

HIGH-PURITY SILICON CRYSTAL GROWTH INVESTIGATIONS

SOLAR ENERGY RESEARCH INSTITUTE

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Goals

- A. OPTIMIZE DOPANTS AND MINORITY CARRIER LIFETIME IN FZ MATERIAL
- B. IMPROVE THE CONTROL OF LIFETIME DEGRADATION MECHANISMS
(IMPURITIES, THERMAL HISTORY, POINT DEFECTS, SURFACE EFFECTS)
- C. CHARACTERIZE LIFETIME-RELATED CRYSTALLOGRAPHIC DEFECTS
(VIA X-RAY TOPOGRAPHY AND OTHER METHODS)

Recent Emphasis

- A. INSTALLATION OF RESIDUAL GAS ANALYSIS (RGA) ON FLOAT-ZONING FURNACE
- B. IMPLEMENTATION OF MINORITY CARRIER LIFETIME MEASUREMENTS
- C. DEVELOPMENT OF POINT DEFECT DEGRADATION PROCEDURES
- D. X-RAY TOPOGRAPHY AND EBIC CHARACTERIZATION OF WEB AND FZ CRYSTALS
- E. CALCULATIONS FOR PURIFICATION BY BOTH EVAPORATION AND SEGREGATION
- F. INVESTIGATION OF THE DEPENDENCE OF LIFETIME ON CRYSTAL COOLING RATE
(BOTH DISLOCATED AND DISLOCATION-FREE CRYSTALS)
- G. GROWTH OF P-TYPE, HEAVILY Ga-DOPED CRYSTALS WITH HIGH LIFETIMES

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ADVANCED SILICON SHEET

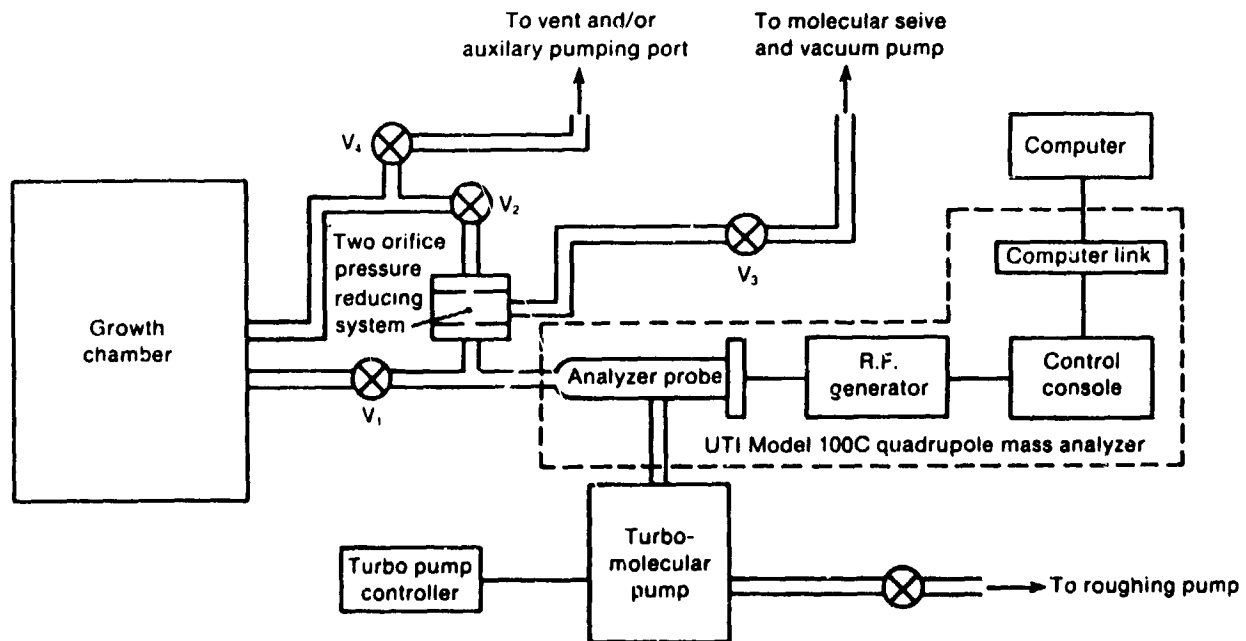
Current Potential Uses of RGA in High-Purity Silicon Growth

Qualitative:

