Bulk Etch Rate of LR 115 Polymeric Radon Detector

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Abstract

In this study, we used strippable LR 115 type 2 which is a Solid State Nuclear Track Detector (SSNTD) widely known for radon gas detection and measurement. The removed thickness of the active layer of samples of this SSNTD, were determined by measuring the average initial thickness (before etching) and residual thickness after 80 to 135 minutes chemical etching in the standard conditions, using an electronic comparator. These results allowed the calculation of the bulk etch rate of this detector in a simple way. The mean value obtained is (3.21 ± 0.21) µm/h. This value is in close agreement with those reported by different authors. It is an important parameter for alpha track counting on the sensitive surface of this polymeric detector after chemical etching because track density depends extremely on its removed layer. This SSNTD was then used for environmental radon gas monitoring in Côte d'Ivoire.

Keywords

Strippable LR 115 Type 2, Chemical Etching, Removed Layer, Bulk Etch Rate

1. Introduction

Radon, a natural radioactive and lung carcinogen gas [1] can be detected by many techniques [2] [3] [4]. The SSNTD are the most widely used detectors in this way by many researchers around the world [5] [6] and LR 115 is the best SSNTD for radon [7]. Alpha particles emitted by radon and its progeny hit the detector and left latent tracks in it. Several different techniques of track revelation are known [8] [9] [10], but, the chemical etching technique is the most frequently used. Many authors had established that the removed active layer of Solid State Nuclear Track Detector during etching is one of the main factors influencing the track parameters or shape characteristics [11] [12] [13]. Ion-track growth in SSNTD has been suggested to base on two parameters, V_t and V_b [14], where V_t is the track etch rate and V_b the bulk etch rate which is one of the most important parameters that control track formation and development and with V_p are needed to simulate track growth and to calculate track parameters [15] [16]. The bulk etch rate is strongly related to the removed thickness of the active layer and it has been shown that V_b depends on many factors like the purity of the basic substances, the molecular structures of polymers, conditions of polymerization, environmental conditions during the irradiation and finally on etching conditions [17]. Yip and contributors[18] showed that the bulk etch rate of LR 115 could not be controlled by temperature and etchant concentration only, and was also affected by the amount of stirring. Therefore, actual monitoring of the active layer thickness is necessary when using this detector. Various techniques were used for the determination of the bulk etch rate [18] [19] [20] [21]. Our main concern in this study is to determine in the standard etching conditions, the bulk etch rate of LR 115 type 2 by measuring the thickness of its active layer before and after chemical etching using an electronic comparator.

2. Materials and Methods

Commercially available, LR-115 type 2 strippable films manufactured by DOSIRAD-France, consist of an active layer or cellulose nitrate on 100 µm clear polyester base. 10 pieces of this detector film (size 2 × 2 cm) were taken. The active layer of each sample was peeled off with a lancet and its thickness (initial thickness) measured on 10 different points covering its surface using an electronic comparator (**Figure 1**). We then deduced from the 100 measurements, the arithmetical mean of the initial thickness of LR 115 type 2 active layer.

36 other samples with the same size were irradiated with a Pu-239 radioactive source which α particle emission rate in 2π sr geometry is 3055 α/s, through a collimator of 21.79 mm height (**Figure 2**) during 5 minutes. Then, these samples were introduced in an etching bath without stirring of NaOH solution with the concentration 2.5 mol/ L at the constant temperature of 60˚C. After 80 minutes, three samples were taken out from the bath, rinsed off with tap water, then put in distilled water before been dried in dry air. Five (5) minutes later, three other samples were submitted to the same process. And so on every 5 minutes until 135 minutes. After been dried, each sample was peeled off with a lancet, its residual thickness measured as for the 10 previous before etching and its removed thickness calculated using the relation:

$$e = e_m - e_r \tag{1}$$

where

e is the removed active layer thickness (µm);

Figure 1. Electronic comparator.

