N76 12487

TITLE

Epitaxial Technology for Low Cost Solar Cells

GRANT

AER 74-15532
(April 1, 1975 - March 31, 1976)
$160,000

CONTRIBUTORS

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Objective: Study of epitaxial solar cell structures on low cost silicon substrates as a means of improving the cell performance compared to direct diffusion into such substrates, and thus allow a wider use of these low cost materials to obtain useful solar cells. The primary emphasis is presently on the use of EFG ribbon material.

Results: Data obtained during the first three months of this grant are reported. The work has included the following: (1) Comparative X-ray topograph of EFG ribbons (grown by Tyco-Mobil) and epitaxial layers deposited on these materials. (2) Study of diodes and solar cells fabricated by diffusion into the ribbon materials and epitaxially formed on the similar material. (3) Carrier concentration distribution studies of ribbon materials using electroreflectance data.

The major conclusions of the work to date are:

(1) The dislocation density in the epitaxial layers is significantly lower than that of the substrate material. As expected, of course, grain and twin boundaries propagate into the epitaxial layers.

(2) The saturation current density of the diodes epitaxially formed on the substrate is commonly 2-3 orders of magnitude lower than for the diodes formed by direct diffusion. However, large variations in EFG ribbon quality were observed, and it appears that the relative difference between the epitaxial and diffused diodes varies accordingly.

(3) The solar cells made epitaxially (particularly if a graded structure is used) are substantially better than those made by direct diffusion into similar material. The difference is observed both in higher I_{sc} and V_{oc}. (All measurements were made under atmospheric conditions using solar illumination for the most part.)

(4) The devices fabricated so far were intended only as comparative study vehicles rather than as state-of-the-art solar cells. Thus, none of the parameters were fully optimized.

The continuing phase of the program will focus on more detailed characterization, with emphasis on minority carrier lifetime, and local variations in device quality which is correlated with the substrate and epitaxial structure. Different structures and fabrication processes will be evaluated in order to optimize the cell parameters, for as wide a substrate quality range as possible.

TITLE : EPITAXIAL TECHNOLOGY FOR LOW COST SILICON SOLAR CELLS

GRANT #: AER 74-15532

RCA LABORATORIES, PRINCETON, N. J./YESHIVA UNIVERSITY

TOTAL GRANT : $160,000 (ONE-YEAR PROGRAM)

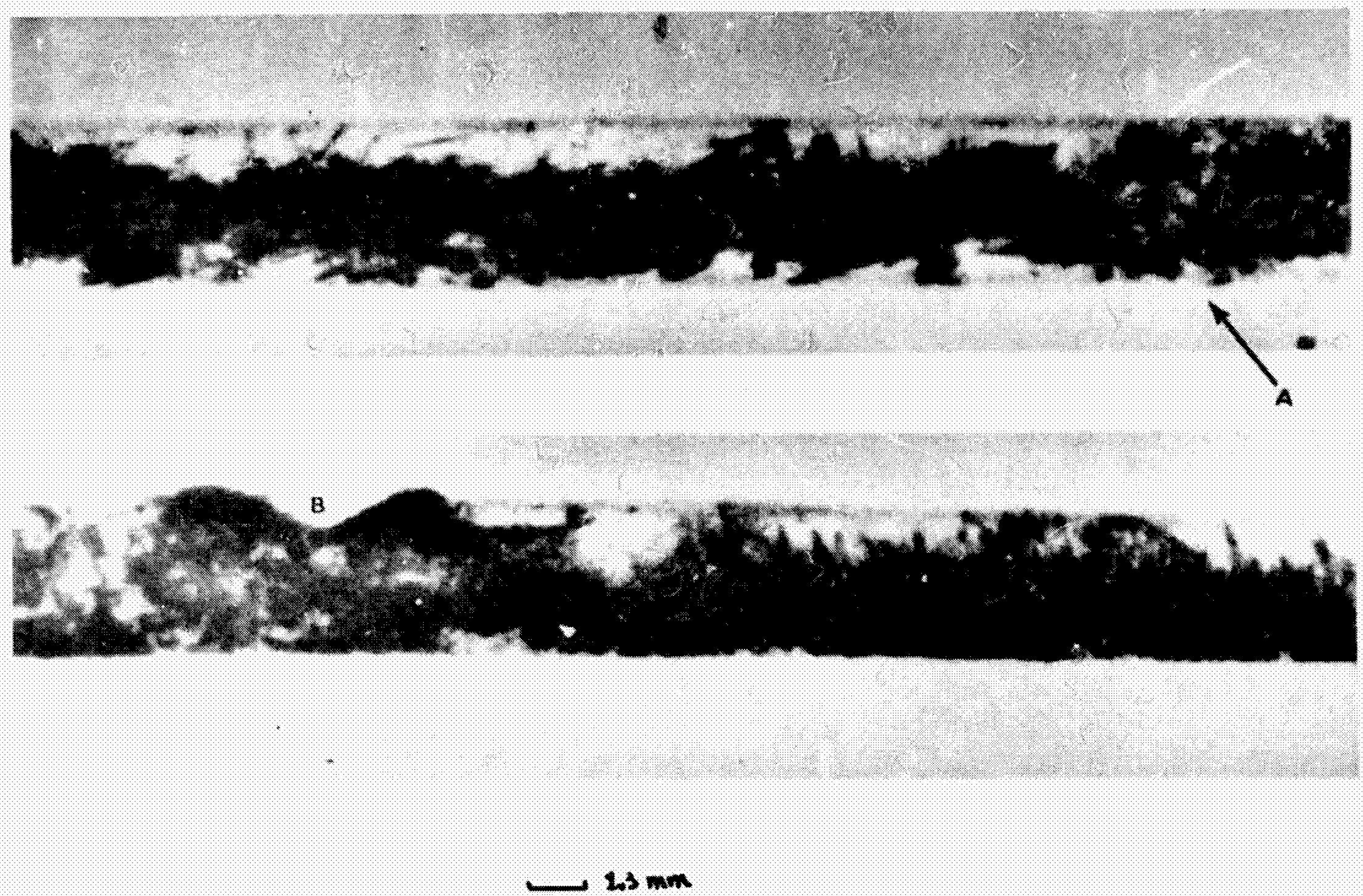
PRINCIPAL INVESTIGATORS : H. KRESSEL/RCA LABORATORIES (PROGRAM SUPERVISOR)
P. RACCAH/YESHIVA UNIVERSITY

