N86-29350

SUMMARY OF HIGH-EFFICIENCY SOLAR-CELL RESEARCH

JET PROPULSION LABORATORY

Ram Kachare

Outline

- TASK OBJECTIVES
- THEORETICAL PREDICTION OF CELL EFFICIENCY
- MODELING OF CELL EFFICIENCY
- HIGH-EFFICIENCY CELL RESULTS
- STATUS AND FUTURE ACTIVITIES

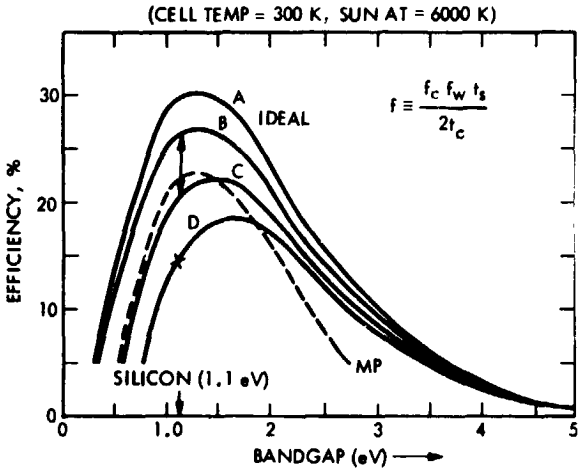
Task Objectives

1. IDENTIFY AND RESOLVE KEY GENERIC PROBLEMS THAT LIMIT CELL EFFICIENCY TO BELOW THEORETICALLY PREDICTED VALUE

AND

2. DESIGN AND FABRICATE CELLS HAVING EFFICIENCY $\geq$ 20 % (AM1.5)

Theoretical Curves for p-n Junction Solar Cell



CURVES	f VALUES	
(A)	1.09×10^{-5} ($f_c = t_s = t_c = 1$)	
(B)	0.68×10^{-5}, $f_c = 1$	$t_s = t_c = 0.9$
(C)	0.68×10^{-8}, $f_c = 10^{-3}$	
(D)	0.68×10^{-11}, $f_c = 10^{-6}$	
(MP)	M-PRINCE, JAP 26,534 (1955)	

f_c = RADIATIVE RECOMBINATION, A FRACTION OF ALL RECOMBINATION PROCESSES REPRESENTED BY f
f_w = RELATED TO ILLUMINATION INTENSITY
t_s and t_c = PROBABILITIES OF PRODUCING ELECTRON-HOLE PAIRS BY PHOTON HAVING ENERGY GRIATER THAN BANDGAP INCIDENT ON THE SURFACE (t_s) AND ENTERING THE BODY OF THE CELL (t_c) RESPECTIVELY.

[SHOCKLEY AND QUIESSER, JAP 32,510 (1961)]

Parameters for Modeling Cell Efficiency

- BASE MATERIAL
  - THICKNESS
  - RESISTIVITY
  - MINORITY CARRIER LIFETIME (τ)
- EMITTER AND BACK-SURFACE (BSF) DOPING
  - SURFACE CONCENTRATION
  - DOPING PROFILE
- HEAVY DOPING EFFECTS
  - BANDGAP NARROWING (B)
  - AUGER RECOMBINATION (A)
- SHOCKLEY-REED-HALL RECOMBINATION
- FRONT (S_F) AND BACK (S_B) SURFACE RECOMBINATION VELOCITIES
- FRONT (AR) AND BACK SURFACE (BSR) OPTICAL PROPERTIES
- FRONT-SURFACE METAL SHADOWING
- SERIES AND SHUNT RESISTANCES

Cell Design Parameters

FIXED:

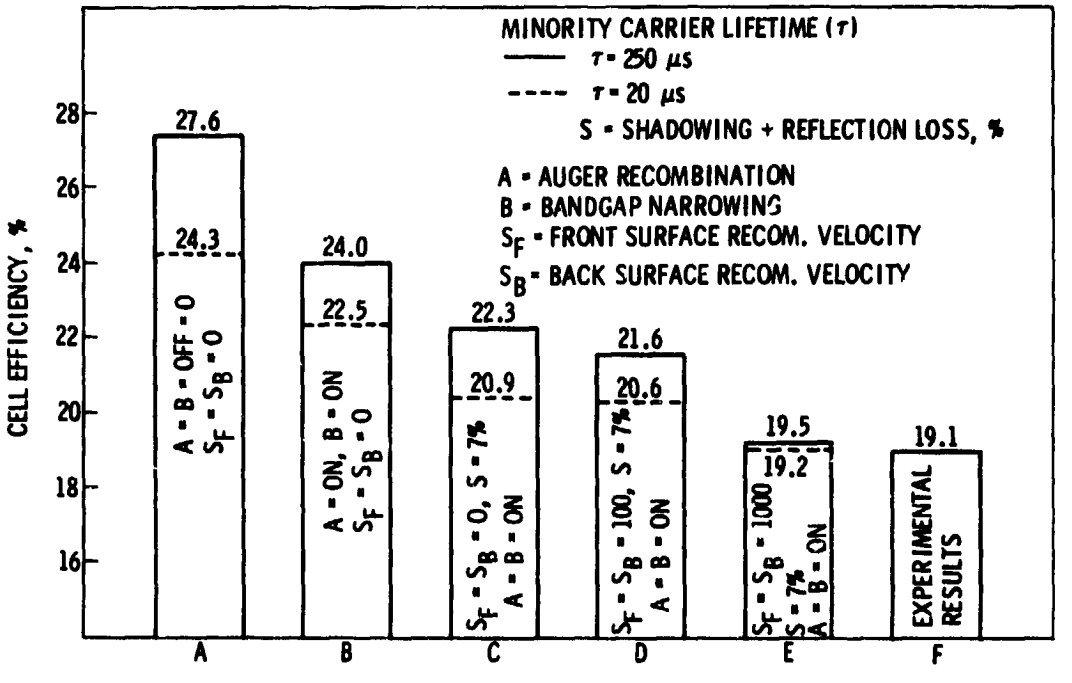
- EMITTER DOPING:
  - PROFILE: COMPLEMENTARY ERROR FUNCTION
  - SURFACE CONCENTRATION = 1×10^{18} P ATOMS/cm^3
- JUNCTION DEPTH = 0.2 μm
- BULK DOPING = 5×10^{17} B ATOMS/cm^3
- CELL THICKNESS = 100 μm; BACK-SURFACE REFLECTOR PROVIDED ($\therefore$ EFFECTIVE THICKNESS $\cong$ 200 μm)
- ILLUMINATION = 100 mW/cm^2

VARIED:

- MINORITY CARRIER LIFETIME (τ)
- HEAVY DOPING EFFECTS: CONSIDERED
  - AUGER RECOMBINATION (A)
  - BANDGAP NARROWING (B)

  } ON OR OFF = 0
- FRONT (S_F) AND BACK (S_B) SURFACE RECOMBINATION VELOCITIES
- FRONT-SURFACE REFLECTION AND METAL SHADOWING LOSSES (S)

Effect of Practical Barriers on Cell Efficiency



High-Efficiency Cell Modeling

USEFUL FOR

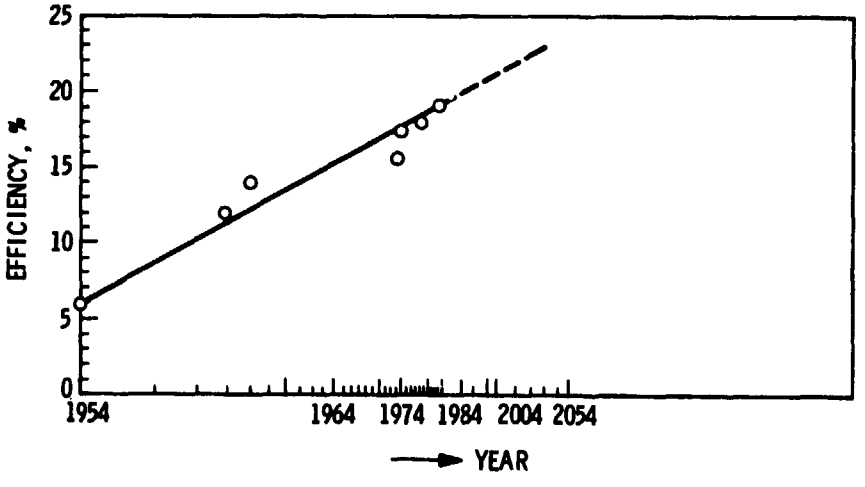
- SENSITIVITY ANALYSIS
  - MATERIALS
  - DEVICE DESIGN
  - DEVICE PROCESSING

  } PARAMETERS
- COMPARISON OF VARIOUS DESIGNS
- ANALYSIS OF EXPERIMENTAL RESULTS
- PREDICTION OF EFFICIENCIES AS
  - VARIOUS TECHNOLOGY BARRIERS ARE OVERCOME
  - DESIGNS AND MATERIAL PROPERTIES CHANGE

