SILICON SCHOTTKY PHOTOVOLTAIC DIODES FOR SOLAR ENERGY CONVERSION (GRANT AER73-03197)

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ABSTRACT

Schottky barrier solar cells (SBSC) are fabricated on <100>, 2 Ω-cm, p-type silicon using an Al ohmic contact, 50 Å Cr and then 50 Å Cu Schottky contact, Al current grid, and SiO antireflection coating. Past research was directed towards showing the potential of a SBSC in solar energy conversion. The present project is designed to improve understanding of the SBSC, improve efficiency to 12%, and evaluate potential towards thin film silicon applications.

Figures 4-10 summarize progress in evaluating the various variables in fabrication. At least 40 Å Cr metal is necessary for a good fill factor but Cr alone has too high a sheet resistance. Cu alone gives low open circuit voltage (V_{oc}). About 40 Å Cr and 50-60 Å Cu produce the best combination for high voltage, current (J), and fill factor (F). It has also been shown that removal of the 5-10 Å interfacial oxide layer between silicon and Cr which grows during heat treatment leads to reduced V_{oc}. Both the oxide and Cr are necessary for a high V_{oc}. Modification of the heat treatment cycle changes the oxide thickness leading to modification of V_{oc}. A sputtered Cu layer reduced V_{oc} due to Cu atom penetration into the silicon. <100> silicon gives higher J_{sc} and F than does <111> silicon.

Large area solar cells have lower F than small area ones. This shows the importance of finger design and low sheet resistance. Examination of substrate resistivity effects show 2 Ω-cm silicon to give slightly higher V_{oc} and 0.4 Ω-cm to give slightly higher J_{sc}.

Figures 11 and 12 show results of using "as-sawn" silicon and chemical polishing (only) to produce a smooth surface. Elimination of mechanical polishing could be a cost reducing step in final production procedures. The chemical polished wafers do show greatly improved performance over unpolished ones but more work is necessary to study different polishing sequences. SBSC made from Tyco silicon show a 5% maximum efficiency. More studies of the Tyco silicon are required for complete analysis.

Figure 14 shows results of an activation energy study to explore current conduction mechanisms. These preliminary results indicate that both thermal and tunneling effects exist in the SBSC fabricated at Rutgers. Optical calculations by computer show that 460 Å Nb_2O_5 gives significantly better antireflection (AR) properties than 755 Å SiO. The lesser thickness of Nb_2O_5 should also lead to reduced absorption loss in the AR coating. A solar simulator assembled using a variac, tungsten lamp, and water filter gives photovoltaic data comparable to direct sunlight illumination.

The most significant achievements in this latest research have been increased fill factor (to 0.74) using baking of the vacuum system to remove moisture, improved understanding of the current flow mechanism, and isolation of processing variables which improve efficiency.

OBJECTIVE OF THE PROJECT

THE OVERALL OBJECTIVE IS TO PRODUCE A 12% EFFICIENT SCHOTTKY SOLAR CELL USING ECONOMICAL SILICON AND FABRICATION METHODS. THIS IS TO BE ACCOMPLISHED THROUGH OPTIMIZATION OF CURRENT BY USE OF NEW AR COATINGS, VOLTAGE BY INTERFACE STUDIES, AND FILL FACTOR BY DEPOSITION STUDIES. FURTHER STUDIES INCLUDE ENVIRONMENTAL EFFECTS, THIN EPITAXIAL SILICON FILMS, SURFACE EFFECTS, AND NEW SOURCES OF SILICON.