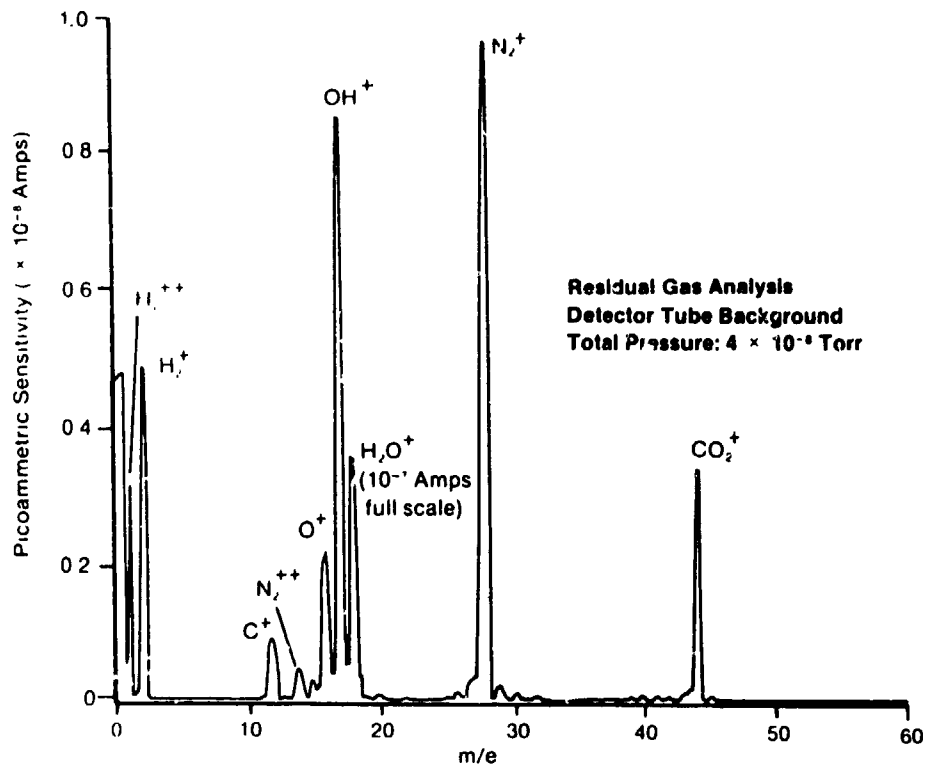
1. Leak checking with growth chamber under argon pressure or under vacuum with helium gun.
2. Run-to-run comparisons of purity levels and location of impurity sources.

Quantitative:

1. Detection of evaporated growth zone impurities in vacuum.
2. Analysis of trace gas impurities in 1-3 Atm. growth ambient.
3. Verification of argon supply purity.



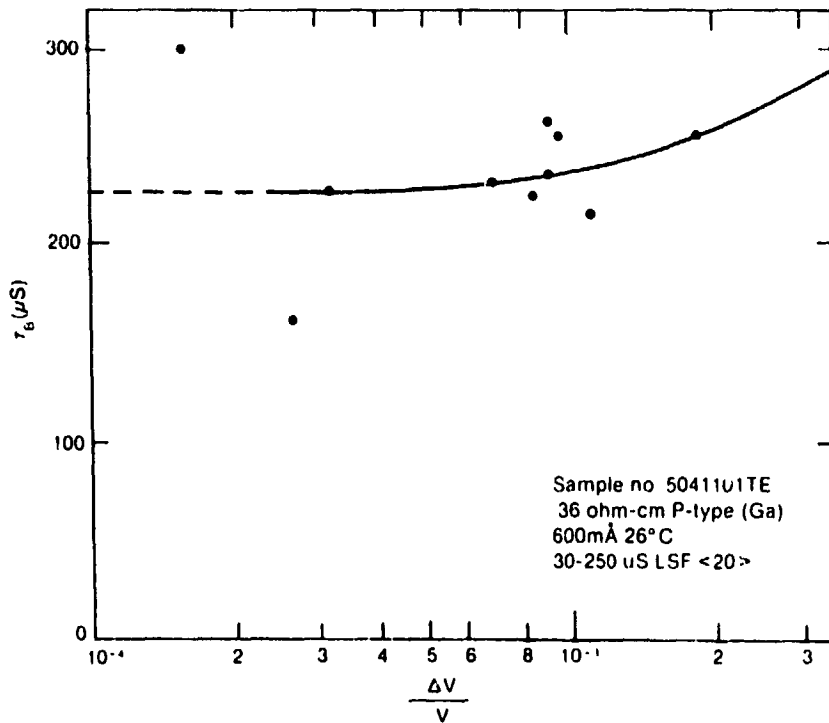
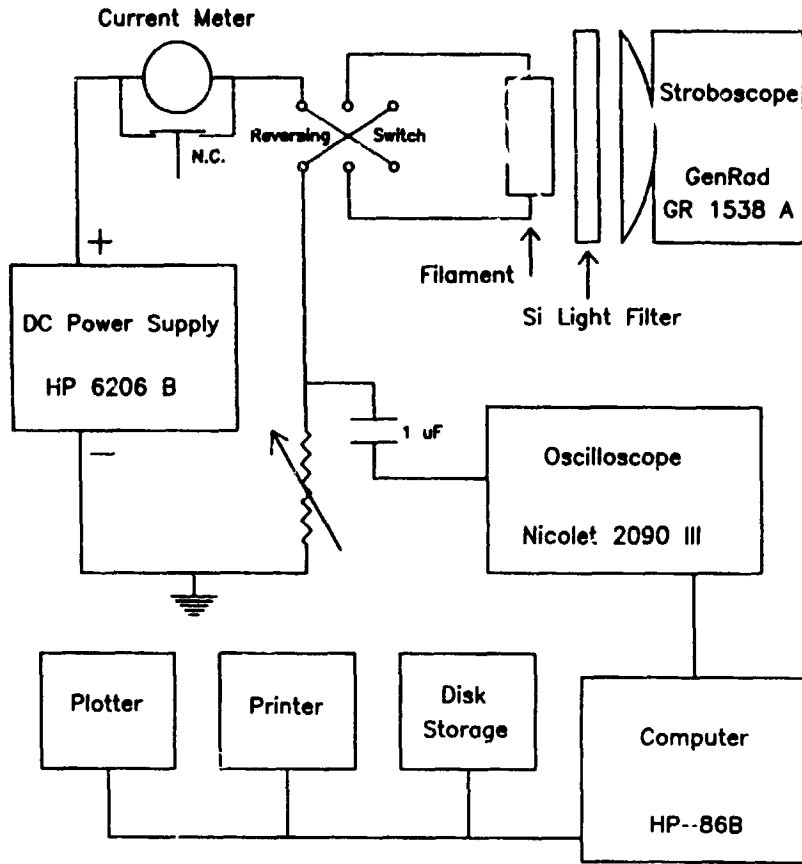
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Minority Carrier Lifetime Measurements in Low Resistivity (<1 ohm-cm) Silicon

