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Kinetics Of Annealing in Various Cr-39 Detectors Manufactured in Different Cure-Cycle Regimes in The Framework of a Novel Approach to Study Progression of Annealing

Anupam Arora
S.D. (PG) College, Panipat

--*ABSTRACT*--

In the present study, annealing induced track repair has been evaluated in various CR-39 detectors manufactured in different cure-cycle regimes. Quantitative measurement of repair of damage has been made with the help of an analytical novel approach to study kinetics of annealing process in dielectric track recorders that employs the use of a parameter most directly related to formation/ repair of tracks compared to other parameters previously employed for the purpose. Effect of crosslinking/ degree of polymerization of CR-39 detectors on the progress of annealing has been assessed.

Keywords: *CR-39 (8 hr), CR-39 (32 hr), CR-39 (96 hr) extent of annealing (y), Track and Bulk Etch Rate (V_T, V_B)*

I. Introduction:

A most revolutionary addition to the family of Solid State Nuclear Track Detectors was CR-39, a polymer already being used in making good quality optical lenses and in many commercial applications, but used as a track detector for the first time in 1978 [2]. Owing to high sensitivity and resolution, excellent etching and optical properties, CR-39 track detector has found widespread use in numerous applications of SSNTDs, besides it has also opened door to newer applications [3], [4] ... [13]. CR-39 is a highly cross-linked thermoset polymer. Its polymerization process involves transformation from unsaturated monomers to a saturated polymer. Polymerization results in growth of chains by attaching the monomer molecules. It results in a polymeric network with a large number of closed zones and also the unused monomer molecules trapped inside the zones. Thus residual unsaturation continues to exist in the polymer. Consequently, structural inhomogeneities exist which are responsible for the non-uniform response of the detector. Therefore, in the manufacturing of CR-39 detectors, specific cure-cycle regimes with specific temperature-time combinations are adopted to ensure uniform rate of polymerization and hence to result in more uniform characteristics of the CR-39 detector.

It is well known that repair of damage/ latent tracks when irradiated SSNTDs are subjected to thermal treatment/ annealing has occupied a center stage in SSNTD research [1]. Annealing studies help us understand the role of temperature in relation to response of a track detector.

Present Study:

In the present study, post irradiation annealing response of various CR-39 detectors manufactured in different cure-cycles has been evaluated in terms of a novel approach to study progress/ kinetics of annealing.

Value of Track Etch Rate (V_T) in excess of Bulk Etch Rate (V_B) relates solely to the damage along the track which makes etching along the track take place more rapidly due to thermodynamic energy considerations. Track Etch Rate can be expressed as [14], [15]

$$V_T = V_B + f \tag{1}$$

and

$$V = \frac{V_T}{V_B} = 1 + \frac{f}{V_B} \tag{2}$$

Also, track diameter [1], $$D = 2\, V_B t \sqrt{\frac{V-1}{V+1}} \tag{3}$$

Annealing results in changes in the values of these parameters. If ΔV_B is the change in bulk etch rate and Δf the change in f resulting from annealing, it is possible to express [14]

$$D_1 = D\left(1 + \frac{x}{100}\right)\sqrt{\frac{(V+1)\,(100-y)}{V\,(100-y)+2x+y+100}} \tag{4}$$

where Percentage Change in Bulk Etch Rate [14]

$$x = \frac{\Delta V_B}{V_B} \times 100$$

and Percentage Change in f term [14]

$$y = \frac{\Delta f}{f} \times 100$$

Track Diameter after annealing (D_1) can be expressed in terms of Track Diameter before annealing (D) as in Eq. (4) [14].

Although Bulk Etch Rate (V_B), Track Etch rate (V_T), Track Diameter (D), each of the said parameters changes by annealing and therefore any of the said parameters can be used to represent the effect of annealing, but each of these parameters does not have exclusive and sole dependence on the damage only, each depends on bulk etch property and so on nature of material also. The most appropriate parameter for evaluation of annealing is the percentage change in f term, expressed as y, as f term relates only to damage and therefore only to the formation tracks and its change on annealing relates only to repair of tracks and on nothing else and thus it can be identified as the most accurate parameter to evaluate the annealing effect. [14, [15].

II. Experimental Details

Detectors CR-39 (8 hrs), CR-39 (32 hrs) and CR-39 (96 hrs) have been obtained from Pershore Mouldings (Worcesteshire, England).

TABLE
CURE CYCLE DETAILS

CR-39 (8 hr.)	Cure cycle starts at 34°C, rises to 45°C over 2 hours then to 65°C and is held for 6 hours followed by cooling to 40°C before removal.
CR-39 (32 hr.)	Cure cycle starts at 34°C, rises to 45°C over 2 hours, then to 65°C and is held for 30 hours followed by cooling to 40°C before removal.
CR-39 (96 hr.)	Cure cycle starts at 34°C, rises to 45°C over 2 hours then to 55°C for 24 hours and then to 65°C for 70 hours followed by cooling to 40°C before removal.

Detectors samples were exposed to 5.45 MeV α particles from $^{241}{}_{Am}$ source in normal incidence in vacuum, 10^{-2} torr, in an exposure unit in the High Energy Physics laboratory, Department of Physics, Kurukshetra University, Kurukshetra. Post irritation annealing of exposed samples was done at 95^0C for various times – 5, 10, 15 hours. The samples were etched in 6.25N NaOH at 60^0C for 20 hours.

III. Results and Conclusion

TABLE

EXTENT OF ANNEALING (y) IN DIFFERENT CR-39 DETECTORS FOR POST IRRADIATION ANNEALING AT 95⁰C FOR VARIOUS TIMES

Detector Type	Annealing time (hours)	y
CR-39 (8 hr)	5	19.56
	10	29.62
	15	36.69
CR-39 (32 hr)	5	8.82
	10	19.33
	15	27.75
CR-39 (96 hr)	5	3.38
	10	10.89
	15	17.01

It is obvious from the results that –

for annealing for 5 hours at 95^0C, track repair (y) is 19.56% for CR-39 (8 hr), 8.82% for CR-39 (32 hr) and 3.38% for CR-39 (96 hr) and similarly for other annealing times.

Precise quantitative evaluation of annealing induced track repair is the unique feature of this simple approach. It offers altogether a new method to investigate kinetics of annealing process.

It can be understood that polymerization in a cure-cycle regime spread over a longer time results in greater degree of polymerization, greater chain lengths, greater value of average molecular weight of chain, and greater degree of cross linking.

From the results it can be, therefore, inferred that extent of track repair is less for more cross-linked detectors and also that damage/ latent track is more stable in more cross-linked detectors thus giving us option to choose suitable detectors based on cure-cycle regimes for specific applications.

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