HIGH-EFFICIENCY MODULE DESIGN

SPIRE CORPORATION

M. B. Spitzer

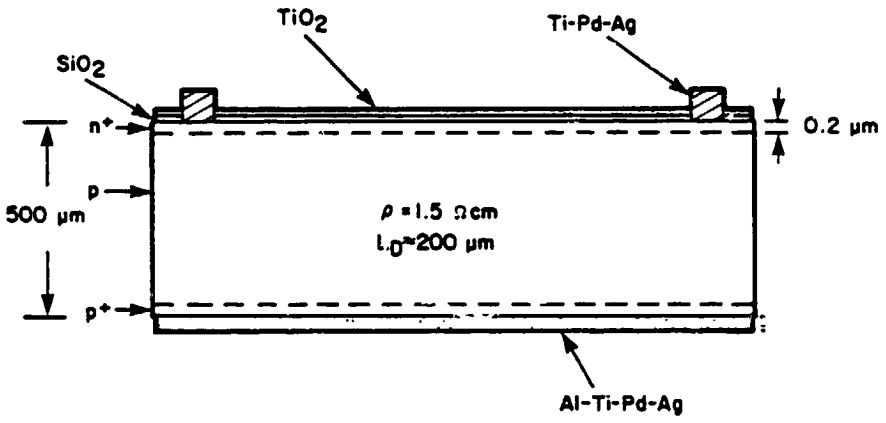
Principal Results

- DELIVERED 75.2 WATT MODULE WITH EFFICIENCY OF 15.2 %, AND ENCAPSULATED CELL EFFICIENCY OF 16.9%.
- OBTAINED ENCAPSULATED CELL EFFICIENCY OF 17.6% IN A 12-CELL MINI-MODULE.
- FABRICATED LARGE -AREA CELLS WITH EFFICIENCY OF OVER 18%.
- EVALUATED THE USE OF BSR CELLS TO REDUCE NOCT.
- HIGH EFFICIENCY WAS OBTAINED WITH CZ.

Objectives

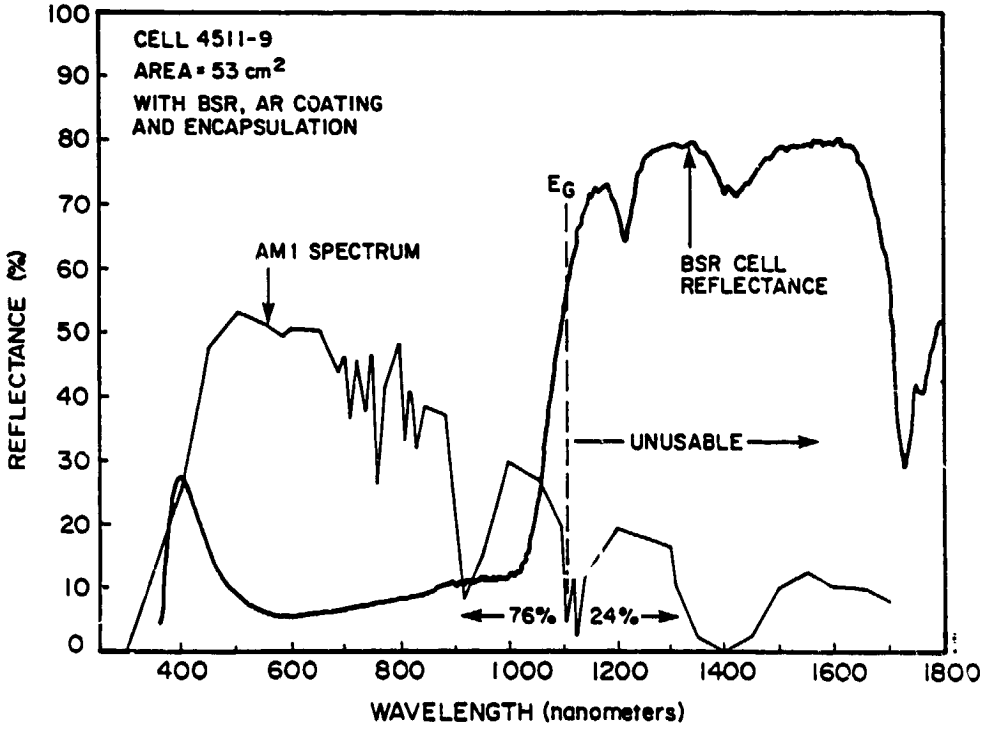
- FABRICATION OF MODULES WITH EMPHASIS ON REDUCED OPERATING TEMPERATURE.
- FABRICATION OF HIGHLY EFFICIENT MODULES.
- EVALUATION OF POSSIBLE TRADE-OFF BETWEEN HIGH EFFICIENCY AND LOW NOCT.

