

N86-29392

ADVANCED SILICON SHEET

ADVANCED DENDRITIC WEB GROWTH DEVELOPMENT

WESTINGHOUSE ELECTRIC CORP.

R. H. Hopkins

Advanced Silicon Sheet Task

Technology Single Crystal Ribbon Growth	Report Date 6/19/85
Approach Silicon Dendritic Web Growth Contractor Westinghouse Electric Corporation Advanced Energy Systems Division JPL Contract 955843	Status <ul style="list-style-type: none"> • Model-Driven Low Stress Design Led to Record Web Width - 6.7 cm • New Length Record with Continuous Replenishment - 7.5 m (4.1 cm Width) • Area Rates - 8 cm²/min (1.5 m) - 13 cm²/min Short Lengths • 5 cm Wide Webs Grown Regularly • Sensor for Closed Loop Control Based on Dendrite Thickness Demonstrated • Software and Hardware Elements for Closed Loop Control Completed • Plastic Flow Modeling Initiated for Stress Reduction
Goals For 1985 Demonstrate <ul style="list-style-type: none"> • Area Growth Rate of 13 cm²/min (2 m Length) • Area Growth Rate of 16 cm²/min (2 m Length) • Closed Loop Growth Control System 	

Outline

Introduction ————— R. H. Hopkins

- Goals
- Organization

Closed Loop Web Growth System Development

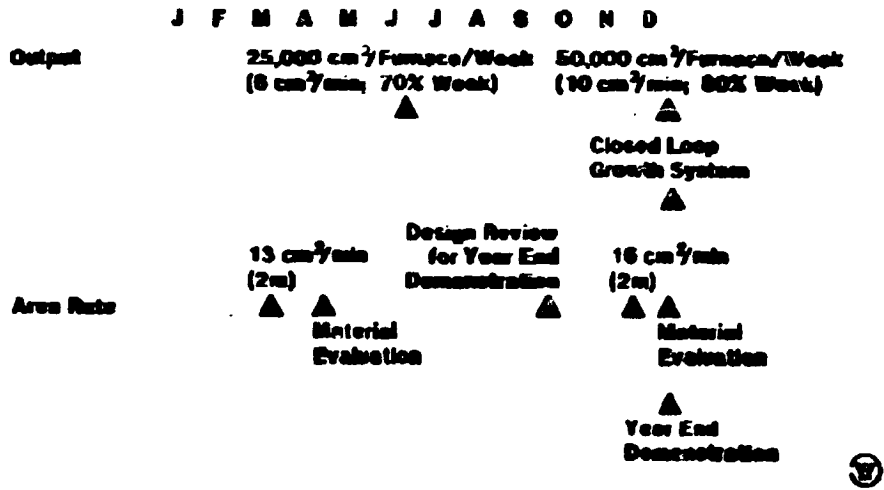
- Dendrite Thickness Monitor
- Closed Loop Control System
- System Monitoring

Stress Reduction for High Area Rate Growth

- Far Stress
- Near Stress

Plastic Deformation ————— J. Spitznagel

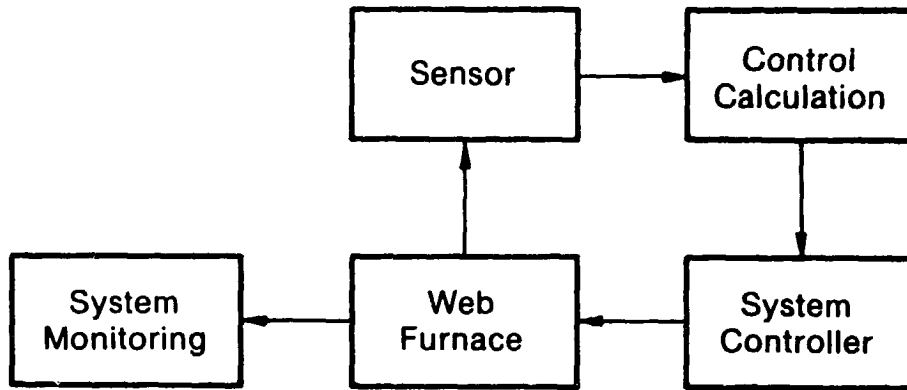
Web Technology Development 1985 Milestones



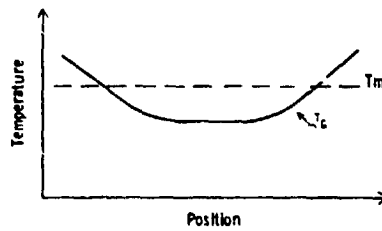
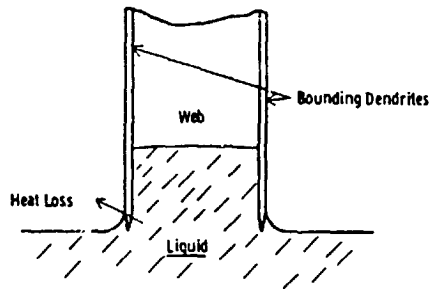
Web Technology Development

Output Team - G.E. Duncan		
System Performance Task	Goals	Date
F.A. Piotrowski	25,000 cm ² /Furnace/Week	6/30/85
Continuous Replacement Task	50,000 cm ² /Furnace/Week	12/31/85
F.A. Pryor/Gr	Closed-Loop Growth Control	12/31/85
Instrumentation and Control Task		
J.R. E. 002		
Area Rate Team - R.H. Hopkins		
Modeling and Analysis Task	Goals	Date
R.G. Seidensticker	13 cm ² /min (2m)	3/31/85
Equipment Concept and Evaluation Task	16 cm ² /min (2m)	12/31/85
J.P. McHugh		
Component Design and Implementation Task		
R.P. Spence		
Characterization Task		
J. Spitznagel		
Information Management - E.L. Kechko		

