A REVIEW OF HIGH-EFFICIENCY SILICON SOLAR CELLS

GEORGIA INSTITUTE OF TECHNOLOGY

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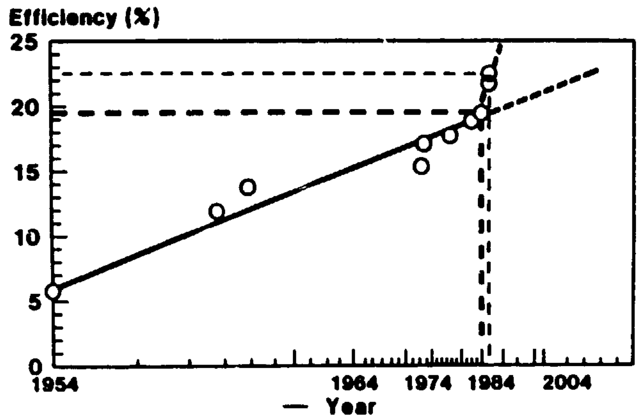
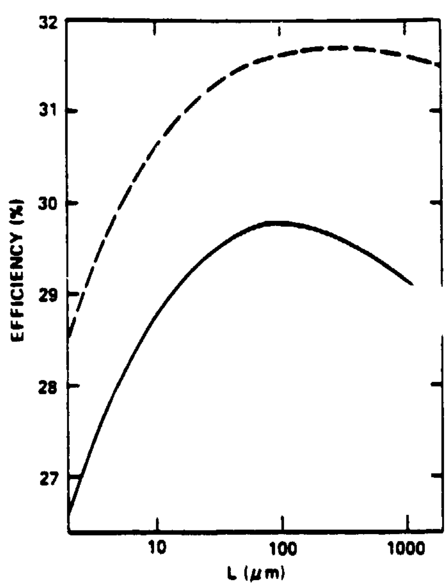
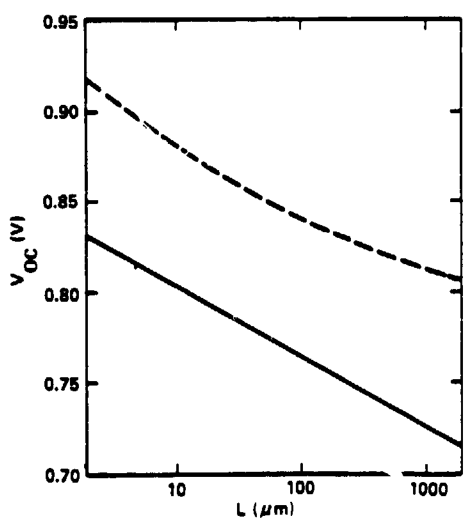
Historical Development of Silicon Solar Cells





Efficiency of silicon solar cells as a function of thickness for textured cells with back reflectors

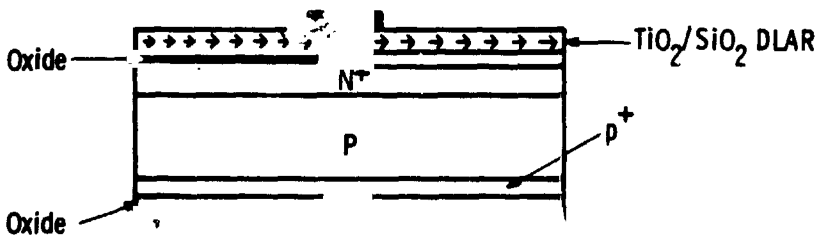


Open-circuit voltage as a function of cell thickness for radiative recombination only (dashed line) and for radiative, Auger and free carrier absorption (solid line).

Operating Parameters of Optimum (100 m) Silicon Solar Cell

		Theory	Practical	
V_{OC}	=	769 mV	710	740
I_{SC}	=	42.2 MA/cm^2	42.0	40.0
FF	=	0.890	0.84	0.85
$V_{MAX\ PWR}$	=	703 mV		
Efficiency	=	29.8%	25.0	25.1