Cell Design

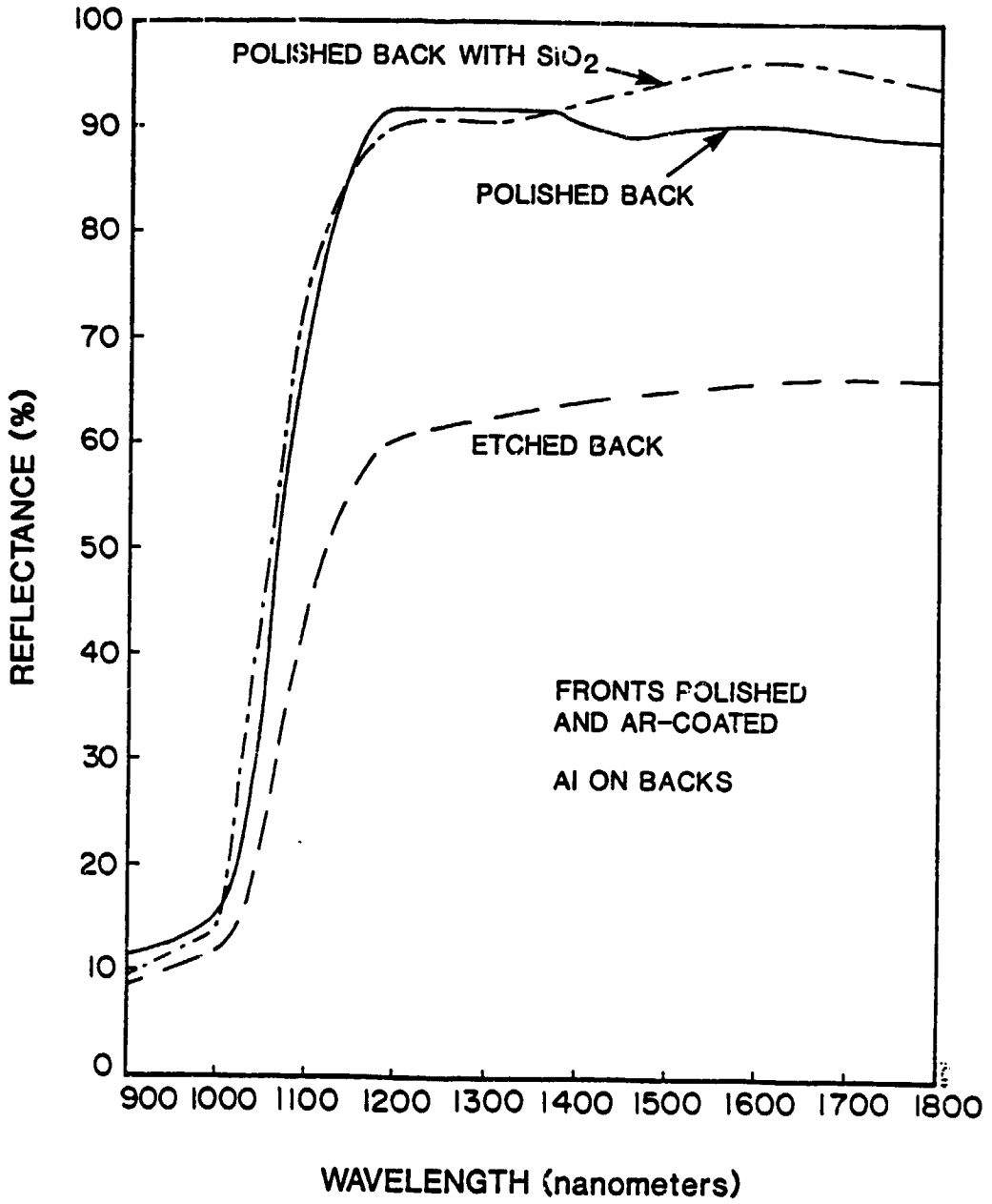


- Al USED FOR BSR
- SiO_2 USED TO PASSIVATE SURFACE
