ION BEAM MODIFICATION OF MATERIALS
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Aspect ratio of heavy ion tracks in track recording dielectrics

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The fabrication of microelectronic circuits depends upon lithography. The ion track technique has recently been developed as an important lithographic technique. In such applications, the aspect ratio, which is defined as the ratio of the track depth to its diameter, is considered as an important parameter of great significance in three dimensional structures. In the present study, the samples of different track recording dielectrics have been irradiated by different heavy ions at normal incidence in the energy range 4-15 MeV/u and the aspect ratio determined by chemical etching in suitable chemical reagents. The variation of aspect ratio with etching time has been studied and observed that it follows a different trend for different dielectrics.

1. Introduction

Heavy ion tracks find potential applications in many branches of science and technology. Recent studies [1-3] conducted at GSI, Darmstadt, highlight the applications of the ion tracks in lithography and micro-electronics. One of the most important parameters in lithographic technique is the aspect ratio which is defined as the ratio of the track depth (or height) to its diameter (or lateral width). This feature is of great significance in 3-dimensional structures where deep trenches or high ridges are requried.

2. Experimental Technique

The passage of heavy ion tracks through track recording insulators leaves behind a damage trail called a latent track that can be observed directly by an electron microscope or revealed by chemical etching using an optical microscope [4]. For our present invetigations, muscovite mica, CR -39 plastic, soda glass and BP-1 phosphate glass, all known for their track recording characterstics, have been selected and optical microscopy used for the measurement of aspect ratio. The samples of mica (thickness - 200 μm) and CR-39 (thickness - 250 μm) plastic were packed in polythene bags and irradiated from the UNILAC accelerator at GSI, Darmstadt, using ^{14}N (10.83 MeV/u), ^{197}Au (11.4 MeV/u and 13.42 MeV/u), and ^{132}Xe (14.5 MeV/u and 5.9 MeV/u) ion beams up to a fluence of 10^4 ions/cm^2 at normal incidence. Similarly, the samples of soda glass (thickness - 1.4 mm) were irradiated by ^{48}Ti (4.0 MeV/u) and ^{56}Fe(4.0 MeV/u) ions at JINR, Dubna and by ^{139}La (14.6 MeV/u) and ^{238}U (11.4 MeV/u and 5.9 MeV/u) ions at GSI, Darmstadt. BP-1 phosphate glass samples (thickness - 1.3mm) were irradiated by ^{238}U (11.4 MeV/u) ions.

Irradiated samples were etched in the laboratory using standard procedures. Mica samples were etched in 20% HF at room temperature. For CR-39, the alkaline etchant 6.25N NaOH at 70°C was found to be most suitable for revealing the latent tracks [5]. The samples of soda glass were etched in 20% HF at room temperature and BP-1 phosphate glass samples were etched in 48% HF at 50°C. In each case, the test samples were repeatedly etched for prolonged intervals to reveal the full depth of latent ion tracks. The etched samples were first washed in running water for 30 minutes and then dried. Carl Zeiss binocular optical microscope was used for measuring the depth and diameter of tracks. Aspect ratio is determined simply by dividing the depth of etched tracks by its diameter. In case of mica, as the etched tracks are diamond shaped , so diameter is measured along both semi-major and semi-minor axes. Corresspondingly, two values of aspect ratio, A_J and A_N, are obtained and from these two values, the mean value of apsect

Table 1.
Values of diameter, depth and aspect ratio of ^{197}Au(11.4 MeV/u) ion tracks in muscovite mica using 20% HF

Etching time (min)	Track Diameter (μm) Semi-major axis (J)	Semi-minor axis(N)	Mean (M)	Track depth D(μm)	Aspect Ratio A_J(D/J)	A_N(D/N)	A_M(D/M)
30	1.70	1.70	1.70	7.00	4.11	4.11	4.11
50	2.15	1.75	1.95	10.50	4.88	6.00	5.38
70	3.00	2.50	2.75	17.50	5.83	7.00	6.36
90	3.50	2.50	3.00	21.00	6.00	8.40	7.00
110	4.65	3.15	3.90	24.50	5.27	7.79	6.28
130	5.25	3.65	4.45	24.50	4.67	6.71	5.51
150	5.65	4.00	4.83	24.50	4.34	6.13	5.08
170	6.00	4.50	5.25	24.50	4.08	5.44	4.67

