ADVANCED SILICON SHEET

N87-16406

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

MOBIL SOLAR ENERGY CORPORATION

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TECHNOLOGY	REPORT DATE
ADVANCED MATERIALS RESEARCH TASK	APRIL 30, 1986
APPROACH STRESS AND EFFICIENCY STUDIES IN EFG **CONTRACTOR** MOBIL SOLAR ENERGY CORPORATION, CONTRACT NUMBER 956312	STATUS: • STRESS ANALYSIS SHOWS POTENTIAL FOR REDUCING SHEET STRESS AT LOWER GROWTH SPEEDS ($\leq$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.
GOALS • TO DEFINE MINIMUM STRESS CONFIGURATION FOR SILICON SHEET GROWTH. • TO QUANTIFY DISLOCATION ELECTRICAL ACTIVITY AND LIMITS ON CELL EFFICIENCY. • TO STUDY BULK LIFETIME DEGRADATION DUE TO INCREASE IN DOPING LEVELS.	

Topics of Presentation

- BRIEF SUMMARY OF WORK 1982-86.
- DEVELOPMENTS SINCE 25TH PIM.

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.

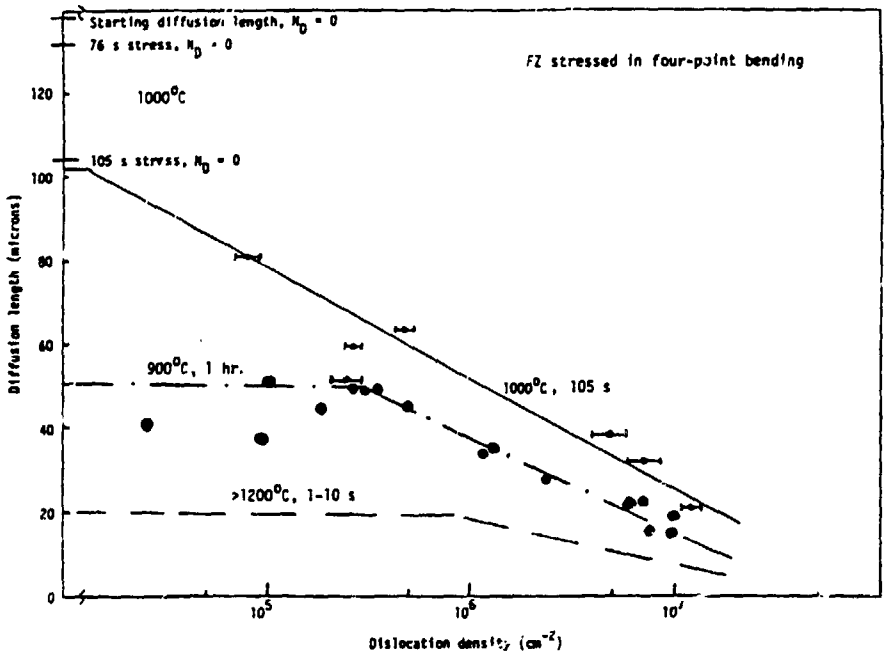
Defect Electrical Activity Studies, 1984-1986: Accomplishments

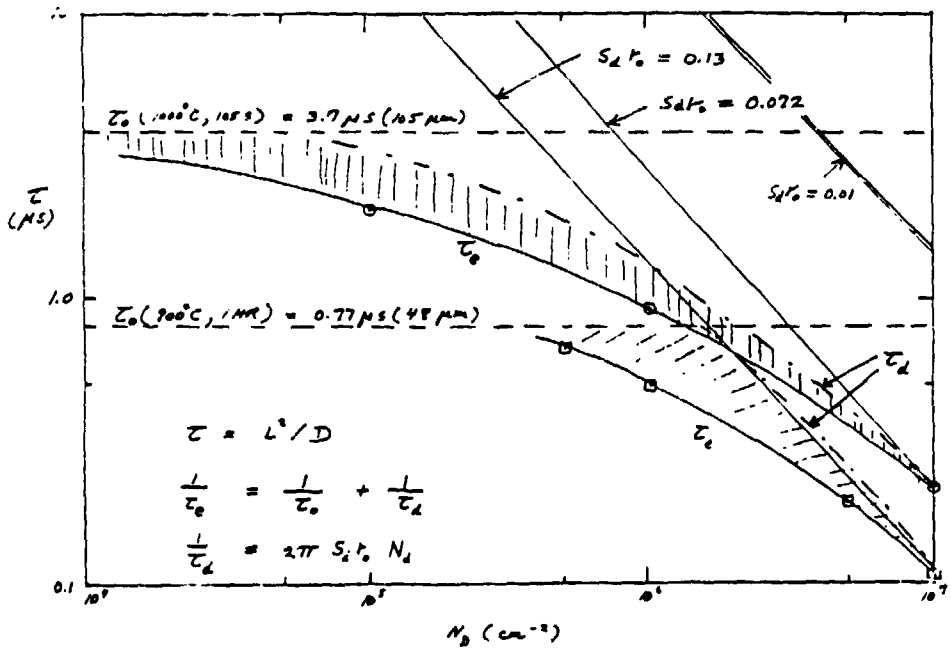
- Developed quantitative minority carrier diffusion length measurements for dislocated, inhomogeneous material using EBIC.
- Obtained quantitative data on dopant (B, Ga) influence on defect densities and electrical activity in EFG material.

