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
PROCESS DEVELOPMENT

Approaches

- DIFFUSION
  - N-TYPE DENDRITIC WEB
    - PHOSPHORUS OR ARSENIC FOR BACK N\textsuperscript{+}N JUNCTION
    - BORON OR ALUMINUM FOR FRONT P\textsuperscript{+}N JUNCTION
  - P-TYPE DENDRITIC WEB (LOW RESISTIVITY)
    - PHOSPHORUS FOR FRONT N\textsuperscript{+}P JUNCTION
    - BORON OR ALUMINUM FOR BACK P\textsuperscript{+}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 DEGRATED 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 SiO₂ 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

\[ \text{N BASE} \]

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, \( r_{\text{max}} = 7\% \)
- ALL BSF ALSO GAVE HIGH RESISTANCE CONTACT WITH \( r_{\text{max}} = 8\% \)
- 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 SHOWN 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

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Results: Excimer Laser

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

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

- **LOW DIFFUSION CONSTANT OF BORON WILL REQUIRE HIGHER POWER INPUT**

- **NO CROSS CONTAMINATION NOTED**

- **CRYSTAL PAIRS PROCESSED BASELINE SEQUENCE \( \hat{\alpha} = 13.7\% \)**
PROCESS DEVELOPMENT

n⁺ p Front Junction by Laser Drive-in

DOPANT CONCENTRATION (1/cm³)

DISTANCE INTO CELL (µM)

10¹⁷
10¹⁶
10¹⁵
10¹⁴
10¹³
10¹²
0
0.125
0.250
0.375
0.500
0.625
0.750
PROCESS DEVELOPMENT

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

Graph showing dopant concentration vs. 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