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

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SPRING COLLEGE ON AMORPHOUS SOLIDS
AND THE LIQUID STATE

14 April - 18 June 1982

IMPURITIES, TRAPS AND RECOMBINATION CENTERS IN A SiHx

(Part II)

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II. BAND TAIL STATES

1. TIME RESOLVED TRANSPORT IN AMORPHOUS SEMICONDUCTORS - GENERAL PHYSICAL CONCEPTS

2. TIME OF FLIGHT EXPERIMENTS

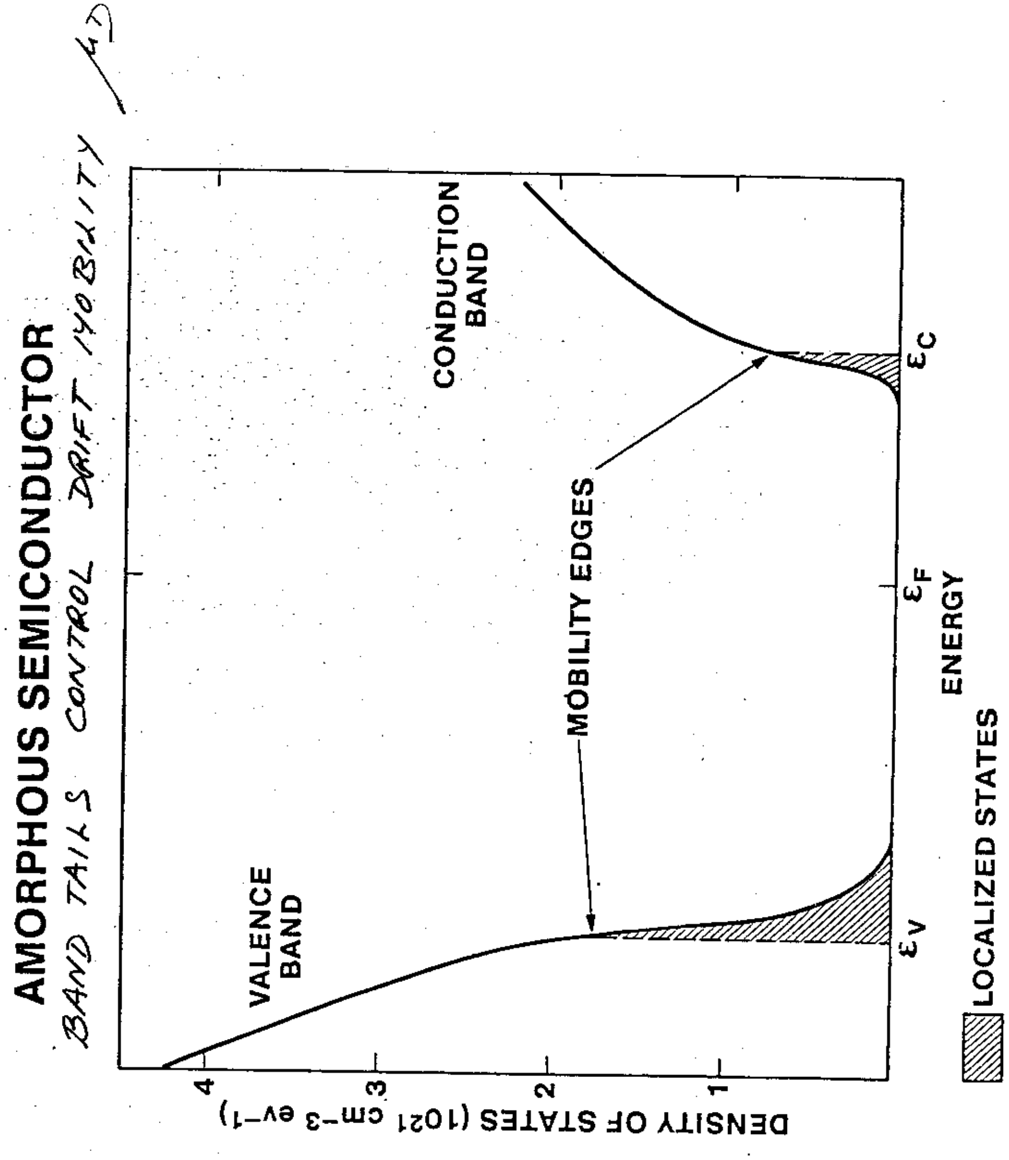
3. MULTIPLE TRAPPING MODEL OF DISPERSIVE TRANSPORT - CURRENT DECAY AT SHORT TIMES ($t < t_T$) - TRANSIT TIME t_T - CURRENT DECAY AT LONG TIMES ($t > t_T$)