PROGRAM BEGAN ON: APRIL 1, 1975

PROGRAM OBJECTIVE

STUDY OF EPITAXIAL SOLAR CELL STRUCTURES ON LOW COST SILICON SUBSTRATES (EFG RIBBON) AS A MEANS OF IMPROVING THE CELL PERFORMANCE COMPARED TO DIRECT DIFFUSION AND THUS ALLOW A WIDER USE OF THE SUBSTRATES PREPARED TO OBTAIN USEFUL DEVICES.

REFLECTION TOPOGRAPH (333)/Cu SHOWING THE REDUCED DEFECT STRUCTURE IN THE EPITAXIAL LAYER (MESAS) COMPARED TO THE ADJOINING EFG SUBSTRATE REGIONS



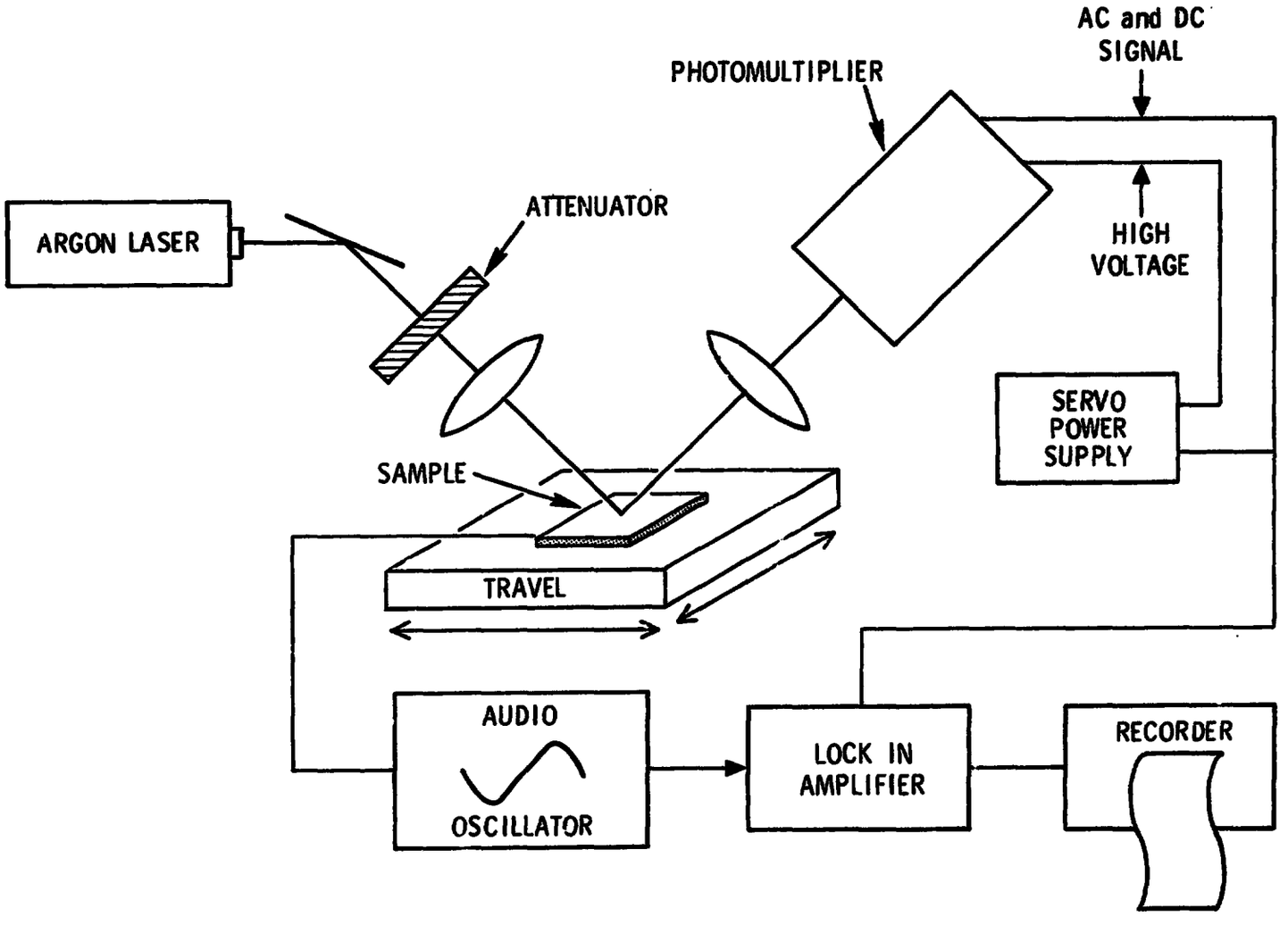
Section topographs showing cross-section defect distribution in silicon/silicon web. The layer is on top and is about 1/3 of the vertical dimension of the image. The high dislocation density in the substrate generally does not propagate into the layer. The twin boundary in the substrate and a growth pit are indicated at A and B, respectively.

