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SPRING COLLEGE ON AMORPHOUS SOLIDS
AND THE LIQUID STATE

14 April - 18 June 1982

ELECTRONIC TRANSPORT IN NON-CRYSTALLINE SEMICONDUCTORS

(Part III)

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1. The transport properties of high quality a-Si:H films are strongly affected by space charge layers at the film surface and/or the substrate interface. Space charge layers exist even after cleaning and drying the surface. The presence of space charge layers can be determined by ~~we~~ observing a large decrease in conductance when a layer is deposited on the film surface, which either donates electrons or holes to the a-Si:H film. H_2O or NH_3 act as electron donors, a Se film as an electron acceptor (hole donor). The effects of the space charge layers have to be understood, or the space charge layers have to be eliminated before one can extract the true bulk properties of a-Si:H.

References: H. Fritzsche, Solar Energy Materials 3 (1980) 4
M. Tanielian et al. Appl. Phys. Lett. 33 (1978) 353
M. Tanielian et al. J. Non-Cryst. Solids 35-36 (1980) 575
H. Fritzsche, Solar Cells 2 (1980)
M. Tanielian, Phil. Mag. (1982) in press

2. Light-induced creation of defects in a-Si:H

First discovered by D.L. Staebler and C.R. Wronski, Appl. Phys. Lett. 31 (1977) 292; J. Appl. Phys. 51 (1980) 3262.
Further studies H. Fritzsche, Solar Energy Mat. 3 (1980) 447.
M. Tanielian, N. Goodman, H. Fritzsche J. de Physique
M. Tanielian, Phil. Mag 1982 (in press)
N. Goodman, Phil. Mag 1982 (in press)

3. Light-induced metastable changes of space charge layers. We discovered that hole accumulation layers adjacent to the top oxide layer of p-type a-Si:H films can be greatly enhanced by light exposure. If one is not aware of these effects and if one interprets the measured conductance as bulk conductance, one obtains very erroneous values for σ_0 and ΔE in the conductivity expression $\sigma = \sigma_0 \exp(-\Delta E/k_BT)$. This is part of the reason for the large scatter in σ_0 and ΔE values quoted and published by different laboratories.

Descriptions and captions of the following figures

Fig. 1. At time $t=0$ a very small partial pressure of NH_3 or H_2O was admitted to ~~an~~ the measuring chamber. The conductance of an undoped a-Si:H increase by many orders of magnitude as the result of an electron accumulation layer created

Fig. 2. The conductance G of p-type a-Si:H film decreased by many orders of magnitude upon exposure to NH_3 or H_2O. This indicates that there was a large hole accumulation layer present which was reduced or eliminated by the donor-type adsorbates.

Fig. 3. By evaporating a Se layer on top of an undoped but slightly n-type a-Si:H film, its conductance was greatly reduced. This proves that this film had an electron accumulation layer. H_2O increases its conductance

Fig. 4 The σ_0 value obtained by neglecting the space charge layers is greatly reduced relative to its true value because the current flows in a narrow region t instead of the whole film thickness d.

Fig. 5 By using a quartz crystal oscillator as a microbalance we proved that water is absorbed in the <u>bulk</u> of evaporated a-Si which is porous.

Fig. 6. a-Si:H is not porous; H_2O is absorbed as one or two layers on the surface.

Fig. 7. Staebler-Wronski Effect: decrease of dark conductance after light exposure.
State A = annealed
State B = after light exposure

Fig. 8. Staebler-Wronski effect in an n-type a-Si:H sample. State B can be returned to state A by annealing in dark.

Fig. 9. Change of σ_0 with ΔE as a-Si:H samples are brought from state A to state B by light exposure.

Fig 10. Doping dependence of Staebler-Wronski effect. Plot of $\log \sigma_B/\sigma_A$ against activation energy of state A. Note that the effect reverses sign when E_F is slightly above midgap.

Fig. 11 Model of photo-created donors and acceptors which explains results of figure 10.

Fig. 12 Quantitative comparison of model of figure 11 with results of figure 10.

Fig. 13 Light-induced creation of defects is observed by the increase in the measured field-effect density of states.

Fig. 14 P-type samples of Si:H, which have a natural oxide layer, show a very large <u>increase</u> in dark conductance after light exposure. This is due to ~~a~~ light-induced transfer of electrons from the a-Si:H film to the oxide layer, thus <u>increasing</u> the hole space charge layer. The presence of a conducting hole accumulation layer is demonstrated by the very large decrease in conductance when H_2O is adsorbed. After removing the oxide layer by a chemical etch (SYE) one observes the normal Staebler-Wronski effect.

This indicates that false conclusions are drawn when one is unaware of space charge layers and their ~~s~~ changes with light.

