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 IV)

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IV DEEP LEVEL DEFECT STATES IN UNDOPED AND IN B AND P DOPED a-Si:H$_x$.

1 • HOW THE FILMS ARE MADE

2 • DENSITY OF STATES MODEL FOR OPT. ABS.

4 • SPIN RESONANCE AND QUENCHING OF PHOTOLUMINESCENCE DUE TO DEFECTS

5 • DLTS (DEEP LEVEL TRAP SPECTROSCOPY)

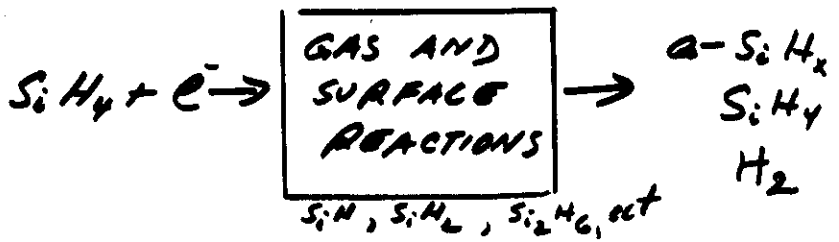
3 • HOLE CAPTURE MEASUREMENTS FROM PICOSECOND INDUCED TRANSITION AND SOLAR CELL COLLECTION EFFICIENCY.

GLOW DISCHARGE DECOMPOSITION OF SILANE (Si:H$_4$)

PROCESS:

• ELECTRON IMPACT IN GAS, FRAGMENTS MOLECULES INTO RADICALS WHICH REACT IN GAS PHASE.

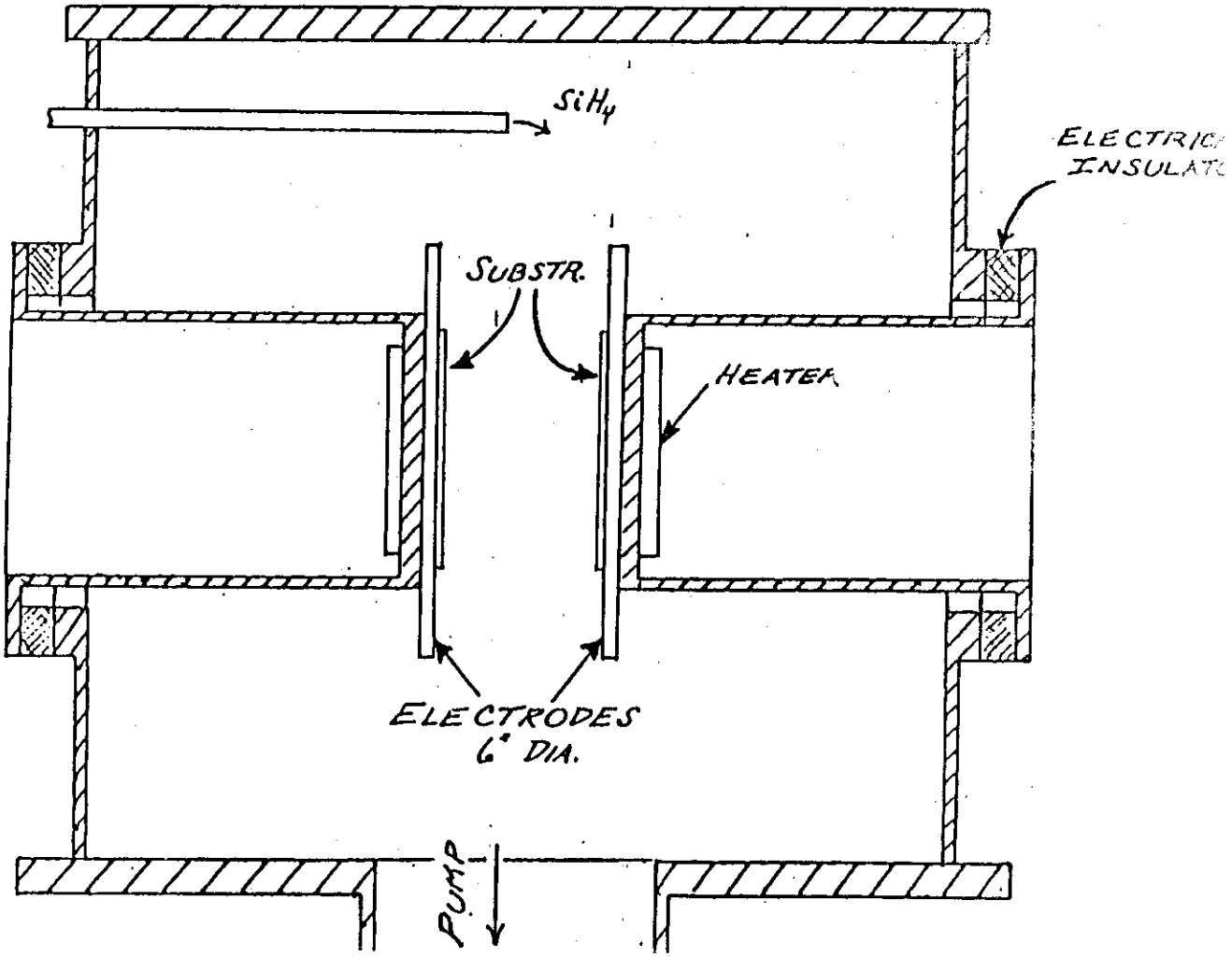
• FILM GROWS BY SURFACE CATALYSED REACTION



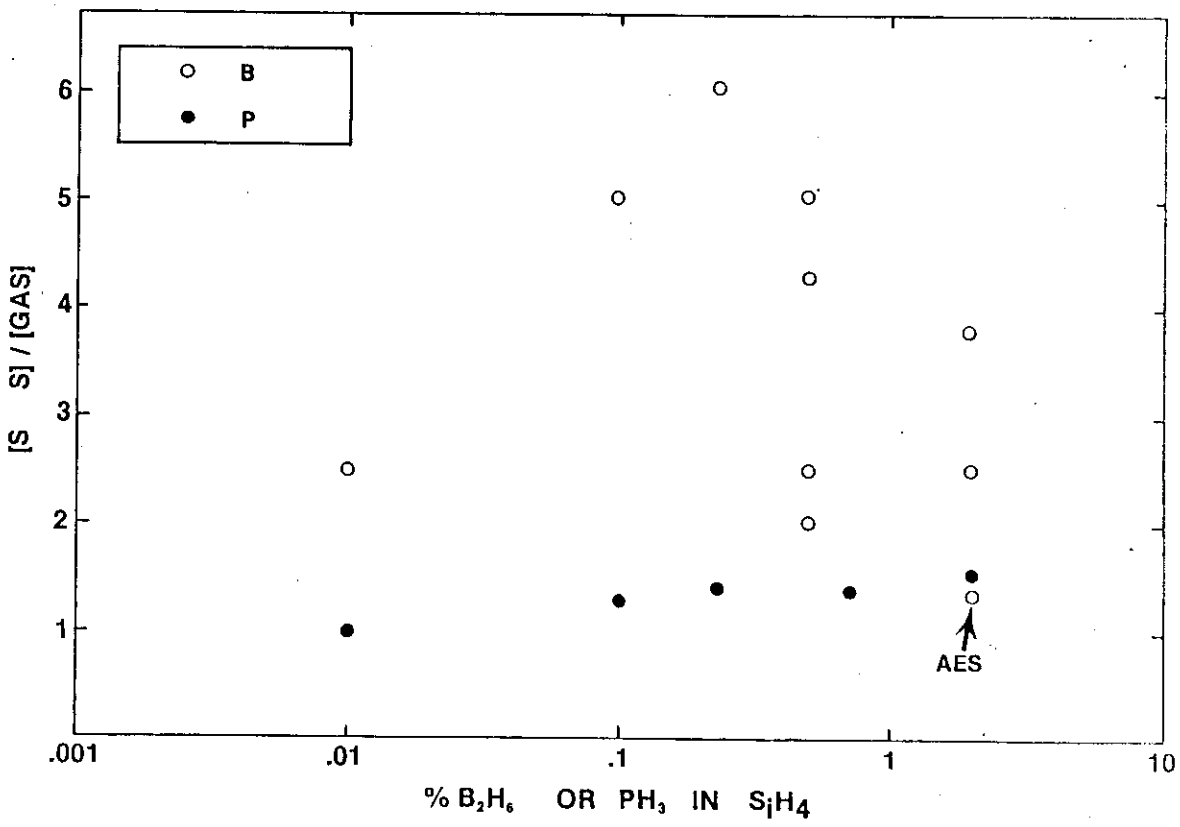
OTHER METHODS:

