INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SPRING COLLEGE ON AMORPHOUS SOLIDS
AND THE LIQUID STATE

14 April - 18 June 1982

IMPURITIES, TRAPS AND RECOMBINATION CENTRES IN A SiHx

(Part V)

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V. AMORPHOUS SEMICONDUCTOR SOLAR CELLS

1. HOW THE SOLAR CELL WORKS.

2. SOLAR SPECTRUM AND THE IDEAL SOLAR CELL.

3. SOLAR CELL PARAMETERS - OPEN CIRCUIT VOLTAGE V_{OC}, SHORT CIRCUIT CURRENT I_{SC}, FILL FACTOR F, AND EFFICIENCY $EF = FI_{SC}V_{OC}$.

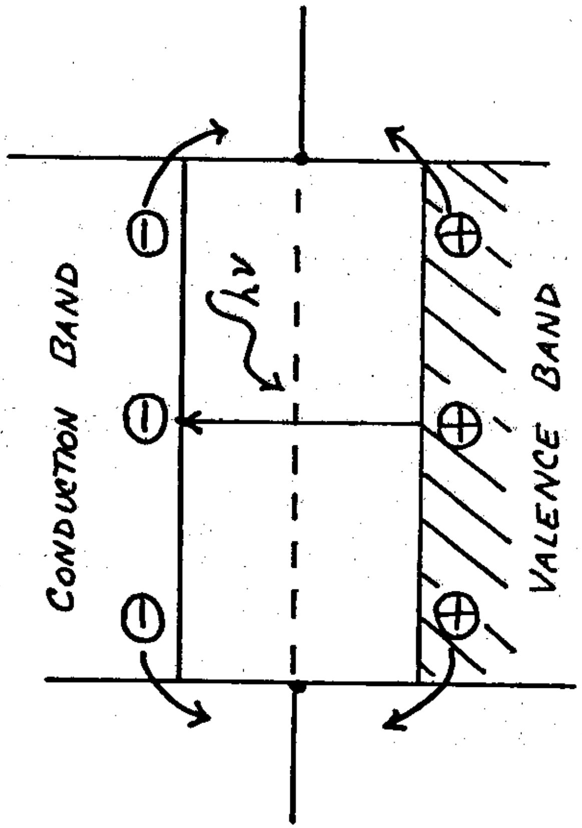
4. RECIPE FOR EFFICIENT THIN FILM SOLAR CELL.

5. COMPARISON BETWEEN c-Si, c-GaA_s and a-SiH_x solar cells.

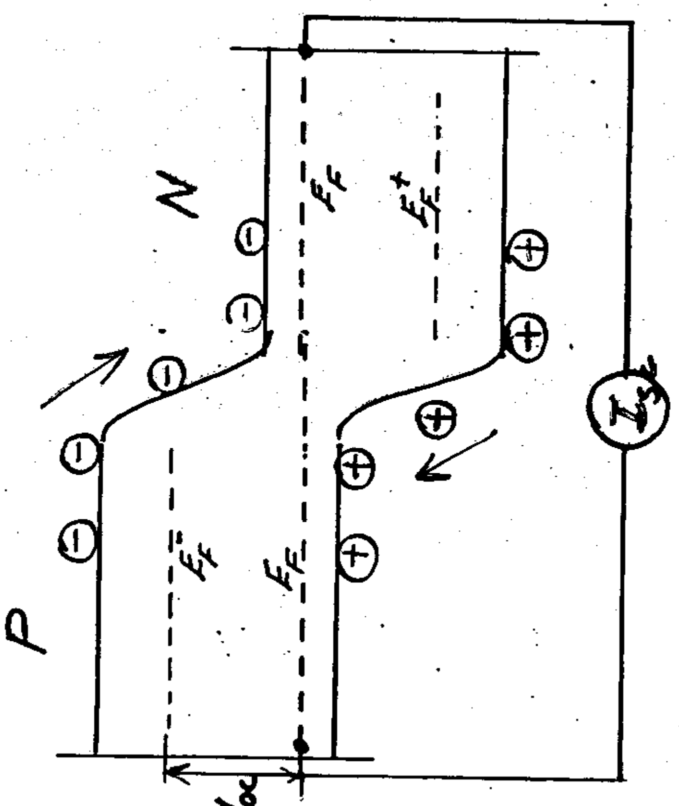
6. FUNDAMENTAL LIMITATIONS ON V_{OC}, I_{SC} AND F IN AMORPHOUS SEMICONDUCTORS.