4. INTERPRETATION OF EXPERIMENTAL RESULTS OF TIME OF FLIGHT FOR a-SiH_x - BAND TAIL PARAMETERS OF a-SiH_x

5. PHOTOCURRENT DECAY IN a-SiH_x:P

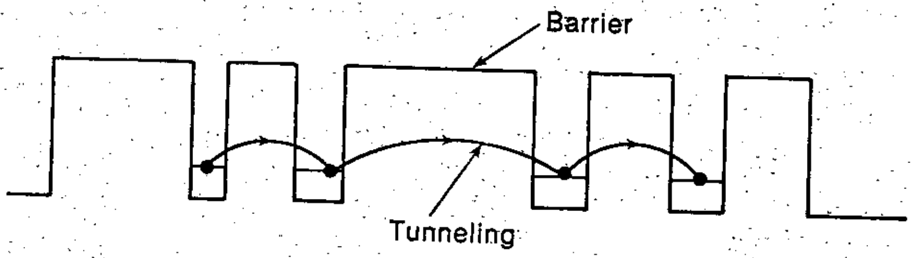
6. INDUCED ABSORPTION

7. MOVIE: "MULTIPLE TRAPPING-DISPERSIVE AND NONDISPERSIVE TRANSPORT."

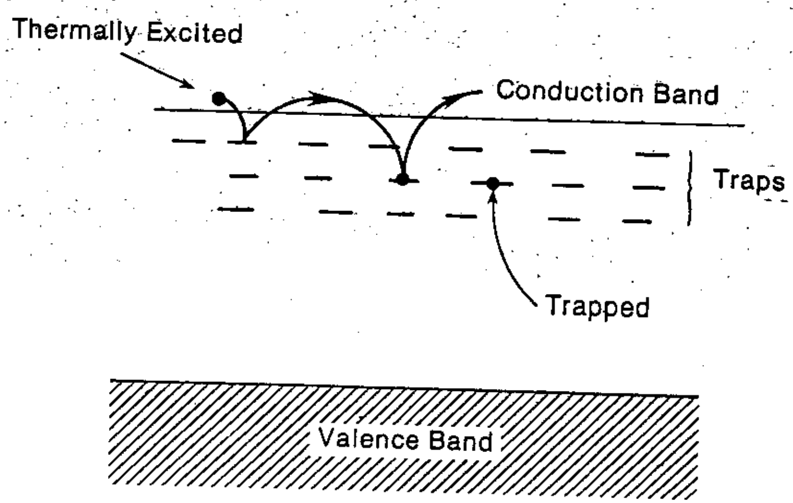


TWO DIFFERENT MECHANISMS FOR DISPERSIVE TRANSPORT

A. Hopping[1]



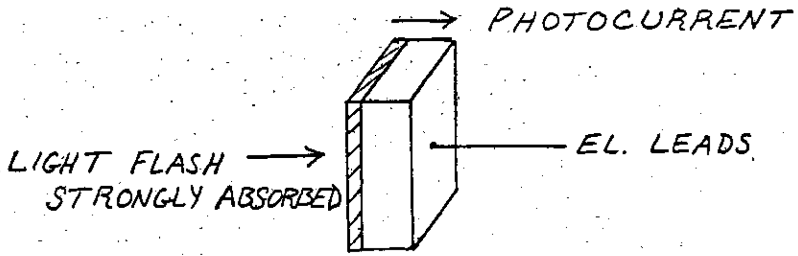
B. Multiple Trapping[2]



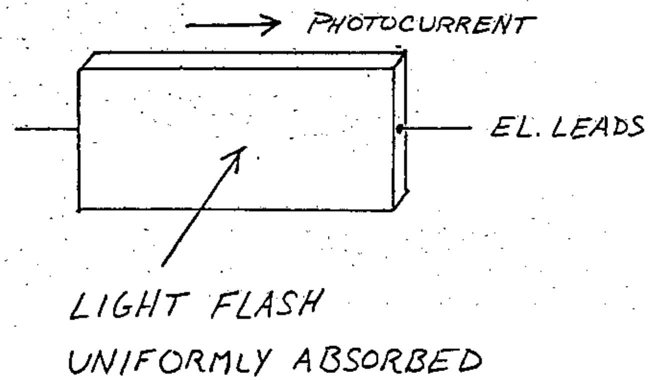
1. Pfister and Scher, Adv. Phys. 27, 747 (1978)

