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Effects of UVC irradiation on alpha-particle track parameters in CR-39

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Abstract

The effects of UVC exposure on the track etch rate V_t and the detector sensitivity V of CR-39 SSNTDs were investigated through the diameters and depths of alpha-particle tracks. Both the bulk etch rate V_b and V_t increased but V decreased. The track diameters and depths were used to derive a V function for CR-39 detectors with and without UV irradiation.

Keywords: CR-39; Ultraviolet; Track etch; Alpha particle

1. Introduction

CR-39 is a commonly used solid-state nuclear track detector (SSNTD). A recent review of SSNTDs was given by Nikezic and Yu (2004). Ultraviolet (UV) irradiation affected the bulk etch and track etch responses (Jaleh et al., 2004), but not all results in the literature were consistent. Hussain (1982) and Arif et al. (1986) observed that track etch rate V_t and bulk etch rate V_b of CR-39 increased with UV exposure time and etching time for both post-irradiated (fission fragment + UV) and pre-irradiated (UV+fission fragment) samples which resulted in the enhancement of the detector sensitivity $V(=V_t/V_b)$. Khayrat and Durrani (1995) found both V_b and V_t increased when CR-39 detectors were exposed to a mercury lamp but the sensitivity decreased for post-irradiated samples. Tidjani (1990a, b) concluded that the track sensitivity decreased for UV irradiated samples although both V_b and V_t increased. Abu-Jarad et al. (1991, 1992) found exposures of CR-39 to UV at wavelengths of 253.7 and 350 nm increased V_b and V_t with a slight enhancement in the sensitivity, while exposures at 300 nm did not change V_b. Wong and Hoberg (1982) found UV exposure over 8 h increased V_b up to 80% but the sensitivity remained nearly constant. Ansari et al. (1991) observed both V_b and V_t increased for samples exposed to sunlight for more than 2 months. In the present work, the effects of UV on alpha-particle tracks in CR-39 were further studied.

2. Methodology

CR-39 detectors with a thickness of 1000 μm were from Page Mouldings (Worcestershire, England). Three sets of detectors were prepared: (1) only irradiated with alpha particles; (2) irradiated with alpha particles and then with UV (alpha + UV) and (3) irradiated with UV and then with alpha particles (UV + alpha).

Alpha-particle irradiations (using 0.1 μCi ^{241}Am source, main emitted alpha energy = 5.49 MeV) were made with energies of 3, 4 or 5 MeV under normal incidence. The alpha-particle energies were varied by changing the source to detector distance under atmospheric pressure and confirmed using an alpha spectroscopy system (ORTEC Model 5030). UV irradiation was performed using a UV lamp (model #9815-25, Cole Palmer) at 257 nm for 10 h at a distance of 5 cm.

After alpha-particle and/or UV irradiation, all detectors were etched in 6.25 N aqueous solution of NaOH at 70 °C. The masking method (Yasuda et al., 1998; Ho et al., 2003) was used to measure V_b. The track openings and lengths were measured under an optical microscope with a magnification of 1000×. For measurements of the track depths, the etched detectors were broken perpendicular to their surfaces, and the edges were then polished to show the longitudinal track profiles (Dörschel et al., 1997).

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3. Results and discussion

3.1. Variation of V_b

Exposures to short-wavelength UV in an atmosphere with oxygen accelerate V_b for CR-39. These UV photons have sufficient energy to cleave the bonds in the polymer chains with the production of free radicals. These radicals can further initiate reactions with molecular oxygen, which results in splitting the macromolecular chains. Scission of polymer chain reduces the average molecular weight of the detector, which subsequently increases V_b by increasing the solubility and the diffusion rate of the etched products (Tse et al., 2006).

The variation of V_b with etching time is shown in Fig. 1. Exposures to UV increased V_b up to 2 times, where unexposed CR-39 had a V_b of 1.23 μm/h (Ho et al., 2003). V_b of UVC-irradiated detectors accelerated significantly towards the exposed surface, and decreased from 2.75 to 1.4 μm/h when the etching time increased from 2 to 14 h. The variation of V_b with the depth of the CR-39 detector could be due to the limited penetration depth of UVC radiation (Tse et al., 2006) as well as the limited penetration of oxygen into deeper regions. In air, extensive photo-oxidation occurs resulting in the large V_b for the CR-39 surface, but the remaining bulk material is left largely unmodified.