Dislocation Electrical Activity

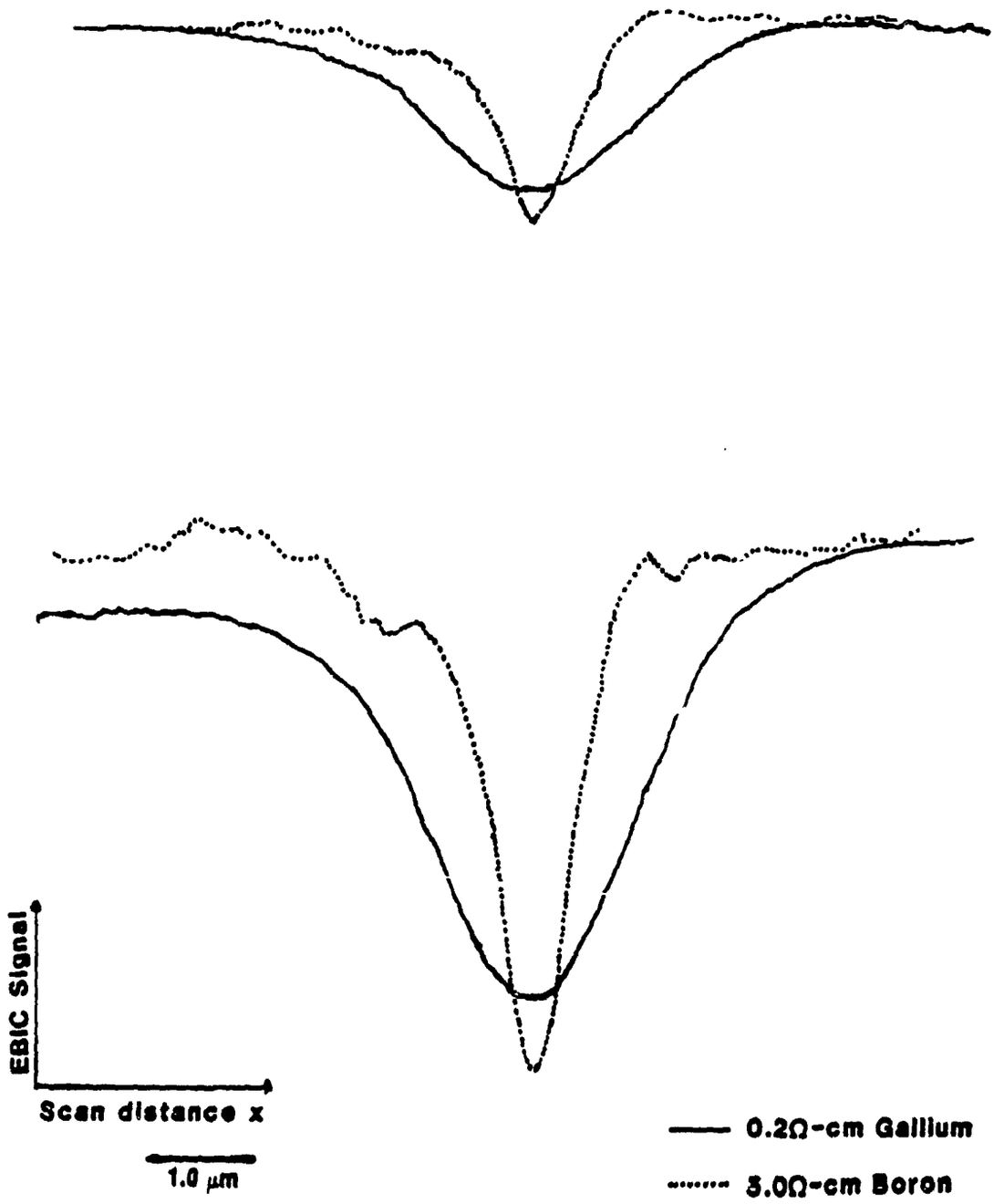
- L vs. N_d relationships established for FZ silicon stressed in temperature range 900-1400°C
  - Microdefect recombination limits in $N_d \lesssim 10^4$ cm^{-2} regions.
  - Dislocation effects give $L \sim N_d^{-1/4}$ above N_d threshold that depends on microdefect recombination level.
- Contrast to as-grown dislocation activity for which $L \sim N_d^{-1/2}$ ($\tau \sim N_d^{-1}$).

