N85-32444

HIGH-PURITY SILICON CRYSTAL GROWTH

SOLAR ENERGY RESEARCH INSTITUTE

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TECHNOLOGY

HIGH PURITY SILICON CRYSTAL GROWTH INVESTIGATIONS

REPORT DATE

9/21/84

APPROACH

INVESTIGATE CRYSTAL GROWTH PARAMATER EFFECTS ON MINORITY CARRIER LIFETIME AND SOLAR CELL EFFICIENCIES USING HIGH PURITY TECHNIQUES SUCH AS FLOAT ZONING (FZ).

CONTRACTOR

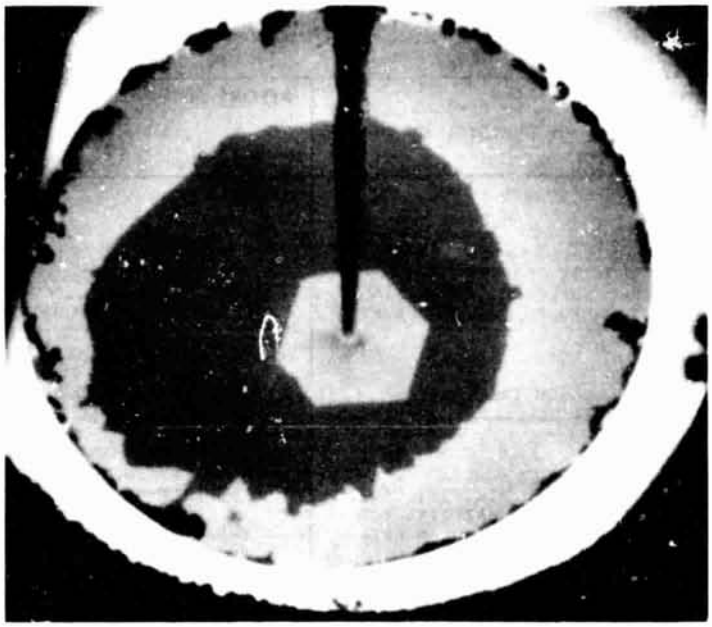
SOLAR ENERGY RESEARCH INSTITUTE

GOALS

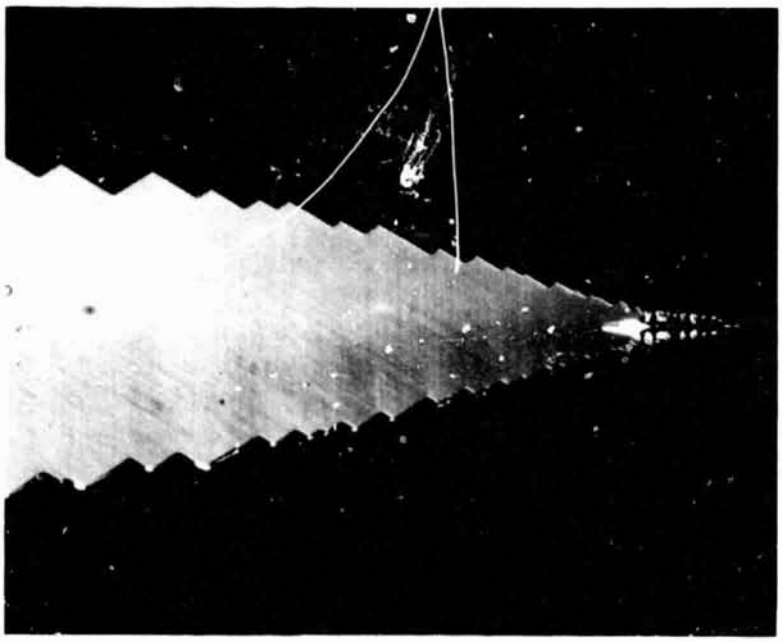
- OPTIMIZE DOPANTS AND MINORITY CARRIER LIFETIME IN FZ MATERIAL FOR HIGH EFFICIENCY SILICON SOLAR CELL APPLICATIONS.
- IMPROVE THE UNDERSTANDING OF LIFETIME DEGRADATION MECHANISMS (POINT DEFECTS, IMPURITIES, THERMAL HISTORY, SURFACE EFFECTS, ETC.
- CRYSTALLOGRAPHIC DEFECT CHARACTERIZATION OF FLOAT-ZONED AND RIBBON CRYSTALS VIA X-RAY TOPOGRAPHY.

STATUS

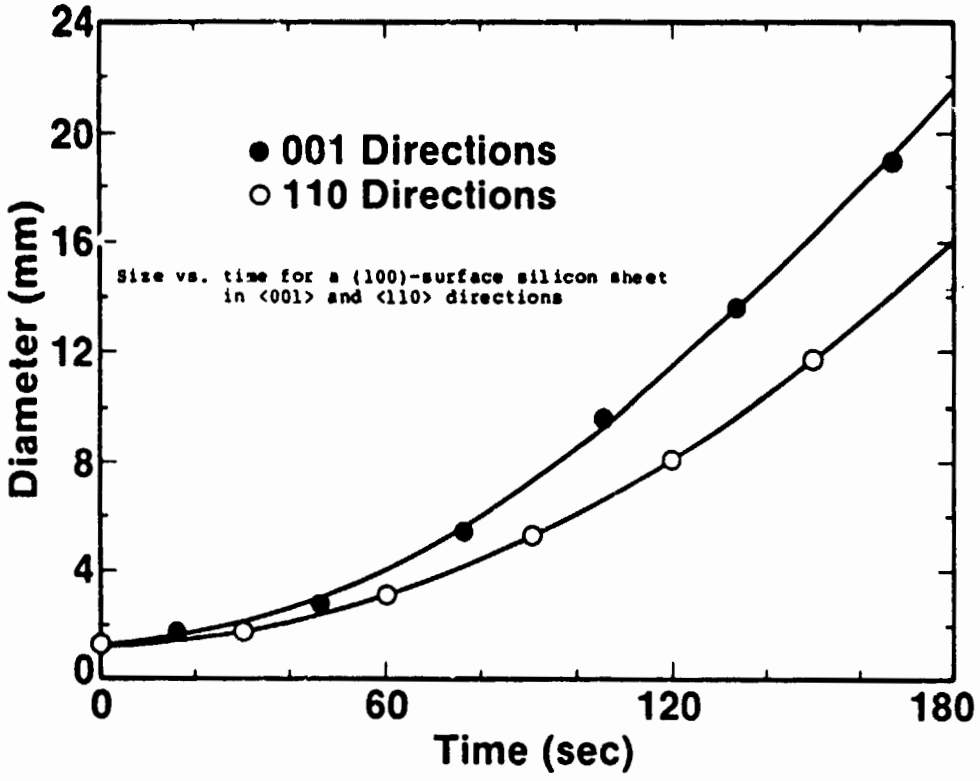
- CONCLUSION OF SOLID/MELT INTERFACE STUDIES.
- FEASIBILITY DEMONSTRATION OF A CRUCIBLE-FREE HORIZONTAL RIBBON GROWTH METHOD.
- GROWTH OF SILICON SHEETS BY ESP FROM A COLD CRUCIBLE
- SOLAR CELL DATA OBTAINED ON COLD CRUCIBLE AND HORIZONTAL CRUCIBLE-FREE RIBBONS.
- X-RAY TOPOGRAPHY USED TO EXAMINE DENDRITIC WEBS AND WEB CELLS, COLD CRUCIBLE CZ, AND FZ CRYSTALS.
- MINORITY CARRIER LIFETIME MEASUREMENT TECHNIQUES UNDER WAY.
- INITIATION OF HEAVILY DOPED, DISLOCATION-FREE, FZ CRYSTAL GROWTH STUDIES.



