N85-32423

SILICON SURFACE PASSIVATION BY SILICON NITRIDE DEPOSITION

UNIVERSITY OF WASHINGTON

Larry C. Olsen

Objectives and Approach

OBJECTIVES

- TO INVESTIGATE THE USE OF PECVD SILICON NITRIDE FOR PASSIVATION OF SILICON SURFACES.
- TO INVESTIGATE MEASUREMENT TECHNIQUES FOR SURFACE RECOMBINATION VELOCITY.
- TO INVESTIGATE THE IMPORTANCE OF SURFACE PASSIVATION TO HIGH EFFICIENCY SOLAR CELLS.

APPROACH

SiN_x FILM DEPOSITION AND CHARACTERIZATION

- ESTABLISH PECVD SYSTEM
- DEVELOP DEPOSITION PROCEDURES

FILM CHARACTERIZATION

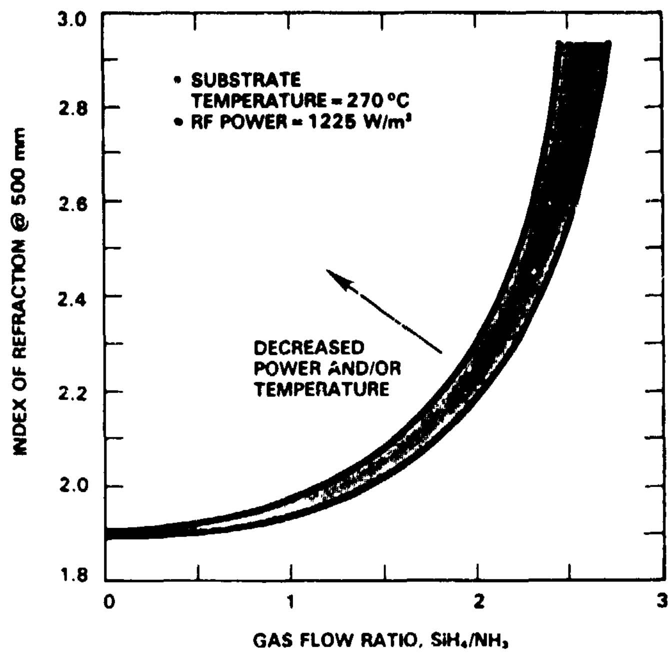
- OPTICAL CHARACTERIZATION -- N and K VS WAVELENGTH AND DEPOSITION PARAMETERS.
- PHYSICAL CHARACTERIZATION

PASSIVATION STUDIES

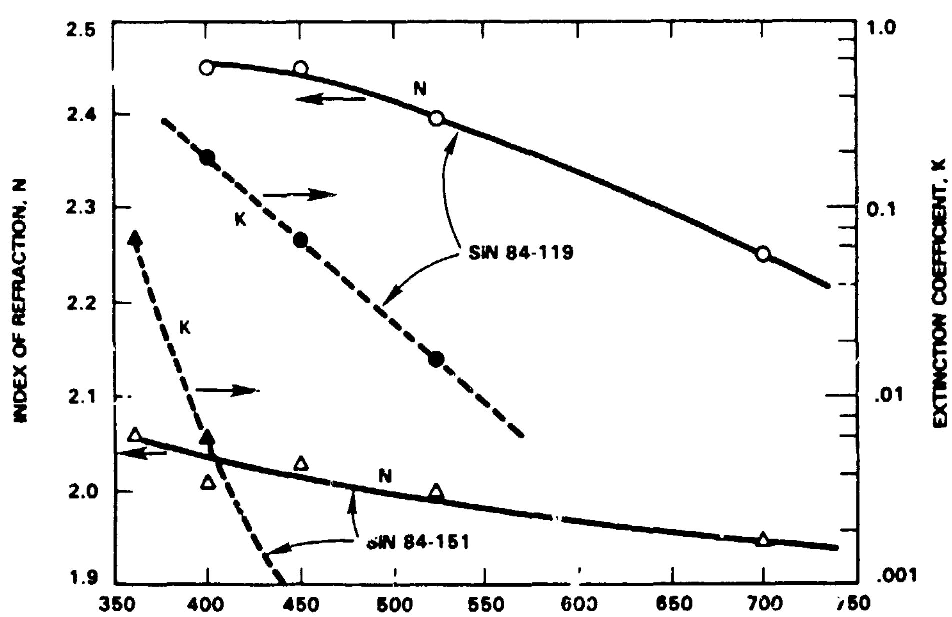
- SURFACE STATE DENSITY AT SiN_x/Si INTERFACE FOR MODERATELY DOPED SILICON SUBSTRATES.
- PHOTORESPONSE OF N/P SOLAR CELLS WITH PECVD SiN_x FILMS.
- CURRENT-VOLTAGE ANALYSES OF SILICON CELLS WITH SiN_x FILMS.
- ROSIER MEASUREMENT

PRECEDING PAGE BLANK NOT FILMED

SiN_x Film Index of Refraction vs Silane-Ammonia Ratio



Optical Constants of SiN_x Films From Ellipsometry Measurements

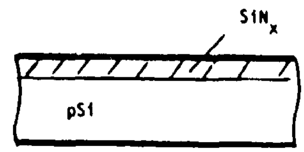


*MEASUREMENTS TAKEN ON EQUIPMENT PROVIDED BY BATTELLE NORTHWEST LABORATORIES

Approaches to Investigation of Surface Recombination in Solar Cells

M-SiN$_x$-pSi STRUCTURE

HIGH FREQUENCY AND QUASI-STATIC C-V MEASUREMENTS TO OBTAIN INTERFACE STATE DENSITY.



