https://ntrs.nasa.gov/search.jsp?R=19860010260 2020-03-20T15:13:09+00:00Z

N86-19731

DEFECTS IN SILICON EFFECT ON DEVICE PERFORMANCE AND RELATIONSHIP TO CRYSTAL GROWTH CONDITIONS

L. Jastrzebski

RCA Laboratories
Princeton, NJ 08540

A relationship between material defects in silicon in performance of electronic devices will be described. A role which oxygen and carbon in silicon play during defects generation process will be discussed.

Electronic properties of silicon are a strong function of the state in which oxygen is in silicon. This various states control mechanical properties of silicon efficiency of internal gettering and formation of defects in device active area. In addition to: temperature, time, ambient, cooling/heating rates of high temperature treatments the oxygen state is a function of crystal growth process. It is well documented that incorporation of carbon and oxygen into silicon crystal is controlled by geometry, and rotation rates applied to crystal and crucible during crystal growths. Also, formation of nucleation centers for oxygen precipitation is influenced by growth process, although there is still a controversy which parameters play a major role.

All these factors will be reviewed with the special emphasis on the area which are still ambiguous and controversial.

PRECEDING PAGE BLANK NOT FILMED

Introduction

DEFECT REDUCTION IN DEVICE ACTIVE AREA

PROBLEMS:

- SOFT JUNCTIONS - LEAKAGE
- LOW LIFETIME - LEAKAGE, DIFFUSION LENGTH DEGRADATION

DEFECTS:

CRYSTALLOGRAPHIC:

- DISLOCATIONS
- STACKING FAULTS
- PRECIPITATES

ELECTRIC ACTIVITY ⇕ DECORATION (HEAVY METALS)

POINT:

- GENERATION/RECOMBINATION CENTERS ⇕ (HEAVY METALS)

MECHANICAL STRENGTH

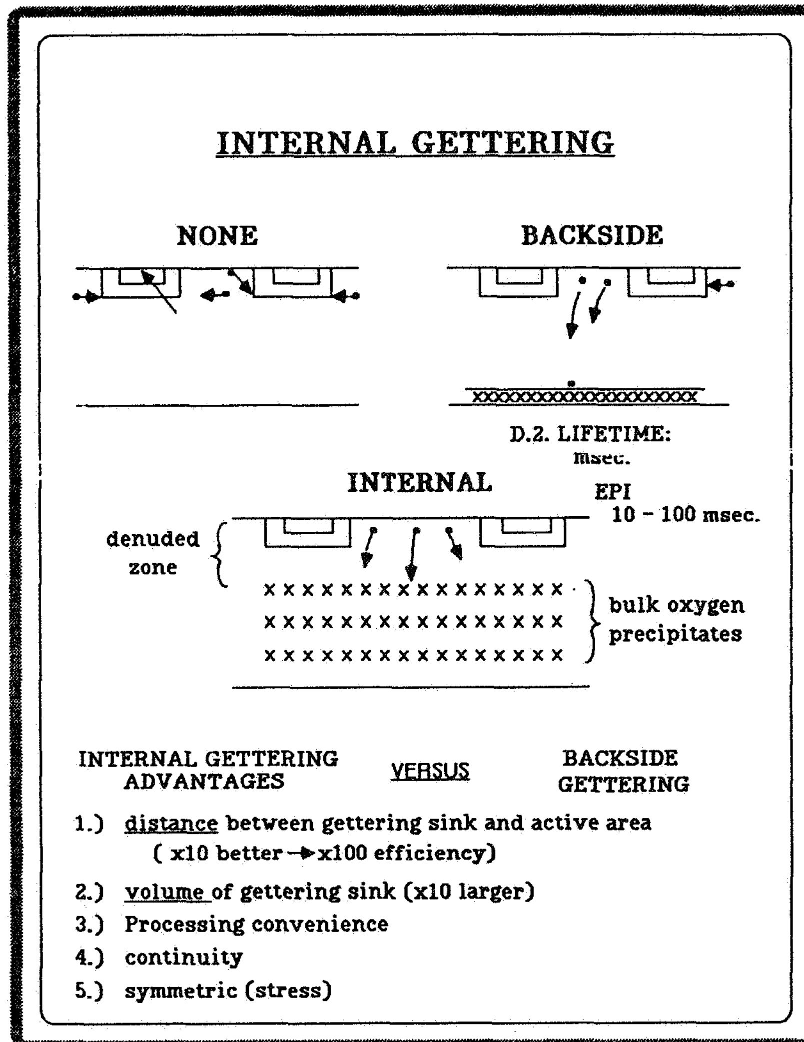
PRECEDING PAGE BLANK NOT FILMED

Goal

ESTABLISH RELATIONSHIP BETWEEN:

1. INTERNAL GETTERING EFFICIENCY AND CHARACTERISTICS OF OXYGEN PRECIPITATES

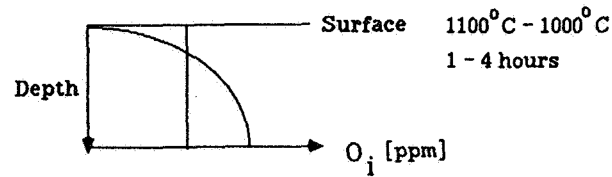
2. CHARACTERISTICS OF SUPPLIED WAFERS AND OXYGEN PRECIPITATION (FOR A GIVEN PROCESS)



ORIGINAL PAGE IS
OF POOR QUALITY

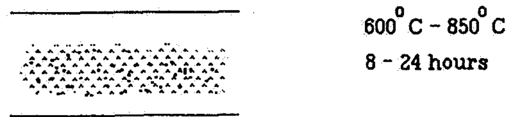
INTERNAL GETTERING PROCEDURE

1.) Outdiffusion of oxygen from surface region.