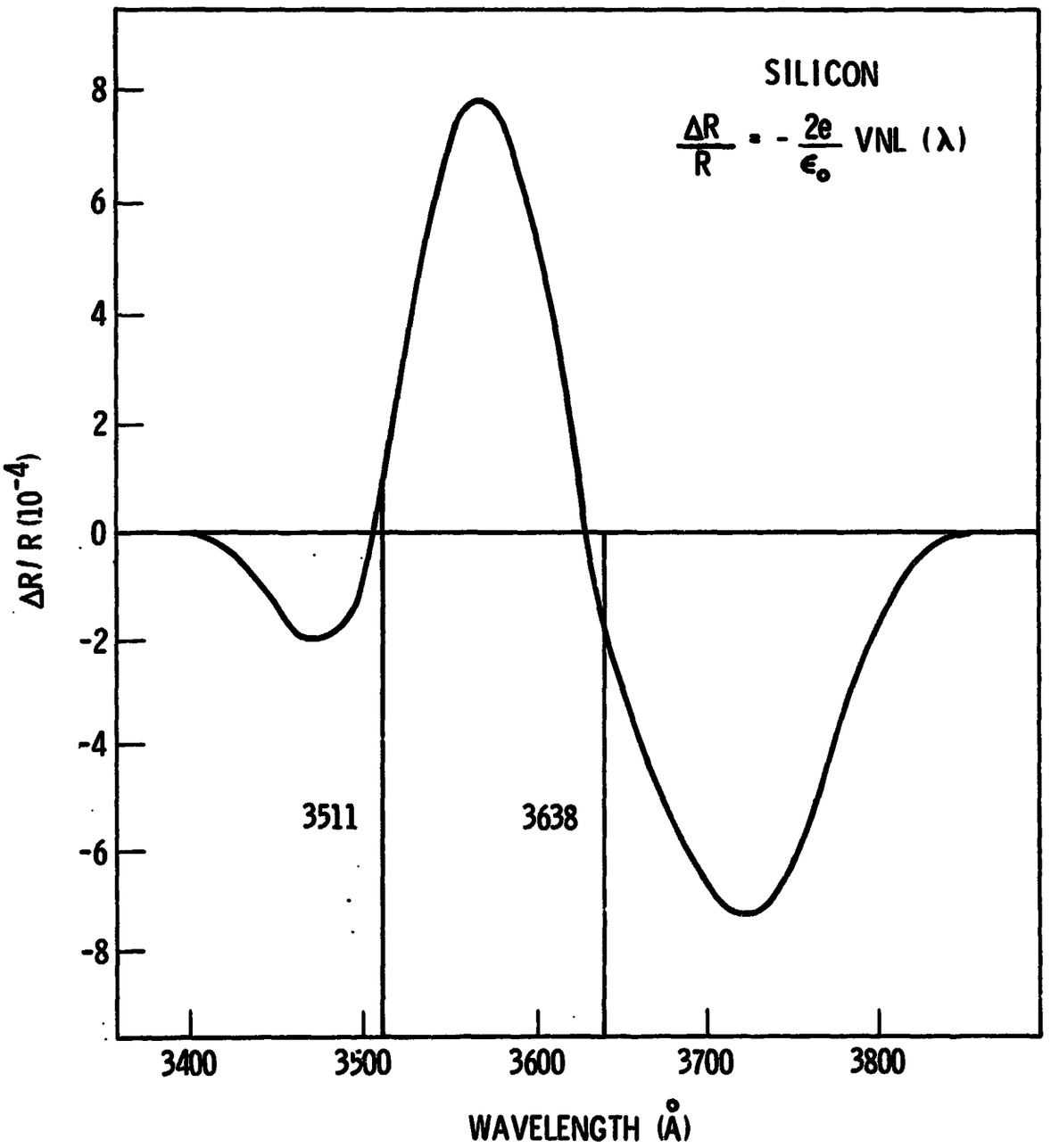
ACTIVITY TO DATE

1. DEFECT ANALYSIS OF RIBBONS AND EPITAXIAL LAYERS TO ESTABLISH METALLURGICAL IMPROVEMENT DUE TO EPITAXY (X-RAY TOPOGRAPHY).

2. CELLS AND DIAGNOSTIC P-N JUNCTION STRUCTURES FABRICATED AND CHARACTERIZED.

3. ELECTROREFLECTANCE EQUIPMENT FOR HIGH RESOLUTION MAPPING OF CARRIERS CONCENTRATIONS COMPLETED. PRELIMINARY CORRELATION BETWEEN GROWTH MORPHOLOGY AND CARRIER CONCENTRATION VARIATION.