SOLAR CELL STRUCTURE

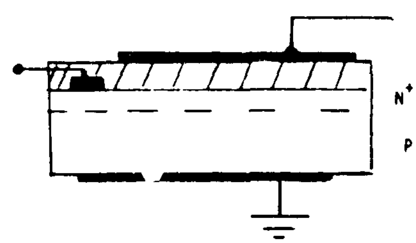
PHOTORESPONSE AT SHORT WAVELENGTHS CAN THEORETICALLY YIELD RECOMBINATION VELOCITY.

I-V CHARACTERIZATION MAY ALLOW IDENTIFICATION OF DOMINANT CURRENT MECHANISMS.

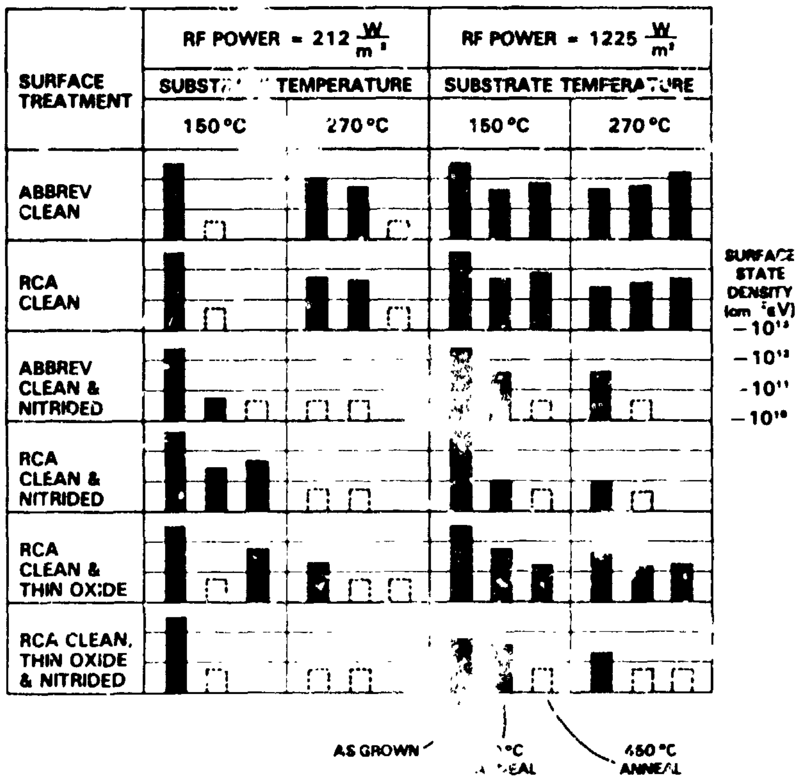
SPECIAL STRUCTURES (ROSIER)

PHOTORESPONSE MEASUREMENT WITH SURFACE POTENTIAL VARIED MAY ALLOW DETERMINATION OF S.

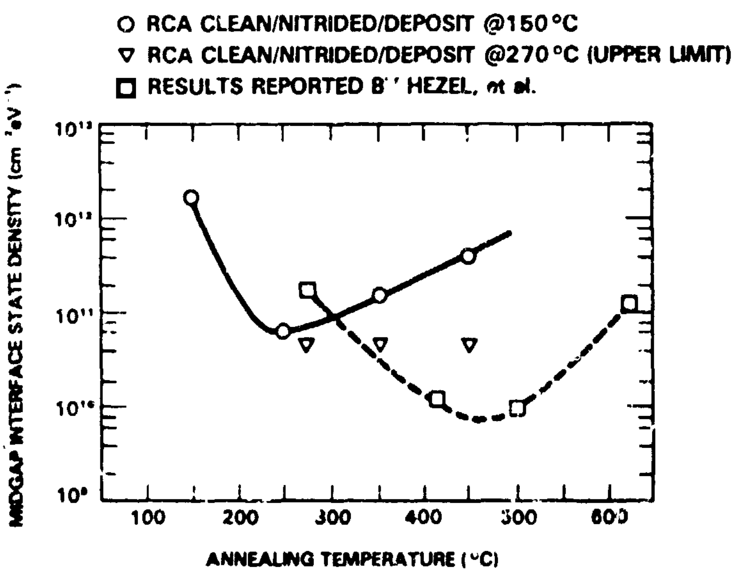
I-V CHARACTERIZATION WITH SURFACE POTENTIAL VARIED ALLOWS DETECTION OF SURFACE RECOMBINATION EFFECTS.