2. Tiedje and Rose, Solid State Comm. 37, 49 (1980)

A. TIME OF FLIGHT



B. PHOTOCONDUCTIVITY DECAY



TIME-OF-FLIGHT EXPERIMENT

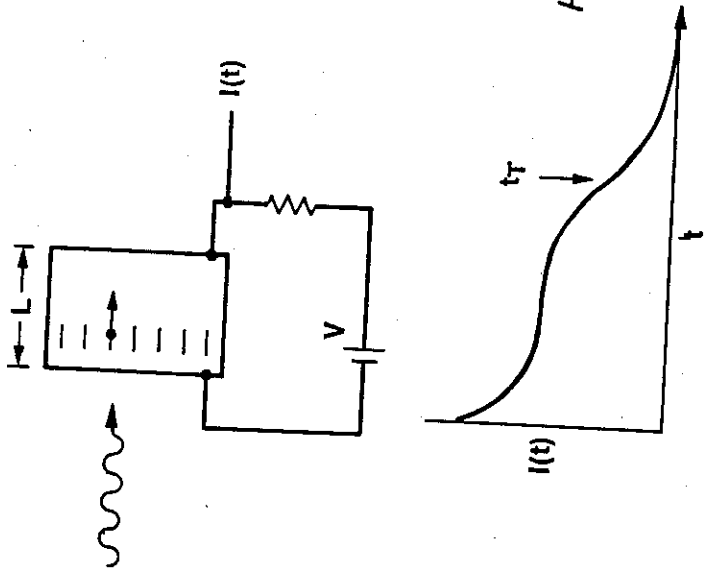
SPACE CHARGE

$\delta Q < VC$

DIELECTRIC RELAX

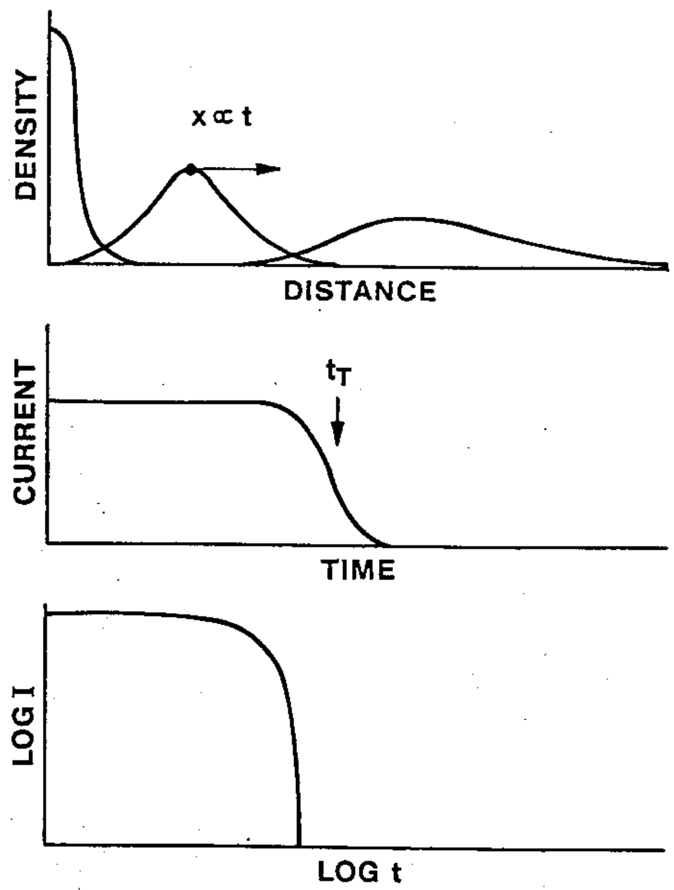
$\tau_T < 1/4\pi\sigma$

$$\mu_D = \frac{L^2}{t_T V}$$



5

DIFFUSIVE TRANSPORT



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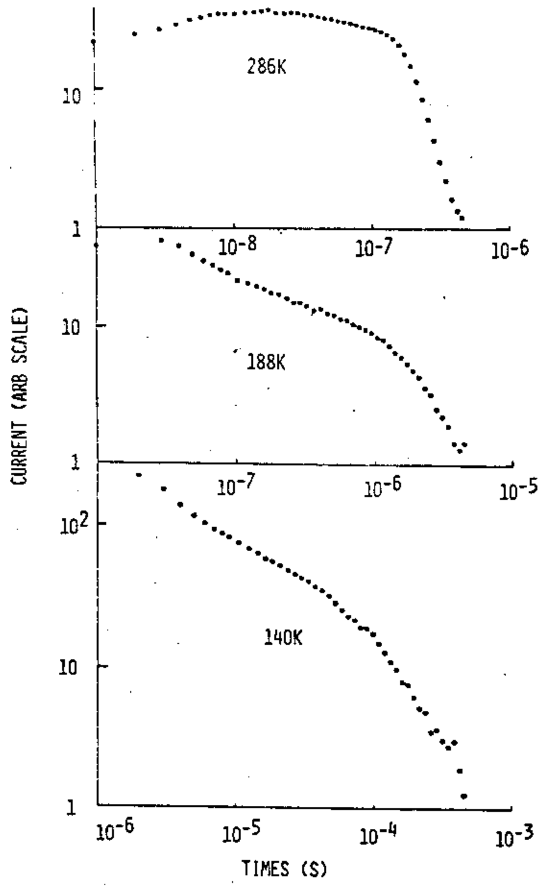
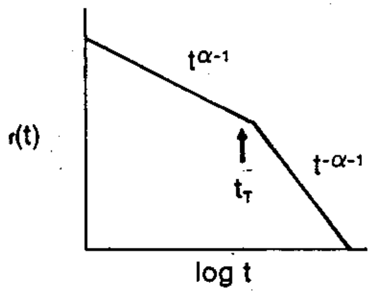
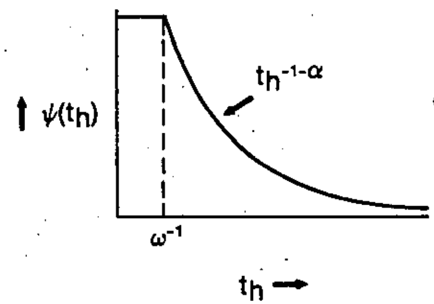


UNIVERSAL OBSERVATION OF POWER LAW IN PHOTOCURRENT DECAY



$t_T \propto \left(\frac{L}{E}\right)^{\frac{1}{\alpha}}$

Scher and Montroll (Phys. Rev. B12, 2455(1975)
broad distribution $\psi(t_h)$ of hopping times

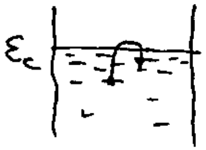


$\omega \sim 10^{12} sec^{-1}$

MULTIPLE TRAPPING MODEL OF DISPERSIVE TRANSPORT

Assumptions:

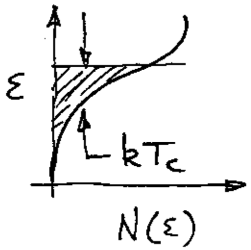
1. Sharp mobility edge.



2. Localized states communicate only through band states.

3. Thermal emission rate from localized states; $R = \nu \exp\left(-\frac{\varepsilon}{kT}\right)$

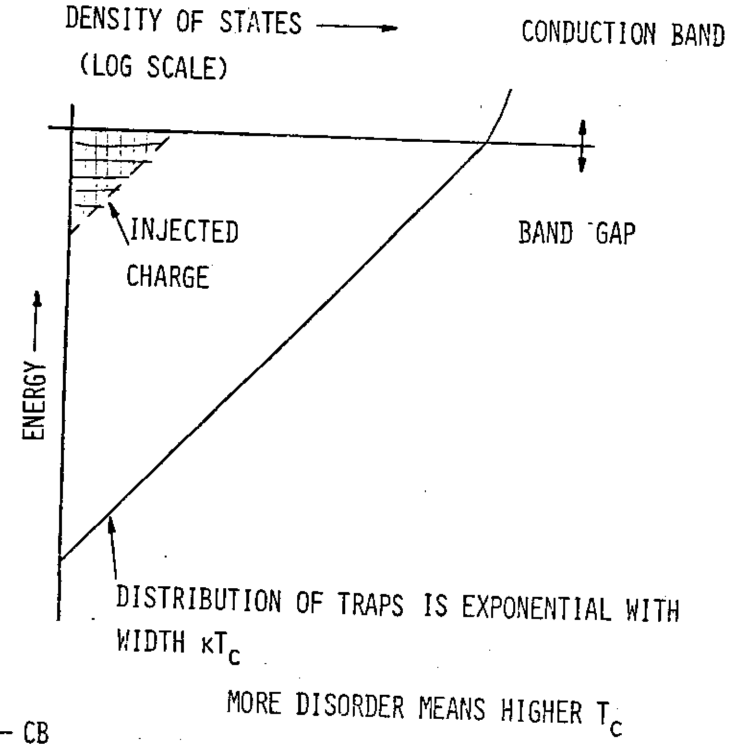
4. Exponential distribution of band tail states.

