Chapter 3

.1 Equipment

The equipment used for the minority carrier lifetime measurement is ELYMAT. As explained in Chapter 2, section 2.2, the ELYMAT uses electrolyte contacts such as dilute HF. This technique can be used on bare silicon wafers to obtain the bulk recombination lifetime. In this technique, minority carriers are generated by a scanned laser beam with a lateral resolution of 1 mm. The parameter measured is the photocurrent induced in a collection junction, either on the illuminated frontside of the wafer in the frontside photocurrent (FPC) mode or on the backside of the wafer in the backside photocurrent (BPC) mode. This equipment is able to measure the minority carrier lifetime (τ) as well as the diffusion length (L) where their relationship is given as

$$L = (D\tau)^{1/2}$$ where D being the diffusion constant.

Minority carrier lifetime is a very sensitive parameter for crystallographic defects for recombination centers : τ is theoretically in order of hours for ideally pure and perfect silicon crystals and 7 to 9 orders of magnitude lower with processed wafers. A contamination level in the order of 10^{12} interstitial Fe atoms per cm^3 (less than 0.1 ppb) would result, according to Shockley-Read-Hall theory, in a recombination lifetime of 10^{-6} seconds corresponding to a diffusion length of roughly 100 μm for p-type silicon wafers. This contamination level is typical for today's wafer processing. It can be extrapolated that diffusion length in order of millimeters will have to be measured in order to account for the extremely low contamination levels to be controlled in the future. A competing mechanism to minority carrier recombination in the bulk of the wafer is their recombination at the surface. This effect may dominate the overall recombination and thus obscure the desired information. Especially, for diffusion length to be measured from the above considerations, which can be considerably larger than the wafer thickness itself, it is indispensable to suppress surface recombination by appropriate surface conditioning. One way is to thermally oxidize the wafers resulting in negligible recombination at the oxide-silicon interface. The ELYMAT uses the electrolyte contacts to suppress surface recombination..

This Chapter will described in detail of the experimental technique using the ELYMAT and subsequently, the result of the real lifetime measurements for bare silicon wafers; its relationship with resisitivity, heat treatment cycle-time and temperature and also the wafer's oxygen content which is believed to have a direct impact on wafer's minority carrier lifetime.

3.0.1 Procedures

The following procedure describes how to measure wafers using the ELYMAT Wafer Measurement System. The equipment consists of :

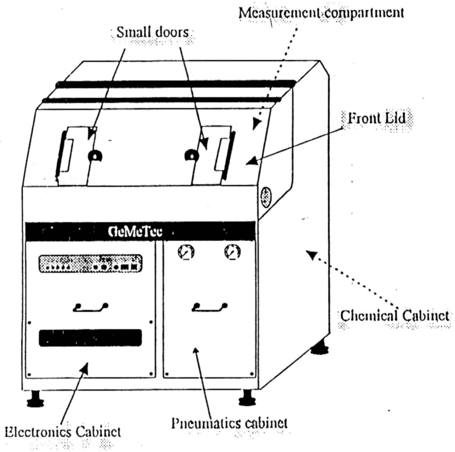
1. ELYMAT II - measuring chamber.
2. Computer HP Vectra 486/66 MHz.
3. Printer HP Desk Jet 660C

A vacuum pencil or wand is needed for the loading and unloading of wafers onto the fixture of the measuring chamber. The equipment uses 1 % HF solution. The solution and fumes are contained in the instrument however, safety awareness need to be taken whenever the chamber door is opened. There is a safety interlock to protect the user from laser radiation. It functions in such a way that whenever the chamber door is opened, the laser beam will be automatically shuts off. Fig. 3.3 shows the ELYMAT II instrument. Fig. 3.4 shows the schematics of the measurement compartment and the schematics of the configuration of the laser/scanner unit.

