SIMULTANEOUS JUNCTION FORMATION
WESTINGHOUSE ELECTRIC CORP.
R.B. Campbell

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

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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 $\mu$m ($P^+N$) AND 0.6 $\mu$m ($N^+N$)

- 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

\[ \text{N BASE} \]

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. \( n_{\text{max}} = 7\% \)

- AL 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)  \( C_0 = 10^{19} \text{cm}^{-2} \)  \( X_j = 0.2 - 0.25 \mu\text{m} \)
  
  P⁺N OR P⁺P (B DOPED) ESSENTIALLY NO JUNCTION
  
  P⁺P (AL DOPED) SHALLOW JUNCTION

- CELL PROPERTIES
  
  P TYPE WEB,  \( n_{\text{max}} = 9\% \) - 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 \( \Delta = 13.7\% \)

DE POOR QUALITY
PROCESS DEVELOPMENT

n⁺p Front Junction by Laser Drive-in

![Graph showing dopant concentration against distance into cell (µM)]
PROCESS DEVELOPMENT

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

![Graph showing dopant concentration versus distance into cell (um)]
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