M. Tanielian, V. Smid, H.F.

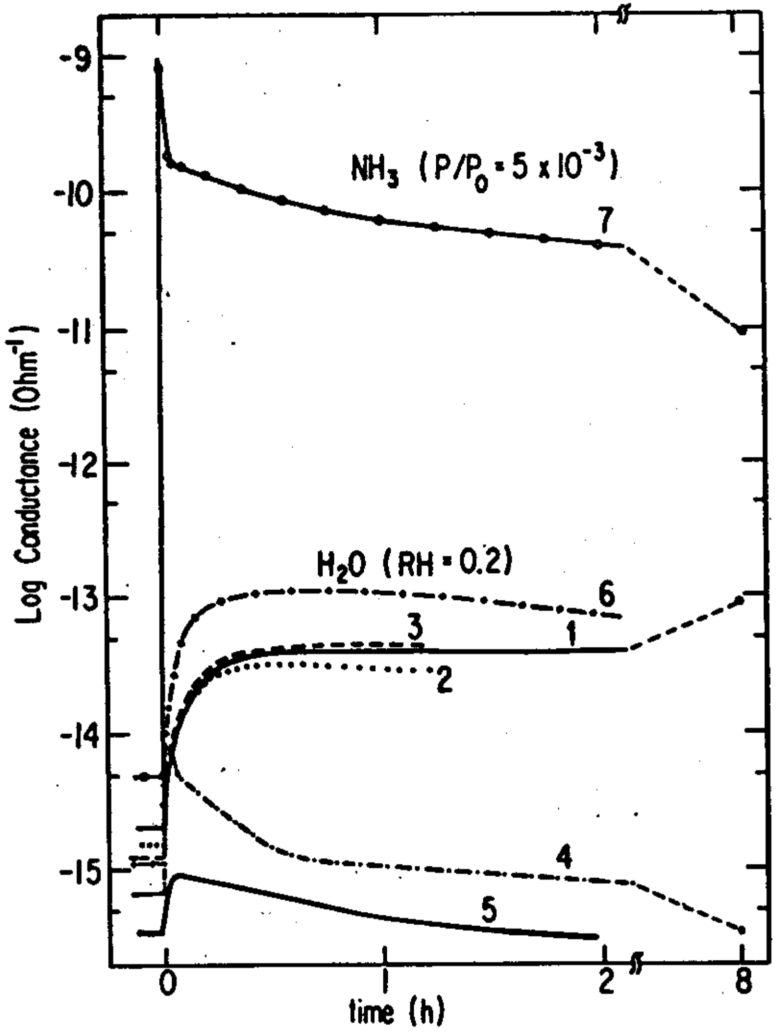


Figure 1

$d = 0.36\,\mu m$ $\Delta E = 0.76$ eV p-type