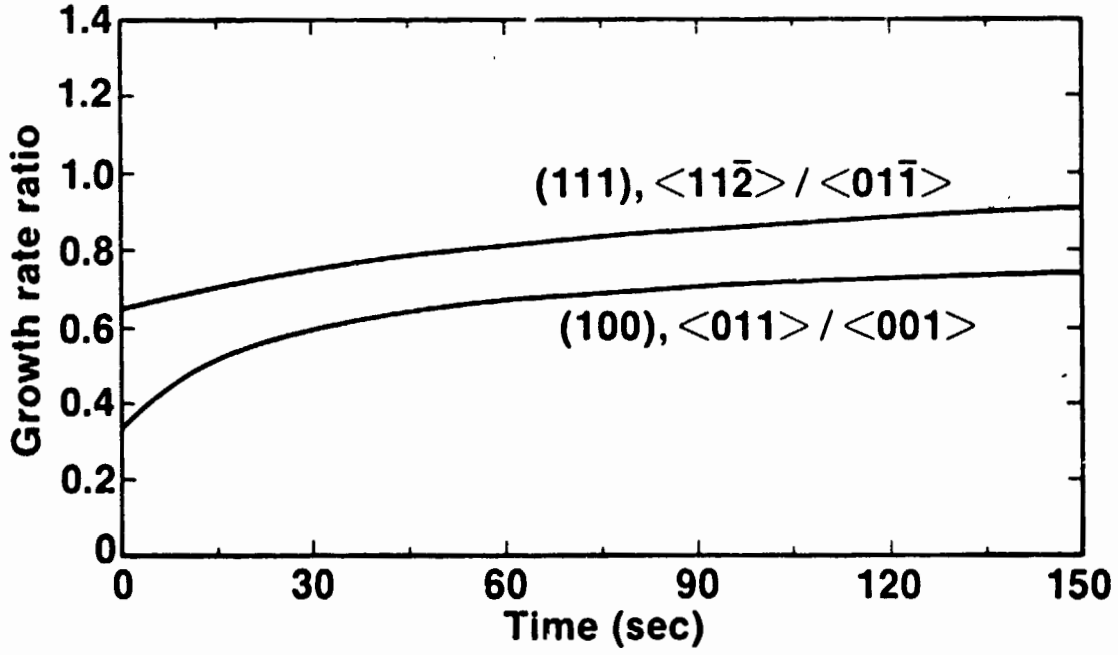
Growth form of a (110)-surface silicon sheet



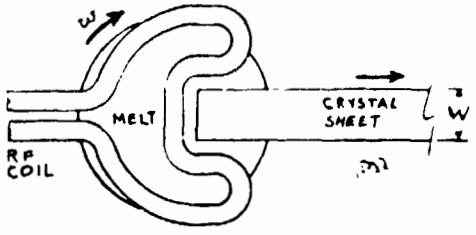
Growth form of a (111)-surface silicon dendrite

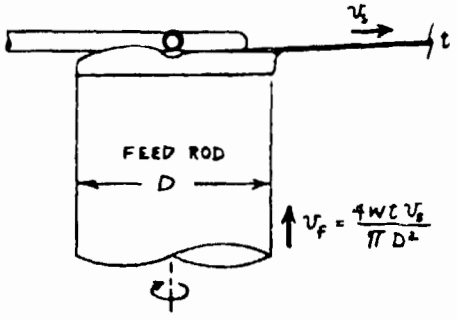


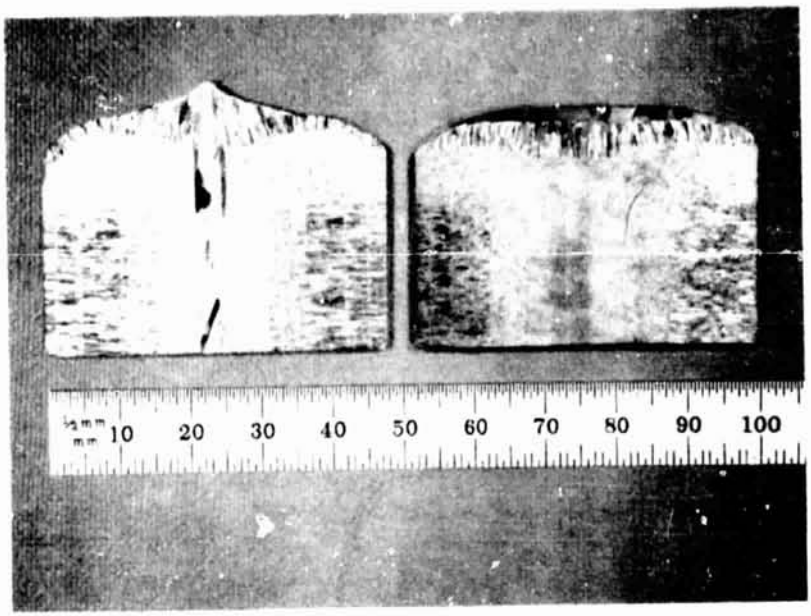
Growth rate anisotrophy ratios for a (111)-surface silicon sheet in $\langle 11\bar{2}\rangle/\langle 01\bar{1}\rangle$ directions and for a (100)-surface Si sheet in <011>/<001> directions



