EE566 Solid State Devices

Spring 2006
Dept of Electrical Engineering
University of Notre Dame
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Assignment 6
SOLUTIONS

PROBLEM 1

The net flux of e^- entering the p-region of the diode $\phi_n = (\Delta n * \Delta x)/\tau_0$

The net flux of e^- & h^+ entering the space charge region $\phi_{n+p} = (\Delta n * \Delta x)/2\tau_0$

The net flux of h^+ entering the n-region of the diode

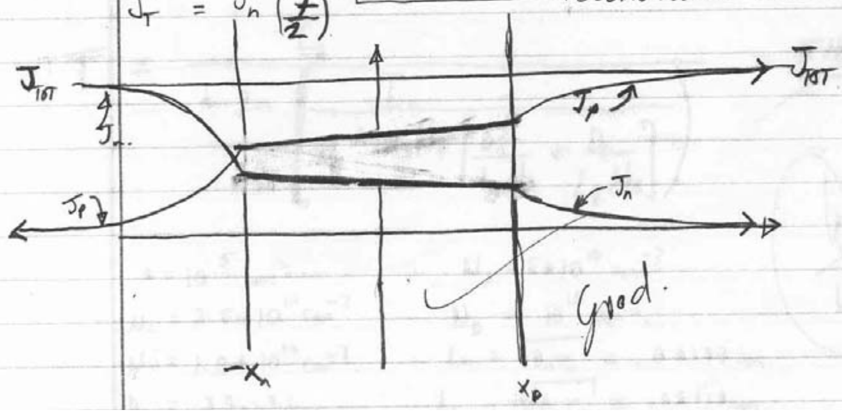
$$\phi_p = \frac{2(\Delta n * \Delta x)}{\tau_0}$$

diff currents

$$J_T = J_n + J_n/2 + 2J_n$$

$$J_T = J_n\left(\frac{7}{2}\right)$$

recombination current



Good.

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PROBLEM 2
(Solution by Amol Singh)

b) The ratio of space charge region recombination current & that of ideal current is given by.

$$\frac{J_r}{J_l} = \frac{W}{2n_i}\left[\frac{L_n}{N_a} + \frac{L_p}{N_d}\right]^{-1} \exp\left(\frac{-qV_a}{2kT}\right)$$

Considering the following values

$L_n = 198\ \mu m$

$L_p = 111\ \mu m$

$N_a = 10^{17}\ cm^{-3}$

$$V_{bi} = \frac{kT}{q} \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

$$W = \left[\frac{2\epsilon_s}{q}\left(\frac{1}{N_a} + \frac{1}{N_d}\right)(V - V_a)\right]^{1/2} \checkmark$$