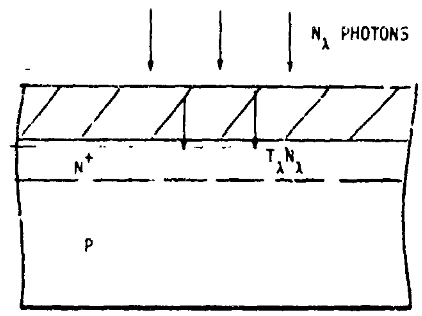
Results of I... State Study of SiN_X on p-Type Si



Interface State Density vs Annealing Temperature for SiN_X on p-Type Si



Internal Photoresponse Analysis



THEORY

$$J_{PH}(\lambda) = S_{INT}(\lambda) \cdot T_\lambda \cdot N_\lambda \cdot q$$

$$S_{INT}(\lambda) = (S_{INT})_{EMITTER} + (S)_{\substack{DEPL.\\WIDTH}} + (S_{INT})_{BASE}$$

$$T_\lambda = T_\lambda(N_{AR}, K_{AR}, N_{Si}, K_{Si})$$

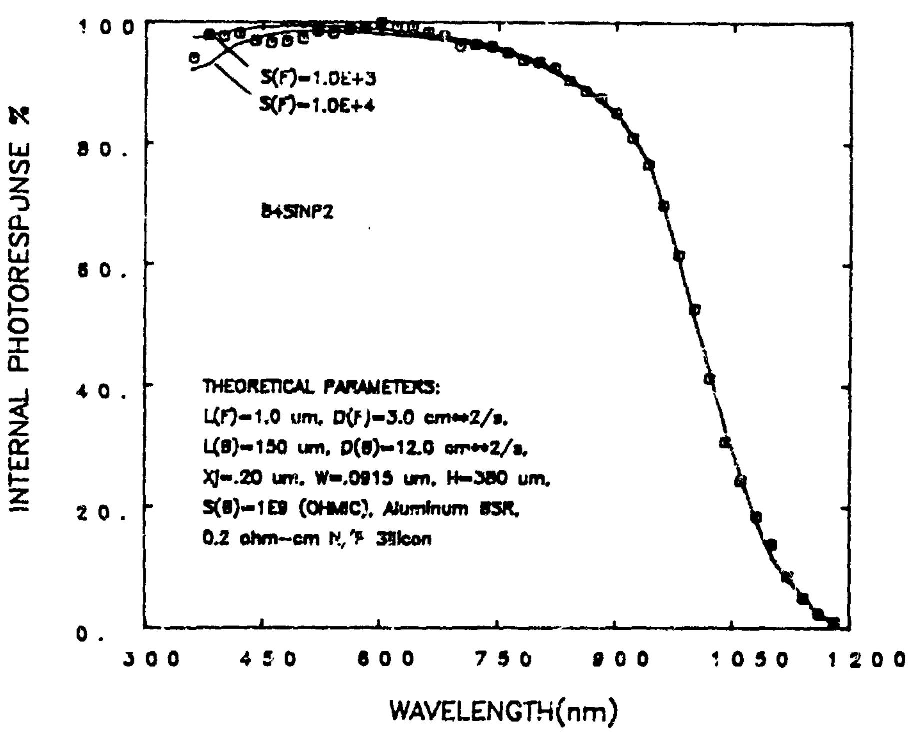
$$= 1 - R_\lambda - A_\lambda$$

EXPERIMENT

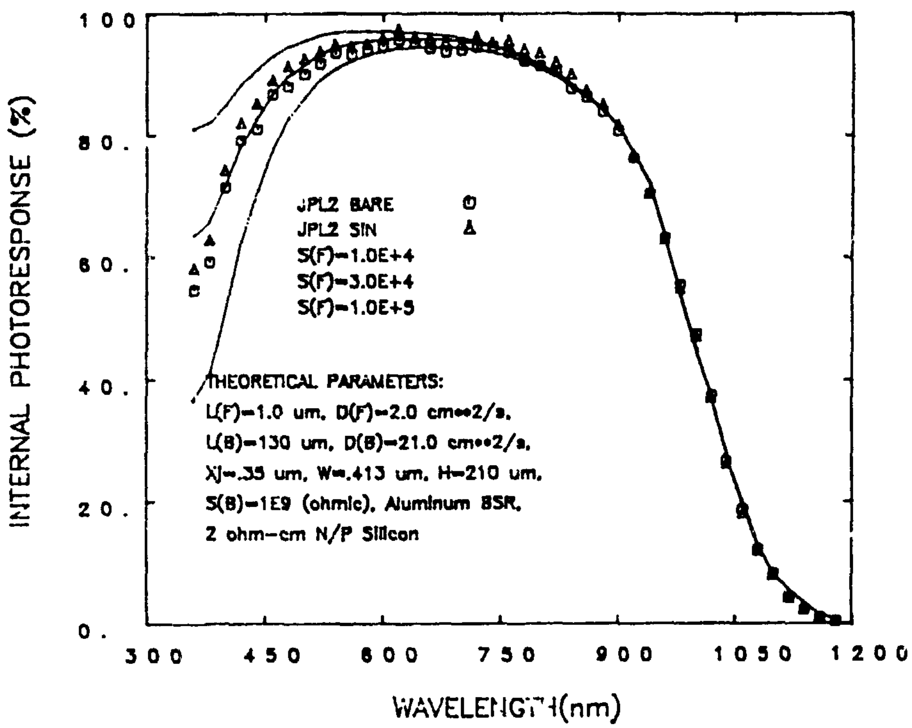
MEASURE: $J_{PH}(\lambda)$, R_λ, N_λ and K_λ of SiN_x