Closed Loop Web Growth System

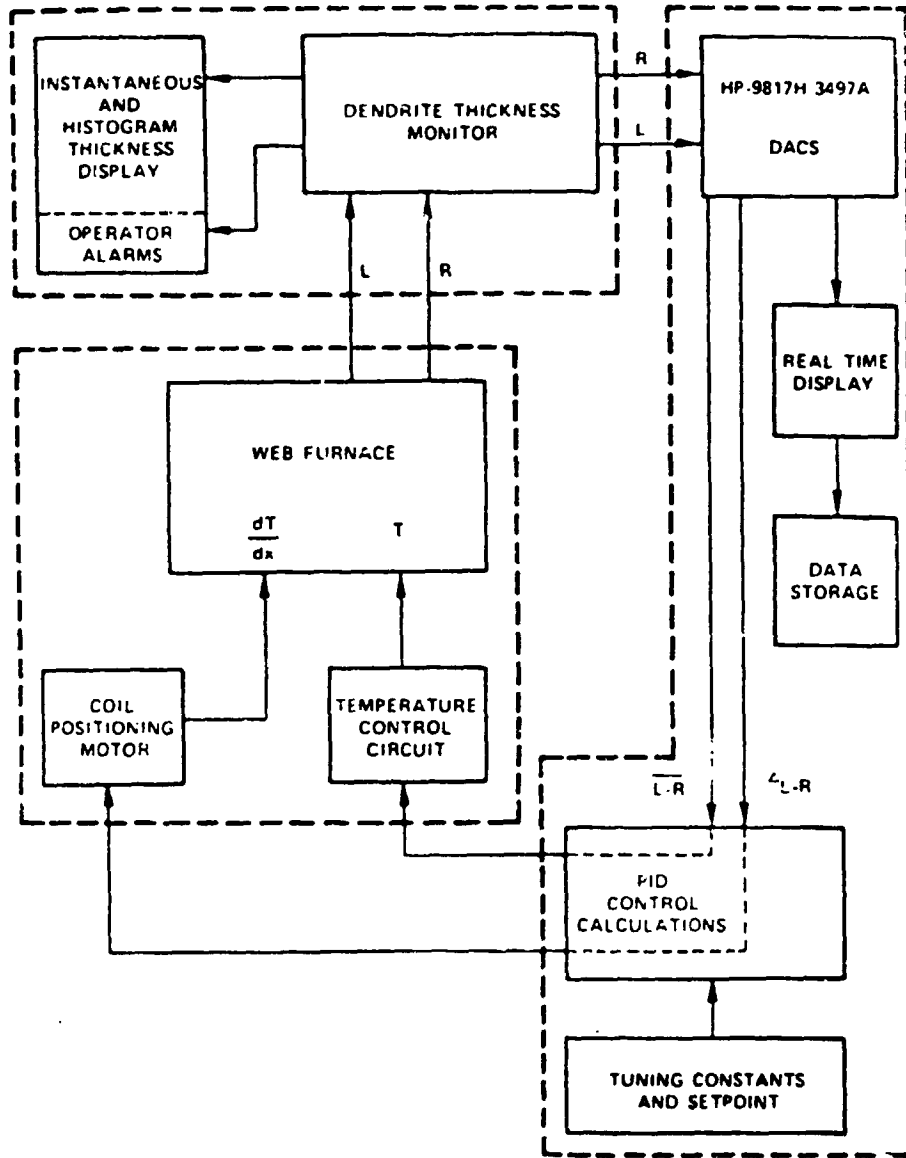


Web Growth Control



- Growth Temperature, T_G - Control Furnace Temperature
- Lateral Symmetry - Control Coil Position

Closed-Loop Control System

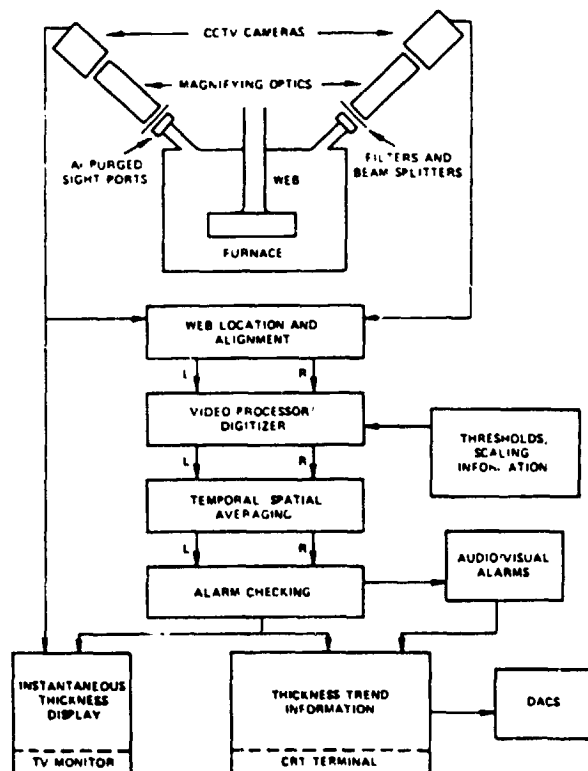


Basis for Web Closed-Loop Control

Dendrite Thickness Controlled Through Digital Feedback Loop

- DTM Provides Input to Two Uncoupled P-I-D Control Equations
 - Average L-R Thickness Controls Temperature
 - Thickness Difference Controls Spatial Temperature Distribution
- RF Coil Position (Left-Right) Adjusted Through PID Output to Motorized Stage for dT/dx Changes
- Temperature (RF Power) Adjusted By Biasing Light Pipe Input to Analog Temperature Controller (Based on PID Control Output)

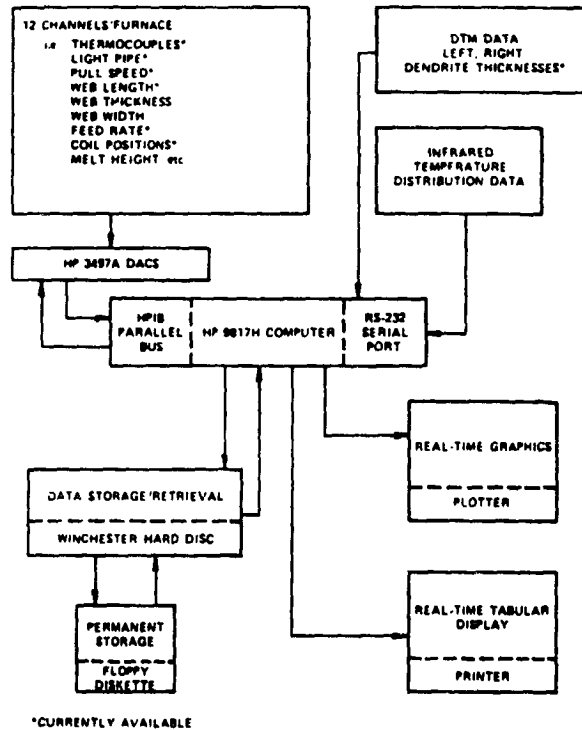
Dendrite Thickness Monitor



Dendrite Thickness Monitor (DTM)