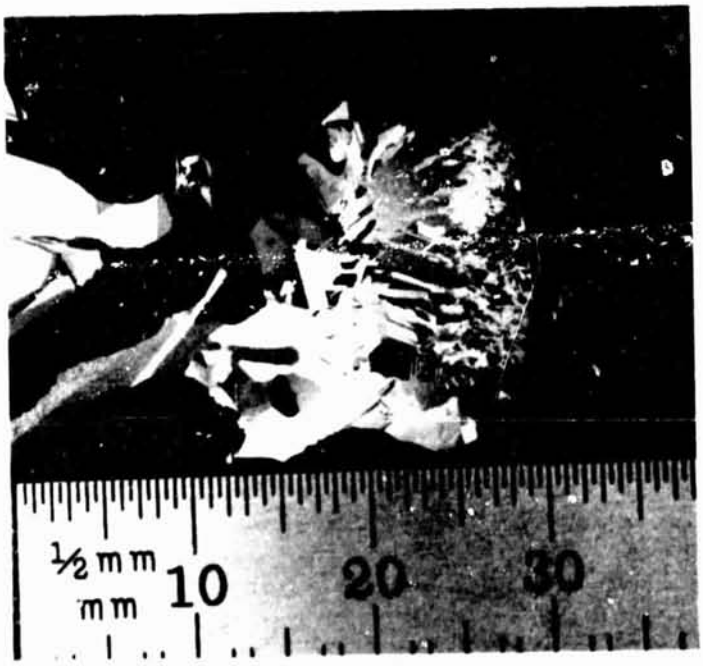
Crucible-Free Horizontal (CFH) Silicon-Ribbon Growth Method







Cross sections of feed rods for CFH silicon ribbon growth. Flattening of interface due to shorting ring is seen at right.