1. High current density at low applied voltages.
 - a. Reduction of applied voltage.
 - b. Control of sample temperature.
 - c. Increased series resistor power ratings.
 - d. Reduction of series R/sample R ratio.
2. Low PCD signal amplitude.
 - a. Increased flash tube intensity by using an extra capacitor.
 - b. Increased sample length.
3. Larger effect of noise on smaller PCD signal.
 - a. Computer averaging of 20 to 100 oscilloscope traces.

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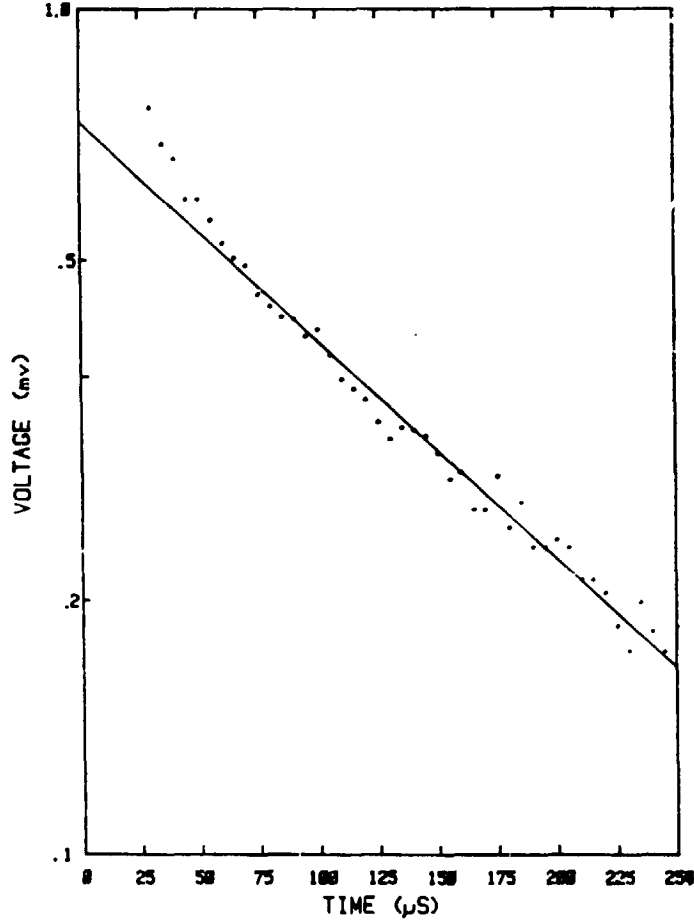
ORIGINAL DOCUMENT
OF POOR QUALITY

Sample number: 5041101TE Date: 5/13/85 Total of 20 traces averaged.