- View-719 VidiconType Dimension Inspection System
- **W** Developed Application Software
 - Visual Display for Operator in Manual Mode
 - Input to Control System in Automatic Mode
- Automatic Calibration and Dendrite Tracking
- Gas Purged Viewport System on Furnace Provides Clean Sightpath
- 50 Microns (1 PIXEL) Resolution; with Software Averaging, Repeatability ~ 10 Microns

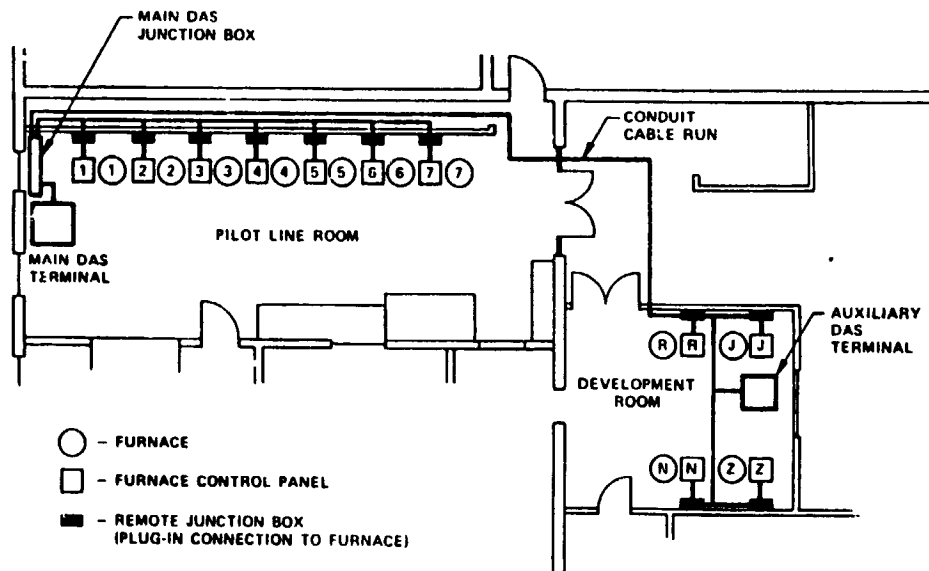
Data Acquisition System



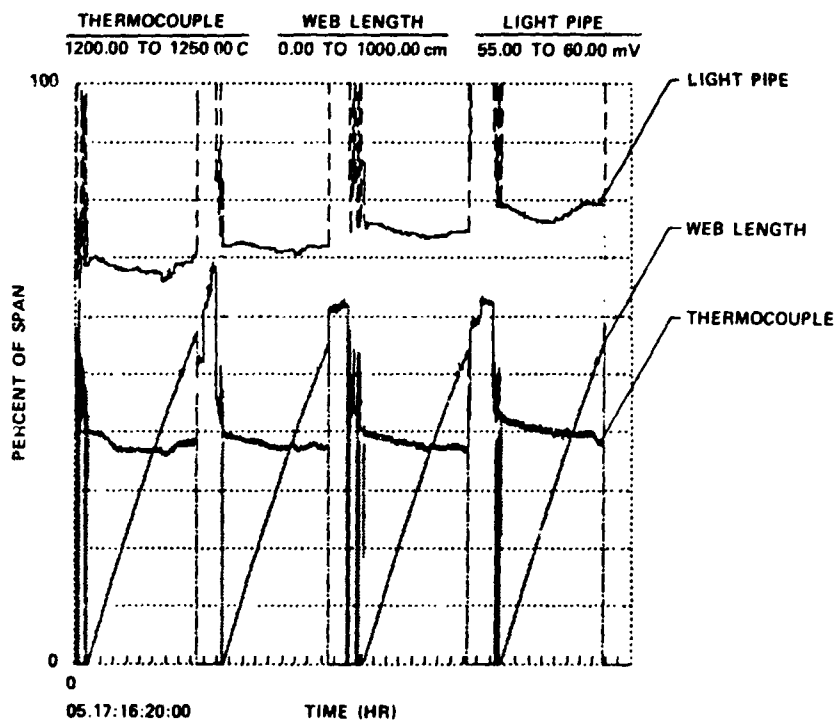
Data Acquisition System (DAS)

- Based on HP-9817H Computer with HP-3497A Data Acquisition System
- Hardware Configuration Allows Maximum of 12 Data Channels Per Furnace
- Anticipated Storage Capacity ~ 1 Week of Data for 11 Furnaces
- Real-Time Graphics or Tabular Display
- Variable Sampling Rate Data Storage with Time Compression/Expansion Capability on Recalled Graphics Display

Data Acquisition Cabling Plan



Monitoring with Real-Time Data Acquisition System



Closed-Loop Development Status

- DTM Tests Successful
 - Operator Acceptance for Manual Operation
 - Adequate Resolution
 - Reduced Terminations/Longer Webs
- Dendrite Thickness Data Compatible with Control Function
- Software for P.I.D. Control Algorithm Complete
- Computer Controlled Coil Positioner and Temperature Control Demonstrated
- Software for Dual Furnace Operation of DTM Complete
- Cabling of Furnaces for Data Acquisition and Monitoring Complete