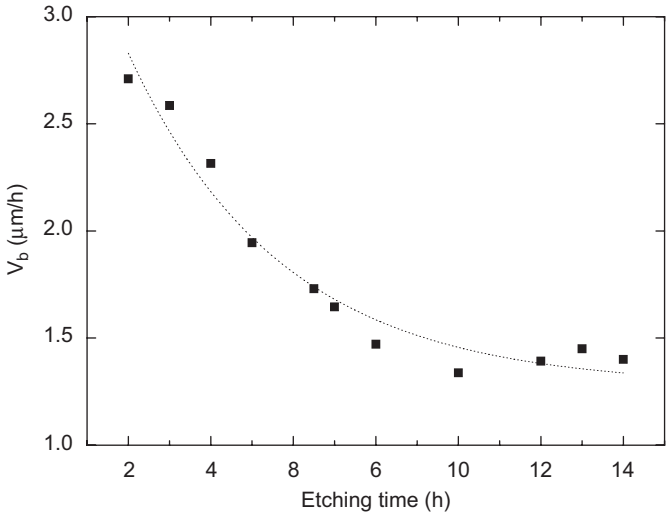

Fig. 1. Variation of the bulk etch rate of the CR-39 detector irradiated with UVC for 10 h as a function of etching time in 6.25 N $NaOH/H_2O$.

3.2. Modifications of CR-39 by alpha particles and UV photons

When exposed to ionizing radiation, the carbonate group in CR-39 is the radiation sensitive link. Two alkyl radicals and a polycarbonate-ended radical are first formed (Thang and Doan, 1995; Malek et al., 2001). The polycarbonate-ended radical is further dissociated into 2,2-oxydiethanol diradical and carbon dioxide during the process of decarboxylation. Irradiation of alpha particles on CR-39 in the presence of O_2 prevents the recombination of the free radical pair and as a result permanent damages are formed along the alpha-particle trajectory. The alpha-particle irradiated CR-39 is easily amenable to sodium hydroxide solution because of yielding of lower molecular weight along the latent track, which enhances the solubility in the etchant. The formation of hydroxyl group in the presence of oxygen will also increase the permeability of aqueous solution.

Tse et al. (2006) studied the photo-oxidation of CR-39 at different wavelengths, and showed that hydroperoxides were formed as primary products by oxidation of the α-position of the oxygen atom of the ether group. Hydroperoxides are unstable and rapidly decompose to form photo-products such as hydroxyl and carbonyl by-products. Repetitions of formation of hydroxyl and carbonyl groups by decomposition of hydroperoxide will cause scission of the hydrocarbon chain. CR-39 could also undergo the Norrish type 1 reaction with cleavage of the bond between the carbonyl group and the adjacent oxygen atom. During photo-oxidation, the hydroxyl group was formed and scission of the polymer chain occurred. Etchant uptake can be enhanced by the additional free volume due to the degassing

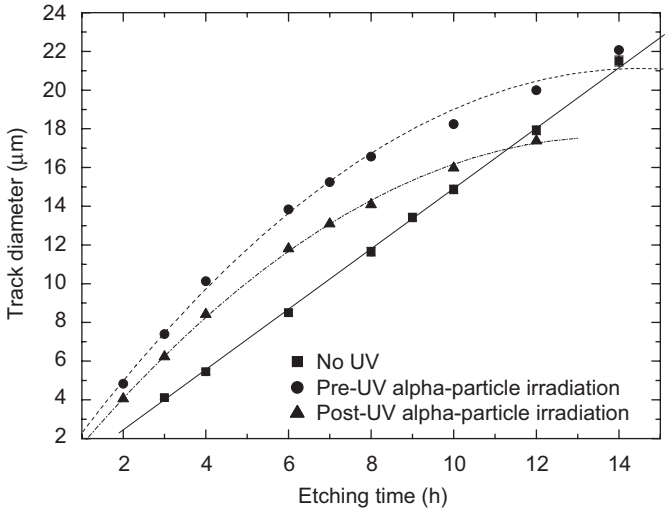

Fig. 2. Variation of the alpha-particle track diameter as a function of etching time in CR-39 detectors with different UV exposures.