Table 2.
Values of diameter, depth and aspect ratio of ^{197}Au(13.42 MeV/u) ion tracks in CR-39 using 6.25N NaOH

Etching time (min)	Track diameter (μm)	Track Depth (μm)	Aspect Ratio
10	1.00	3.50	3.50
20	2.00	7.00	3.50
30	3.00	10.50	3.50
40	4.00	14.00	3.50
50	5.00	17.50	3.50
60	6.00	21.00	3.50
70	7.00	24.50	3.50
80	8.00	28.00	3.50
90	9.00	28.00	3.10
100	10.00	28.00	2.80
110	11.00	28.00	2.55
120	12.00	28.00	2.33

ratio A_M is determined. The tracks in CR-39 plastic and in both types of glasses are circular, so only one value of aspect ratio is determined.

Table 3.
Values of diameter, depth and aspect ratio of ^{238}U (11.4 MeV/u) ion in Soda glass

Etching time (min.)	Track diameter (μm)	Track depth (μm)	Aspect ratio
3	24	35	1.40
4	34	45	1.32
5	41	50	1.26
6	50	50	1.00
7	56	55	0.90
8	62	55	0.88
9	69	60	0.87
10	77	65	0.84
12	93	75	0.81
13	99	75	0.75
15	115	85	0.74

3. Results and Discussion

Table 1 gives the values of aspect ratio for ^{197}Au (11.4 MeV/u) in muscovite mica. The variation of aspect ratio with etching time is

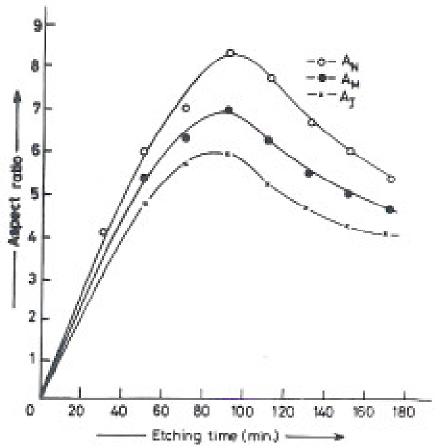

Fig.1. Plot of aspect ratio versus etch time for mica using ^{197}Au (11.4 MeV/u) ion tracks revealed by 20% HF

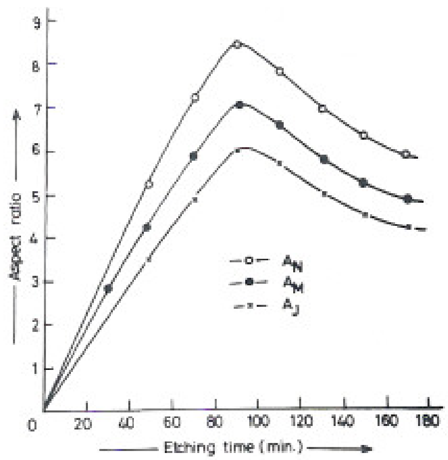

Fig.2 Plot of aspect ratio versus etch time for mica using ^{14}N (10.83 MeV/u) ion tracks revealed by 20% HF.

shown in fig. 1. From this figure, it is clear that the aspect ratio for ^{197}Au ion first increases monotonocally, attains its maximum value, then starts decreasing. A similar behaviour is observed for ^{14}N and other ions (Fig.2). The slow decrease is due to constant increase of diameter of etched track at a rate corresponding to bulk etch rate even when the full track depth is revealed.