Peak voltage: .7656v $\Delta V/V$: $1.06E-3$ at 30 μS
FILAMENT LIFETIME= 160 WULK LIFETIME= 214 μS
Sample dimensions HxWxL= 7.5 7.5 27 OR Diameter= 0 Rs=1275.6

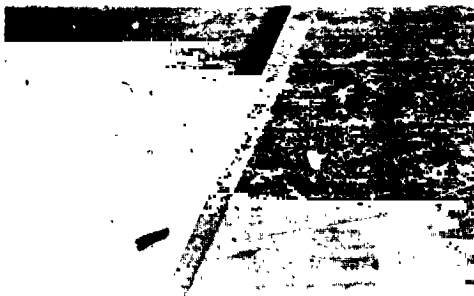
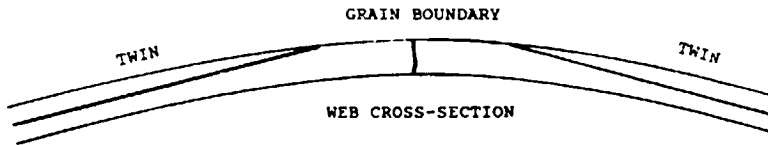
Measurement temperature= 26 Sample current= 300
Resistance: 2.5 Voltage: .72 Resistivity: .36 Type: P
Series R: 10.4 Maximum series current: 693
Predicted V at 2000 μS is: $4.97E-6$

Plot for points from t=30 to 250 μS
LSF Done 32.8 Minutes
LTPLOT



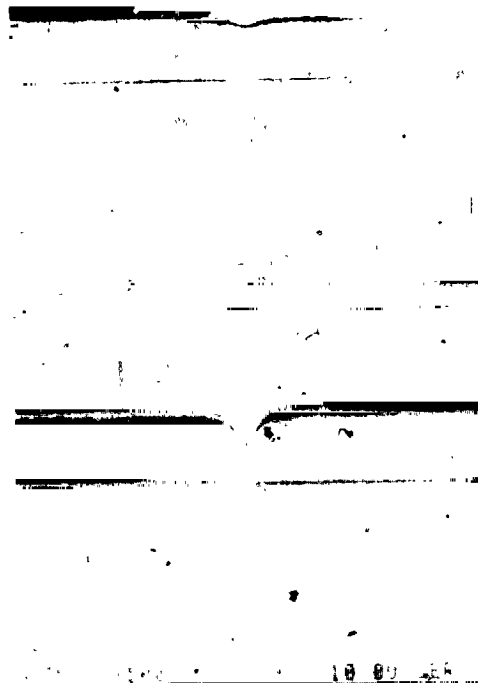
Procedure for Copper Decoration

1. ETCH 1 CM THICK SAMPLE IN NaOH
2. APPLY SATURATED, HOT CuSO_4 /WATER TO WARM SAMPLE
3. HEAT TO 850°C FOR 1 HR.
4. COOL TO 750°C OVER A 4 MIN. PERIOD
5. COOL TO 400°C OVER A 2 MIN. PERIOD
6. COOL TO 200°C OVER A 4 MIN. PERIOD
7. COOL TO $<50^\circ\text{C}$ OVER A 4 MIN. PERIOD
8. REMOVE A THIN WAFER ABOUT 2 MM FROM SURFACE OF SAMPLE