- NO EDGE PASSIVATION USED

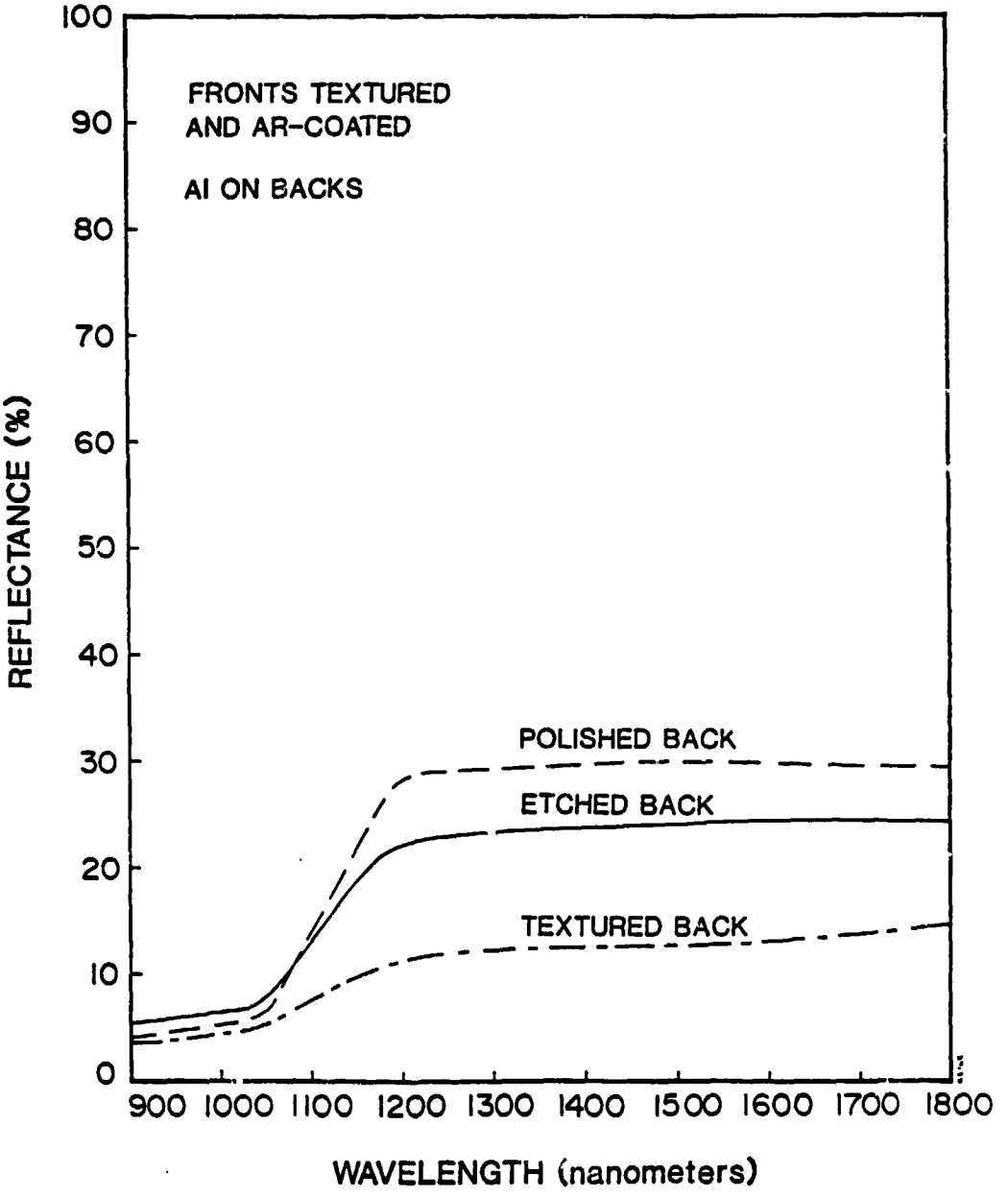
Reflectance Versus Wavelength (Cell 4511-9)