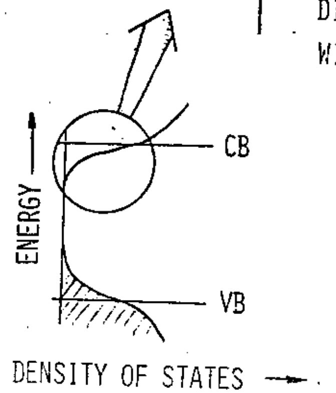


TIEDJE AND ROSE GIVE SIMPLE PHYSICAL PICTURE OF THEORY OF SCHER AND MONTROLL

INITIALLY MOST OF THE ELECTRONS ARE CAPTURED BY SHALLOW TRAPS

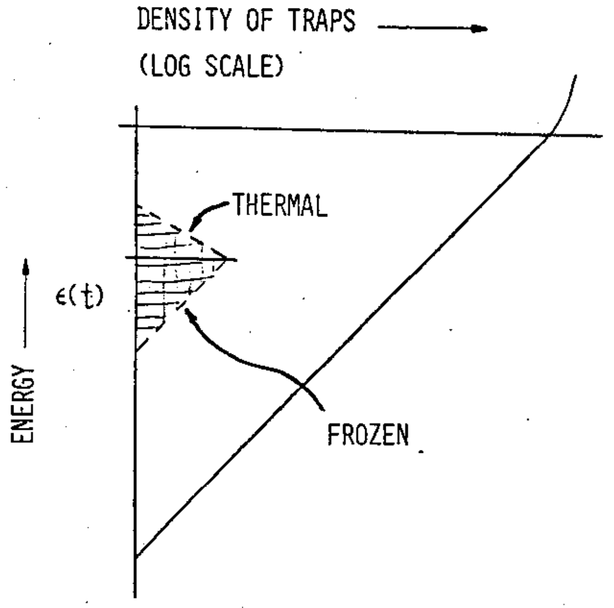
START: $t = 0^+$





ELECTRONS SINK DEEPER INTO THE TRAP DISTRIBUTION WITH TIME

LATER TIME:



ε(t) - EFFECTIVE TRAP LEVEL

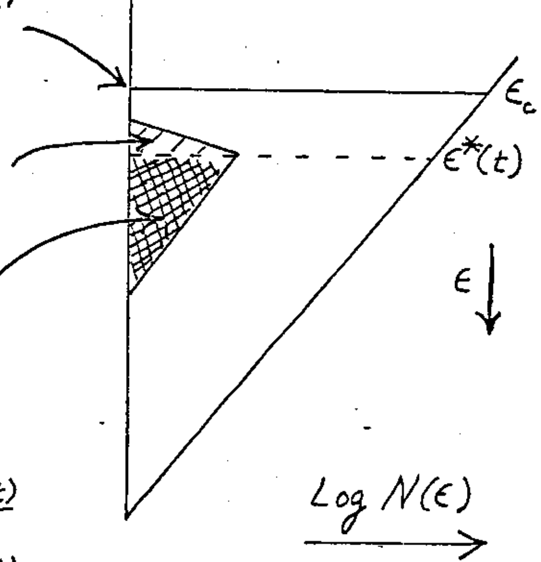
(A. ROSE, INVITED TALK, AM. PHYS. SOC. MARCH 1981)

CURRENT DECAY AT SHORT TIMES $(t<t_T)$

$$\mu_D = \mu \frac{n_{free}}{n_{free} + n_{trap}}$$

$$n_{free} = \xi k T N_{co} e^{-\frac{\epsilon^*(t)}{kT}}$$

$$n_{trap} \begin{cases} \xi \int_{\epsilon^*}^{0} N_{to} e^{-\frac{\epsilon}{T_c}} e^{\frac{\epsilon - \epsilon^*}{kT}} d\epsilon \\ + \xi \int_{\epsilon^*}^{\infty} N_{to} e^{-\frac{\epsilon}{kT_c}} d\epsilon \end{cases}$$



$\xi(t)$ = occupation factor

$$\mu_D = \mu \alpha (1-\alpha) \frac{N_{co} e^{-\frac{\epsilon^*(t)}{kT}}}{N_{to} e^{-\frac{\epsilon^*(t)}{kT_c}}}$$

$$\left.\begin{array}{l} \epsilon^*(t) = kT \ln \omega t \\ N_{co} = N_{to} \\ n_{trap} >> n_{free} \end{array}\right\} \mu_D = \alpha(1-\alpha)(\omega_0 t)^{\alpha - 1}$$

"OCCUPATION FACTOR" $\xi(t) = \frac{g}{L} \frac{T}{T_c} \left(\frac{1}{T} - \frac{1}{T_c} \right) e^{\frac{\epsilon^*(t)}{kT_c}}$

g = TOTAL NUMBER OF ELECTRONS INJECTED

CURRENT DECAY AT SHORT TIMES ($t < t_T$)

$$I(t) = e\, g\, \mu_0 E/L \quad \left(= \frac{Qv}{L}\right)$$

$$I(t) = \frac{eg\mu E}{L}\, \alpha(1-\alpha)\, (\omega_0 t)^{\alpha+1}$$

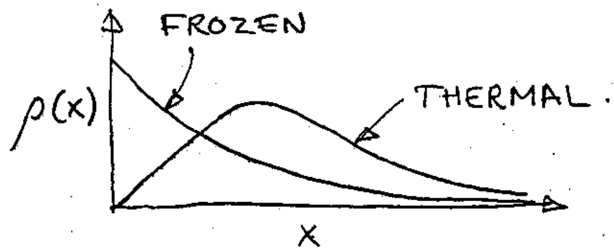
$$\int_0^{t_T} \mu_0 E\, dt = L$$

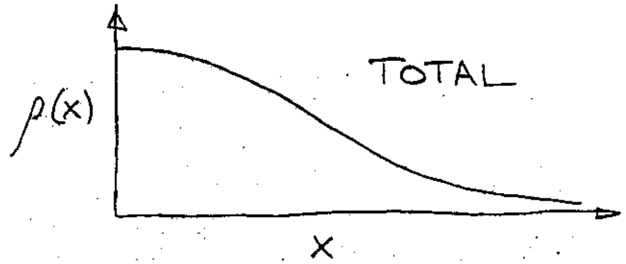
$$t_T = \omega_0^{-1} \left(\frac{\omega_0}{1-\alpha}\right)^{\frac{1}{\alpha}} \left(\frac{L}{\mu E}\right)^{\frac{1}{\alpha}}$$