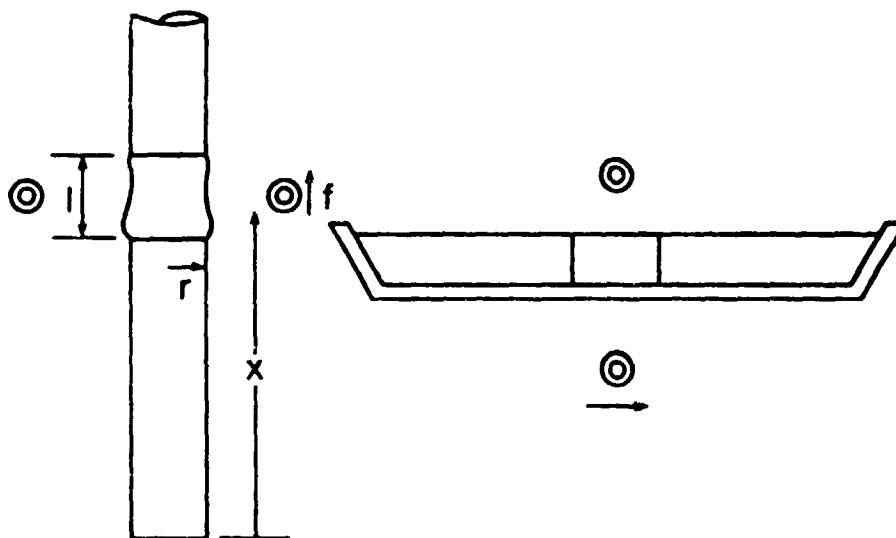


<-TWIN->

<-GRAIN->
BOUNDARY



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$$C_n(x)/C_o = (k/(k+g))^n [1 - (1-k-g)Z_n e^{-(k+g)x}]$$

where

$$Z_n = n - \sum_{s=1}^{n-1} (n-s)(k+g)^{s-1} e^{-s(k+g)} \left(\frac{(s+x)^{s-2}}{s!} \right) \{ (s-1)x + (s+x)[1 - (k+g)x] \}$$

and

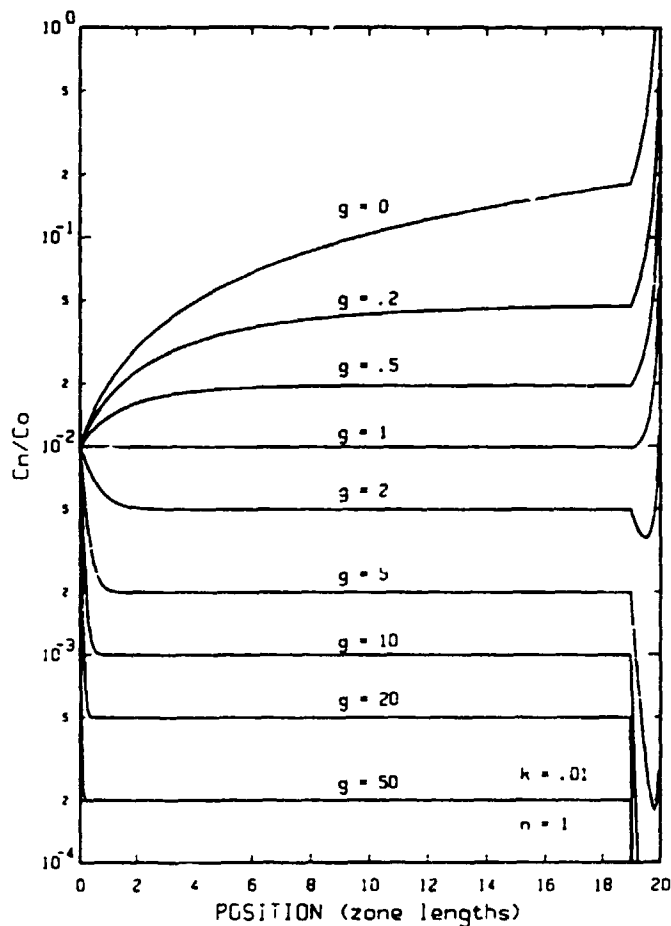
- n = number of zone passes
- k = effective segregation coefficient
- g = effective evaporation coefficient
- x = position in units of zone length
- C_o = original uniform impurity concentration
- $C_n(x)$ = impurity concentration at x after n passes.

In the last zone (or for normal freezing):

