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STRESS STUDIES IN EDGE-DEFINED FILM-FED GROWTH OF SILICON RIBBONS

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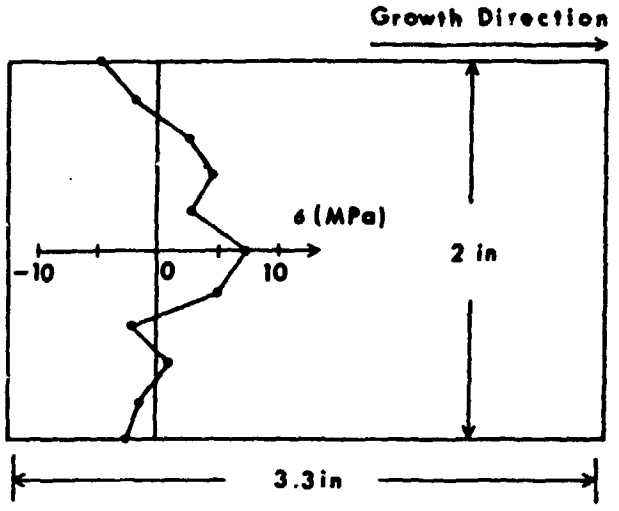
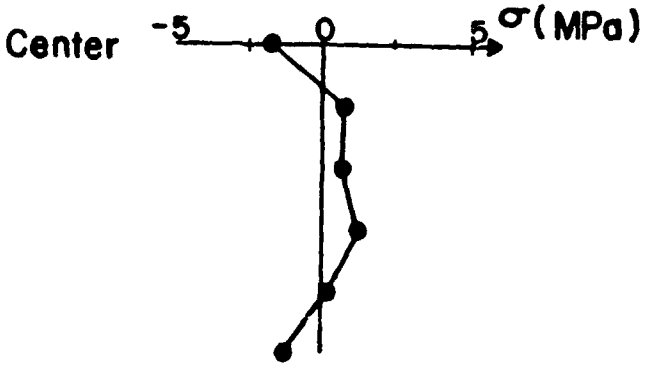
TECHNOLOGY	REPORT DATE
ADVANCED MATERIALS RESEARCH TASK	JUNE 19, 1985
APPROACH STRESS AND EFFICIENCY STUDIES IN EFG **CONTRACTOR** MOBIL SOLAR ENERGY CORPORATION, CONTRACT NUMBER 956312	**STATUS** • HORIZONTAL TEMPERATURE VARIATIONS CAN GIVE STRESS REDUCTIONS, BUT NOT SUFFICIENT TO OVERCOME CREEP LIMITATIONS ON GROWTH SPEED IN VERTICAL MODE. • QUANTITATIVE HIGH RESOLUTION EBIC ANALYSIS DEVELOPED: - EBIC STUDIES DEMONSTRATE POINT DEFECT LIMITATIONS ON DIFFUSION LENGTH IN FZ AND CZ SILICON HEAT TREATED AND STRESSED ABOVE 1200°C AND COOLED RAPIDLY. NO DEPENDENCE ON OXYGEN OR CARBON LEVELS. SIMILAR RESULTS FOR EFG SHEET. • LOW RESISTIVITY AS-GROWN EFG MATERIAL DIFFUSION LENGTHS IMPROVED BY GALLIUM OVER BORON DOPANT.
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.	

Low-Stress EFG Configurations

- STRESS, DISLOCATION DENSITIES REDUCED ONLY AT EXPENSE OF GROWTH SPEED CAPACITY:
  - FOR INTERFACE GRADIENTS $\leq 1000^{\circ}C$, SPEED IS LIMITED TO 1-1.5 CM/MIN.
  - $N_D \leq 1 \times 10^5/cm^2$, LÜDERS STRAIN OCCURRENCE ELIMINATED, RESIDUAL STRESS IS REDUCED.
- HORIZONTAL GRADIENT MODELING SHOWS SOME PROMISE FOR STRESS MANIPULATION BELOW $1200^{\circ}C$ TO $900^{\circ}C$, WHERE CREEP IS STILL SIGNIFICANT, BUT WILL NOT ALLOW SPEED CAPACITY INCREASES.
- INCLINED INTERFACE GROWTH APPEARS TO BE ONLY ALTERNATIVE TO OVERCOME HIGH TEMPERATURE CREEP LIMITATION.



