CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Effects of Concave Etching and Convex Etching on Wafers

The objective of this work is to compare if there is any impact on the quality of the wafers using the standard characterization tools when two different etching methods are used.

In this chapter, the effects of concave and convex etching tested on polished wafer will be discussed on flatness, LPD' s and sub-surface damages. For the lifetime measurement, the wafers in etched form will be discussed.

4.1 Flatness

All the etched wafers which have been polished have equally flat surface. This is because during polishing process, approximately 18 micron thickness of the substrate from the wafer surface are removed. The concave and convex shaped is not seen after polishing. Figure 4.1a – 4.1d shows the wafer mapping after polishing for the concave and convex etched wafer.

Figure 4.1 (e) and (g) show the flatness parameter table for the etched and polished wafer. The total thickness variation (TTV) which is the difference between the maximum and minimum thickness of the wafer for convex etched wafer is higher (2.63 μm for 100mm and 4.38 μm for 125mm wafers) compared to concave etched wafer (1.28μm for

100mm and 1.46μm for 125mm wafers) due to the dome shaped of the wafer surface. The TIR-bf (global total indicator readout best fit) is the sum of difference between the highest point above and below an established focal plane. The best fit represents the least square fit to the front surface of wafer using all points within the flatness quality area which has been described in Chapter 3.

The site measurements taken are 20 x 20 mm for each site (perpendicular to the major flat of the wafer). The reference plane chosen is the back center, the plane that passes through the center of the site that is parallel with the global back reference plane (as shown in Figure 3.7). The rolloff of the wafer is the difference between the thickness of the wafer center and the linearly interpolated center thickness. A positive or a negative value will indicate that the interpolated center thickness is above or below the actual center thickness respectively. The rolloff is graphically shown in Figure 3.9.

For all the flatness parameter measured, the convex etched wafer has higher flatness deviation compared to concave etched. This can be explained by the dome shaped wafer due to the convex etcher (Figure 2.1 (e) and 2.1 (f)). However, as seen in Figure 4.1(h) and 4.1 (f), the after polished flatness parameter of both etchants for both diameters shows no significant deviation from each other. This is due to the polishing process which removes approximately 18 microns, where the etching effect on the wafers are eliminated.

Figure 4.1 (i and j) shows the flatness capability in terms of percentage cumulation (sorted pareto in accumulation percentage in terms of yield) for TTV (both for 100mm and 125mm wafer) while Figure 4.1k and 4.1l) show the STIR. TTV and STIR are chosen because they are among the most popular flatness parameters selected by the customer. For the specification of TTV at 2.5μm, 100mm wafer for polished convex etched wafer gives a yield of only 60% compared to polished concave etched wafer which is about 81%. For the same specification, 125mm polish convex etched wafer will yield 74% compared to 81% for the polished concave etched wafer.

The high capability in flatness for the polished concave etched on both diameters can be explained by the thickness distribution of the etched wafers. As shown in Figure 4.1m and 4.1n, if the wafers within the block have same thickness, the removal will be uniform and both the wafers will have a very flat surface after polishing. However, if the wafer thickness varies highly within the block, the wafers will then be tapered after polished. This is due to the non –uniform removal. In this case, wafer A will have higher removal than wafer B. Figure 4.1 (q) show the center thickness distribution for the 125mm concave and convex etched wafer. The convex etched wafer has larger thickness distribution (3 Sigma = 7.14μ) compared to concave etched (3 Sigma = 4.44μ). Therefore, thickness of wafer on the polishing block for convex etched wafers varies significantly compared to concave etched and will result in lower flatness capability after polishing. Figure 4.1r shows the wafer flatness for the polished concave and convex etched wafer. The same reasoning can be used for the 100 mm diameter also as seen in Figure 4.1 (s) and 4.1 (t). For the 100mm convex etched wafers (Figure 4.1 (s)), the

Gaussian distribution is not observed for the thickness. This could be due to the impact of earlier process of slicing and lapping. The slicing thickness and lapping removal has a wide acceptable tolerance limit from the target thickness because the number of wafers processed per cycle is less (15-30) compared to etching process (50 wafers). If the thickness variation after lapping is large, the thickness after etching process is also large even though the etching rate is constant.

For STIR, if the customer requires a specification of 0.5 μm, 100mm polished convex etched wafer yield is only 46.3% compared to 65.2% for polished concave etched wafer. For 125mm wafer, the yield for polished convex etched wafer is 73.5% compared to 86.5% for polished concave etched wafer.

