SIMULTANEOUS JUNCTION FORMATION
WESTINGHOUSE ELECTRIC CORP.
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Contract Information

OBJECTIVE: INVESTIGATE HIGH-RISK, HIGH-PAYOFF IMPROVEMENTS TO WESTINGHOUSE BASELINE PROCESS SEQUENCE

TIME PERIOD: MARCH, 1984 - OCTOBER, 1984

Contract Tasks

- EVALUATE FEASIBILITY OF SIMULTANEOUSLY FORMING BACK & FRONT JUNCTIONS OF SOLAR CELLS USING LIQUID DOPANTS ON DENDRITIC WEB SILICON
- COMPARE SIMULTANEOUS DIFFUSION TO SEQUENTIAL DIFFUSION
- TEST OF BELT FURNACE FOR DIFFUSION PROCESS

WHEN SHOWN FEASIBLE:
- DEVELOP PROCESS CONTROL PARAMETERS AND SENSITIVITIES
- PERFORM COST ANALYSES

Potential Benefits

- FEWER PROCESSING STEPS
- LESS OPPORTUNITY FOR CONTAMINATION AND BREAKAGE DURING PROCESSING DUE TO HANDLING
- LESS COSTLY PROCESS

HOWEVER

- PROCESS WILL REQUIRE CAREFUL SELECTION OF DOPANTS, DIFFUSION MASKS, AND WEB CONDUCTIVITY TYPE
Approaches

- DIFFUSION
  - N-TYPE DENDRITIC WEB
    - PHOSPHORUS OR ARSENIC FOR BACK N'N JUNCTION
    - BORON OR ALUMINUM FOR FRONT P'N JUNCTION
  - P-TYPE DENDRITIC WEB (LOW RESISTIVITY)
    - PHOSPHORUS FOR FRONT N'P JUNCTION
    - BORON OR ALUMINUM FOR BACK P'P JUNCTION
    - BACK SURFACE DAMAGE
- BASELINE PROCESS EXCEPT FOR DIFFUSION
- TEST OF VARIOUS VENDORS' DOPANTS AND DIFFUSION MASKS
- EXCIMER LASER DRIVE IN
  - PHOSPHORUS, BORON, AND ALUMINUM DOPANTS
PROCESS DEVELOPMENT

Results: n-Type Web

- LIQUID SOURCE - SEQUENTIAL DIFFUSION OF B (FRONT) AND P (BACK) PRODUCED CELLS WITH $n_{AV} > 13\%$

- LIQUID SOURCE - SIMULTANEOUS DIFFUSION USING B & P PRODUCED JUNCTION DEPTHS OF 0.25 µm ($P^+N$) AND 0.6 µm ($N^+N$)

- SUITABLE JUNCTIONS ALSO OBTAINED USING BORON (FRONT) AND ARSENIC (BACK)

- IN ANY EXPERIMENT WHERE TWO DOPANT SPECIES WERE PRESENT, CELL PROPERTIES WERE DEGRADED DUE TO CROSS DOPING OF THE FRONT JUNCTION

- CELL EFFICIENCIES VARIED FROM <1% TO 6-7% WITH A FEW CELLS >10%

- CROSS DOPING ALSO OCCURRED WHEN SiO$_2$ DIFFUSION MASKS (LIQUID OR THERMAL) WERE USED

- EFFECT ALSO OCCURRED AT LOWER DIFFUSION TEMPERATURES

- PROBLEM DUE TO HIGH MOBILITY OF P AT DIFFUSION TEMPERATURES REQUIRED

- EFFECT STUDIED USING DARK IV AND CONDUCTIVITY MEASUREMENTS
PROCESS DEVELOPMENT

Shorting Paths in Front p⁺n Junction Due to Contamination With Back-Surface Dopant

\[ \begin{array}{cccc}
N & N & N & N \\
\end{array} \]

N BASE

\[ \begin{array}{cccc}
N^+ & N^+ & N^+ & N^+ \\
\end{array} \]