REACTIVE SPUTTERING
CVD (POST DEP HYDROGENATION)
CVD OF Si$_2$H$_6$
HOMO CVD

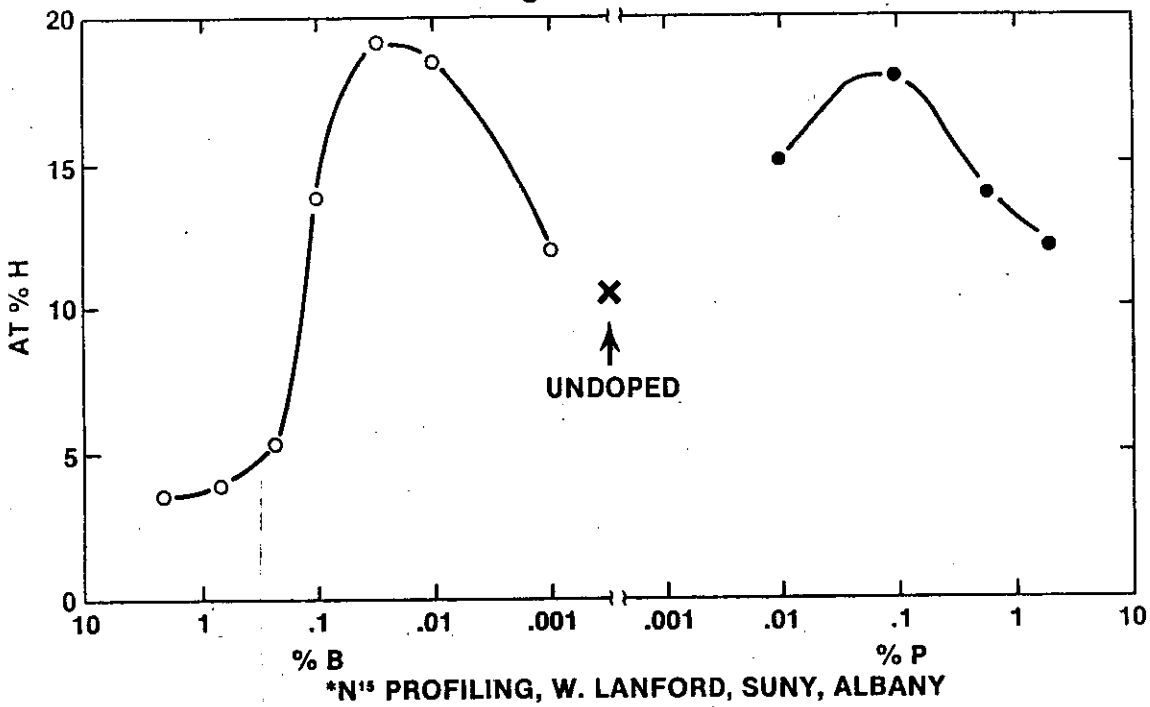
PLASMA REACTOR



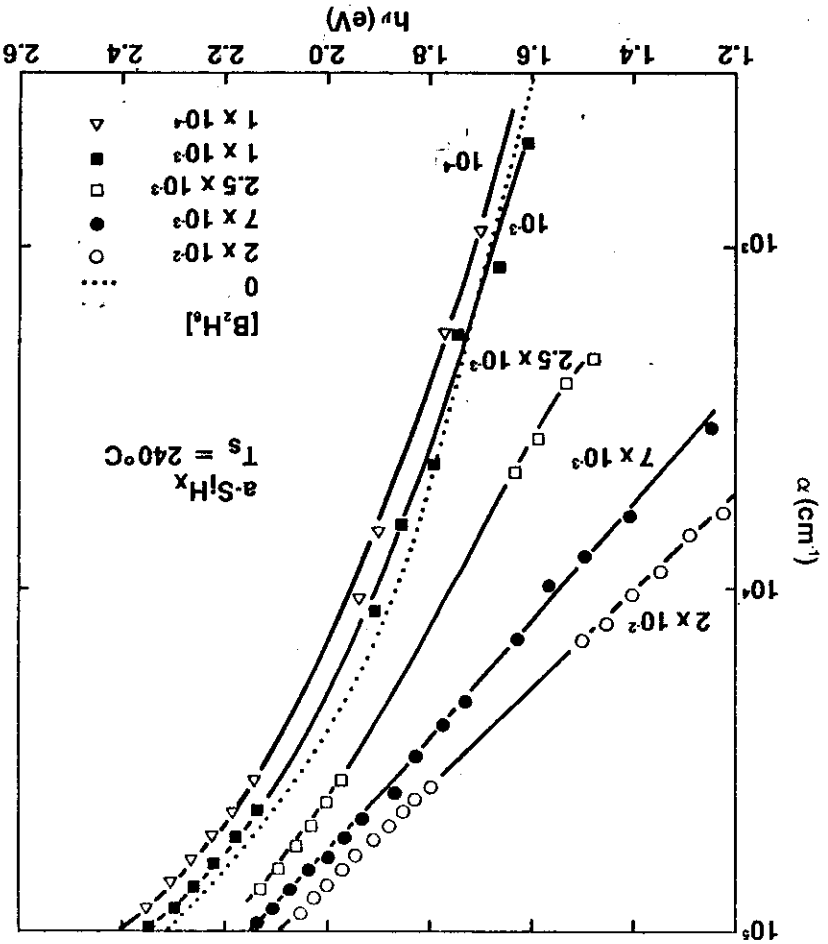
DOPANT INCORPORATION IN a-Si_xH_x

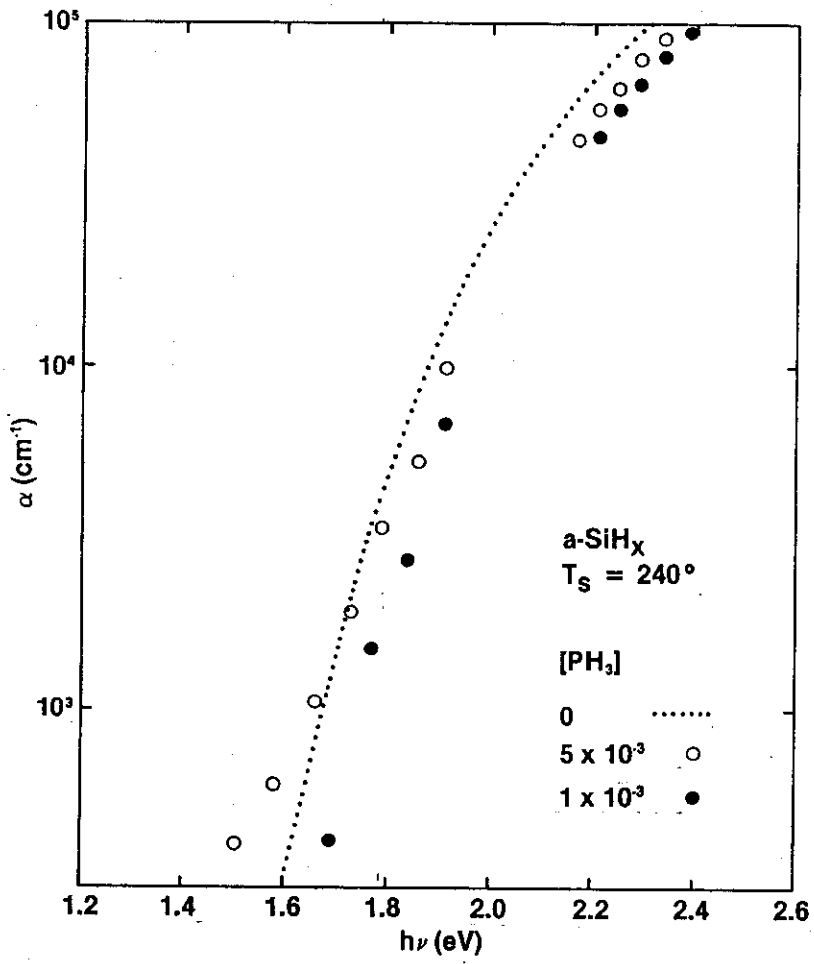