Reflectance Versus Wavelength
(Various Cell Backings With Fronts Polished and AR-Coated)



Reflectance Versus Wavelength
(Various Cell Backings With Fronts Textured and AR-Coated)



Mini-Module Fabrication and Performance Data

MINI-MODULE	CELL FRONT SURFACE	CELL BACK SURFACE	AVE.CELL EFFICIENCY(1)	ENCAP.CELL EFFICIENCY(2)	MODULE EFFICIENCY(2)	NOCT (°C)	MODULE EFF. AT NOCT(3)
1	POLISHED	POLISHED	16.2 (0.2)	15.9	13.2	45	11.9
2	TEXTURED	ETCHED	17.9 (0.3)	16.8	14.0	50	12.2
3	TEXTURED	POLISHED	17.6 (0.2)	16.8	14.0	49	12.3
4	POLISHED	ETCHED	15.7 (0.2)	15.5	12.9	47	11.5

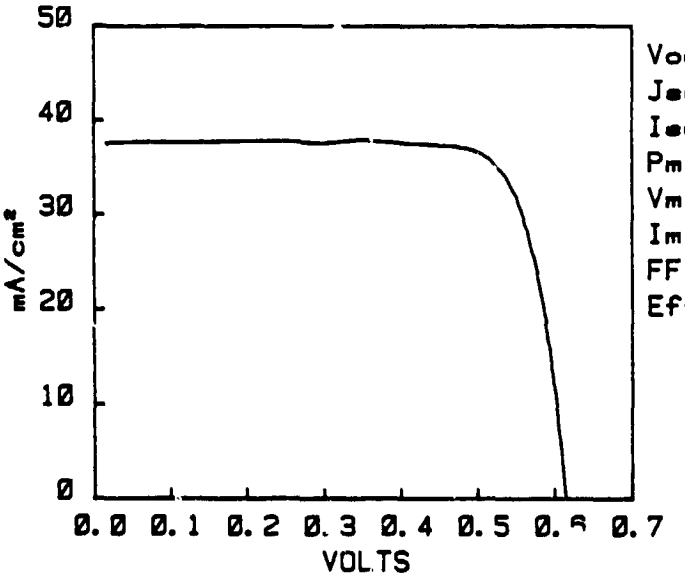
Notes: (1) Cell efficiency is the average of the 12 cells in the module. The standard deviation is shown in parenthesis. Spectrum was direct, AM1.5, 100mW/cm^2. T=25°C.

(2) Measured at JPL, global spectrum, AM1.5, 100mW/cm^2, T corrected to 25°C.

(3) Measured at JPL, global spectrum, AM1.5, 100mW/cm^2, T corrected to NOCT.

Characteristics of High-Efficiency Cell No. 10

Lot: 4751 AM1.5, 28°C
Cell: 10 Date: 12/19/85
Area: 53.04 cm^2 Time: 13:45:07
Material: Si AR Coating: TiO2



Voc = 0.615 V
Jsc = 37.7 mA/cm^2
Isc = 2.002 A
Pm = 0.9804 W
Vm = 0.509 V
Im = 1.929 A
FF = 79.7 %
Eff = 18.5 %

Performance Data for Ten Deliverable Cells

CELL	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF (%)	EFF (%)
1	607	33.5	74.8	15.2
2	604	33.3	76.8	15.4
3	604	33.4	74.4	15.0
4	607	33.2	77.6	15.6
5	604	33.3	78.2	15.7
6	604	33.0	77.3	15.4
7	607	33.4	76.8	15.6
8	609	33.5	77.3	15.8
9	609	33.6	77.2	15.8
10	601	33.7	76.0	15.6

NOTES: INSOLATION WAS AM1.5, 100 mW/cm^2. T=28°C.
AREA=53 cm^2.