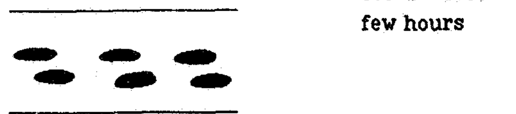
1100°C - 1000°C
1 - 4 hours

2.) Nucleation step.



600°C - 850°C
8 - 24 hours

3.) Precipitate growth.



900°C - 1050°C
few hours

Internal Gettering (Bipolar Process)

1. EFFECT ON CIRCUIT PERFORMANCE/YIELD FOR BIPOLAR
2. MECHANISM OF INTERNAL GETTERING/EFFICIENCY
3. OXYGEN PRECIPITATION KINETICS/CHARACTERISTICS OF AS-GROWN WAFERS

ACCORDING TO PUBLISHED RESULTS

INTERNAL GETTERING EFFICIENCY

- DEPTH OF DENUDED ZONE
- AMOUNT OF PRECIPITATED OXYGEN

PRECIPITATION KINETICS ←——→ STARTING WAFERS CHARACTERISTICS

- INTERSTITIAL OXYGEN CONCENTRATION
- CARBON CONCENTRATION
- COOLING RATE OF CRYSTAL BULL

NAKANISHI....

JAP. J. APPL. PHYS. (1980)

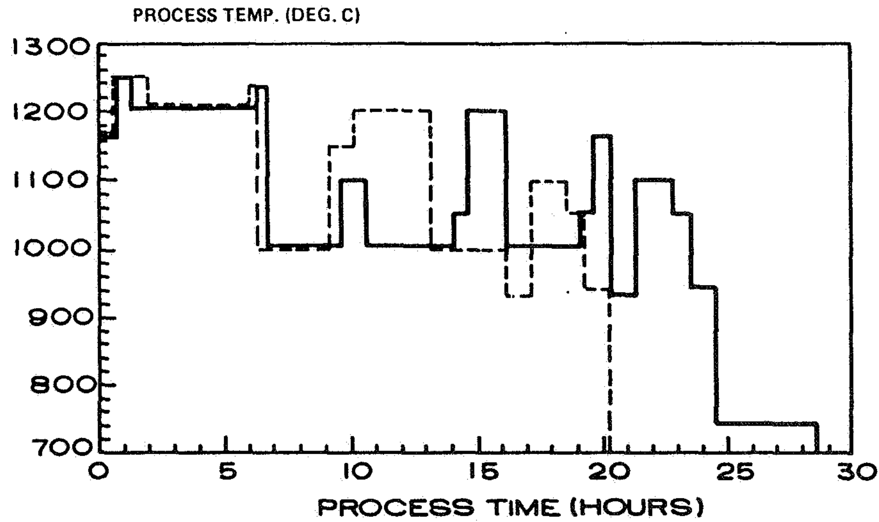


FIG. 1 TIME VS TEMP OF I^2L (SOLID LINE) AND ANALOG (DASHED LINE) PROCESSES.

Efficiency of Internal Gettering

FUNCTION OF:

- DEPTH OF DENUDED ZONE
- AMOUNT OF PRECIPITATED OXYGEN
- PRECIPITATES MORPHOLOGY
- PRECIPITATION KINETICS

EACH PROCESS (BIPOLAR, CMOS, CCD) HAS DIFFERENT REQUIREMENTS:

- DEVICE SENSITIVITY
- TIME/TEMPERATURE
- EQUIPMENT

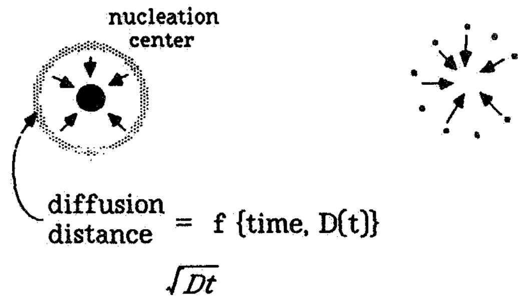
RELATIONSHIP OF I.G. TO STARTING CHARACTERISTICS OF SILICON WAFERS:

- INTERSTITIAL OXYGEN CONCENTRATION
- CARBON CONCENTRATION
- NONINTERSTITIAL OXYGEN CONCENTRATION
- POINT DEFECTS ← COOLING, ???

GROWTH VELOCITY FLUCTUATIONS? → POINT DEFECTS

(heterogeneous)

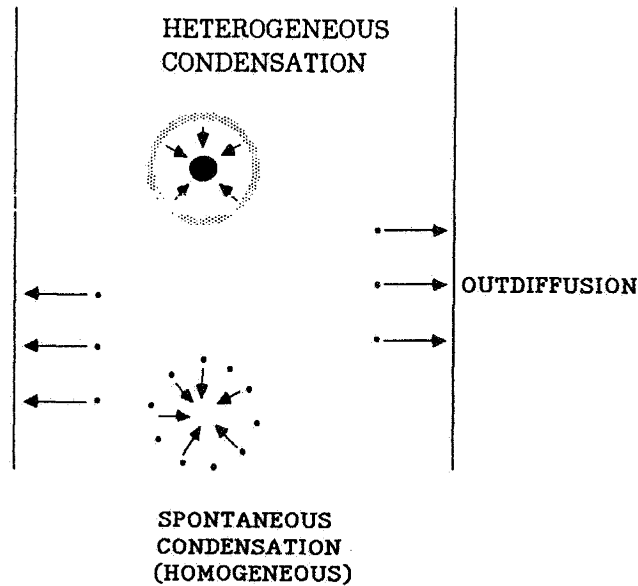
spontaneous
nucleation
(homogeneous)



Heterogeneous and homogeneous nucleation
can take place in the same time.

Contribution of each of them will
change with temperature.