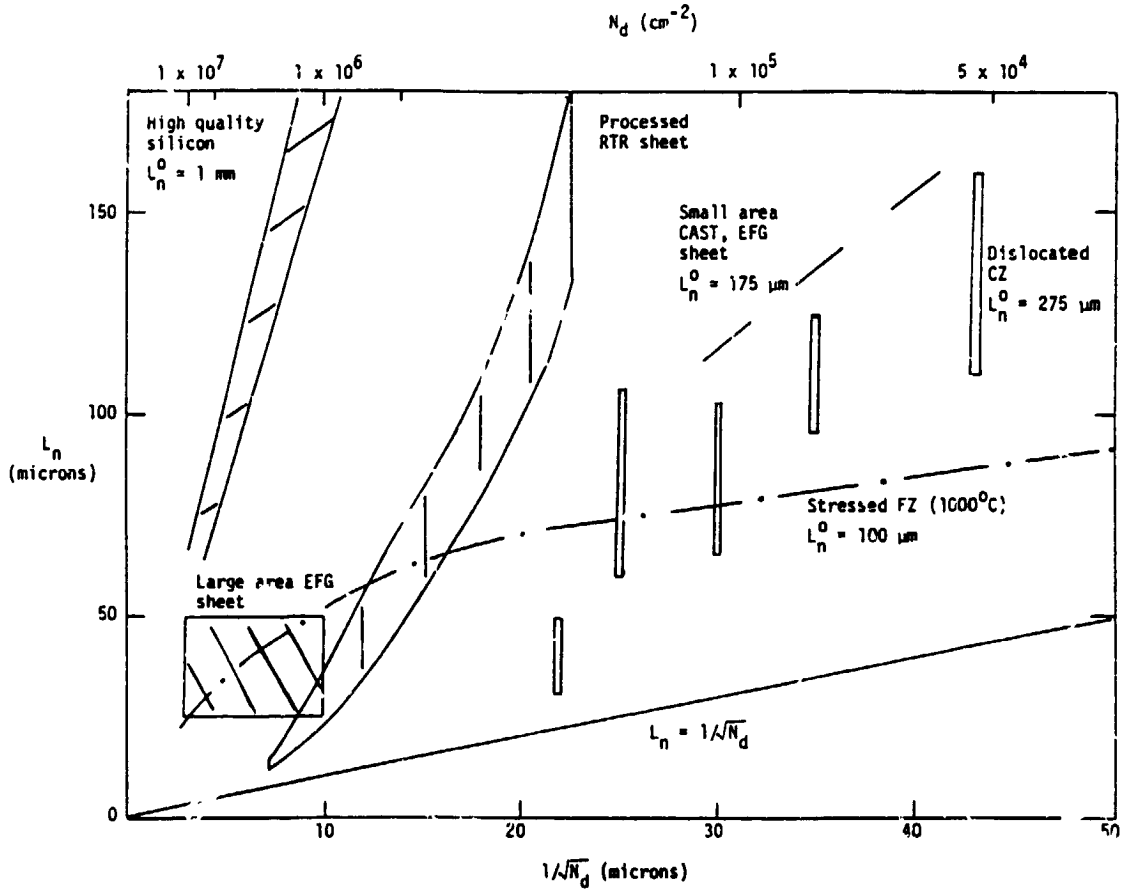
Diffusion Length Dependence on Heat Treatment and Dislocation Density





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





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.