7. HOW TO FURTHER IMPROVE THE EFFICIENCY.

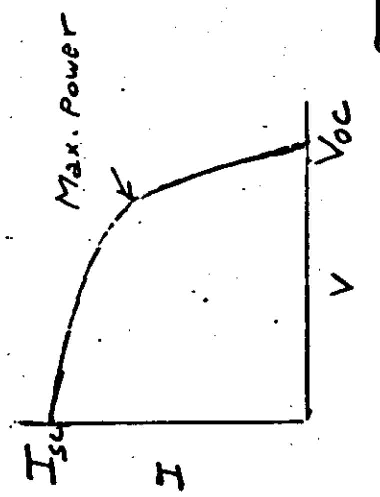
FIRST WE NEED A SEMICONDUCTOR TO ABSORB SOLAR PHOTONS



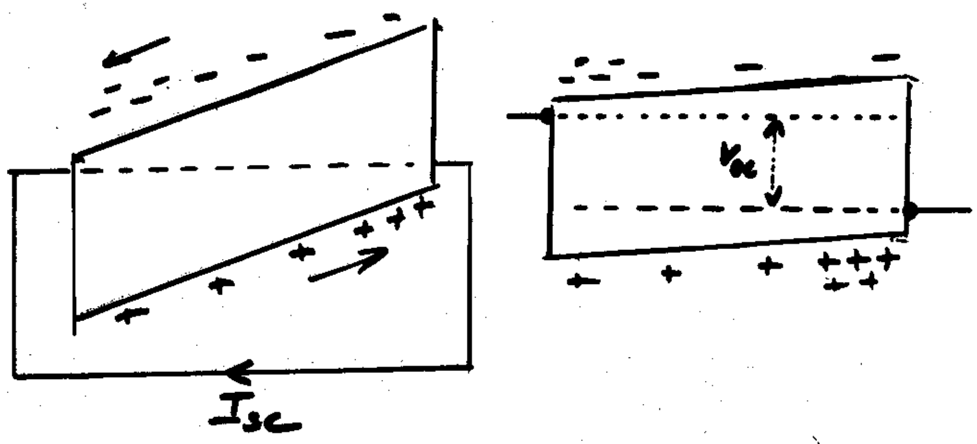
PHOTOVOLTAIC EFFECT REQUIRES BLOCKING CONTACTS

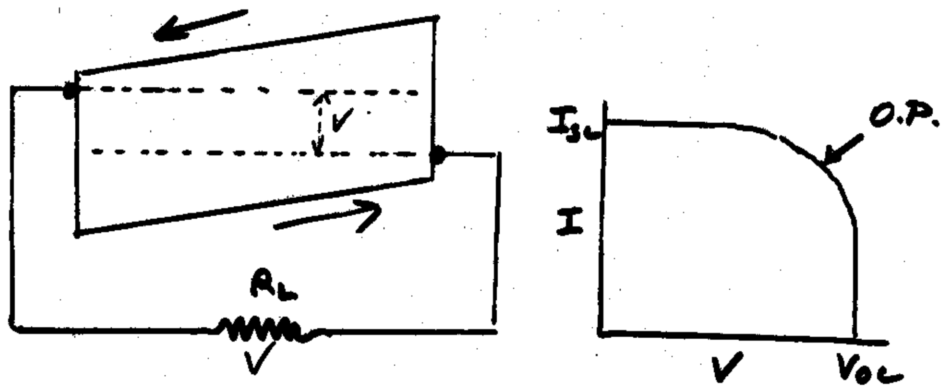


$$EFF = FF \cdot I_{sc} \cdot V_{oc}$$



SOLAR CELL DEVICE PARAMETERS

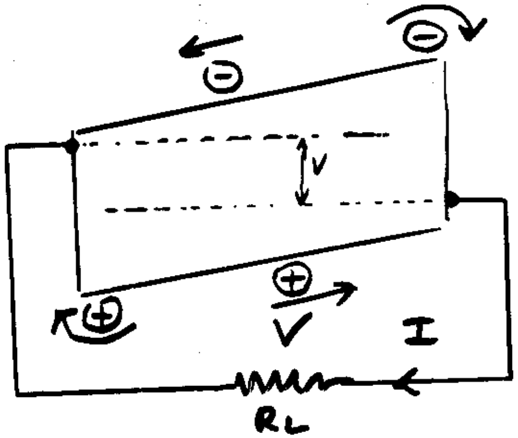


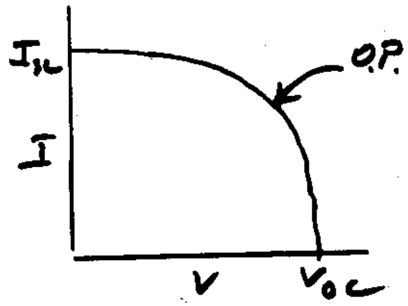


$$EFF = \frac{V_{oc} \times I_{sc} \times F}{W}$$

V_{oc} – OPEN CIRCUIT VOLTAGE
I_{sc} – SHORT CIRCUIT CURRENT
F – FILL FACTOR.