HYDROGEN CONCENTRATION* AS FUNCTION OF P AND B DOPING
T_S = 240°C

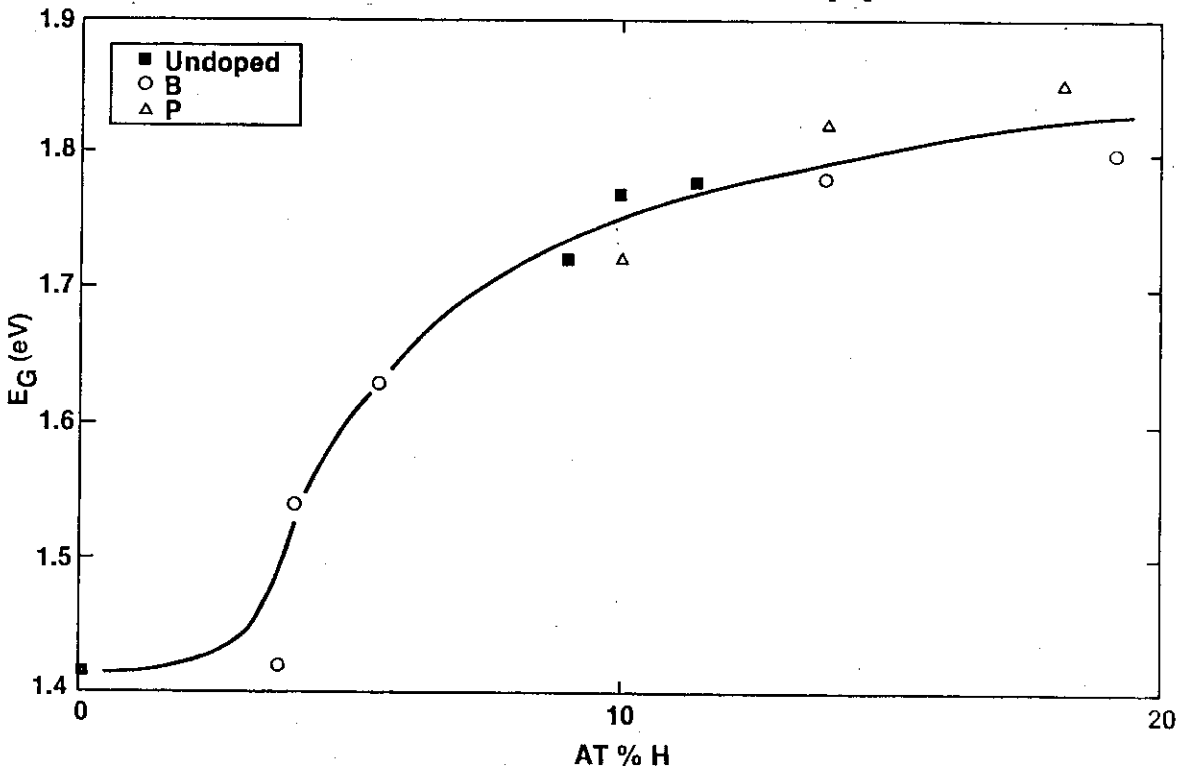


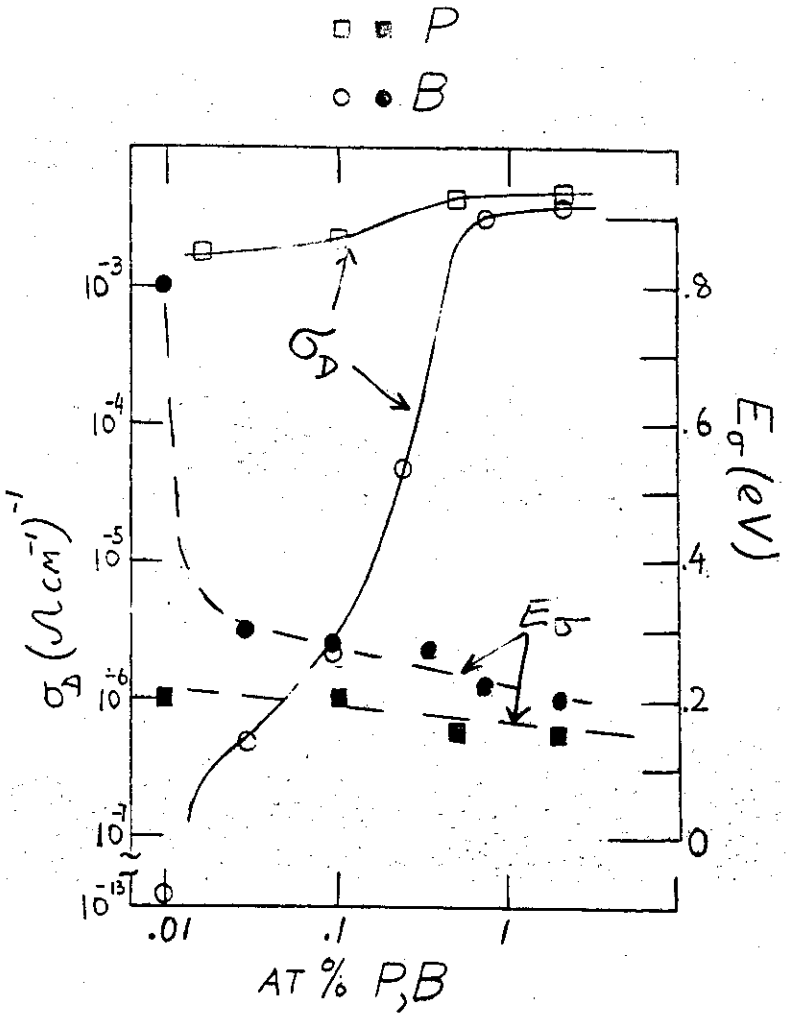
*N^{15} PROFILING, W. LANFORD, SUNY, ALBANY





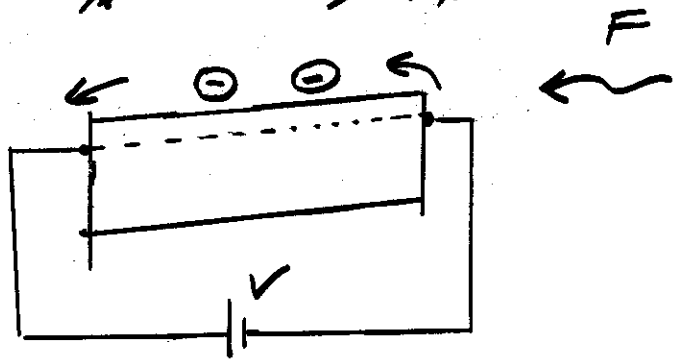
VARIATION OF OPTICAL BANDGAP WITH [H]