Point-Defect Condensation During Cooling of Silicon Ingot



Crystal Growth

1. INCORPORATION OF OXYGEN FROM SiO_2 CRUCIBLE INTO THE SILICON MELT

2. INTERFACIAL PHENOMENA--EFFECT OF GROWTH KINETICS:

   EFFECT OF *TEMPERATURE* FLUCTUATIONS {
   - INCORPORATION OF OXYGEN INTO THE SOLID
   - FORMATION OF HETEROGENEOUS NUCLEATION *CENTERS*
   - FORMATION OF POINT DEFECTS

   ABE "SEMICONDUCTOR SILICON 1981"

3. COOLING AFTER GROWTH:

   - CONDENSATION OF POINT DEFECTS
   - INITIAL STAGE OF OXYGEN PRECIPITATION

   850° - 650°C TEMPERATURE RANGE

   NAKANISHI...JAP. J. APPL. PHYS. (1980).

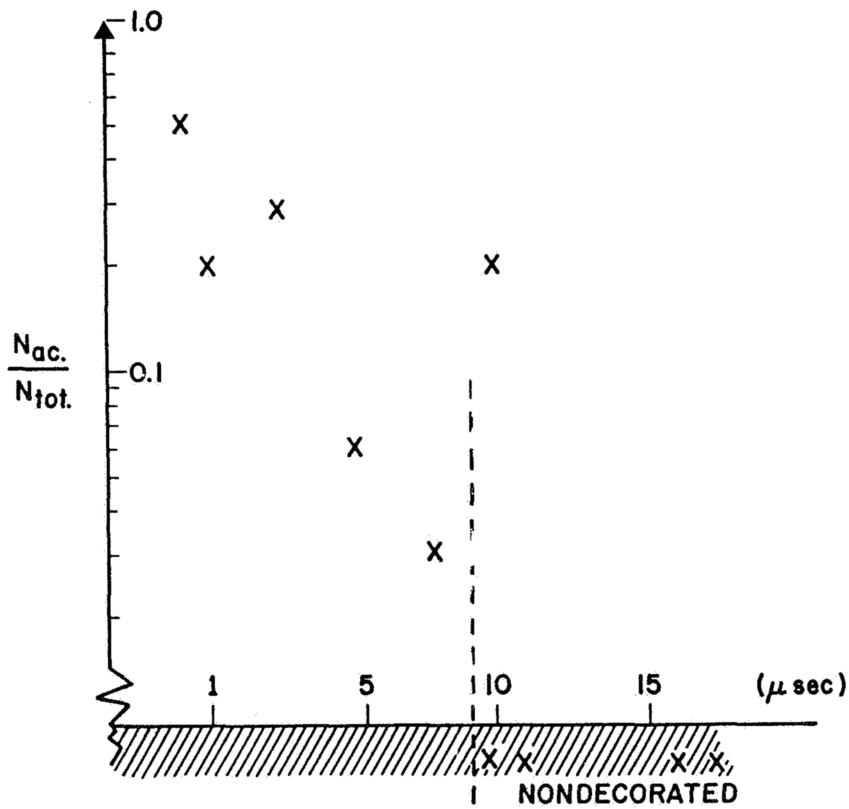
Comparison Between Oxygen Precipitation Models

	Driving Force	Kinetic Limiting Step	Precipitation Centers
Homogeneous	Critical value value of super-saturation	Condensation or diffusion of oxygen	None
Heterogeneous	Oxygen super-saturation (interstitial oxygen concentration minus oxygen solubility)	Diffusion of oxygen	Impurities clusters: carbon, donors, acceptors. Point clusters: small vacancy complexes. <u>Non</u>interstitial oxygen

Depth of Denuded Zone

SAME FOR ALL SUPPLIERS

1-1	35 [μM]
1-2	30
2-1	32
3-1	28
3-2	35
4	30
5-1	30



Probability of Decoration ($\frac{\text{Electrically Active}}{\text{Total}}$ Defects) as a Function of Lifetime.

ORIGINAL PAGE IS
OF POOR QUALITY

Table I. Parameters of As-Grown Wafers

Group(*)	Interstitial Oxygen (ppm) 20 30 40	Non-Interstitial Oxygen in As Grown (ppm)	Carbon Concentration (ppm)
1-1(**)		None	1-3.5
1-2		≈1.5	1-3.5
2-1		None	None
2-2		None	0.3-0.6
3-1		≈2	0.6-1.0
3-2		≈3	<2(***)
4		None	0.3-0.8
5-1(****)		None	None
5-2		None	None

(*) First number corresponds to supplier.

(**) According to supplier 1 group 1-2 had higher precipitation rate than 1-1.

(***) Two subgroups: (1) carbon less than 0.5 ppm; (2) carbon 1-2 ppm.

(****) Group 5-1 had 3 μm backside damage, 5-2 had 10 μm backside damage.

Table II. Efficiency of Internal Gettering; Yield Improvement (See Text) and the Amount of Precipitated Oxygen During I^2L and Analog Processes

Group	Preheat Treatment Yes	Preheat Treatment No	Initial Interstitial Oxygen (PPMA)	Yield Loss Due to Leakage, Analog: % Experiment / % Standard	Yield Loss Due to Leakage, Analog: Normalized to Lowest Loss Observed	Yield Loss Due to Leakage, I^2L: Normalized to Lowest Loss	Precipitated Oxygen: Analog	Precipitated Oxygen: I^2L
1-1-I	X	X	30-34	.46 .31	2.7 1.8	1.12	19 20	19 22
1-1-II		X	30-34	.93	1.15			
1-2	X	X	30-35	1.1 .6	3.5 6.1		21 22	21 24
2-1	X	X	22-25	1.1	2.0		2 9	6 10
2-2	X	X	24-28	1.4	2.7		3 14	5 16
3-1	X	X	22-26	1.4	2.5	1.46 3.4	6 11	11 14
3-2	X	X	27-29	.83 .73	1.6 1.3	1.22 3.1	15 15	18 18
4	X	X	37-42	1.2 .54	2.2 1.0	1.0	10 23	8 23
5-1	X	X	30-33	.84	1.3		8 16	12 19
5-2	X	X	30-32	1.05	1.65	1.25	13 16	11 17