PLANNED ACTIVITY LAST 6 MONTHS

I. PROCESS VARIABLES WHICH INFLUENCE SOLAR CELL PERFORMANCE

AREA
SUBSTRATE RESISTIVITY
SUBSTRATE ORIENTATION
HEAT TREATMENT
DEPOSITION PROCEDURES
WAFER POLISHING
NEW AR COATINGS

II. MISCELLANEOUS

NEW COMPUTER PROGRAMS
SOLAR SIMULATOR
CURRENT MECHANISM STUDIES

FIGURE 4

PROCESSING STUDY

Sample	Process	V_{OC} (V)	J_{SC} (mA/cm^2)	F	P (mW/cm^2)
134	Cu Schottky metal	0.23	11.8	0.39	0.7
136	25 Å Cr, then Cu	0.46	22.6	0.39	4.0
143	100 Å Cr	0.45	13.3	0.40	2.4

INTERFACE STUDY

	Normal	V_{OC} = 0.45-0.53
123 & 124	Re-etch after heating	≈ 0
126 & 127	As above, then re-heat	0.45

FIGURE 5

EFFECT OF ADDITIONAL OXIDE BETWEEN SCHOTTKY METAL AND SILICON

SAMPLE	ADDITIONAL OXIDE	AREA (CM^2)	I_o (MA)	I_{SC} (MA)	V_{OC} (V)
141	18 Å E	0.67	0.055	8	0.23
142	31 Å E	3.0	0.050	1.6	0.20
144	12 Å G	2.7	0.092	0.88	0.17
146	22 Å G	3.3	0.022	0.14	0.14

E - EVAPORATED SRO, THICKNESS MEASURED

G - GROWN IN O_2 @ 620°C, THICKNESS ESTIMATED

FIGURE 6

EFFECT OF HEAT TREATMENT ON PERFORMANCE

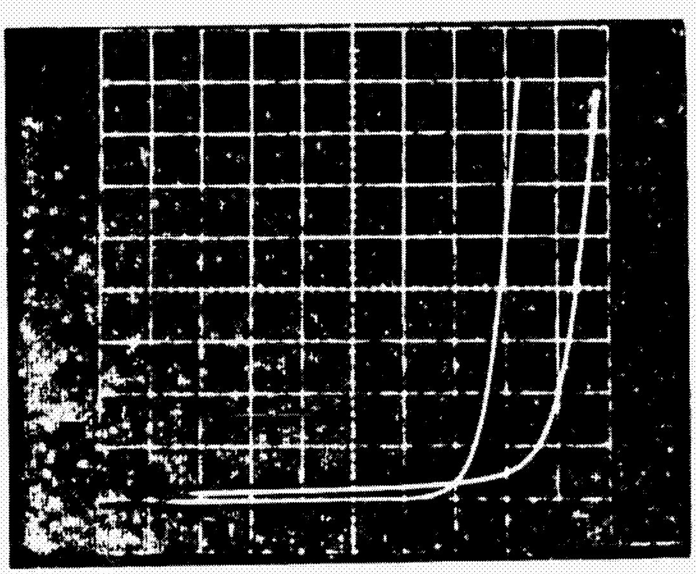
SAMPLE	HEAT CYCLE	I_o (mA)	J_{sc} (mA/cm^2)	V_{oc} (V)	F	P_o (mW/cm^2)
147	STANDARD*	0.012	18.4	0.40	0.62	4.6
148	INC. N_2	0.003	17.8	0.48	0.37	3.2
149	SOAK @ 620°C FOR 2 MIN.	0.0015	17.7	0.50	0.25	2.2
150	300-650°C	0.34	27.2	0.51	0.48	6.65

*STANDARD - RAMP FROM 25°C TO 620°C IN AIR WITH LIGHT N_2 FLOW.
COOL TO 300°C AND REMOVE FROM FURNACE.

NOTE: ELIMINATING N_2 OR REPLACING WITH A_R GIVES NO SIGNIFICANT CHANGE.