DIODE SOLAR CELL





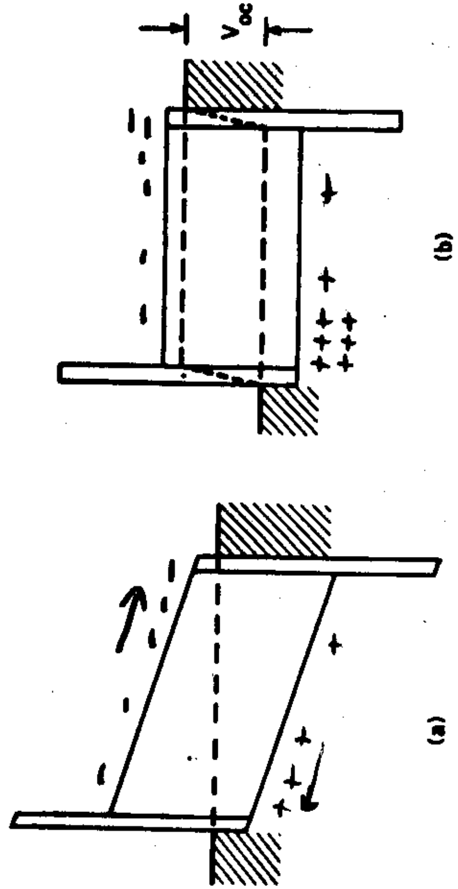
$$I = I_{sc} - I_0\left(e^{\frac{eV}{kT}} - 1\right)$$

$$(I=0) \qquad V_{oc} = kT \ln\left(\frac{I_{sc}}{I_0} + 1\right)$$

$$F = \frac{(IV)_{max}}{I_{sc} V_{oc}} \approx 0.9$$

TO DO BETTER WE NEED IDEAL BLOCKING CONTACTS.