of volatile fragments, which is a consequence of the polymer's chain scission. Formation of the hydroxyl or hydroperoxy group is also related to V_b of CR-39. Both alpha-particle irradiation and UV exposures can induce main chain scission and cross linking, even though they have different initial events.

3.3. Variation of track diameters and depths

The track diameters as a function of etching time and removed layer thickness are shown in Figs. 2 and 3, respectively. The diameters were enlarged for UV irradiated samples. The diameter was larger for (alpha + UV) than for (UV + alpha). The track lengths as a function of etching time and removed layer thickness are shown in Figs. 4 and 5, respectively. After 8-h etching, the track lengths were 18.1, 17.0 and 15.3 μm in CR-39 with no UV irradiation, (alpha + UV) and (UV +

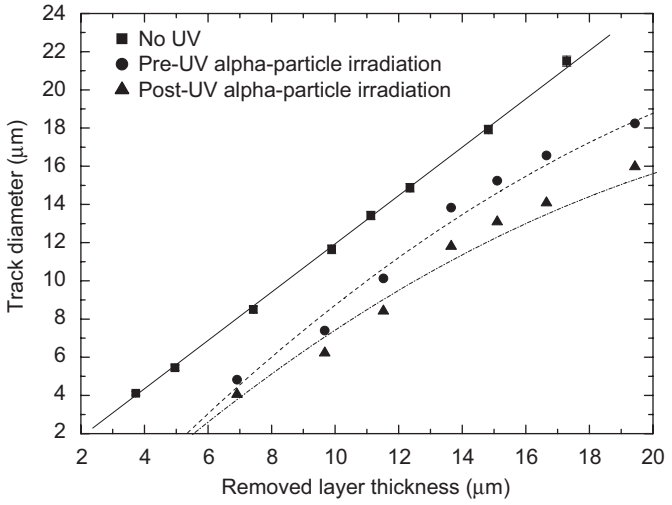

Fig. 3. Variation of the alpha-particle track diameter as a function of removed layer thickness in CR-39 detectors with different UV exposures.

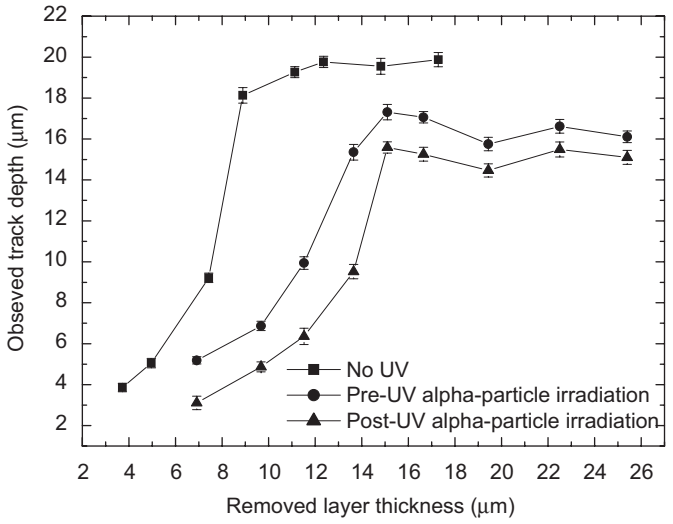

Fig. 5. Variation of observed alpha-particle track depth as a function of removed layer thickness in CR-39 detectors with different UV exposures.

