N85-32424

IMPORTANT LOSS MECHANISMS IN HIGH-EFFICIENCY SOLAR CELLS

C.T. SAH ASSOCIATES

C. Tang Sah

Study of Material Properties and High-Efficiency Solar-Cell Performance on Material Composition

TASKS

(1) Impurity and Defect Levels Limiting High Efficiency Cells

- New CVCT - one p/n diode.
- Ti, Zn, Au, others.

(2) Computer Model - Exact

- Matured - 1978. Including All Recombination Mechanisms and ΔE_G.
- Applied - TR.1-5(78-81)
  - TR.1 (83)

(3) Fundamental Limitations on High Efficiency Cells.

- Mechanisms
- < 20% Cells.
- > 20% Cells.
- Ultimate Cells.

PRECEDING PAGE BLANK NOT FILMED

Outline

(1) RECOMBINATION LOSS MECHANISMS

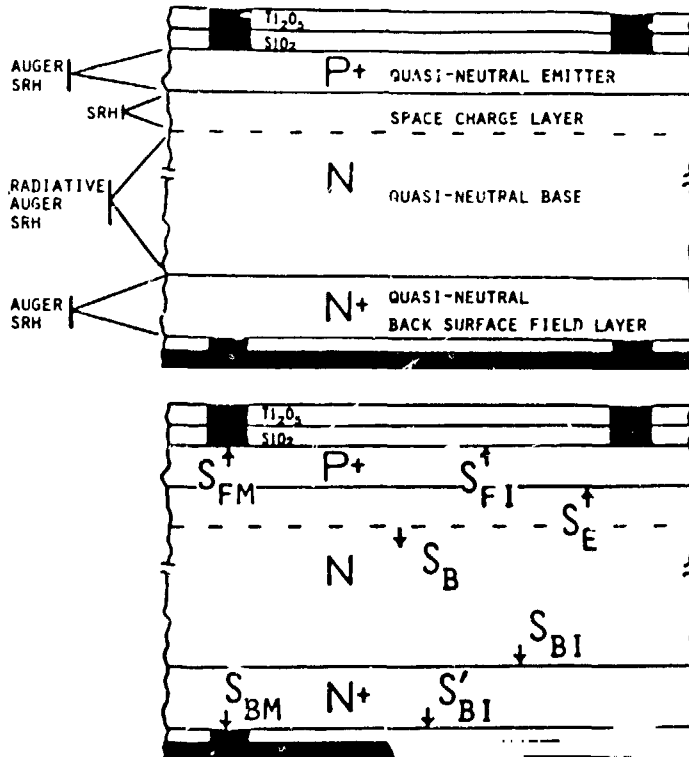
(2) HIGH EFFICIENCY CELLS (<20%)

(3) VERY HIGH EFFICIENCY CELLS (>20%)

(4) ULTRA HIGH EFFICIENCY CELLS (~25%)

Recombination Loss Mechanisms

- INTRINSIC - Interband
  - Auger 25%
  - Radiative 25%
- EXTRINSIC - Band-Bound
  - Impurities
  - Defects
  - Damages
- LOCATIONS
  - Bulk
  - Interfaces
  - Perimeters



Performance Parameters of Very-High-Efficiency Ideal Diode Silicon Solar Cells (AM1 or AM1.5, 24°C)

SOURCE	J_1 (A)	J_{SC} (mA)	V_{OC} (mV)	FF	EFF (%)
Theory	2.0×10^{-16}	36.0	840	0.8664	26.0
Theory	2.0×10^{-15}	36.0	780	0.8588	24.0
Theory	2.0×10^{-14}	36.0	720	0.8501	22.0
Theory	2.0×10^{-13}	36.0	660	0.8402	20.0

SOLAR CELL EQUATIONS

$$J = J_L - J_1\left(e^{\frac{qV}{kT}} - 1\right)$$ RAD H+L, ~~AUG L~~, ~~SRH L~~

$$- J_{\frac{2}{3}}\left(e^{\frac{3qV}{2kT}} - 1\right)$$ AUG H

~~$- J_m\left(e^{\frac{qV}{mkT}} - 1\right)$~~ ~~SRH SCL~~, ~~SRH H~~, ~~Interface + Surfaces~~

—— CAN BE ELIMINATED

HIGH-EFFICIENCY SILICON SOLAR CELL RESEARCH

(1) RECOMBINATION LOSS MECHANISMS

(2) HIGH EFFICIENCY CELLS (<20%)

** BASE RECOMBINATION DOMINATED PERFORMANCE

* CELL PERFORMANCE DATA AND BASE RECOMBINATION LOSS THEORY
(Analyzed by author or/and Sah)

