PROCESS RESEARCH OF NON-CZOTHRALSII
SILICON MATERIAL

WESTINGHOUSE ELECTRIC CORPORATION
ADVANCED ENERGY SYSTEMS DIVISION
R. B. Campbell

Contract Objectives

• INVESTIGATE SIMULTANEOUS DIFFUSION OF LIQUID PRECURSORS IN A DENDRITIC WEB
SILICON TO FORM SOLAR CELL STRUCTURES

• INVESTIGATE PROCESS CONTROL PARAMETERS

• PERFORM COST ANALYSIS OF THE SIMULTANEOUS JUNCTION FORMATION PROCESS

Potential Benefits of Simultaneous Diffusion

• REDUCE NUMBER OF PROCESSING STEPS

• LESS COSTLY PROCESSING (CAPITAL EQUIPMENT, MATERIALS)

• MORE RAPID PROCESSING

• MORE UNIFORM CELL PARAMETERS
Simultaneous Junction Formation by Flash Diffusion

- **Novel Technique Developed to Achieve Simultaneous Diffusion Without Cross-Doping**

- Web strips coated with liquid precursors (B and P doped) and heated with a tungsten-halogen light source.

- Nominal times - 10-20 sec

  Nominal temperature - 1050°C - 1150°C

- $N^+P^+$ and $P^+N^+$ cells fabricated

- No cross contamination noted

Heatpulse™ Annealing Chamber

- Temperature Monitor
- Wafer
- Quartz Isolation Tube
- Tungsten-Halogen Lamps
- Water-Cooled Reflective Enclosure
Heatpulse™ Temperature-Time Profile

Sample No. WESTINGHOUSE - DENDRITIC WEA
Flash Diffusion: N-Type WEB Front Junction
(Dopant Concentration Versus Distance into Cell)
Flash Diffusion: N-Type WEB Back Junction
(Dopant Concentration Versus Distance into Cell)

48125 CELL 21A
n⁺n
x = 0.8 µm
C₀ = 2 x 10²⁰/cm³
Simultaneous Junction Formation by Flash Diffusion

OVERALL RESULTS

- SUITABLE JUNCTION DEPTHS ACHIEVED FOR N-TYPE DENDRITIC WEB
  - P⁺N - 0.15 µm to 0.25 µm
  - N⁺N - 0.25 µm to 0.40 µm
- FOR P-TYPE MATERIAL FRONT N⁺P JUNCTION DEEPER THAN OPTIMUM TO ACHIEVE REQUIRED P⁺P BSF
- ANNEALING OF DIFFUSED MATERIAL REQUIRED TO ACHIEVE HIGHEST EFFICIENCY - 750-800°C FOR 10 - 30 MIN
- EFFICIENCIES GREATER THAN 15.2% OBTAINED ON N-BASE CELLS - 24.5 cm² AREA
- P BASE CELLS GAVE MAXIMUM EFFICIENCY OF 12.5%

Flash Diffusion Verification

- 48 WEB STRIPS EACH OF: 0.4 QC N TYPE GROWTH RUN
  - 6 QC P TYPE R499
  - 0.2 QC N TYPE GROWTH RUN
  - 2 QC N TYPE S332
  - STRIPS 3 CM X 13 CM

- RUN R499 - 110 µm NOMINAL THICKNESS
  - RUN S332 - 100 µm NOMINAL THICKNESS
- COAT WITH LIQUID PRECURSORS (B & P DOPED)
- DIFFUSE AT 1300°C/10 SEC IN AP6ON
- LESS THAN 1% OF STRIPS BROKEN DURING DIFFUSION
- ANNEAL AT TEMPERATURES 900°C TO 750°C AND TIMES 10 MIN. TO 60 MIN. (6 CONDITIONS)
- FINISH BASELINE PROCESS
## Flash Diffusion Verification: Samples Diffused 1100°C/10 s

Back Surface Reflector (No Passivation)

<table>
<thead>
<tr>
<th>ANNEALING TEMP (°C)</th>
<th>ANNEALING TIME (MIN)</th>
<th>N BASE CELLS</th>
<th>P BASE CELLS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.4 - 0.3 μm</td>
<td>2.0 μm</td>
</tr>
<tr>
<td>&gt;900</td>
<td>30</td>
<td>13.8</td>
<td>14.2</td>
</tr>
<tr>
<td>900</td>
<td>30</td>
<td>12.8</td>
<td>--</td>
</tr>
<tr>
<td>900</td>
<td>10</td>
<td>13.5</td>
<td>14.6</td>
</tr>
<tr>
<td>800</td>
<td>30</td>
<td>14.4</td>
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<tr>
<td>800</td>
<td>10</td>
<td>14.3</td>
<td>14.8</td>
</tr>
<tr>
<td>750</td>
<td>60</td>
<td>14.0</td>
<td>15.1</td>
</tr>
</tbody>
</table>

