PULSED EXCIMER LASER PROCESSING

ARCO SOLAR, INC.

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Goal

TO DEMONSTRATE THE COST EFFECTIVE FEASIBILITY OF FABRICATING HIGH EFFICIENCY SOLAR CELLS ON CZ WAFERS USING A PULSED EXCIMER LASER FOR JUNCTION FORMATION, SURFACE PASSIVATION, AND FRONT METALLIZATION.

Objectives

1. JUNCTION FORMATION
   A. ION IMPLANT PARAMETERS
   B. SURFACE CONDITIONS
   C. LASER ANNEALING
      - LASER BEAM UNIFORMITY & OVERLAP FACTOR
      - LASER ENERGY DENSITY

2. METALLIZATION
   LASER-ASSISTED CHEMICAL VAPOR DEPOSITION
   A. DEPOSITION RATE
   B. ADHESION
   C. PLATE UP

3. SURFACE PASSIVATION (SiO₂)
   A. DEPOSITION RATE
   B. ADHESION
   C. EFFECTIVENESS IN PASSIVATION
PROCESS DEVELOPMENT

1. JUNCTION FORMATION

A. IMPLANT PARAMETERS

1. IMPLANT ENERGY: SHALLOW JUNCTION REQUIRES LOW KEV
   LOWEST AVAILABLE - 5 KEV
   OPTIMIZED JUNCTION DEPTH 20.25 MICRON

   EXTENSIVE SEARCH FOR LOWER ENERGY IMPLANT SERVICES
   UNSUCCESSFUL.

   ALTERNATE APPROACHES INCLUDED:

   - PH₃, BF₂ MOLECULAR IMPLANT AT CALCULATED ENERGY 3 KEV
     (EFF 9.1%)

   - 6²P₂ ION IMPLANT AT 5 KEV
     GOOD RESULT ON FZ MATERIAL (EFF 210.8%)  
     COULD NOT REPEAT ON CZ
     DEPTH PROFILE SUGGESTED SLOWER GRADIENT THAN ³¹P₁

   EMPIRICALLY CHOSEN - 1.8 TO 2.5 x 10¹⁵ ATOMS/CM²
     SHEET RHO - 40-60 OHMS/SQ

   AGREEABLE TO THE SUGGESTED SURFACE CONCENTRATION PER UNIT AREA
   FOR CRITICAL MISFIT DISLOCATION GENERATION.

   HOWEVER, JUNCTIONS ALWAYS HAVE A DEGENERATE LAYER DEEPER THAN
   0.1 MICRON, LIMITING BLUE RESPONSE.
PROCESS DEVELOPMENT

SPREADING RESISTANCE ANALYSIS

FZ
P2 IMPLANT
5 KEV 2E15 ATM/CM²

CZ
P2 IMPLANT
5 KEV 2E15 ATM/CM²
PROCESS DEVELOPMENT

SPREADING RESISTANCE ANALYSIS

B45 #1 J=1.4 J/cm²
I.I. = 2.5 x 10¹⁵/cm²
@ 5 KeV

ORIGINAL PAGE IS OF POOR QUALITY
I.B. SURFACE CONDITIONS

SURFACE CONDITION SERIOUSLY AFFECTED CELL VOC AND FILL FACTOR;
MUCH MORE CRITICAL THAN IN CONVENTIONAL THERMALLY DIFFUSED
CELL. (LIQUID PHASE DIFFUSION VS SOLID PHASE DIFFUSION.)

SURFACE FINISHING:

- TEXTURED SURFACE NOT RECOMMENDED FOR LASER ANNEALING;
  NONUNIFORM MELTING INTRODUCED STRESS ON SURFACE.

- CHEMICALLY POLISHED SURFACE ALSO LOWERED FILL FACTOR,
  ALTHOUGH TO LESSE EXTENT.

- ONLY HIGH QUALITY CHEM-MECH POLISHED WAFER FOUND SUITABLE
  FOR THE PROCESS.

SURFACE CLEANING: (BEFORE AND AFTER IMPLANT)

BESIDES STANDARD DEGREASING AND ACID RINSING, ION IMPLANTED
WAFER MUST BE SPRAY ETCHED WITH 1% HF FOLLOWED BY SPRAY RINSE
WITH 18 MEG-OHM DOUBLE-FILTERED & 0.2 MICRON ABSOLUTE DI
WATER.

Laser-Annealed, Chemically Polished Silicon Wafer
PROCESS DEVELOPMENT

Surface Contamination After Cleaning

Laser Annealed
I.C. LASER ANNEALING

- Because of nonuniform laser (Excilite 1) beam, overlap factor was found best at 50%. 4x annealing on each spot.