Therefore, significant yield improvement can be obtained if the etch thickness to polishing has smaller distribution. Concave etched wafers is therefore favorable compared to convex etched wafer. The box -whiskers plot in Appendix C shows the overall result of flatness distribution for the wafers tested.

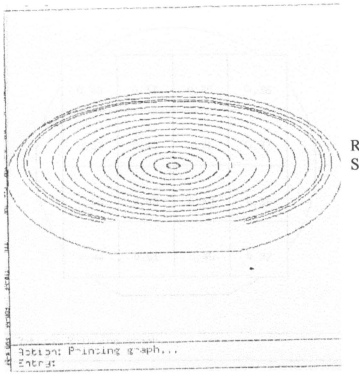


Figure 4.1 (a) Wafer Mapping of 100mm Concave Etched Wafer After Polish

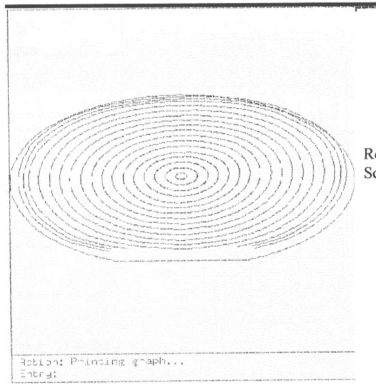


Figure 4.1 (b) Wafer Mapping of 125mm Concave Etched Wafer After Polish

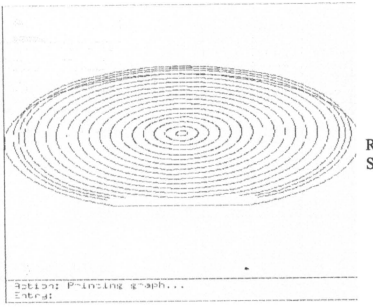


Figure 4.1 (c) Wafer Mapping of 125mm Convex Etched Wafer After Polish

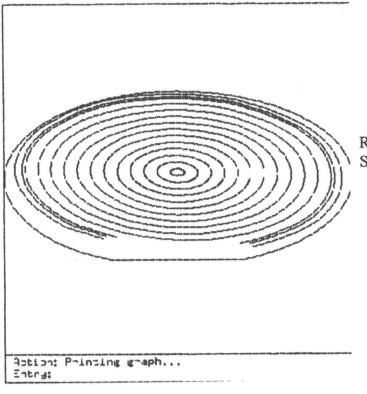


Figure 4.1 (d) Wafer Mapping of 100 mm Convex Etched Wafer After Polish

Diameter 100mm		Cen.Thck	TTV	TIRBF	SFPD	STIR	TAPER	ROLLOFF	n
Convex Etched wafer	Ave	543.61	2.63	2.39	1.01	1.85	-0.19	1.81	100
	Std	3.02	0.45	0.45	0.79	0.31	0.61	0.70	
Concave Etched Wafer	Ave	543.44	1.28	0.85	-0.10	0.80	-0.12	-0.03	100
	Std	2.75	0.25	0.23	0.61	0.20	0.61	0.27	

Figure 4.1 (e) Flatness Parameter Table for 100mm Diameter Wafer Before Polishing

Diameter 100mm		Cen.Thck	TTV	TIRBF	SFPD	STIR	TAPER	ROLLOFF	n
Convex Etched Polish Wafer	Ave	526.81	2.17	0.34	-0.14	0.74	1.82	-0.05	100
	Std	3.20	0.97	0.08	0.45	0.29	0.97	0.15	
Concave Etched Polished Wafer	Ave	528.13	1.90	0.37	-0.09	0.68	1.51	-0.09	100
	Std	2.61	1.05	0.15	0.44	0.34	1.10	0.15	

Figure 4.1 (f) Flatness Parameter Table for 100mm Diameter Wafer After Polishing

Diameter 125mm		Cen.Thick	TTV	TIRBF	SFPD	STIR	TAPER	ROLLOFF
Convex Etched wafer	Ave	643.00	4.38	4.27	1.95	2.95	-0.29	3.70
	Std	2.38	0.38	0.35	0.16	0.27	0.40	0.35
Concave Etched Wafer	Ave	646.41	1.46	0.90	-0.19	0.83	-0.47	0.01
	Std	1.48	0.25	0.21	0.60	0.20	0.60	0.22

Figure 4.1 (g) Flatness Parameter Table for 125mm Diameter Wafer Before Polishing

