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Radiation Measurements 36 (2003) 141 – 143
Radiation Measurements
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Effects of stirring on the bulk etch rate of CR-39 detector

J.P.Y. Ho, C.W.Y. Yip, D. Nikezic[1], K.N. Yu*

Department of Physics and Materials Science, City University of Hong Kong, Tat Chee Avenue, Kowloon Tong, Kowloon, Hong Kong

Received 21 October 2002; accepted 23 April 2003

Abstract

It is well established that the bulk etch rates for solid state nuclear track detectors are affected by the concentration and the temperature of the etchant. Recently, we found that the bulk etch rate for the LR 115 detector to be affected by stirring during etching. In the present work, the effects of stirring on the bulk etch rate of the CR-39 detector is investigated. One set of sample was etched under continuous stirring by a magnetic stirrer at 70°C in a 6.25 N NaOH solution, while the other set of samples was etched without the magnetic stirrer. After etching, the bulk etch thickness was measured using Form Talysurf PGI (Taylor Hobson, Leicester, England). It was found that magnetic stirring did not affect the bulk etch of the CR-39 detector, which was in contrast to the results for the LR 115 detector.

Keywords: CR-39; Bulk etch rate; Stirring

1. Introduction

It is now well established that track developments in solid state nuclear track detectors (SSNTDs) depend strongly on $V = V_t/V_b$ or the ratio of the track etch rate to the bulk etch rate. Therefore a precise control of the bulk etch rate, among others, is crucial for track studies. Nevertheless, for most studies using SSNTDs, the etching rate is presumed to be surrogated by the etching conditions, which involve only the temperature and the concentration of the etchant, and the etching duration.

In a recent study, Yip et al. (2003) investigated the effects of stirring on the bulk etch rate of the LR 115 detector. By employing a standard etchant of 10% aqueous solution of NaOH maintained at 60°C, the bulk etch rate under magnetic stirring was found to be $6.65 \pm 0.34\ \mu\text{m}\,\text{h}^{-1}$ and that under no magnetic stirring to be $3.61 \pm 0.14\ \mu\text{m}\,\text{h}^{-1}$ (Yip et al., 2003). It is expected that, even when no magnetic stirring is applied, the strength of convection in the etchant cannot be controlled. Therefore, the bulk etch rate for the LR 115 detector cannot be simply surrogated by the temperature and the concentration of the etchant, and the etching duration.

After obtaining the results for the LR 115 detector, it becomes pertinent to study whether such dependence on the amount of stirring also exists in the bulk etch rate of the CR-39 detector, which is another commonly used SSNTD. This forms the objective of the present paper. Comparisons with the results for the LR 115 detector will also be made.

2. Methodology

In order to study the bulk etch rate of the CR-39 detector, we have to devise a method which is capable of accurately and directly determining the thickness of the etched layer (the bulk etch). Various methods have been proposed or employed for determination of the bulk etch rate of SSNTD. For example, one relied on the difference between detector mass before and after etching, and another was based on measurements of track opening diameters (Durrani and Bull, 1987). Nevertheless, these were indirect measurements.

Recently, Nikezic and Janicijevic (2002) proposed a "peel-off" method to directly measure the bulk etch for the LR 115 detector based on surface profile measurements using an instrument called "Form Talysurf" (Taylor Hobson, Leicester, England). The LR 115 detectors consisted of an

* Corresponding author. Tel.: +852-2788-7812; fax: +852-2788-7830.
E-mail address: peter.yu@cityu.edu.hk (K.N. Yu).
[1] On leave from University of Kragujevac, Yugoslavia.