Schematic Diagram of Westinghouse 18.3% Efficient Silicon Cell Design

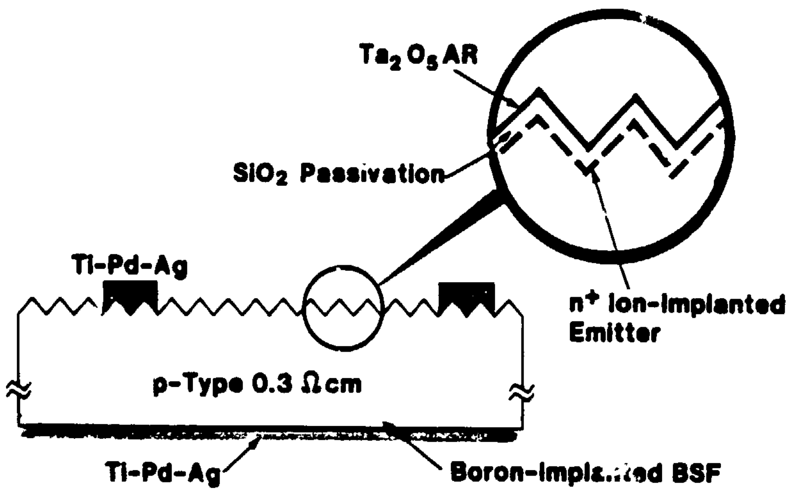


Effect of Oxide Passivation and Double-Layer AR Coating on 0.2 - 0.3 Ohm-cm Float-Zone Silicon Cells Fabricated by Conventional Metallization and Lithography

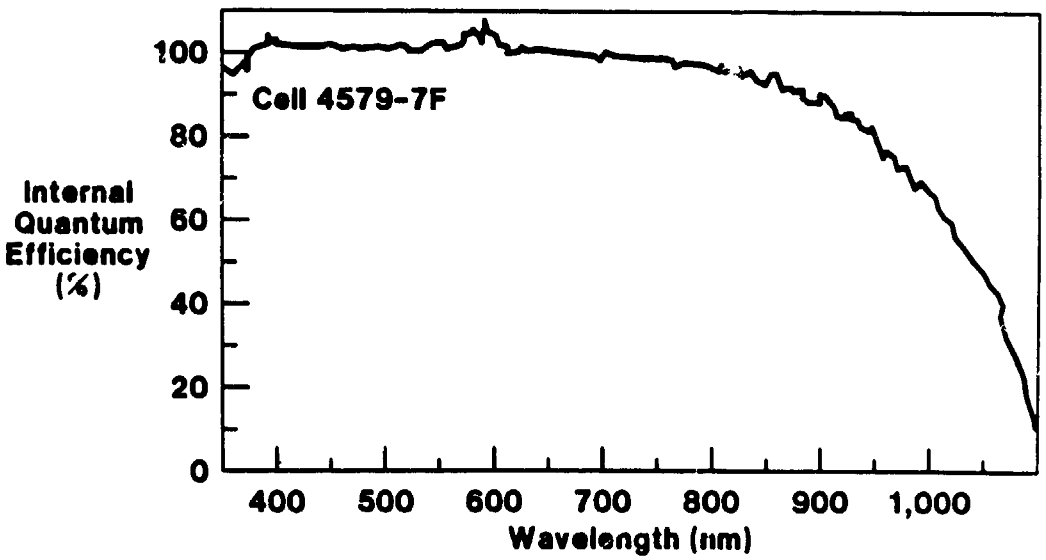
Cell ID	Short-Circuit Current J_{sc} mA/cm^2	Open-Circuit Voltage V_{oc} Volts	Fill Factor	Cell Efficiency %
	No Passivation and Single-Layer AR			
Q-1	33.0	0.606	0.790	15.7
Q-2	33.0	0.607	0.790	15.8
Q-3	32.8	0.605	0.790	15.6
	Passivation and Single-Layer AR			
14-1	34.0	0.621	0.800	16.9
14-2	34.0	0.620	0.809	17.0
14-9	34.1	0.620	0.805	17.1
	Passivation and Double-Layer AR			
4-1	35.9	0.623	0.809	18.1
4-2	36.2	0.622	0.809	18.2
4-3	36.1	0.623	0.815	18.3

*AMI, 100 mW/cm^2 Illumination

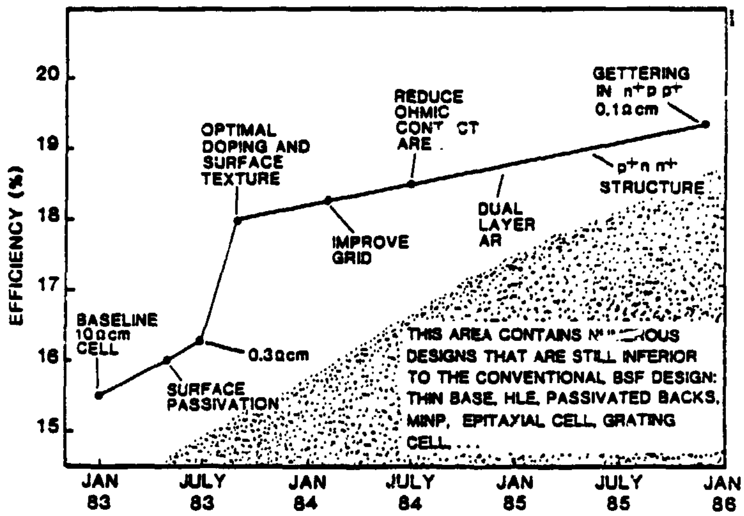
Spire Corporation's Approach to High-Efficiency Solar Cells