TRANSIT TIME (EXACT SOL'N)

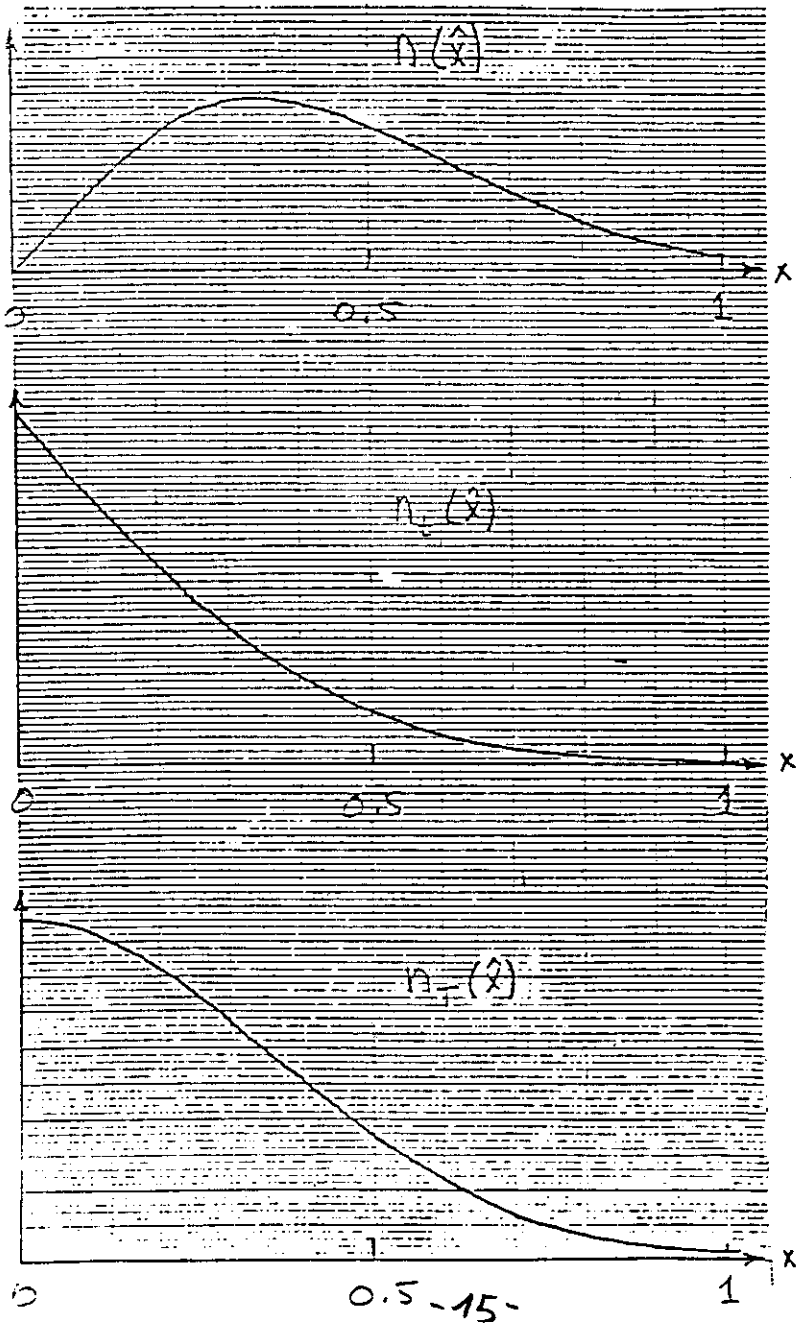
$$t_T = \frac{1}{\nu} \left(\frac{\nu L}{\mu_0 E}\right)^{\frac{1}{\alpha}} \left[\frac{\alpha\, \Gamma(\alpha)^2}{2 \sin \alpha \pi}\right]^{\frac{1}{2\alpha}}$$

SPATIAL DISTRIBUTION : ($\alpha = \frac{1}{2}$)





$\alpha = 1/2$



THERMAL

$x\, e^{-x^2}$

DEEP

$\mathrm{erfc}\,(x)$

TOTAL

e^{-x^2}

CURRENT DECAY AT LONG TIMES $(t > t_T)$

Thermal Emission Limited

$$t = \omega_0^{-1} e^{\frac{\epsilon^*(t)}{kT}}$$

$$\Delta t = \frac{t \Delta \epsilon^*}{kT}$$

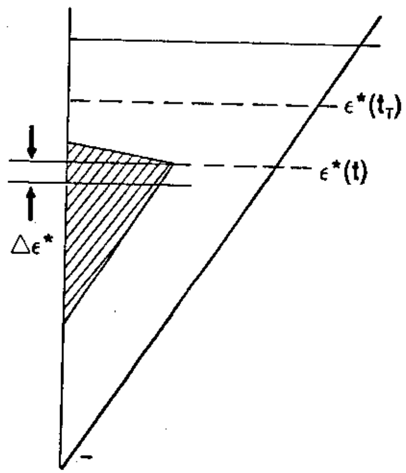
$$\Delta Q \propto N_{to} e^{-\frac{\epsilon^*(t)}{kT_c}} \Delta\epsilon^*$$

$$I(t) = \frac{\Delta Q}{\Delta t} \propto \frac{1}{t}\, e^{-\frac{\epsilon^*(t)}{kT_c}}$$

$$I(t) \propto \frac{e^{-\frac{\alpha\epsilon(t)}{kT}}}{t}$$

$$I(t) \propto t^{-\alpha-1}$$

$$I(t) = e\, \mu E g \alpha (1-\alpha)\, (\omega_0 t_T)^{2\alpha} (\omega_0 t)^{-\alpha-1}$$



PREDICTIONS OF MULTIPLE-TRAPPING MODEL

1. Photocurrent decay:

$$I(t) \propto \begin{cases} t^{\alpha-1} & - \quad t < t_T \\ t^{-\alpha-1} & - \quad t > t_T \end{cases}$$

where $\alpha = \frac{T}{T_c}$.