Characteristics of High-Efficiency Module Cells

Lot: 4751 — Spire Corporation
Originator: LMG — Illumination: AM1.5 (100 mW/cm²)
Date: 12/19/85 — Temperature: 28 C
Comment: Module Cells
Resistivity: 1.50 Ω-cm — Thickness: 20 mils — Surface: Tex
Material: Si — AR Coat: TiO2

Cell	Area (cm²)	Voc (V)	Isc (A)	Jsc mA/cm²	Pm (W)	Vm (V)	Im (A)	FF (%)	Eff. (%)
1	53.04	0.616	2.007	37.8	0.9639	0.498	1.934	78.0	18.2
2	53.04	0.615	2.020	38.1	0.9685	0.510	1.898	78.0	18.3
3	53.04	0.614	2.001	37.7	0.9686	0.511	1.895	78.9	18.3
4	53.04	0.608	1.964	37.0	0.9417	0.518	1.816	78.8	17.8
5	53.04	0.613	1.989	37.5	0.9702	0.521	1.862	79.6	18.3
6	53.04	0.612	1.987	37.5	0.9553	0.504	1.895	78.6	18.0
7	53.04	0.613	1.988	37.5	0.9656	0.504	1.915	79.3	18.2
8	53.04	0.608	1.948	36.7	0.9477	0.510	1.857	80.0	17.9
9	53.04	0.612	1.979	37.3	0.9625	0.519	1.856	79.5	18.1
10	53.04	0.615	2.002	37.7	0.9804	0.509	1.928	79.7	18.5
11	53.04	0.614	1.999	37.7	0.9787	0.519	1.885	79.7	18.5
12	53.04	0.606	1.934	36.5	0.9036	0.494	1.831	77.0	17.0
13	53.04	0.613	1.992	37.5	0.9730	0.509	1.912	79.6	18.3
14	53.04	0.610	1.962	37.0	0.9411	0.508	1.851	78.6	17.7
15	53.04	0.612	1.963	37.0	0.9531	0.510	1.868	79.3	18.0
16	53.04	0.610	1.961	37.0	0.9575	0.521	1.836	80.0	18.1
17	53.04	0.610	1.962	37.0	0.9554	0.524	1.824	79.8	18.0
18	53.04	0.613	1.972	37.2	0.9710	0.509	1.906	80.3	18.3
19	53.04	0.611	1.974	37.2	0.9625	0.507	1.900	79.8	18.1
20	53.04	0.611	1.971	37.2	0.9475	0.507	1.870	78.7	17.9
21	53.04	0.614	1.988	37.5	0.9699	0.514	1.888	79.4	18.3
22	53.04	0.607	1.944	36.6	0.9356	0.518	1.806	79.3	17.6
23	53.04	0.612	1.981	37.3	0.9613	0.511	1.880	79.2	18.1
24	53.04	0.613	1.991	37.5	0.9593	0.506	1.895	78.6	18.1
25	53.04	0.614	1.997	37.7	0.9755	0.520	1.877	79.6	18.4
mean		0.612	1.979	37.3	0.9588	0.511	1.875	79.2	18.1
std dev		0.002	0.021	0.4	0.0165	0.007	0.034	0.8	0.3