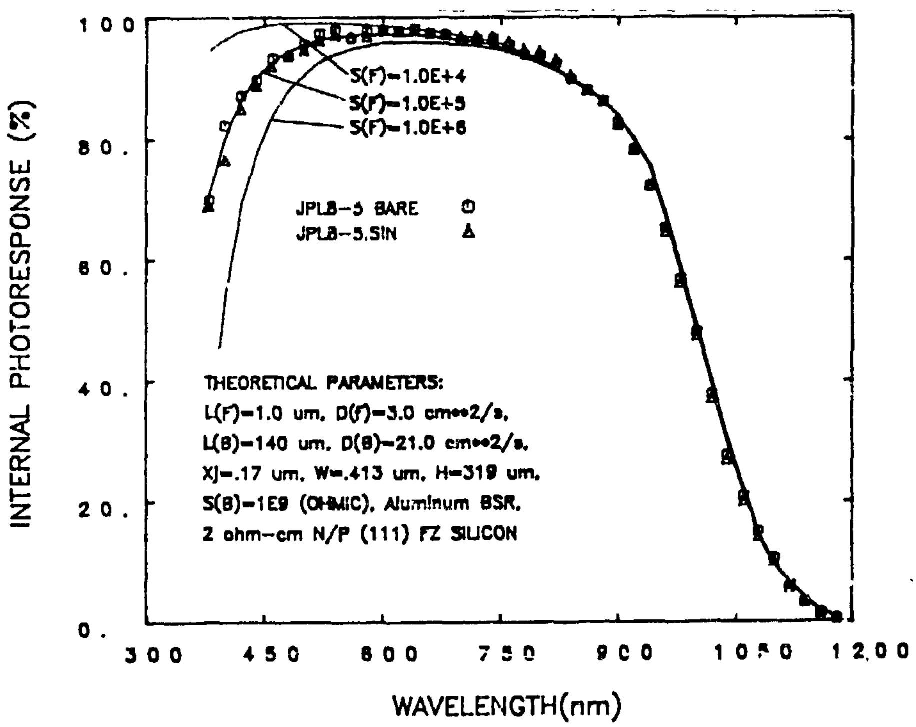
ANALYSIS: HAVE OBTAINED $S_{INT}(\lambda)$ FOR CELLS WITH SiN_x LAYERS.
DETERMINED S_F ASSUMING A HOMOGENEOUS EMITTER.

Internal Photoresponse vs Wavelength for Si n-p Cell With 100 Angstroms SiO_2



Internal Photoresponse vs Wavelength for JPL Cell



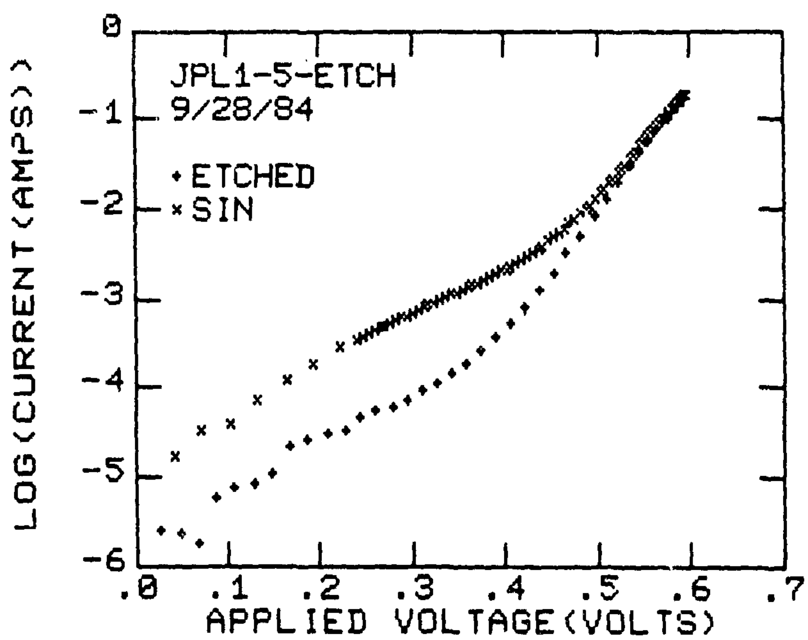


Illuminated Characteristics of JPL Cells (Fabricated by ASEC)

CELL	ORIENTATION	AR LAYER	AM1* EFFICIENCY (%)	I_{sc} (mA)	V_{oc} (mV)	FF	TOTAL AREA J_{sc} (mA/cm^2)
2-3	(100)	SiO_x	15.2	130	583	.798	32.6
4-1	(100)	SiO_x	14.7	129	579	.786	32.3
1-5	(100)	SiN_x	14.6	130	570	.793	32.7
2-6	(100)	SiN_x	14.7	130	571	.791	32.7
9-1	(111)	SiO_x	15.0	130	581	.795	32.5
10-2	(111)	SiO_x	15.7	134	588	.796	33.5
8-5	(111)	SiN_x	14.4	128	570	.786	32.0
9-2	(111)	SiN_x	14.8	130	573	.792	32.9

*EFFICIENCY MEASURED AT JCGS WITH ELH SIMILATOR. THE SIMULATOR HAS BEEN CALIBRATED BY EXCHANGING A REFERENCE CELL WITH SERI.