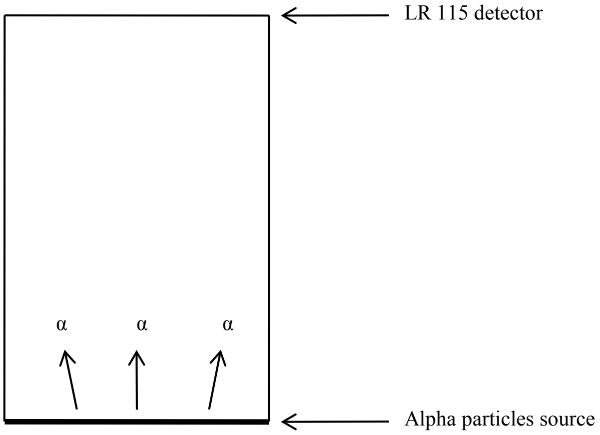

Figure 2. Schematic of irradiation system.

e_m, the mean of its initial thickness (μm);

and e_r, its residual thickness (μm).

Chemical etching of an irradiated SSNTD foil works on the principle that the solution preferentially attacks the damaged core of the latent track and penetrates along its length with a velocity V_t or track etch rate while, the undamaged area of the foil is attacked at a lower rate with a velocity V_b also called bulk etch rate. V_b is generally constant for given etching conditions but not V_t which depends on the amount of damage present in the region of the core. Finally the track leads to the formation of a cone with semi-cone angle δ also known as the critical angle of etching and given mathematically by:

$$\sin\delta = \frac{V_b}{V_t} \tag{2}$$

For the present experiment, we deduced the bulk etch rate of LR 115 type 2 using the formula:

$$V_b = \frac{e}{t} \tag{3}$$

where

V_b is the bulk etch rate (μm/h);

and t the etching time (h).

3. Results and Discussion

The arithmetical mean of the initial thickness of LR 115 type 2 active layer obtained from all the measurements is (12.45 ± 0.34) µm.

Our other experimental results are reported in the **Table 1** below. Using these data, two graphs are drawn in **Figure 3** and **Figure 4**.

In **Figure 3**, the thickness of the removed active layer of LR 115 type 2 increases linearly with the etching time.

According to our results, under the standard etching conditions the removed thickness obtained for 120 min of etching is 6.68 µm, and the corresponding residual thickness of the active layer is 5.77 µm. This last value fits well the important criteria for an optimum alpha track counting on strippable LR 115 type 2 film using a spark counter which is that the residual thickness of its active layer must range between 5.5 and 6.5 µm [22].

Figure 4 shows that for etching times between 80 and 135 minutes a constant bulk etch rate was attained considering the bar errors. Its calculated arithmetical mean is (3.21 ± 0.21) µm/h. This value agrees with those obtained by other authors [23] [24]. Therefore, it's possible to evaluate, with this constant value of V_b, the removed active layer thickness at any etching time using the previous equation (3).

Our calculated bulk etch rate is a little different from the value of, 3.61 ± 0.14 µm/h, obtained by Yip and contributors [18], both in the same etching conditions. The difference may be due to the fact that the initial thickness of LR 115 type 2 active layer is not exactly 12 µm, as usually taken for granted.

Now that V_b was determined, it can be combined with the track etch rate V_t to give the V function ($V = V_t / V_b$), which is required for calculating track parameters [25] [26] [27]. For example, with a normally incident track, we have the following relation:

$$D = d = 2V_b t\sqrt{\frac{V-1}{V+1}} \tag{4}$$

where

D is the major axe of the track opening;

d its minor axe;

and t the etching time.

In fact, the track opening being the intersection of a cone with a plane surface, the resulting shape is a conic section which is an ellipse with major axis D and minor axis d.