1350-4487/03/$ - see front matter
doi:10.1016/S1350-4487(03)00111-2

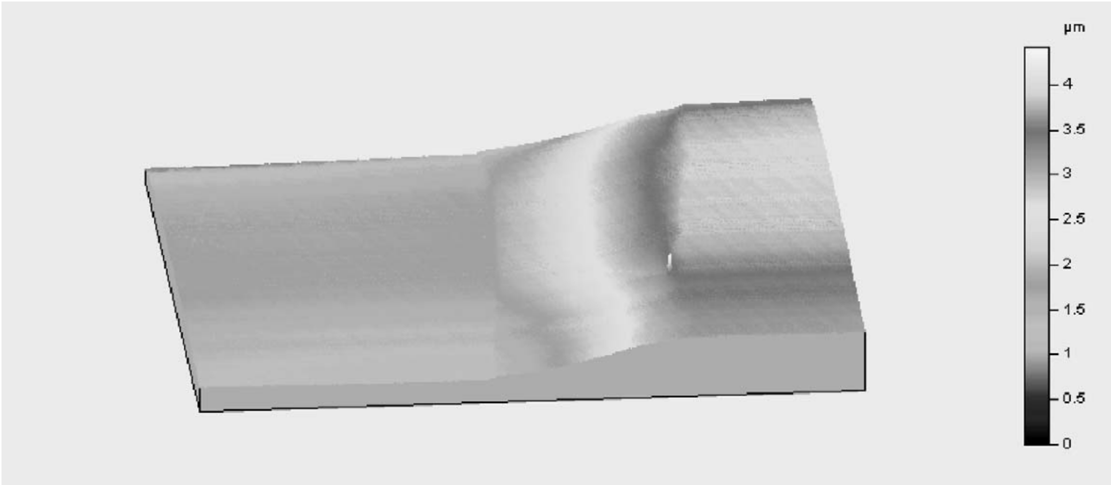

Fig. 1. The three-dimensional profile for a CR-39 detector after etching for 2 h without stirring given by Form Talysurf PGI.

active layer of red cellulose nitrate on a polyester base substrate. Before etching, a portion of the cellulose nitrate layer was removed by a razor. The thickness of the active layer was then measured before and after etching and the difference gave the bulk etch (Nikezic and Janicijevic, 2002).

The CR-39 detectors used in the present study were purchased from Page Mouldings (Pershore) Limited (Worcestershire, England). A major difference between the CR-39 detector and the LR 115 detector is that the former does not have an active layer on top of a substrate. Therefore, the "peel-off" method for the LR 115 detector does not apply here. Instead, we employ the "masking method" (Yasuda et al., 1998) to determine the bulk etch of the CR-39 detector. Each CR-39 detector used for our experiments was cut to a size of about 1.5×1.5 cm^2. Before etching, half of a piece of CR-39 detector was masked by epoxy (Araldite Rapid, Vantio Ltd., Cambridge, UK) which was a material resistant to the etchant. The epoxy needed a few hours to set.

After etching, the masked part of the detector remained unetched. The epoxy mask was removed and the bulk etch could then be determined by the difference in the heights of the exposed part and the masked part of the detector. In the present work, the surface profiling instrument called Form Talysurf PGI (Taylor Hobson, Leicester, England) was employed to determine this height difference. The measuring system is based on a laser interferometric transducer. A computer-controlled stylus passes slowly across a surface of interest during measurements, while the data are processed by the computer to generate an output graph showing the profile of the scanned surface.

Form Talysurf PGI (FTPGI) is in fact a more advanced version of the Form Talysurf (FT). First, FTPGI can give three-dimensional profiles while FT gives two-dimensional profiles. An example of a three-dimensional profile for a CR-39 detector after etching for 2 h without stirring given by FTPGI is shown in Fig. 1. Second, manual leveling of a surface is allowed in FTPGI but not in FT. The masked and the exposed surfaces are expected to be horizontal. However, these surfaces are often plotted as tilted surfaces during the automatic FT plotting, which makes determination of the height differences difficult and less accurate. An example of the cross-sectional view of a CR-39 detector after etching for 2 h without stirring scanned by FTPGI is shown in Fig. 2.

Two sets of CR-39 detectors (each set containing six detectors) were etched in two separate beakers to determine the effect of stirring of the etchant. As mentioned before, all detectors were partially masked before etching. The detectors were etched in 6.25 N NaOH maintained at 70°C by a water bath, which is the most frequently used etching condition for CR-39 detectors. The temperature was kept constant with an accuracy of ±1°C. One set of detectors were etched under no stirring while the other set of detectors were etched using a magnetic stirrer (Model No: SP72220-26, Barnstead/Thermolyne, IA, USA).

At each of the selected time intervals, i.e., 0.5, 1, 2, 3, 4 and 5 h, for both etching under magnetic stirring and under no stirring, a piece of CR-39 detector was taken out from the corresponding beaker. The detectors were immediately rinsed by distillated water and the epoxy masks were removed at the same time. The bulk etches were then determined using FTPGI. In actual measurements, a mean value for bulk etch was obtained by taking the average of height differences at 10 different positions.