Effect of Reactive Ion Etching Cell Edges



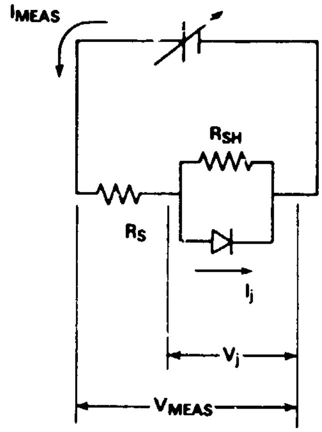
Approach to Dark I-V Analysis

<u>I-V RELATIONSHIP</u> (V_j >> kT)

$I_{MEAS} = I_j + V_j/nkT$

$V_j = V_{MEAS} - R_S\ I_{MEAS}$

$I_j = I_{o1}\ \exp(BV_j) + I_{o2}\ \exp(V_j/nkT)$



<u>FITTING PROCEDURE</u>

1. SELECT R_S AND R_{SH}
2. GENERATE (I_j, V_j)
3. CONSIDER (I_j, V_j) FOR REGION 1

   $I_j \approx I_{o1}\ \exp(BV_j)$

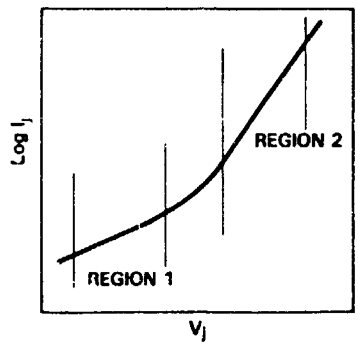
   $Log_e(I_j) = Log_e(I_{o1}) + BV_j$

   LEAST SQUARES FIT $\Rightarrow I_{o1}$, B
4. CONSIDER (I_j, V_j) FOR REGION 2

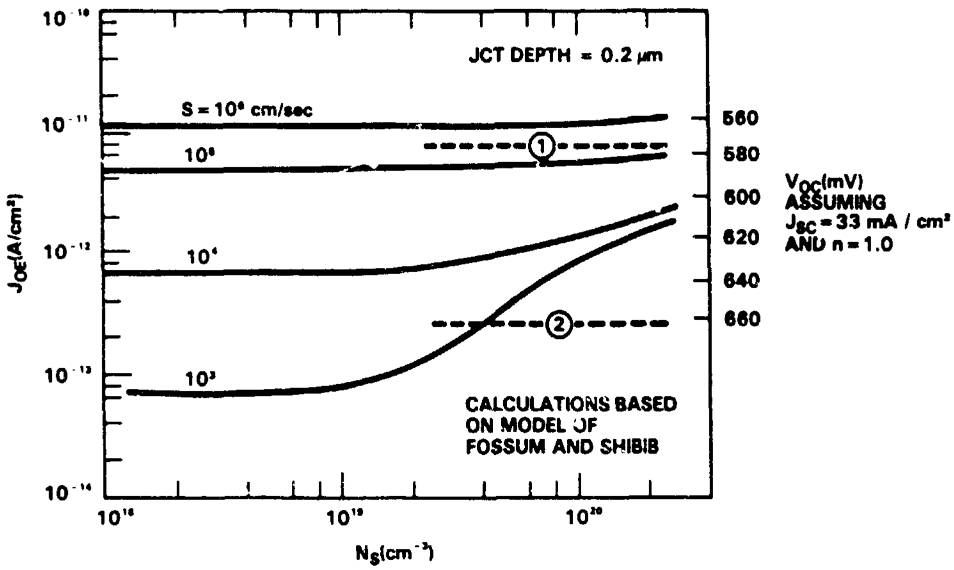
   $I_{j2} = I_j - I_{o1}\ \exp(BV_j)$

   $= I_{o2}\ \exp(V_j/nkT)$

   LEAST SQUARES FIT $\Rightarrow I_{o2}$, B
5. ITERATE BETWEEN REGIONS 1 AND 2 UNTIL ACHIEVE CONVERGENCE.
6. CARRY OUT STEPS 1 THROUGH 5 FOR ARRAY OF R_S AND R_{SH} VALUES. SELECT VALUES OF PARAMETERS WHICH PROVIDE BEST FIT TO DATA.