HIGH STRESS, 2 CM/MIN, $N_D \sim 10^6$ TO $10^7/CM^2$



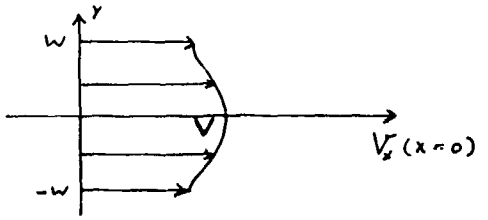
LOW STRESS, 1 CM/MIN, $N_D \lesssim 1 \times 10^5/CM^2$

New Interpretation of Stress-Strain Effects in High-Speed Sheet Growth (J. W. Hutchinson, Harvard University)

- NON-THERMAL INELASTIC STRAIN CONTRIBUTES TO INTERFACE VELOCITY NONUNIFORMITY

$$\varepsilon_{TOT} = \varepsilon^E + \varepsilon^I + \varepsilon^T$$

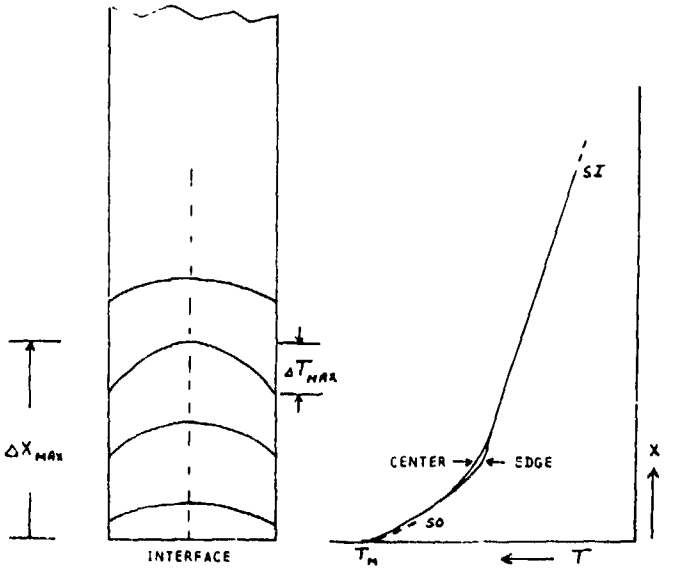
$$\varepsilon^I = \underbrace{\varepsilon^C}_{\text{CREEP STRAIN}} + \underbrace{\varepsilon^M}_{\text{MISFIT STRAIN}}$$



VELOCITY PROFILE ACROSS STRIP AT X = 0

- IMPLICATIONS OF VELOCITY NONUNIFORMITY ON INTERFACE SHAPE, STRUCTURE UNKNOWN.

Stress Analysis with Horizontal Temperature Gradients



- HIGH CREEP CONDITION, V = 3 CM/MIN, WIDTH OF 5 CM.
- PARABOLIC HORIZONTAL PROFILE:
  - HORIZONTAL INTERFACE PROFILE.
  - PEAK DIFFERENCE ΔT_{MAX} OCCURS AT DISTANCE ΔX_{MAX} FROM INTERFACE.

Maximum Residual (Room Temperature) Stress (MPa) for Horizontal Temperature Field Variations

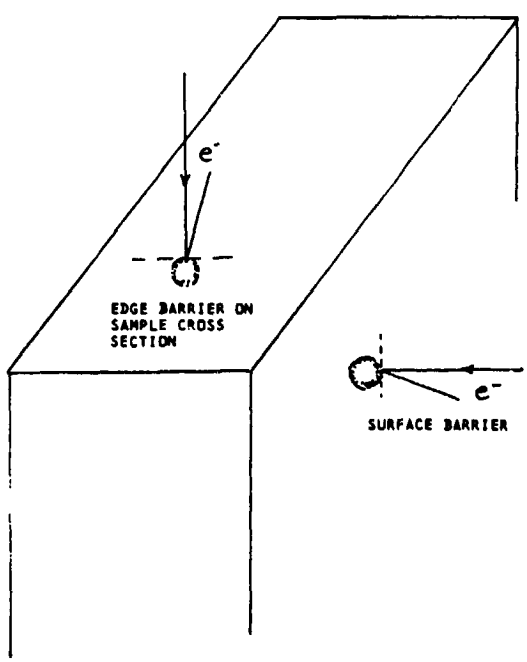
A) SO = 500°C/CM, SI = 60°C/CM

ΔX_{MAX} (CM)	ΔT_{MAX} 0	50	100	150	200
0.5	67.0	63.0			
1.0	67.0	62.8	59.9		
2.0	67.0	69.6	77.4	85.6	84.0
3.0	67.0	68.8	74.5		