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:

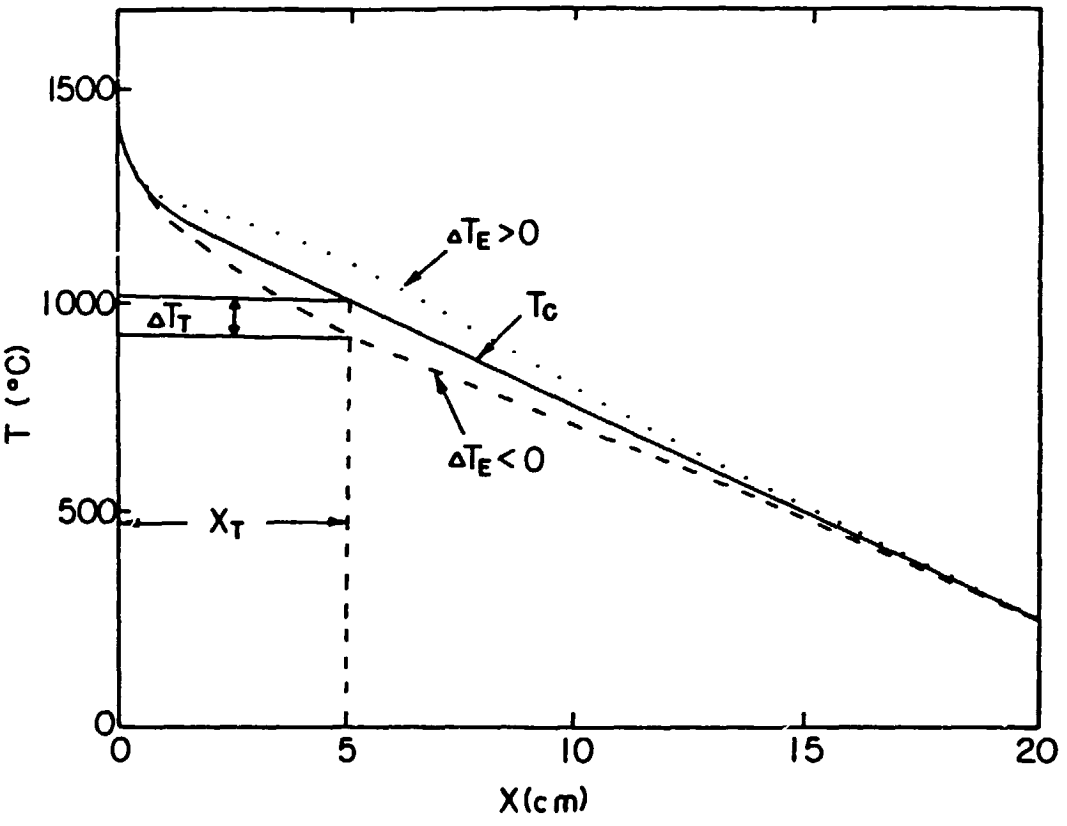
L: 100-200 MICRONS
η: 13-15% (45 CM^2 AREAS)

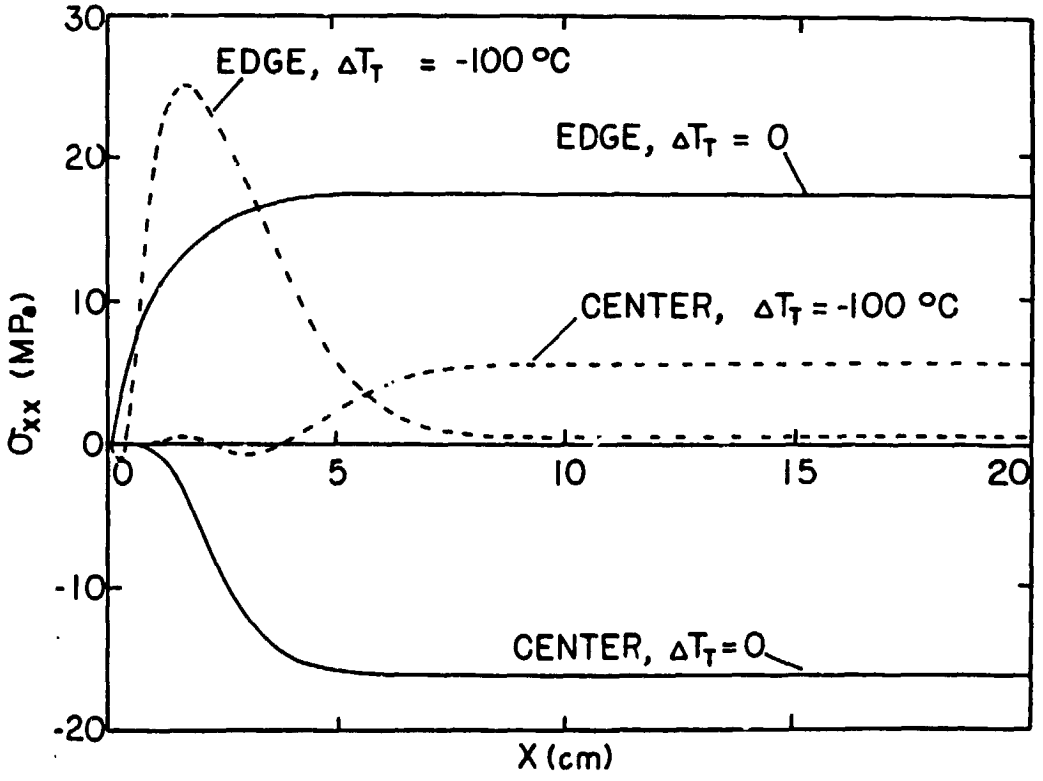
FUTURE REQUIREMENTS:

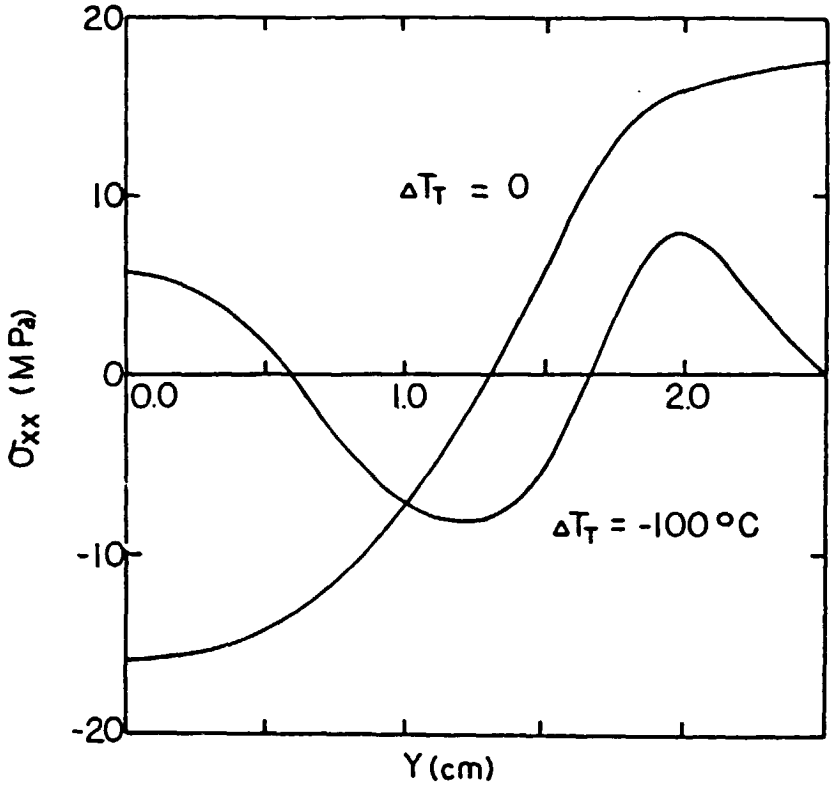
L: 200-300 MICRONS
η: $\geq$16%

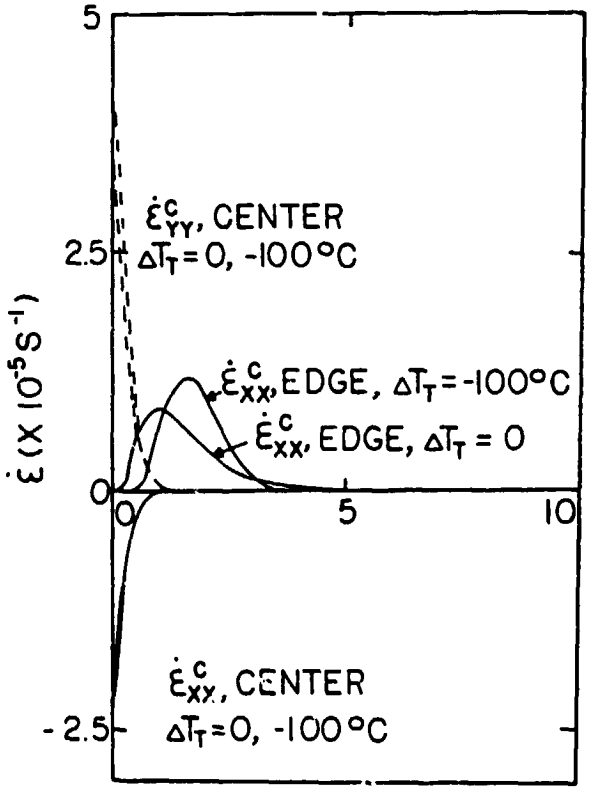
FUNDAMENTAL NEED IS FOR DEVELOPMENT OF MODELS FOR AND IDENTIFICATION OF RELATIVE CONTRIBUTIONS OF POINT DEFECTS AND DISLOCATIONS TO LIFETIME LIMITATIONS, PARTICULARLY IN LOW RESISTIVITY SILICON.