AC and DC
SIGNAL
PHOTOMULTIPLIER
ATTENUATOR
ARGON LASER
HIGH
VOLTAGE
SERVO
POWER
SUPPLY
SAMPLE
TRAVEL
AUDIO
OSCILLATOR
LOCK IN
AMPLIFIER
RECORDER


SILICON
$\frac{\Delta R}{R} = -\frac{2e}{\epsilon_o} VNL(\lambda)$
8
6
4
2
0
-2
-4
-6
-8
$\Delta R/R\ (10^{-4})$
3511
3638
3400
3500
3600
3700
3800
WAVELENGTH (Å)

TYR-2

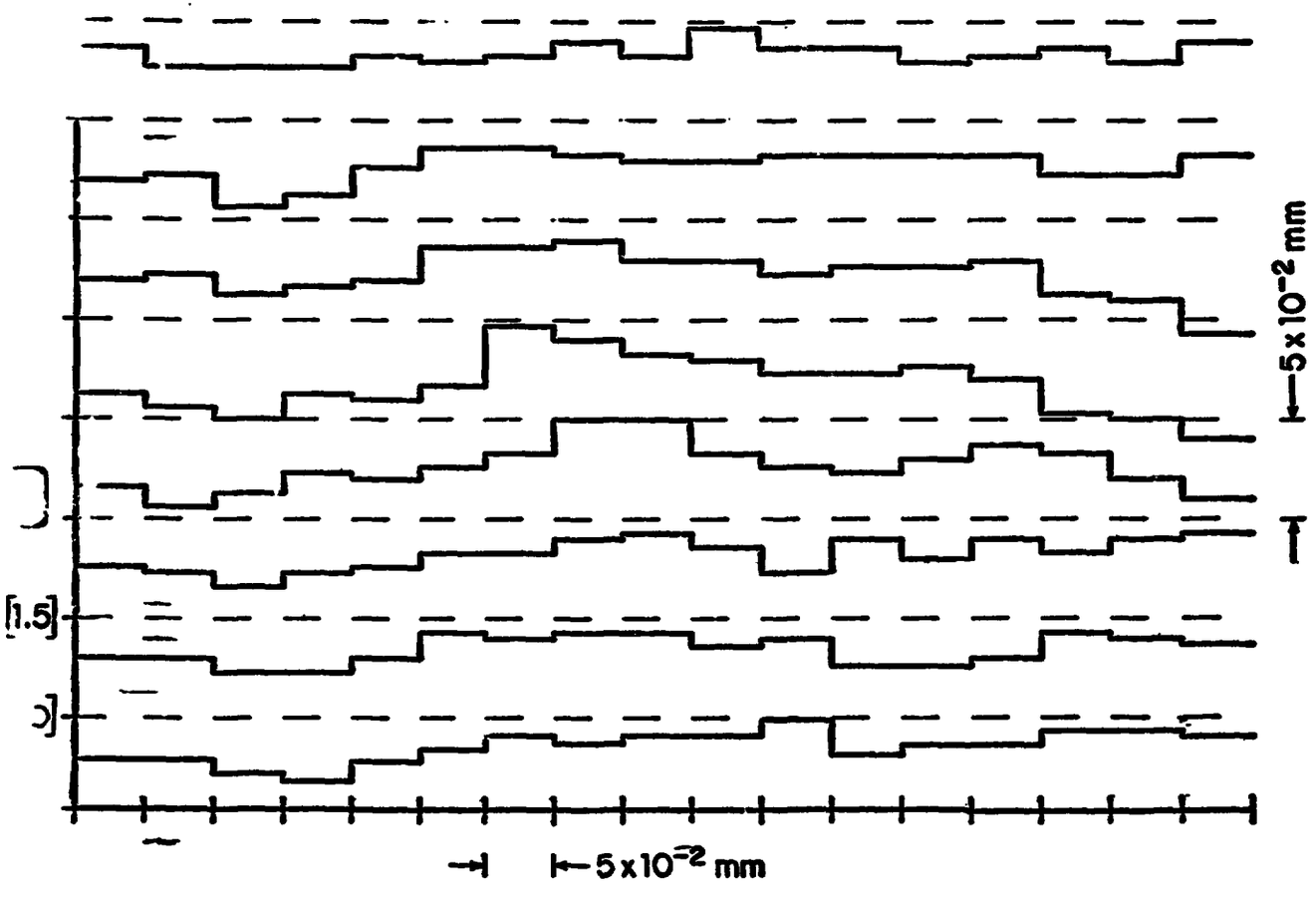


TABLE 1

EPITAXIAL DIODES

#	I_0 (V_a = -2 V), A/cm^3
A1	3.7×10^{-7}
B1	8.6×10^{-8}
C1	9.8×10^{-8}
D1	1.1×10^{-6}
A2	2.2×10^{-7}
B2	2.5×10^{-6}
C2	2.1×10^{-7}
D2	5.5×10^{-7}
A3	1.26×10^{-7}
B3	2.01×10^{-5}
C3	2.15×10^{-5}
D3	5.15×10^{-7}
A4	2.8×10^{-7}
B4	3.4×10^{-7}
C4	5.9×10^{-7}
D4	4.8×10^{-5}