Emitter J_O vs Surface Donor Concentration for Shallow-Junction n-p Cell

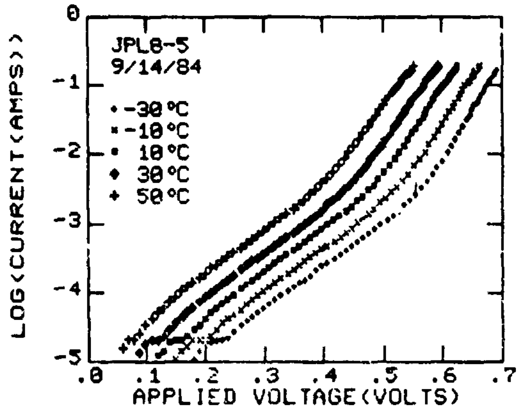


1 J_{OB} FOR 2 Ohm-cm N/P CELL WITH THICKNESS OF 15 MILS, L(BASE) = 130 μm, D = 21 cm²sec⁻¹ (APPROXIMATE CELLS PROVIDED BY JPL).
2 J_{OB} FOR 0.2 Ohm-cm N/P CELL WITH THICKNESS OF 15 MILS, L(BASE) = 150 μm, D = 21 cm²sec⁻¹.

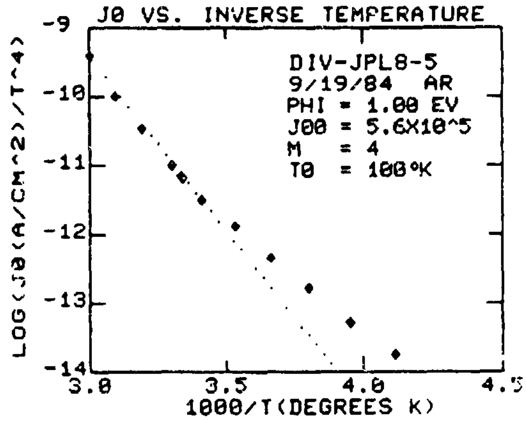
I-V Parameters for Dark Characteristics

CELL	JCT DEPTH (m)	BASE RESISTIVITY (Ohm-cm)	LARGE VOLTAGE MECHANISM: ORDERS OF MAGNITUDE FOR FIT	AVERAGE ERROR (%)	J_0 (A/cm²)	n	ACTIVATION ENERGY (eV)	POSSIBLE CURRENT MECHANISM
JPL 6 (SiN_x)	0.4	2	2.5	.30	2.1 E-11	1.07	0.96	DEPL LAYER RECOMB VIA SHALLOW TRAP
JPL 8-5 (SiN_x)	0.2	2	2.8	.20	1.7 E-11	1.02	1.00	EMITTER RECOMB WITH S = 10^5 to 10^6 cm/sec
JPL 9-1 (SiO_x)	0.2	2	2.8	.19	3.1 E-11	1.06	0.94	DEPL LAYER RECOMB VIA SHALLOW TRAP
JCGS MINP 84-2	0.2	0.2	2.0	.4	1.3 E-12	1.02	1.10	EMITTER RECOMB WITH S = 10^3 to 10^4 cm/sec

Analysis of Temperature-Dependent I-V Characteristics of JPL Cell



I-V DATA



ACTIVATION ENERGY ANALYSIS

Theory for I-V Characteristics

1. **EMITTER RECOMBINATION CURRENT**

$J = J_{OE}\left[\exp\left(\frac{V}{nkT}\right) - 1\right]$

$n = 1$

FOR RM TEMP ANALYSIS:

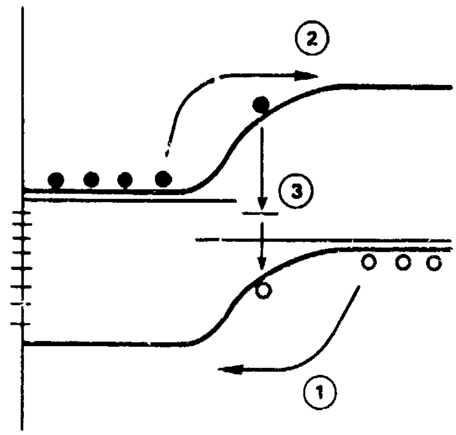
$J_{OE} = \frac{e n_i^2}{N_D^{(eff)}} \cdot GF$

GF IS A FCT OF W_H, S_P, D_{PO} & τ_P

FOR INTERPRETATION OF TEMPERATURE DEPENDENT DATA:

$J_{OE} = J_{OO}(T) \exp\left(\frac{-\phi}{kT}\right)$

$\phi = 1.20 - (\Delta E)_{\text{EMITTER BGN}}$



2. **BASE REGION RECOMBINATION CURRENT**

$J = J_{OB}\left[\exp\left(\frac{V}{nkT}\right) - 1\right]$

$n = 1$

$J_{OB} = \frac{e n_i^2}{N_A} \frac{L_n}{\tau_n} \cdot G_F$

$= J_{OO}(T) \exp\left(\frac{-\phi}{kT}\right)$

$\phi = 1.20 - (\Delta E)_{\text{BASE BGN}}$

3. **DEPLETION LAYER RECOMBINATION CURRENT**

$J = J_{OR} \exp\left(\frac{V}{nkT}\right)$ $V >> kT$

$J_{OR} = J_{OO} \exp\left(\frac{-\phi}{kT}\right)$

$\phi = (E_t - E_v)$ OR $(E_c - E_t)$ $n = 1$ TO 2

FOR $n \simeq 2$, $\phi \simeq Eg/2$ FOR $n \simeq 1$, $\phi \simeq 0.8$ eV

4. **TUNNELING/RECOMBINATION**

$J = J_{OT} \exp(BV)$ $V >> kT$

B TEMPERATURE INDEPENDENT

$J_{OT} = J_{OO} \exp\left(\frac{-\phi}{kT}\right)$

ϕ TYPICALLY 0 TO 0.5 eV

5. **FIELD EMISSION**

$J = J_{OF} \exp(CV)$

$C = \frac{1}{nkT} + B$

$J_{OF} = J_{OO} \exp(-\phi/kT)$

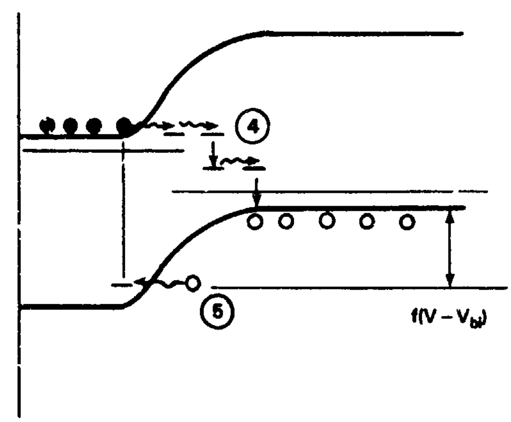
$\phi = fV_{bi}$ $f = n^{-1}$

6. **EDGE LEAKAGE CURRENTS**

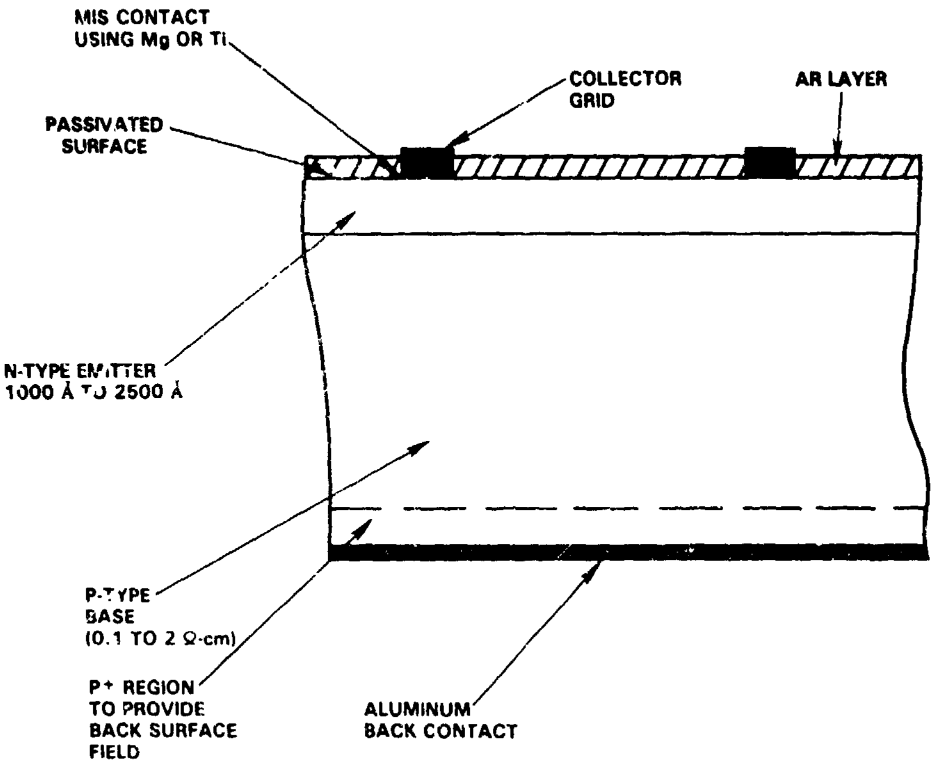
CURRENT MECHANISMS (3), (4) OR (5)

