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Quantitative Evaluation of Repair of Damage/ Latent Tracks Due To Annealing Using a Novel Approach of Study of Annealing Kinetics in Solid State Nuclear Track Detectors.

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

Abstract :

In the present work, quantitative evaluation has been made of the repair of damage/ latent tracks in CR-39 detectors subjected to annealing using altogether a new approach for the study of annealing kinetics. This approach has a general application and not limited to the use of CR-39 detectors only.

It has been shown that a specific repair of damage on account of annealing can be quantitatively expressed in terms of a specific parameter in a most faithful and accurate manner compared to many other available parameters.

This parameter used for quantitative evaluation of annealing induced repair of damage has no dependence on bulk properties of the detector unlike all other parameters. It relates only to damage irrespective of nature of material of detector and therefore most appropriate to express damage quantitatively.

Keywords: *CR-39 (DOP), CR-39 (no additive), Track Annealing, Track Etch Rate (V_T), Bulk Etch Rate (V_B), Etch Rate Ratio (V), Track Diameter (D).*

I. Track Detectors :

Passage of energetic charged particles in insulating solids results in latent tracks that arise due to energy loss of charged particles by way of interactions with the atoms/ electrons of the Solid. [1], [2]. Radial dimension of latent tracks, $30A^0 – 100A^0$, is too small for the use of optical microscope for their observation. However, it is possible to enlarge the tracks by employing Chemical Etching to suitable dimensions so as to observe using ordinary optical microscopes [1]. Dielectric Tracks Recorders/ Solid-State Nuclear Track Detectors since the discovery of latent tracks have found important applications in various areas of Science and Engineering [1], [2], [3], [4]. Many mechanisms have been suggested for track formation. Since the phenomena that cause tracks to form are happening at atomic level, also the very short time scale of the interactions involved therein, it becomes a challenging task to suggest and understand accurate mechanisms leading to formation of tracks. Different criteria have seemed plausible for inorganic solids and polymers. Whereas Ion Explosion Spike Model is found more appropriate to account for track formation in inorganic solids, the restricted energy loss fits more appropriately in case of polymers/ organic solids [1]. Many studies have shown that annealing of irradiated SSNTDs results in repair of latent Tracks/ damage. Systematic study of different aspects of Track Annealing is very important. It is so for various applications of dielectric Track Recorders and also for the understanding of track repair kinetics and mechanism that can also throw light on Track Formation Mechanism [5], [6], [7], [8], [9]. Systematic study of Track repair may yield crucial inputs important to understand track formation.

II. Present Study:

Track Etch Rate (V_T) in a Solid State Nuclear Track Detector that contains tracks resulting from passage of energetic charged particles can be expressed as [10]

$V_T = V_B + f$ (1)

[10]

Where V_B is Bulk Etch Rate

and *f* relates to extent of damage which in turn relates to energy loss of charged particles $(\frac{dE}{dx})$

$$V = \frac{V_T}{V_B} = 1 + \frac{f}{V_B} \quad (2)$$

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

If x represents the percentage increase in Bulk Etch Rate and y represents percentage decrease in the *f* term on account of annealing, the track diameter D_1 (after annealing) can be expressed in terms of track diameter D (before annealing) [11] as $D_1 = D\left(1 + \frac{x}{100}\right)\sqrt{\frac{(V+1)\,(100-y)}{V\,(100-y)+2x+y+100}}$ (4)

It has been elaborated earlier [11] that the parameter 'y' which relates only to repair of damage on annealing and on no other parameter can be most appropriate and accurate to evaluate repair of damage quantitatively. In the present study, repair of damage has been quantitatively evaluated in terms of value of y in CR-39 (DOP) and CR-39 (no additive) detectors.

CR-39, it is well known, is a track detector most widely used for its unique features and response.

III. Experimental Details:

CR-39 (DOP) and CR-39 (no additive) detectors, have been obtained from Pershore Mouldings (Worcesteshire, England). DOP (dioctyl phthalate) is an additive. Both detectors have been manufactured using a cure cycle that rises to 90^0C in a rising manner over 32 hours followed by cooling to 40^0C before removal. Detector samples of CR-39 (no additive) and CR-39 (DOP) 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.

IV. Results :

For CR-39 (DOP) annealed at 95^0C for 20 hrs, in the unannealed state of the detector, it is observed

V_B = 0.69 μm/ hr, V = 3.44,
V_T = 2.37 μm/ hr, f = 1.68 μm/ hr

and D = 20.5 μm

Annealing leads to (storage time = 2 hr.)

V_{B1} = 1.3 μm/ hr, V_1 = 2.03,
V_{T1} = 2.64 μm/ hr, f_1 = 1.34 μm/ hr
and D_1 = 30.2 μm

Using the above data in eq. (4),

Percentage change in *f* i.e. y = 20.24%

Hence the term that relates only to damage, on account of annealing, reduces by ~ 20% and thus annealing effect has so far proceeded upto about 20%.

However, change in V_T ~ + 11%
change in V ~ – 41%
and change in D ~ + 47%

No doubt that V_T, V and D are affected by annealing, however, a 20% repair of the damage manifests as ~ + 11% change in V_T, ~ – 41% change in V and ~ + 47% change in D and obviously, it would be more justified to represent the extent of annealing only in terms of y. This example is only representative and the interpretation holds good irrespective of the nature of detector and the annealing/ etching conditions.

Determination of y

We have explicitly expressed the track diameter after annealing in terms of track diameter in the unannealed sample. In any partial stage of annealing and for any annealing temperature – time and etching time combination, the experimentally determined value of track diameter (D1) is substituted in eq. (4) as the case may be and knowing D, V (unannealed state) and x (percentage increase of bulk etch rate on account of annealing), y can be determined. Values of y (extent of annealing) so determined are presented in the Table below for various CR-39 detectors annealed at a fixed temperature 95^0C for various times-5, 10, 15 hours.

TABLE
EXTENT OF ANNEALING (Y) IN DIFFERENT CR-39 DETECTORS FOR POST IRRADIATION ANNEALING AT 95^0C FOR VARIOUS TIMES

Detector Type	Annealing time (hours)	y
CR-39 (without Additive)	5	6.86
	10	13.71
	15	18.04
CR-39 (DOP)	5	1.85
	10	3.70
	15	7.47

V. Conclusion:

Extent of Repair of damage/ Latent tracks has been quantitatively evaluated for CR-39 detectors subjected to annealing. Whereas Bulk Etch Rate, Track Etch Rate Etch Rate Ratio and Track Diameter, all parameters change consequent to annealing and any of these parameters also can represent effect of annealing by this viewpoint, however, each of these parameters also depends on bulk etching properties/ nature of the material and not exclusively and singularly on the damage only. Percentage change of the term that relates only to damage, which itself has the only absolute intrinsic connection with the formation of tracks and is expressed as 'y' quantitatively, and determined above for CR-39 detectors, is the most accurate and faithful evaluation of annealing effect in the purest form. The approach is a general one for application to any SSNTD, be not CR-39 only.

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