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 $n_{AV} \geq 13\%$

- **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

\[ \text{N BASE} \]

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)  Co = 10¹⁹/cm²  x_j = 0.2 - 0.25 µm
  - P⁺N OR P⁺P (B DOPED)  ESSENTIALLY NO JUNCTION
  - P⁺P (AL DOPED)  SHALLOW JUNCTION

- CELL PROPERTIES
  - P TYPE WEB,  n_max = 9% - DUE TO HIGH RESISTANCE BACK CONTACT (BOTH B & AL BSF)
  - N TYPE WEB,  n_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 -  13.7%

ORIGINAL PAGE REPRODUCED OF POOR QUALITY
PROCESS DEVELOPMENT

n⁺p Front Junction by Laser Drive-in

![Graph showing dopant concentration vs distance into cell (μm)]
PROCESS DEVELOPMENT

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

![Graph showing dopant concentration versus 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