Diameter 125mm		Cen.Thick	TTV	TIRBF	SFPD	STIR	TAPER	ROLLOFF
Convex Etched Polish Wafer	Ave	627.51	1.97	0.61	0.02	0.67	1.06	0.08
	Std	2.27	1.29	0.19	0.46	0.29	1.61	0.28
Concave Etched Polished Wafer	Ave	633.15	1.52	0.50	-0.05	0.51	0.80	-0.07
	Std	1.24	1.08	0.16	0.35	0.29	1.36	0.23

Figure 4.1 (h) Flatness Parameter Table for 125mm Diameter Wafer After Polishing

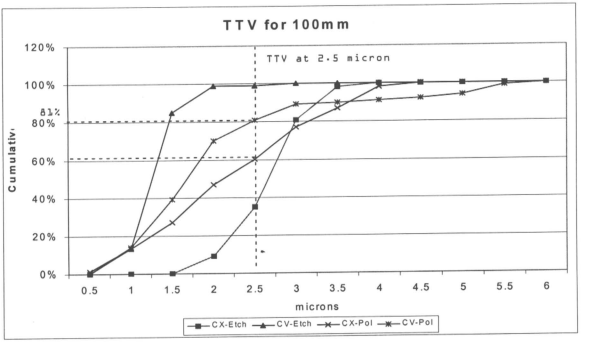


Figure 4.1(i) Cumulative chart for TTV (100mm)

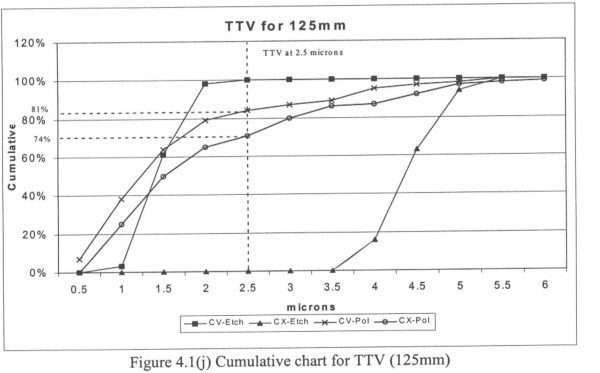


Figure 4.1(j) Cumulative chart for TTV (125mm)

Legend

CV-Etch = Concave Etched wafer before polish
CX-Etch = Convex Etched wafer before polish
CV-Pol = Concave Etched wafer after polish
CX-Pol = Convex Etched wafer after polish

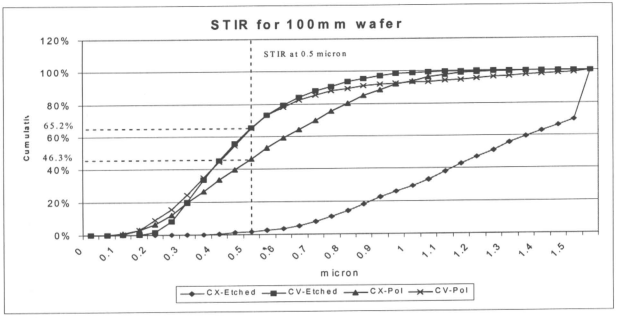


Figure 4.1(k) Cumulative chart for TTV (100 mm)

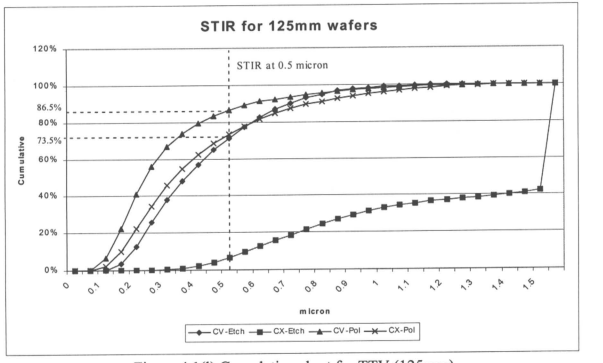


Figure 4.1(l) Cumulative chart for TTV (125mm)

Legend

CV-Etch = Concave Etched wafer before polish
CX-Etch = Convex Etched wafer before polish
CV-Pol = Concave Etched wafer after polish
CX-Pol = Convex Etched wafer after polish

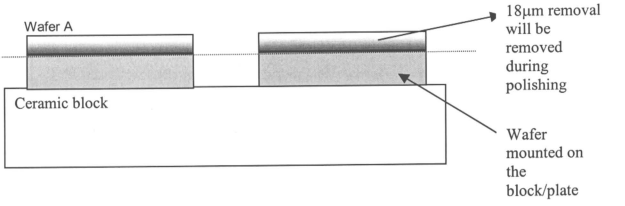


Figure 4.1 (m) Wafers on the ceramic block before polished. The wafer thickness are the same.