$$C_n(x) = C_n(N-1)(N-x)^{(k-1)} e^{-g[x-(N-1)]}$$

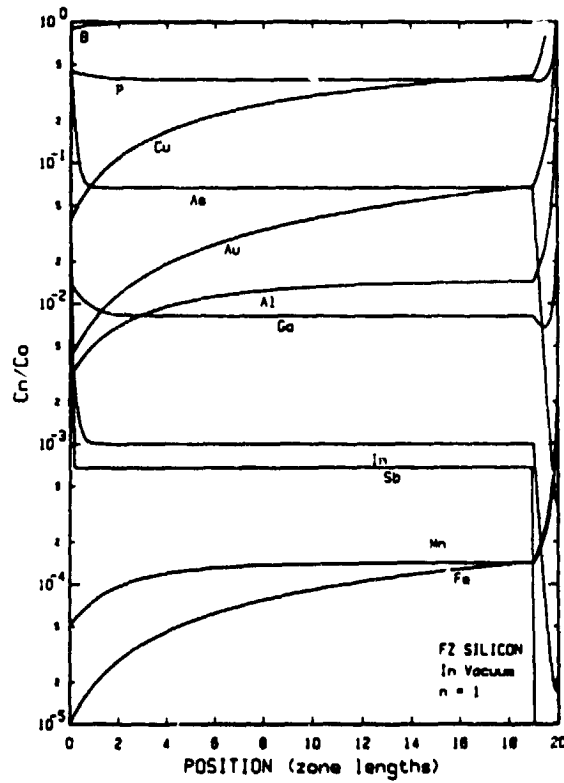
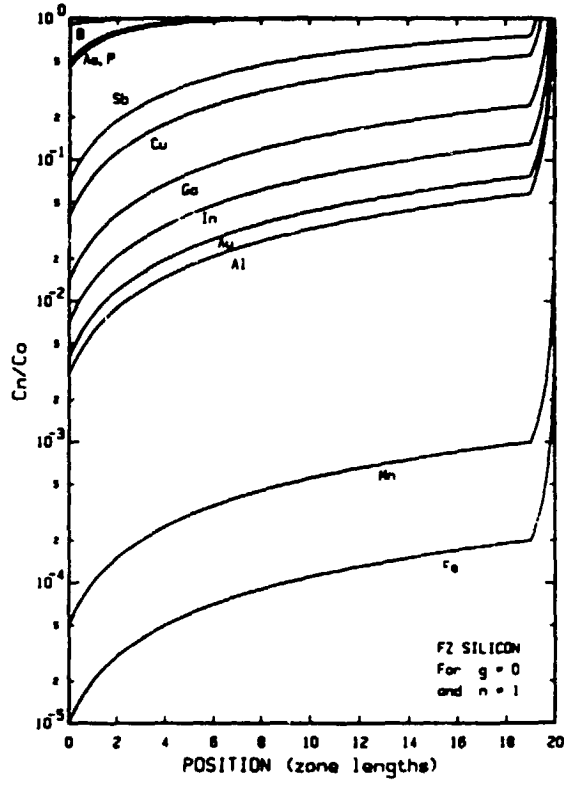
where $N-1 < x < N$ and N = ingot length in zone length units.

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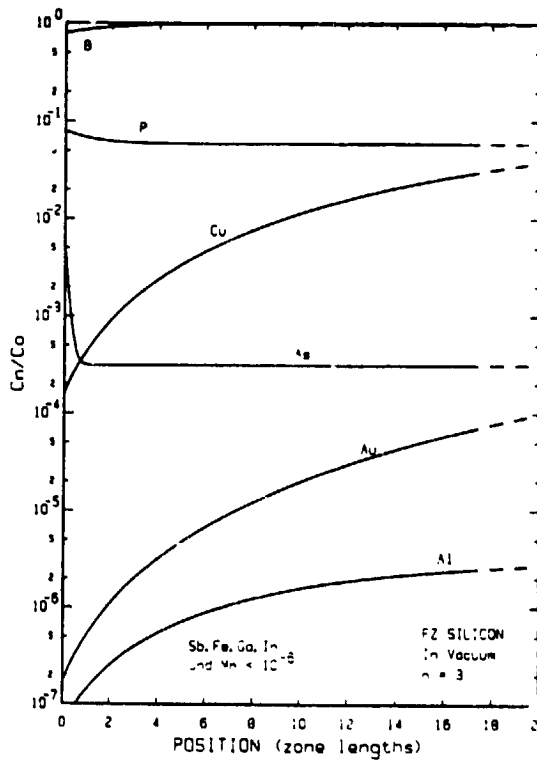
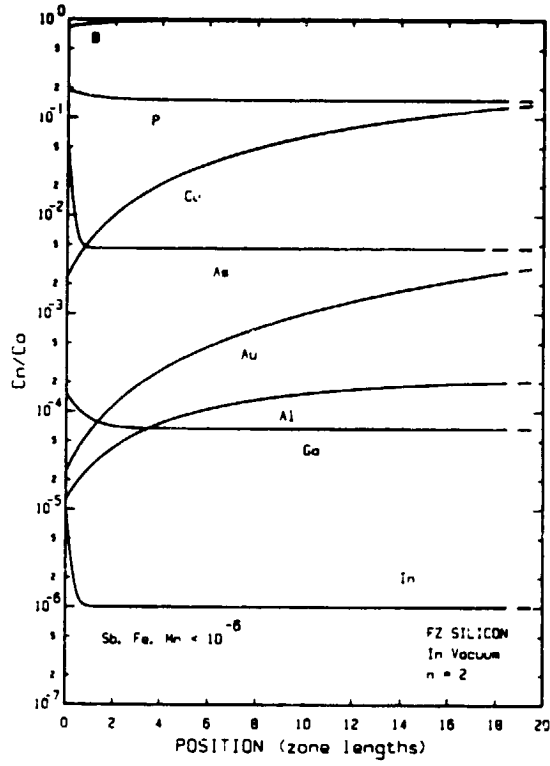


