Radiation Physics and Chemistry 107 (2015) 183–188

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Fast detection of alpha particles in DAM–ADC nuclear track detectors

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HIGHLIGHTS

- Suitable analyzing software has been used.
- Samples of DAM–ADC detectors have been irradiated with fission fragments.
- Fast detection method of alpha particles in DAM–ADC detectors.
- The dependence of etching efficiency upon etchant concentrations.

ARTICLE INFO

Article history:
Received 6 June 2014
Received in revised form
3 October 2014
Accepted 29 October 2014
Available online 6 November 2014

Keywords:
Fission fragments
Alpha particles
DAM-ADC
Etching efficiency

ABSTRACT

Fast detection of alpha particles in DAM–ADC nuclear track detectors using a new chemical etchant was investigated. ^{252}Cf and ^{241}Am sources were used for irradiating samples of DAM–ADC SSNTDs with fission fragments and alpha particles in air at normal temperature and pressure. A series of experimental chemical etching are carried out using new etching solution (8 ml of 10 N NaOH+ 1 ml CH_3OH) at 60 °C to detect alpha particle in short time in DAM–ADC detectors. Suitable analyzing software has been used to analyze experimental data. From fission and alpha track diameters, the value of bulk etching rate is equal to 8.52 μm/h. Both of the sensitivity and etching efficiency were found to vary with the amount of methanol in the etching solution and etching time. The DAM–ADC detectors represent the best efficiency applicable in detectors in the entire range of alpha energies (from 1 to 5 MeV). The activation energies of this etchant have been calculated; track activation energy, E_T, has been found to be lower than the bulk activation energy, E_B, for the DAM–ADC nuclear track detectors. These results are in more agreement with the previous work.

1. Introduction

Solid state nuclear track detectors (SSNTDs) have been successfully employed in a large variety of applications in science and technology has been gained much interest (Price, 2005, 2008, Ashry et al., 2012; El-Hawary et al., 1999). Especially, qualitative and quantitative analysis of alpha particles in radioactive environmental and biological samples (Gaillard et al., 2005; Nikezic and Yu, 2004). The sensitivity of the plastic detector is known to be affected by the purity of monomer and molecular structure (Portwood et al., 1986). Diallyl maleate (DAM) is a highly active monomer with a powerful affinity for many materials. Therefore, DAM is used as a raw material for many chemical products, such as adhesives, ion exchange resin, etc. It had been found that DAP (diallyl phthalate) and ADC have two allyl radicals, which are the components inherent in DAM. The molecule of DAM has four hands to link with another similarly to ADC and DAP. The DAM must have highly cross-linked three dimensional network structures in the plates. In the case of DAM, there is a possibility that the central carbon–carbon double bond contribute the cross-linking (Tsuruta, 1999, 2000).

DAM, ADC, and mixtures of DAM and ADC (DAM–ADC) were cast into polymer plates under three kinds of polymerizing

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http://dx.doi.org/10.1016/j.radphyschem.2014.10.013
0969-806X/

conditions. Pure ADC plate was sensitive to both of fission fragments and alpha particles. On the other hand, pure DAM plate was found to be sensitive to fission fragments, but to be insensitive to alpha particles. The mixtures of DAM and ADC form co-polymers containing various ratios and show various intermediate characteristics between DAM and ADC polymer (Ashry et al., 2012). The observed characteristics in DAM–ADC co-polymers are similar to those observed in the case of DAP–ADC (Tsuruta et al., 2011). These characteristics are suitable for control of the sensitivity as the nuclear track detector. The fabrication of the copolymers makes it possible to adjust the discrimination level for the detection of heavy charged particles (Tsuruta et al., 2011).

Chemical etching is an essential method being used in various studies of surfaces and technical applications (Fleischer et al., 1975). If a piece of material containing the latent track is exposed to some chemically aggressive solution, such as NaOH or KOH solution, the chemical reaction would be more intensive in the latent track (Nikezic and Yu, 2004). It is found that, The fierce bulk etch rates for NaOH/ethanol etchants compared to that for the 6.25 N NaOH/H_2O etchant are due to the miscibility of ethanol with the organic etched products from etching the ADC detector (Tse et al., 2007). The optimum etching condition, 10 N NaOH with etching temperature 343 K and etching time is 2.5 h has been used successively to register alpha particles in the DAM–ADC detector with energy in the range from 1 to 5 MeV (El-Samman et al., 2014).

In the present study, we introduce a new etchant solution for DAM–ADC detector to investigate several important parameters that control the track formation such as the bulk etch rate (V_B), track etching rate (V_T), sensitivity, etching efficiency, and registration efficiency for alpha particles in short etching time, in order to approve the benefit of these plates as the nuclear track detectors.