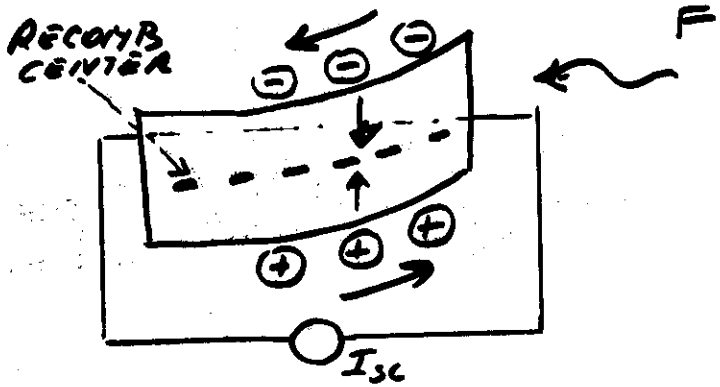


PHOTOCONDUCTIVITY

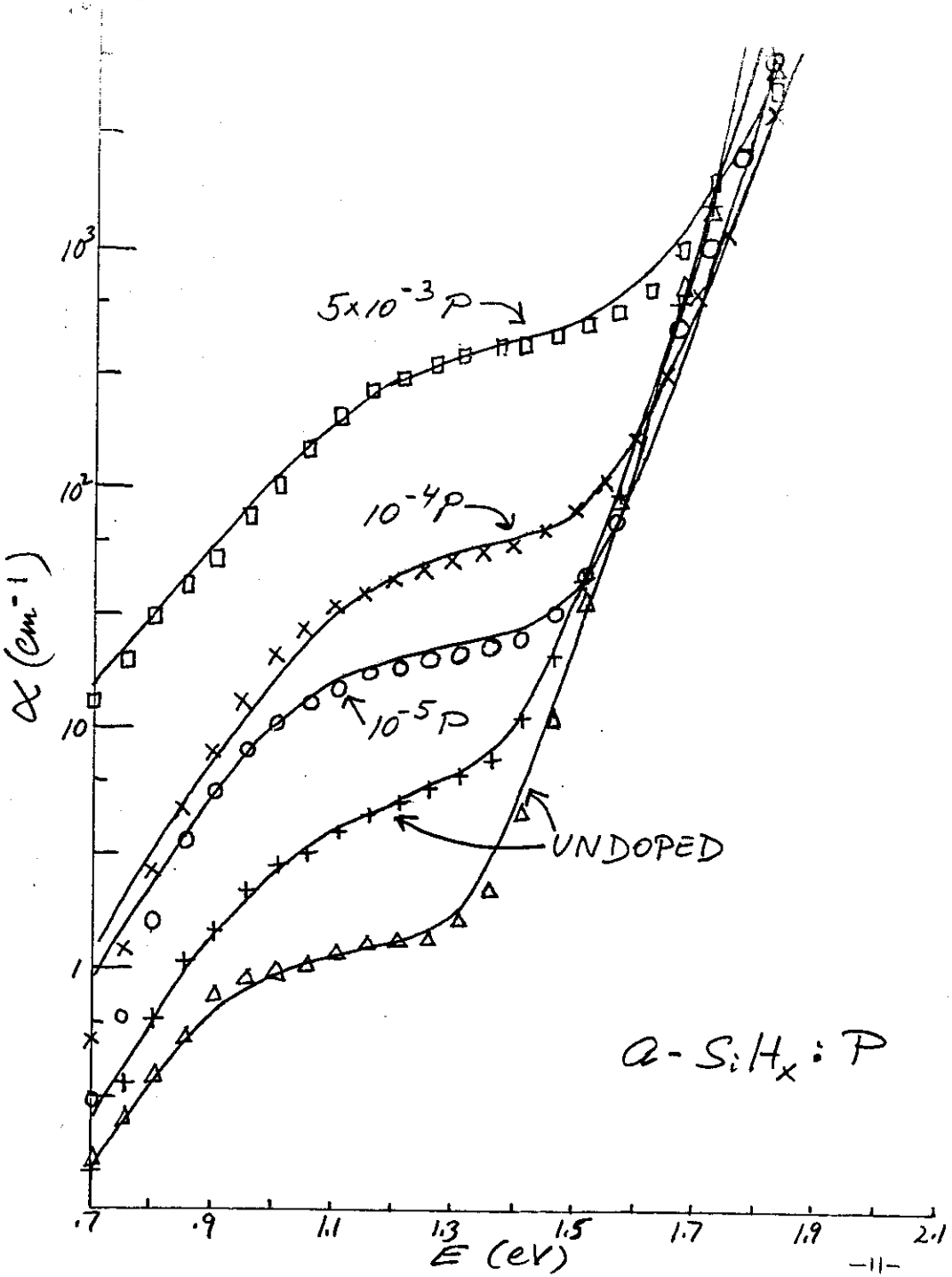
$$I_n = F\alpha L^2 \mu_n \tau_n V$$



SOLAR CELL COLLECTION EFFICIENCY



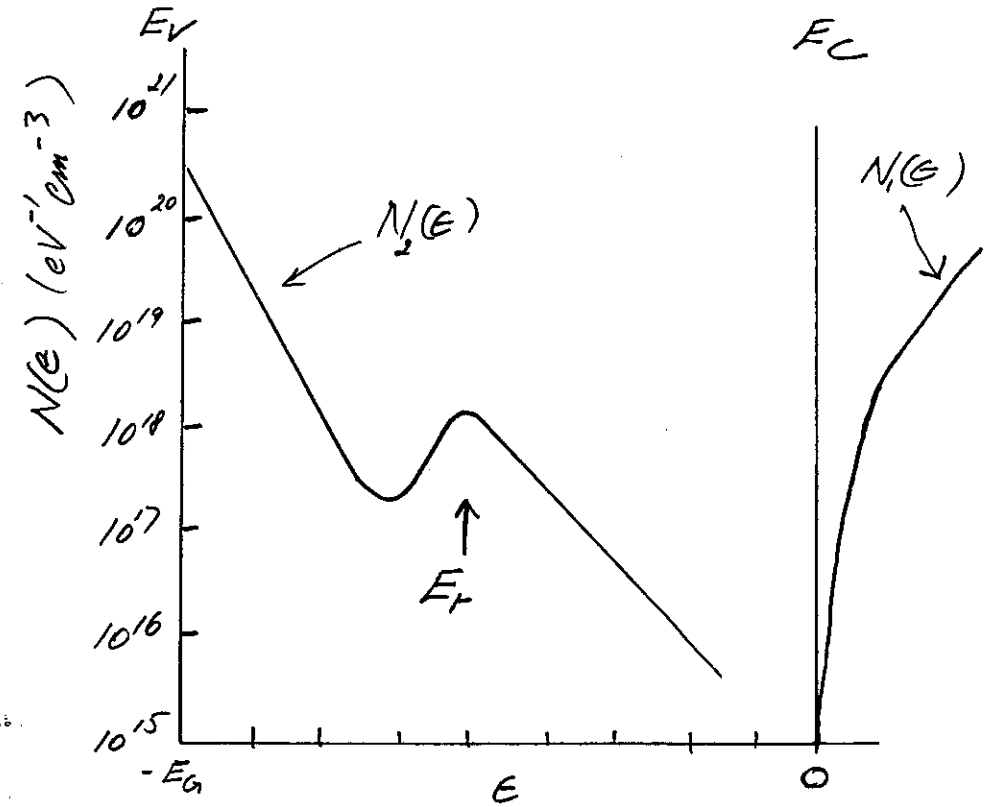
$$I_{sc} = F\alpha L\eta$$



DENSITY OF STATES MODEL

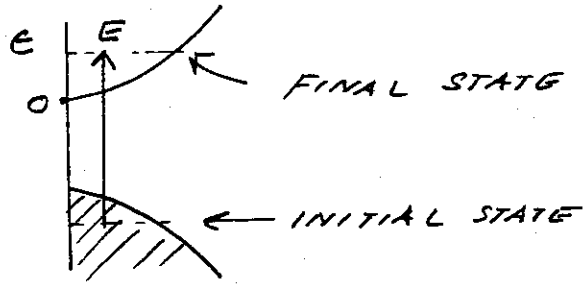
$$N_2(\epsilon) = N_0 e^{\frac{-\epsilon - E_G}{E_0}} + N_r \operatorname{sech}\left(\frac{-\epsilon - E_r}{E_{r0}}\right)$$

$$N_1(\epsilon) \propto \epsilon^{\frac{1}{2}}$$



OPTICAL ABSORPTION

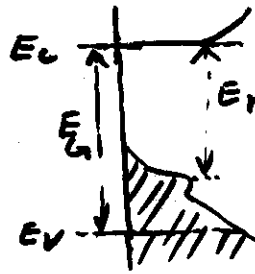
$$\alpha E = C \int_0^{\infty} N_1(\epsilon) N_2(\epsilon - E)\, d\epsilon$$



ASSUMPTION – CONSTANT MATRIX EL.

DEFECT STATES IN a-Si:H$_x$: P

P	E_G (eV)	E_0 (eV)	E_r (eV)	n_r cm^{-3}	τ_p (sec)	τ_n (sec)
0	1.70	.047	.84	6×10^{15}	$1\cdot10^{-7}$	1×10^{-7}
10^{-5}	1.73	.050	.97	6×10^{16}	5×10^{-10}	1×10^{-7}
10^{-4}	1.79	.062	1.02	3×10^{17}	2×10^{-10}	5×10^{-6}
10^{-3}	1.85	.070	1.04	5×10^{17}	4×10^{-11}	1×10^{-5}
5×10^{-3}	1.80	.072	1.07	1.8×10^{18}		

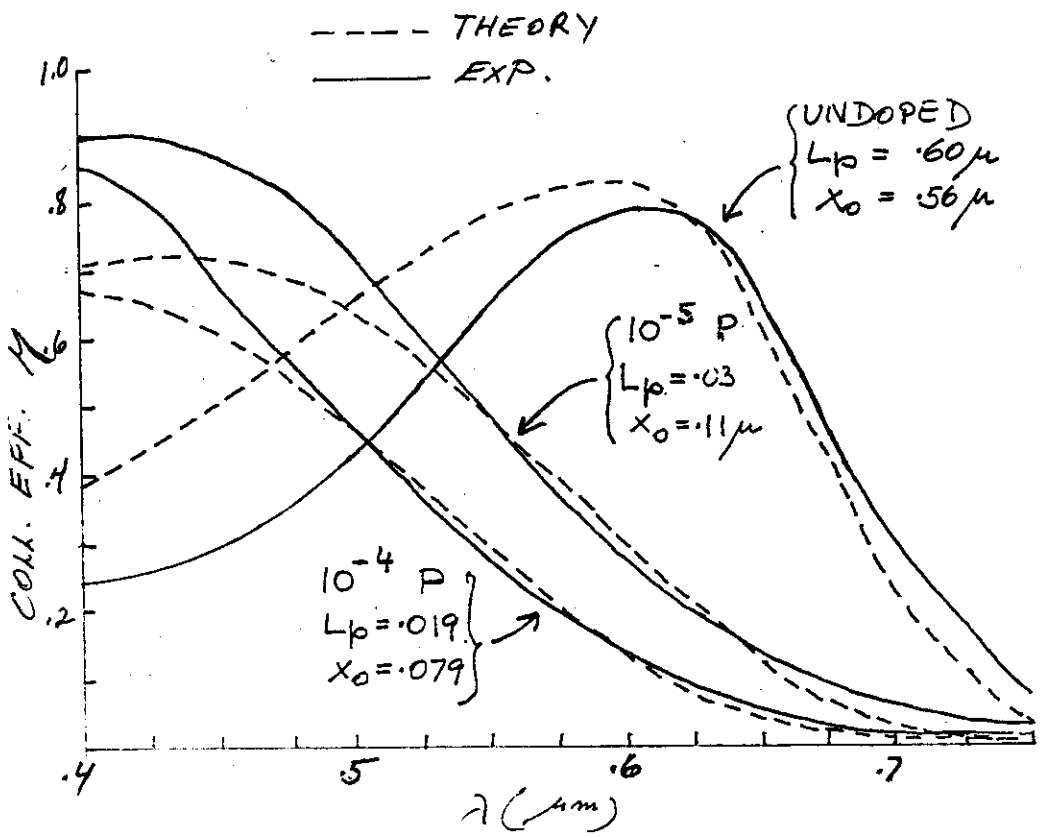


$N_0 = 10^{21}\ eV^{-1}cm^{-3}$

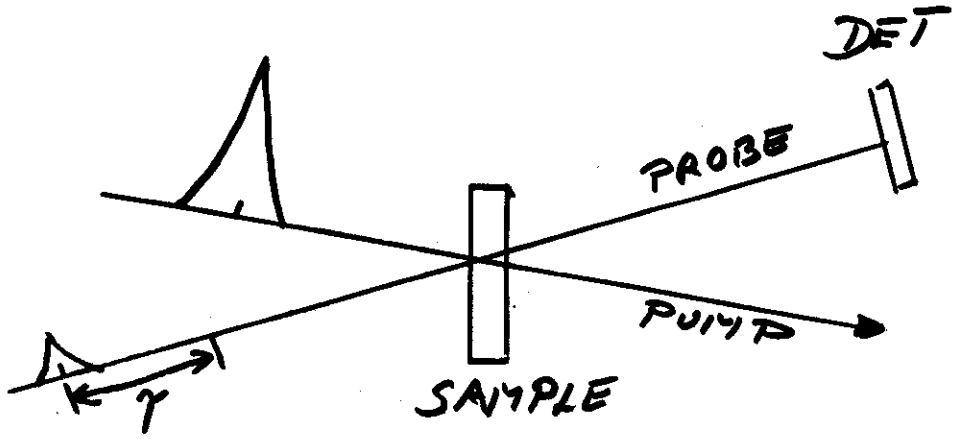
$$L_p = \sqrt{\tau_p D_p}$$
$$D_p = \frac{kT}{e}\mu_p$$
$\Big\}\ \tau_p$