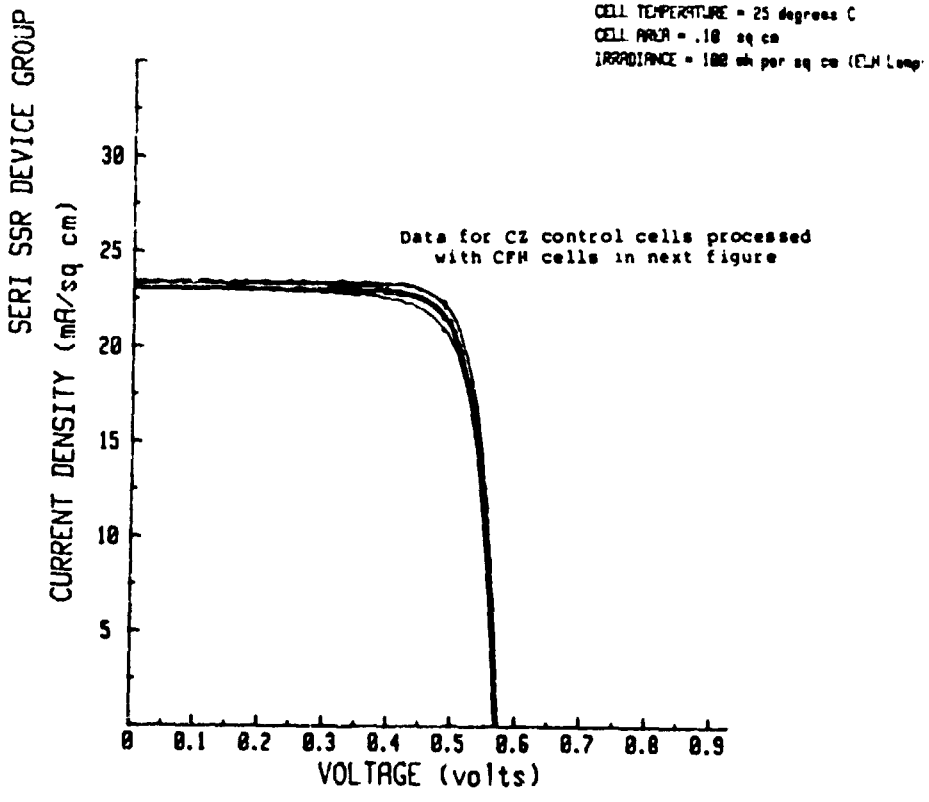


Lapped and etched cross section of a short CFH silicon sheet

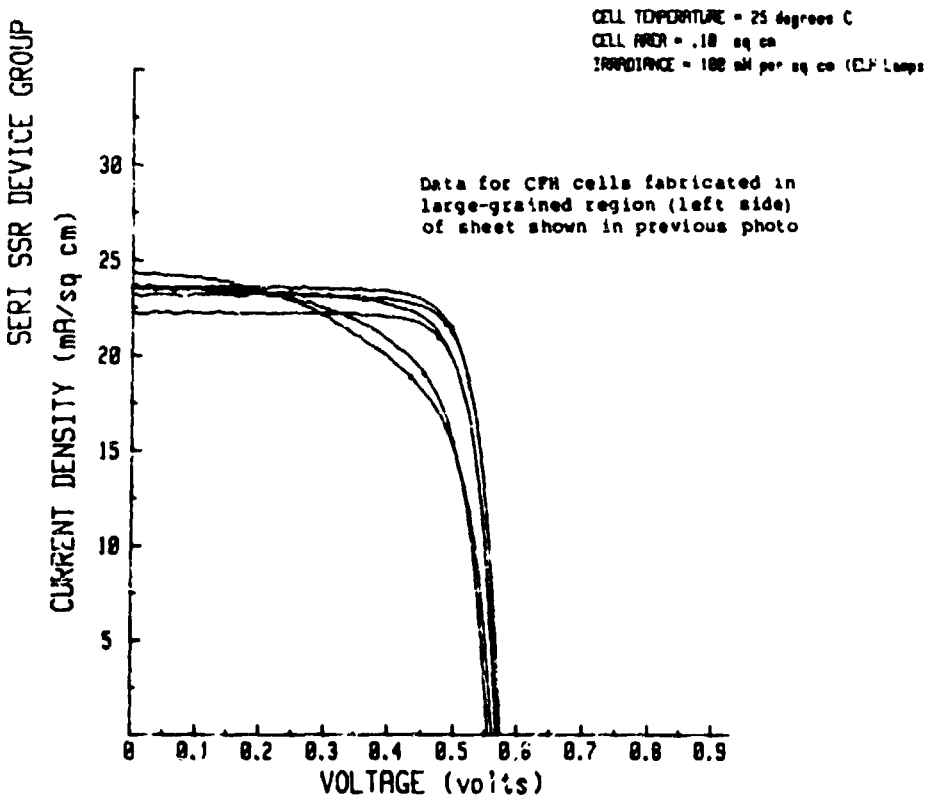
SILICON SHEET

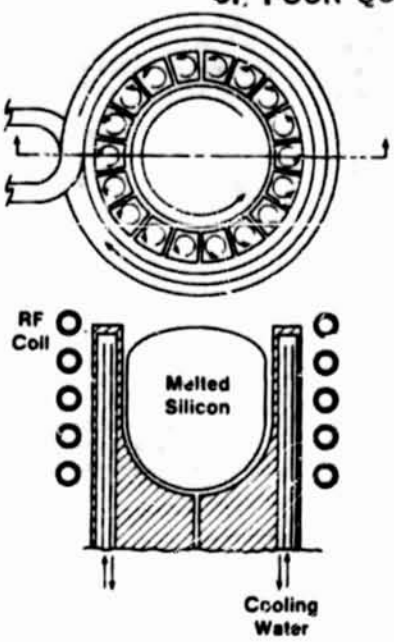
	5/12/84 CONTROL 1 NO ARC	5/12/84 CONTROL 1-2 MESA DEFINED	5/12/84 CONTROL 1-3	5/12/84 CONTROL 2-1	5/12/84 CONTROL 2-2	5/12/84 CONTROL 2-3
Voc	.573 v	.573 v	.567 v	.566 v	.565 v	.566 v
Isc	2.4 mA	2.3 mA	2.3 mA	2.3 mA	2.3 mA	2.3 mA
Jsc	23.5 mA/cm^2	23.3 mA/cm^2	23.0 mA/cm^2	23.1 mA/cm^2	23.3 mA/cm^2	23.2 mA/cm^2
Vmp	.486 v	.488 v	.485 v	.496 v	.486 v	.495 v
Imp	2.2 mA	2.2 mA	2.1 mA	2.1 mA	2.2 mA	2.2 mA
Pmax	1.1 mW	1.1 mW	1.0 mW	1.1 mW	1.0 mW	1.2 mW
FF	.81	.81	.78	.81	.82	.82
Eff	10.9 %	10.8 %	10.2 %	12.6 %	12.5 %	12.5 %

CELL TEMPERATURE = 25 degrees C
CELL AREA = .10 sq cm
IRRADIANCE = 100 mW per sq cm (ELH Lamp

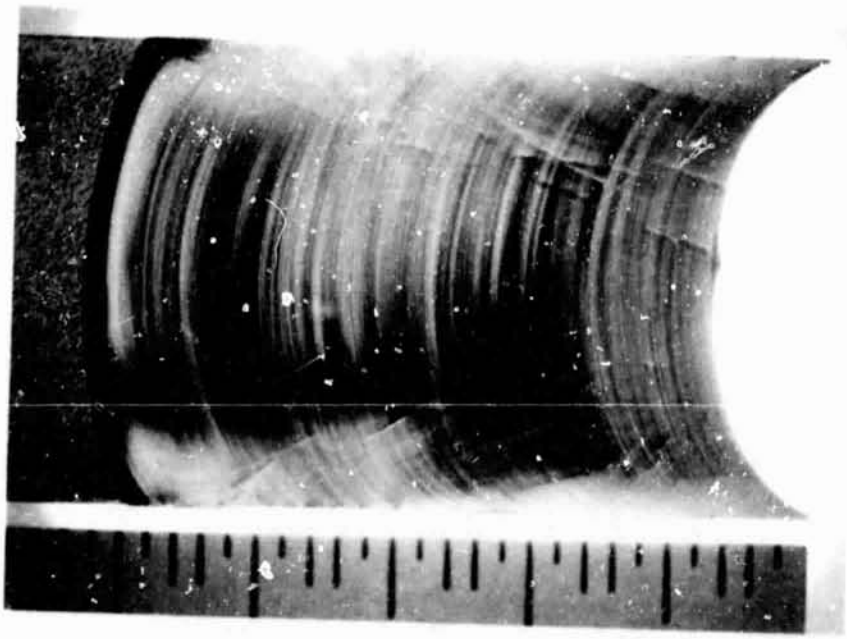


	5/12/84 HORIZONTAL RIBBON LARGE -1	5/12/84 NO ARC Lg-2	5/12/84 Lg-3	5/12/84 Lg-4	5/12/84 Lg-5	5/12/84 Lg-6
Voc	.562 v	.573 v	.573 v	.565 v	.553 v	.565 v
Isc	2.4 mA	2.4 mA	2.3 mA	2.2 mA	2.4 mA	2.4 mA
Jsc	24.4 mA/cm^2	23.6 mA/cm^2	23.2 mA/cm^2	22.3 mA/cm^2	23.5 mA/cm^2	23.6 mA/cm^2
Vmp	.433 v	.496 v	.486 v	.475 v	.453 v	.475 v
Imp	1.9 mA	2.2 mA	2.2 mA	2.1 mA	1.9 mA	2.1 mA
Pmax	.8 mW	1.1 mW	1.1 mW	1.0 mW	.9 mW	1.0 mW
FF	.68	.79	.79	.79	.67	.76
Eff	8.2 %	10.7 %	10.5 %	10.0 %	8.7 %	10.1 %

