (>30%) of DAP (Kodaira et al., 2008a).

Another approach to raising the detection threshold of CR-39 PNTD is to use a Potassium–Ethanol–Water (PEW) solution for the etching process. It is known that PEW solution can desensitize the track registration sensitivity of CR-39 PNTD and the desensitization of sensitivity is more effective for low LET particles (Somogyi & Hunyadi, 1979; Ogura et al., 2001b). In addition to the desensitization effect, the etching solution markedly improves the quality of the etched surface of the detector (Ogura et al., 2001b). Therefore using PEW solution as

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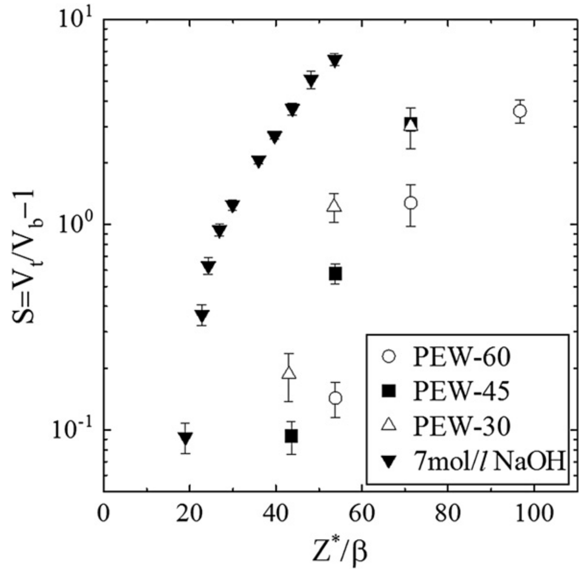

Fig. 1. The variation of track registration sensitivity for four concentrations of the PEW etchant as a function of Z^*/β.

an etchant is expected to raise the detection threshold and to improve etched surface condition. In this study, PEW-*x* solution expressed by 17 wt% KOH + *x* wt% C_2H_5OH + (83 − *x*) wt% H_2O was used.

2. Experiment

The 0.9 mm thick CR-39 PNTD named BARYOTRAK was used. CR-39 PNTDs were exposed to heavy ions from Fe to Xe with energies below 500 MeV/nucleon, covering the range of $36 \leq Z^*/\beta \leq 115$, at the Heavy Ion Medical Accelerator in Chiba (HIMAC) at the National Institute of Radiological Sciences (NIRS). Here, Z^* and β denote the effective charge of ion and its velocity, respectively. The incident angle was normal to the detector surface. The exposed density was ~2000 ions/cm^2 for each detector. The detectors were etched in PEW-*x* solutions with 30, 45 and 60 wt% concentrations of ethanol at the temperature of 70 °C. The etching time was selected to be about 20 μm for the amount of bulk etch, i.e. 100 min for $x = 30$ wt%, 30 min for $x = 45$ wt% and 15 min for $x = 60$ wt%, respectively.

After etching, track diameter was automatically measured using a high-speed imaging microscope (HSP-1000) (Yasuda et al., 2005). The amount of bulk etch was obtained by a direct measurement of thickness change of the CR-39 PNTD before and after etching by using a micrometer. Track registration sensitivity ($S = V_t/V_b - 1$) was calculated from the diameter of the track and the amount of bulk etch, *B*. Here, V_t is the track etch rate and V_b is the bulk etch rate, which are given by track geometry.

3. Results and discussion

3.1. Comparison of track registration sensitivity for varying concentrations of ethanol

Track registration sensitivities for several Z^*/β points were obtained from CR-39 PNTDs etched by PEW-*x* solution with 30, 45 and 60 wt% concentration of ethanol. Fig. 1 shows the response curves, that is the variation of track registration sensitivity as a function of Z^*/β, for each PEW-*x* solution at the temperature of 70 °C. As a reference, the response curve obtained by etching in 7 mol/*l* sodium hydroxide (NaOH) solution at the temperature of 70 °C is also shown. There is a tendency to shift the response curve to higher Z^*/β regions and to raise the detection threshold with increasing concentrations of ethanol in PEW-*x* solution. However, the inclination of response curves for PEW-30 and 60 are gradual compared to PEW-45. The charge resolution of the detector is related to the inclination ($\Delta S/\Delta(Z^*/\beta)$). PEW-45 was determined to be the optimal etchant for detect UH nuclei in GCRs. Hereafter, we employ the PEW-45 solution as the optimum etchant.

3.2. Characteristics of CR-39 detector etched by PEW-45

As mentioned above, the bulk etch rate (V_b) for PEW is faster than using a sodium hydroxide solution. A profile of bulk etching is shown in Fig. 2. It was found that there is a linear relationship between etching time and the amount of bulk etch, and the

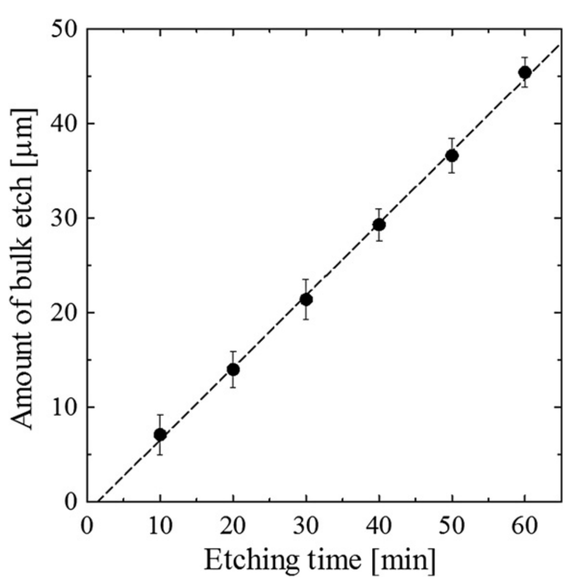

Fig. 2. The relationship between etching time and the amount of bulk etch of the CR-39 detector etched by PEW-45 solution. V_b is 0.76 μm/min (i.e. 45.6 μm/h).

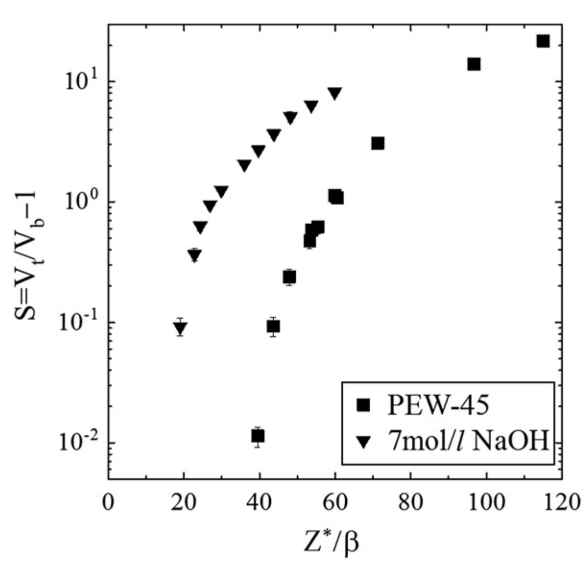

Fig. 3. A detailed response curve of CR-39 PNTD etched by PEW-45 solution at the temperature of 70 °C. The response curve obtained by 7mol/*l* NaOH etching at the temperature of 70 °C is also shown as a reference.