Area Rate

TECHNICAL ISSUES

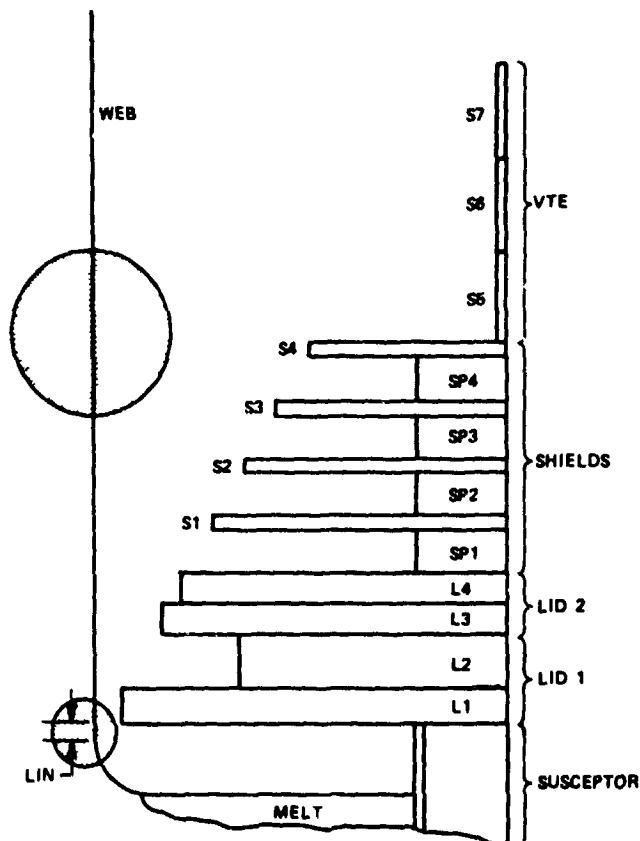
1. Low Stresses → Wide Crystals

- Far Stress
- Near Stress

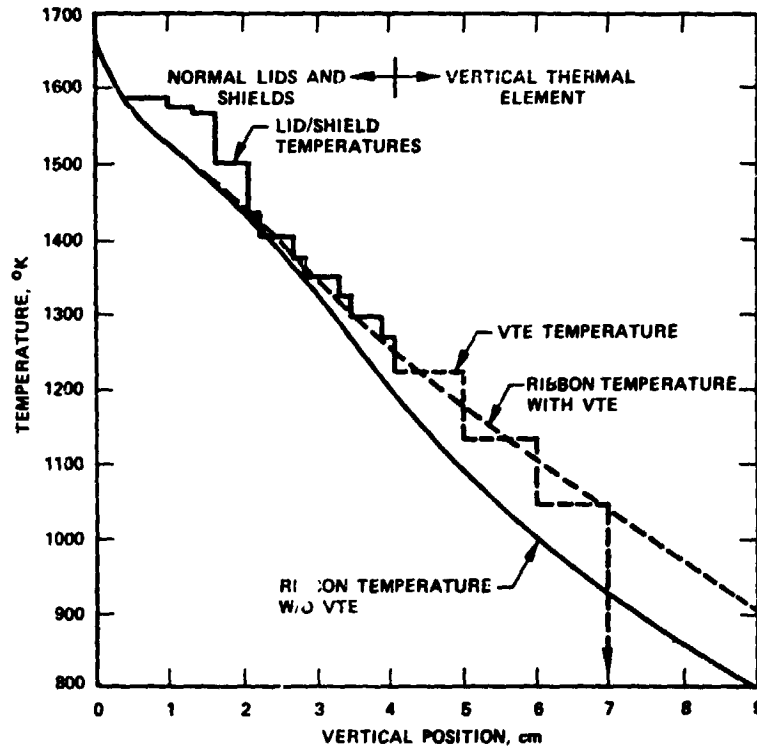
2. Maximum Interface Heat Loss → High Speed

- Growth Stability with Deep Melts
- Stress Trade-Offs

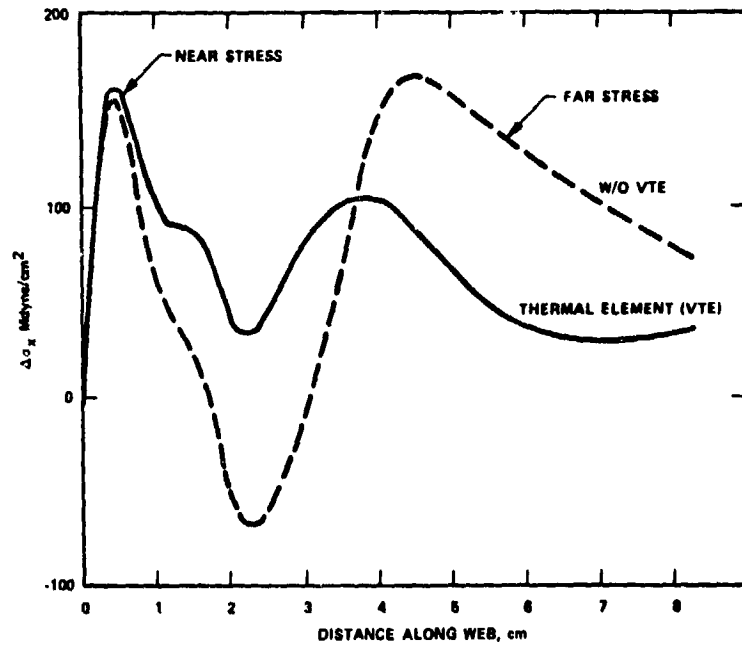
Schematic Growth Configuration (for modeling)