1 Minority Carrier Lifetime vs Wafer Resistivity

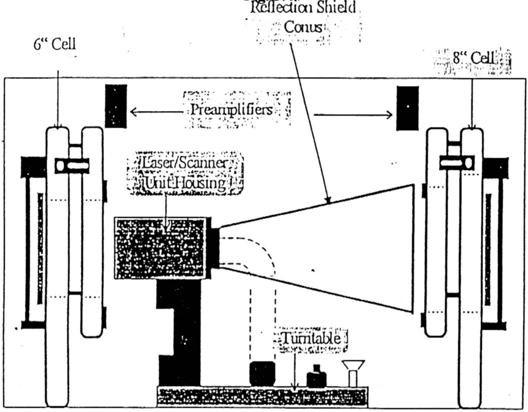
Since it is unclear whether the minority carrier lifetime measurement of ELYMAT is destructive or non-destructive, only 10 sets of wafers were taken from the production for this study which were taken after the annealing process where the wafers were heat treated at a temperature of 650^{o}C using ultraclean nitrogen gas. Prior to the heat treatment process, these wafers were surface passivate using the SCI cleaning chemistry after etching. Sample taken were 4" wafer of p-type and 1-0-0 orientation. Fig. 3.5 shows the relationship of minority carrier lifetime with resistivity at 2 different heat treatment temperatures i.e. at 650^{o}C and 1100^{o}C. The wafer's resistivity is not influenced by the heat treatment temperature. However, the minority carrier lifetime is showing an inverse relationship with temperature; at 650^{o}C the result shows that minority carrier lifetime is directly proportional to wafer resistivity but at 1100^{o}C, it is the reverse. The result also indicates that the magnitude of minority carrier lifetime decreases, significantly with heat treatment temperature. This could be resulted from more impurities being diffused into the wafer during high

Fig. 3.3

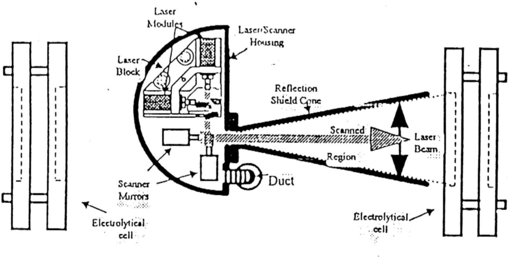


Overview on ELYMAT equipment.

Fig. 3.4.

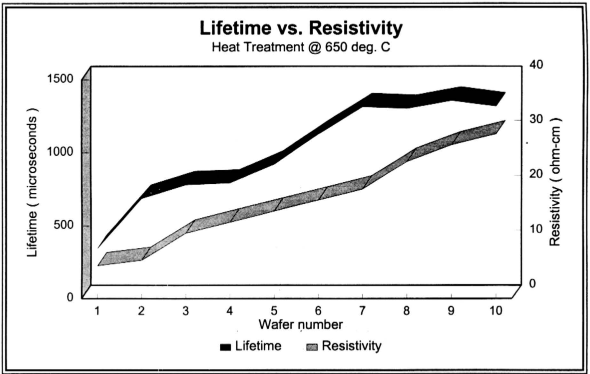


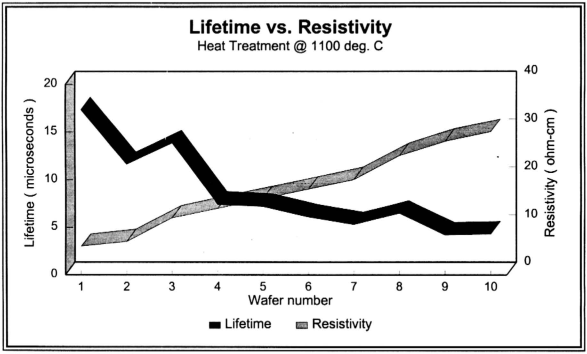
Schematics of the Measurement Compartment under the Front Lid.



Schematic of the configuration of the Laser/Scanner Unit; the Electrolytical Double Cells are also shown for completeness.

Fig. 3.5





umber	1	2	3	4	5	6	7	8	9	10
y (ohm-cm)	6	7	12	14	16	18	20	25	28	30
me (microsec.) @ 650 deg. C	345.3	687.1	780.0	791.8	920.4	1125.7	1314.6	1302.4	1356.7	1317.2
me (microsec.) @ 1100 deg. C	17.3	11.6	13.8	7.4	7.2	6.1	5.3	6.5	4.2	4.3

temperature heat treatment. Therefore, this conclude that the heat treatment temperature is crucial and an optimum heat treatment is necessary to obtain high wafer minority carrier lifetime. We can also deduce that the minority carrier lifetime is directly proportional to the wafer's resistivity only at certain heat treatment temperature i.e. for this experiment is at 650^{o}C. Therefore, highly doped wafers such as N+ and P+ type which have resistivity of below 1 ohm-cm will have very low minority carrier lifetime. This is clearly shown on the lifetime mapping of Fig. 3.6. These wafers will have an application for high switching devices.