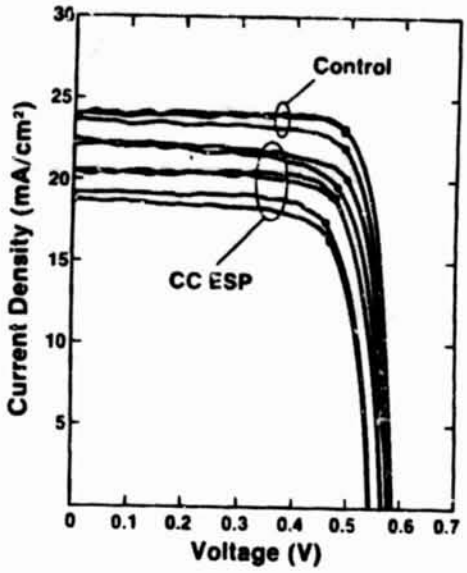




Principle of cold crucible melt confinement showing instantaneous current directions



17-mm-wide ESP silicon sheet grown using quartz capillary filaments

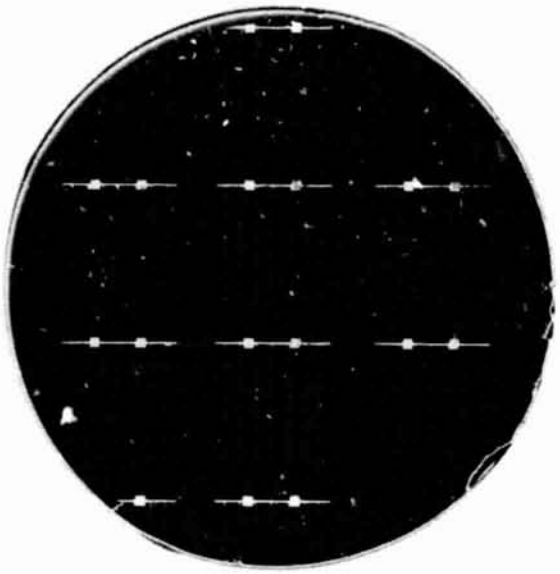


Solar cell I/V curves for cold crucible ESP and conventional CZ control material

Dislocation-free silicon crystal being pulled from a cold crucible

Properties of Cz Cold Crucible Crystals

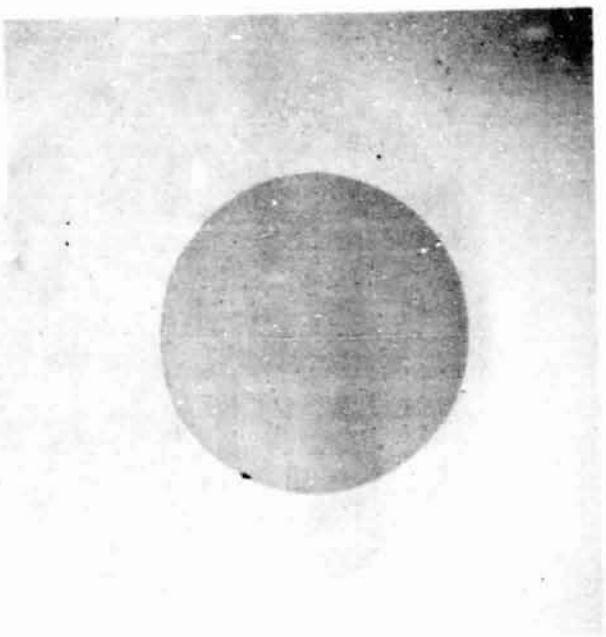
* MINORITY CARRIER LIFETIME: 195 microsec.
  (<111>, P, ~150 OHM-CM, DF)
* HALL MOBILITY: 295 $cm^2/V-sec$
  (<100>, P, 2.6 OHM-CM, DF)
* OXYGEN/CARBON: similar to FZ
* GOLD CONTENT (NAA): 0.14 ppbw
* COPPER CONTENT (NAA): 15 ppbw



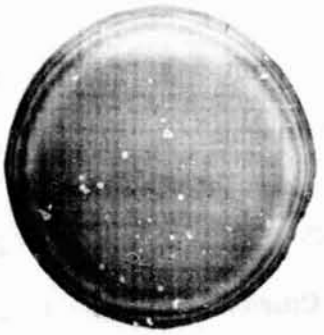
Solar cells on a (100) dislocation-free wafer from a cold crucible CZ crystal

Cell Measurement Conditions	Cell Description	No. of Cells	V_{oc} (mV)	J_{sc} (mA/cm²)	FF (%)	Eff. (%)
100 mW/cm², ELH lamps, 25° C, no AR coating, 0.1 cm² cell area	Cz Control	3	573(±1)	23.8(±.2)	80(±1)	10.9(±.3)
	Cold Crucible	8	579(±3)	24.9(±.4)	81(±1)	11.7(±.2)
100 mW/cm² SERI filtered Xenon simulator 28° C, no AR coating, 0.1-cm² cell area	Cz Control	3	561(±.4)	22.9(±.1)	79.4(±.3)	10.2(±.1)
	Cold Crucible	4	568(±.7)	23.5(±.4)	78.9(±.2)	10.6(±.2)