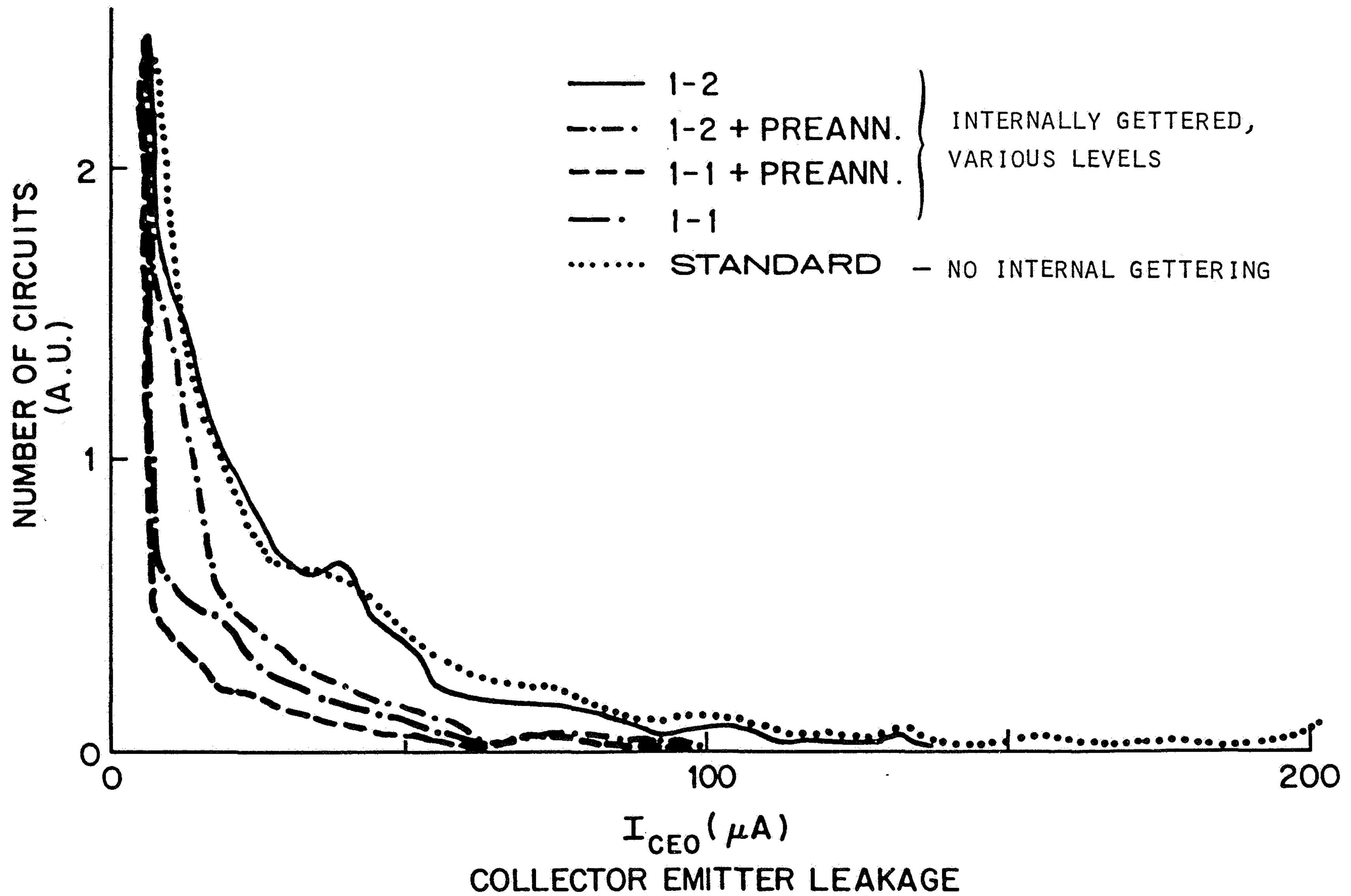


Figure 2. Leakage Distribution for Analog Circuits Made on Standard and Internally Gettered Wafers (1-1, 1-2)