For a normally incident track, $D = d$ is simply called diameter of track opening. Then, in the case of plastics like LR 115 where V_t is very much greater than V_b so that V is very much greater than 1, the Equation (4) gives approximately.

$$D = d = 2V_b t \tag{5}$$

The values of track opening diameters calculated using Equation (5) are reported in **Table 2** below.

Table 1. Removed thickness and bulk etch rate as a function of etching time.

Etching time (min)	Removed thickness (μm)	Bulk etch rate (μm/h)
80	3.85 ± 0.23	2.85 ± 0.17
85	4.22 ± 0.30	2.97 ± 0.21
90	4.37 ± 0.29	2.91 ± 0.19
95	5.16 ± 0.33	3.27 ± 0.21
100	5.17 ± 0.38	3.10 ± 0.23
105	5.88 ± 0.44	3.36 ± 0.25
110	6.22 ± 0.40	3.39 ± 0.22
115	6.80 ± 0.44	3.54 ± 0.23
120	6.68 ± 0.42	3.34 ± 0.21
125	6.78 ± 0.44	3.26 ± 0.21
130	7.12 ± 0.54	3.28 ± 0.25
135	7.39 ± 0.47	3.28 ± 0.21

Table 2. Track opening diameter as a function of etching time for a normally incident track.

Etching time (min)	Track opening diameter (μm)
80	7.60 ± 0.45
85	8.42 ± 0.60
90	8.73 ± 0.57
95	10.36 ± 0.67
100	10.33 ± 0.77
105	11.76 ± 0.88
110	12.43 ± 0.81
115	13.57 ± 0.88
120	13.36 ± 0.84
125	13.58 ± 0.88
130	14.21 ± 1.08
135	14.76 ± 0.95

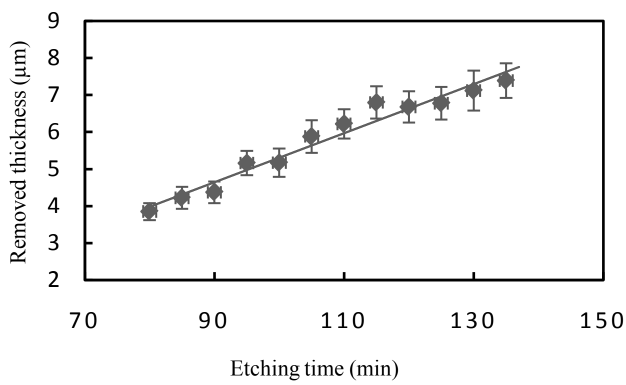

Figure 3. Removed thickness as a function of etching time.

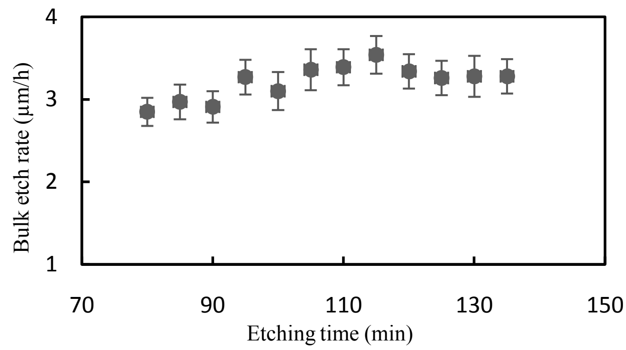

Figure 4. Bulk etch rate as a function of etching time.

4. Conclusion

Bulk etch rate is one of the most important factors controlling track developments in SSNTD. So, that requires precise measurement of this parameter. The result on the bulk etch rate of LR 115 type 2 film obtained under standard etching conditions without stirring during an etching time ranging between 80 and 135 minutes and using an electronic comparator is (3.21 ± 0.21) μm/h. This value agrees well with those reported by other authors. Moreover, the measured thickness of the residual active layer at the etching time of 120 minutes fits well the spark counter use criteria for an optimum alpha track counting on strippable samples of this detector as it was the case for those exposed to radon gas in Côte d'Ivoire.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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