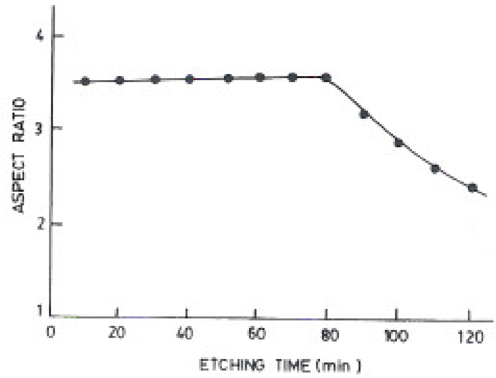

Fig.3. Plot of aspect ratio versus etch time foı CR- 39 using ^{197}Au (13.42 MeV/u) ion tracks revealed by 6.25 N NaOH

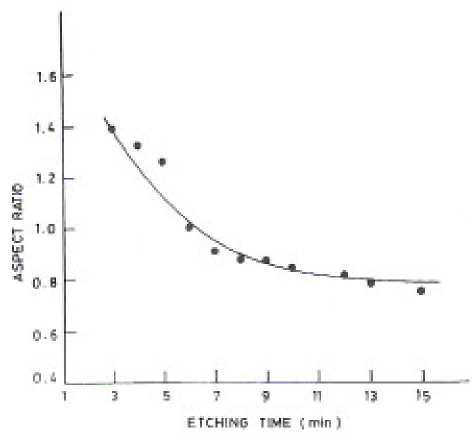

Fig. 4. Plot of aspect ratio versus etch time for soda glass using ^{238}U (11.4 MeV/u) ion tracks revealed by 20% HF.

The behaviour of CR-39 plastic is quite regular. Ion tracks are circular in shape and hence there is only one value of etched track diameter. Moreover, both the track depth and diameter increase linearly with etching time in a regular pattern. As a consequence, the aspect ratio remains constant over a long interval and then starts decreasing after the full depth of etched track is revealed (Fig.3).

Table 4.
Values of diameter, depth and aspect ratio of ^{238}U (11.4 MeV/u) ion in BP-1 phosphate glass

Etching time (min.)	Track diameter (μm)	Track depth (μm)	Aspect ratio
40	4.03	73.26	18.18
80	6.85	80.00	11.67
120	9.00	85.00	9.44
160	11.00	85.00	7.72
200	13.00	90.00	5.92
240	15.00	90.00	6.00
300	18.00	95.00	5.27
360	20.00	95.00	4.75
420	23.00	100.00	4.00
480	25.00	100.00	4.00
540	27.00	100.00	3.70
600	30.00	100.00	3.03

The aspect ratio vlaues for soda glass and BP-1 phosphate glass are given in tables 3 & 4 rspectively. The variation of the aspect ratio with etching time for both the soda glass and BP-1 phosphate glass is shown in figures 4 & 5 respectively. it is revaled that the aspect ratio in both the glasses decreases exponentially with the etching time. The aspect ratio in BP-1 glass is very high in comparison to its value for soda glass.

4. Conclusion

(I) It is interesting to note from aspect ratio data that for different ion tracks in mica, the mean aspect ratios are exactly the same provided the etching conditions are kept the same.

(ii) Although the value of aspect ratio is high for mica, yet its variation is quite.irregular with etching time. Compared with mica, CR-39 plastic has constant value of aspect ratio and hence is a better material for generation of ion track structures which have application in lithography micro-electronics industry.

iii) As the aspect ratio value for BP-1 phosphate glass is very high in comparison to the value for soda-glass, BP-1 phosphate glass can be exploited in microelectronics and material science lithography, with inherent advantage of its better sensitivity in comparison to other glasses.

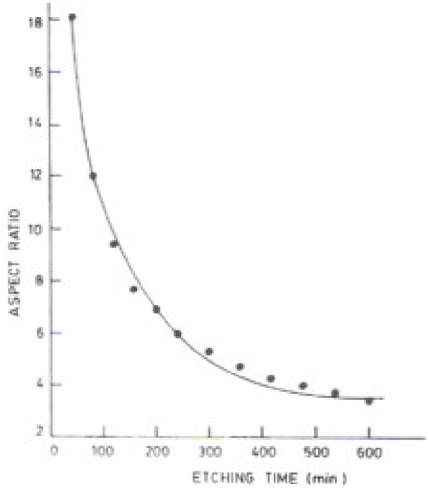

Fig. 5. Plot of aspect ratio versus etch time for BP-1 phosphate glass using ^{238}U (11.4 MeV/u) ion tracks revealed by 48% HF.

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