CURRENT LIMITATIONS

- MAINLY DUE TO LACK OF RELIABLE DATA ON:
  - HEAVY DOPING EFFECTS
    - AUGER RECOMBINATION COEFFICIENT
    - BANDGAP NARROWING
  - FRONT- AND BACK-SURFACE RECOMBINATION VELOCITIES
  - MINORITY CARRIER LIFETIME (THIN EMITTER)
  - MINORITY CARRIER MOBILITY

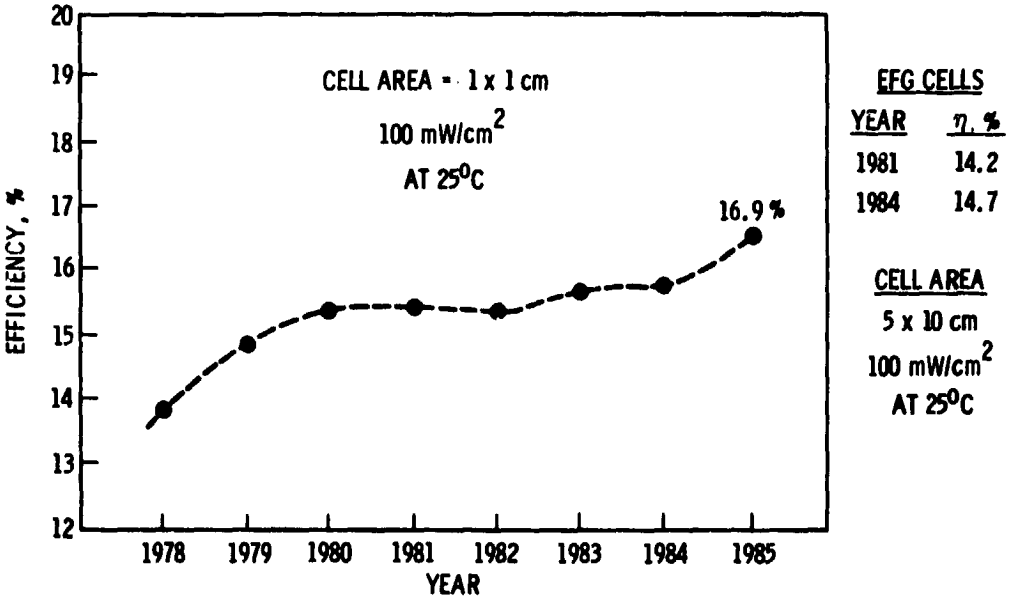
Historical Development of Silicon Solar Cells



Recent High-Efficiency Results

SUBSTRATE RESISTIVITY, Ω-cm	CELL EFFICIENCY, %	SOURCE	CELL AREA, cm^2
0.25	18.4	WESTINGHOUSE	4.0
0.30	18.1	SPIRE CORP.	4.0
0.15	18.1	ASEC	4.0
0.25	19.1	UNIVERSITY OF SOUTH WALES, AUSTRALIA	4.0
0.30	17.1	CATHOLIC UNIVERSITY OF LEUVEN, BELGIUM	1.0?
0.30	17.5	SANDIA LAB CONC.	4.0
0.20	17.4	JPL	8.0

History of Highest-Efficiency (η) Web and EFG Cells



Current Technical Status

- THEORETICAL KNOWLEDGE OF HIGH-EFFICIENCY DEVICE CONCEPT EXISTS
- EXPERIMENTAL UNDERSTANDING OF THE CONCEPT IS NOT MATURE
- QUALITY OF SILICON SHEET CONTINUES TO BE A MAJOR TECHNICAL BARRIER

Future Activities

- DEVELOPMENT OF SURFACE PASSIVANT(S)
- SURFACE / INTERFACE CHARACTERIZATION
- FRONT-SURFACE RECOMBINATION VELOCITY AND LIFETIME (IN THIN EMITTER) MEASUREMENT TECHNIQUE
- UNDERSTANDING AND CONTROL OF BULK LOSS
- HIGH-EFFICIENCY DEVICE DESIGN MODELING OPTIMIZATION