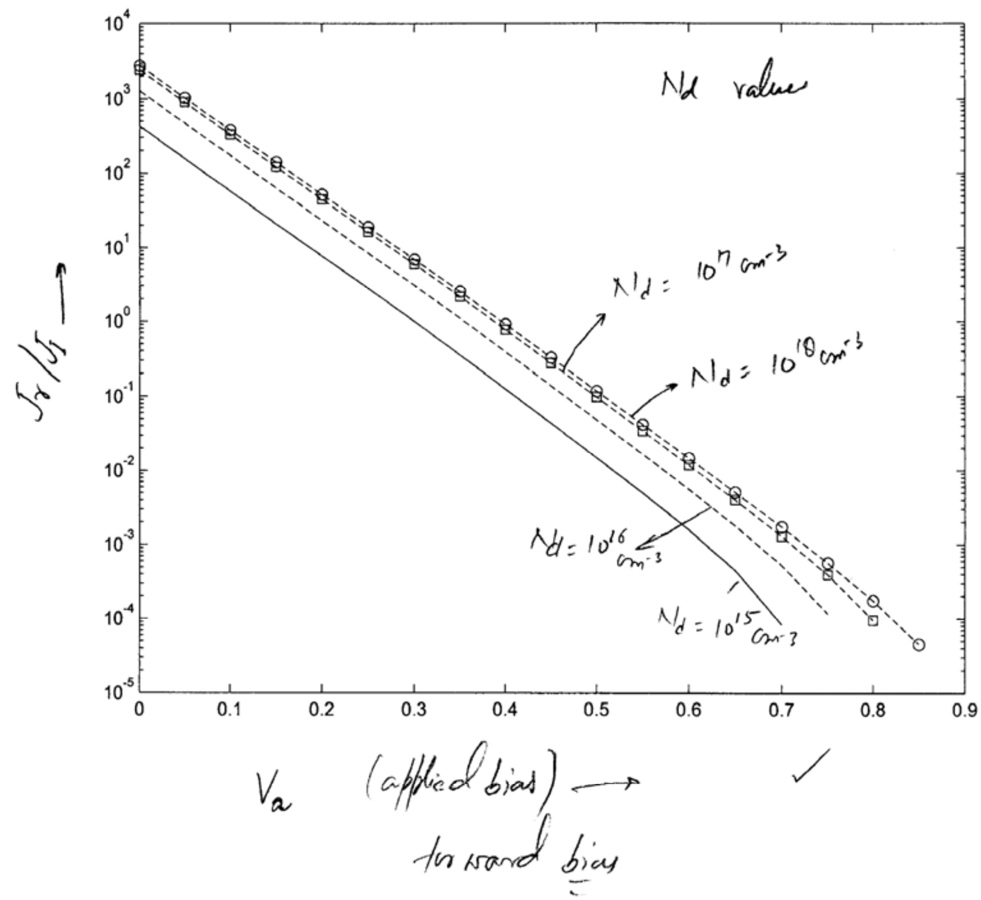
For generation current

$$\frac{J_g}{J_t} = \frac{x_i}{2n_i}\left[\frac{L_n}{N_a} + \frac{L_p}{N_d}\right]^{-1}$$

where $$x_i = \left(\frac{2\epsilon_s kT}{q^2 N_d}\right)^{1/2}\left[\left(\ln\frac{N_d}{n_i} - \frac{qV_a}{kT}\right)^{1/2} - \left(\ln\frac{N_a}{n_i}\right)^{1/2}\right]$$