2. Field dependence:

$$t_T \propto \left(\frac{L}{E}\right)^{\frac{1}{\alpha}}$$

3. Temperature dependence: (Tiedje to be pub., Butcher & Clark, PM, 1980)

Exact $(T<T_c)$:

$$\mu_D(T) = \mu_0 (\nu t_0)^{\frac{T_c}{T}-1} \left[\frac{\alpha\,\Gamma^2(\alpha)}{2\sin\alpha\pi}\right]^{\frac{1}{2\alpha}}$$

Approx: (Tiedje & Rose SSC 1981)

$$\mu_D(T,t) \simeq \mu_0 \frac{\alpha(1-\alpha)}{(\nu t)^{1-\alpha} - \alpha}$$

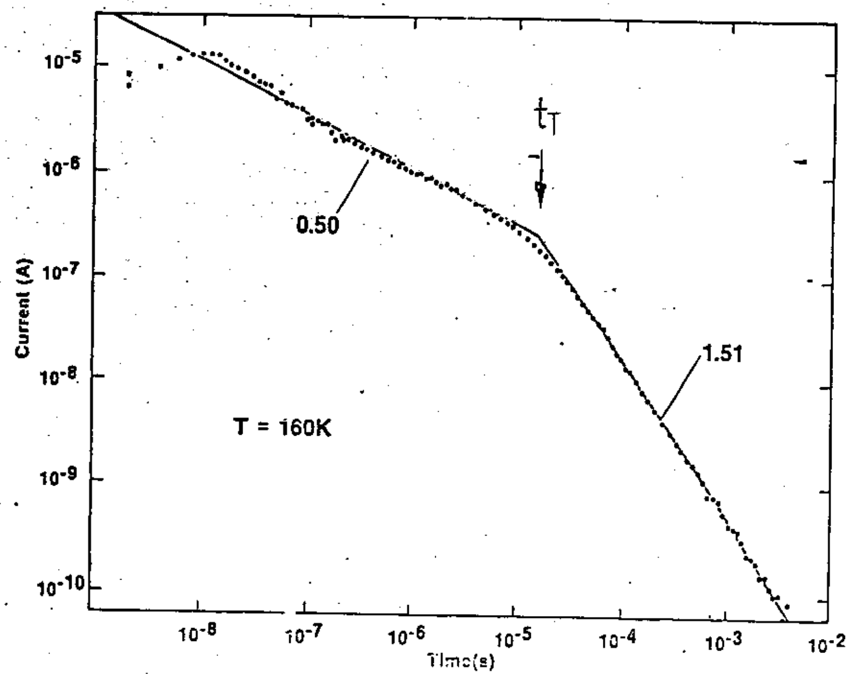
IN EXCELLENT AGREEMENT WITH EXPERIMENT

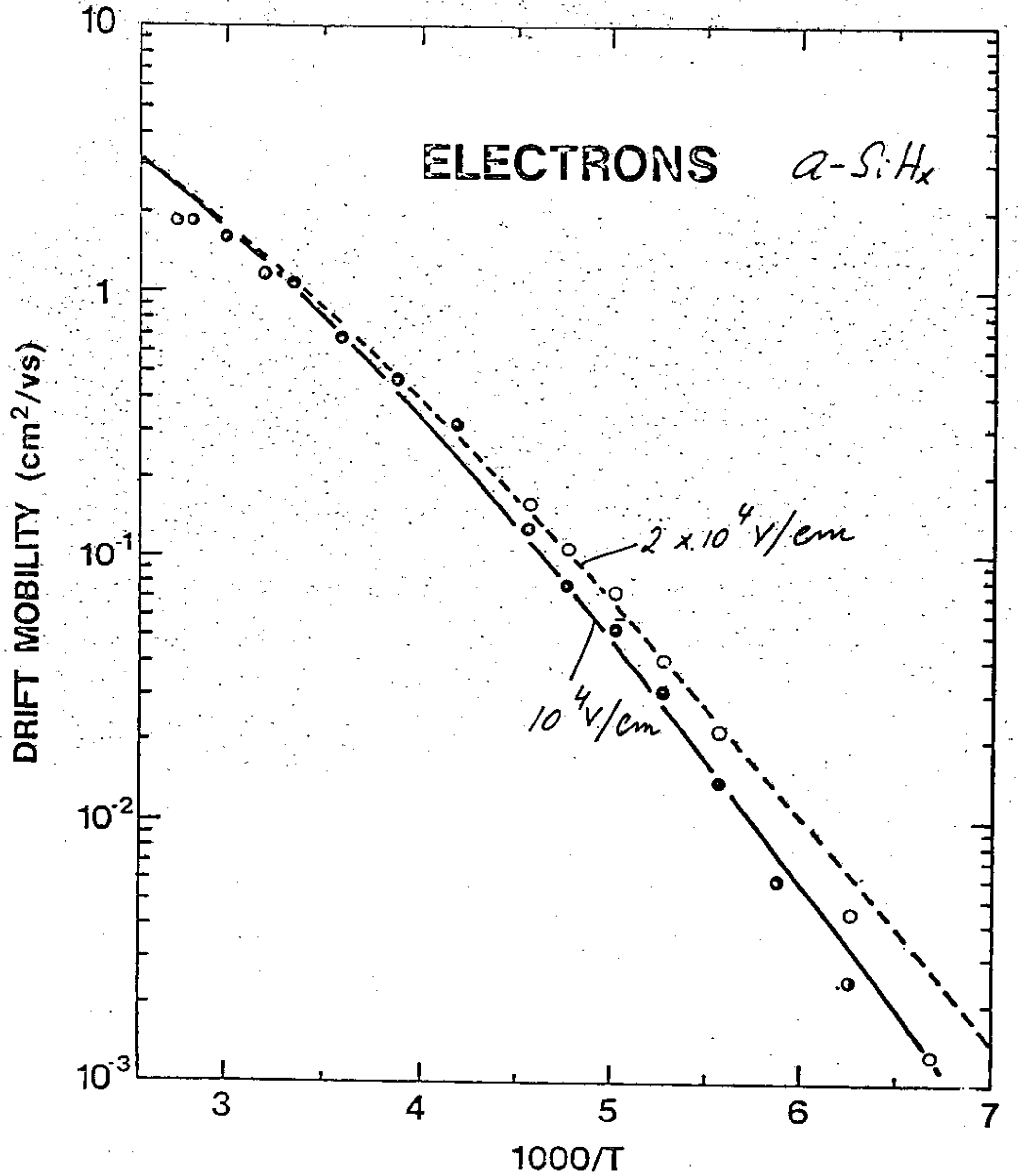
a-SiHx

$$I(T) \propto \begin{cases} t^{\alpha-1} & : \quad t < t_T \\ t^{-\alpha-1} & : \quad t > t_T \end{cases}$$