Cell data comparing cold crucible CZ and conventional control CZ PV performance

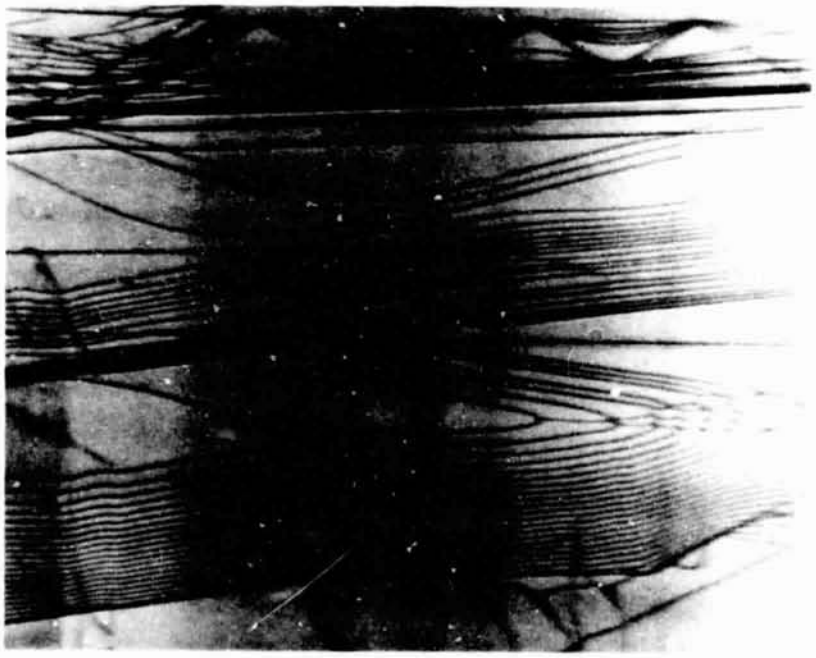


(220) transmission x-ray topograph of a (111) dislocation-free cold crucible CZ wafer

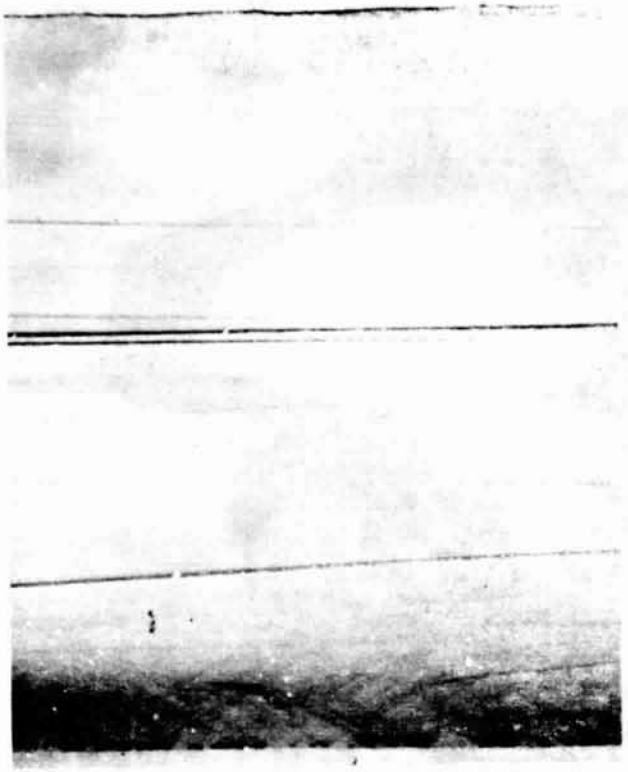


(220) transmission x-ray topograph of a (100) dislocation-free cold crucible CZ wafer

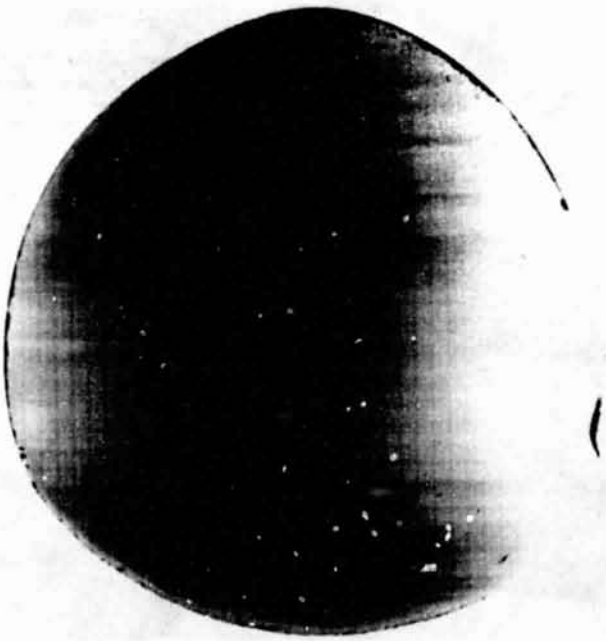
(220) transmission x-ray topograph of a moderately stressed Si dendritic web crystal showing lattice bending