However, 50% overlap also drives junction deeper than desired with the presence of a flat degenerate layer limiting blue response.

Junction must be etched back in HF:HNO₃ solution in order to recover short wavelength response.

- Energy density
  Empirically found - 1.5 J/cm²
  Lower than 1.4 J/cm² -- incomplete annealing
  Higher than 1.6 J/cm² -- surface damage
Surface Damage at 1.6 J/cm², 50% Overlap

II. METALLIZATION

CONDITIONS: ArF at 198 nm, Output Energy -15 mJ
Energy Density -1.2 J/cm².

REACTION CHAMBER PRESSURE -5 TORR, BEAM PERPENDICULAR TO SURFACE.

CHEMICAL REACTION: WF₆ + 3H₂ → W + 6HF

RESULTS (PRELIMINARY):
- TUNGSTEN LINE OBTAINED -5-10 MILS WIDE
- PASSED TAPE TEST
- THICKNESS -500-1000Å (250 SHOTS);
  HOWEVER, DOUBLE HUMP STRUCTURE: FLAT AT THE CENTER.
- EXACT METAL COMPOSITION IS BEING DETERMINED BY AUGER ANALYSIS.
JUNCTION DEPTH PROFILES OF 1.4 J/cm² LASER-ANNEALED SAMPLES WITH 5% AND 50% OVERLAP.

RESULTS FROM COLLABORATIVE PROJECT BETWEEN ARCO SOLAR AND OAK RIDGE NATIONAL LABORATORY
DEKTAK MEASUREMENT ACROSS THE DEPOSITED METAL LINE. NOTE THE VALLEY IS BELOW THE WAFER SURFACE.
PROCESS DEVELOPMENT

III. SURFACE PASSIVATION

CONDITIONS: ARF AT 198 NM, OUTPUT ENERGY - MAX

CHAMBER PRESSURE ~6-10 TORR, BEAM PARALLEL TO WAFER SURFACE.

CHEMICAL REACTION: SiH₄ + 4N₂O → SiO₂ + 2H₂O + 4N₂

DEPOSIT RATE ~600-800 Å/Min

(EXPERIMENT TO BE PERFORMED)

Summary of Achievements

1. BATCH MODE LASER ANNEALING ACCOMPLISHED ON 50 2"x2" CZ WAFERS.

BEST CELL EFFICIENCY AFTER AR COATING IS 16.1% (WITHOUT BSF).

SPECTRAL RESPONSE IS SUPERIOR TO COMMERCIAL THERMALLY DIFFUSED CELL (WITH BSF) IN BLUE WAVELENGTH.

LOWER Vₜₒₖ IN LASER ANNEALED WAFER IS DUE TO LASER BEAM EDGE DAMAGE.

2. LCVD TUNGSTEN LINES ON SILICON SURFACE SUCCESSFULLY DEPOSITED WITH GOOD ADHESION.
PROCESS DEVELOPMENT

SINGLE/POLY

LIGHT IV AT 25C
OPERATOR: D WONG
CELL: ASEC LA 03A
Date/time: 18-JUN-85 12:36:57

AREA: 4.00 (sq.cm)

Isc: 0.134 (amps)
Jsc: 33.50 (mA/sq)
Voc: 0.689 (volts)

Ipn: 0.125 (amps)
Jpn: 31.36 (mA/sq)
Vpn: 0.514 (volts)

Pn: 0.064 (watts)
Eff: 78.99 %
Eff: 16.11 %

ASEC CONTACTS AND A/R
LASER ANNEALED
SURFACE DIRTY, HEAT TREATED

B62 LASER ANNEALED a
1.47 J/cm²

Sample: ASEC METALIZATION, HEAT TREATED #3
Voltage: 0.880 Volts  Light Bias: H

Date/time: 18-JUN-85 15:45:44  Operator: D WONG
System Calibrated 18-JUN-85 15:21:06  Standard Cell #325

ASEC METALLIZATION, HEAT TREATED #3

WAVELENGTH (nanometers)  ABS - QUANTUM EFFICIENCY

Jsc= 34.51 mA/cm²

427
Damages at the laser beam edges that led to $V_{OC}$ degradation.

Problems

1. Junction Formation
   Process expensive and time-consuming. Cell efficiency matches but is not higher than conventional thermal process.

2. Unable to process large area (5") cells due to lack of ion implant facility.

3. Metallization
   Slow process. Silver plating on tungsten is questionable.

4. Passivation
   Can CVD SiO$_2$ deactivate the dangling silicon bonds on the surface?