FIGURE 7

EFFECT OF SPUTTERING OF CONDUCTIVE METAL ON SOLAR CELL PERFORMANCE



SAMPLE 174

0.1 V/DIV

5 mA/DIV

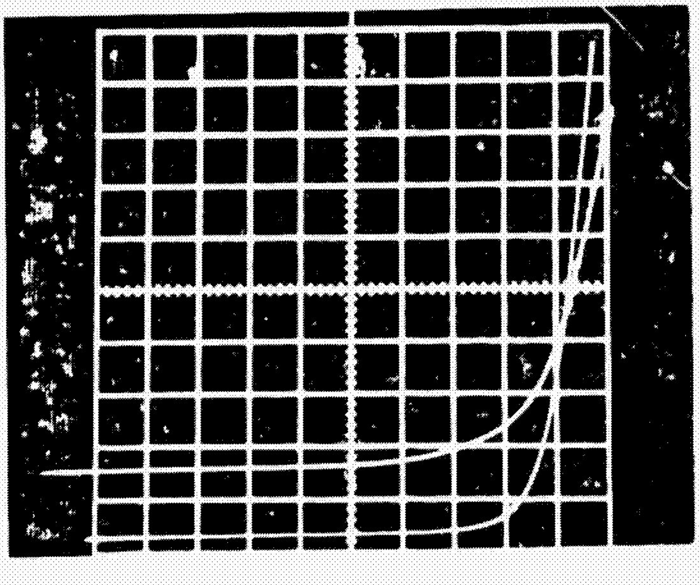
CURVE ON LEFT-SPUTT. AU

CURVE ON RIGHT-EVAP. AU

FIGURE 8

EFFECT OF SUBSTRATE ORIENTATION ON PERFORMANCE

Sample	Orientation	I_o (mA)	J_{sc} (mA/cm^2)	V_{oc} (V)	F	P_o (mW/cm^2)
171A	100	0,24	20,8	0,43	0,65	5,8
171B	111	0,34	12,1	0,43	0.54	2,8