$$\sigma_n = \alpha F e \mu_n \tau_n \rightarrow \tau_n$$

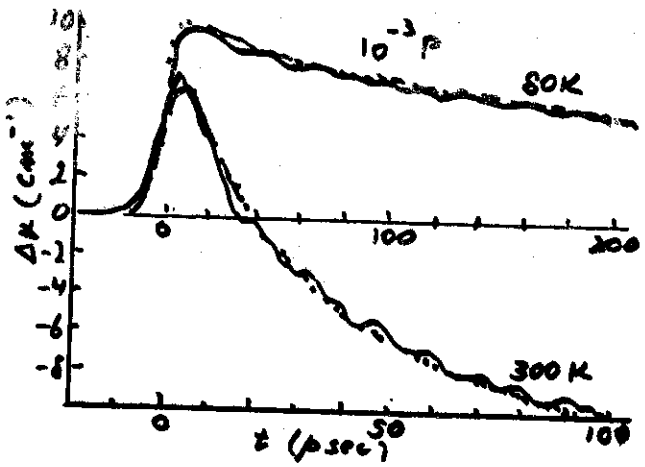
a-SiH_x : P

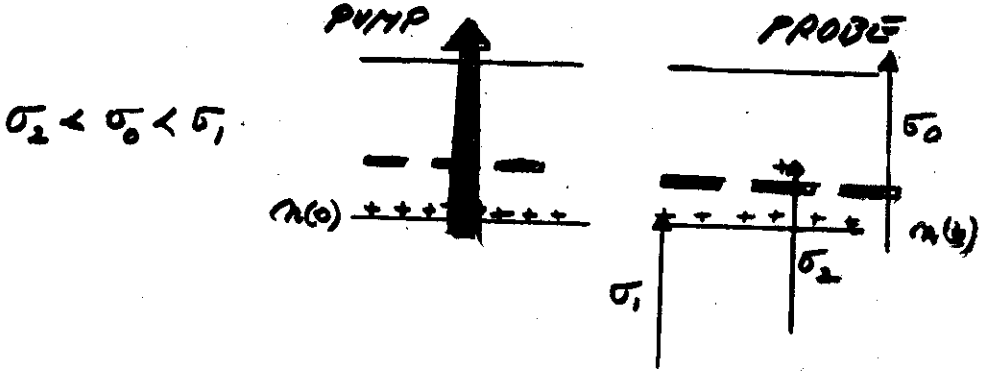


PICOSECOND INDUCED OPTICAL ABSORPTION AND TRANSMISSION*



* TAUC AND COWORKERS (BROWN U.)

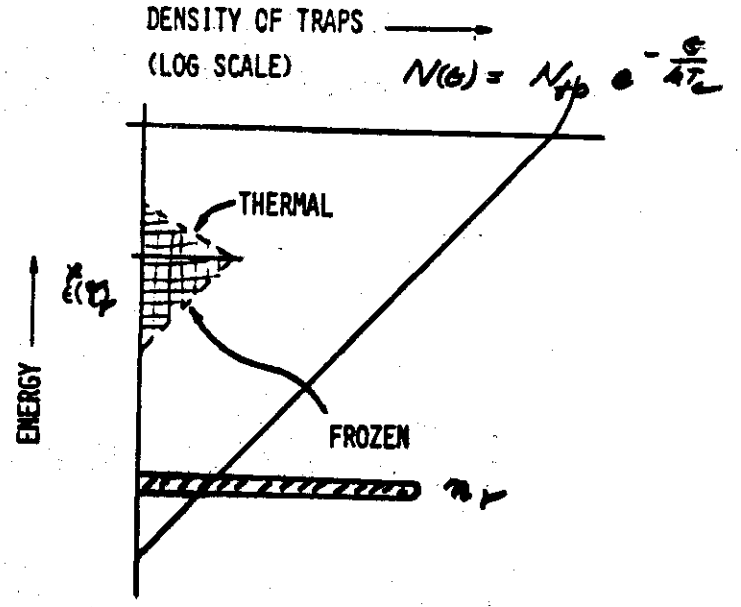




$$\Delta K = (\sigma_1 - \sigma_0)\, n(t) + (\sigma_2 - \sigma_0)\,(n(0) - n(t))$$

VARDENY ET AL PHYS. REV. LETT. (82)

MULTIPLE TRAPPING AND RECOMBINATION* (OR DEEP TRAPS)



CAPTURE RATE BY RECOMB. C. EQUALS TRAPPING RATE BY TAIL STATES:

$$K_+ \int_{\mathcal{E}^*(T_t)}^{\infty} N(\mathcal{E})\, d\mathcal{E} = K_+ n_t$$

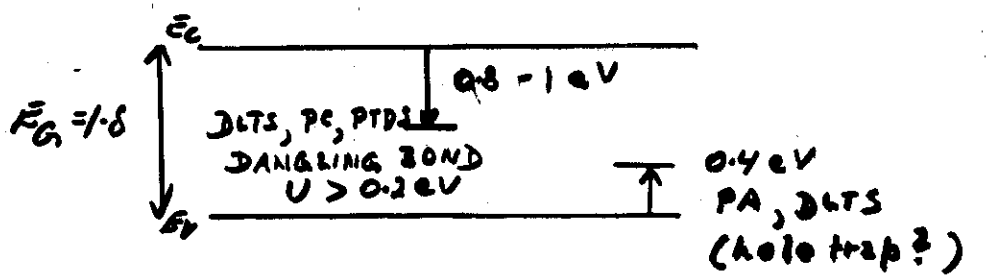
$$T_t = \omega^{-1} \left(\frac{K_+ N_{t0} k T_c}{K_+ n_t} \right)^{\frac{T_c}{T}}$$

$$n_t(t) = \frac{n_0}{1 + (t/T_t)^{T/T_c}}$$

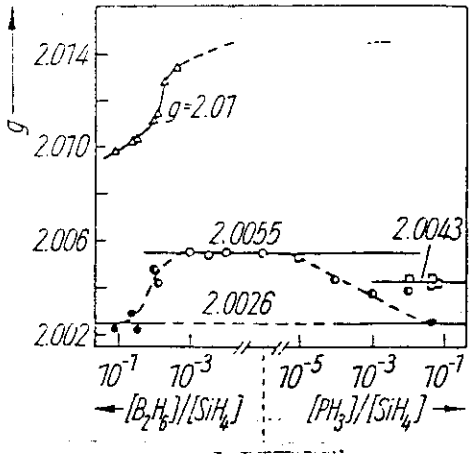
* J. ORNSTEIN AND M. A. KASTNER SOLID STATE COMM. 40, 85 (81)

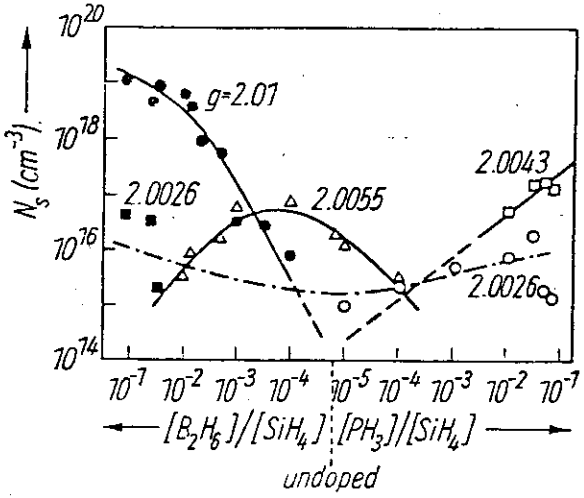
[P]	RC. (cm^{-3}) n_r	RC. $(\AA)$ N_h	PIC. SEC. TRANS. $(\AA)$ λ_h
0	6×10^{15}	2	
10^{-5}	6×10^{16}	15	
10^{-4}	3×10^{17}	20	
10^{-3}	5×10^{18}	50	50 * (ASSUME $\frac{1}{\lambda_h} = 1\AA$)

$$\frac{1}{\tau_p} = N_p n_r = 4\pi D \frac{r_h}{n_r}$$



PA Photo ind. abs
Pc Photo cond
PTDS Photo thermal spec
DLTS Deep leve trap spec
BLTS Bacon lettuce and tomato sandwich

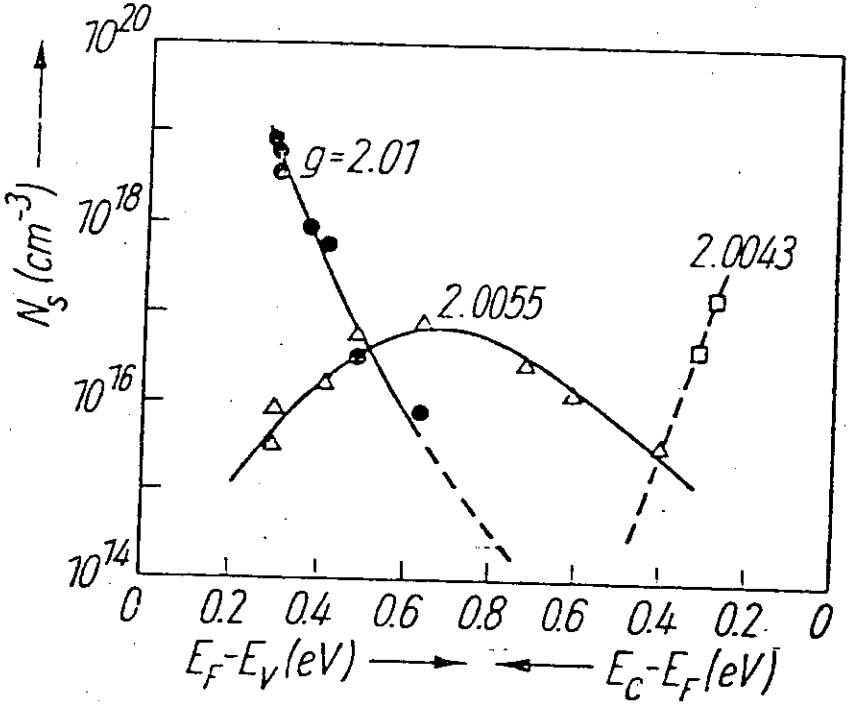


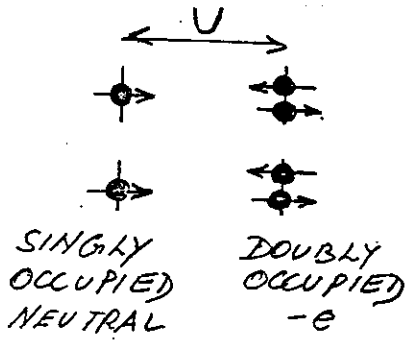


H. DERSCH, J. STUKE AND J. BEICHLER

PHY. STAT. SOL. b105 265 (1981)