.2 Minority carrier lifetime vs. heat treatment time

The objective of this experiment is to understand the relationship of minority carrier lifetime versus the heat treatment time. Each heat treatment cycle time is 20 minute @ 650^{o}C. Ultraclean nitrogen gas is being used during this process. Since it is not known whether the minority carrier lifetime measurement by ELYMAT is a destructive or non-destructive test, therefore only 10 sets of wafers which were from the same ingot and had gone through the same process cycles before heat treatment were taken. These wafers were 4" diameter, p-type, 1-0-0 and resistivity of 6 ohm-cm. Fig. 3.7 shows the relationship of wafer minority carrier lifetime versus heat treatment time. The minority carrier lifetime is inversely proportional to the heat treatment time at 650^{o}C. The longer the wafer sits in the heat treatment furnace, the more impurities are able to be diffused or driven into the wafer which will degraded the minority carrier lifetime. Similar to the heat treatment temperature, the optimum heat treatment processing time is also critical. As mentioned above and shown in Fig. 3.5, the

Fig. 3.6

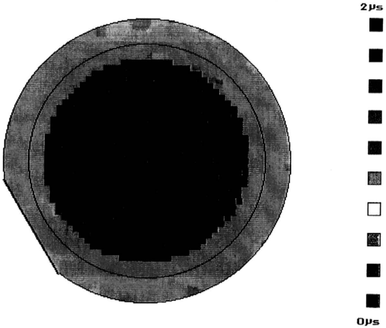
ELYMAT LIFE TIME MEASUREMENT Version 3.788 (29f7)

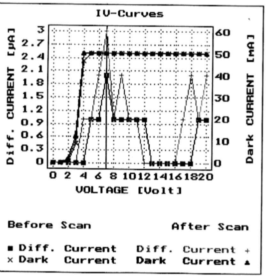
Comment : N+ TYPE : 1-1-1
Operator : SHAMSUL
Sample : SAS-UY-394
Filename : POL1BPC
Bias : 7 Volt
Contact : BPC
Raster : 2 mm/point
Type : p - 1 Ωcm
Thickness : 525 μm
Lasertype : 905 nm (IR)
PhotoCurr : 0.48 mA
Diameter : 4 Inch

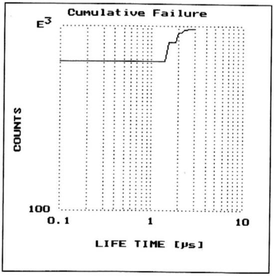
Date: 03/12/96
Time: 15:29:37

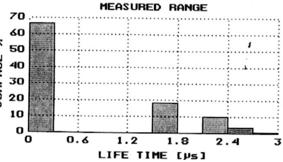
Data from scan	
Life Time	
Average	: 1.326 μs
Deviation	: 0.813 μs
Minimum	: 0 μs
Maximum	: 2.071 μs
Dark Current	
Average	: 50469 μA
Minimum	: 50463 μA
Maximum	: 50473 μA
Diffusion Current	
Average	: 0 μA
Deviation	: 1 μA
Minimum	: 0 μA
Maximum	: 2 μA