Sample 171

0,1 V/div

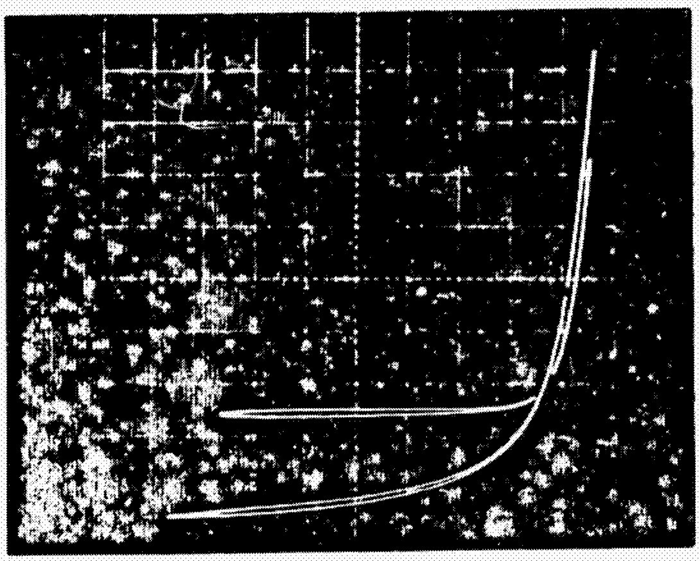
5 mA/div for A

10 mA/div for B

FIGURE 9

EFFECT OF SOLAR CELL AREA
ON PERFORMANCE

SAMPLE	V_{OC} (V)	F
167,S	0.43	0.71
167,L	0.41	0.52
153,S	0.47	0.67
153,L	0.47	0.60



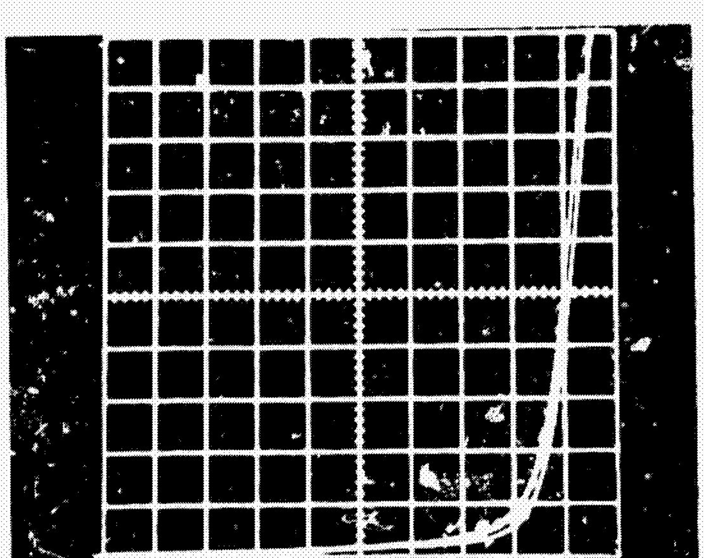
SAMPLE 167

0.1 V/DIV
0.1 MA/DIV SMALL
2 MA/DIV LARGE

FIGURE 10

EFFECT OF SUBSTRATE RESISTIVITY ON PERFORMANCE

SAMPLE	RESISTIVITY (Ω-CM)	I_o (MA)	J_{sc} (MA/CM^2)	V_{oc} (V)	F	P (MW/CM^2)
112	0.4	0.08	5.9	0.40	0.46	1.08
113	2	0.03	5.64	0.42	0.64	1.52
172B	0.4	0.9	19.6	0.41	0.68	5.3
172B	2	0.11	16.9	0.44	0.74	5.2