Internal Quantum Efficiency of Spire Corp. Cell



Spire Progress in Silicon Cell Design and Performance



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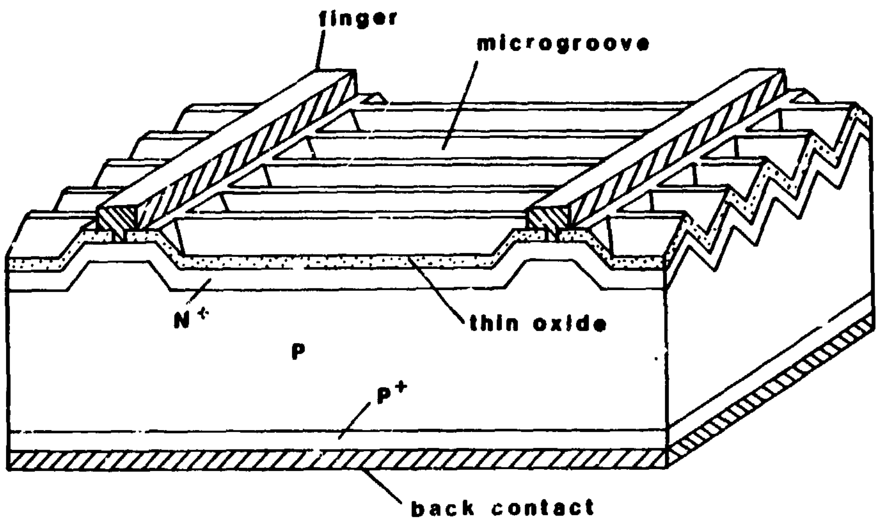
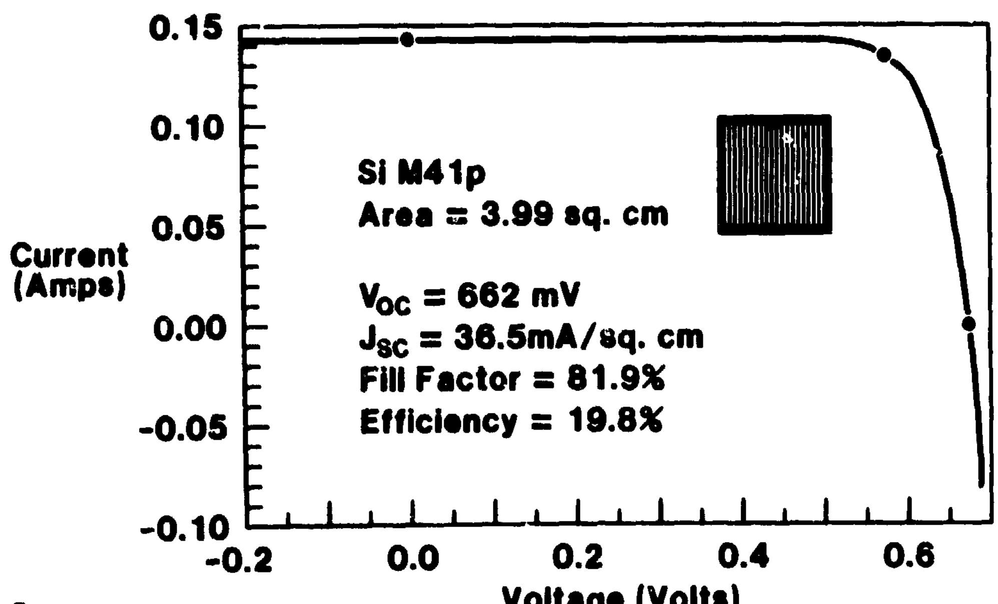
mean	0.612	1.981	37.3	0.9611	0.512	1.877	79.3	18.1
std dev	0.002	0.019	0.4	0.0121	0.007	0.034	0.6	0.2



Output Current-Voltage Characteristics of an Improved PESC Cell Fabricated on a 0.2 Ωcm Substrate