IDEAL BLOCKING CONTACTS

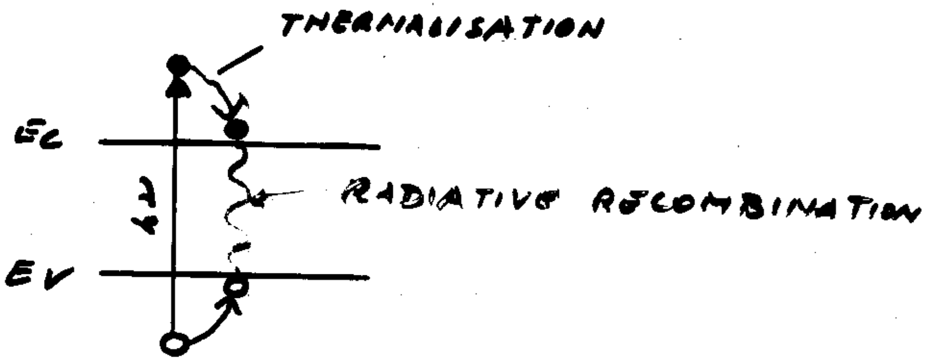


$$eV_{oc} = kT \ln\left(\frac{I_{sc}}{I_o} + 1\right)$$

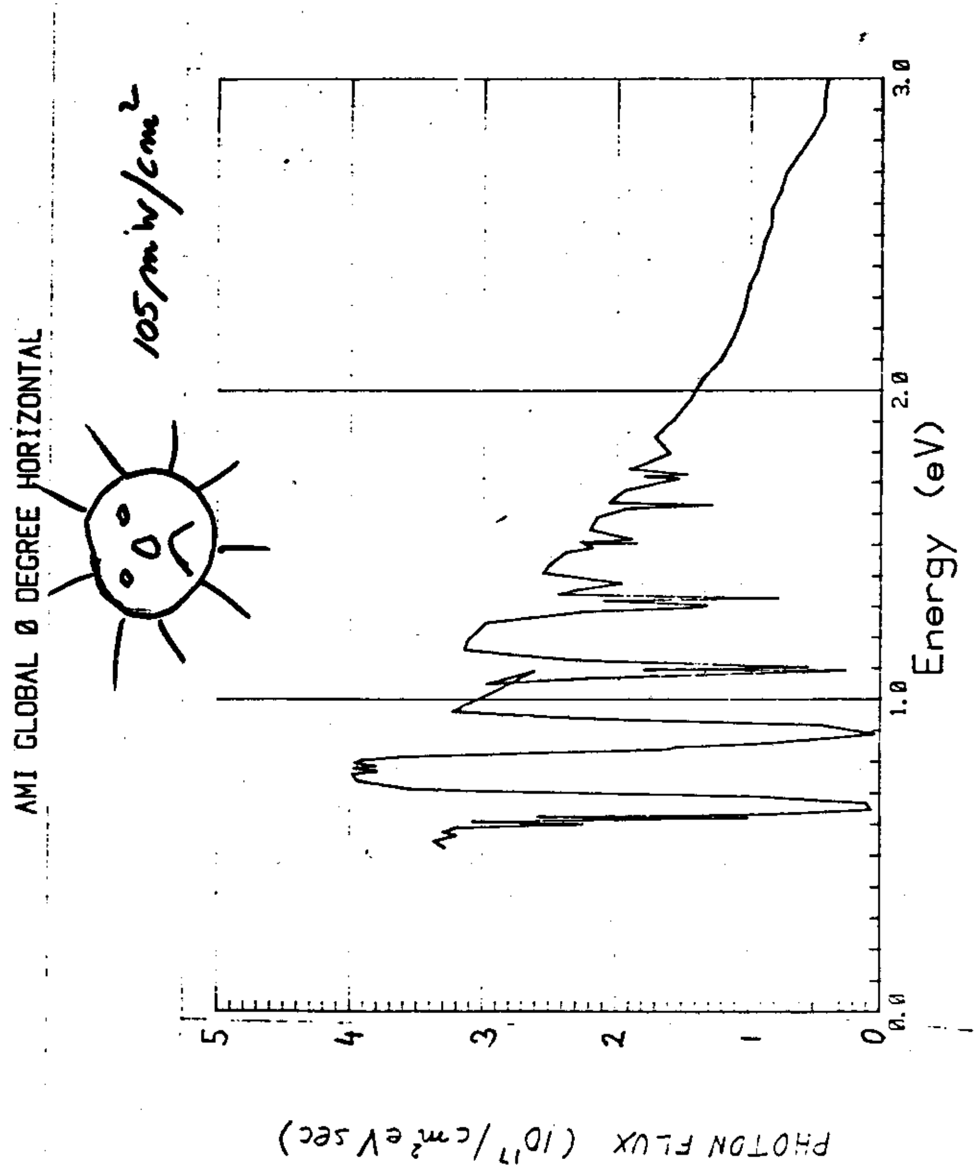
I_o NOW LIMITED BY RECOMBINATION IN BULK