Impurity in Silicon	Effective Segregation Coefficient	Effective Evaporation Coefficient
Aluminum	0.003 (a)	0.2 (e)
Antimony	0.07 (a)	100 (e)
Arsenic	0.5 (a)	7 (e)
Boron	0.9 (a)	0.007 (e)
Copper	0.04 (b)	0.035 (b)
Gallium	0.014 (a)	1.7 (e)
Gold	0.004 (b)	0.012 (b)
Indium	0.007 (a)	7 (e)
Iron	0.00001 (c)	0.035 (e)
Manganese	0.00005 (c)	0.35 (e)
Phosphorus	0.45 (d)	0.71 (d)

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ORIGINAL FIGURE IS
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Growth configuration for studying minority carrier lifetime
as a function of crystal cooling rate after solidification



Growth of a 34 mm diameter [100] dislocation-free FZ crystal

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Gallium Doping

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$$m = WCV/kL_A$$

WHERE

m = MASS OF PURE GALLIUM APPLIED TO SEED END OF INGOT

W = ATOMIC WEIGHT OF GALLIUM

C = DESIRED UNIFORM DOPANT CONCENTRATION IN CRYSTAL

V = ZONE MELT VOLUME

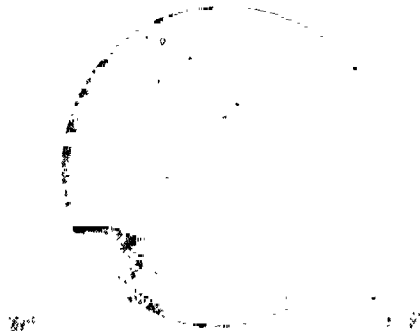
k = EFFECTIVE SEGREGATION COEFFICIENT OF Ga IN Si

L_A = AVOGADRO'S NUMBER

m IS ABOUT 6 mg FOR A 0.3 OHM-CM, 34 mm DIAMETER CRYSTAL



(220) X-ray topograph (nuclear emulsion plate) of a dislocation-free, 0.34 Ohm-cm, Ga-doped, (100) wafer from a float-zoned, [100] crystal with minority carrier recombination lifetime >200 microseconds



(422) X-ray topograph (DEF-5 film) of a copper-decorated vacuum float-zoned, dislocation-free (111) silicon wafer