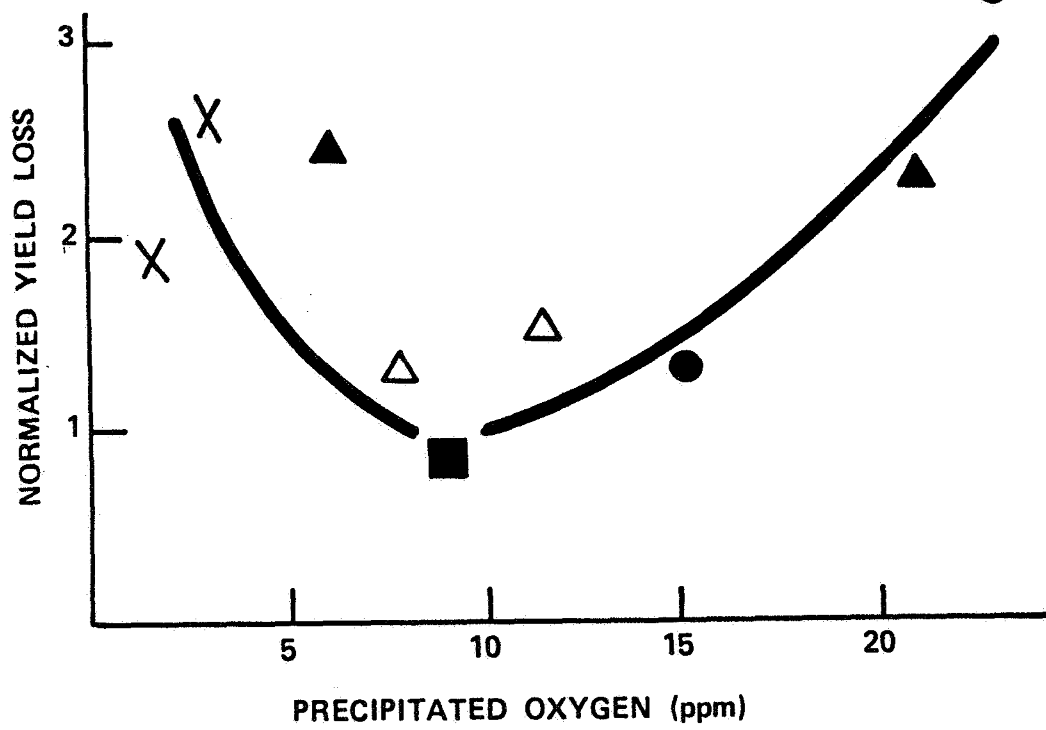


Figure 4. Normalized Yield Loss as a Function of Amount of Precipitated Oxygen After Completion of the Analog Process (Wafers Without Preannealing) O - Group 1, X - Group 2, - Group 3, - Group 4

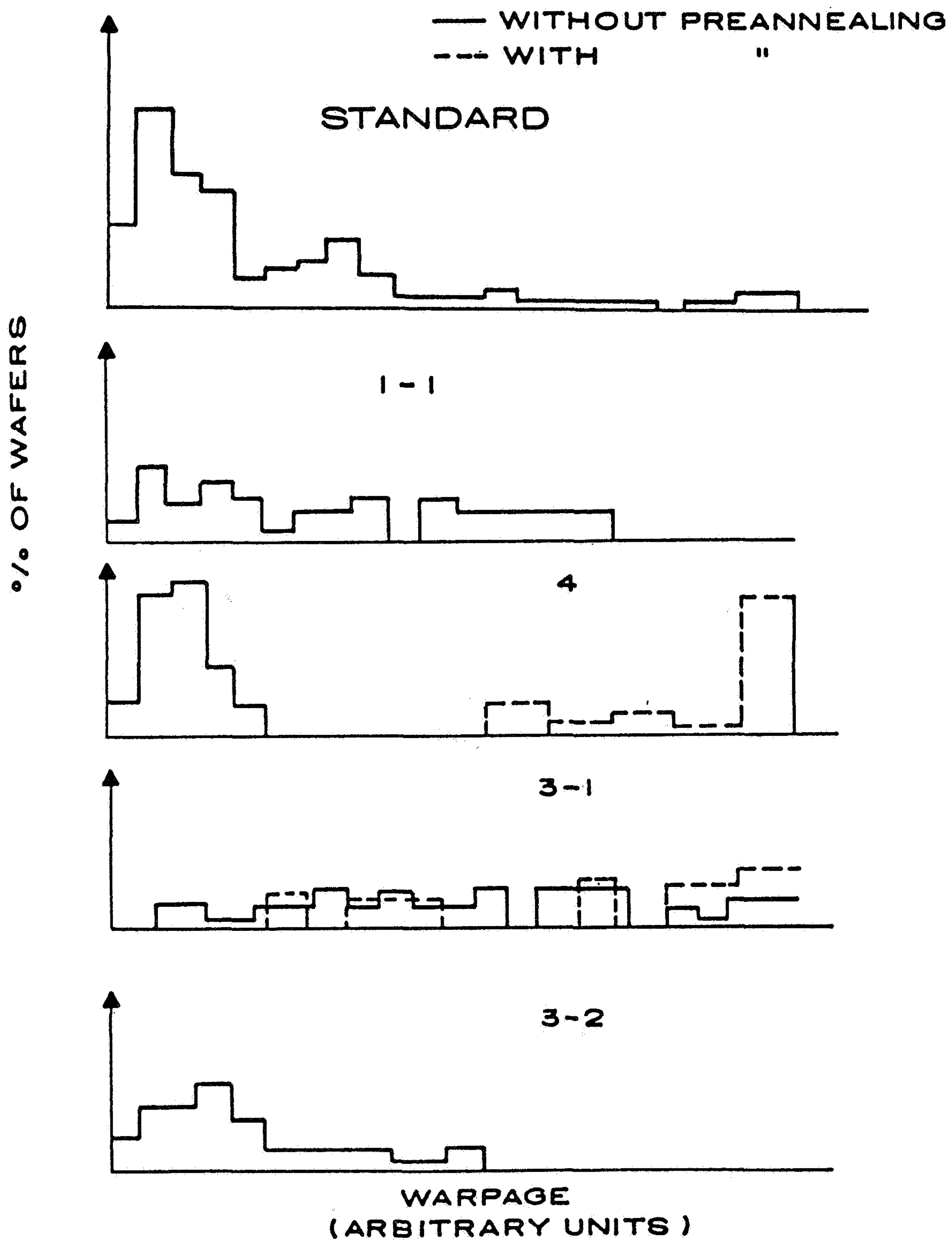


Figure 6. Histogram of Warpage in the Wafers from Different Groups After Completion of Analog Process