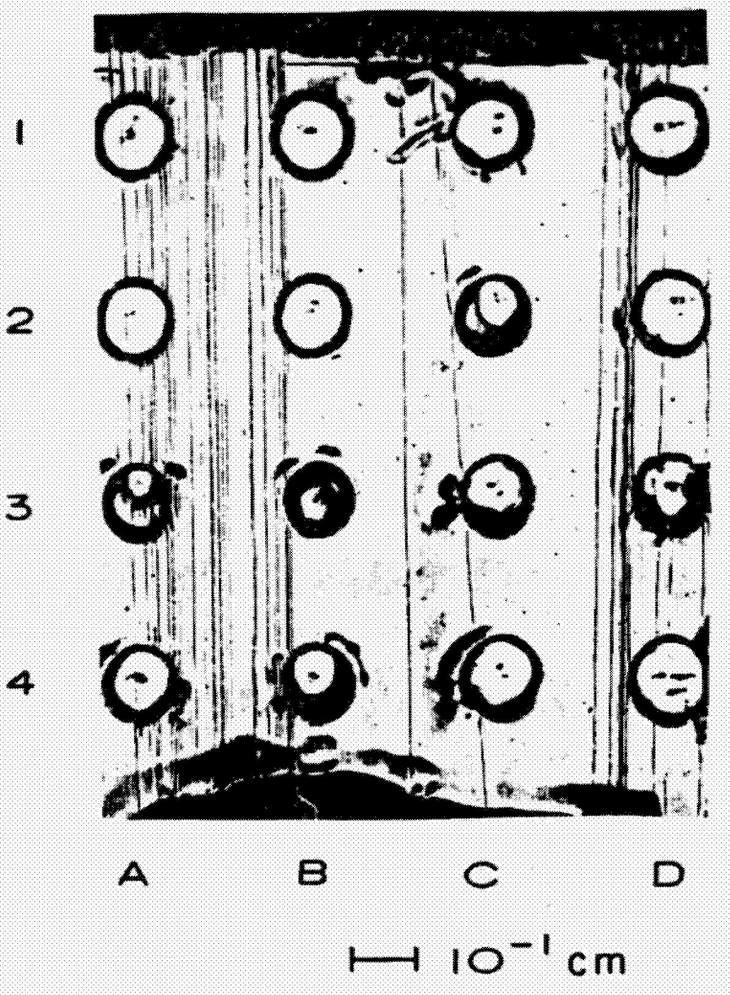


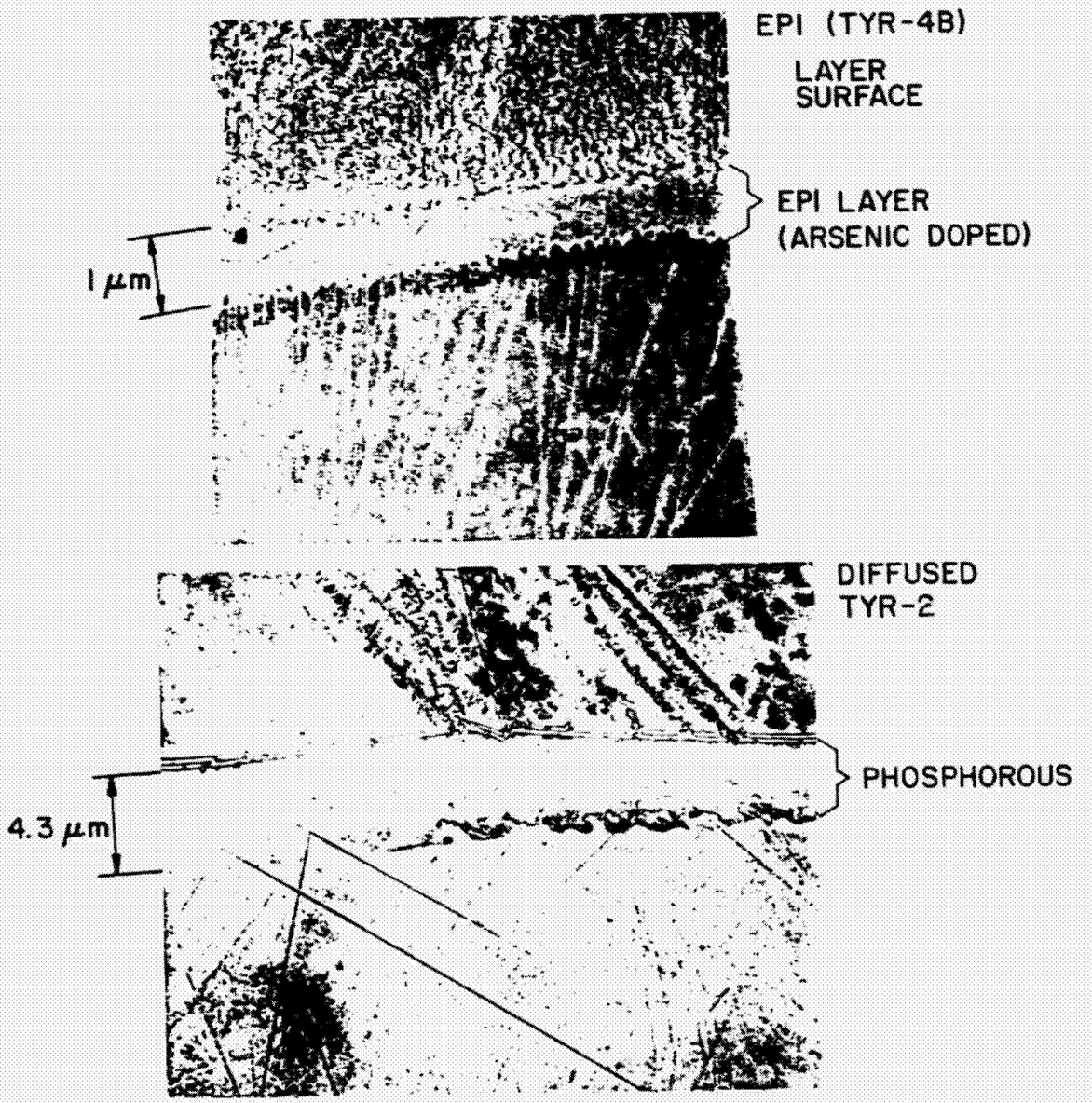
Figure 2 - Microphotograph of mesas etched out from epitaxial material deposited on ribbon substrate. The saturation current density for each of the diodes is given in Table 1.