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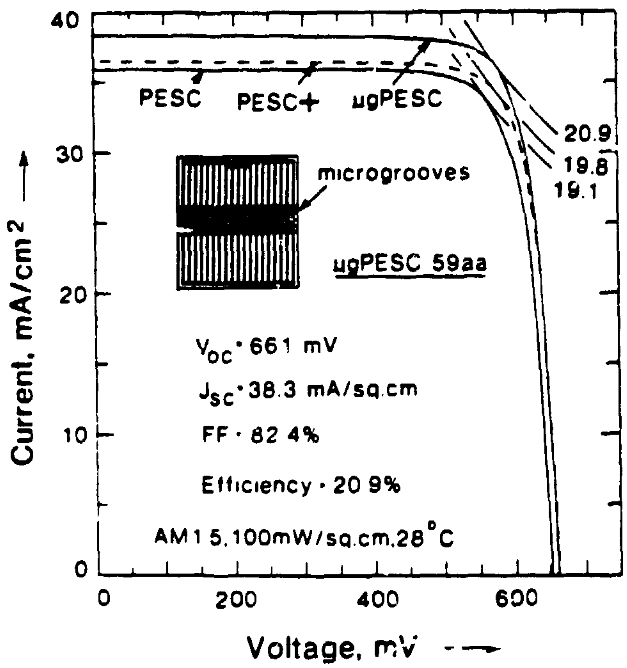
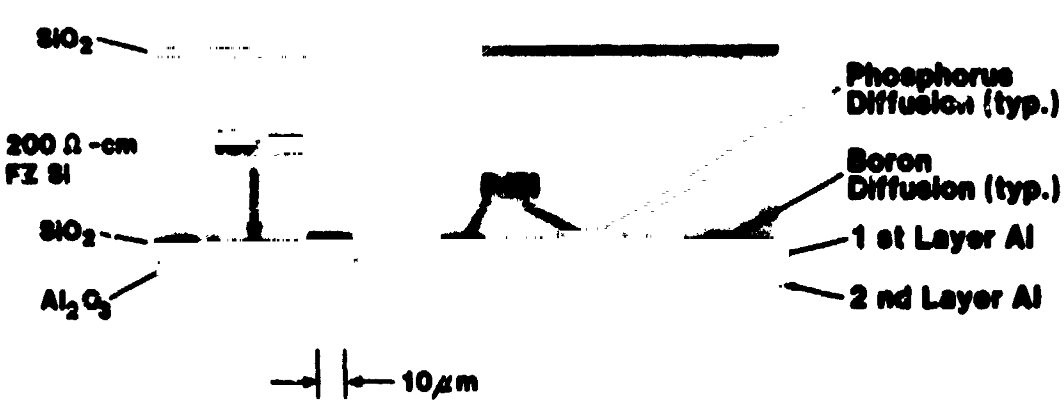


Output characteristics of a high efficiency microgrooved PESC solar cell measured under standard terrestrial test conditions (AM1.5, 100 mW/cm², 28°C) compared to those of previous generations of nongrooved PESC cells calibrated by the Solar Energy Research Institute (SERI), Colorado. The inset shows the contact design for the cell.

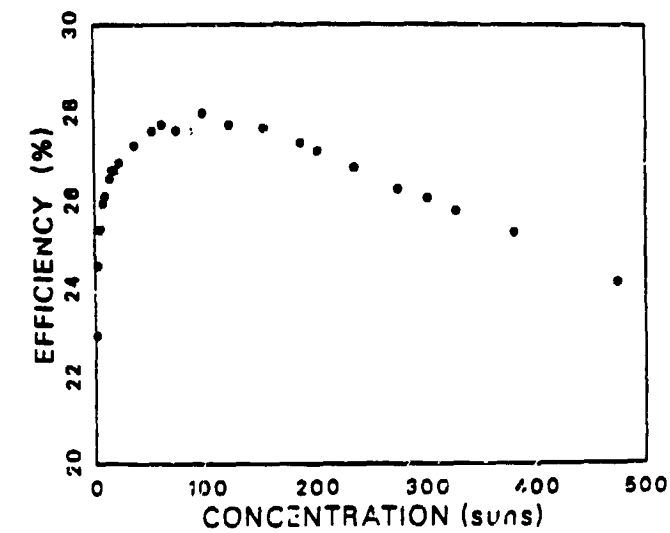
Green, Appl. Phys. Lett., Vol. 48, No. 3, 20 January 1986.

