ADVANCED SILICON SHEET

N87-16406

STRESS AND EFFICIENCY STUDIES IN EDGE-DEFINED FILM-FED GROWTH

MOBIL SOLAR ENERGY CORPORATION

J. Kalejs

<table>
<thead>
<tr>
<th>TECHNOLOGY ADVANCED MATERIALS RESEARCH TASK</th>
<th>REPORT DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>APPROACH STRESS AND EFFICIENCY STUDIES IN EFG</td>
<td></td>
</tr>
<tr>
<td>CONTRACTOR MOBIL SOLAR ENERGY CORPORATION, CONTRACT NUMBER 956312</td>
<td></td>
</tr>
</tbody>
</table>

STATUS:

- Stress analysis shows potential for reducing sheet stress at lower growth speeds (<2 cm/min for EFG) exists:
  - When sheet edges are cooler than centerline.
  - Reductions sensitive to creep below 1200°C.
- Quantitative relationships established between L and N_d for FZ silicon stressed above 900°C:
  - \( L \sim N_d^{-1/4} \).
  - Point defect contributions to degradation defined.
- Dopants in EFG material shown to influence dislocation activity, point defect recombination.

Topics of Presentation

- Brief summary of work 1982-86.
- Developments since 25th PIM.

229
Stress Studies, 1982-1986: Accomplishments

- Developed finite element analysis for calculating residual stress with plastic deformation in high speed sheet growth (with Prof. J. Hutchinson, Harvard U.).

- Verified quantitative finite element model for EFG control variable relationships/temperature profile calculations (with Prof. R.A. Brown, MIT).

- Developed residual stress measurement technique for EFG material using shadow Moire interferometry (with Prof. S. Danyluk, U. of Illinois at Chicago).

- Transient creep investigated in silicon for 800-1400°C in strain (10^-3) and strain rate (10^-4 s^-1) regimes of sheet growth.

Defect Electrical Activity Studies, 1984-1986: Accomplishments

- Developed quantitative minority carrier diffusion length measurements for dislocated, inhomogeneous material using EBIC.

- Obtained quantitative data on dopant (B, Ga) influence on defect densities and electrical activity in EFG material.

Dislocation Electrical Activity

- L vs. \( N_d \) relationships established for FZ silicon stressed in temperature range 900-1400°C
  - Microdefect recombination limits in \( N_d \leq 10^4 \text{ cm}^{-2} \) regions.
  - Dislocation effects give \( L \sim N_d^{-1/4} \) above \( N_d \) threshold that depends on microdefect recombination level.

- Contrast to as-grown dislocation activity for which \( L \sim N_d^{-1/2} ( \sim N_d^{-1}) \).
Diffusion Length Dependence on Heat Treatment and Dislocation Density

\[ \tau = \frac{L^2}{D} \]

where:

\[ \frac{1}{\tau_c} = \frac{1}{\tau_0} + \frac{1}{\tau_d} \]

\[ \frac{1}{\tau_d} = \frac{2\pi S_d \rho_d N_d}{\lambda T} \]

[Graph showing diffusion length vs. dislocation density with various temperature and time conditions marked]

**ORIGINAL PAGE 2**

**OF POOR QUALITY**

231
ADVANCED SILICON SHEET

EBIC Line Scans of Dislocations in High and Low Resistivity EFG Silicon Ribbon

---

EBIC Signal

Scan distance x

---

1.0 μm

---

0.2Ω-cm Gallium

3.0Ω-cm Boron
Dislocation Versus Point Defect Limitations on Lifetime

- Results suggest electrical activity of grown-in dislocations differs from creep-related dislocations.

- \( L \sim N_d^{-1/4} \) \( (\tau \sim N_d^{-1/2}) \); dependence may be related to dislocation "debris" or total area swept-out by dislocations, requires point defect-dislocation interaction dynamics to be included.

- \( L \) is not equal to mean dislocation separation \( \ell = N_d^{-1/2} \) for any situation, indicating only small fraction of core sites are active.

233
ADVANCED SILICON SHEET

Future Directions for Electrical Activity Studies

Development of passivation schemes for defects and processing/passivation optimization crucial to viability of current sheet material for low-cost photovoltaic industry.

Current EFG Status:
\[ L: \text{100-200 microns} \]
\[ \eta: \text{13-15\% (45 cm}^2\text{ areas)} \]

Future Requirements:
\[ L: \text{200-300 microns} \]
\[ \eta: \text{>16\%} \]

Fundamental need is for development of models for and identification of relative contributions of point defects and dislocations to lifetime limitations, particularly in low resistivity silicon.

- Finite element modeling of effects of transverse isotherm nonuniformity on stress

- Stress redistribution in finite size blanks
  - L. Bucciarelli (MIT).

- Stress relaxation measurement in silicon between 800°C and 1200°C
  - Plans for experiments.
Advanced Silicon Sheet

Transverse Isotherm Effects: Conclusions

- Nonuniformity leads to higher maximum stress in the sheet
  - Increases tendency for buckling.
  - Increases defect density.
  - Only edge cooling reduces residual stress.

- Significant compensation for high axial temperature profile nonuniformity cannot be produced for moderate (100-300°C) edge cooling.

- Residual stress distribution is fundamentally altered
  - Possible there are temperature distributions which reduce stress to zero.
  - Creep behavior between 800°C and 1200°C needs to be studied.
Coordination of Frame and Stress Components
Sign Convention

FIGURE 1.
COORDINATE FRAME & STRESS COMPONENTS
SIGN CONVENTION
ADVANCED SILICON SHEET

Residual Stress Distribution in Semi-Infinite Ribbon

Note: $y=0$ is ribbon center line
Note: $\sigma_{xx}$ is plotted; other stress components are zero.

Stress Component Variation with "x" at $y = 0.0$

Note: Half length of ribbon $L = 4*(\text{the half width})$
Note: For $x$ negative:
- $\sigma_{xx}$ is symmetrical
- $\sigma_{yy}$ is symmetrical
- $\sigma_{xy}$ is antisymmetrical
Advanced Silicon Sheet

Stress Component Variation with "x" at y = 0.5

Stress Redistribution in Finite Size Blanks: Summary

- Method for calculating shear flow developed
  - Can be obtained for any size blank.
  - Can be related to grown-in thermoelastic stress in semi-infinite sheet.

- Significant stress redistribution at blank end produces large tensile non-zero \( \sigma_{yy} \) component.

Stress Relaxation Measurements in Silicon (800°C – 1200°C)

- Previous creep measurements obtain
  \[
  \frac{\partial \varepsilon}{\partial t}, \sigma \text{ constant}
  \]

  Constitutive law: \( \varepsilon \sim F(T) \sigma^N \)

- Relaxation measurements will obtain
  \[
  \frac{\partial \sigma}{\partial t}, \varepsilon \text{ constant}
  \]