TABLE 2

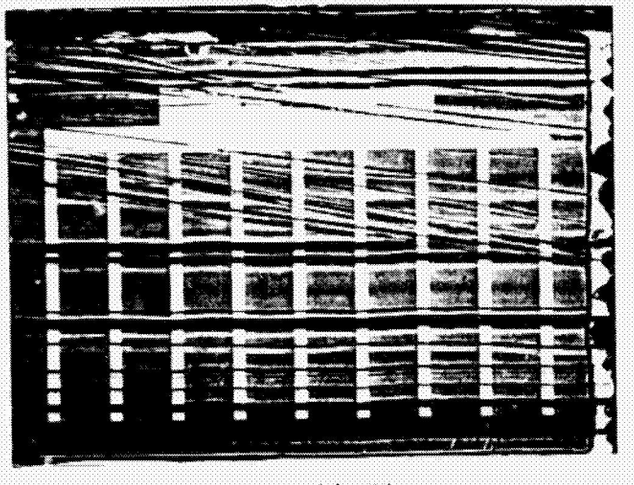
DIFFUSED DIODES

#	I_0 (V_a = -2 V), A/cm^2
A1	3.5×10^{-4}
B2	4.5×10^{-5}
B3	3.5×10^{-5}
C1	2.4×10^{-5}
C3	2.7×10^{-5}

STAINED JUNCTION CROSS SECTIONS



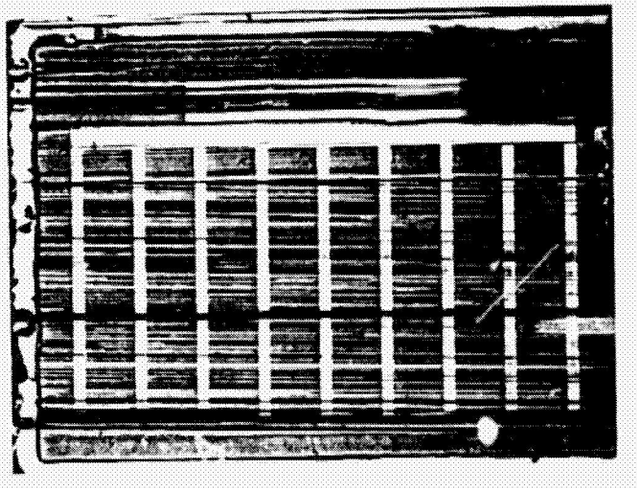
CORRELATION OF PHYSICAL APPEARANCE WITH CELL PERFORMANCE



TYR-4A #1

J_{SC} = 20.1 mA/cm^2

V_{OC} = 539 mV

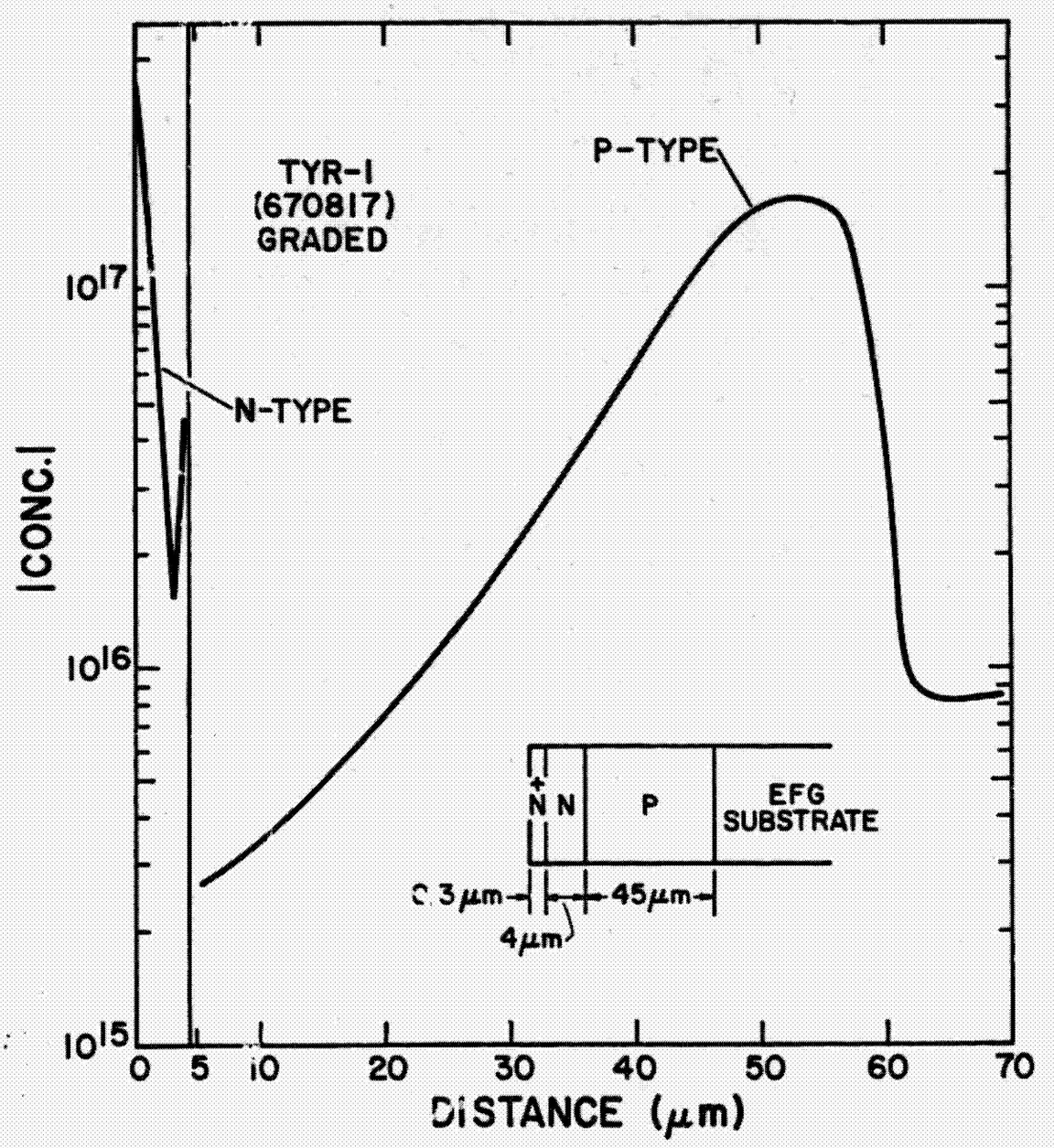


TYR-4A #2

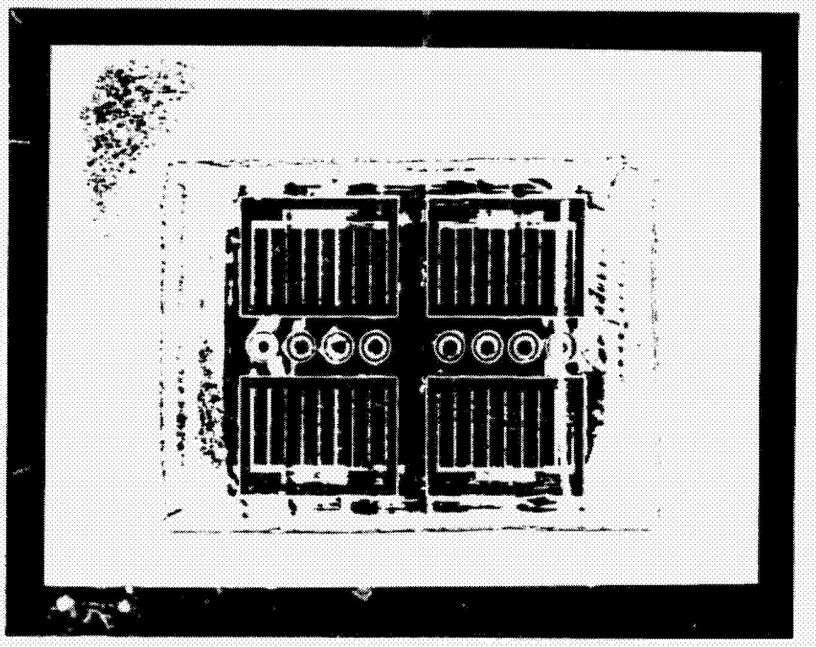
J_{SC} = 16.8 mA/cm^2

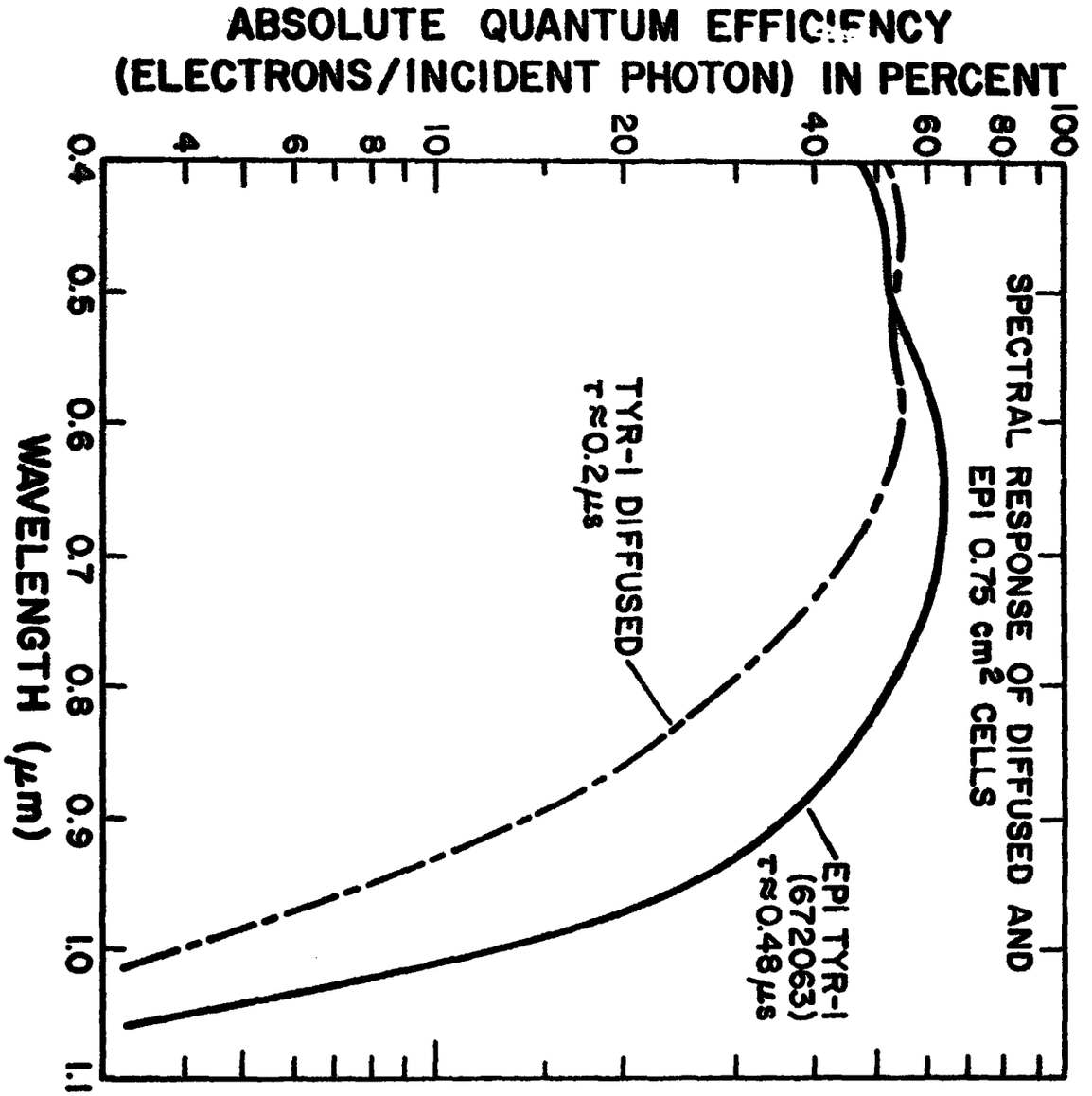
V_{OC} = 477 mV

1 cm


TYR-1
(670817)
GRADED
P-TYPE
N-TYPE
|CONC.|
10^{17}
10^{16}
10^{15}
0
5
10
20
30
40
50
60
70
DISTANCE (μm)
N+
N
P
EFG
SUBSTRATE
3μm
45μm
4μm

TEST PATTERN




ABSOLUTE QUANTUM EFFICIENCY
(ELECTRONS/INCIDENT PHOTON) IN PERCENT
4
6
8
10
20
40
60
80
100
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