Exclusions	
Histograms	: No
Plot	: No
Statistics	: Yes









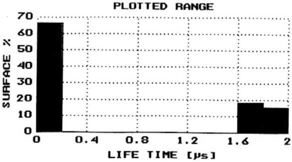
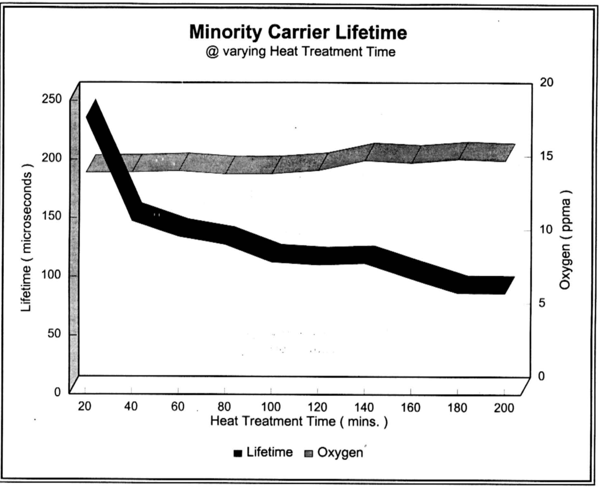


Fig. 3.7

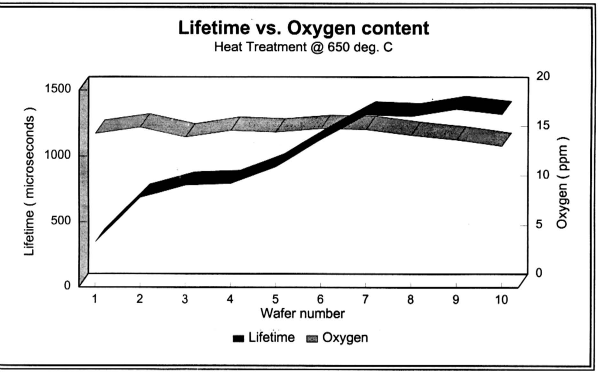


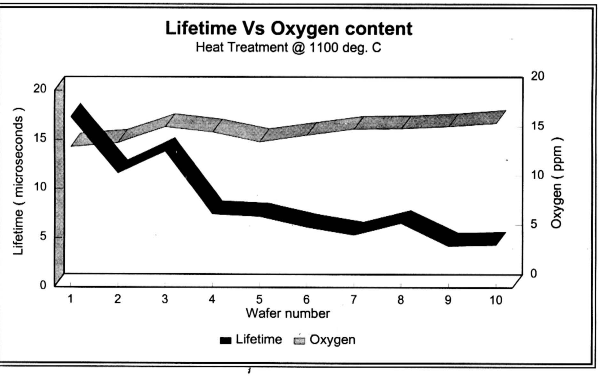
umber	1	2	3	4	5	6	7	8	9	10
atment time (mins.)	20	40	60	80	100	120	140	160	180	200
me (microsec.)	235.7	147.4	134.1	127.4	112.5	110.2	111.6	98.9	86.4	86.1
ppm)	15.08	15.12	15.22	15.00	15.02	15.25	15.93	15.76	16.01	15.89

minority carrier lifetime is inversely proportional to heat treatment temperature. One of the factor that will have a direct significant affect on minority carrier lifetime is wafer oxygen content. Fig. 3.8 show the relationship of oxygen content with minority carrier lifetime. The wafer oxygen content is measured using a DIGILAB 4000 FTIR by BioRad. This is equipment is capable of measuring oxygen and carbon content of bare silicon wafer. Since oxygen content in a wafer is a controlled parameter, which is normally specified by customer at a range of 14 - 18 ppm, the result does not significantly indicate that there exist a relationship between the wafer minority carrier lifetime and the oxygen content. With the oxygen content being constant, the minority carrier lifetime varies greatly with heat treatment temperature. Therefore, heat treatment process is critical in controlling the wafer minority carrier lifetime.

Fig. 3.9 and 4.0 is a typical example of minority carrier lifetime maps of bare silicon wafers obtained from two heat treatment processes. At 1100^{o} C, the lifetime map shows a significant ' ring ' like pattern on the wafer surface whereby the center of the ring pattern shows the highest lifetime value and towards the edges of the wafer, one will observed a degradation in the minority carrier lifetime. This is believed to be contributed to the crystal pulling process whereby the centrifugal force during crystal pulling had dispersed the impurities towards the wafer edges as demonstrated in Fig. 4.1. Upon shaping the crystal rod into wafers, the impurities ' ring-like ' distribution pattern is more prominent. This pattern is obvious when the wafers were heat treated at temperature of 1100^{o} C. From this result, we can conclude or expect to observed lower minority carrier lifetime at the edges of the wafers.