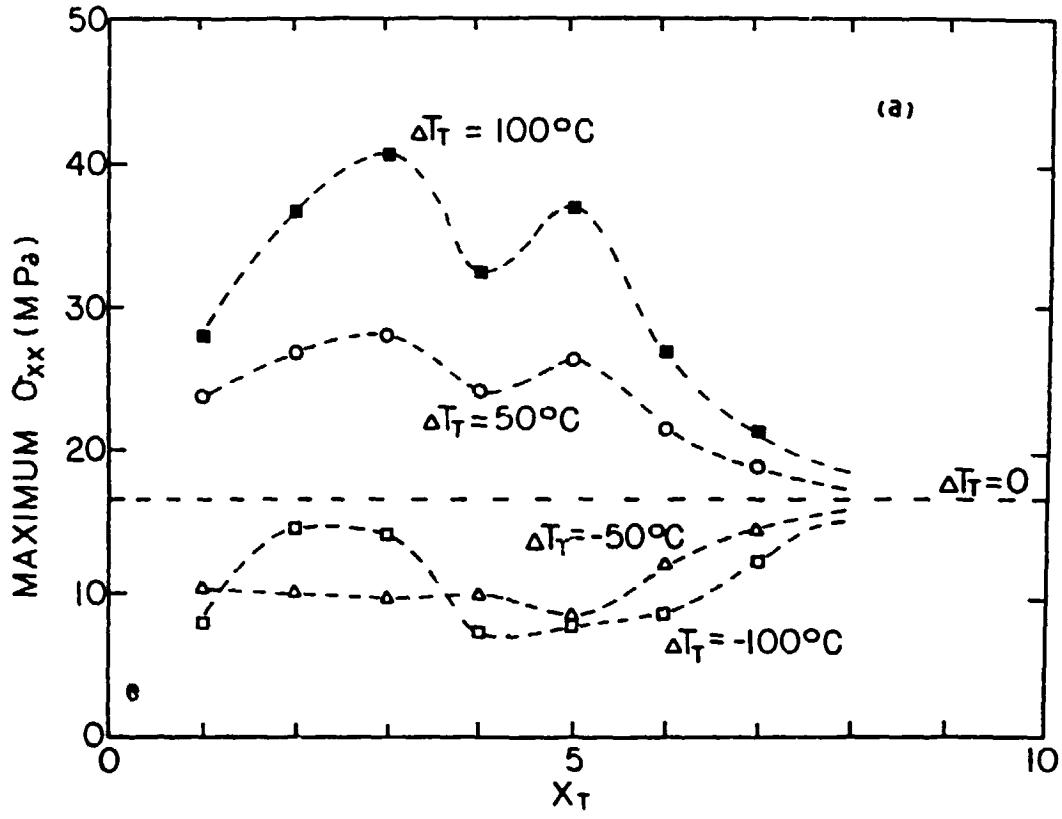
- FINITE ELEMENT MODELING OF EFFECTS OF TRANSVERSE ISOTHERM NONUNIFORMITY ON STRESS
  - P. MATAGA, J. HUTCHINSON (HARVARD U.).
- STRESS REDISTRIBUTION IN FINITE SIZE BLANKS
  - L. BUCCIARELLI (MIT).
- STRESS RELAXATION MEASUREMENT IN SILICON BETWEEN 800°C AND 1200°C
  - PLANS FOR EXPERIMENTS.