ESR OF P AND B DOPED $Si:H_x$





DANGLING BOND STATES

POSITIVE CORRELATION U

DERSCH ET AL

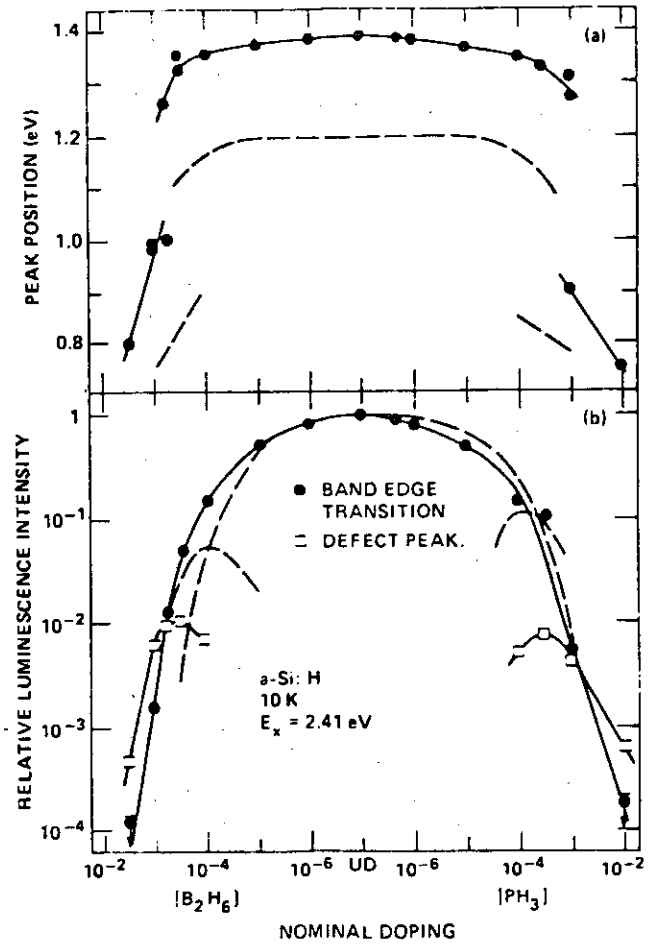


FIG. 3. (a) peak position and (b) intensity of the luminescence of doped samples. The dashed curves are equivalent data reported by Fischer *et al.* (Ref. 16) at a measurement temperature of 77 K.

R.A. STREET, D.K. BIEGELSEN AND J.C. KNIGHTS PHYS. REV B24, 969 (1981)

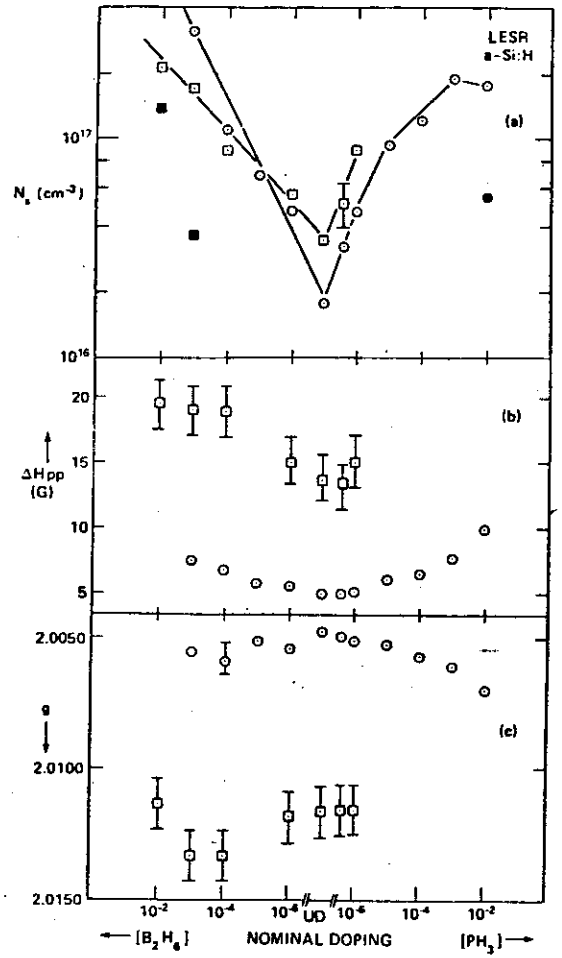


FIG. 13. LESR data for singly doped *a*-Si:H showing (a) the spin densities; (b) the peak-to-peak widths; and (c) the *g* values. The broad line is represented by squares and the narrow lines by circles. The closed data points in (a) are equilibrium ESR data on the only samples with detectable signals.

STREET ET AL

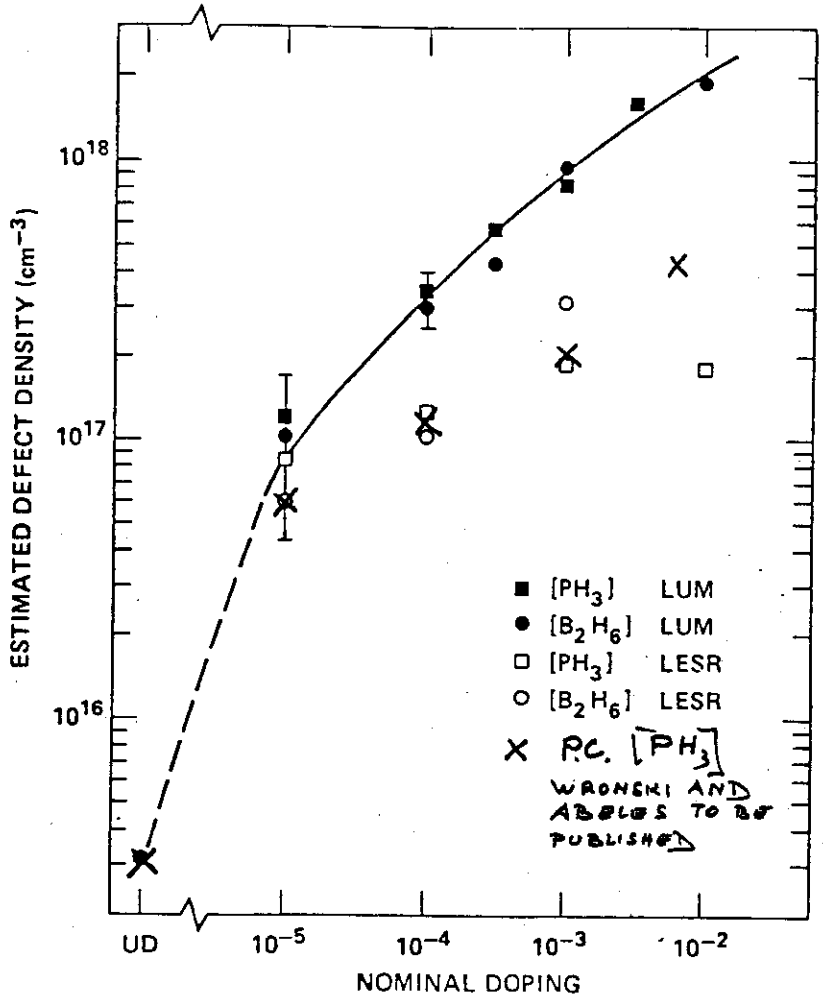


FIG. 17. Estimated defect density obtained from the luminescence and ESR data as described in the text.

STREET ET AL

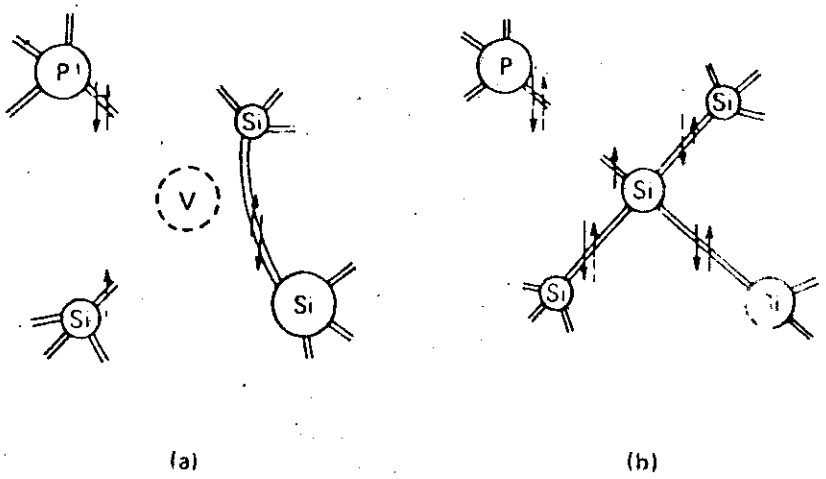
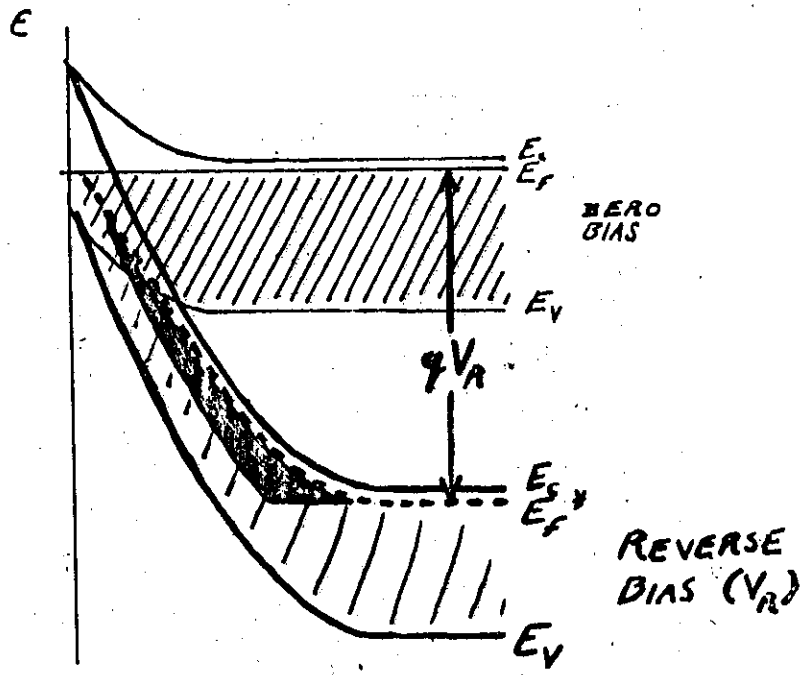


FIG. 18. Possible structures for impurity-defect complexes in doped *a*-Si:H.