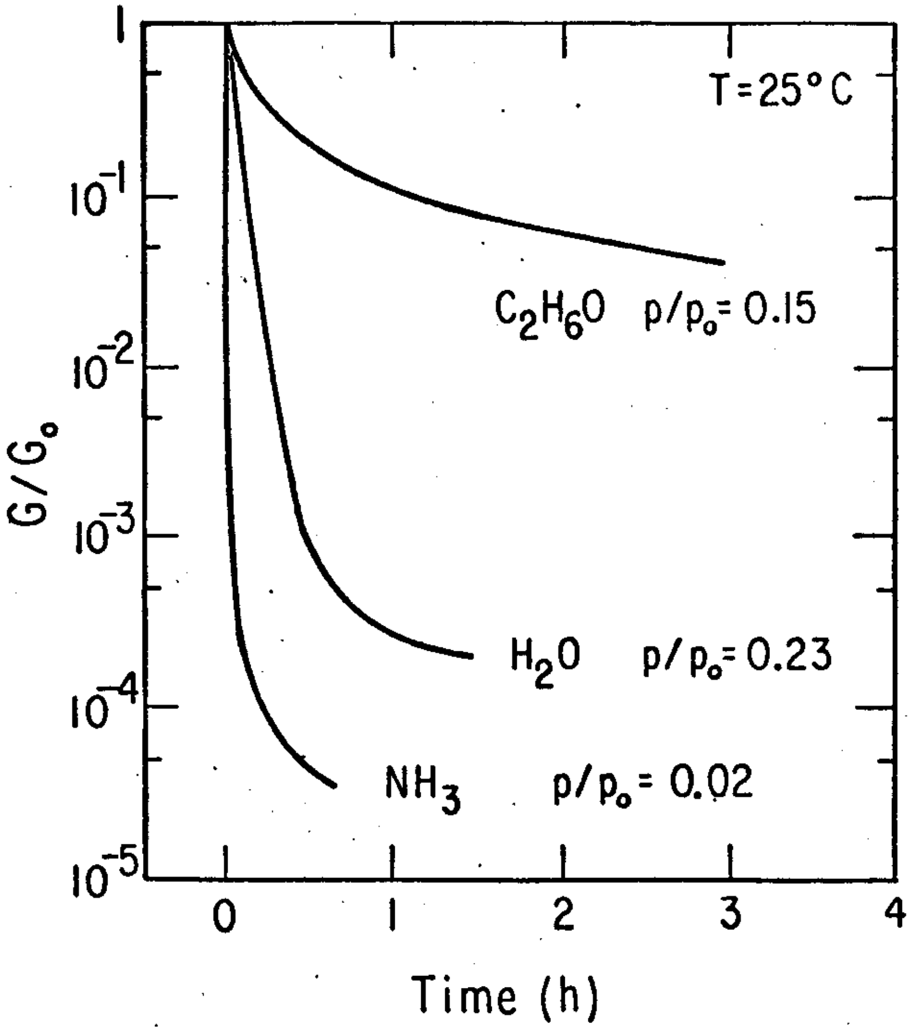
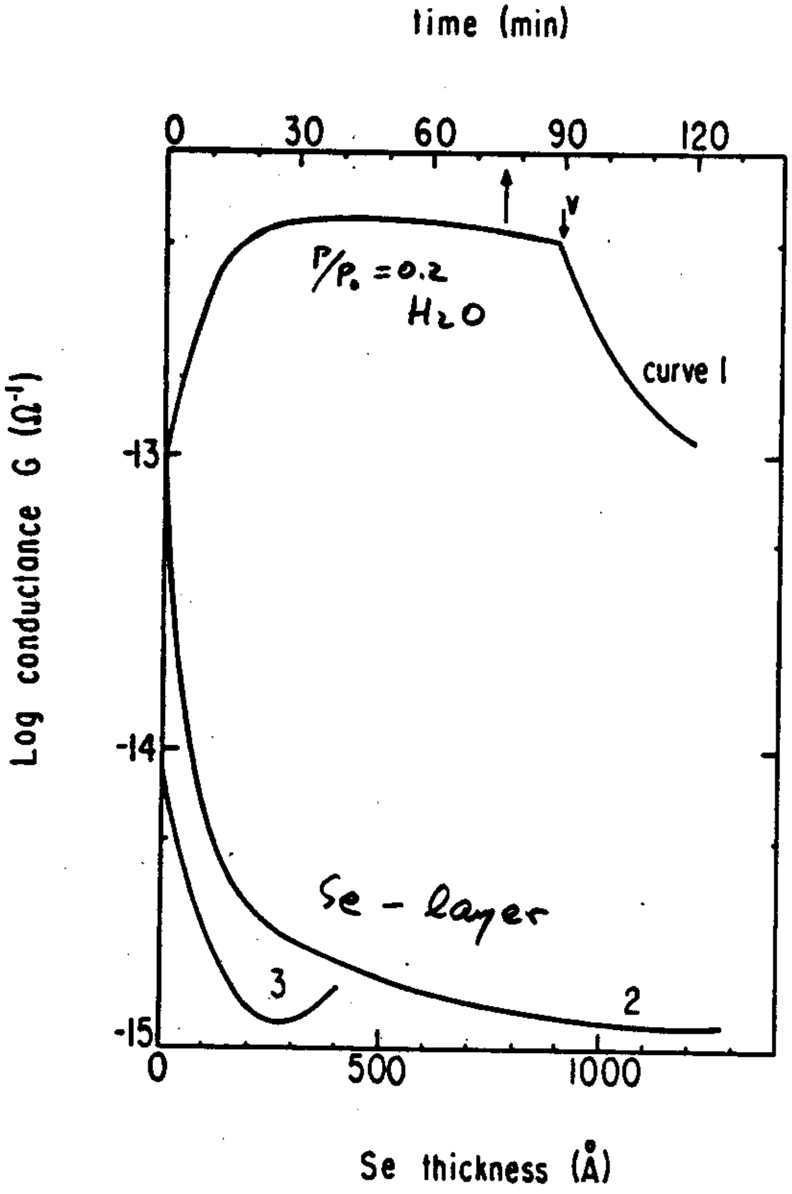
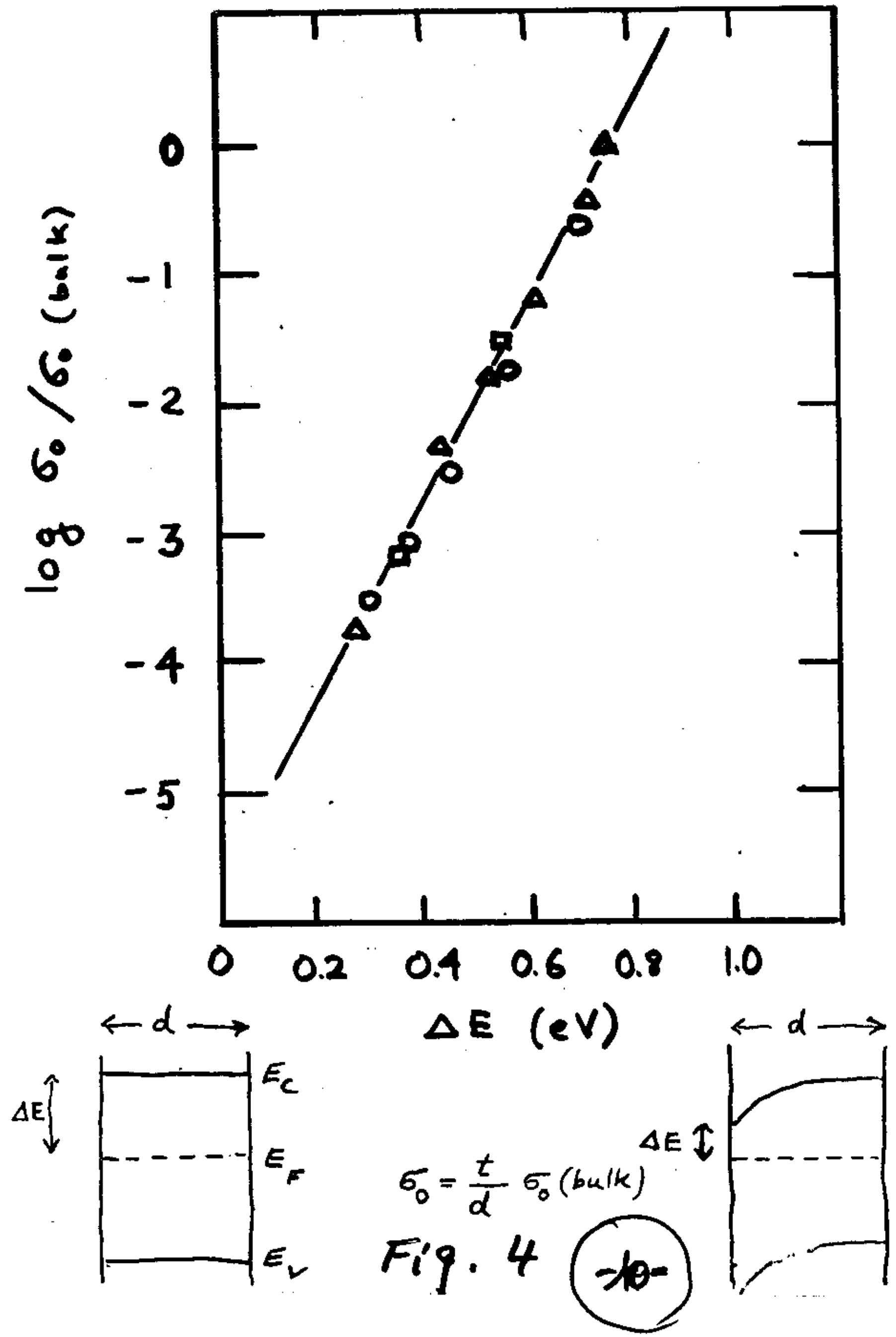