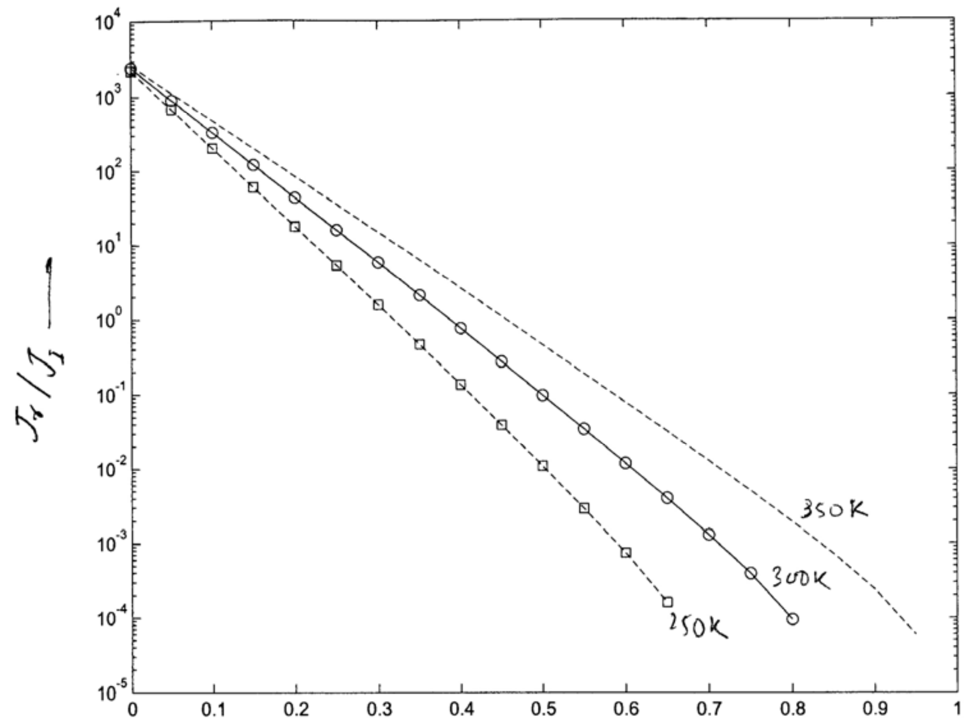
where V_a is -ive as it is reverse bias

Recombination ratio



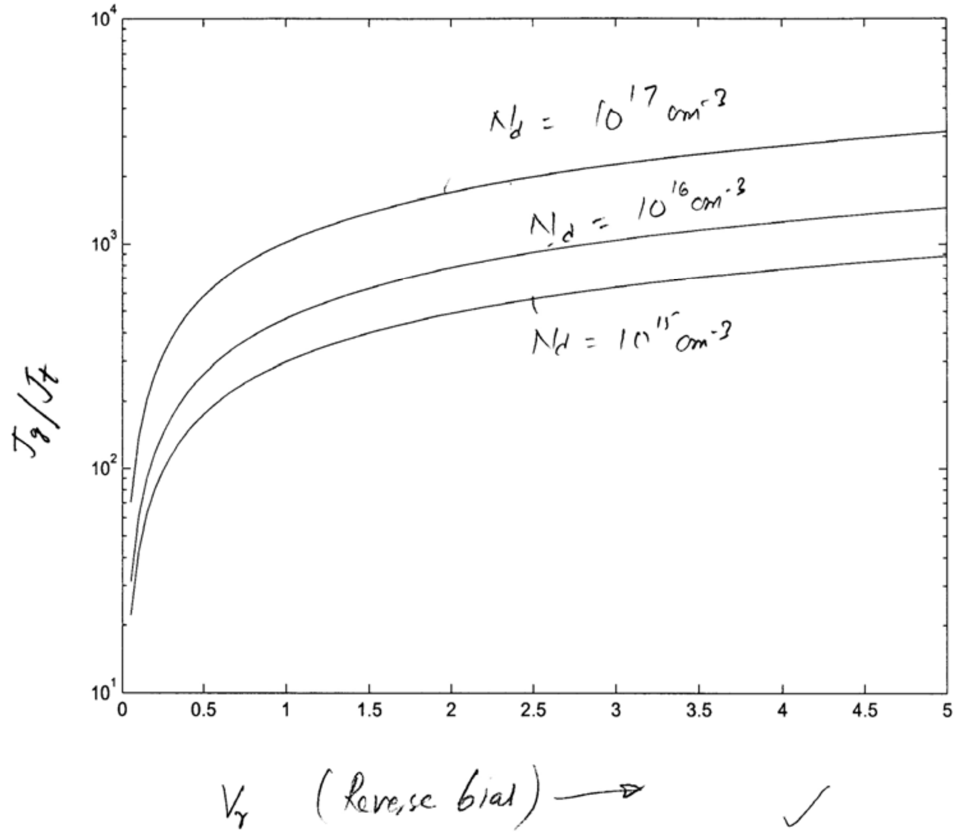
Recombination ratio

As a function of temp

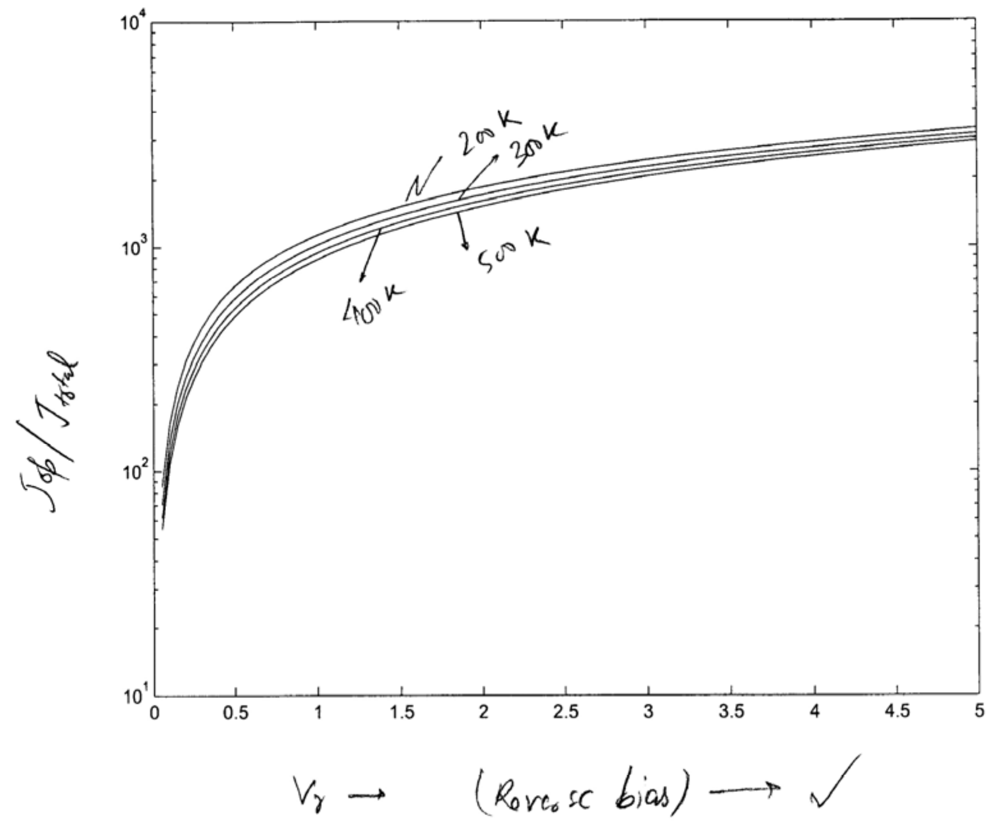


$V_a \longrightarrow$ (applied bias)

For Generation ratio



For generation case



PROBLEM 3

John Grant ...

3.

5.18 Using Charge Control Analysis we know

a. $Q_p = \frac{(W_B - x_p)^2}{2D_n} J_n \quad W_B = 3\mu m$

Since $N_D >> N_A$ we can assume that the current is carried predominately by e^-'s. We can expect W_B to be much greater than x_p $\therefore$

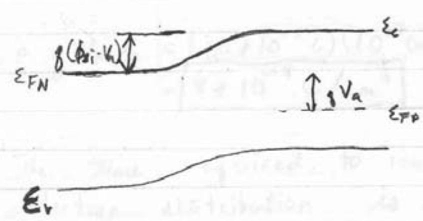
$$Q_p = \frac{(W_B)^2}{2D_n}\frac{I}{A} = 5.77 * 10^{-9}\ C/cm^2$$ ⇐ refer to back for more exact #.

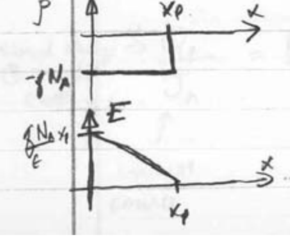
We will justify the assumption in part (b.) of this problem.

b. $$I_n = \left(q\frac{A D_n}{W}\frac{n_i^2}{N_A}\right)\left(e^{qV_a/KT} - 1\right)$$