R.A. STREET, D.K. BIEGELSEN AND J.C. KNIGHTS

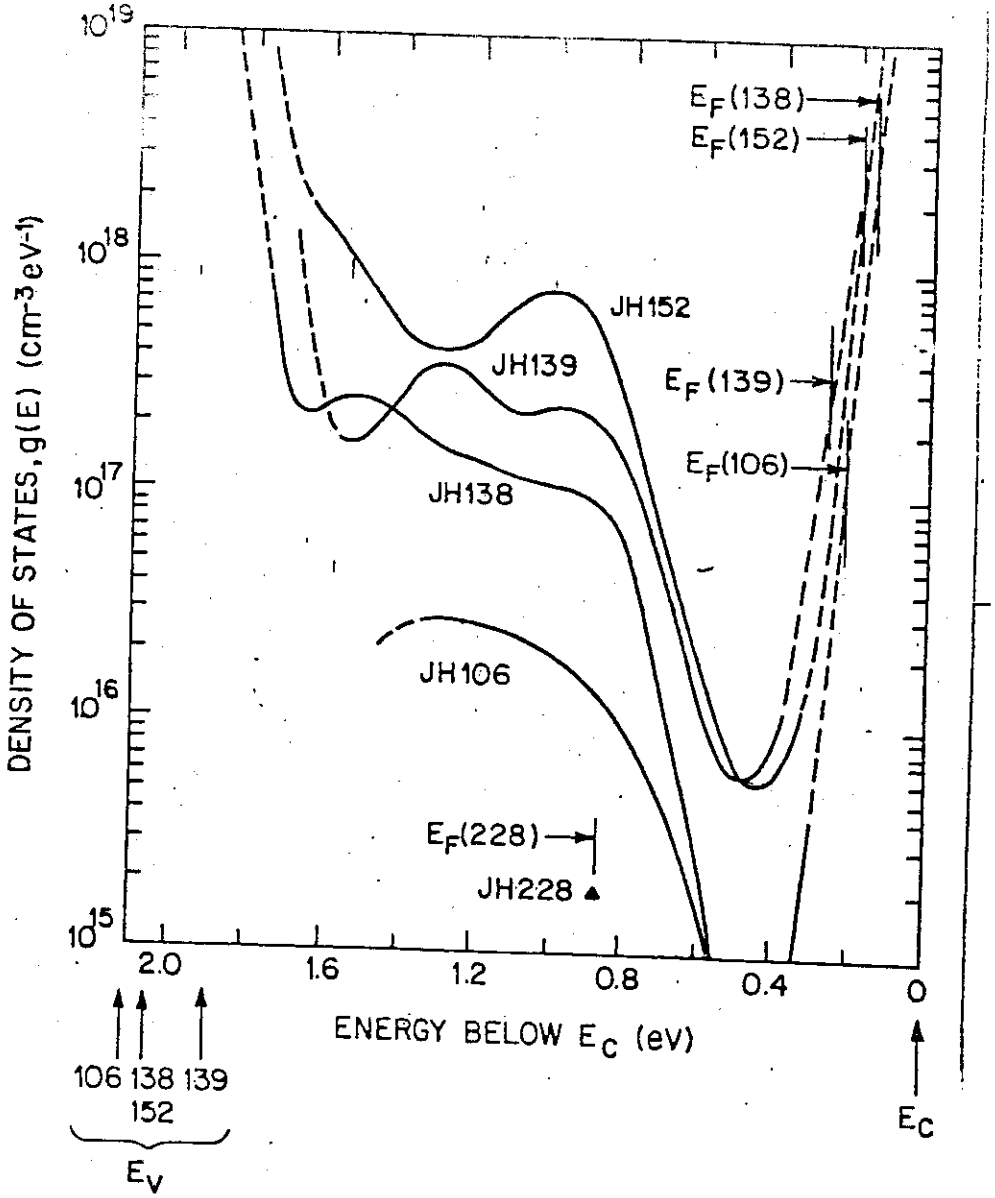
DEEP LEVEL TRAP SPECTROSCOPY DLTS

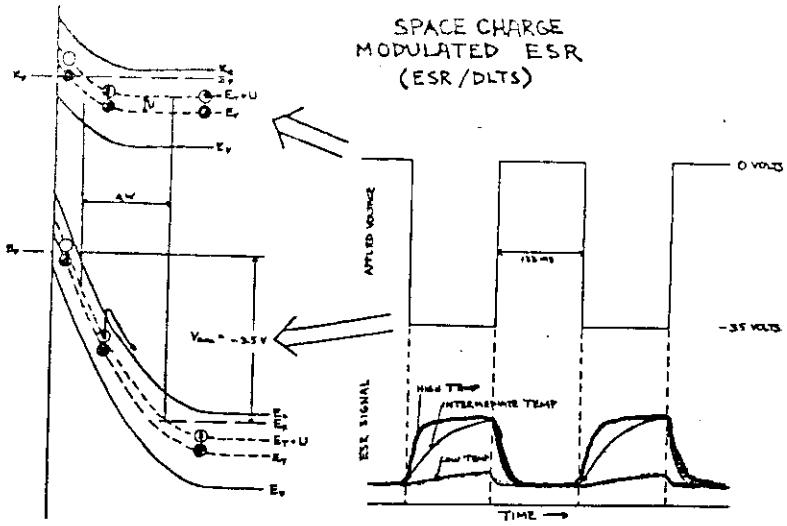
D.V. LANG, J.D. COHEN & J.P. HARBISON PHYS. REV B 28 #8 (83)