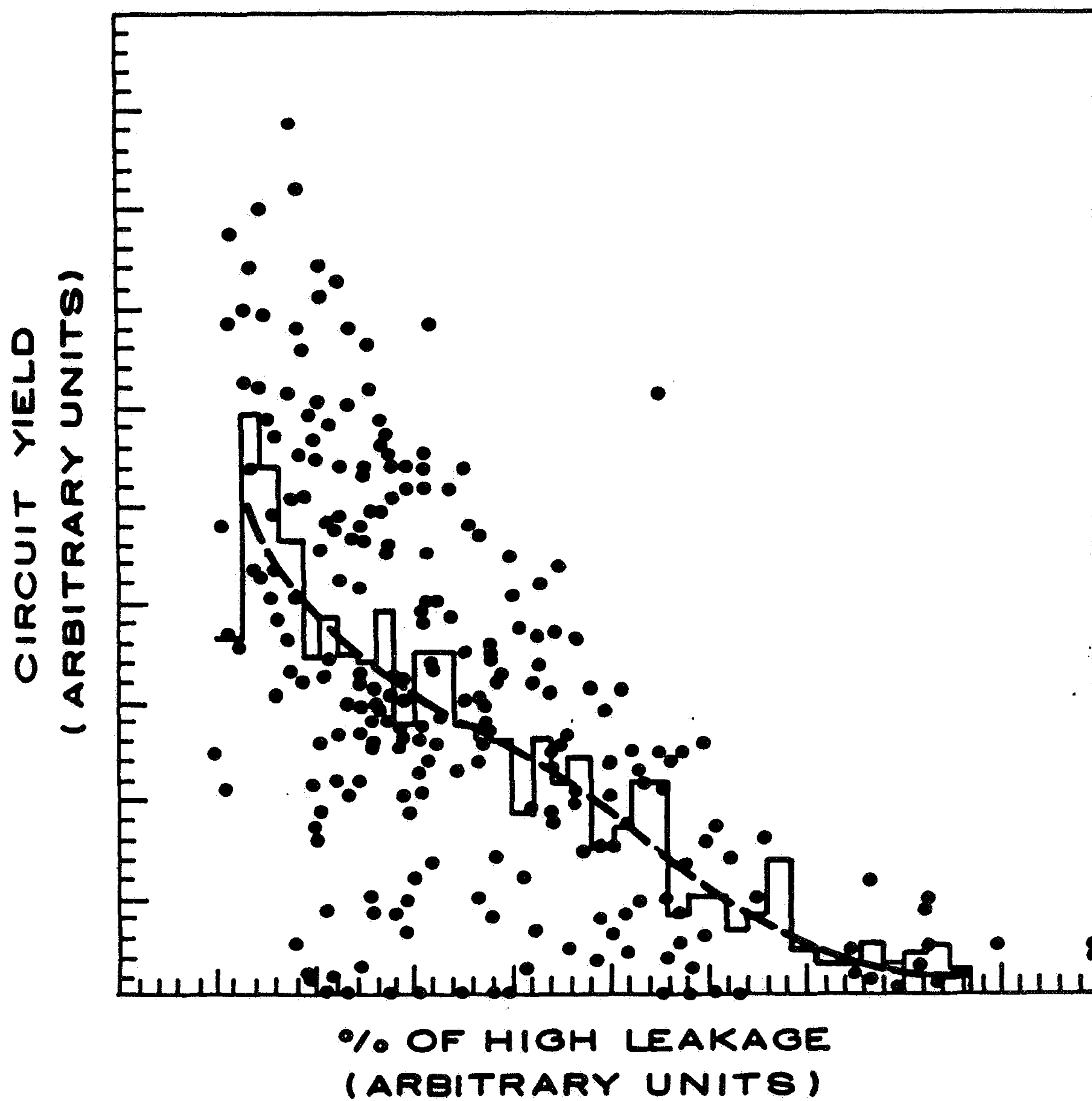
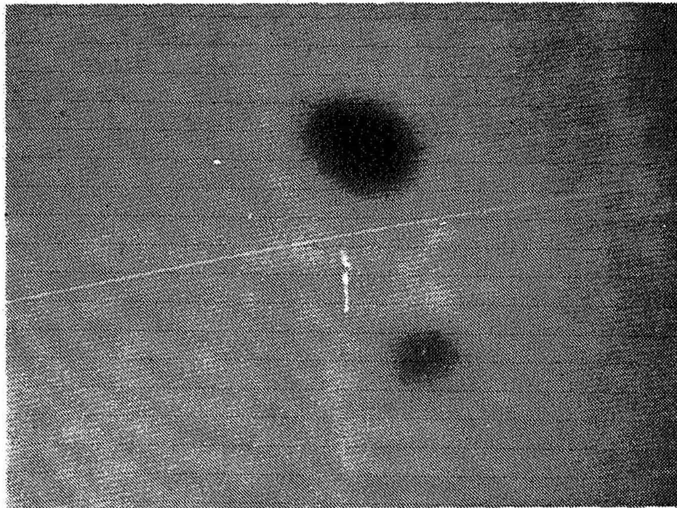


Figure 3. I^2L Circuit Yield Versus % of Highly Leaky Circuits

ORIGINAL PAGE IS
OF POOR QUALITY



EBIC

Dash Etch

15 μm

Decoration of Crystallographic Defects by Heavy Metals.
Only two out of four defects are electrically active.