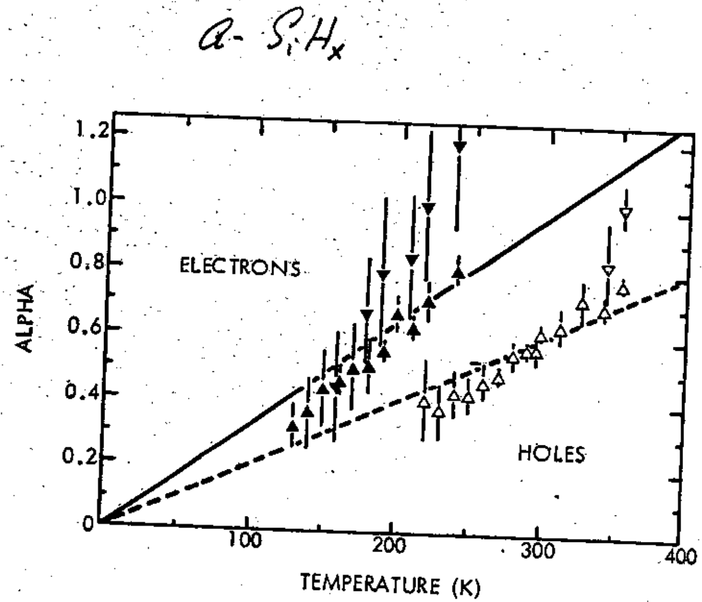
WHERE $\alpha = \frac{T}{T_C}$

EXPERIMENT:





ELECTRONS
a-Si:H$_x$
DRIFT MOBILITY (cm^2/vs)
10
1
10^{-1}
10^{-2}
10^{-3}
2×10^4 V/cm
10^4 V/cm
3
4
5
6
7
1000/T

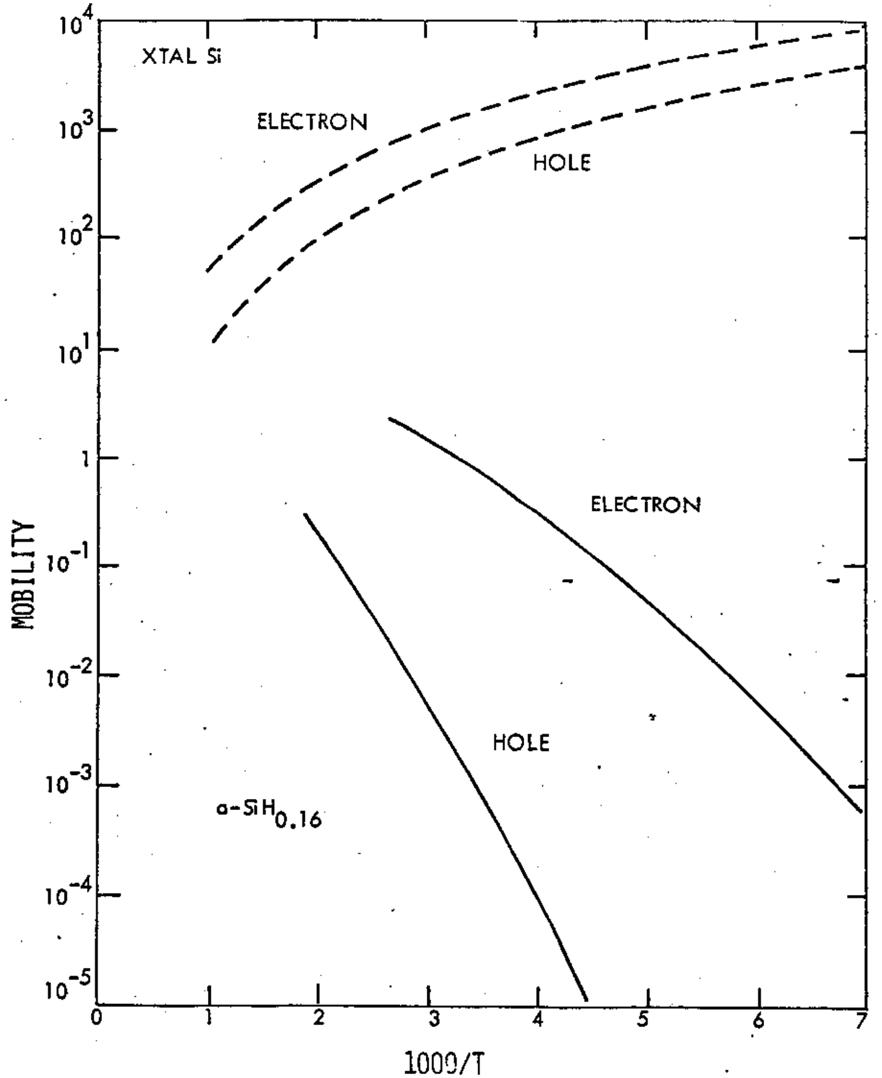


a-SiH$_x$
ALPHA
1.2
1.0
0.8
0.6
0.4
0.2
0
ELECTRONS
HOLES
100
200
300
400
TEMPERATURE (K)