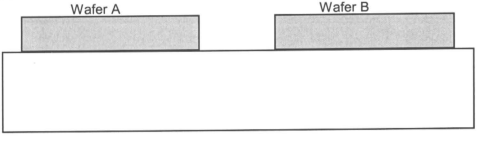


Figure 4.1 (n) After polished, wafer is very flat due to uniform removal.

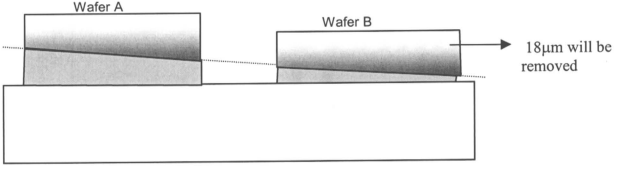


Figure 4.1 (o) Wafers with high thickness variation before polish (thickness wafer A > wafer B)

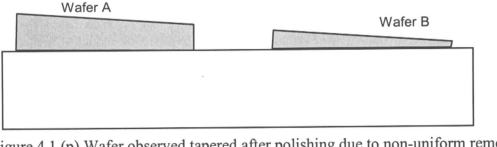


Figure 4.1 (p) Wafer observed tapered after polishing due to non-uniform removal

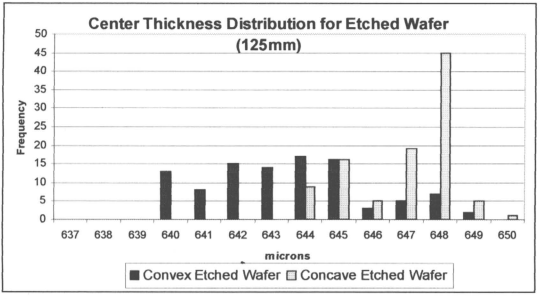


Figure 4.1 (q) Center Thickness Distribution for 125mm Concave and Convex Etched wafer. Convex etched wafer has larger thickness distribution compared to concave etched.

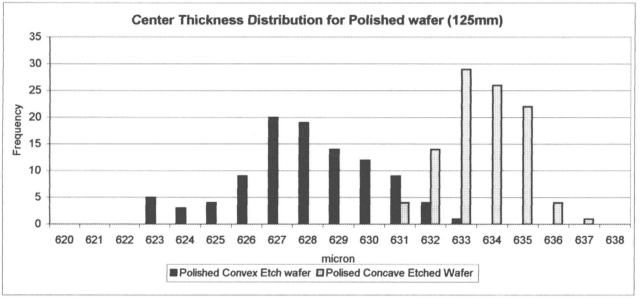


Figure 4.1 (r) Center Thickness Distribution for 125mm Polished Concave and Convex Etched wafer. Polished convex etched wafer has larger thickness distribution compared to polished concave etched wafer.

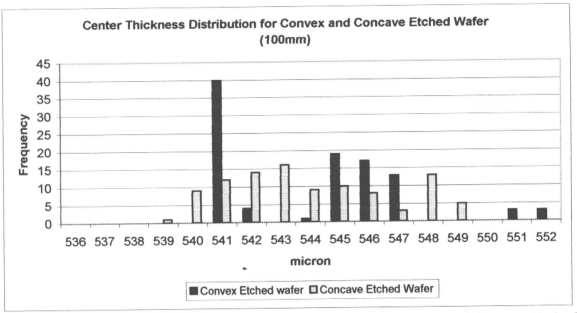


Figure 4.1 (s) Center Thickness Distribution for 100mm Concave and Convex Etched wafer. Convex etched wafer has larger thickness distribution compared to concave etched.

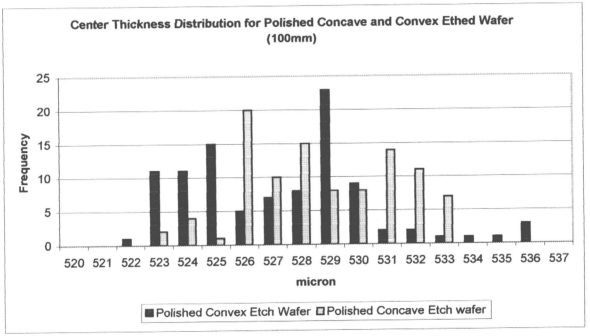


Figure 4.1 (t) Center Thickness Distribution for 100mm Polished Concave and Convex Etched wafer. Polished convex etched wafer has larger thickness distribution compared to polished concave etched wafer.