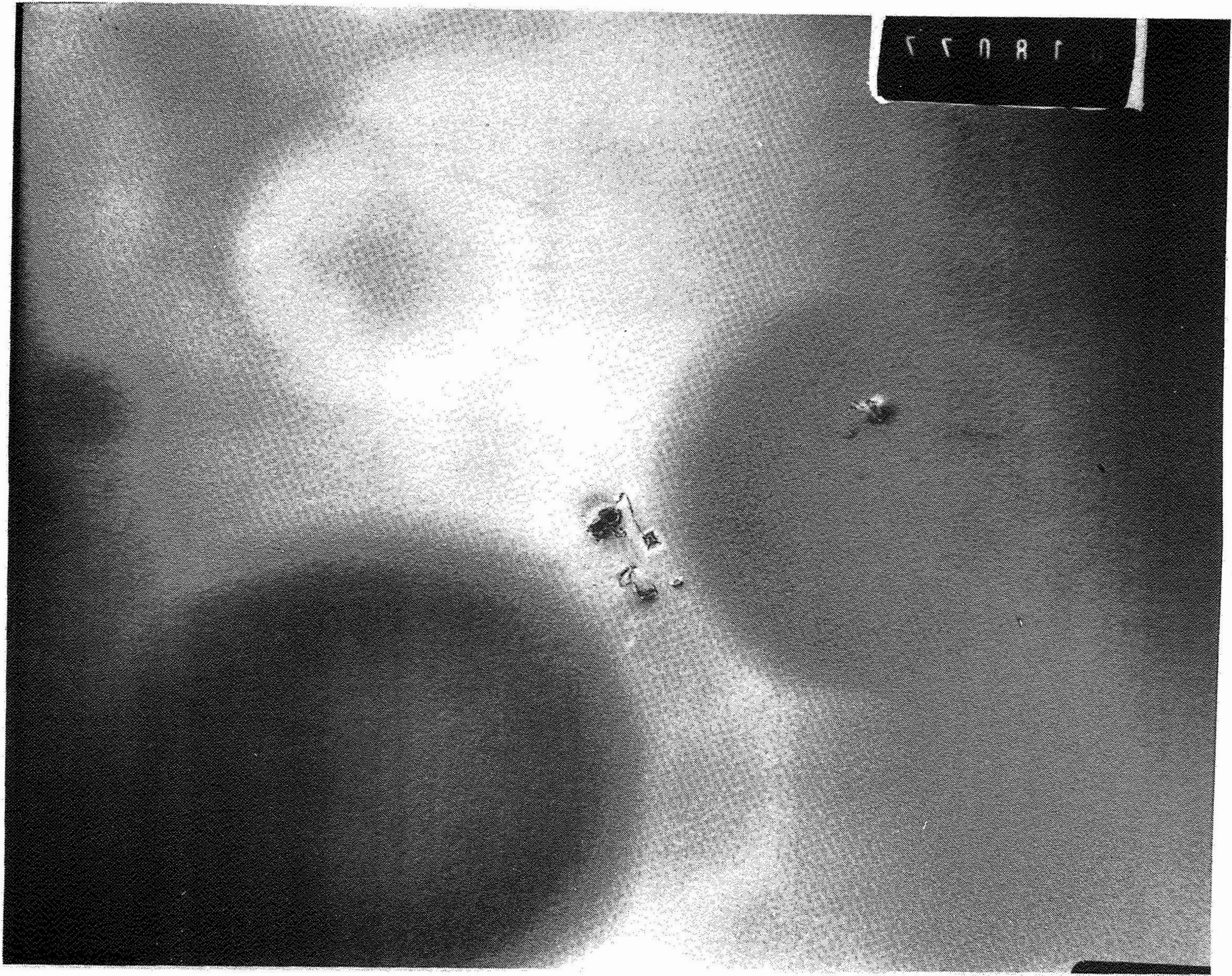
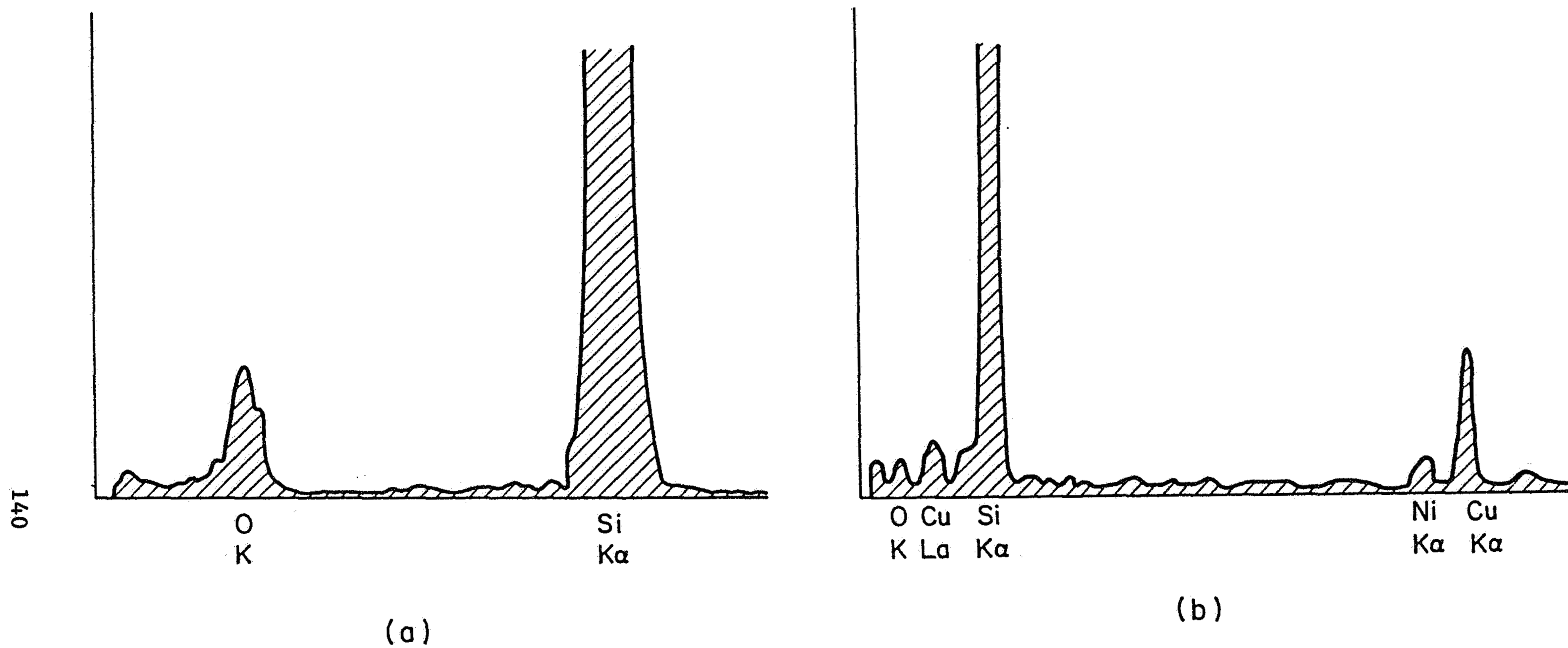