SAMPLE 172

0.1 V/DIV

5 MA/DIV

FIGURE 11

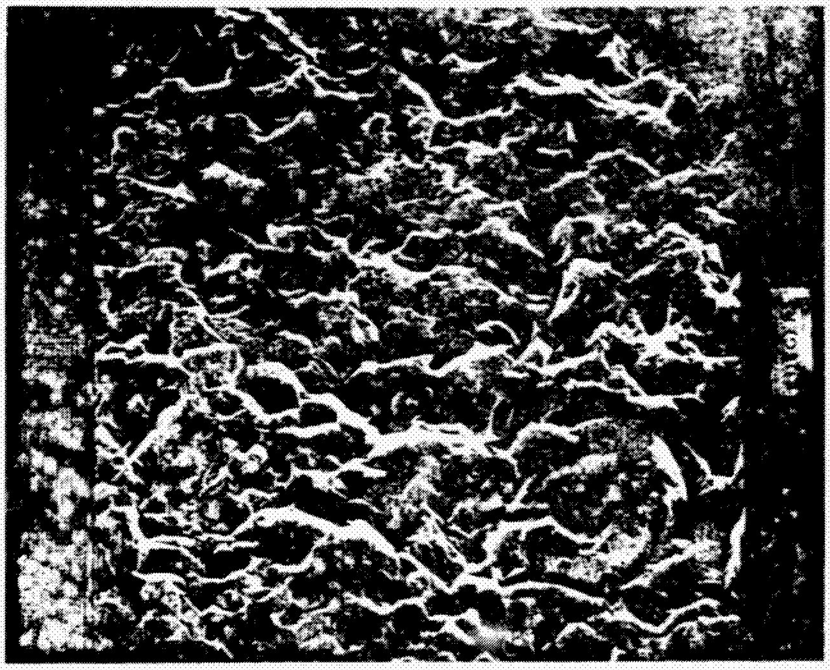
CHEMICAL POLISHING STUDY

STUDY THE FABRICATION OF SCHOTTKY SOLAR CELLS
USING "AS-SAWN" SILICON AND CHEMICAL POLISHING

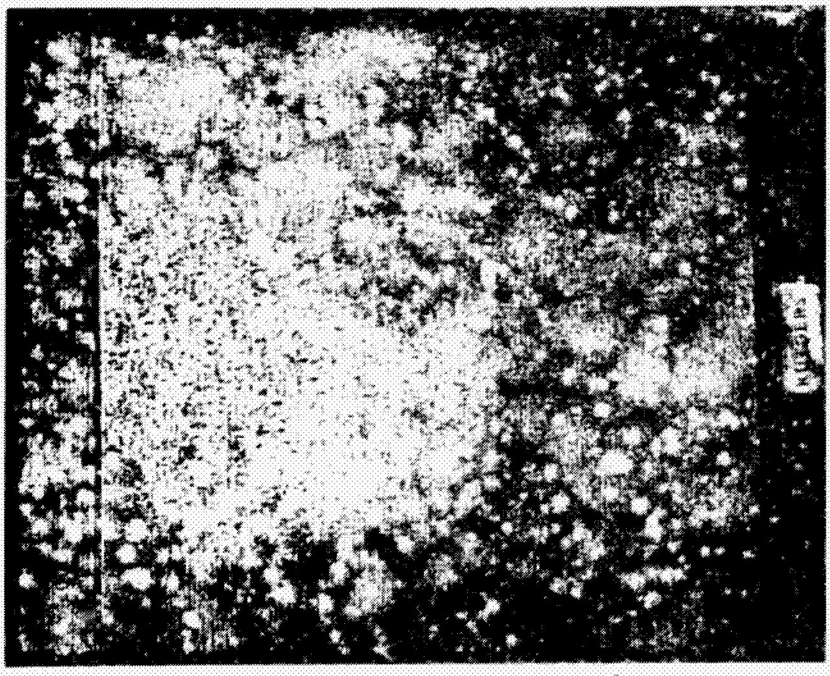
SAMPLE	POLISH	RESULT			
		V_{OC} (V)	J_{SC} (mA/cm^2)	F	P_o (mW/cm^2)
111	"As-sawn"	No photo-response			
117	HF, HNO3	0.31	13.8	.35	1.63
138	HF, HNO3, Acetic	0.27	4.6	.25	.31