1500
1000
500
0
T (°C)
ΔT_E > 0
ΔT_T
T_C
ΔT_E < 0
X_T
0
5
10
15
20
X(cm)


30
20
10
0
-10
-20
σxx (MPa)
EDGE, ΔT_T = -100 °C
EDGE, ΔT_T = 0
CENTER, ΔT_T = -100 °C
CENTER, ΔT_T = 0
0
5
10
15
20
X (cm)


20
10
0
-10
-20
0.0
1.0
2.0
σ_{xx} (MPa)
Y (cm)
ΔT_T = 0
ΔT_T = -100 °C


5
2.5
0
-2.5
0
5
10
$\dot{\varepsilon}$ (X 10^{-5} S^{-1})
$\dot{\varepsilon}^c_{YY}$, CENTER
ΔT_T = 0, -100 °C
$\dot{\varepsilon}^c_{XX}$, EDGE, ΔT_T = -100°C
$\dot{\varepsilon}^c_{XX}$, EDGE, ΔT_T = 0
$\dot{\varepsilon}^c_{XX}$, CENTER
ΔT_T = 0, -100 °C



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

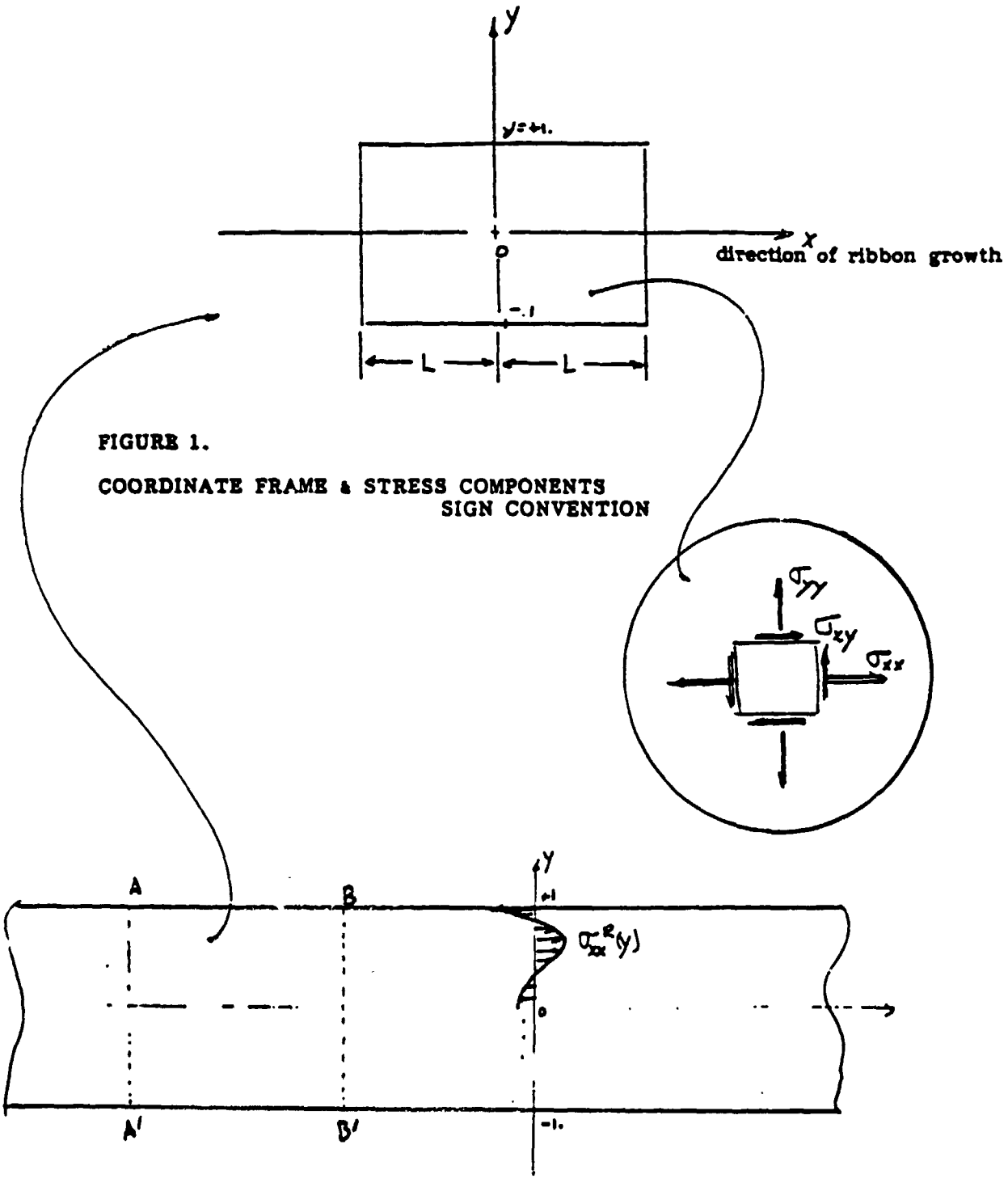
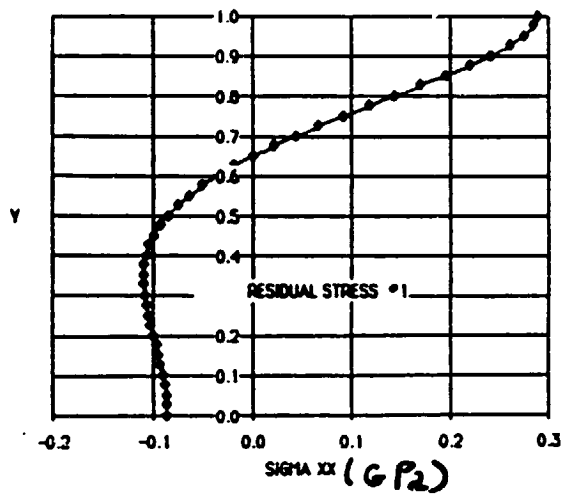