4.2 Light point Defects (LPDs) and Haze

Figure 4.2 a and 4.2b shows the LPD and Haze measurement done using the CR80 for the polished convex and concave etched wafer. Five wafers for each diameter were used for this measurement. The results show that the LPD (maximum 1000 counts at 0.13 μm) and Haze (<2 ppm) are still within internal specification when comparing between the polished convex etched and concave etched wafers. This is because the particles or the microroughness measured here are directly linked to the polishing condition of the polishers and cleaning (the polishing pad lifetime, polishing workpiece temperature, cleaning with SC1 or the scrubbing process). The LPD's for 100mm for particle size at 0.13μm averages at 27 and 20 counts for concave etched and convex etched respectively and for 125mm, they are at 109 counts and 164 counts respectively. The difference between the counts for 100mm and 125mm are due to different equipment (polishers and scrubbers) specifically optimized for them and also the difference in their process condition. Variation of the average counts for all particle sizes for 125mm wafer is observed, however, they are still within the specification (maximum 1000 counts) for normal process. Figure 4.2c and 4.2 f show the wafer mapping obtained from the CR80 in 2-D and 3-D for particles and haze.

		Particle Size (microns)								Haze/
	N	0.12	0.13	0.16	0.18	0.2	0.3	0.5	0.7	ppm
Concave Etch 100mm Polish wafer	1	24	13	6	5	5	1	0	0	0.982
	2	25	13	5	2	2	0	0	0	0.99
	3	23	15	2	1	1	1	1	1	0.957
	4	85	77	51	32	21	6	5	1	1.017
	5	34	18	3	2	2	0	0	0	1.008
	Average	38.2	27.2	13.4	8.4	6.2	1.6	1.2	0.4	0.9908
Convex Etch 100mm Polish Wafer	6	25	17	9	5	4	1	0	0	0.995
	7	34	18	7	5	5	2	0	0	1.003
	8	25	19	10	8	4	4	3	1	1.009
	9	30	22	13	8	7	2	1	0	1.0013
	10	31	24	15	11	6	2	2	0	1.0014
	Average	29	20	10.8	7.4	5.2	2.2	1.2	0.2	1.0019

Figure 4.2 (a) The LPD counts for 100mm wafers

		Particle Size (microns)								Haze/
	N	0.12	0.13	0.16	0.18	0.2	0.3	0.5	0.7	ppm
Convex Etch 125mm Polish wafer	1	137	81	7	5	5	3	2	2	1.13
	2	232	177	8	4	3	2	2	1	1.127
	3	269	223	10	2	1	0	0	0	1.127
	4	267	173	15	7	2	1	0	0	1.177
	5	212	168	7	3	3	1	1	1	1.2
	Average	223.4	164.4	9.4	4.2	2.8	1.4	1	0.8	1.1522
Concave Etch 125mm Polish wafer	6	200	153	7	2	1	0	0	0	1.14
	7	157	131	48	26	12	6	4	3	1.114
	8	109	76	11	7	6	3	3	2	1.117
	9	131	100	15	6	5	1	0	0	1.125
	10	133	88	12	11	8	4	2	1	1.114
	Average	146	109.6	18.6	10.4	6.4	2.8	1.8	1.2	1.122

