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Verification of angular dependence for track sensitivity on several types of CR-39

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Abstract

We verified the angular dependence of track registration sensitivity for four types of CR-39 plastic nuclear track detectors using heavy ion beams. These detectors have been launched with several types of luminescence detectors on the Russian segment of the International Space Station (ISS) to intercompare passive radiation dosimeter components from several institutions. CR-39 detectors were irradiated by several kinds of heavy ions with several hundred MeV/n. All the etched tracks were analyzed using a high-speed microscope (HSP-1000) with ellipse fitting software (PitFit). Reduction of sensitivity was observed near the region of the critical angle. Corrections were made using an empirical method based on the known structure of the galactic cosmic ray spectrum.

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Keywords: CR-39; Solid state detector; Space radiation dosimetry

1. Introduction

The CR-39 (allyl diglycol carbonate) nuclear track detector has been used for various fields. This detector is a particularly useful tool to measure LET information for space radiation dosimetry (Benton, 1984; Benton et al., 2002a, b; Doke et al., 2002; Tawara et al., 2002) and to measure the elemental and isotopic compositions of ultra-heavy cosmic rays for astrophysics (Hasebe et al., 2006). Since the track formation sensitivity ($S \equiv V_t/V_b - 1$; where V_t and V_b denote the track etch rate and the bulk etch rate, respectively) is essentially constant for relativistic nuclei with identical charge, we can get physical values using this technique. In these fields, however, it is well known that the track formation sensitivity (detector response) depends on the dip angle (Hayashi and Doke, 1980; Doke et al., 1997), and the correction of angular dependence of response is a key point in obtaining physical values. As verified by Hayashi and Doke using cosmic ray data and accelerated ion exposures, different types of CR-39 detector show specific characteristics for angular dependence. They developed an empirical method for the correction of angular dependence, which they used to explain the difference in LET distribution as measured by the silicon telescope type real-time radiation monitoring device (RRMD) and by CR-39 detectors in spacecraft. They also stated that the angular dependence will be dependent on the hardness of detectors. The hardness against etching may not be the same in the vicinity of the surface and inside of the detector. We have studied the track evolution at the early stage of etching (the bulk etch is about 20–1000 nm) for high energy C and Si ions in CR-39 detectors using an atomic force microscope (Yamamoto et al., 1999). According to our results, the track diameters increased linearly with the amount of bulk etch, but retardation of track length growth was observed at

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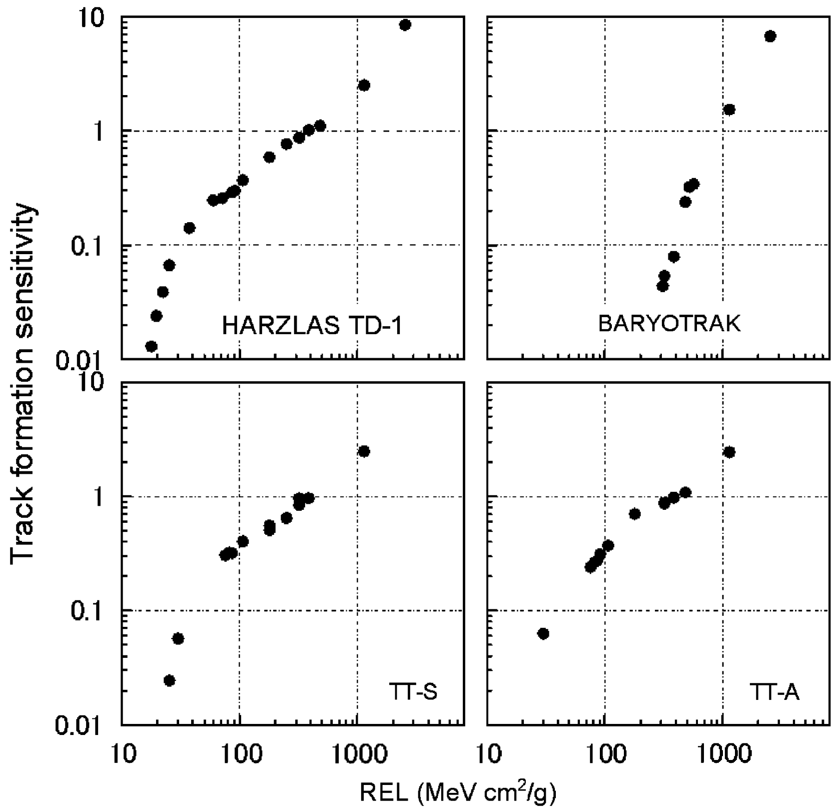