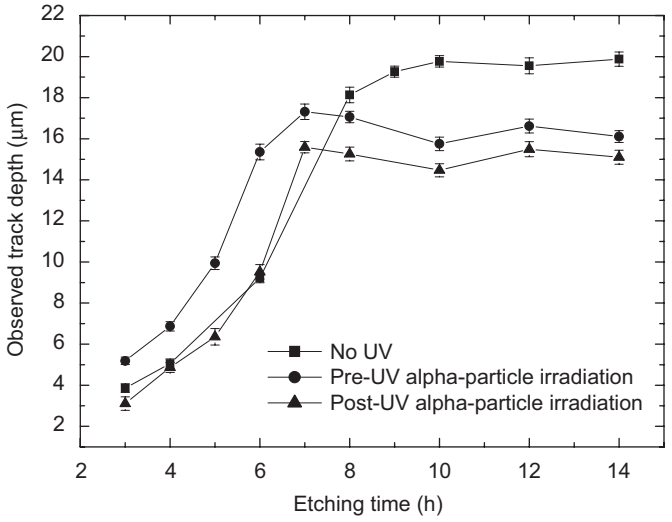

Fig. 4. Variation of observed alpha-particle track depth as a function of etching time in CR-39 detectors with different UV exposures.

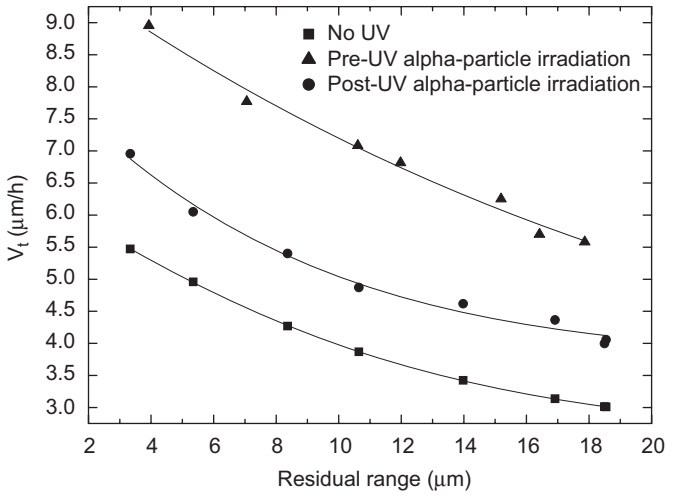

Fig. 6. The variations of V_t as a function of the residual range of alpha particles in CR-39 detectors with different UV exposures.

alpha), respectively. V was reduced for (alpha + UV) and (UV + alpha).

3.4. Variation of V_t

V_t was studied by measuring the track depth and the track diameter as a function of etching time. The sensitivity V for no UV irradiation, (alpha + UV) and (UV + alpha) were obtained in the form $V = 1 + \exp(-a_1 \times R' + a_4) - \exp(-a_2 \times R' + a_3) + \exp(a_3) - \exp(a_4)$ with four parameters a_1, a_2, a_3 and a_4 where R' was the residual range of the alpha particles in CR-39 (Brun et al., 1999; Yu et al., 2005). The residual ranges were calculated using the SRIM code (http://www.srim.org/). The best-fitted parameters (a_1, a_2, a_3 and a_4) for no UV irradiation, (alpha + UV) and (UV + alpha) were found as (0.1, 1.24, 1.52 and 1.31), (0.08, 1.2, 1.3 and 1.1) and (0.12, 1.2, 1 and 0.8), respectively.

The sensitivity V decreased for UV irradiation, while that for (alpha + UV) was higher than that for (UV + alpha). V_t was calculated as follows: V_b was first determined at a particular removed layer thickness h of the detector; for this h, R' was determined to calculate V, and V_t can be obtained by $V \times V_b$. The variations of V_t with R' for different UV exposures are shown in Fig. 6.

All CR-39 samples exposed to UVC showed enhancements in V_t. However, (alpha + UV) led to a much higher V_t than (UV + alpha). As mentioned before, both alpha-particle and UV irradiation of CR-39 led to increased scissions of the polymer chains and additional formation of hydroxyl groups in the track region, which in turn enhanced the solubility into the etchant. For (alpha + UV), the UV radiation dissociated the products of radiolysis of latent tracks into low-molecular substances. The resultant substances diffuse rapidly into the etchant (Gruhn and Benton, 1981; Vilensky et al., 2003).

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