Figure 4.2 (b) The LPD counts for 125mm wafers

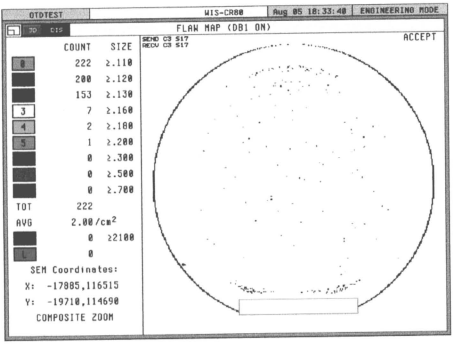


Figure 4.2c The LPD map of concave etch 125 wafer in 2D from CR80

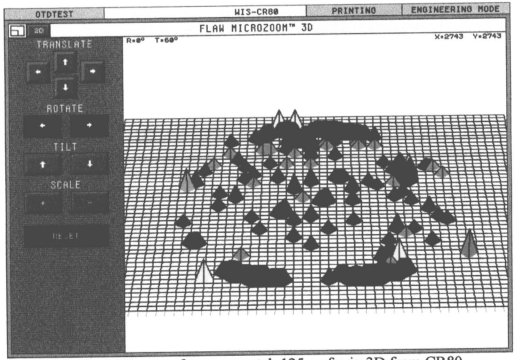


Figure 4.2 (d) The LPD map of concave etch 125 wafer in 3D from CR80

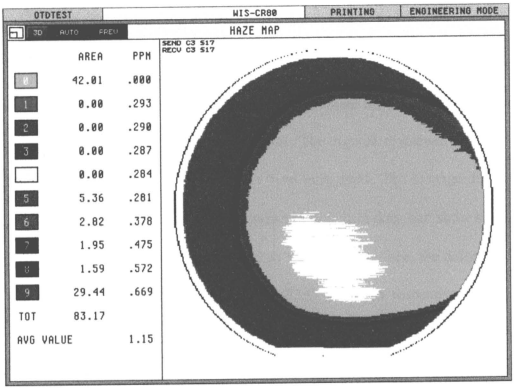


Figure 4.2 (e) The Haze map of concave etch 125 wafer in 2D from CR80

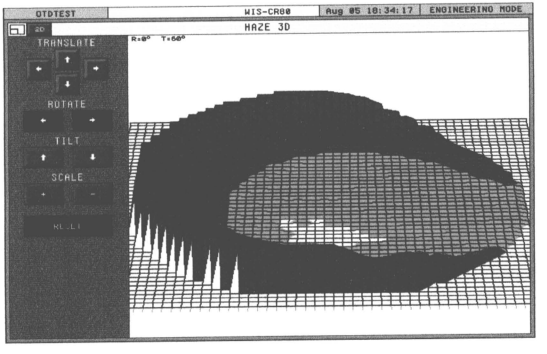


Figure 4.2 (f) The Haze map of concave etch 125 wafer in 3D from CR80

4.3 Sub-Surface damages (OSDA)

Figure 4.3 (a) and 4.3 (b) shows the OSDA measurement on the polished concave and convex etched wafer for 100mm and 125mm. The figures displayed are the defects counts for surface < 0.5μm and from 0.5 to 5μm bulk depth. The average defect counts for both 125mm and 100mm wafers for depths below 0.5μm does not show a significant difference. However, for depth between 0.5 to 5 μm from surface, the defect counts for 125mm between convex and concave etched (7335 and 6065 respectively) differ from 100 mm (15088 and 15330 respectively). These again, could be linked to different process conditions between 100mm and 125mm wafers. The standard deviation varies largely due to the high defect counts seen on some wafers. These variations exist because the polishing process has a removal tolerance of (18 ± 4) micron. Therefore higher removal (>18 micron) will remove more sub-surface damage compared to lower removal. Also from the OSDA mapping attached (Figure 4.3 c to 4.3 f), streak pattern is observed on the surface. This could be caused by chemical residue due to insufficient drying, more to cleaning related and not the etching process itself. Hence, the OSDA measurements can be better used as a comparison for investigation and not as a statistical analysis.

	Convex Etching			
	125mm <1-0-0>		100mm <1-0-0>	
Depths	0.5um	5um	0.5um	5um
Defect counts	311410	3881	303809	15808
	319612	5515	307084	15454
	323030	5738	296821	15969
	264537	6785	336976	14123
	276312	14759	318644	14088
Average	298980	7336	312667	15088
Std. Dev	25852	3837	14943	827

Figure 4.3(a) OSDA measurement of defects counts over depth for Convex Etching

	Concave Etching			
	125mm <1-0-0>		100mm <1-0-0>	
Depths	0.5um	5um	0.5um	5um
Defect counts	239164	11470	337105	15190
	283914	12934	318664	17819
	187313	1471	307914	15781
	361970	3373	305419	15586
	257613	1078	315607	12276
Average	265995	6065	316942	15330
Std. Dev.	62549	4862	5868	1987

Figure 4.3(b) OSDA measurement of defects counts over depth for Concave Etching

Convex etching,

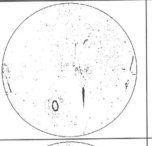
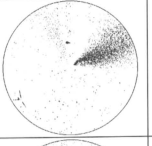
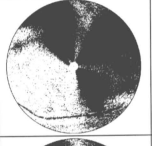
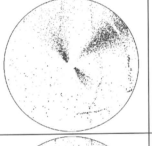
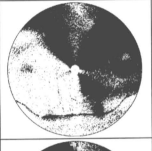
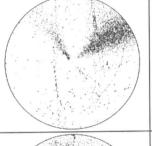
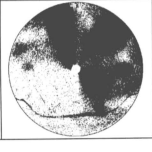
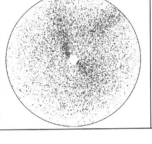
	125mm, <1-0-0>		
	Surface ~ 0.5 μm depth Trigger Level: 1200	0.5 ~ 5 μm depth in bulk Trigger Level: 1600	Defect counts
Wafer No 1			0.5 μm: 311410 5 μm: 3881
Wafer No 2			0.5 μm: 319612 5 μm: 5515
Wafer No 3			0.5 μm: 323030 5 μm: 5738
Wafer No 4			0.5 μm: 264537 5 μm: 6785
Wafer no 5			0.5 μm: 276312 5 μm: 14759