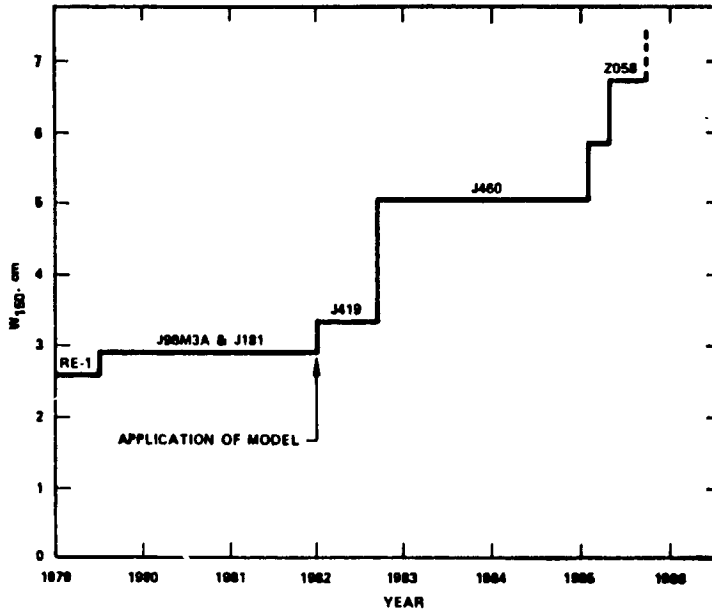
Calculated Web Thermal Profiles



Far Stress Reduction by Thermal Element Above Shield Stack



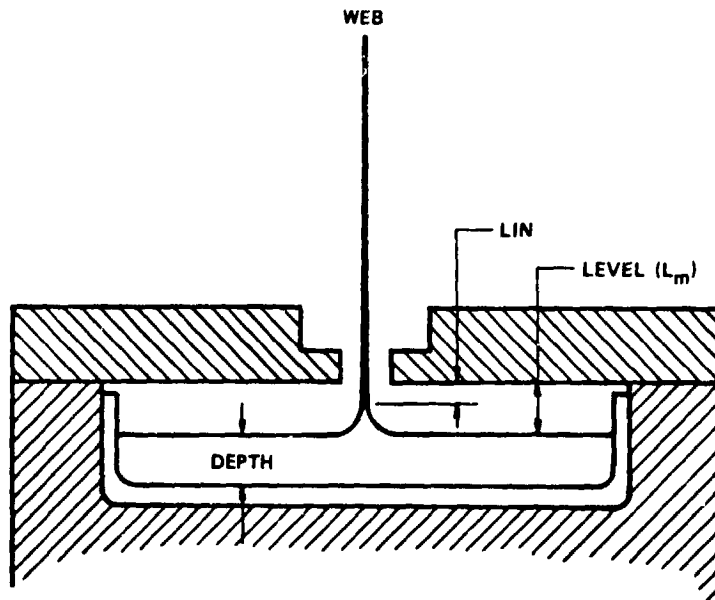
Undeformed Web Width



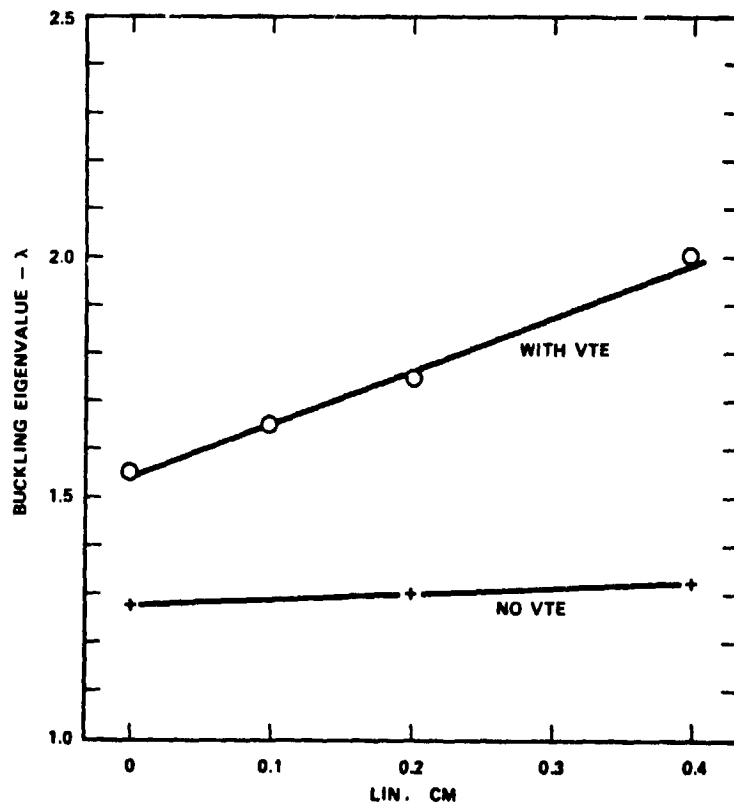
Recent Wide Web Crystals

CRYSTAL	W (cm)	t (μm)	V (cm/min)	Area Rate (cm ² /min)
N126-14	5.0	210	1.13	5.6
N127-3	5.6	170	1.13	6.3
N127-4	5.0	140	1.43	7.1
ZC58-4	5.8	160	1.05	6.1
Z059-2	5.0	135	1.13	5.6
N128-15	4.9	75	1.88	9.2
N128-16	5.2	95	1.65	8.6
N128-19	5.2	130	1.43	7.4
Z060-14	4.5	135	1.57	7.1
R483-10	4.8	145	1.38	6.6
N130-11	5.4	140	1.28	6.9
R485-7	4.8	105	2.04	9.8
N132-2	4.7	145	1.28	6.0
R486-12	5.0	210	1.38	6.9
R486-13	4.8	150	1.38	6.6
N132-2	4.7	145	1.28	6.0
Z063-2	5.5	130	1.35	7.4
J55-13	5.2	125	1.29	11.5
J551-15	5.5	150	1.02	6.7
J552 1	6.7	...	1.29	5.6
J554-1	5.4	170	1.15	8.1
J554 2	5.3	165	1.15	6.2
J555-1	5.0	205	1.15	6.1
J55-6	5.2	85	2.65	5.8
J557-2	5.3	150	1.15	13.3
J557-5	6.4	170	1.29	6.0
J557-6	6.4	190	1.15	7.4
J557-7	5.0	160	1.15	5.8
J557-8	5.3	165	1.15	6.1
J559-8	5.0	170	1.15	6.1
J560-2	6.0	155	1.15	5.8
N141-1	5.2	150	1.28	6.9
Z066-7	5.0	140	1.22	6.7
Z069-1	4.8	170	1.31	6.1
Z069-8	4.8	165	1.22	6.3
Z070-17	4.8	135	1.31	5.9
N142-3	4.8	120	1.28	6.3
R492	5.1	155	1.11	6.1
				5.7