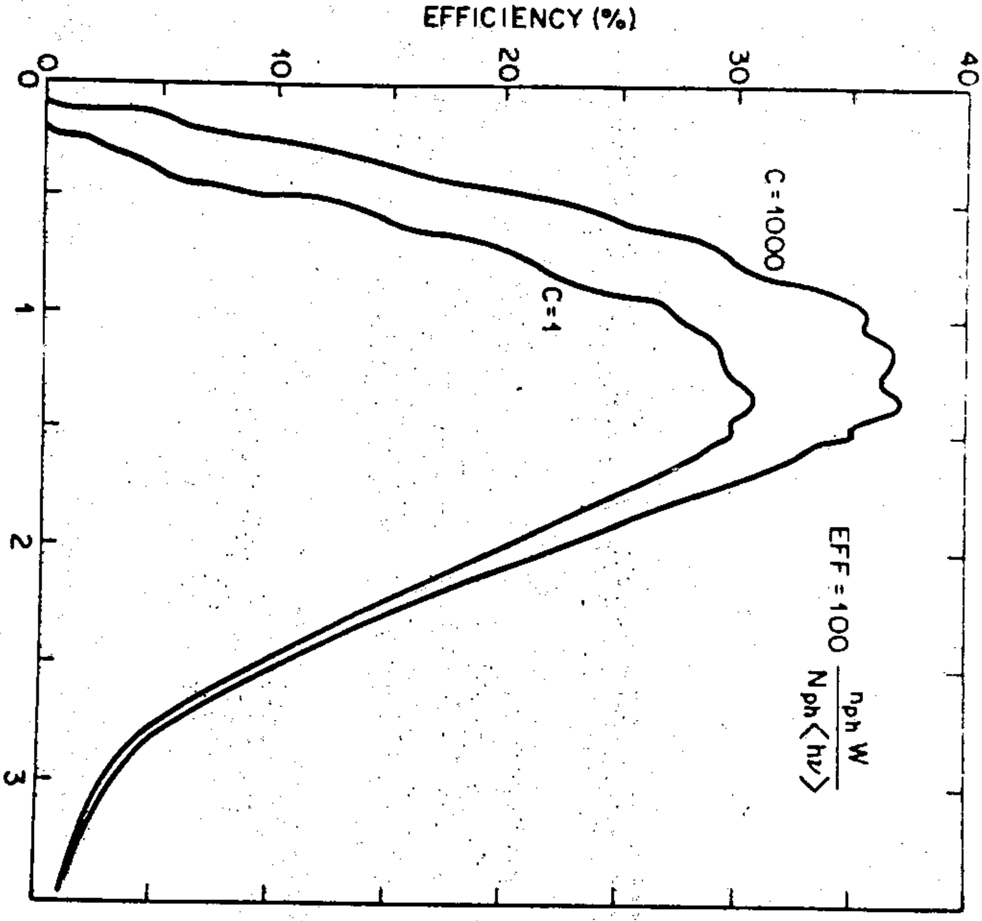
FUNDAMENTAL LIMITATIONS ON EFFICIENCY OF SOLAR CELL

1. RADIATIVE RECOMBINATION
2. E_G DOES NOT MATCH BROAD SOLAR SPECTRUM



A. ROSE J. APPL. PHYS. 31, 1640 (1960)
W. SHOCKLEY AND H.A. QUEISSER J. APPL. PHYS., 32 510 (1961)





C. H. Henry, J. Appl. Phys. <u>51</u> 4494 (1980).

EXPERIMENTAL VALUES OF SOLAR CELL PARAMETERS

	E_G (EV)	V_{OC} (V)	I_{SC} (MA/CM^2)	FF	EFF (%)
A-SiH_x (A)	1.7	0.91	13.5	0.62	7.6
C-Si (B)	1.12	0.60	36	0.78	17
C-GAAs (C)	1.42	0.98	30	0.76	22

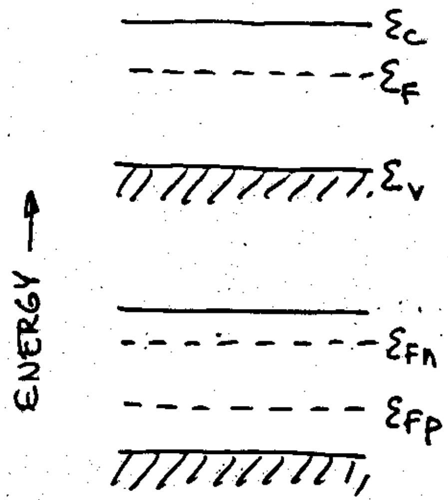
(A) A-SiH_x/A-SiC_y HETEROSTRUCTURE
Y. TAWADA, M. KONDO, H. OKOMOTO AND Y. HAMAKAWA

(B) M. S. BAE AND R. V. D'AIELLO

(C) GAAs/AL_xGA_{1-x} HETEROSTRUCTURE, J. M. WOODALL AND H. J. HOVEL

V_{oc} ESTABLISHED BY

QUASI-FERMI LEVELS

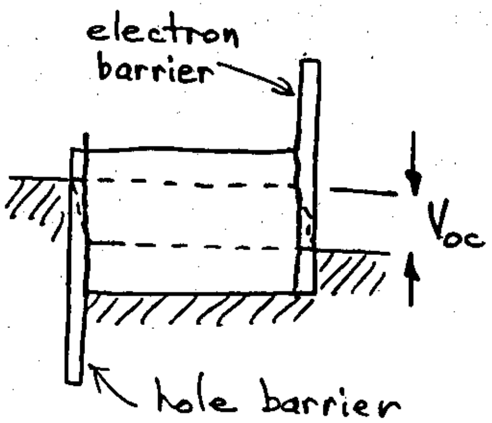


DARK

ILLUMINATED

$$n \propto \exp\left(\frac{\mathcal{E}_{Fn}}{kT}\right)$$

$$p \propto \exp\left(-\frac{\mathcal{E}_{Fp}}{kT}\right)$$



DEVICE

$$V_{oc} = \mathcal{E}_{Fn} - \mathcal{E}_{Fp}$$

V_{oc} LIMIT

BY DETAILED BALANCE :