Figure 2



time (min)
0
30
60
90
120
V
$P/P_0 = 0.2$
H_2O
curve 1
Log conductance G (Ω^{-1})
-13
-14
-15
Se - layer
3
2
0
500
1000
Se thickness (Å)

Fig. #3



$\log \sigma_0 / \sigma_0$ (bulk)
0
-1
-2
-3
-4
-5
0
0.2
0.4
0.6
0.8
1.0
ΔE (eV)
d
ΔE
E_c
E_F
E_v
d
ΔE
$\sigma_0 = \frac{t}{d}\, \sigma_0$ (bulk)

Fig. 4

H. F. & C.C. Tsai   Solar Energy Mat. 1 (1979) 471

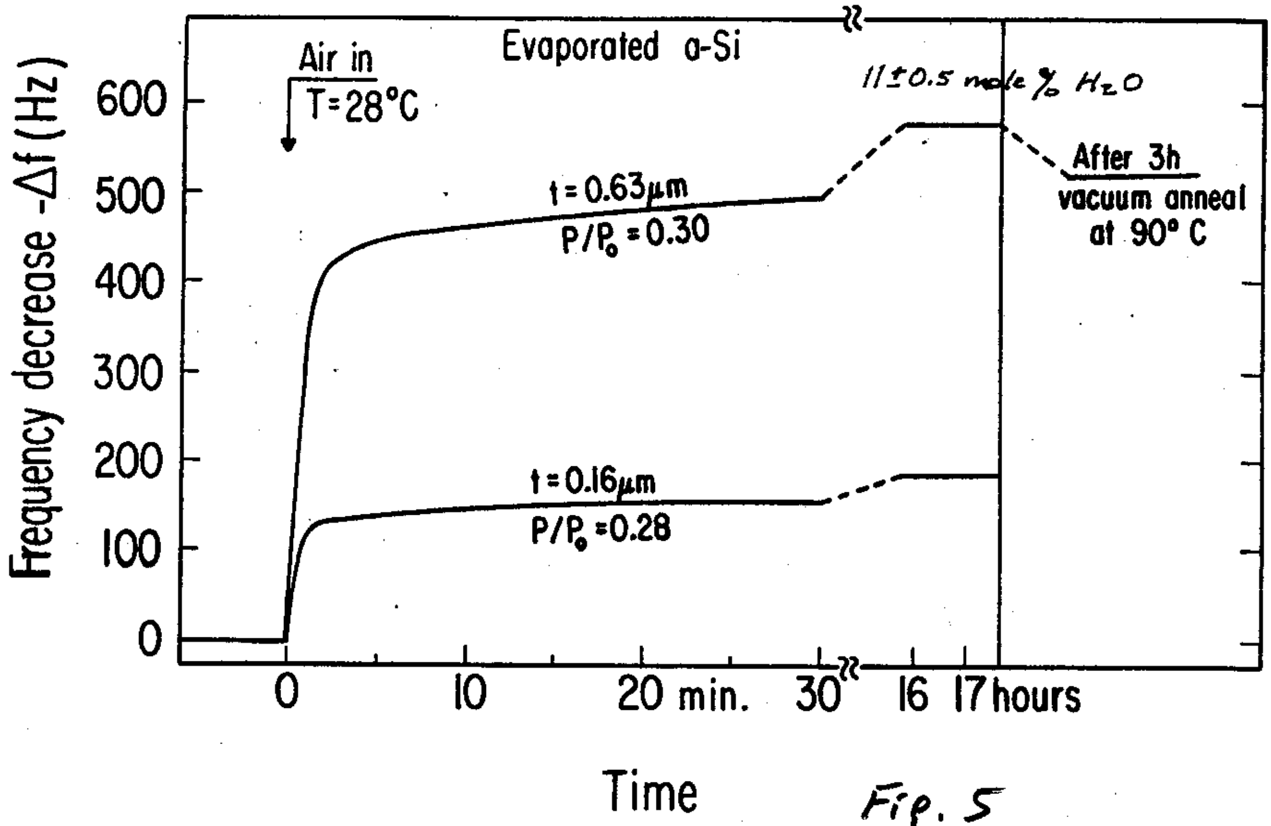


Fig. 5

H. F. & C.C. Tsai   Solar Energy Mat. 1 (1978) 471

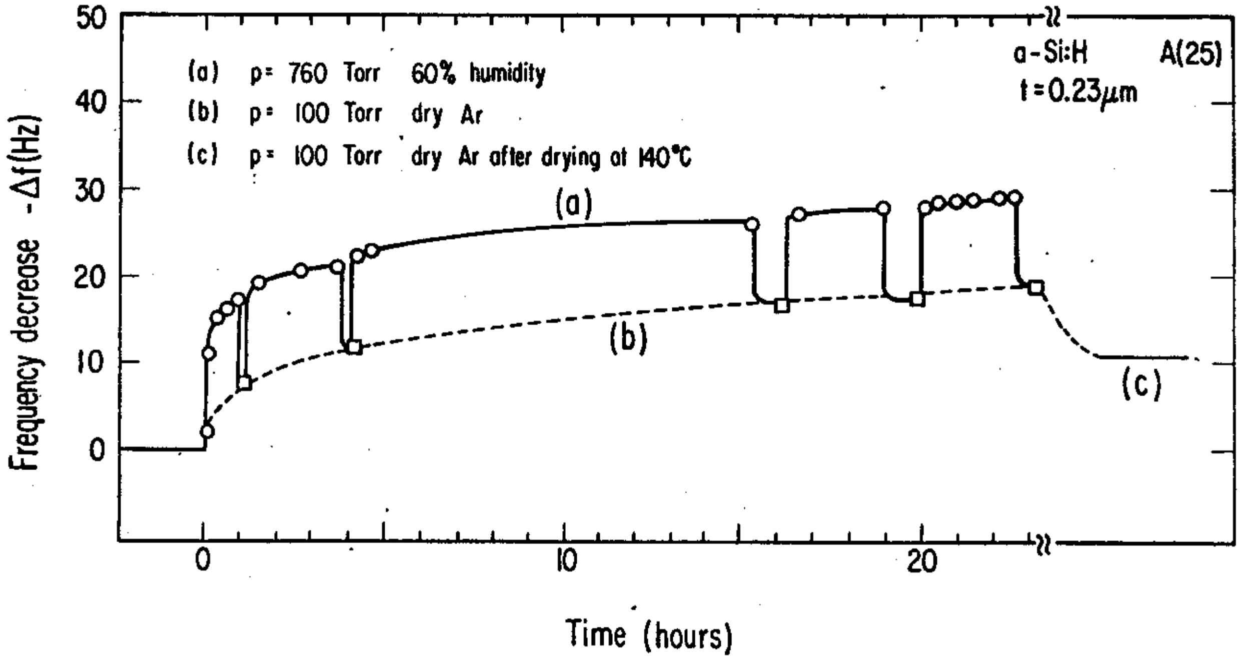
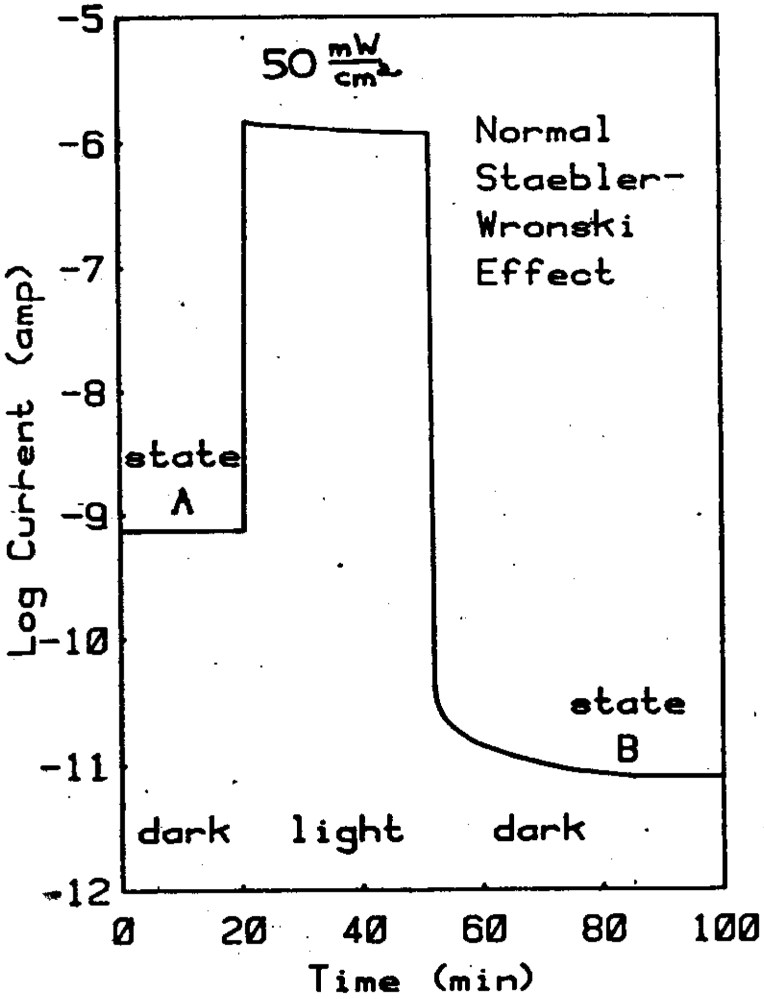
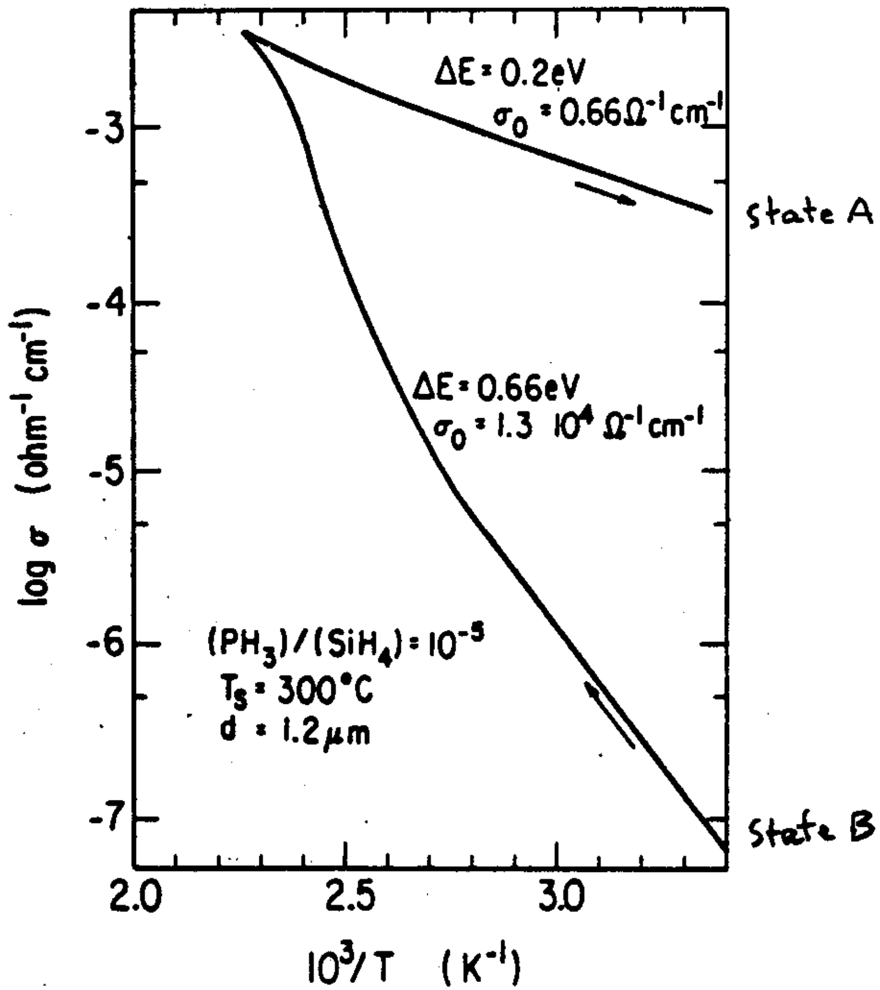