Melt Geometric Parameters

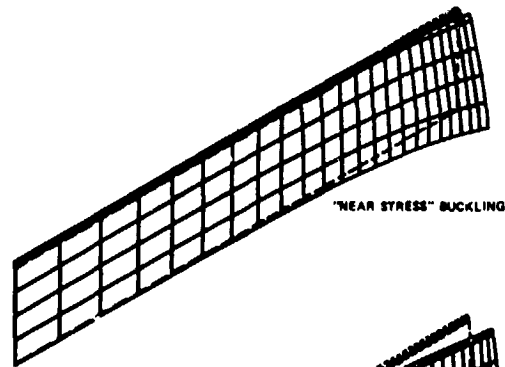
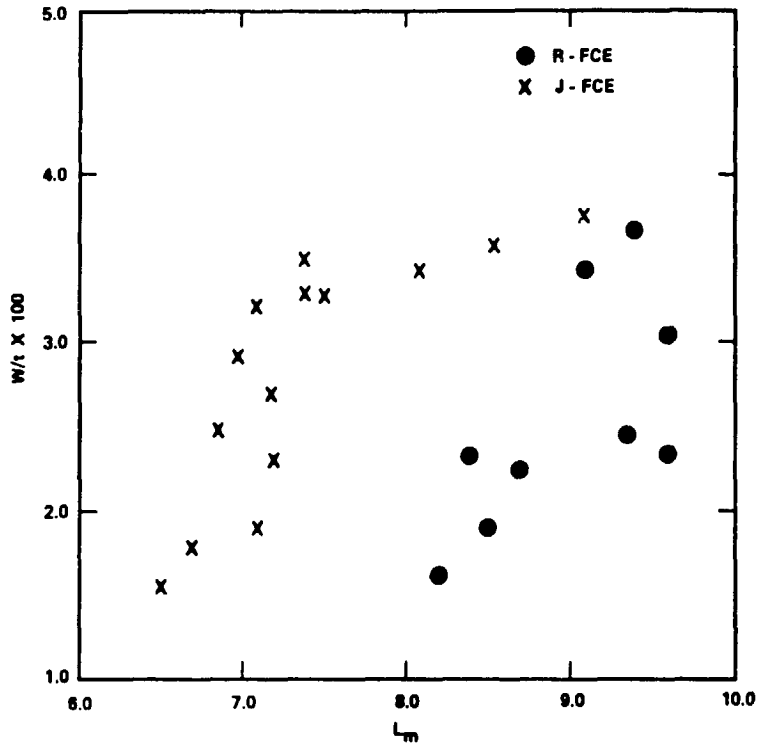


Variation in Web Buckling Eigenvalue with Crystal-Liquid Interface Position

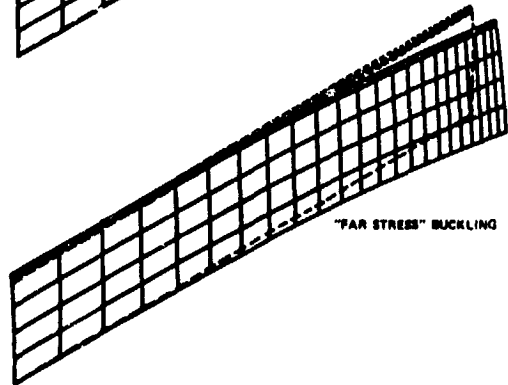


ADVANCED SILICON SHEET

Normalized Buckling Width Versus Melt Level



"NEAR STRESS" BUCKLING



"FAR STRESS" BUCKLING

Near Stress Reduction

APPROACHES

Model

- Direct Stress Calculation from Hypothetical Lid Design
- General Analysis from Synthetic Temperature Profiles
- Guidance from Effective Ambient Temperature Calculation

Fabricate and Test Lids

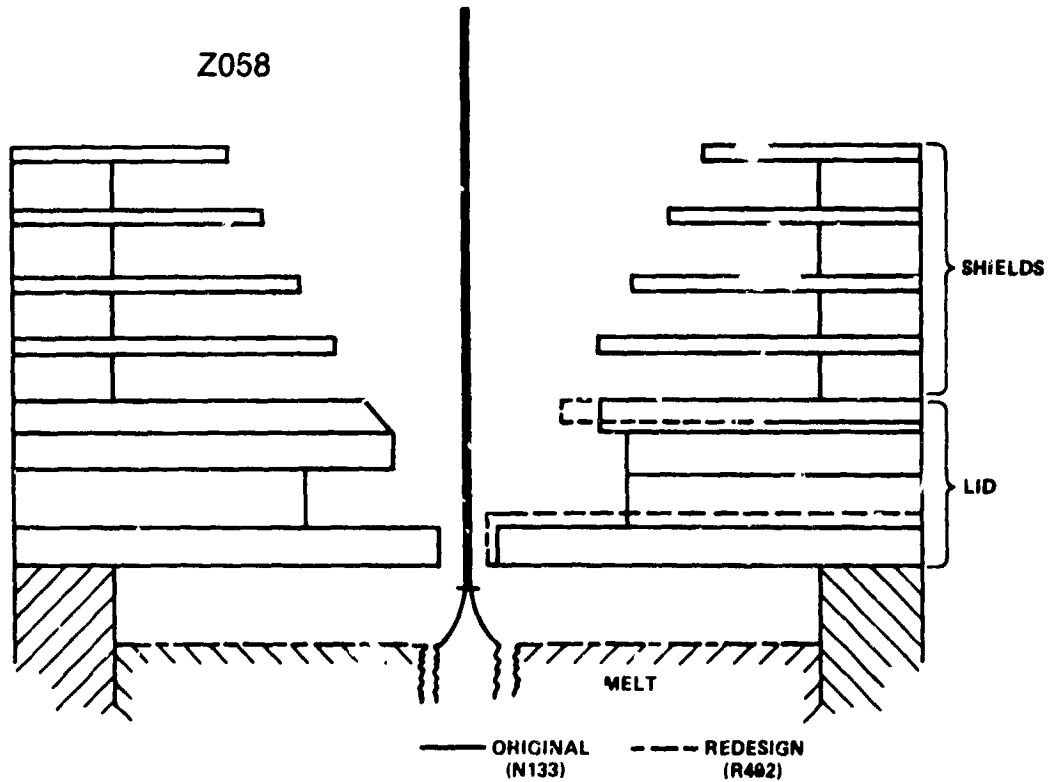
Evaluate Parametric Effects on Crystal Quality