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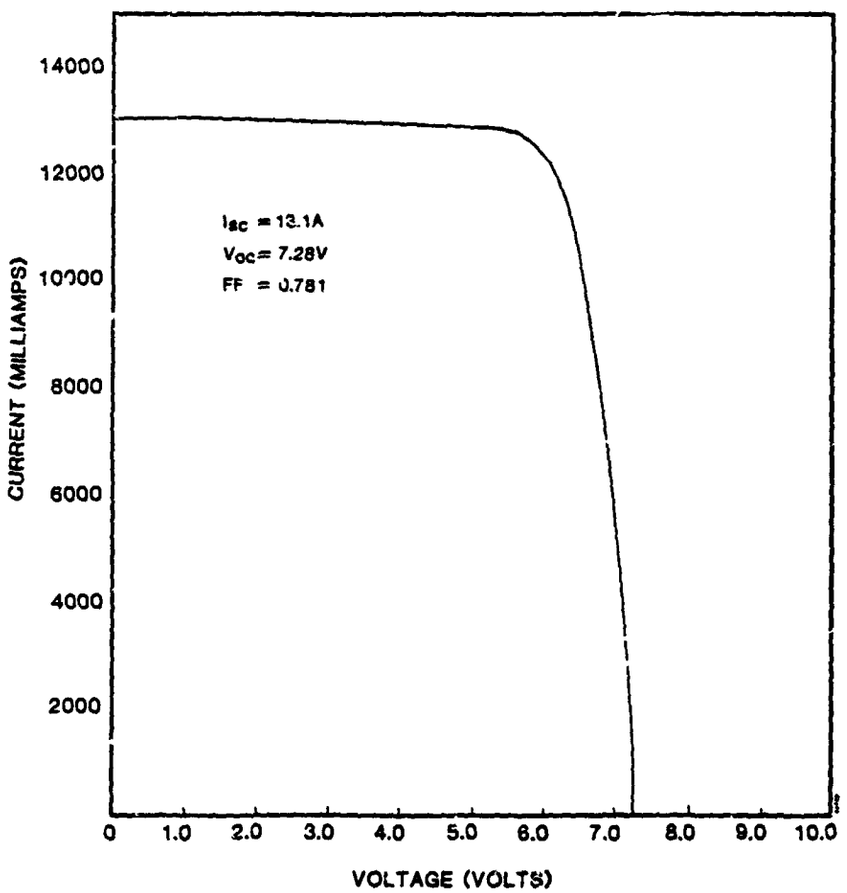
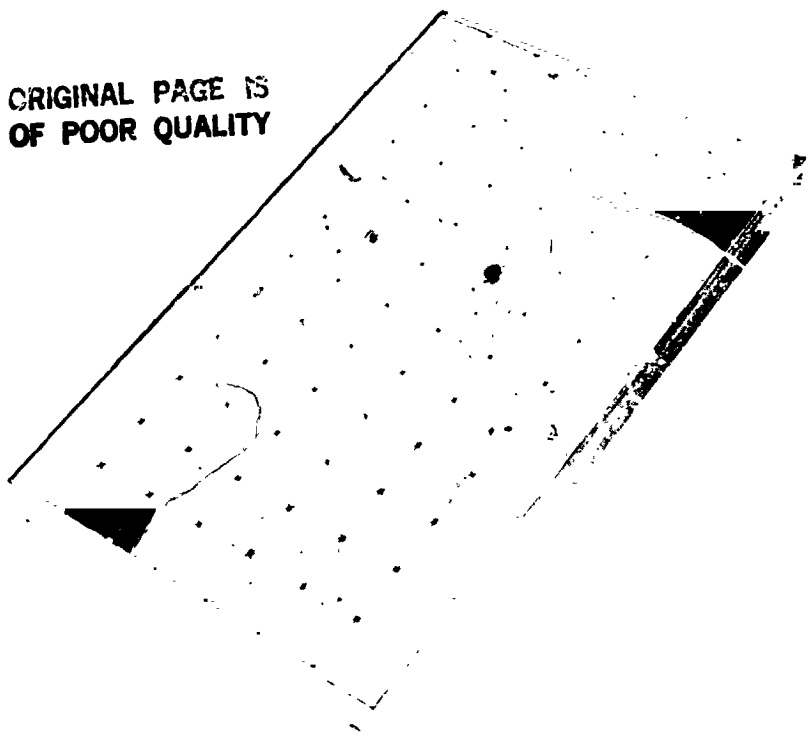
mean	0.612	1.981	37.3	0.9611	0.512	1.877	79.3	18.1
std dev	0.002	0.019	0.4	0.0121	0.007	0.034	0.6	0.2

I-V Curve for SPIRE High-Efficiency Solar Cell Module



SPIRE High-Efficiency Solar Cell Module



Mini-Module Performance

MODULE	ENCAP. CELL EFFICIENCY (%)	V_{OC} (V)	I_{SC} (A)	MODULE EFF. (%)
BEST FZ MINI-MODULE	17.6	7.33	1.92	14.7
BEST CZ MINI-MODULE	17.0	7.13	2.00	14.2

NOTES: INSOLATION WAS AM1.5, 100 mW/cm^2. T=25°C PACKING DENSITY IS 0.833. CELL AREA IS 53.04 cm^2. 12 CELLS PER MODULE.

Findings

- BSR's CAN REDUCE NOCT BY REFLECTION OF SUB-BANDGAP RADIATION.
- HIGH EFFICIENCY TECHNIQUES CAN BE UTILIZED IN LARGE-AREA CELLS.
- MODULES WITH EFFICIENCY GREATER THAN 15% CAN BE FABRICATED.
- THE ABOVE RESULTS CAN BE APPLIED TO CZ SILICON.