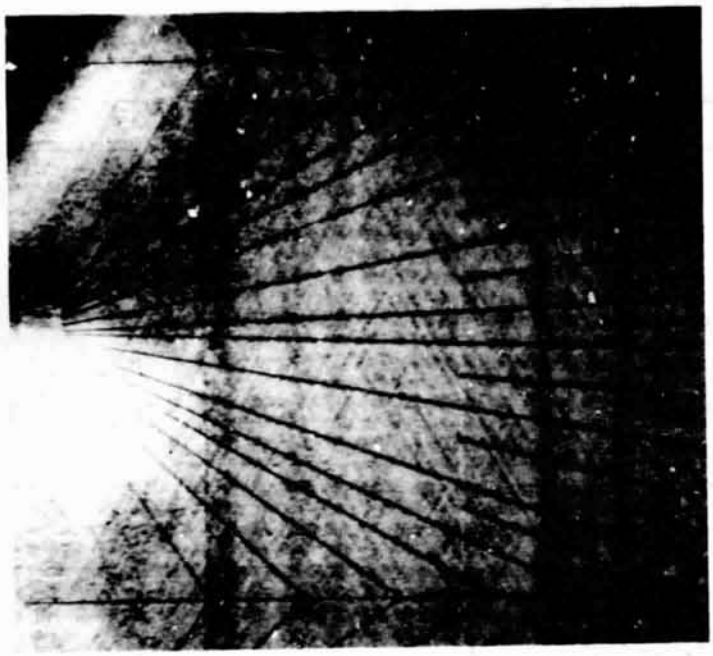
Enlarged detail of same topograph



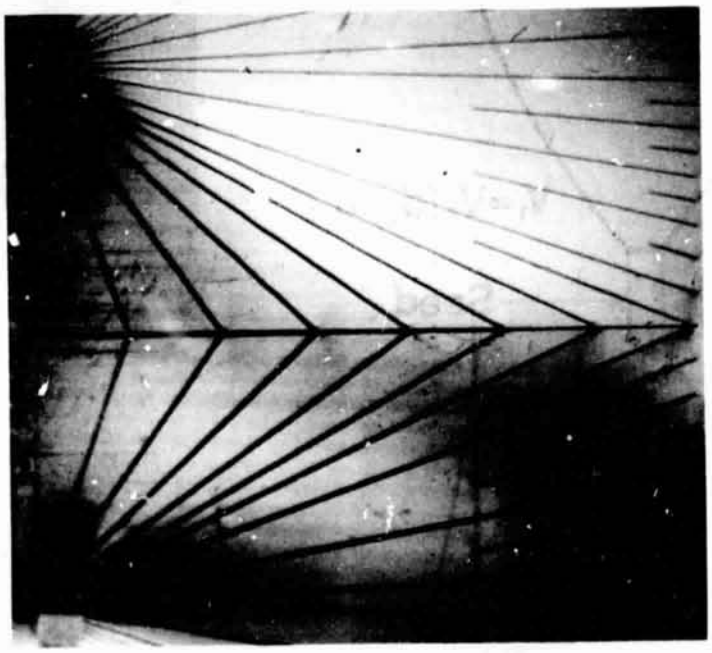
(220) transmission x-ray topograph of same dendritic web, with oscillation



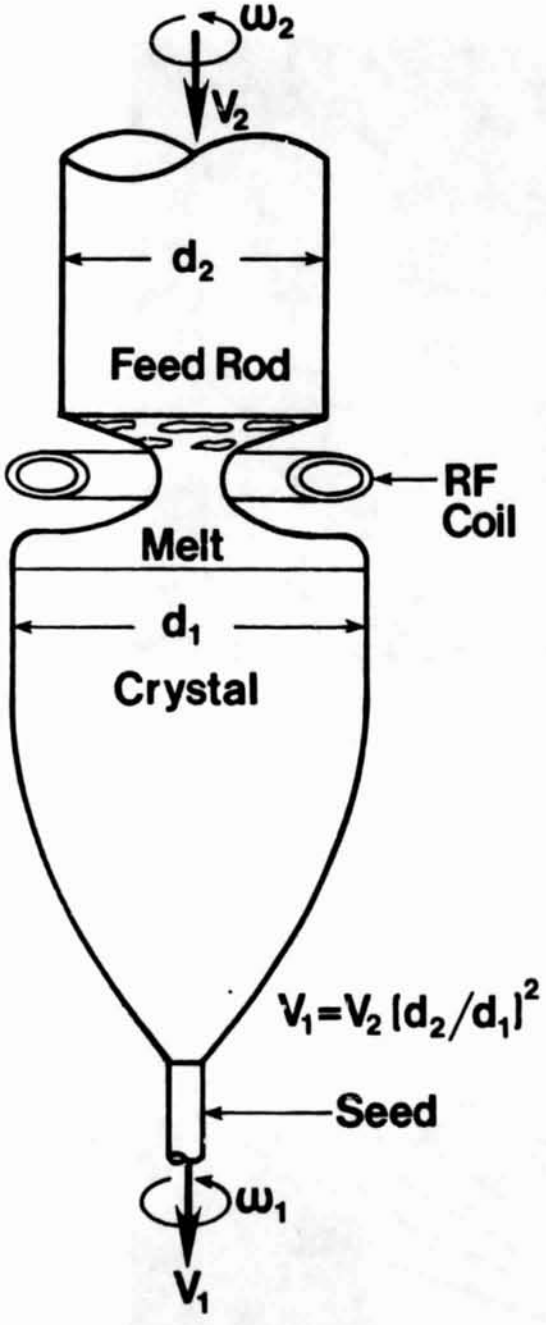
(220) transmission x-ray topograph of a dislocation-free 0.1 ohm-cm Ga-doped float-zoned silicon crystal wafer

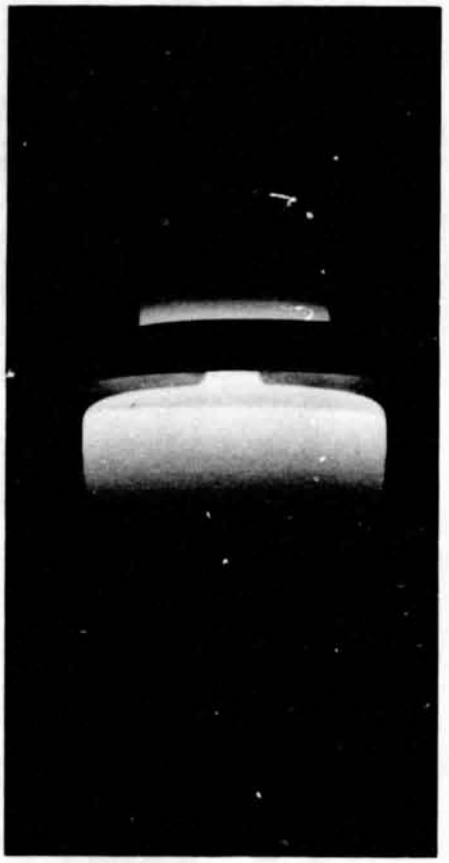


($\bar{1}11$) transmission x-ray topograph of a <8% efficient (111) dendritic web solar cell

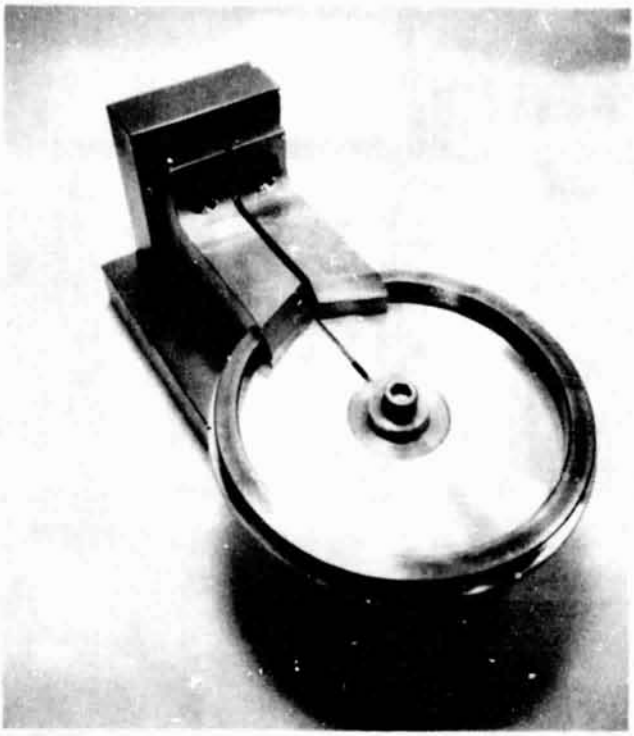


($\bar{1}11$) transmission x-ray topograph of a >13% efficient (111) dendritic web solar cell