Fig. 3.8





umber	1	2	3	4	5	6	7	8	9	10
ime (microsec.) @ 650 deg. C	345.3	687.1	780.0	791.8	920.4	1125.7	1314.6	1302.4	1356.7	1317.2
(ppm) @ 650 deg. C	15.60	16.25	15.25	15.93	15.76	16.12	16.03	15.45	14.98	14.34
ime (microsec.) @ 1100 deg. C	17.3	11.6	13.8	7.4	7.2	6.1	5.3	6.5	4.2	4.3
(ppm) @ 1100 deg. C	14.28	14.69	16.29	15.76	14.78	15.45	16.09	16.12	16.34	16.7

Fig. 3.9

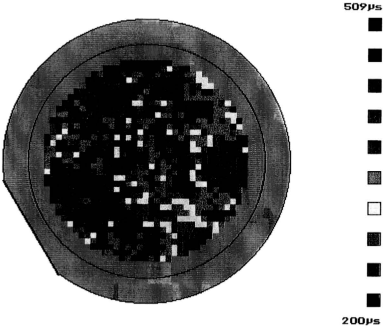
ELYMAT LIFE TIME MEASUREMENT Version 3.788 (29f7)

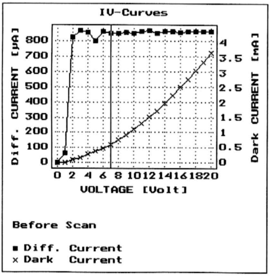
Comment : P TYPE : 1-0-0
Operator : SHAMSUL
Sample : MAX-VX-01E
Filename : EQC4BPC
Bias : 7 Volt
Contact : BPC
Raster : 2 mm/point
Type : p - 6 Ωcm
Thickness : 543 µm
Lasertype : 905 nm (IR)
PhotoCurr : 1.19 mA
Diameter : 4 Inch

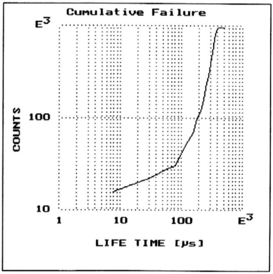
Date: 03/12/96
Time: 13:51:32

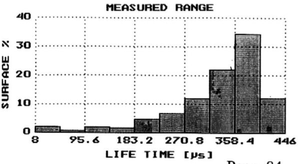
Data from scan	
Life Time	
Average	339.6 µs
Deviation	61.61 µs
Minimum	200.2 µs
Maximum	446.2 µs
Dark Current	
Average	474.9 µA
Minimum	463 µA
Maximum	516 µA
Diffusion Current	
Average	1058 µA
Deviation	22 µA
Minimum	979 µA
Maximum	1088 µA

