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## GLASS-Si HETEROJUNCTION SOLAR CELLS

The objective of this program is the development of a low temperature, low-cost process to combine a wide band gap top surface material with silicon to form a heterojunction solar cell. The top material, in addition to forming a junction, provides an optically transparent window, low resistance contact, and an optical match for low reflectivity. The requirements for an overall low-cost array require, in addition to a low-cost process, a low cost substrate material such as polycrystalline silicon.

Progress during this six month period is best indicated by the achievement of an increase in efficiency on polycrystal silicon from an initial 2% to over 7% (as measured both at INNOTECH and NASA-Lewis facilities). The cells were produced in the 2 cm by 2 cm and 1 cm by 1 cm size, with top-side grid metallization. The polycrystalline silicon has crystal grains varying from 5 $\mu$ m to 5mm. The junction is an n+/n heterojunction between an SnO<sub>2</sub>-based glass and the polycrystalline silicon. Voltages of up to 475mV were measured under open circuit conditions.

For single crystal substrates, efficiencies very close to 10% were measured. These cells had the same structure as the polycrystalline cells described above. Open-circuit voltages as high as 529mV were measured.

Short-circuit current density for single crystal approaches 30mA/cm<sup>2</sup> for the polycrystalline units; the short-circuit is about 90% of the short-current measured for the single crystal units. We believe this demonstrates the potential of solar cells using polycrystalline materials to achieve 90% of the efficiency of a non-textured single-crystal solar cell.

The cells are n+-type SnO<sub>2</sub> based glass on an n-type silicon forming an n+/n junction. Theoretical investigation of the current generation model and barrier layer model is underway. The built-in voltage and the resulting open-circuit voltage is process dependent.

Work on p+/n heterojunction using In<sub>2</sub>O<sub>3</sub>-based glass resulted in cells of 3% efficiency on polycrystalline material and 4% efficiency on single crystal material. Values of 337 mV were achieved for open-circuit voltage. This low voltage is the main limit for high efficiencies.

Work on other glass/silicon systems did not show appreciable promise. Cells with fine grain polycrystalline material had lower photocurrent than the polycrystalline material reported on above.

As the number of grain boundaries increases, further losses in current must be tolerated. The experiments were limited and information as to  $V_{oc}$  reduction due to reduction of effective lifetime with fine grain sizes could not be determined.

Initial work on spray coating of glass on silicon substrates showed very promising results. We believe this method can lead to a vacuum-free process.

The contract work for the next year will be focused towards achieving 10% efficiency on polycrystalline materials and 14% efficiency on single crystal cells. Further understanding of the n<sup>+</sup>/n glass-Si heterojunction will be a prime effort. We are excited about this technology as representing a potentially lower cost, viable alternate to diffusion.

GLASS-SI HETEROJUNCTION SOLAR CELLS  
NSF GRANT AER74-17631

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING  
SYRACUSE UNIVERSITY  
SYRACUSE, NEW YORK

INNNOTECH CORPORATION  
NORWALK, CONNECTICUT

PERIOD OF GRANT: 1 AUG. 1974 - 31 JULY 1975

FUNDING FOR 1 AUG. 1974 - 31 JULY 1975: \$313,900

PRINCIPAL INVESTIGATOR:

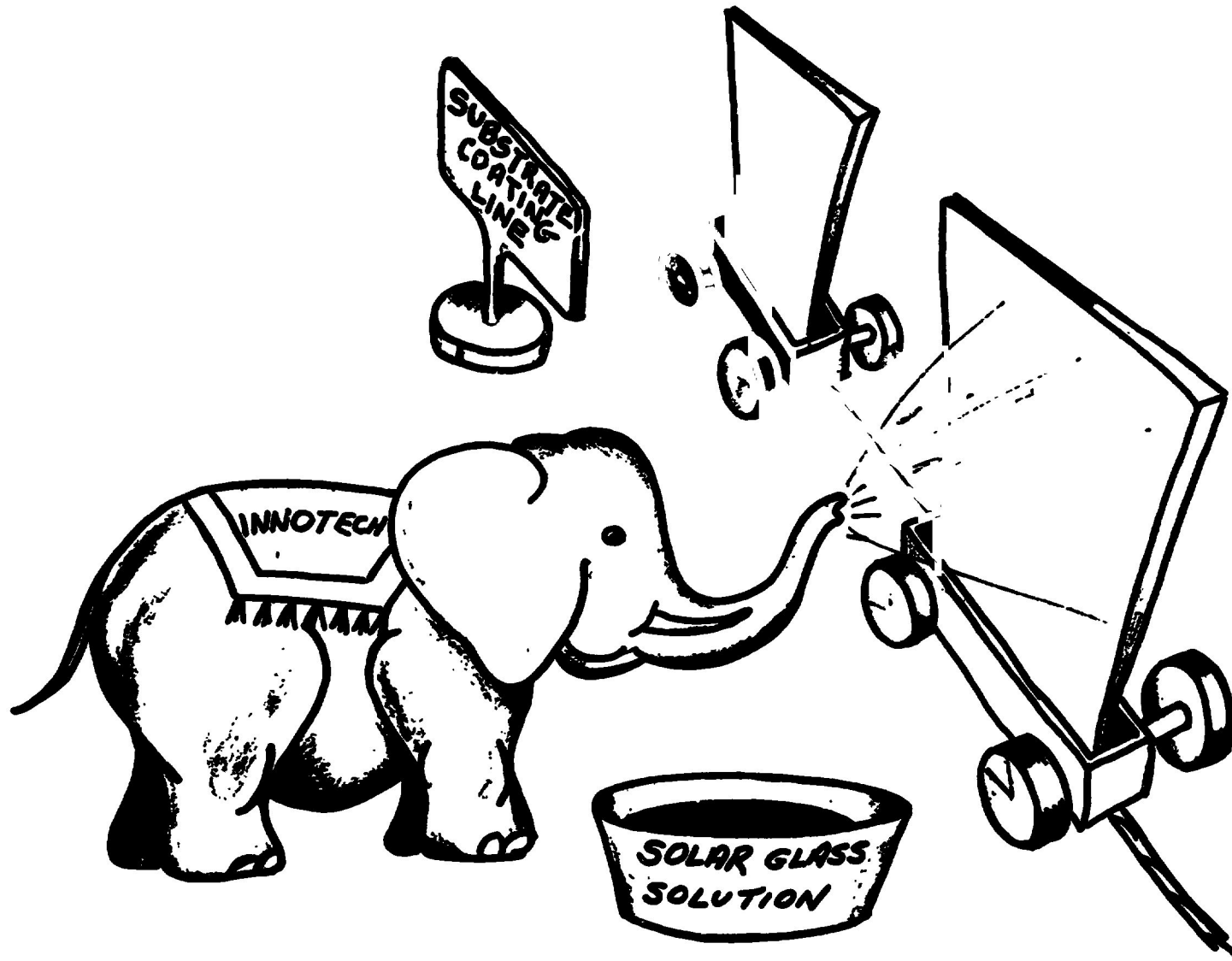
R.L. ANDERSON  
SYRACUSE UNIVERSITY

## OVERALL OBJECTIVES OF PROJECT

THE PURPOSE OF THIS PROJECT IS TO INVESTIGATE THE FEASIBILITY OF FABRICATING LOW-COST SOLAR CELLS SUITABLE FOR TERRESTRIAL APPLICATION. THESE CELLS CONSIST OF GLASS-SILICON HETEROJUNCTIONS. SPECIFIC GOALS INCLUDE THE PREPARATION AND CHARACTERIZATION OF GLASS-MONOCRYSTALLINE Si AND GLASS-POLYCRYSTALLINE Si HETEROJUNCTIONS, AND MODELING THESE DEVICES.

PLANNED ACTIVITY LAST 6 MONTHS

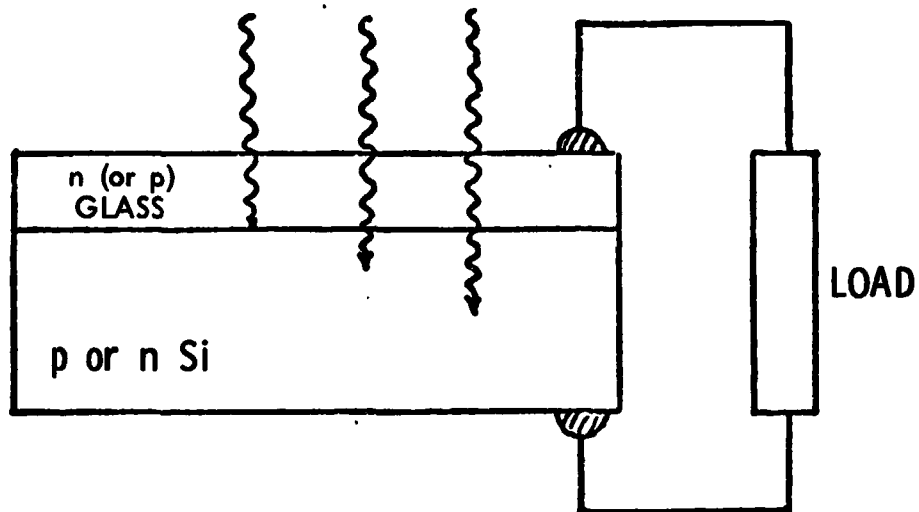
- DEVELOP PRELIMINARY THEORY OF HETEROJUNCTION SOLAR CELLS
- INCREASE OPEN CIRCUIT VOLTAGE ON EXISTING AND NEW GLASS/SILICON MATERIAL SYSTEMS
- PRODUCE LARGE SIZE CELLS ON VARIOUS SUBSTRATES
- DEVELOP PROCESSING TECHNIQUES
- INCREASE FILL FACTOR



