A REVIEW OF HIGH-EFFICIENCY SILICON SOLAR CELLS

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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).
PLENARY SESSIONS

Operating Parameters of Optimum (100 m) Silicon Solar Cell

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Theory</th>
<th>Practical</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{oc}$</td>
<td>769 mV</td>
<td>710</td>
</tr>
<tr>
<td>$I_{sc}$</td>
<td>42.2 MA/cm²</td>
<td>42.0</td>
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<tr>
<td>FF</td>
<td>0.890</td>
<td>0.84</td>
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<tr>
<td>$V_{max} PWR$</td>
<td>703 mV</td>
<td>740</td>
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<tr>
<td>Efficiency</td>
<td>29.8%</td>
<td>25.0</td>
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Theory Practical

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

<table>
<thead>
<tr>
<th>Short-Circuit Current $J_{sc}$ mA/cm²</th>
<th>Open-Circuit Voltage $V_{oc}$ Volts</th>
<th>Fill Factor</th>
<th>Cell Efficiency %</th>
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<tbody>
<tr>
<td>Cell ID</td>
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<tr>
<td>No Passivation and Single-Layer AR</td>
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<tr>
<td>Q-1</td>
<td>33.0</td>
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*AM1. 100 mW/cm² 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

<table>
<thead>
<tr>
<th>Cell</th>
<th>Vac (V)</th>
<th>Jsc (mA/cm²)</th>
<th>Pm (W/cm²)</th>
<th>Voc (V)</th>
<th>Im (A)</th>
<th>FF (%)</th>
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<td>1.97</td>
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<td>0.972</td>
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<td>0.899</td>
<td>1.97</td>
</tr>
</tbody>
</table>

Mean: 0.62 V, 1.977 A, 37.3 W/cm², 0.9588 V, 0.511 A, 1.875 A, 79.2 %, 18.1 %

Std dev: 0.062 V, 0.021 A, 0.4 W/cm², 0.0165 V, 0.007 A, 0.034 A, 0.8 W/cm², 0.3 %
PLENARY SESSIONS

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

Si M41p
Area = 3.99 sq. cm

V_{OC} = 662 mV
J_{SC} = 36.5 mA/sq. cm
Fill Factor = 81.9%
Efficiency = 19.8%
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.


Stanford University Approach to High-Efficiency Solar Cells

Structure of the Point-Contact-Cell
**Evolution of High-Efficiency Silicon Solar Cell Performance Over Recent Years as Measured by the Solar Energy Research Institute (AM 1.5, 100 mW/cm², 28°C)**

<table>
<thead>
<tr>
<th>Date</th>
<th>Cell Description</th>
<th>$V_{OC}$ (mV)</th>
<th>$J_{SC}$ (mA cm$^{-2}$)</th>
<th>FF (%)</th>
<th>η (%)</th>
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<tr>
<td>May 1983</td>
<td>ASEC</td>
<td>620</td>
<td>34.8</td>
<td>79.3</td>
<td>17.1</td>
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<tr>
<td>Aug. 1983</td>
<td>Westinghouse (4 Ωcm)</td>
<td>600</td>
<td>36.2</td>
<td>79.3</td>
<td>17.2</td>
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<tr>
<td>Sept. 1983</td>
<td>UNSW MINP (0.20 cm)</td>
<td>641</td>
<td>35.5</td>
<td>82.2</td>
<td>18.7</td>
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<tr>
<td>Sept. 1983</td>
<td>SPIRE textured (0.2 cm)</td>
<td>622</td>
<td>36.1</td>
<td>80.1</td>
<td>18.0</td>
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<tr>
<td>Dec. 1983</td>
<td>UNSW PESC (0.2 μcm)</td>
<td>653</td>
<td>36.0</td>
<td>81.1</td>
<td>19.1</td>
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<tr>
<td>May 1984</td>
<td>Westinghouse L LAR (0.1 – 0.2 cm)</td>
<td>627</td>
<td>36.0</td>
<td>80.0</td>
<td>18.1</td>
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<td>Feb. 1985</td>
<td>Westinghouse (0.3 cm)</td>
<td>623</td>
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<td>81.5</td>
<td>18.3</td>
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<td>May 1985</td>
<td>UNSW PESC (0.25 cm)</td>
<td>649</td>
<td>37.0</td>
<td>82.2</td>
<td>19.8</td>
</tr>
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<td>May 1985</td>
<td>UNSW PESC (0.20 cm)</td>
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<td>36.5</td>
<td>81.9</td>
<td>19.8</td>
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<tr>
<td>Oct. 1985</td>
<td>S. IRE textured (0.32-cm n-type)</td>
<td>635</td>
<td>36.3</td>
<td>81.6</td>
<td>18.8</td>
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<td>Jan. 1985</td>
<td>UNSW microgrooved PESC (0.12 cm)</td>
<td>654</td>
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<td>82.9</td>
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<td>UNSW microgrooved PESC (0.20 cm)</td>
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<td>April 1986</td>
<td>Stanford University (Point contact cell)</td>
<td>682</td>
<td>41.5</td>
<td>78.5</td>
<td>22.2</td>
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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, ΔVG, TA, Nxj, 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

Module Efficiency

- 25%
- 15%
- 10%
- Planning Target

Levelized Electricity Cost (£/kWh in Constant 1982$)

Area-related balance-of-system costs assumed at $550/m²

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