$$V_a = \frac{KT}{q}\ln\left(\frac{I\,W N_A}{q A D_n n_i^2} + 1\right)$$

$V_a = .741\ V$

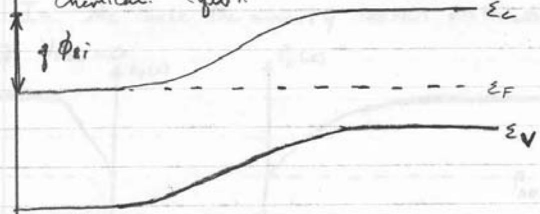




$$\frac{q N_A x_p^2}{2\epsilon} = \phi_{Bi} - V_a$$

$$x_p = \sqrt{\frac{2\epsilon(\phi_{Bi} - V_a)}{q N_A}}$$

At Chemical Equil.



By Incapection

$$\phi_{Bi} = \frac{kT}{q} \ln\left(\frac{N_A N_c}{n_i^2}\right) = .985V.$$

$$\phi_{Bi} - V_a = .19V.$$

$$x_p = \sqrt{\frac{2(11.9)(8.854*10^{-12}F/m)(.19V)}{(1.602*10^{-19}C)(10^{17}cm^{-3})((100cm)^3)/1m^3}}$$

$$= 50nm \approx .05um$$

$$Q_f = \frac{(W_B - x_p)^2}{2D_n}\frac{I}{A} = \boxed{5.6*10^{-8}\ C/cm^2} \approx 3.5\% \text{ diff. in part (a.)}$$

$$Q_{sc} = qN_A x_p = (1.6*10^{-19}C)(10^{17}cm^{-3})(5*10^{-6}cm).$$
$$= \boxed{8*10^{-8}\ C/cm^2}$$

c. The time required to reach the stead-state electron distribution is

Stored charge → @ steady state

$$\frac{Q_n}{J_n} = \frac{(W_B - x_p)^2}{2D_n} = \frac{(3\times10^{-4}cm - .05*10^{-4}cm)^2}{2\ (39cm^2/sec)} = \boxed{1.12ns}$$