LOW COST SOLAR CELL PROCESSING LINE

## PROJECT CONCEPTS

### INCIDENT RADIATION



SCHEMATIC DIAGRAM OF GLASS-Si HETEROJUNCTION CELL

### ADVANTAGES OF CELL

1. OPTICALLY TRANSPARENT WINDOW
2. LOW SERIES RESISTANCE
3. LOW REFLECTIVITY
4. LOW COST

## BEST CELL RESULTS

Evap.  $n^+ - \text{SnO}_2 / n - \text{Si}$  CELL

@ AM 1 100  $\text{mW}/\text{cm}^2$

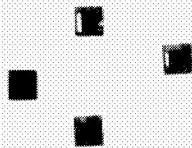
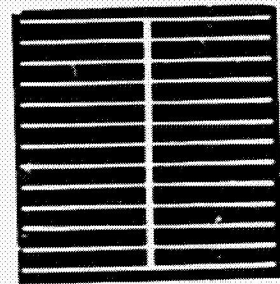
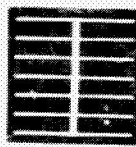
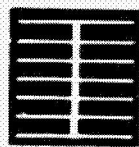
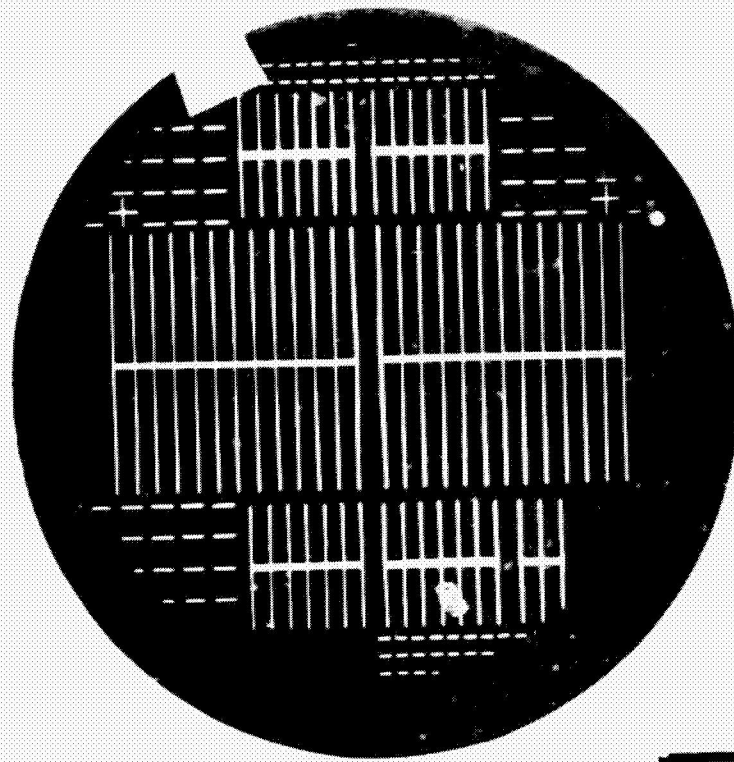
AREA	Voc mV	Isc mA	FF %	Eff. %	Location
4 $\text{cm}^2$	468	106	56	5.94	NASA
Polycrystal	466	109	55	7.0	INNOTECH
4 $\text{cm}^2$	523	117	61	9.41	NASA
Single Crystal	516	122	58	9.1	INNOTECH
1 $\text{cm}^2$	463	26	60	7.18	NASA
Polycrystal	470	32	53	8.0	INNOTECH
1 $\text{cm}^2$	521	29.4	64	9.54	NASA
Single Crystal	524	36	53	10.1	INNOTECH