Figure 4.3c OSDA mapping for polished convex etched 125mm wafer.

Convex etching,

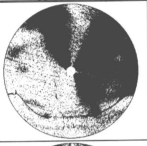
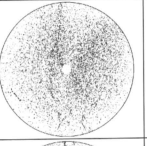
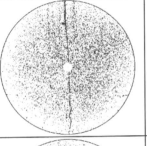
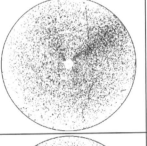
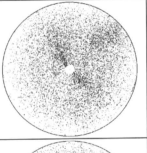
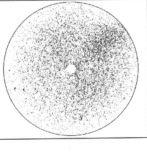
	100mm <1-0-0>		
	Surface ~ 0.5 μm depth Trigger Level: 1200	0.5 ~ 5 μm depth in bulk Trigger Level: 1600	Defect counts
Wafer No 1			0.5 μm: 303809 5 μm: 15808
Wafer No 2			0.5 μm: 307084 5 μm: 15454
Wafer No 3			0.5 μm: 296821 5 μm: 15969
Wafer No 4			0.5 μm: 336976 5 μm: 14123
Wafer no 5			0.5 μm: 318644 5 μm: 14088

Figure 4.3(d) OSDA mapping for polished convex etched 100mm wafer.

Concave etching,

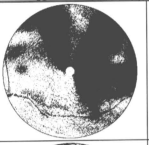
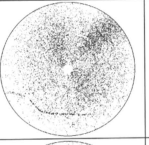
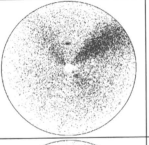
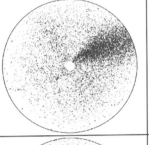
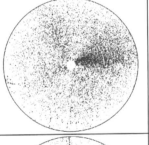
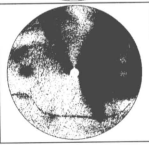
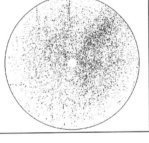
	100mm <1-0-0>		
	Surface ~ 0.5 μm depth Trigger Level: 1200	0.5 ~ 5 μm depth in bulk Trigger Level: 1600	Defect counts
Wafer No 1			0.5 μm: 337105 5 μm: 15190
Wafer No 2			0.5 μm: 318664 5 μm: 17819
Wafer No 3			0.5 μm: 307914 5 μm: 15781
Wafer No 4			0.5 μm: 305419 5 μm: 15586
Wafer no 5			0.5 μm: 315607 5 μm: 12276

Figure 4.3e OSDA mapping for Concave etched polished wafer for 100mm

Concave etching,

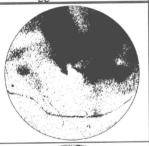
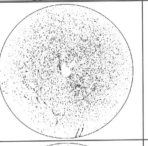
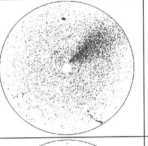
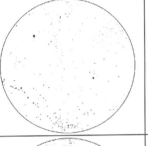
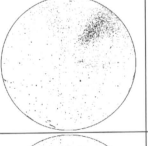
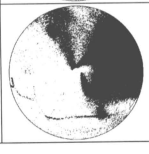
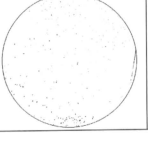
125mm, <1-0-0>			
	Surface ~ 0.5 μm depth Trigger Level: 1200	0.5 ~ 5 μm depth in bulk Trigger Level: 1600	Defect counts
Wafer No 1			0.5 μm: 239164 5 μm: 11470
Wafer No 2			0.5 μm: 283914 5 μm: 12934
Wafer No 3			0.5 μm: 187313 5 μm: 1471
Wafer No 4			0.5 μm: 361970 5 μm: 3373
Wafer no 5			0.5 μm: 257613 5 μm: 1078

Figure 4.3f OSDA mapping for polished concave etched 125mm wafer.