USUAL SHUNTING MECHANISM

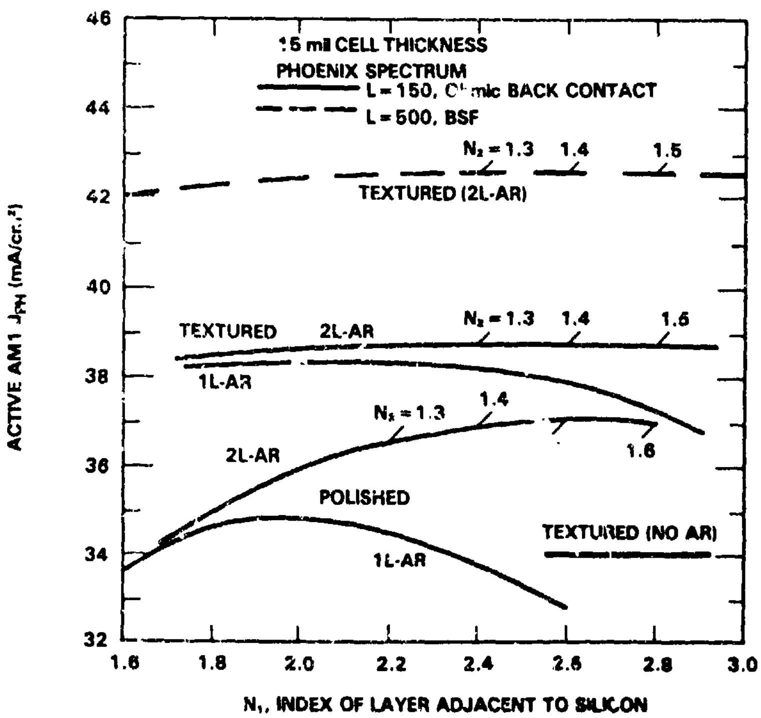
$J_{SH} = V/R_{SH}$



MINP Cell Concept



Calculated J_{ph} for Single and Double AR Layers



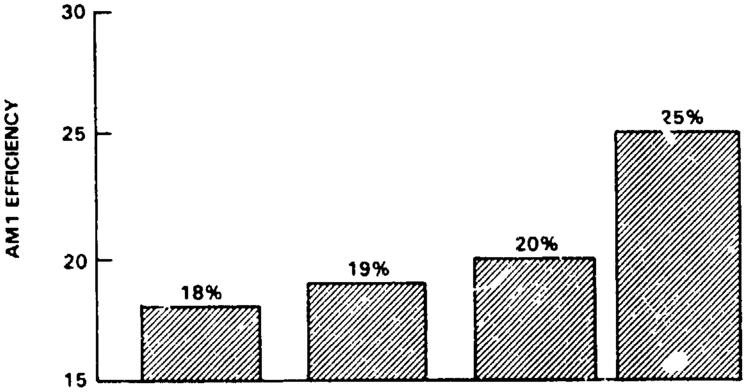
Projected Performance

TO ACHIEVE 20%

- MUST REDUCE J_{OE} BY DECREASING N_S AND S_p
- NEED SLIGHT IMPROVEMENT IN L

TO ACHIEVE 25%

- NEED F&P DIFFUSION LENGTH
- MUST REDUCE S_p TO 10^2
- WITH THESE VALUES OF L AND S_p, J_o WILL BE DECREASED TO $\cong 3 \times 10^{-14}$ A/cm²
- MUST USE DOUBLE AR WITH TEXTURED SURFACE OR WITH COMPLETE OPTICAL CONFINEMENT



J_{SC}(mA/cm²)	36.0	36.0	36.7	40.9
V_{OC}(mV)	630	650	670	720
FF	.794	.812	.820	.850
J_o(A/cm²)	1×10^{-12}	4.5×10^{-13}	2×10^{-13}	3×10^{-14}
n-VALUE	1.0	1.0	1.0	1.0
N_S(cm⁻³)	6×10^{19}	4×10^{19}	2×10^{19}	2×10^{19}
SURF REC VEL	10^4	10^3	10^3	10^3
DIFF LENGTH	150	150	200	500 (F&P)
GRID SHADOW	4%	4%	3%	2%
CELL THICKNESS	15 mils	15 mils	15 mils	10 mils
BACK SURF	Ohmic	Ohmic	BSF	BSF

Key Results and Future Work

KEY RESULTS

ESTABLISHED PECVD SYSTEM.

DEVELOPED PROCEDURES FOR GROWTH OF SiN_x WITH APPROPRIATE OPTICAL PROPERTIES FOR SINGLE AR COATING.

DETERMINED APPROACH FOR ACHIEVING SURFACE STATE DENSITY $<5\times10^{10}$ $cm^{-2}eV^{-1}$ ON MODERATELY DOPED SILICON.

DEVELOPED APPROACH FOR REACTIVE ION ETCHING CELL EDGES TO INCREASE CELL FF VALUES.

HAVE INITIATED STUDIES OR ROSIER MEASUREMENTS ON SOLAR CELLS.

CHARACTERIZED CELLS WITH SiN_x AND SiO_x AR COATINGS WITH I-V ANALYSIS AND PHOTORESPONSE TO OBTAIN ESTIMATED VALUES FOR S.

FUTURE WORK

INVESTIGATE EFFECT OF SiN_x ON SURFACE RECOMBINATION FOR MODERATELY DOPED N-TYPE MATERIAL.

INVESTIGATE FEASIBILITY OF ROSIER METHOD FOR MEASURING S ON SILICON SOLAR CELL STRUCTURES.

INVESTIGATE MINP SILICON SOLAR CELLS.

-- DEVELOP DBLAR AND REDUCE SHADOWING TO ACHIEVE J_{SC} = 36 mA/cm²

-- REDUCE CURRENT LOSSES SUCH THAT $J_o = 5\times10^{-13}$ A/cm² AND n = 1.0 TO ACHIEVE V_{OC} = 650 mV, FF = .81 and EFF = 19%.