$$V_{oc} = E_g - kT\, f(\alpha_c, \alpha_v) \ln \frac{F}{N_v^2 L_a S v_{th}}$$

$$f(\alpha_v, \alpha_c) = \frac{1}{1+\alpha_v}\left(1 + \frac{2+\alpha_v}{2+\alpha_c}\right)$$

$$\left.\begin{aligned} \alpha_v &= \frac{T}{T_v} \\ \alpha_c &= \frac{T}{T_c} \end{aligned}\right\} \longleftarrow \text{BAND TAIL PARAMETERS}$$

F – Solar Flux

L_a – Avg. Absorption Depth

S – Capture Crossection

N_v – Density of States at $\mathcal{E}_v$

v_{th} – Thermal Velocity.

ULTIMATE V_{oc}

$E_g = 1.72\,ev$ (Cody et al)

$S = 10^{-15}\,cm^2$ (Neutral Center)

$T_v = 500K$ } FROM DRIFT MOBILITY

$T_c = 312\,K$

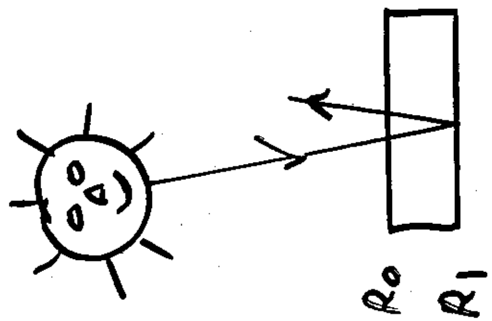
$$\Rightarrow \boxed{V_{oc} = 1{,}0 \pm 0{,}1\,V}$$

UPPER LIMIT SHORT CIRCUIT CURRENT, I_{sc}:

FRONT REFLECTION $R_0 = 0$

BACK REFLECTION $R_1 = 1$

EXTRACTION EFFICIENCY 100%



$$I_{sc} = q\int(1-e^{-2\alpha d})N_{h\nu}\,dh\nu$$

$$\underline{20\,mA/cm^2}$$

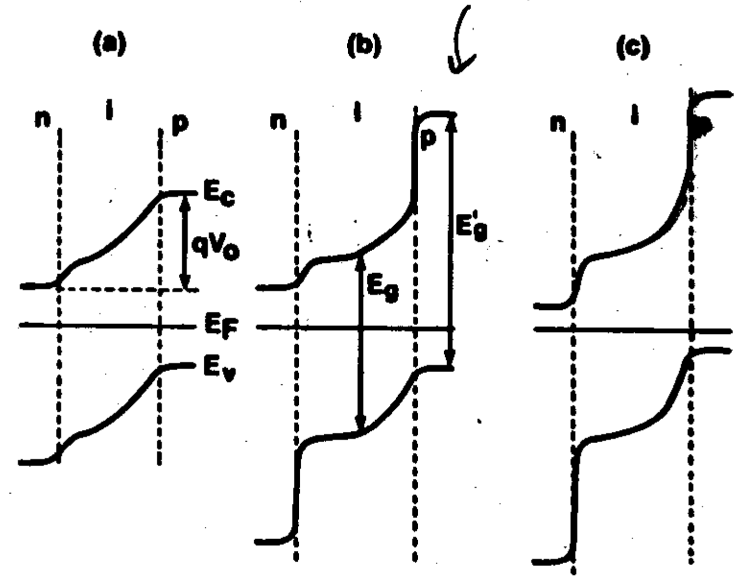
UPPER THEORETICAL LIMITS AND EXPERIMENTAL VALUES OF a-SiH_x SOLAR CELL PARAMETERS

	E_G (EV)	V_{OC} (V)	I_{SC} (mA/cm^2)	FF	EFF (%)
EXPERIMENTAL SiH_x	1.72	0.91	13.5 (15)	0.62	7.6 (8.5)
THEORETICAL SiH_x (BAND TAIL RECOMB.)	1.72	0.97	20	0.87	17
IDEAL SOLAR CELL (RAD. RECOMB.)	1.35	1.03	34	0.89	31

a-$Si:H_x:B,P$ dead layers

a-$Si:C\,H_x:B$ OPT. WINDOW BETTER BLOCKING.

MORE DOPING IMPROVES qV_0



B. ABELÈS ET. AL., THIN SOLID FILMS (1982) IN PRINT

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