↑ current source

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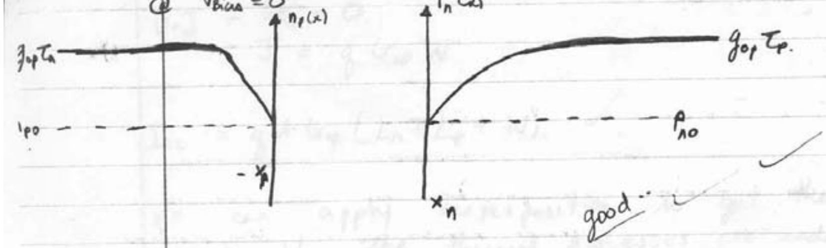
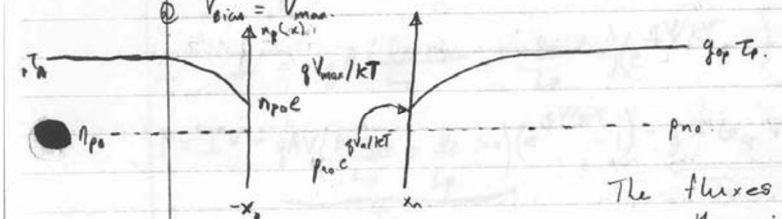
PROBLEM 4

4. In the bulk the minority carrier distribution will be:

@ $V_{bias} = 0$

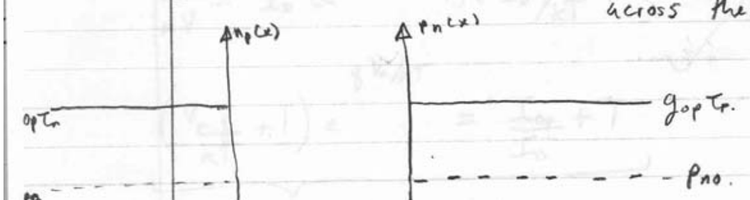


@ $V_{bias} = V_{max}$



The fluxes have different signs than in the case where minority carriers are injected across the depletion region.

@ $V_{bias} = V_{oc}$



In the $V_{bias} = 0$, obviously @ the edges of the depletion region the dominant current mechanism for minority carriers is diffusion $\therefore$ $J_{n,diff} = \dfrac{q D_n G_{op} \tau_n}{L_n} = q\, G_{op} L_n$.

$$J_{p,diff} = \frac{q D_p G_{op} \tau_p}{L_p} = q\, G_{op} L_p.$$

In the depletion region we know

$$\nabla \cdot J - G_{op} = 0.$$

$$J = q G_{op} W.$$

$$I_{sc} = q A G_{op} (L_n + L_p + W).$$

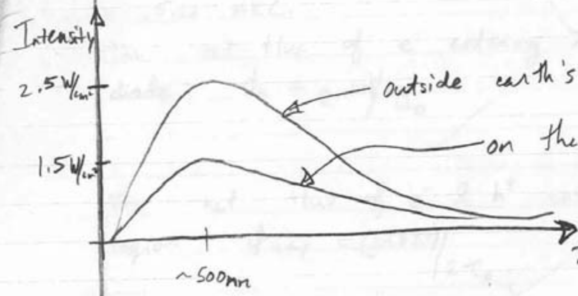
We can apply superposition to get the net current b/c the thermal processes are independent of the optical.

$$\therefore \quad I = qA\left(\frac{D_n n_{po}}{L_n} + \frac{D_p}{L_p} p_{no}\right)\left(e^{qV/kT} - 1\right) - qAG_{op}(L_n + L_p + W)$$

$$P = IV = \underbrace{qAV\left(\frac{D_n n_{po}}{L_n} + \frac{D_p}{L_p} p_{no}\right)}_{I_0}\left(e^{qV/kT} - 1\right) - \underbrace{qAG_{op}}_{I_{op}}V(L_n + L_p + W).$$

$$\frac{dP}{dV} = I_0\left(e^{qV/kT} - 1\right) + I_0 \frac{q}{kT} V\left(e^{qV/kT}\right) - I_{op} = 0.$$

$$\underbrace{\left(\frac{V_m q}{kT} + 1\right) e^{qV_m/kT} = \frac{I_{op}}{I_0} + 1}_{\text{Transcendental.}}$$



references?