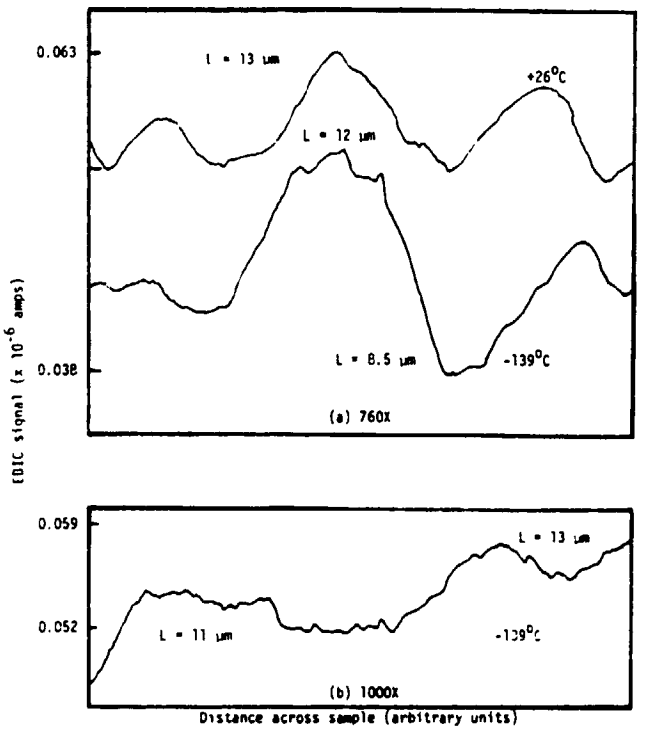
B) SO = 1250°C/CM, SI = 40°C/CM

ΔX_{MAX} (CM)	ΔT_{MAX} 0	50	100	200	300
0.5	474	486	501		
1.0	474	472	470		
2.0	474	460	446		
3.0	474	459	444	415	387
5.0	474	463	453	433	414

EBIC Measurement Configurations



- DESIRE HIGH RESOLUTION ON L MEASUREMENT.
- RELATE SAMPLE INHOMOGENEITIES IN L TO BULK L (LARGE AREA MEASUREMENT).



High magnification EBIC line scans in stressed carbon-rich (111) CZ silicon.

High-Resolution EBIC Results

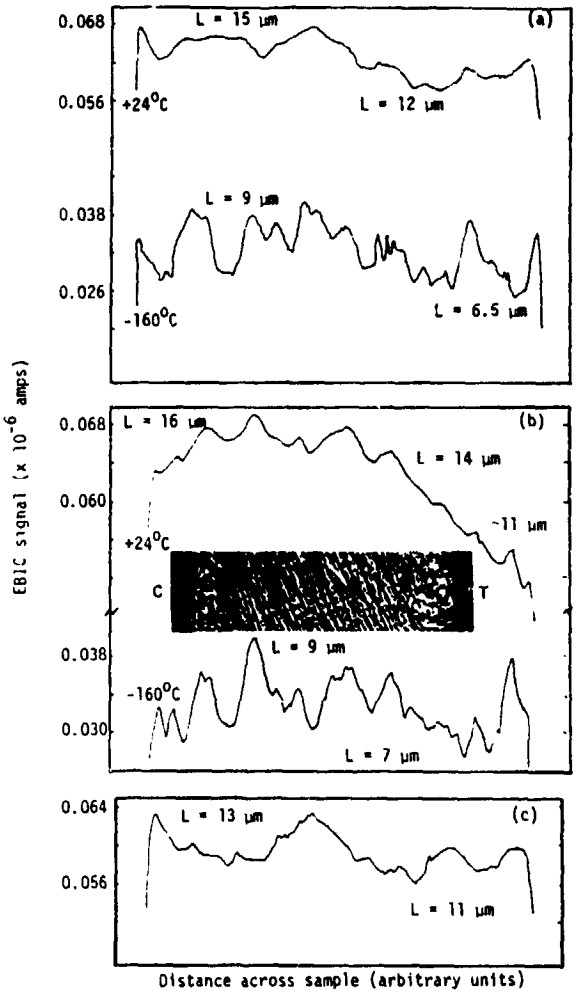
- LARGE DIFFERENCES FOUND BETWEEN SURFACE AND EDGE CROSS SECTION MEASUREMENTS OF DIFFUSION LENGTH BY EBIC.
- DIFFERENCE ATTRIBUTED TO ABILITY TO RESOLVE DIFFUSION LENGTH INHOMOGENEITIES IN NEAR-SURFACE REGIONS OF STRESSED SAMPLES AT $\geq$ 500X.
- CAUTION MUST BE EXERCISED IN INTERPRETATION OF EDGE CROSS SECTION EBIC MEASUREMENTS DUE TO GEOMETRICAL EFFECTS IN ADDITION TO MATERIAL INHOMOGENEITIES.