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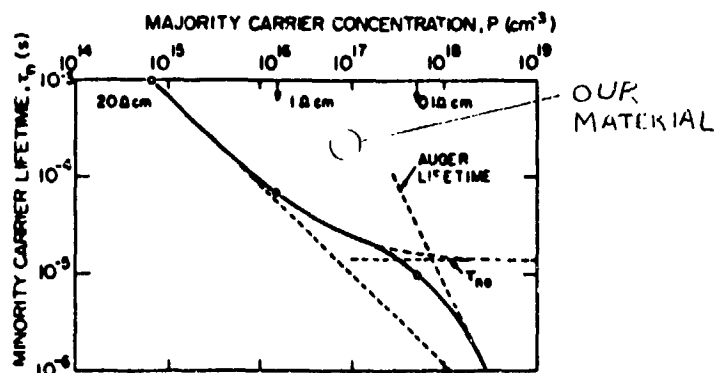
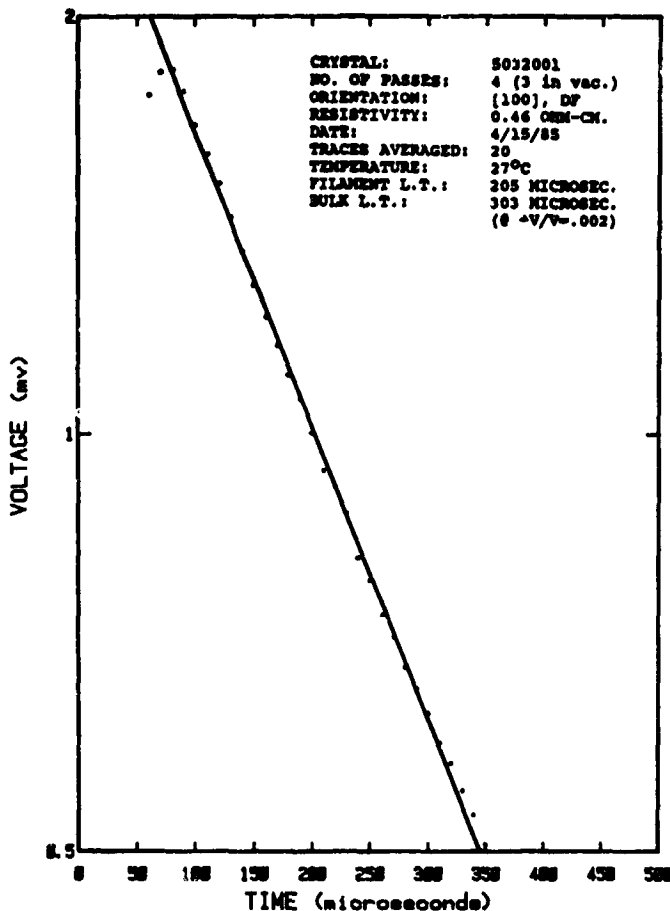
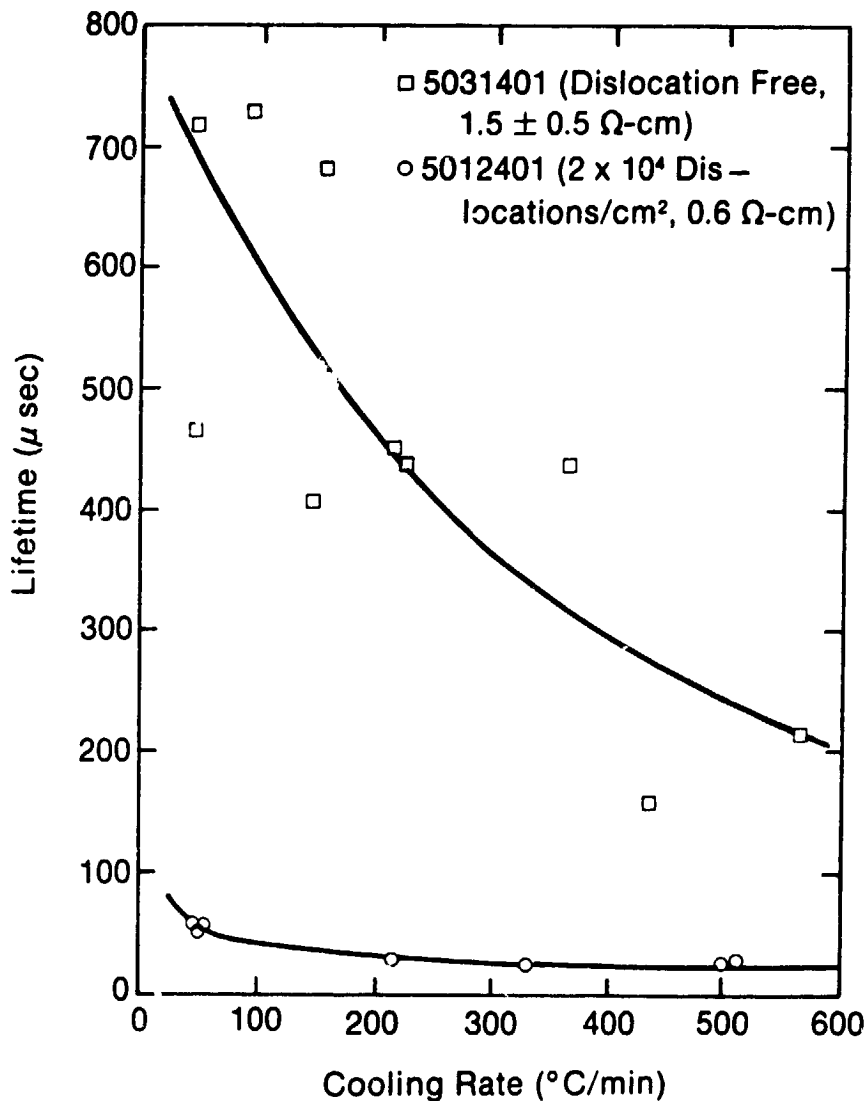


Fig. 3. The minority-carrier lifetime versus majority-carrier concentration relationship used for p-type material. For n-type material the Auger cutoff is shifted slightly towards lower concentrations. Otherwise, τ_p is taken as identical to τ_n . The three circles indicate the points determined by the experts group (see Acknowledgment).
 (from Welf)

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Future Plans

- A. INVESTIGATE DOPANT SPECIES EFFECTS ON MINORITY CARRIER LIFETIME
- B. INVESTIGATE FEED ROD CLEANING EFFECTS ON MINORITY CARRIER LIFETIME
- C. INVESTIGATE SURFACE PROXIMITY EFFECTS ON MINORITY CARRIER LIFETIME
- D. GROW AND CHARACTERIZE HIGH-LIFETIME, HEAVILY-DOPED, FZ CRYSTALS