Fig. 1. Track formation sensitivities as a function of the restricted energy loss (calibration curve) at dip angle of 90° for different types of CR-39: HARZLAS TD-1, BARYOTRAK-P(CR), TT-A and TT-S.

the early stage of the etching. The probable cause of this track length growth retardation was considered to be due to the insufficient erosion and exchange of etchant into the cone end of the track at the early stage of the etching process (Yasuda et al., 2001). The reduced sensitivity at the reduction of dip angle might be explained by this qualitative explanation.

Several variations of CR-39 track detectors were developed and commercialized in Japan with different track formation sensitivities and varying track registration thresholds for use in specific applications. For example, the HARZLAS TD-1 was developed by Fukuvi Chemical Industry in 1995. Details of the curing cycle for polymerization of HARZLAS TD-1 and its response to low energy protons have been described (Ogura et al., 1997, 2001). Hayashi and Doke (1980) verified the angular dependence of the detector made from the TS-16N type monomer (allyl diglycoal carbonate) which was provided by Tokuyama Soda Co., Ltd. The "Early BARYOTRAK" (manufacturing period: 1987–1992) was an improved product of the TS-16N detector by Fukuvi Chemical Industry, and appeared as "Lantrak" elsewhere (Ipe et al., 1992). From 1993 to 1996, the "BARYOTRAK type-P(MR)" was developed with a purified (99.4%) MR-3 type monomer (allyl diglycoal carbonate; Mistsui Touatsu Chemical Co.). In 1997, the BARYOTRAK type-P(CR) was fabricated from purified (99.4%) CR-39™ monomer (PPG Industries). This series of detector does not include any antioxidant and is mainly used for routine neutron dosimetry.

We have recently developed a new CR-39 detector with two variations. TechnoTrak type-A (TT-A) consists of purified (99.7%) CR-39™ monomer (PPG Industries) with a phenolic antioxidant (0.05 wt%), and type-S (TT-S) consists of non-purified CR-39™ monomer with 0.01 wt% antioxidant. Track registration threshold and anti-aging effects of the phenolic antioxidant were previously examined (Koguchi et al., 2005). Surface roughness of the detectors after long etching was examined and reported in separated papers (Yasuda et al., 1999; Koguchi et al., 2005).

These newly developed detectors have been launched with several types of luminescence detectors on the Russian segment of ISS to intercompare passive radiation dosimeter components from several institutions as a series of experiments to establish a "reference standard" for space radiation monitoring as part of the ICCHIBAN project (Uchihori and Benton, 2004; Yasuda et al., 2006). As part of this work, an investigation was carried out to calibrate for four types of commercialized CR-39 detectors using heavy ion beams. The angular dependence of track registration sensitivity was also verified as a first step to check their characteristics for practical use for space dosimetry.

2. Experiments

We used four types of CR-39 track detectors in this study: HARZLAS TD-1 and BARYOTRAK type-P(CR) from Fukuvi Chemical Industry and TT-S and TT-A from Chiyoda Technol Corporation. To calibrate these detectors, we used heavy ions from HIMAC and protons from the cyclotron facility in NIRS. The detectors were exposed to heavy ions from helium to iron