Highest reported efficiencies 36.9%.
Multi-junction cells exhibit the highest efficiency because the spectrum has a bandwidth in which most of the power is contained. Solar cells consisting of only one semi-conducting may not be able to create EHP from the photon of longer wavelength. However, if the energy of the photon is much greater than the photon ehp quickly recombine @ the surface. One way to mitigate the problem of the spectrum not being monochromatic is to employ cells which contain multiple bandgaps.

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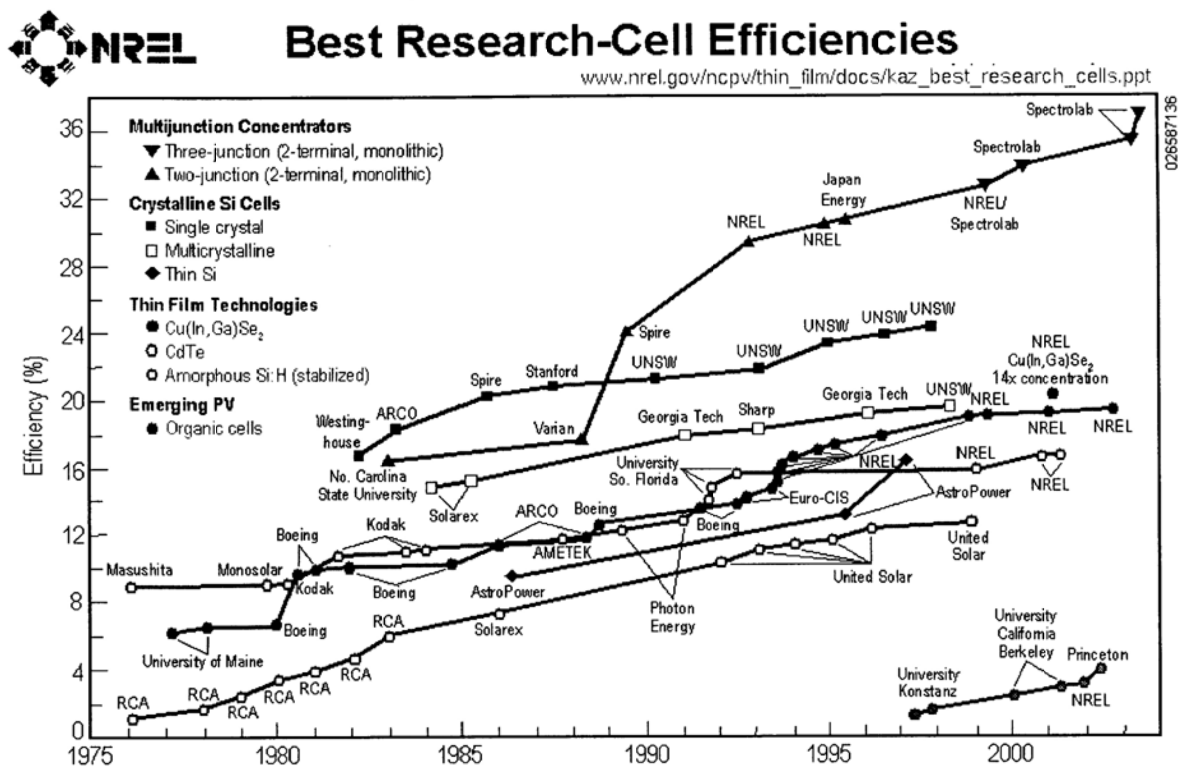
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Best Research-Cell Efficiencies
www.nrel.gov/ncpv/thin_film/docs/kaz_best_research_cells.ppt
Multijunction Concentrators
Three-junction (2-terminal, monolithic)
Two-junction (2-terminal, monolithic)
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Amorphous Si:H (stabilized)
Emerging PV
Organic cells
Efficiency (%)
Spectrolab
Spectrolab
Japan Energy
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Solarex
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Sharp
Georgia Tech
UNSW
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NREL Cu(In,Ga)Se2 14x concentration
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