HIGH-PURITY SILICON CRYSTAL GROWTH INVESTIGATIONS
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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 DECORATION 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
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.
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.
Current Meter
DC Power Supply
N.C. Reversing Switch
Filament
Si Light Filter
Stroboscope
GenRad GR 1538 A

Oscilloscope
Nicolet 2090 III

Plotter Printer Disk Storage
Computer HP-86B

Sample no 5041u1TE
36 ohm-cm P-type (Ga)
600mA 26°C
30-250 μS LSF <20>
Sample number: 50411010TE Date: 5/13/85 Total of 30 traces averaged.
Peak voltage: 2.7454V 4V/V: 1.066-3 at 30 μs
Filament lifetime: 1.66 Bulk lifetime: 214 μs
Sample dimensions Estimated: 7.5 7.5 27 OR Diameter: 0 Rs=1.275.6

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

Plot for points from t=30 to 250 μs
LST Done 32.8 Minutes
LITPLOT

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Procedure for Copper Decoration

1. ETCH 1 CM THICK SAMPLE IN NaOH
2. APPLY SATURATED, HOT CuSO4/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°C OVER A 4 MIN. PERIOD
8. REMOVE A THIN WAFER ABOUT 2 MM FROM SURFACE OF SAMPLE
\[ C_n(x)/C_o = (k/(k+g))^n \left[ 1-(1-k-g)Z_n e^{-(k+g)x} \right] \]

where

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

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.
### Impurity in Silicon

<table>
<thead>
<tr>
<th>Impurity</th>
<th>Effective Segregation Coefficient</th>
<th>Effective Evaporation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>0.003 (a)</td>
<td>0.2 (e)</td>
</tr>
<tr>
<td>Antimony</td>
<td>0.07 (a)</td>
<td>100 (e)</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0.5 (a)</td>
<td>7 (e)</td>
</tr>
<tr>
<td>Boron</td>
<td>0.9 (a)</td>
<td>0.007 (e)</td>
</tr>
<tr>
<td>Copper</td>
<td>0.04 (b)</td>
<td>0.035 (b)</td>
</tr>
<tr>
<td>Gallium</td>
<td>0.014 (a)</td>
<td>1.7 (e)</td>
</tr>
<tr>
<td>Gold</td>
<td>0.004 (b)</td>
<td>0.012 (b)</td>
</tr>
<tr>
<td>Indium</td>
<td>0.007 (a)</td>
<td>7 (e)</td>
</tr>
<tr>
<td>Iron</td>
<td>0.00001 (c)</td>
<td>0.035 (e)</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.00005 (c)</td>
<td>0.35 (e)</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.45 (d)</td>
<td>0.71 (d)</td>
</tr>
</tbody>
</table>
ADVANCED SILICON SHEET

FZ SILICON
For g = 0
and n = 1

FZ SILICON
In Vacuum
n = 1
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
ADVANCED SILICON SHEET

Gallium Doping

\[ m = \frac{WCV}{kL_A} \]

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
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, $\tau_p$ is taken as identical to $\tau_n$. The three circles indicate the points determined by the experts group (see Acknowledgment).
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