FIGURE 12

SCANNING ELECTRON MICROSCOPE STUDY



"As-sawn" silicon
Mag. = 2000



Chemical polished silicon
mag. = 2000

FIGURE 13

TYCO 120

AREA = 1.21 cm^2

V_{oc} = 0.43 V

I_{sc} = 25 mA

$V_{oc}\ I_{sc}$ = 8.9 mW/cm^2 } SUNLIGHT

P_o = 4.16 mW/cm^2 } 80-100 mW/cm^2

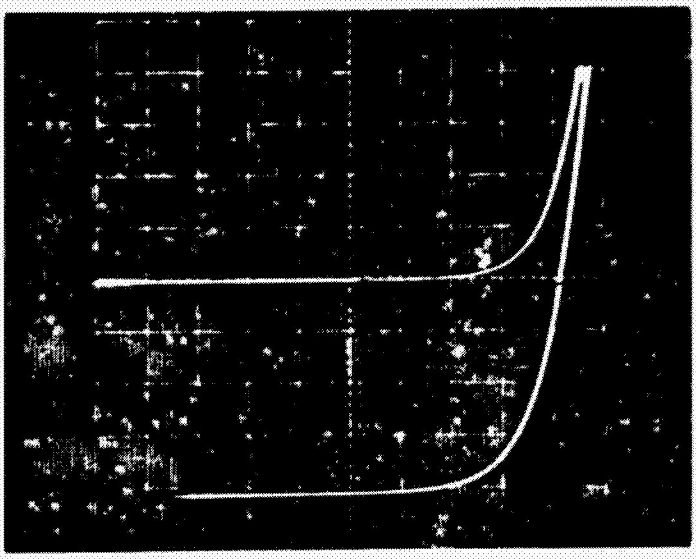


FIGURE 14

ACTIVATION ENERGY