Results: p-Type Web

- Shallow B-doped BSF due to low temperature diffusion (required for front p-doped junction); high resistive contact probably Schottky barrier. \( n_{\text{max}} = 7\% \)
- All BSF also gave high resistance contact with \( n_{\text{max}} = 8\% \)
- Cells of >12% efficiency fabricated using phosphorus front doping only with the back surface damaged (0.5 ncm - 1.5 ncm)
- No noticeable cross doping in cells

Belt Furnace Test

- Test carried out at Radiant Technology Corporation
- Proper temperature and temperature gradients obtained
- Suitable junction depths obtained
- Cells showed effect of cross-doping
Junction Formation Using an Excimer Laser

APPROACH
HEAT SURFACES OF WEB WITH LASER TO DRIVE IN LIQUID DOPANTS

CONDITIONS
WAVELENGTH - 3080 nm
POWER INPUT TO WEB 1 - 2 J/cm²

EXPERIMENT
DRIVE IN B, P, AND AL INTO BOTH N-TYPE AND P-TYPE WEB
INITIAL STUDY CARRIED OUT AT MATHEMATICAL SCIENCES NORTHWEST, INC.

Sample 17B, p-Base Web, Phosphorus Emitter 1.15 J/cm²
PROCESS DEVELOPMENT

Sample 17B, p-Base Web, Boron BSF 1.15 J/cm²

Results: Excimer Laser

- JUNCTION CHARACTERISTICS
  N⁺N or N⁺P (PHOS. DOPED) \( C_0 = 10^{19}/\text{cm}² \) \( x_j = 0.2 - 0.25 \text{ nm} \)
  P⁺N or P⁺P (B DOPED) ESSENTIALLY NO JUNCTION
  P⁺P (AL DOPED) SHALLOW JUNCTION

- CELL PROPERTIES
  P TYPE WEB, \( n_{\text{max}} = 9\% \) - DUE TO HIGH RESISTANCE BACK CONTACT (BOTH B & AL BSF)
  N TYPE WEB, \( n_{\text{max}} = 1\% \) - POOR B DOPED EMITTER

- LOW DIFFUSION CONSTANT OF BORON WILL REQUIRE HIGHER POWER INPUT
- NO CROSS CONTAMINATION NOTED
- CRYSTAL PAIRS PROCESSED BASELINE SEQUENCE - \( \approx = 13.7\% \)

374

DUE POOR QUALITY
PROCESS DEVELOPMENT

**n⁺p Front Junction by Laser Drive-in**

![Graph showing dopant concentration vs. distance into cell (μM)](image)
PROCESS DEVELOPMENT

$p^+p$ Back Junction by Laser Drive-in

DOPANT CONCENTRATION (1/CM³)

DISTANCE INTO CELL (μM)
PROCESS DEVELOPMENT

Conclusions

- **SEQUENTIAL DIFFUSION OF N-TYPE WEB - USING LIQUID R & P SOURCES,**
  CELLS WITH AVERAGE EFFICIENCIES ~13% PRODUCED

- **SIMULTANEOUS DIFFUSION - N TYPE WEB - WITH PRESENT DOPANTS AND**
  DIFFUSION MASKS, A SUITABLE PROCESS HAS NOT BEEN DEFINED. PROBLEM
  DUE TO HIGH MOBILITY OF PHOSPHORUS AT TEMPERATURES REQUIRED FOR
  BORON DIFFUSION WHICH CAUSES FRONT JUNCTION CONTAMINATION.

- **SIMULTANEOUS DIFFUSION - P TYPE WEB - AL BSF WITH PHOSPHORUS**
  DOPED EMITTER GAVE BEST RESULTS. FURTHER STUDY REQUIRED TO
  OBTAIN LOW RESISTANCE BACK CONTACT AND OPERATIONAL BSF.

- **EXCIMER LASER DRIVE IN**
  - EXCELLENT PHOSPHORUS DOPED JUNCTIONS FABRICATED BOTH N^P AND N^N
  - FURTHER STUDY REQUIRED TO PRODUCE BORON DOPED LAYERS FOR P^N
    AND P^P JUNCTIONS
  - NO CROSS-CONTAMINATION PROBLEM OBSERVED