WAVELENGTH (μm)
SPECTRAL RESPONSE OF DIFFUSED AND
EPI 0.75 cm² CELLS
TYR-1 DIFFUSED
τ≈0.2μs
EPI TYR-1
(672063)
τ≈0.48μs

COMPARATIVE SOLAR CELL DATA

Device Lot	Process		V_{oc} (mV)	J_{sc} (mA/cm^2)	Max. Power (mW/cm^2)	Fill Factor	Efficiency (%)	Solar Intensity (mW/cm^2)	A.R. Coating
NASA-A[a]	Diffused	n/p	545	27.6	10.8	0.72	11.6	93	Ta_2O_5
TYR-1 (EFG)	Diffused	n/p	504	19.8	6	0.6	6.2	96	SiO_2
	Epi (graded)[b]	n/p	523	22.8	7.8	0.65	8.3	94.4	SiO_2
	Epi (uniform)[c]	n/p	542	19.2	6.24	0.60	6.6	94.4	SiO_2
TYR-3 EFG	Diffused	n/p	78	9	---	---	---	95	SiO_2
	Epi[b]	n/p	540	23.3	8.3	0.66	9	92	SiO_2
TYR-4 EFG	Epi[b]	n/p	539	20.1	4.4	0.41	4.8	91.7	SiO_2
	Epi[b]	n/p	477	16.8	---	low	---	91.7	SiO_2

(a) Cell provided by NASA with calibration under atmospheric conditions. It was used as a standard to establish the solar intensity.

(b) Graded impurity profile in p-region.