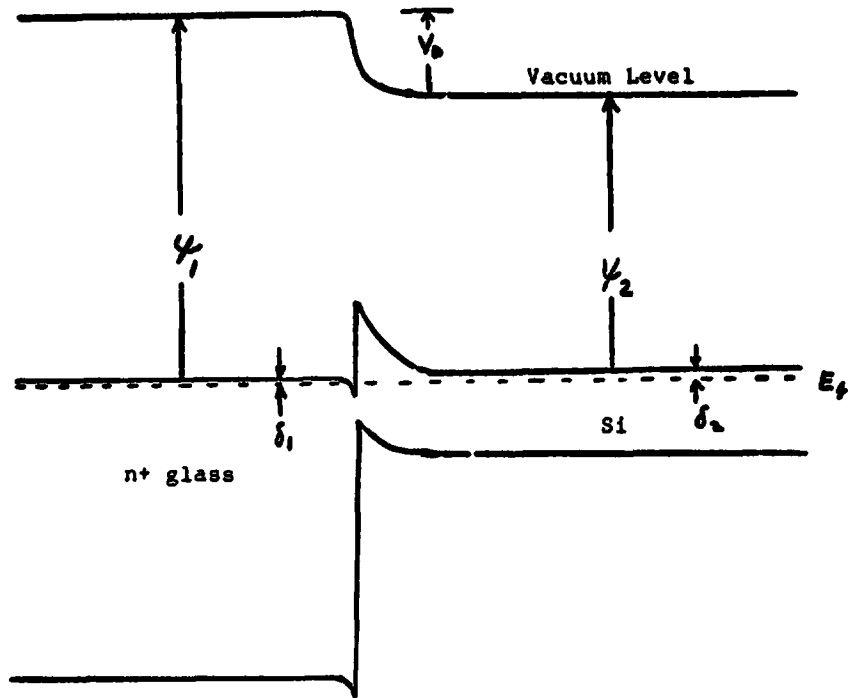


**CRYSTAL SIZE: 5  $\mu$ m – 5mm**

**PHOTOGRAPH OF  
n – TYPE POLYCRYSTALLINE WAFER**



PHOTOGRAPH OF COMPLETED TEST  
WAFER AND SOLAR CELLS



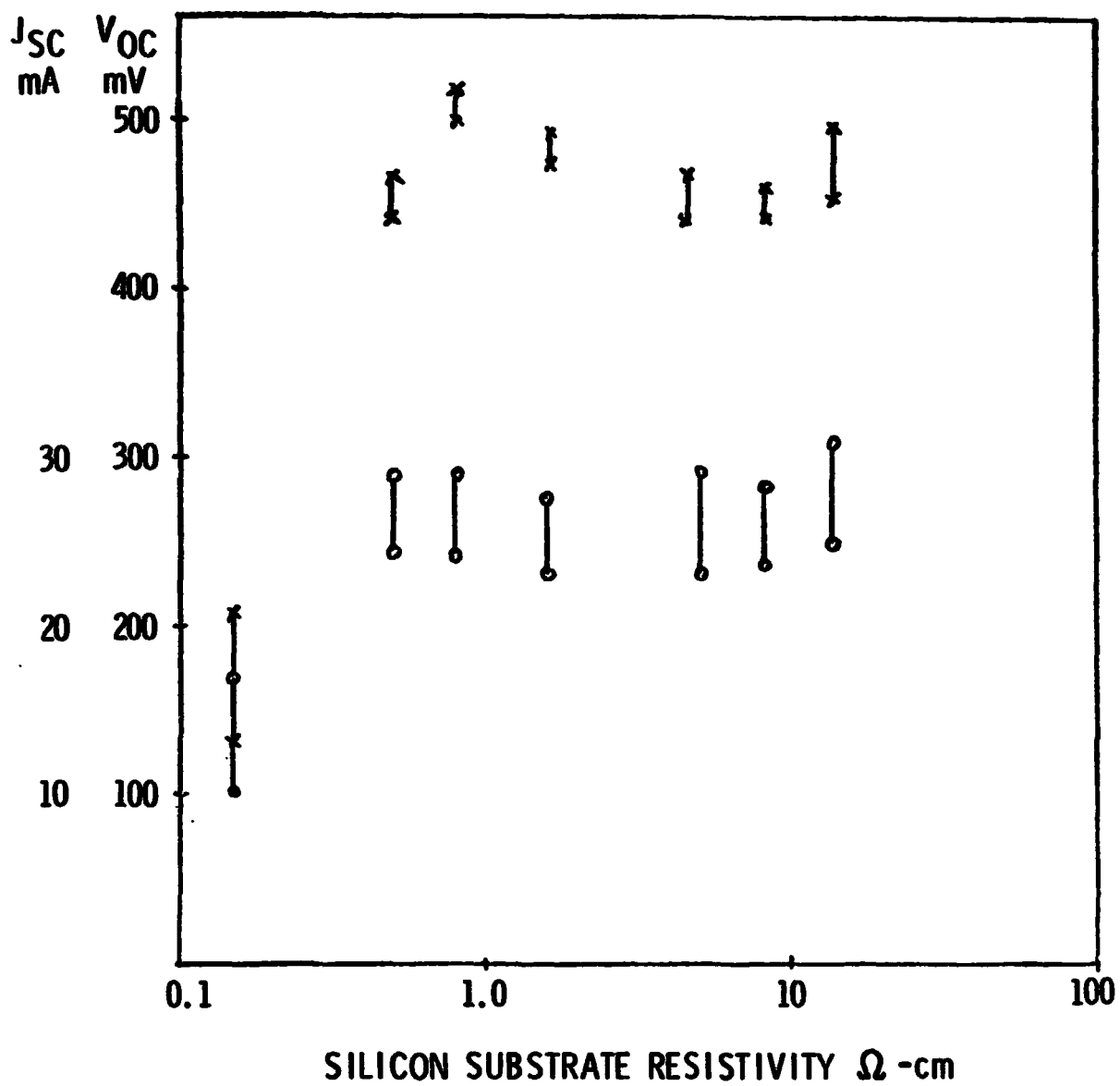
$$V_0 = \psi_1 - \psi_2 + \delta_2 - \delta_1$$