Fig. 6



50 mW/cm²
Normal
Staebler-
Wronski
Effect
state
A
state
B
dark
light
dark
-5
-6
-7
-8
-9
-10
-11
-12
Log Current (amp)
0
20
40
60
80
100
Time (min)

Fig. 7



ΔE = 0.2eV
σ0 = 0.66Ω⁻¹cm⁻¹
State A
ΔE = 0.66eV
σ0 = 1.3 10⁴ Ω⁻¹cm⁻¹
(PH3)/(SiH4) = 10⁻⁵
Ts = 300°C
d = 1.2μm
State B
-3
-4
-5
-6
-7
log σ (ohm⁻¹ cm⁻¹)
2.0
2.5
3.0
10³/T (K⁻¹)

Fig. 8

~~D.L. Staebler~~, C.R. Wronski
J. Appl. Phys. ~~(illegible)~~ 51 (1980) 3262

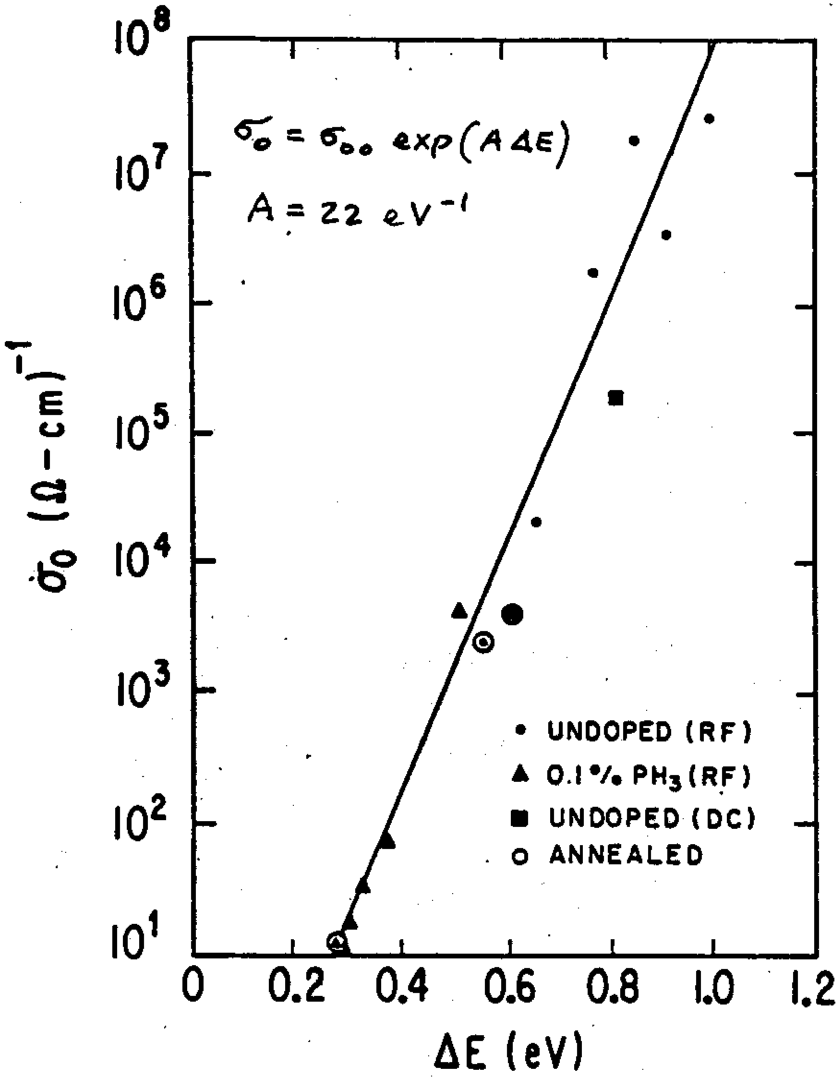


Fig. 9

-15-

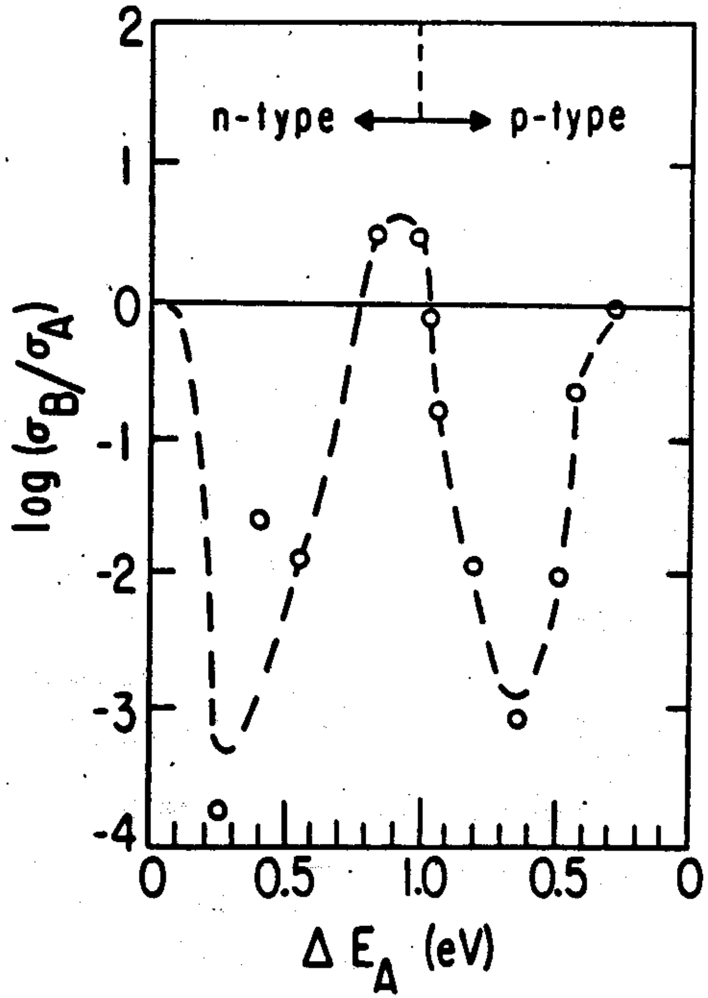
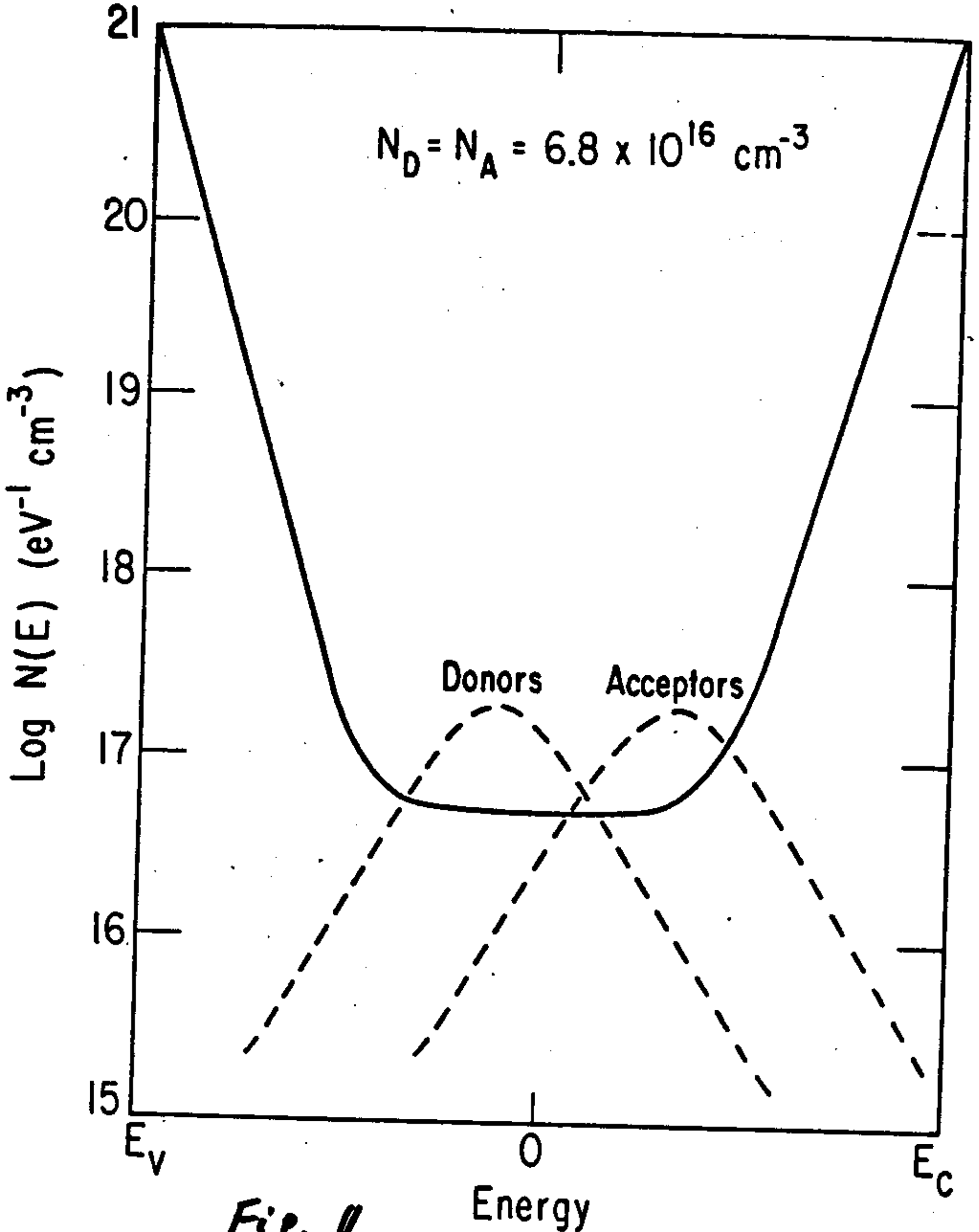