DRIFT MOBILITY FITTING PARAMETERS a-SiHx

	ELECTRONS	HOLES
FREE CARRIER MOBILITY (CM^2/VS)	13	0.7
WIDTH OF BAND TAIL (K)	312	500
ATTEMPT FREQUENCY (s^{-1})	4.6×10^{11}	16×10^{11}
TRAP DEPTH (eV)	0.09 - 0.34	0.28 - 0.51

TEMPERATURE DEPENDENCE OF MOBILITIES DEFINES WIDTH OF BAND TAILS



(T. TIEDJE, INVITED TALK, AM. PHYS. SOC., MARCH 1981)

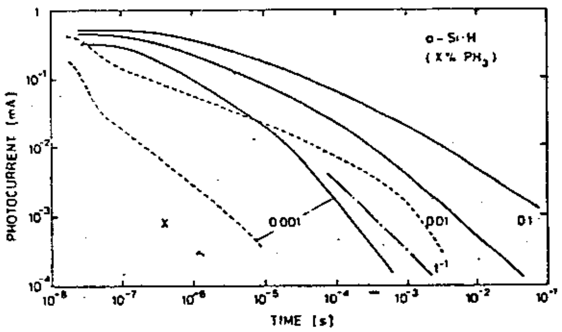
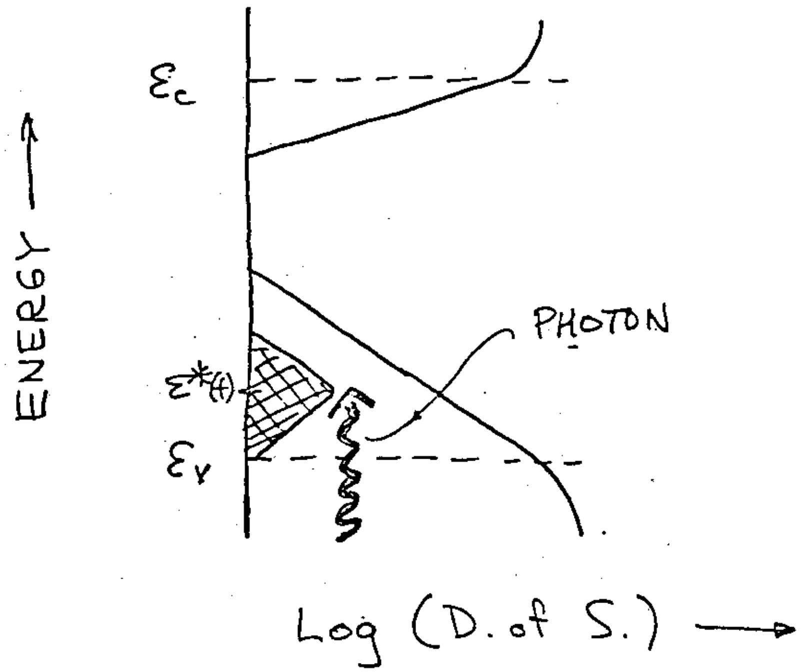


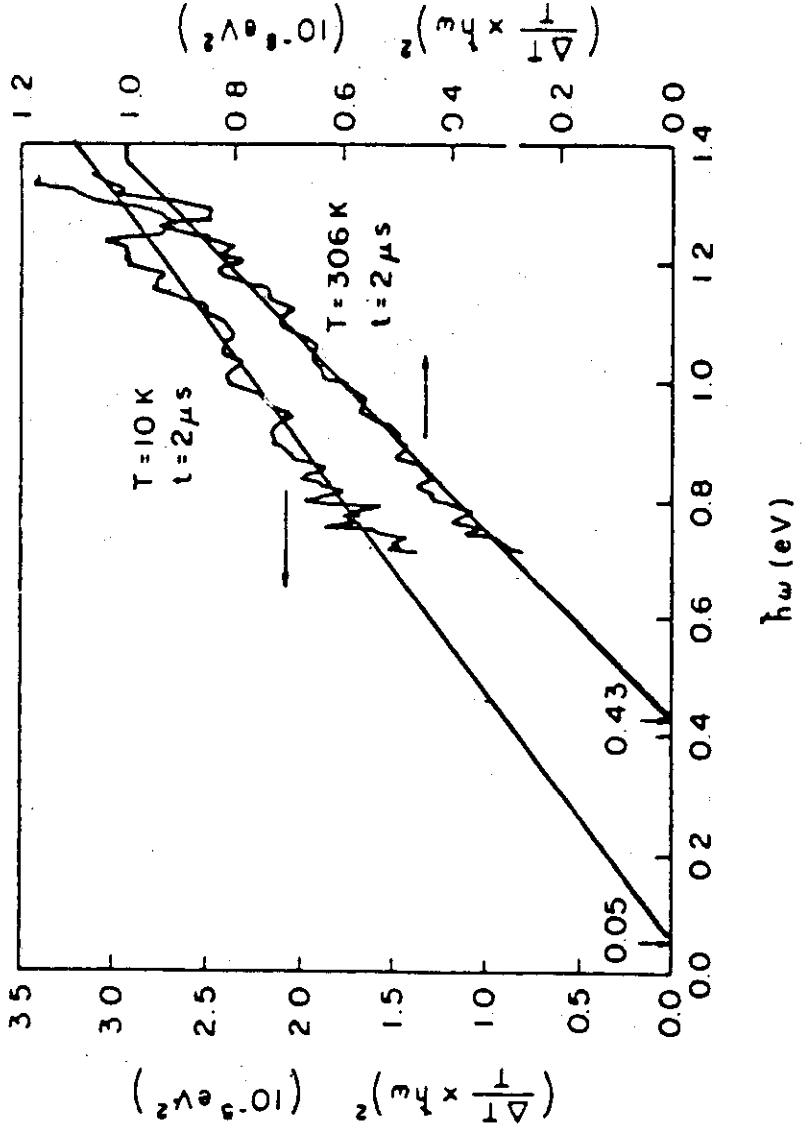
Fig.19

INDUCED ABSORPTION



$$\Delta\alpha \sim \frac{(\varepsilon - \varepsilon^*(t))^{1/2}}{\varepsilon}$$

Ray, Vardeny, Tauc



Ray, Vardeny, T.

$$\mathcal{E}^*(t) = kT \ln \omega_0 t$$