Exclusions	
Histograms	No
Plot	No
Statistics	Yes









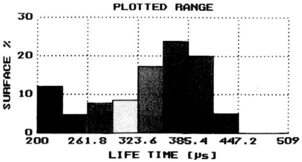


Fig. 4.0

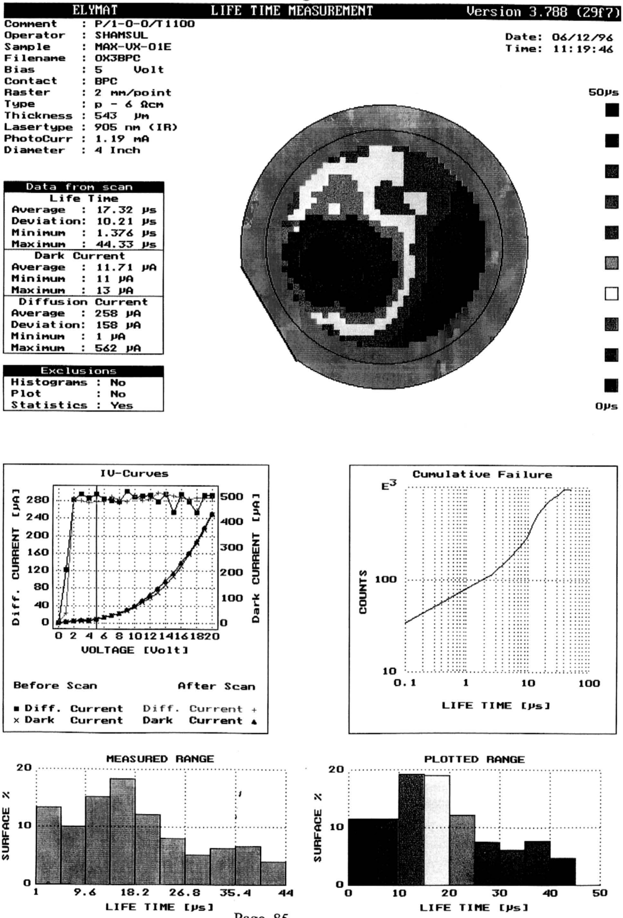
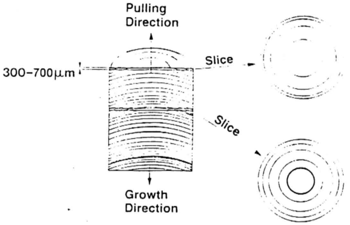
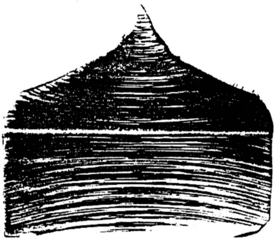

ELYMAT
LIFE TIME MEASUREMENT
Version 3.788 (29f7)
Comment : P/1-0-0/T1100
Operator : SHAMSUL
Sample : MAX-VX-01E
Filename : OX3BPC
Bias : 5 Volt
Contact : BPC
Raster : 2 mm/point
Type : p - 6 Ωcm
Thickness : 543 μm
Lasertype : 905 nm (IR)
PhotoCurr : 1.19 mA
Diameter : 4 Inch
Date: 06/12/96
Time: 11:19:46
50μs
0μs
Data from scan
Life Time
Average : 17.32 μs
Deviation: 10.21 μs
Minimum : 1.376 μs
Maximum : 44.33 μs
Dark Current
Average : 11.71 μA
Minimum : 11 μA
Maximum : 13 μA
Diffusion Current
Average : 258 μA
Deviation: 158 μA
Minimum : 1 μA
Maximum : 562 μA
Exclusions
Histograms : No
Plot : No
Statistics : Yes
IV-Curves
Diff. CURRENT [μA]
Dark CURRENT [μA]
VOLTAGE [Volt]
0 2 4 6 8 10 12 14 16 18 20
0 40 80 120 160 200 240 280
0 100 200 300 400 500
Before Scan
After Scan
■ Diff. Current
× Dark Current
Diff. Current +
Dark Current ▲
Cumulative Failure
E3
COUNTS
100
10
0.1 1 10 100
LIFE TIME [μs]
MEASURED RANGE
SURFACE %
20
10
0
1 9.6 18.2 26.8 35.4 44
LIFE TIME [μs]
PLOTTED RANGE
SURFACE %
20
10
0
0 10 20 30 40 50
LIFE TIME [μs]

Fig. 4.1



Schematic illustration of Czochralski crystal cross section containing curved crystal-melt interfaces and planar wafers sliced at different portions.



Growth striations revealed by chemical etching for shoulder part of Czochralski silicon. (Courtesy of J. W. Moody, Monsanto Electronic Materials Company, and A. Yamaguchi, Monsanto Japan, Limited.)