EBIC Characterization

- SCOPE OF THE PRESENT STUDY:
  - CZ SILICON OF VARIOUS CARBON LEVELS AND FZ SILICON STRESSED ABOVE 1200°C, AND EFG SHEET.
  - CRYSTAL GROWTH FURNACE 17 AND SEALED, EVACUATED QUARTZ AMPOULE ANNEALS.
- DISLOCATION DENSITY DEPENDENCE OF L WITH N_D UP TO ~1 x $10^7/cm^2$.
  - EFFECT OF POST-DEFORMATION ONE-HOUR ANNEALS AT 575°C AND 850°C.

FZ and Cz Silicon Wafer Description for Samples Stressed at 1370°C in Four-Point Bending

Sample	O_i (cm^{-3})	C_s (cm^{-3})	N_D (As-Grown) (cm^{-2})	Stress (MPa)	N_D^C (cm^{-2})	N_D^E (cm^{-2})
(111) FZ (#15)	$<10^{16}$	$<10^{16}$	0	8	1×10^6	$<10^4$
(111) FZ (#17)	$<10^{16}$	$<10^{16}$	0	14	1×10^7	5×10^4
(100) CZ (#25)	$\sim 10^{18}$	$<10^{16}$	0	14	$\sim 10^7$	$<5 \times 10^4$
(111) CZ (#9,	$\sim 10^{18}$	4×10^{17}	$\sim 10^4$	7	$\sim 10^6$	2×10^4



EBIC line scans for stressed FZ silicon sample #17C in central high dislocation density (~1 x 10^7/cm^2) region: (a) after four-point bending at 1370°C; (b) after one-hour anneal at 575°C; (c) after one-hour anneal at 850°C.

Observations

- ANNEALS ABOVE 1200°C IN EVACUATED QUARTZ AMPOULE IN QUARTZ TUBE FURNACE AND CRYSTAL GROWTH FURNACE HAVE SIMILAR EFFECTS IN DEGRADING L.
- L IS 15-25 MICRONS IN DISLOCATION-FREE REGIONS; DISLOCATIONS UP TO ~1 X 10^7/CM^2 DEGRADE IT TO 10-15 MICRONS.
- SUBSEQUENT ONE-HOUR ANNEALS AT 575°C AND 850°C RAISE L BY FACTOR OF TWO AT BEST (MUCH BELOW STARTING L ~ 150 MICRONS).
- L VALUES ARE INDEPENDENT OF OXYGEN AND CARBON CONCENTRATIONS, AND SIMILAR TO EFG AS-GROWN MATERIAL.

Conclusions

- L IS POINT DEFECT LIMITED TO RANGE OF ABOUT 20 MICRONS AND IS FIXED BY COOLING RATE FROM HIGH TEMPERATURES.
- IN-DIFFUSION OF SLOW DIFFUSING IMPURITIES RULED OUT -- NO GRADIENTS.
- IF IN-DIFFUSION BY IRON OCCURS, DISLOCATIONS, CARBON AND OXYGEN DO NOT PRODUCE SIGNIFICANT GETTERING WITH ANNEALING FOR ONE HOUR AT 575°C AND 850°C.

Comparison of Boron and Gallium-Doped EFG Material As-Grown Quality as a Function of Resistivity

RESISTIVITY (OHM-CM)	DOPANT TYPE	SPV L (MICRONS)
UNDOPED (> 15)		40-60
5	BORON	38
	GALLIUM	70
1	BORON	40
	GALLIUM	55
0.2	BORON	27
	GALLIUM	45

Future Work

- EBIC STUDIES OF FZ SILICON STRESSED AT 600-1000°C, COOLED UNDER LOAD
  - SUGGESTION IS THAT DISLOCATION ELECTRICAL ACTIVITY MAY DIFFER WHEN COOLED WITH AND WITHOUT STRESS.
  - USE INFORMATION TO HELP IDENTIFY TEMPERATURE OF GENERATION OF DISLOCATIONS IN EFG SHEET-STRESS CONDITIONS.
  - PHOSPHORUS GETTERING (900°C) RESPONSE.
- CONTINUED CHARACTERIZATION AND COMPARISON OF LOW RESISTIVITY BORON AND GALLIUM DOPANT EFFECTS.
- MODELING OF HORIZONTAL TEMPERATURE PROFILES IN SHEET GROWTH.
- EXAMINATION OF FEASIBILITY OF INCLINED INTERFACE EFG FOR STRESS REDUCTION.