3. Results and discussions

The experimental relationship between the amount of bulk etch (μm) and the etching time (h) for the CR-39 detector

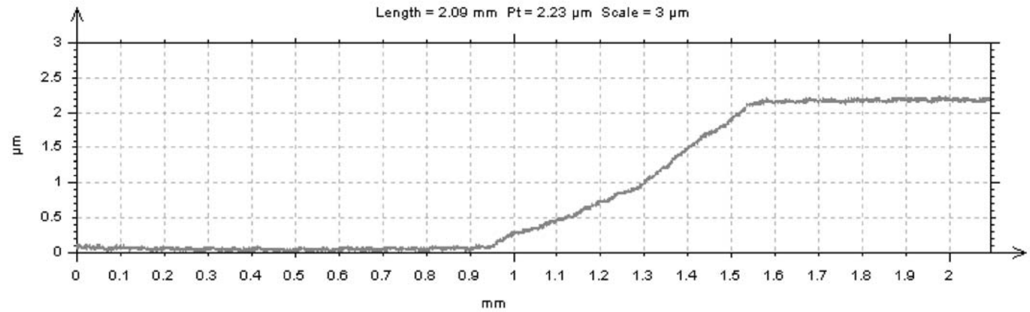

Fig. 2. The cross-sectional view of the CR-39 detector after etching for 2 h without stirring scanned by Form Talysurf PGI.

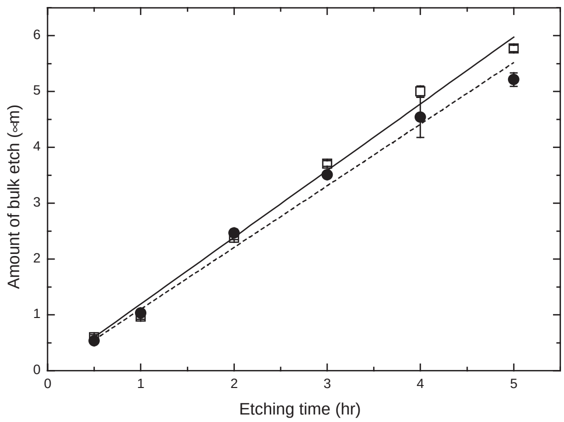

Fig. 3. Relationship between the amount of bulk etch (μm) (measured by Form Talysurf PGI) and the etching time (h) for the CR-39 detector. Open squares and solid line: data obtained with etching under no stirring and the corresponding best fit line; solid circles and dashed line: data obtained with etching under magnetic stirring and the corresponding best fit line.

is shown in Fig. 3, for the detectors etched under magnetic stirring and under no stirring. One can see in Fig. 3 that the bulk etch rates are similar under magnetic stirring and under no stirring. By linear fitting the data for the two sets of samples by the equation $y = Bx$, where y is amount of bulk etch (μm) and x is etching time (h) of the detector, we have

$B = 1.104 \pm 0.024$ for etching under magnetic stirring,

$B = 1.195 \pm 0.028$ for etching under no stirring.

In other words, the bulk etch rates are 1.10 ± 0.02 and 1.20 ± 0.03 $\mu m\,h^{-1}$ for etching under magnetic stirring and under no stirring, respectively. The observation of similar bulk etch rates with and without magnetic stirring for the CR-39 detector is in sharp contrast to that for the LR 115 detector. The bulk etch rates for the LR 115 detector were found to be 6.65 ± 0.34 and 3.61 ± 0.14 $\mu m\,h^{-1}$ for etching under magnetic stirring and under no stirring, respectively (Yip et al., 2003). The different phenomenon can be a result of the different chemical structures and the hydrophilic properties of the two SSNTDs, but further investigations have to be carried out to confirm the underlying causes.

Now that the bulk etch rate for the CR-39 detector is not affected by the amount of stirring, control of the etching conditions for CR-39 is feasible. In this way, the etching rate can be satisfactorily surrogated by the etching conditions involving only the temperature and the concentration of the etchant, and the etching duration, as already assumed for most studies using CR-39 detectors. Further monitoring the detector thickness when using the CR-39 detector in the studies of ^{222}Rn concentrations is not necessary.

Acknowledgements

The present research is supported by the CERG grants CityU1081/01P and CityU1206/02P from the Research Grant Council of Hong Kong.

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