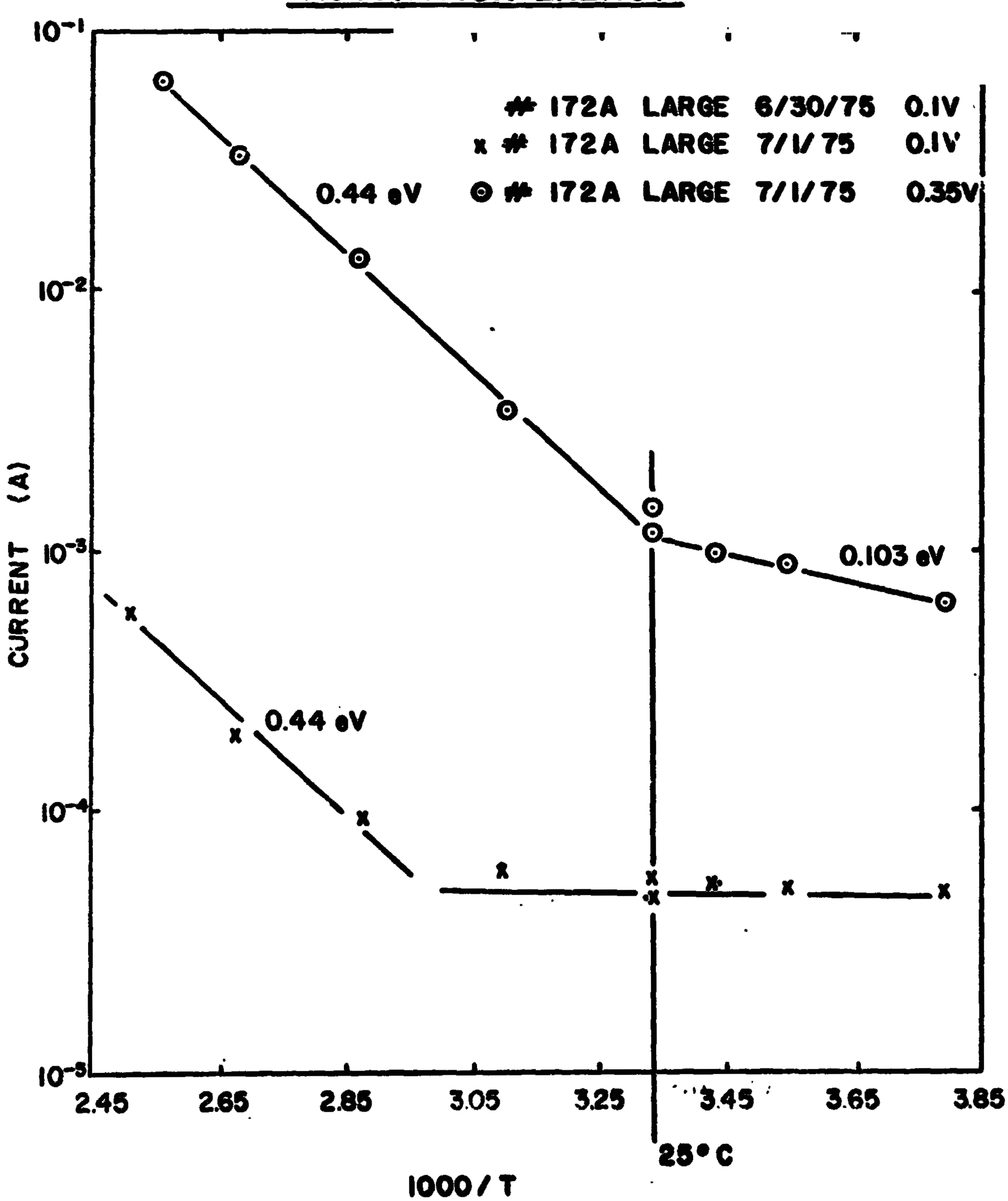


FIGURE 15

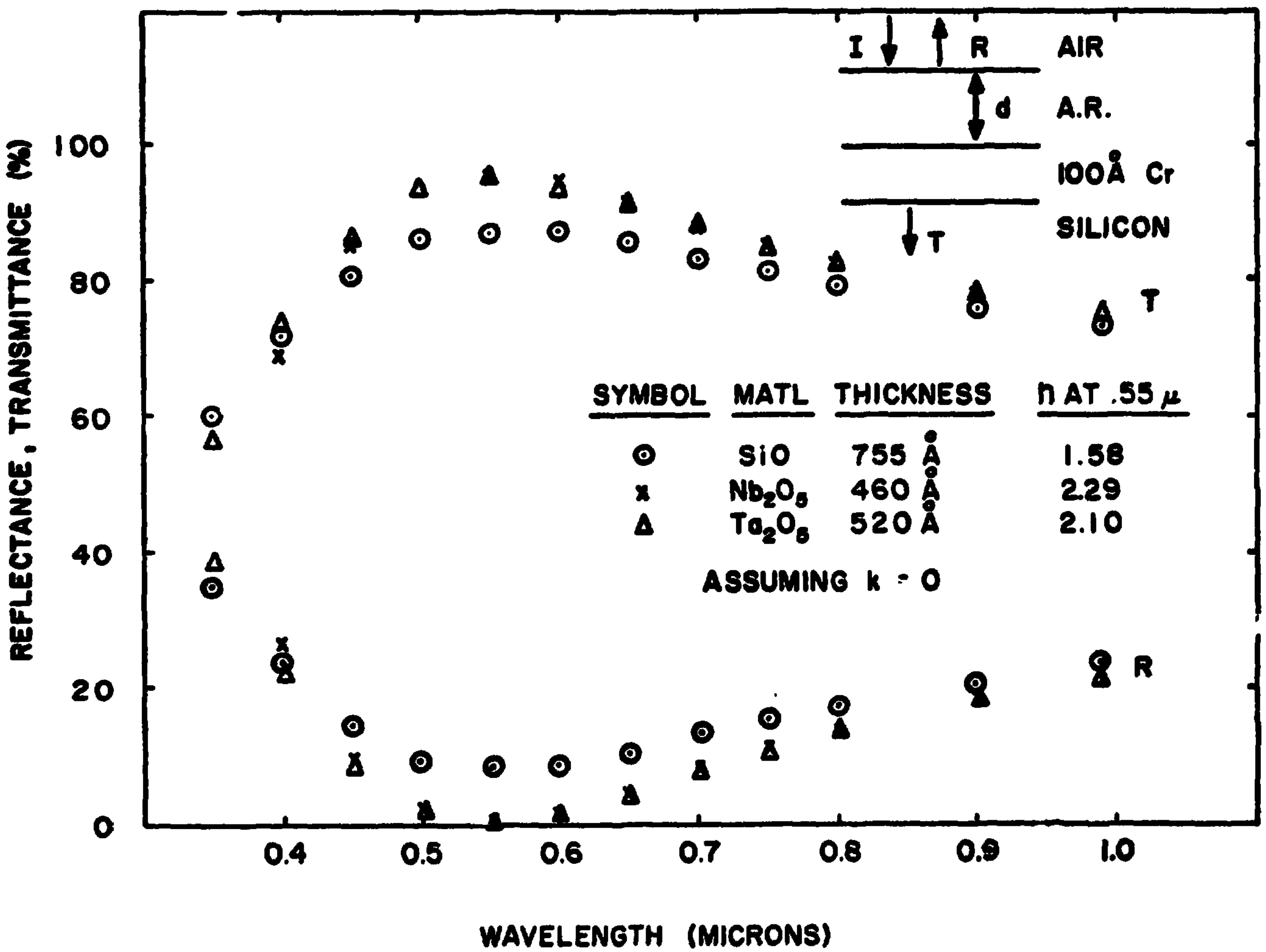

I
R
AIR
d
A.R.
100Å Cr
SILICON
T
T
R
SYMBOL
MATL
THICKNESS
n AT .55 μ
SiO
755 Å
1.58
Nb2O5
460 Å
2.29
Ta2O5
520 Å
2.10
ASSUMING k = 0
REFLECTANCE, TRANSMITTANCE (%)
100
80
60
40
20
0
0.4
0.5
0.6
0.7
0.8
0.9
1.0
WAVELENGTH (MICRONS)