SIMPLIFIED ENERGY BAND DIAGRAM AND BARRIER VOLTAGE EQUATION FOR n+/n HETEROJUNCTION  
NEGLECTING SURFACE STATES AND SiO<sub>2</sub> BARRIER LAYER

DEVELOPMENT OF AN ECONOMICAL SILICON SOLAR CELL  
GRANT No. GI-43091  
18 MONTHS, INITIATED 1JUNE 1974

\$114,100

PRINCIPAL INVESTIGATOR:  
JOSEPH LINDMAYER  
SOLAREX CORPORATION



RESISTIVITY OF WAFER vs OPEN-CIRCUIT VOLTAGE AND SHORT-CIRCUIT CURRENT

## BEST CELL RESULTS

SPRAY  $n^+ - \text{SnO}_2 / n - \text{Si}$  CELL

@ AM 1 100  $\text{mW}/\text{cm}^2$

AREA	Voc mV	Isc mA	FF %	Eff. %	Location
4cm <sup>2</sup>	4.1	80.5	43	3.49	NASA
Polycrystal	405	83	44	3.7	INNOTECH
4cm <sup>2</sup>	514	100.5	48	6.15	NASA
Single Crystal	486	105	46	5.9	INNOTECH
1cm <sup>2</sup>	425	19	56	4.49	NASA
Polycrystal	436	23	52	5.2	INNOTECH
1cm <sup>2</sup>	468	25.5	54	6.39	NASA
Single Crystal	477	32	45	6.9	INNOTECH

## BEST CELL RESULTS

Evap. n<sup>+</sup> — In<sub>2</sub>O<sub>3</sub> / P -Si CELL

@ AM 1 100 mW/cm<sup>2</sup>

AREA	Voc mV	Isc mA	FF %	Eff. %	Location
4cm <sup>2</sup>	337	96	38	3.32	NASA
Polycrystal	332	100	33	2.8	INNOTECH
4cm <sup>2</sup>	317	95	54	4.09	NASA
Single Crystal	315	100	53	4.4	INNOTECH
1cm <sup>2</sup>	359	23.1	56	4.61	NASA
Polycrystal	340	2.9	51	5.0	INNOTECH
1cm <sup>2</sup>	343	24.9	57	4.9	NASA
Single Crystal	322	30	50	5.0	INNOTECH