Modeling New Lids for Interface Stress Reduction

(LIN = 0)

<u>Model Case</u>	<u>Remarks</u>	<u>V Web (cm/min)</u>	<u>σ_y (0) (Md/cm²)</u>	<u>$\Delta\sigma_x$ (near) (Md/cm²)</u>
J460	Baseline	1.53	-645	155
New 1 (N-133)	Std. T's	1.53	-612	145
New 1 (N-133)	Hotter Cavity	1.52	-591	139
New 1 (N-133)	Hot/Deeper Cavity	1.48	-581	140

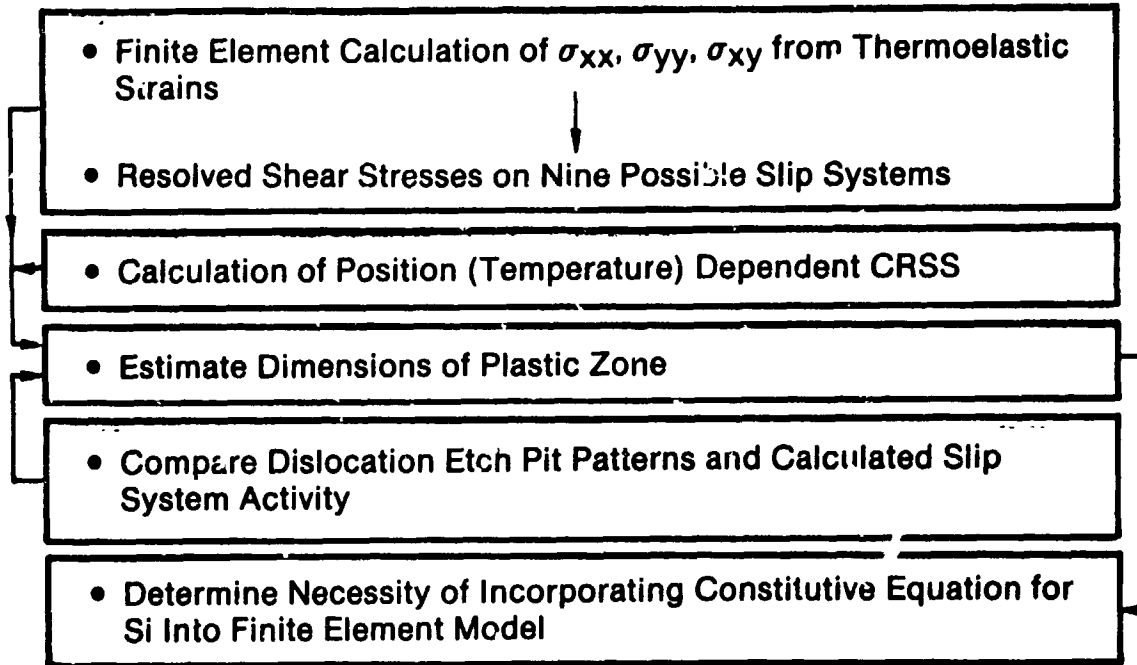
Lid Designs for Interface Stress Reduction



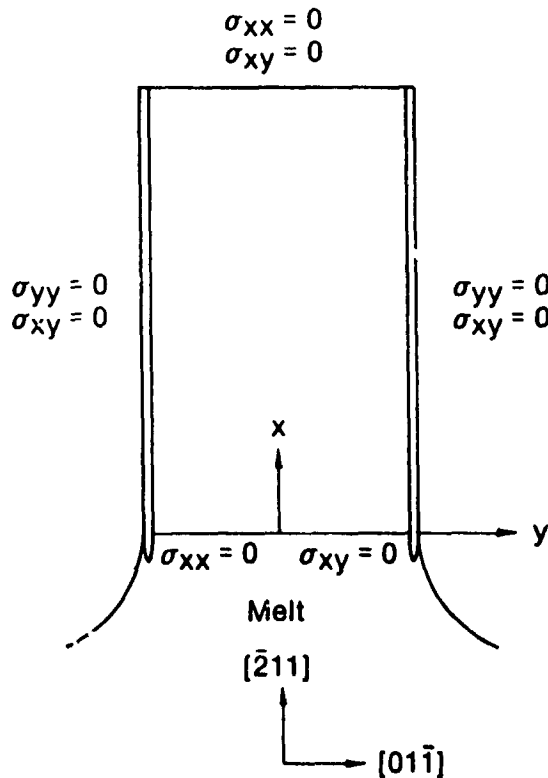
Typical Web Etch Pit and Stress Data

Growth Configuration	J435	Z058 (Far Stress Control)	R492 (Near Stress Control!)
Residual Stress (Mdyn/cm ²)	20-40 (Tensile)	<10 (T and C)	<10 (Compressive)
Etch Pit Density (cm ⁻²)	20-30K	~3K	<5K

Plasticity Effects in Web Growth

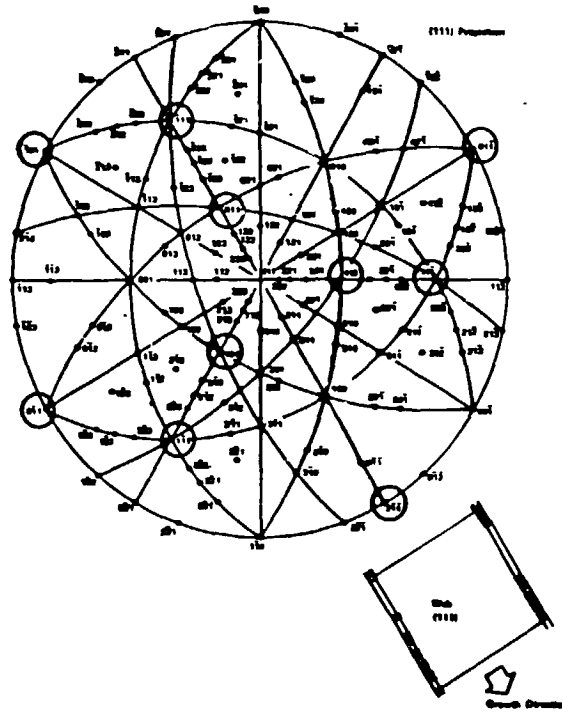


Web Geometry



Web Slip Systems

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Calculation of Resolved Shear Stresses

$$\sigma_{ij} = a_{ix} a_{jx} \sigma_{xx} + [a_{ix} a_{jy} + a_{iy} a_{jx}] \sigma_{xy} + a_{iy} a_{jy} \sigma_{yy}$$