## Diffusion Length in Flash-Diffused Cells

<table>
<thead>
<tr>
<th>ANNEAL TEMP (°C)</th>
<th>ANNEAL TIME (MIN)</th>
<th>N TYPE CELLS</th>
<th>P TYPE CELLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>30</td>
<td>--</td>
<td>55</td>
</tr>
<tr>
<td>900</td>
<td>10</td>
<td>--</td>
<td>25</td>
</tr>
<tr>
<td>800</td>
<td>60</td>
<td>--</td>
<td>92</td>
</tr>
<tr>
<td>800</td>
<td>30</td>
<td>--</td>
<td>75</td>
</tr>
<tr>
<td>600</td>
<td>10</td>
<td>--</td>
<td>75</td>
</tr>
<tr>
<td>750</td>
<td>60</td>
<td>65</td>
<td>--</td>
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</table>

## Representative Data from Selected Flash-Diffused Cells

<table>
<thead>
<tr>
<th>Cell</th>
<th>Base Conductivity</th>
<th>Resistivity (Ω-cm)</th>
<th>&quot;yc&quot; (°C/min)</th>
<th>Eff. (%)</th>
<th>J&lt;sub&gt;31&lt;/sub&gt; (A/cm²)</th>
<th>J&lt;sub&gt;302&lt;/sub&gt; (A/cm²)</th>
<th>Ln (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7N</td>
<td>N</td>
<td>0.32</td>
<td>500/30</td>
<td>13.4</td>
<td>4.13E-19</td>
<td>2.8E-4</td>
<td>160</td>
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<tr>
<td>47K</td>
<td>N</td>
<td>0.32</td>
<td>900/30</td>
<td>13.1</td>
<td>1.1E-12</td>
<td>1.8E-5</td>
<td>125</td>
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<tr>
<td>47N</td>
<td>N</td>
<td>2.0</td>
<td>500/30</td>
<td>14.2</td>
<td>1.2E-12</td>
<td>2.5E-5</td>
<td>170</td>
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<tr>
<td>58N</td>
<td>N</td>
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<td>800/60</td>
<td>14.8</td>
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<td>135</td>
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<tr>
<td>65N</td>
<td>N</td>
<td>2.0</td>
<td>800/30</td>
<td>14.7</td>
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<td>1.4E-6</td>
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<tr>
<td>18N</td>
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<td>150/60</td>
<td>15.2</td>
<td>8.9E-13</td>
<td>7.1E-6</td>
<td>160</td>
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<tr>
<td>48P</td>
<td>P</td>
<td>9.0</td>
<td>800/30</td>
<td>12.5</td>
<td>3.2E-12</td>
<td>4.2E-8</td>
<td>50</td>
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<td>57P</td>
<td>P</td>
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<td>71P</td>
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<td>8.0</td>
<td>800/30</td>
<td>12.2</td>
<td>2.7E-12</td>
<td>2.7E-8</td>
<td>70</td>
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<tr>
<td>77P</td>
<td>P</td>
<td>7.0</td>
<td>800/10</td>
<td>12.2</td>
<td>5.1E-12</td>
<td>6.0E-8</td>
<td>72</td>
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</table>
Flash Diffusion Results (Cell Efficiency Versus Annealing Temperature/Time)

Quantum Efficiency Plot
Simultaneous Junction Formation by Flash Diffusion: Cost Analysis

- COMPARISON SIMULTANEOUS JUNCTION FORMATION (FLASH DIFFUSION) WITH SEQUENTIAL DIFFUSION

- TWO PRODUCTION LEVELS CONSIDERED
  - 1 MW/yr - SEMI-AUTOMATED
  - 25 MW/yr - FULLY AUTOMATED

- COSTS CALCULATED IN 1985 $ FOR DIFFUSION PROCESS STEP

- FORMAT A'S PREPARED

Cost Analysis

ALL COSTS - 1985 $/WATT

<table>
<thead>
<tr>
<th>PRODUCTION LEVEL (MW/yr)</th>
<th>SIMULTANEOUS - FLASH DIFFUSION</th>
<th>SEQUENTIAL DIFFUSION</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.57</td>
<td>0.92</td>
</tr>
<tr>
<td>25</td>
<td>0.072</td>
<td>0.134</td>
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Simultaneous Junction Formation by Flash Diffusion: Conclusions

CONCLUSIONS:

- SIMULTANEOUS JUNCTION FORMATION BY FLASH DIFFUSION VERIFIED
- NO CROSS-CONTAMINATION NOTED
- ANNEALING REQUIRED AFTER DIFFUSION TO ACHIEVE HIGHEST CELL EFFICIENCY
- TECHNIQUE IS COMPATIBLE WITH WESTINGHOUSE BASELINE PROCESS SEQUENCE
- N-BASE CELLS WITH EFFICIENCIES OF 15% 2% FABRICATED USING FLASH DIFFUSION (AREA ~ 24.5 CM²)
- COST ANALYSIS SHOWS SAVING OF 60 - 85% IN DIFFUSION PROCESS STEP