Figure 13. Plate-like Precipitates Observed in "3-2" and "4" Wafers

ORIGINAL PAGE IS
OF POOR QUALITY



EDAX Composition Analysis Taken From Plate-like Precipitate (a)--
Notice Only Si and O- and (b) Precipitate on Stacking Fault From
Group 4 (Figure 12b)--Notice Presence of Heavy Metals

DISCUSSION

WITT: Do you have to invoke heterogeneous and homogeneous nucleation to explain the difference in behavior? I'm asking because it is certainly possible to have different types of nuclei for which the activation energy for growth differs very, very significantly. There are many who seriously doubt your curves of homogeneous nucleation, in principle.

JASTRZEBSKI: In general, I agree with you. Homogeneous nucleation will probably never take place, but it is a question of how close are we to homogeneous nucleations. The homogeneous type of nucleations that I'm referring to are a certain type of precipitation process of the oxygen. This precipitation process of oxygen has helped in a way. You can think of it as a kind of decay time. When this time is as high as we were ever able to see, we called this homogeneous. Probably the baseline will change in the future. I believe we have different types of heterogeneous centers, for it's very difficult to measure this in any direct way.

DYER: Do you know of any way in which the internal gettering of the type that you have been speaking of could be a benefit to a typical solar cell?

SCHWUTTKE: May I comment on this? Using internal gettering the way it is being used for MOS processing is not a good approach for solar cells. We are dealing with recombination lifetimes. You will kill the cell if you precipitate, as it is done for MOS processing, to get a denuded zone. I believe you [Jastrzebski] have chosen about the most difficult experiment you can do to follow the kinetics of oxygen, namely a bipolar process. You just can't use a bipolar process to study oxygen kinetics. You should get out of the high-oxygen-concentration regime and concentrate on low oxygen.

MORRISON: How might co-doping of metallic impurities be affecting a heterogeneous deposition process in your material, and the process you are describing?

JASTRZEBSKI: Stacking faults are related to the presence of metallic impurities. Homogeneous nucleation of stacking faults isn't very likely. Metallic impurities will act as nucleation centers and you will have heterogeneous nucleation of stacking faults around this metallic impurity precipitate.

RAO: You showed oxygen precipitates in two samples. If you have the same type of precipitate, then you should find the defect generation around that, which is the result of the lattice parameter mismatch of the interface. If that is the case, why are you getting a decorated stacking fault in one case and a non-decorated stacking fault in the other, and what was the character of the two stacking faults that you had seen, the one that was decorated and the one that was not decorated?

JASTRZEBSKI: You have defects around the precipitate that are punch-out dislocation loops. I can only speculate why you have a difference. My working hypothesis is that you have a difference when, in the process, impurities are coming from this formation of the stacking faults and cristobalites. I suspect that in one case we're having a different driving force from the nucleation that is a heterogeneous type of precipitation. Different precipitation rates will give you different defect densities, and cause a different gettering action. I believe that this is the reason you are seeing a difference between precipitate gettering by stacking faults. The clean stacking faults usually form later in the process because of a difference in the oxygen supersaturation in the precipitation.

WOLF: You said the problem is really the heavy metals you introduce during the processing. That means that your final heat treatment that does the gettering has to come after all the high-temperature processes.

JASTRZEBSKI: No. This is the dispute of internal gettering. You can have gettering in the stages when you form the precipitates. In oxygen, for example, the precipitation is taking place during processing, so you have gettering throughout all the processing steps. For example, with phosphorus you can only have gettering when you introduce the phosphorus through the back of the wafer.

WOLF: You are saying that each time you go to a high temperature the heavy metals move towards the getters. Evidently they must be moving very fast.

JASTRZEBSKI: Not really, it depends on what kind of impurity you have. You are talking about something between 10 and 25 µm for these heavy metals.

ELWELL: The original model of internal gettering was that the precipitate would punch out dislocation loops which would be decorated by the heavy metals. The efficiency of this process should depend on how fast you precipitate. Do you believe in that as a classical model or do you have data that would make us think that is a long way off?

JASTRZEBSKI: No, I don't. The comparison of different-morphology precipitates has not been proven.

ELWELL: You take whatever microdefects are present in the "as grown" crystal and, you don't do any heat treatment. Is that correct?

JASTRZEBSKI: We do not have any microdefects in the as-grown crystal, at least according to the classical sense of microdefects that you find by etching.

ELWELL: There could be 50 Å precipitates.

JASTRZEBSKI: Definitely no. This is why you sometimes have oxygen in non-interstitial states, which causes this completely different change in the precipitation kinetics.

SCHWUTTKE: For the record, I don't believe that we are dealing with cristobalites. Our measurements of the denuded zone using transmission electron microscopy indicate that we are dealing with amorphous silicon. The dislocation loops are punched out due to the volume strain generated by the growth of the amorphous silicon.

WITT: Do I understand it that there are two types of precipitates, one of them with gettering capabilities and the other one not?

JASTRZEBSKI: That is correct.

WITT: If that is so, have you been able through, say, STEM, to identify the gettering action or the presence of heavy metals on some and the absence on others?

JASTRZEBSKI: Yes, we have. Using STEM we see heavy-metal precipitates on this particular stacking fault when we normally did not see any heavy-metal precipitates. In another case, when it was a very quick precipitation rate, it was the opposite.