Where

a_{ix} = Cosine of Angle Between Normal to Slip Plane and $[2\bar{1}\bar{1}]$

a_{jx} = Cosine of Angle Between Slip Direction and $[2\bar{1}\bar{1}]$

a_{iy} = Cosine of Angle Between Normal to Slip Plane and $[01\bar{1}]$

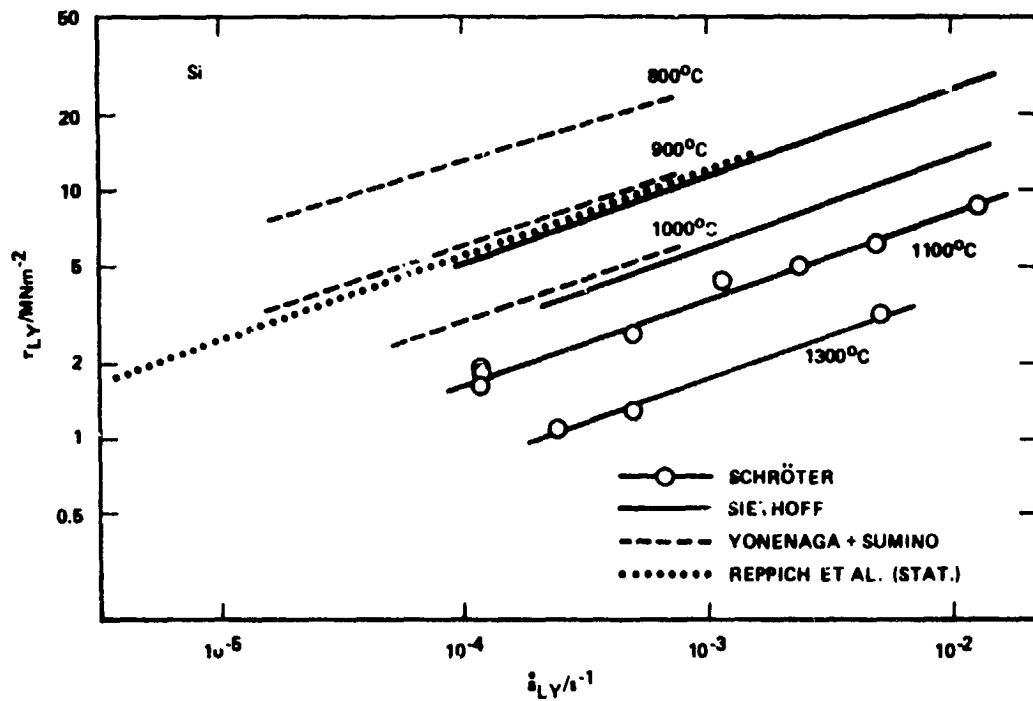
a_{jy} = Cosine of Angle Between Slip Direction and $[01\bar{1}]$



Resolved Shear Stresses for Single Crystal (111) Web Silicon

<u>Plane</u>	<u>Direction</u>	<u>Resolved Shear Stress</u>
(1 $\bar{1}\bar{1}$)	[011]	$-0.272 \sigma_{xx} + 0.470 \tau_{xy}$
(1 $\bar{1}\bar{1}$)	[110]	$0.136 \sigma_{xx} - 0.408 \sigma_{yy}$
(1 $\bar{1}\bar{1}$)	[$\bar{1}$ 01]	$-0.408 \sigma_{xx} + 0.471 \tau_{xy} + 0.408 \sigma_{yy}$
(11 $\bar{1}$)	[011]	$-0.272 \sigma_{xx} - 0.470 \tau_{xy}$
(11 $\bar{1}$)	[101]	$0.136 \sigma_{xx} - 0.943 \tau_{xy} - 0.408 \sigma_{yy}$
(11 $\bar{1}$)	[$\bar{1}$ 10]	$-0.408 \sigma_{xx} - 0.471 \tau_{xy} + 0.816 \sigma_{yy}$
($\bar{1}$ 11)	[110]	$-0.272 \sigma_{xx} - 0.471 \tau_{xy}$
($\bar{1}$ 11)	[101]	$-0.272 \sigma_{xx} + 0.471 \tau_{xy}$
($\bar{1}$ 11)	[0 $\bar{1}$ 1]	$0.943 \tau_{xy}$

Lower Yield Stress as a Function of Strain Rate in FZ and Cz Silicon



Critical Resolved Shear Stress Criterion for First Iteration

$$\dot{\epsilon}_{avg} = \frac{\partial(\alpha T)}{\partial t}$$

$$\approx 5 \times 10^{-5} \text{ s}^{-1}$$

$$\tau_{LY} = 1.505 \times 10^{-3} \text{ EXP } [9283/T]$$

τ_{LY} = Shear Stress at Lower Yield Point in MPa

T = Web Temperature, °K (T ≥ 1000K)

<u>T°K</u>	<u>τ_{LY} (MPa)</u>
1073 (800°C)	8.6
1173 (900°C)	4.1
1273 (1000°C)	2.2
1373 (1100°C)	1.3
1573 (1300°C)	0.55

Problems/Concerns

- (1) Reduction in Interface Stress for High Speed Growth Requires Analytical and Experimental Effort: Calendar Year Ambitious Schedule is Ambitious
- (2) Uncertainties in High Temperature Properties of Silicon Impact Stress Modeling