3.3 Variation in lifetime with wafer type, orientation and ingot source

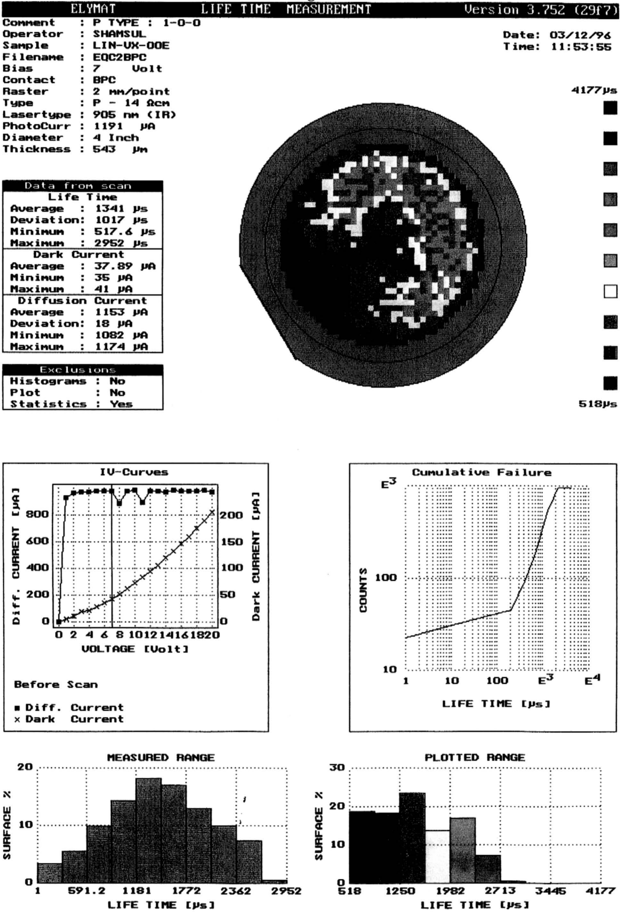
Sample wafers of the same diameter (4 ") of different type, orientation and from dirrent ingot source were taken for lifetime measurement. Table below shows the comparison of average minority carrier lifetime of 6 wafers of each parameters, different types; n or p-type, orientation; 1-0-0 or 1-1-1 and ingot source.

	Wafer parameters	Avg. Minority Carrier Lifetime (microseconds)
Type	n	315
	p	205
Orientation	1-0-0	355
	1-1-1	179
Ingot source	A	102
	B	426
	C	298
	D	306

The result above shows that minority carrier lifetime values may vary with wafers type, orientation and the ingot source. As mentioned in the early discussion, lifetime depends strongly on the crystal purity mainly with respect to metallic impurities - that is, so-called lifetime killers, which act as trap centers. Therefore, it is extremely critical that process-induced defects, either surface defects caused by transition metal contamination during cleaning, etching or polishing processes, or interior defects due to oxygen precipitation and Si-O precipitate, need to be controlled during the wafer shaping and the device fabrication processes.

It was also observed that the std. deviation of minority carrier lifetime varies largely. At one point on a wafer surface, one can observed very high minority carrier lifetime and on another point on the same wafer, the value can be very low. This typical observation is shown in Fig. 4.2. This phenomenon is a yield impacting factor to the device manufacturers. Therefore, from the above results, it clearly indicates that it is extremely important that the wafer minority carrier lifetime is being measured and studied in a microscopic level.

Fig. 4.2


ELYMAT LIFE TIME MEASUREMENT Version 3.752 (29f7)
Comment : P TYPE : 1-0-0
Operator : SHAMSUL
Sample : LIN-UX-00E
Filename : EQC2BPC
Bias : 7 Volt
Contact : BPC
Raster : 2 mm/point
Type : P - 14 Ωcm
Lasertype : 905 nm (IR)
PhotoCurr : 1191 μA
Diameter : 4 Inch
Thickness : 543 μm
Date: 03/12/96
Time: 11:53:55
4177μs
518μs
Data from scan
Life Time
Average : 1341 μs
Deviation: 1017 μs
Minimum : 517.6 μs
Maximum : 2952 μs
Dark Current
Average : 37.89 μA
Minimum : 35 μA
Maximum : 41 μA
Diffusion Current
Average : 1153 μA
Deviation: 18 μA
Minimum : 1082 μA
Maximum : 1174 μA
Exclusions
Histograms : No
Plot : No
Statistics : Yes
IV-Curves
Diff. CURRENT [μA]
Dark CURRENT [μA]
VOLTAGE [Volt]
Before Scan
■ Diff. Current
× Dark Current
Cumulative Failure
COUNTS
LIFE TIME [μs]
MEASURED RANGE
SURFACE %
1 591.2 1181 1772 2362 2952
LIFE TIME [μs]
PLOTTED RANGE
SURFACE %
518 1250 1982 2713 3445 4177
LIFE TIME [μs]