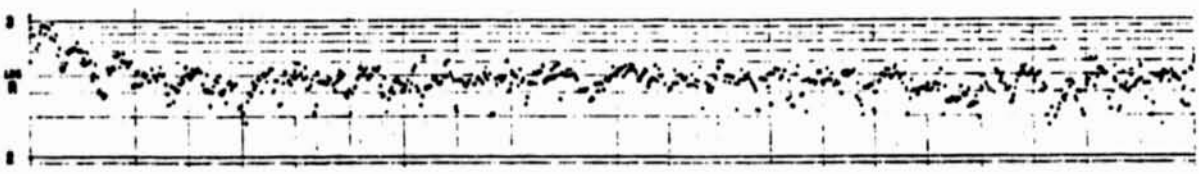




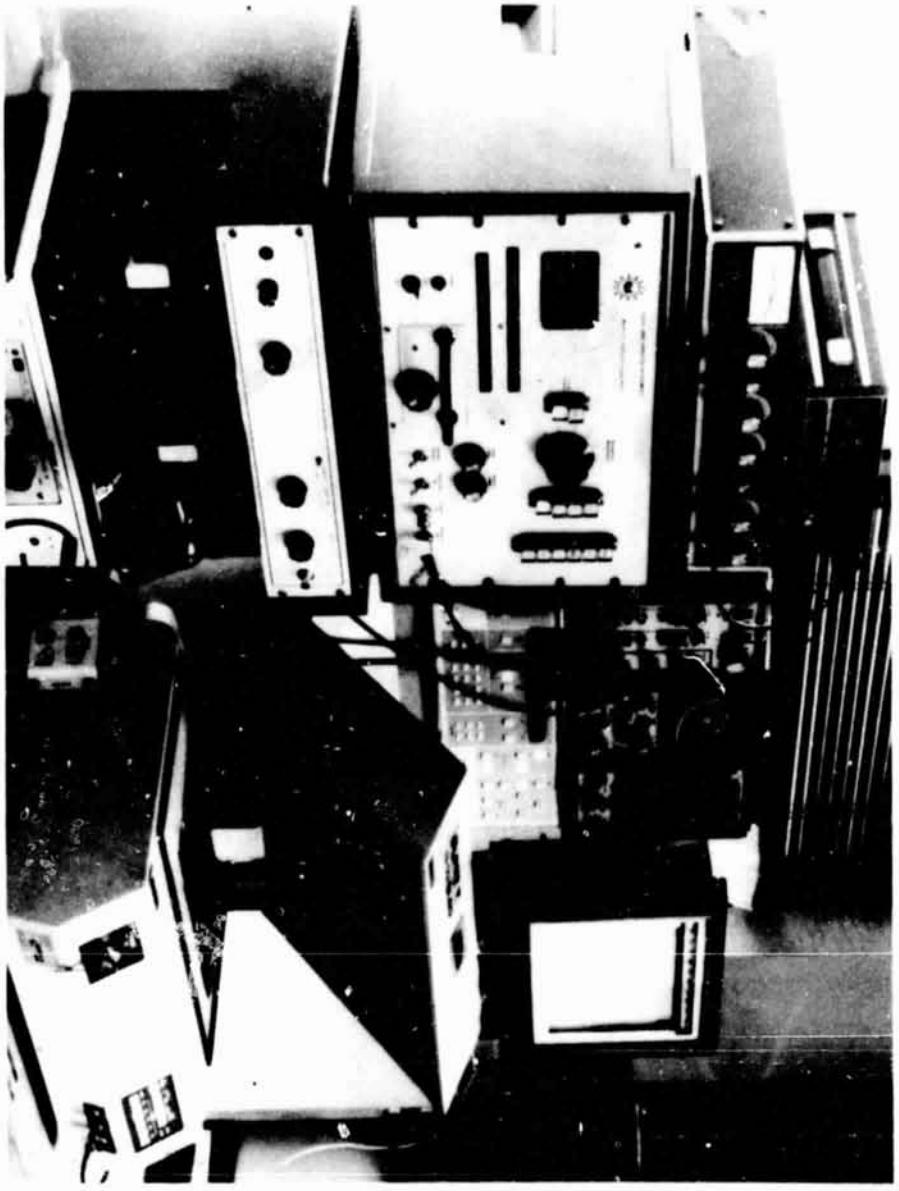
Schematic diagram of the float-zoning crystal growth process



Float-zoning RF coil assembly
and jig for silver soldering



Spreading resistance along a diameter
of a (111), Ga doped, 0.1 ohm-cm silicon wafer.



Apparatus for diffusion length, minority carrier ingot lifetime, and minority carrier wafer lifetime measurements

Minority carrier bulk lifetimes in the range 900–1300 microseconds have been measured for the 5 ohm–cm Ga–doped FZ crystals using the ASTM photoconductive attenuation method on 1x1x2 cm samples. We have not yet been able to measure 0.1 ohm–cm samples.

Problems and Concerns

- AVAILABILITY OF HIGH PURITY POLYCRYSTALLINE SILICON FEED RODS
- SCAN AND SLIT IRREGULARITIES OF X-RAY TOPOGRAPHY CAMERA
- MINORITY CARRIER LIFETIME MEASUREMENTS IN HEAVILY DOPED Si
- CHANGE OF FLOAT-ZONING TECHNICIANS AND DELAY DUE TO TRAINING