(c) Uniform impurity profile in p-region.

MAJOR CONCLUSIONS

* DISLOCATION DENSITY IN THE EPITAXIAL LAYER IS LOWER THAN IN THE EFG SUBSTRATE.

* THE SATURATION CURRENT DENSITY OF DIODES EPITAXIALLY FORMED ON THESE SUBSTRATES IS MUCH LOWER THAN OBTAINED BY DIRECT DIFFUSION INTO THE SUBSTRATES.

* THE I_{sc} AND V_{oc} AND EFFICIENCY OF EPITAXIAL SOLAR CELLS ARE GENERALLY HIGHER THAN THOSE MADE BY DIFFUSION INTO THE EFG MATERIAL.

* GOOD QUALITY SOLAR CELLS ($\sim$ 9%) HAVE BEEN MADE EPITAXIALLY IN SOME EFG MATERIAL WHICH DOES NOT YIELD USEFUL DEVICES BY DIRECT DIFFUSION.

* A SENSITIVE ELECTROREFLECTANCE APPARATUS HAS BEEN CONSTRUCTED WHICH ALLOWS THE DIRECT DETERMINATION OF CARRIER CONCENTRATION VARIATIONS. SPATIAL VARIATIONS IN EFG MATERIALS MUCH GREATER THAN THOSE ENCOUNTERED IN CONVENTIONALLY-GROWN BULK Si HAVE BEEN DETECTED.