CRYSTAL SIZE:  $5\mu\text{m} - 5\text{mm}$

PHOTOGRAPH OF p-TYPE POLYCRYSTALLINE WAFER



## OTHER SILICON SUBSTRATES

- EPI POLYCRYSTALLINE ( PROF. CHU-SMU)  
POOR INNOTECH RUN FOR  $V_{oc}$   
PHOTOCURRENT -  $20\text{mA}/\text{cm}^2$  - ABOUT 2/3 OF SINGLE CRYSTAL IN RUN
- EPI POLYCRYSTALLINE ON SILICON (EPI REACTOR)  
PHOTOCURRENT -  $15\text{ mA}/\text{cm}^2$  - ABOUT 1/2 OF SINGLE CRYSTAL IN RUN
- VACUUM DEPOSITED POLYCRYSTALLINE ON GLASS AND METAL (PROF. FANG - BC)  
SHORTED THROUGH TO SUBSTRATE
- RIBBON
  - N+  $\text{In}_2\text{O}_3/\text{P Si}$  - GOOD AS SINGLE CRYSTAL - FIRST GROUP
  - N+  $\text{In}_2\text{O}_3/\text{P Si}$  - HIGH LEAKAGE - SECOND GROUP
  - N+  $\text{SnO}_2/\text{N Si}$  - POOR  $V_{oc}$   $I_{sc}$  AND FF

## OTHER GLASSES

- $V_2O_5$
- $.5V_2O_5 .5P_2O_5$
- $.85V_2O_5 .15P_2O_5$
- CABAL GLASSES
- $2Sb_2O_3.SnO_2$
- $TiO_2$
- $Ca_2SnO_4$  (G. HAACKE - AMERICAN CYANAMID)

## HETEROFACE CELLS

$N+In_2O_3/N+Si/PSi$

- EFFICIENCY 10%
- LOW PRIORITY PROGRAM

## SUMMARY OF KEY RESULTS

- 7% EFFICIENCY USING POLYCRYSTALLINE MATERIAL WITH 1 CM<sup>2</sup> AND 4 CM<sup>2</sup> SOLAR CELLS
- 10% EFFICIENCY USING SINGLE CRYSTAL
- BEST RESULTS ON N<sup>+</sup>/N JUNCTIONS WITH SnO<sub>2</sub> BASED GLASS
- GOOD REPRODUCIBILITY
- SPRAYED GLASS HETEROJUNCTION SHOWS PROMISING INITIAL RESULTS FOR A VACUUM-FREE PROCESS

## MAJOR PROBLEMS

### TECHNICAL

- UNDERSTANDING EFFECT OF SURFACE STATES AND  $\text{SiO}_2$  BARRIER ON  $V_{\text{OC}}$  AND  $V_{\text{D}}$
- EFFECT OF VARIOUS PROCESSING PARAMETER ON  $V_{\text{OC}}$  AND  $V_{\text{D}}$
- INCREASE OF  $V_{\text{OC}}$
- SUPPLY OF POLYCRYSTALLINE MATERIAL

### COST

- FUNDS EXHAUSTED - NEED CONTINUING SUPPORT EFFECTIVE 1 AUGUST

PLANNED ACTIVITY FOR NEXT 12 MONTHS

- DEVELOP BETTER THEORETICAL UNDERSTANDING OF THE GLASS/S<sub>1</sub> INTERFACE TO ACHIEVE HIGHER V<sub>OC</sub>
  
- INCREASE EFFICIENCY
  - HIGHER V<sub>OC</sub>
  - HIGHER I<sub>SC</sub>
  - TEXTURE ON SINGLE CRYSTAL
  - HIGHER FILL FACTOR
  - BETTER CONTACT
  - LOWER SHEET RESISTANCE
  - IMPROVE GRID STRUCTURE
  
- PRODUCE LARGER (> 4 cm<sup>2</sup>) POLYCRYSTALLINE AND SINGLE CRYSTAL CELLS
  
- DEVELOP VACUUM FREE PROCESSING
  - SPRAY GLASS AND OTHERS
  - METALLIZATIONS
  
- INVESTIGATE OTHER GLASSES
  
- IMPROVE TEST SETUP - CORRELATE TO ERDA APPROVED TEST LOCATIONS

## PLANNED RENEWAL REQUESTS

MAJOR GOAL - 12 MONTHS

- 10% EFFICIENCY ON POLYCRYSTALLINE SILICON
- 14% EFFICIENCY ON SINGLE CRYSTAL SILICON
- HIGH REPRODUCIBILITY
- BETTER JUNCTION UNDERSTANDING
- VACUUM FREE PROCESSING

DATES

1 AUGUST 1975 TO 31 JULY 1975

ESTIMATED COSTS

\$449,000 ( INNOTECH AND MIT )