2. Materials and methodology

The molecular formula of the DAM–ADC detector used in the present study is expressed as ($C_{22}H_{30}O_{11}$), its thickness is 1 mm and density is 1.2 g/cm^3. The main constituents of the detector plate are the DAM (15%) and ADC (85%). A small amount of diisopropyl peroxy dicarbonate (IPP) was used as a polymerizing initiator. The co-polymer of DAM–ADC detector was obtained from Yamamoto Kogaku Co., Ltd., Japan. The relationship between the concentration of DAM and the etch pit diameter of alpha particle and fission fragment have been studied by Tsuruta et al. (2011); up to 10% or 25% of the concentration of DAM, the diameter has a tendency to increase. When the concentrations exceed those percentages, on the other hand, the diameter decreases gradually. Samples of DAM–ADC detector with an area of 1.0×1.0 cm^2 were carefully cut with laser beam.

A group of DAM–ADC detectors were exposed to a thin open ^{252}Cf disk source as an alpha, fission fragment and fast neutrons source of activity 9.65×10^{-3} μCi and surface area of 19.64 mm^2. ^{252}Cf disk source was contact with detectors and all samples were exposed for 20 min to the source. Another group was exposed to thin ^{241}Am disk source that emit alpha with energy of 5.5 MeV and activity 0.924 μCi. Using a variable length of air column, energies from 1 to 5 MeV were used.

Mixture of 10 N sodium hydroxide and pure methanol (CH_3OH) with different ratios were used as the etching solutions at 55, 60 and 65 °C. It is found that the fierce bulk etch rates for NaOH/alcoholic etchants compared to that for the 6.25 N NaOH/H_2O etchant are due to the miscibility of alcoholic with the organic etched products from etching the solid state detector (Tse et al., 2007). The etching was done in a bottle with a tight lid to prevent change in the concentration of the etching solution due to vaporization of water and absorption of moisture.

For etching process, a water path of stabilizing temperature with accuracy ± 0.5 °C was used. All etched samples were held at the same depth in the etchant solution. After etching the samples were immersed in running water for suitable time interval to remove all etchant products from the surfaces. Finally, the samples were carefully dried and then used for analysis. For estimation of track diameter an optical microscope fitted with a magnification of 400× was used. The microscope was connected with a web digital camera to capture the sample image from microscope and save it in P.C unit, software program (INFINITY ANALYZE software) was used to analyze the tracks after calibration.

The bulk etch rate V_B is the rate of removing of the undamaged surface of the detector due to the chemical reaction between the etching solution and the detector material, and it can be determined using the following equation.

$$V_B = \frac{D_{ff}}{2t_e} \tag{1}$$

Where D_{ff} is the track diameter of fission fragment projectile that bombarded the detector as shown in Fig. 1, and t_e is the etching duration. The traditional method for determining the track etching rate of solid state nuclear detector is based on the measurement of track diameter (D). The relation between V_T and D takes into account the removal of a detector layer $h = V_B t$ and bulk etching rate (Durrani and Bull, 1987). In this method DAM–ADC detectors were exposed to normal incident alpha particle of energy 2 MeV and then etched for etching time 60 min. with different etching concentrations at different etching temperatures. From the track

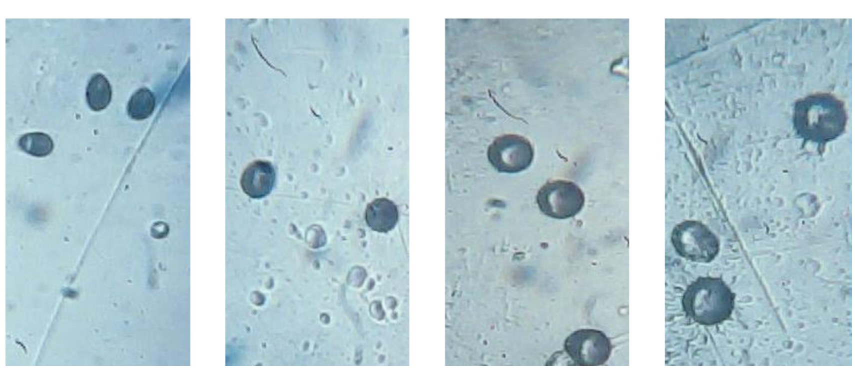

Fig. 1. Typical optical images of fission tracks in the DAM–ADC detector with etching condition (8 ml of 10 N NaOH +1 ml CH_3OH) at 60 °C.