FIGURE 1.

COORDINATE FRAME & STRESS COMPONENTS SIGN CONVENTION

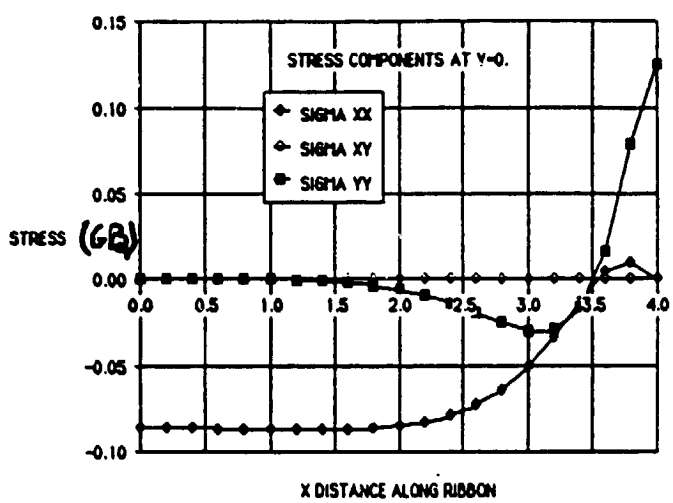
Residual Stress Distribution in Semi-Infinite Ribbon

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

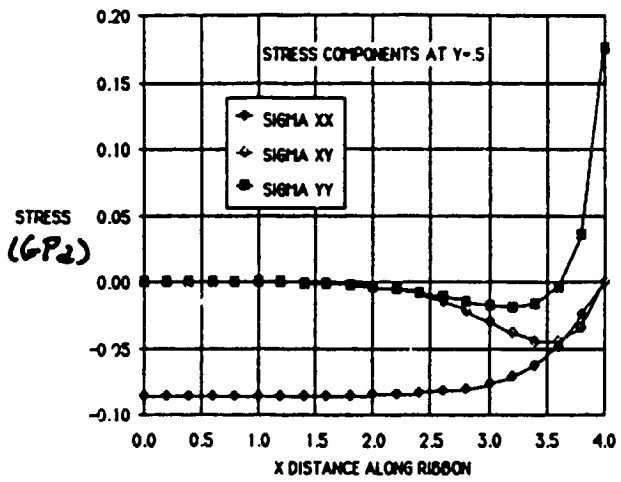


Stress Component Variation with "x" at y = 0.0

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



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 σ_{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: $\dot{\varepsilon} \sim F(T)\, \sigma^N$

- RELAXATION MEASUREMENTS WILL OBTAIN

$$\frac{\partial \sigma}{\partial T}, \ \varepsilon \text{ CONSTANT}$$