FIGURE 16

MISCELLANEOUS

1. A SOLAR SIMULATOR HAS BEEN ASSEMBLED USING A TUNGSTEN LAMP, VARIAC, AND WATER FILTER. RESULTS COMPARE FAVORABLY WITH DIRECT SUN DATA.
2. 12μ EPITAXIAL LAYER (2Ω-CM) ON A <111>, 0.001 SUBSTRATE GIVES A 50% LOW CURRENT.

SUMMER RESEARCH PARTICIPANTS

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K. NG
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T. POON

FIGURE 17

SUMMARY OF KEY RESULTS

1. CR SCHOTTKY METAL OF 40-50 Å IS BEST.
2. THE OXIDE INTERFACE GIVES HIGH V_{OC}.
3. AN INTERFACE OF 5-12 Å IS PROBABLE.
4. HEAT TREATMENT FROM 300-650^{o}C GIVES HIGH V_{OC}.
5. SPUTTERED SCHOTTKY CONDUCTIVE METAL GIVES LOW V_{OC}.
6. <100> GIVES BETTER J & F THAN <111>.
7. 0.4Ω-CM GIVES HIGHER J.
   2 Ω-CM GIVES HIGHER V_{OC}.
8. TYCO SILICON PRODUCES A PROMISING SCHOTTKY SOLAR CELL.
9. ACTIVATION ENERGY STUDIES MAY LEAD TO ANSWERS ABOUT THE CONDUCTION MECHANISM.
10. NB_2O_5 AND TA_2O_5 GIVE PROMISING ANTIREFLECTION IMPROVEMENTS.
11. A SIMPLE SOLAR SIMULATOR GIVES RESULTS COMPARABLE TO SUNLIGHT ILLUMINATION.
12. F = 0.74 HAS BEEN ACHIEVED USING VACUUM SYSTEM BAKING PRIOR TO EVAPORATION.

FIGURE 18

MAJOR PROBLEMS

1. Understanding the conduction mechanisms and role of the interfacial layer.

2. Reproducibility of sheet resistance values from run to run.

3. Simultaneously achieving high V_{OC}, F, and I_{SC}.

FIGURE 19

PLANNED ACTIVITY FOR NEXT 6 MONTHS

1. BEGIN STUDIES OF EPITAXIAL LAYERS.
2. EXPAND ELECTRONIC TESTING TO IDENTIFY CURRENT FLOW MECHANISMS.
3. CONDUCT MICROSCOPIC STUDY OF SILICON SURFACE AND INTERFACE.
4. OPTIMIZE THE FABRICATION PROCESS.
5. EXPAND COMPUTER STUDIES.
6. STUDY NEW AR COATINGS.
7. SEND SOLAR CELLS TO NASA LEWIS FOR TESTING.
8. INITIATE ENVIRONMENTAL TESTING AND LIFE STUDIES.
9. CONTINUE FABRICATION OF SCHOTTKY SOLAR CELLS USING NEW SILICON SOURCES (IF AVAILABLE).

FIGURE 20

PLANNED RENEWAL REQUESTS

MAJOR GOALS

1. ACHIEVE 15% EFFICIENCY ON SINGLE CRYSTAL SILICON.
2. ACHIEVE 6% EFFICIENCY ON THIN FILM POLYCRYSTALLINE SILICON.

PERSONNEL

ASSOCIATE INVESTIGATOR IN PHYSICS

ASSOCIATE INVESTIGATOR IN MATERIALS SCIENCE

THREE RESEARCH ASSISTANTS

DATE

JUNE 1, 1976 - MAY 31, 1977

COST

$40,000