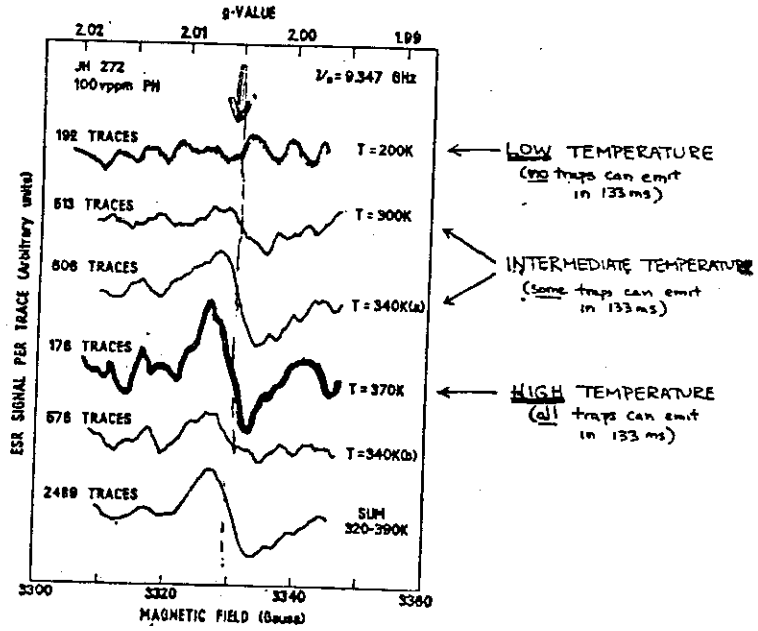


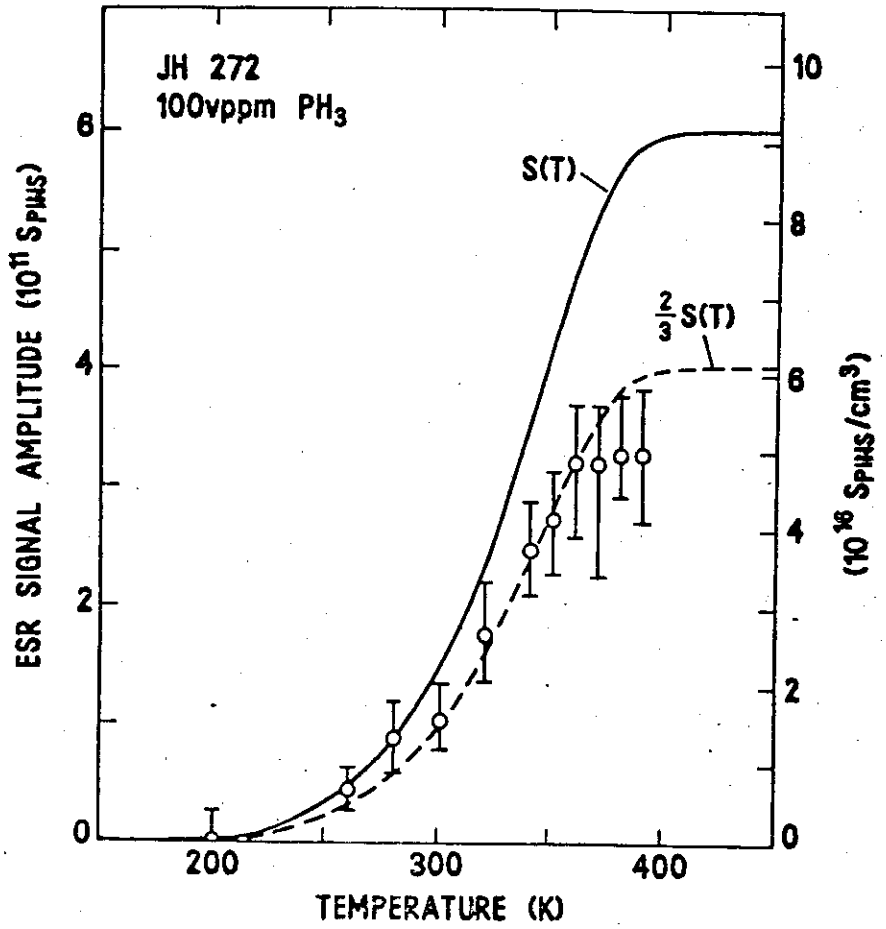
$$E_c - E_F^* = \frac{E_G}{2} + kT \ln \frac{\omega_n}{\omega_p}$$

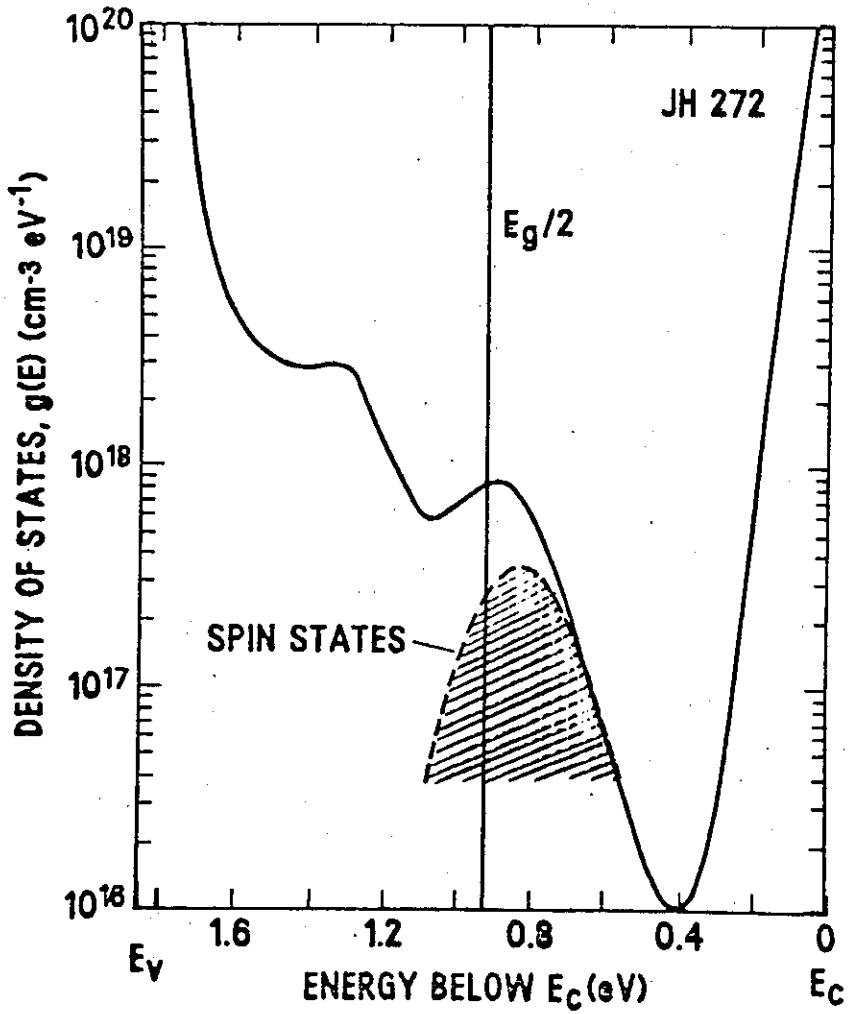
$$\tau(\epsilon) = \omega_0^{-1} \exp \frac{\epsilon}{kT}$$

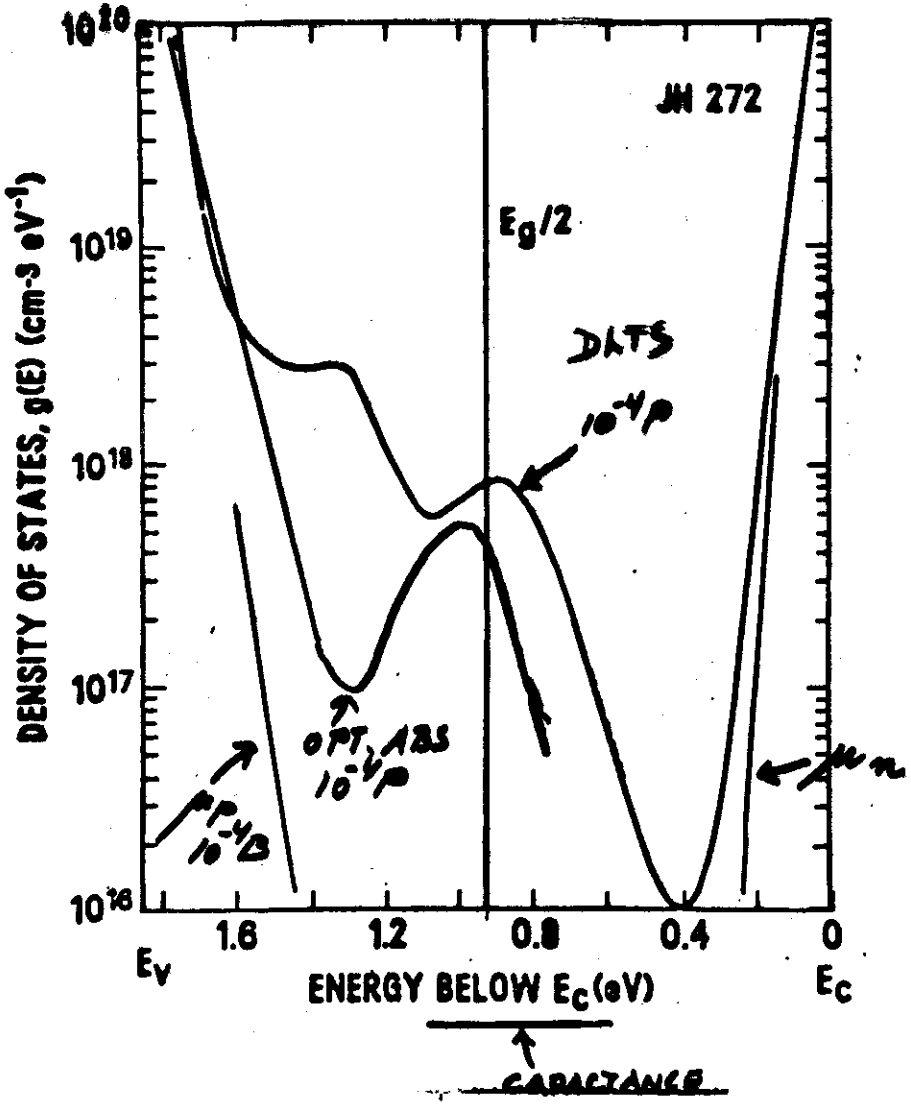

DENSITY OF STATES, g(E) (cm⁻³ eV⁻¹)
10¹⁹
10¹⁸
10¹⁷
10¹⁶
10¹⁵
E_F(138)
E_F(152)
JH152
JH139
E_F(139)
E_F(106)
JH138
JH106
E_F(228)
JH228
2.0
1.6
1.2
0.8
0.4
0
ENERGY BELOW E_C (eV)
106 138 139
152
E_V
E_C


SPACE CHARGE
MODULATED ESR
(ESR/DLTS)
APPLIED VOLTAGE
0 VOLTS
-35 VOLTS
133 ms
ESR SIGNAL
TIME


g-VALUE
2.02
2.01
2.00
1.99
JH 272
100 ppm PH
ν₀ = 9.347 GHz
192 TRACES
T = 200K
LOW TEMPERATURE
(no traps can emit in 133 ms)
513 TRACES
T = 300K
808 TRACES
T = 340K(a)
INTERMEDIATE TEMPERATURE
(some traps can emit in 133 ms)
176 TRACES
T = 370K
HIGH TEMPERATURE
(all traps can emit in 133 ms)
576 TRACES
T = 340K(b)
2489 TRACES
SUM
320-390K
ESR SIGNAL PER TRACE (Arbitrary units)
3300
3320
3340
3360
MAGNETIC FIELD (Gauss)






JH 272
$E_g/2$
DLTS
10^{-4}/p
OPT. ABS
10^{-4}/p
PP
10^{-4}/p
10^{20}
10^{19}
10^{18}
10^{17}
10^{16}
DENSITY OF STATES, g(E) (cm^{-3} eV^{-1})
1.6
1.2
0.8
0.4
0
E_V
ENERGY BELOW E_C (eV)
E_C
CAPACITANCE