4.4 Lifetime measurement using EELYMAT

For the lifetime measurements of minority carriers using ELYMAT, only 125mm of p type with resistivity ranging between 10-20 ohms cm were used. These etched wafers from convex and concave etchers were surface passivate using SC1 cleaning chemistry. These wafers were then subjected to the tube heat treatment whereby they were annealed at 650 degrees Celsius for about 20 minutes.

Figure 4.4 a shows the lifetime measurements of both convex and concave etched wafers. For the 125mm wafer, five samples were used. The average lifetime recorded for concave etched wafers is 381.7μs and for the convex etched wafers is about 374.8μs. No significant changes in the lifetime was observed and fits the internal specification of more than 200μs. This is because lifetime measurements is affected if there are any contaminants or vacancies in the bulk of the wafer and not influenced by the surface morphology of the wafers due to the etching properties. The lifetime mapping for convex etched and concave etched wafers is shown in Figure 4.4 b and 4.4c.

N	Convex Etched	Concave Etched
1	455.2	296.5
2	390.4	425.1
3	257.1	515.4
4	420.4	385.6
5	350.8	286.1
Average	**374.8**	**381.7**
Std	**76.2**	**95.1**

Figure 4.4 (a) Lifetime of minority carriers measured using ELYMAT for 125mm wafers.

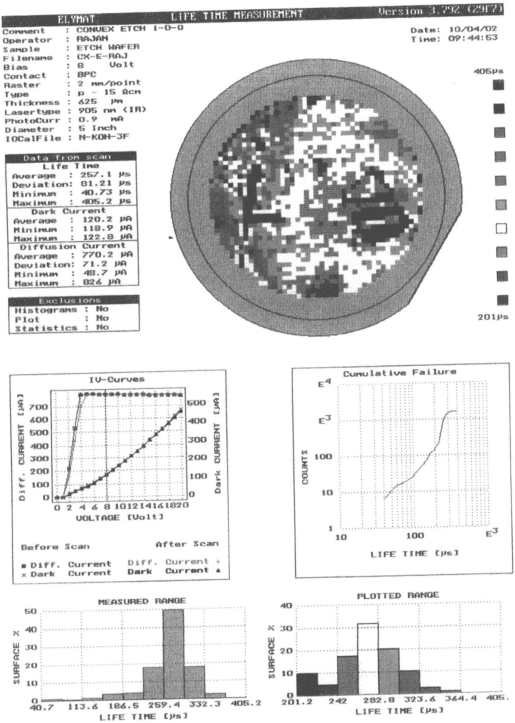


Figure 4.4 (b) Lifetime for Convex Etched wafer

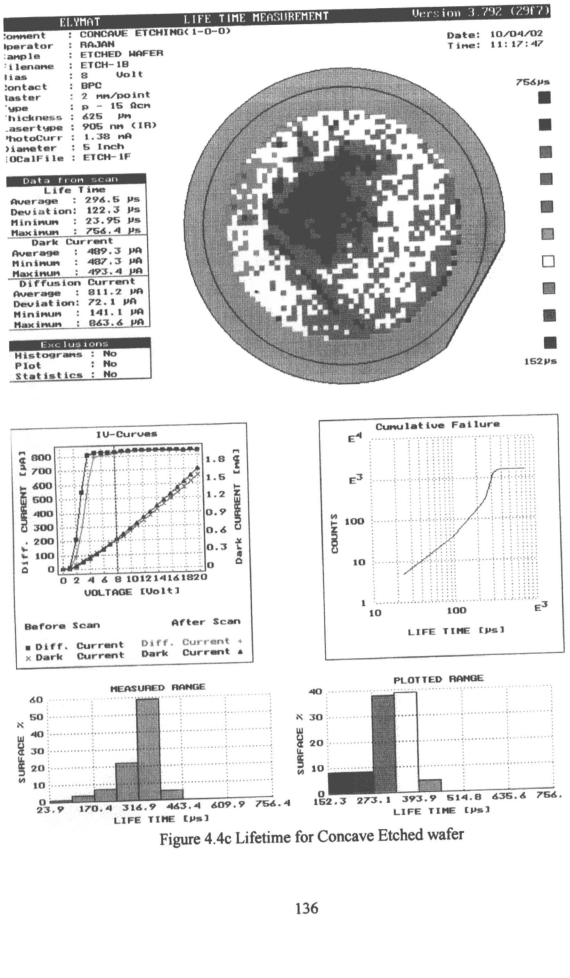


Figure 4.4c Lifetime for Concave Etched wafer