SOURCE (author)		CELL TYPE	RHO ohm-cm	THICK (um)	Lb (um)	TAU (us)	JSC (mA)	VOC (mV)	FF	EFF% AM1	Seff (cm/s)
Green	Cal		0.2		170		36.0	660	0.840	19.7	850
Green	Exp	M/I/N/P	0.2	280		20	36.0	653	0.811	19.1	
Spitzer	Cal		0.3			13	36.2	627	0.834	18.8	1100
Spitzer	Exp	N+/P/P+	0.3	380	150		36.2	622	0.801	18.0	
Rohatgi	Cal		4.0			23	35.9	605	0.830	18.2	650
Rohatgi	Exp	N+/P/P+	4.0	150	26		35.9	605	0.786	17.1	
ASEC	Cal										
ASEC	Exp	N+/P					34.75	620	0.793	17.1	
ASEC	MaxExp	N+/p					34.85	623	0.799	17.1	

* BASE DIFFUSION LENGTH AND BSF SURFACE RECOMBINATION VELOCITY DATA

SOURCE	TYPE	RHO	TBASE	LB	TAU	SRV	JSC	VOC	EFF%
Neugroschel	N+/P/P+	10	227	450	(60)	105	-	-	-
Neugroschel	N+/P/P+	10	92	600	(103)	180	-	-	-
Neugroschel	N+/P/P+	1.5	220	600	(136)	380	38*	617	-
Neugroschel	P+/N/N+	7.0	320	503	(200)	80	39*	605	-
Computed-Sah	P+/N/N+	0.6	50	320	39	(128)eff	36.0	660	20.0
Green	M/I/N/P	0.2	280	(170)	20	(850)eff	36.0	653	19.1
Spitzer	N+/P/P+	0.3	380	150	(13)	(1100)eff	36.2	622	18.0
Rohatgi	N+/P/P+	4.0	150	263	(23)	(652)eff	35.9	605	17.1
ASEC	N+/P						34.8	620	17.1

Legend: Dimensions: RHO(ohm-cm); TBASE, LB(microns); TAU(microsec.); SRV(cm/s); JSC(mA/cm^2); VOC(mV); Values in ( ) are computed. ( )eff is the effective value to give the J1. All at AM1.5 except * at AM0.

(1) RECOMBIANTION LOSS MECHANISMS
(2) HIGH EFFICIENCY CELLS (<20%)

(3) VERY HIGH EFFICIENCY CELLS (>20%)

* BASE RECOMBINATION ELIMINATED

REDUCE BULK RECOMBINATION
- High Base Lifetime
- Low Defects (Float-Zone)
- Low Residual Impurities (FZ)

REDUCE BACK SURFACE RECOMBINATION LOSS
- Thin Epitaxial Base.
- Graded Base.
- Back Surface Field.
- Oxidized Back Surface.
- Interdigited Back Contact.
- Doped-diffused Back Contact.

HIGH-EFFICIENCY SILICON SOLAR CELL RESEARCH

(1) RECOMBINATION LOSS MECHANISMS
(2) HIGH EFFICIENC CELLS (<20%)

(3) VERY HIGH EFFICIENCY CELLS (>20%)

* BASE RECOMBINATION ELIMINATED

** EMITTER RECOMBINATION LIMITING
(Data yet to be obtained.)

BULK EMITTER
= Auger (Hi Dop Effect)
= SRH (with EGN Hi Dop Effect)
o Residual Impurity Centers
o Point-Pair Defects (Hi Dop)
= Gross Defect (Hi Dop Effect)
o Grain Boundary
o Dislocation
o Lattice Faults
o Diffusion Piper

EMITTER/OXIDE INTERFACE
= Interface States Monitoring
o DOS by MOS HFCV (Terman's)
o SRV by SCD DCIV (Fosier's)
= Interface States Reduction
o Dry/Low-Temp Oxide
o Hydrogen Passivation (Stable?)

EMITTER/CONTACT INTERFACE
= M/I/P Tunneling Oxide
(Green)
= Polysilicon Emitter
(Ning-Isaac-Neugroschel)
= Floating Emitter Transistor
(TI & JPL/Cheng-Sah)
o Epitaxial Base/Front-Back
Contacts.
o All Back Contacts.

Summary

(1) RECOMBINATION LOSS MECHANISMS

* Residual Impurities.
* Lattice Defects.
* Interface States.
* Interband Auger & Radiative.

(2) HIGH EFFICIENCY CELLS (<20%)

* J1 > 2.0E-13 A/cm^2
* Back Surface Recombination.
** Base Recombination LIMITING.

(3) VERY HIGH EFFICIENCY CELLS (>20%)

* J1 < 2.0E-13 A/cm^2
* Eliminate Base Recombination.
* Eliminate Back Surface & BSF
Layer Recombiantion Losses.
* Emitter Recombination LIMITING.

(4) ULTRA HIGH EFFICIENCY CELLS (~25%)

* J1 < 1.0E-16 A/cm^2
* Eliminate All Extrinsic
Recombination Losses.
o Residual Impurities.
o Lattice Defects.
* Eliminate Perimeter Damage.
* Design away Auger Emitter
Recombiantion.
** Interband Auger and Radiative
in Base LIMITING.