Stanford University Approach to High-Efficiency Solar Cells

Structure of the Point-Contact-Cell



Stanford Point Contact Cell FT11-3B



ONE SUN: V_{OC} = 682 mV, J_{SC} = 41.5 mA/cm^2,
FF = 0.785, EFF. = 22.2%

Evolution of High-Efficiency Silicon Solar Cell Performance Over Recent Years as Measured by the Solar Energy Research Institute (AM 1.5, 100 mW/cm^2, 28°C)

Date	Cell Description[a]	V_{oc} (mV)	J_{sc} (mA cm^{-2})	FF (%)	η (%)
May 1983	ASEC	620	34.8	79.3	17.1
Aug. 1983	Westinghouse (4 Ωcm)	600	36.2	79.3	17.2
Sept. 1983	UNSW MINP (0.2 Ωcm)	641	35.5	82.2	18.7
Sept. 1983	SPIRE textured (0.2 Ωcm)	622	36.1	80.1	18.0
Dec. 1983	UNSW PESC (0.2 Ωcm)	653	36.0	81.1	19.1
May 1984	Westinghouse LLAR (0.1 – 0.2 Ωcm)	627	36.0	80.0	18.1
Feb. 1985	Westinghouse (0.3 Ωcm)	623	36.1	81.5	18.3
May 1985	UNSW PESC (0.25 Ωcm)	649	37.0	82.2	19.8
May 1985	UNSW PESC (0.2 Ωcm)	662	36.5	81.9	19.8
Oct. 1985	SPIRE textured (0.3 Ω-cm n-type)	635	36.3	81.6	18.8
Jan. 1986	UNSW microgrooved PESC (0.1 Ωcm)	654	37.0	82.9	20.1
	UNSW microgrooved PESC (0.2 Ωcm)	661	38.3	82.4	20.9
April 1986	Stanford University (Point contact cell 500 Ω-cm)	682	41.5	78.5	22.2

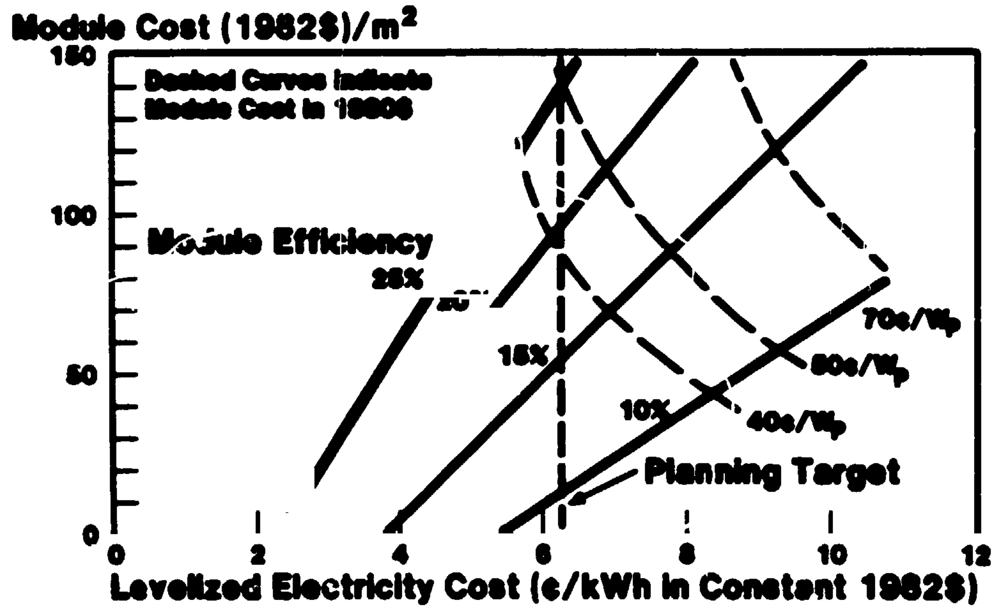
Silicon Material/Processing Research

- More Sensitive And Better Methods To Detect And Identify Lifetime Limiting Traps In Silicon
- Role Of Carbon And Oxygen Content On Defect Formation And On Cell Performance
- Role Of Dopants And Their Interactions With Defects And Impurities
- Process Induced Defects
- Gettering, Defect Passivation Or Defect Elimination During Crystal Growth And Processing

Measurements/Modeling Issues

- Considerable Amount Of Ambiguity And Assumptions Are Involved In Modeling And Device Design
- All Parameters In Actual Device Are Not Known Accurately Enough To Do Precise Modeling; S, ΔV_G, T_A, N_{xj}, L
- Concern About The Values Of Minority Carrier Mobility And Diffusivity At High Doping Concentrations
- Need For Innovative Cell Design

Flat-Plate PV Module Cost as a Function of Levelized Electricity Cost



Area-related balance-of-system costs assumed at $50/m²