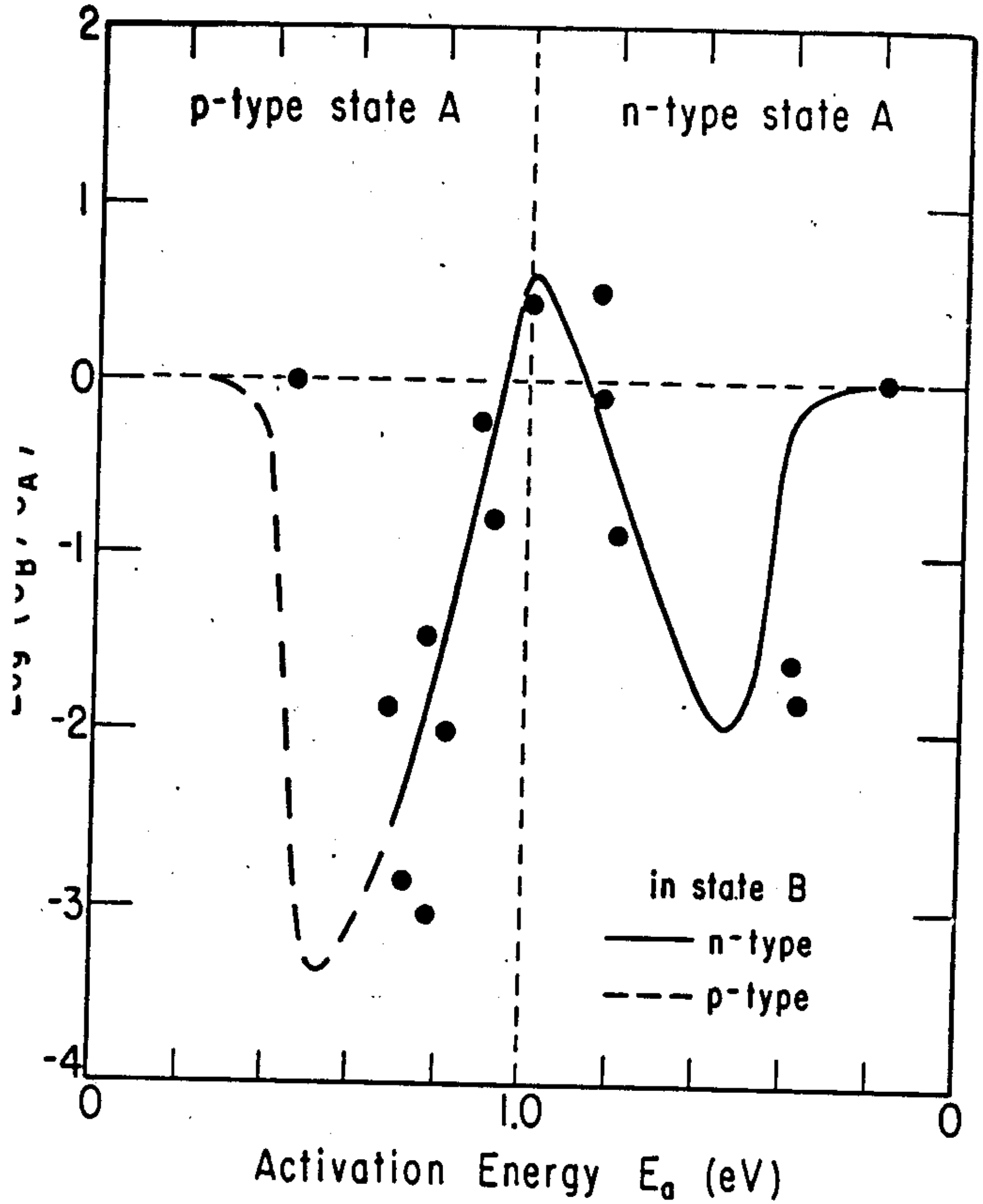
Fig. 10

-16-



$N_D = N_A = 6.8 \times 10^{16}$ cm^{-3}
Donors
Acceptors
Log N(E) (eV^{-1} cm^{-3})
21
20
19
18
17
16
15
E_V
0
E_C
Energy

Fig. 11



p-type state A
n-type state A
in state B
n-type
p-type
2
1
0
-1
-2
-3
-4
0
1.0
0
Activation Energy E_a (eV)

Fig 12

N. B. Goodman

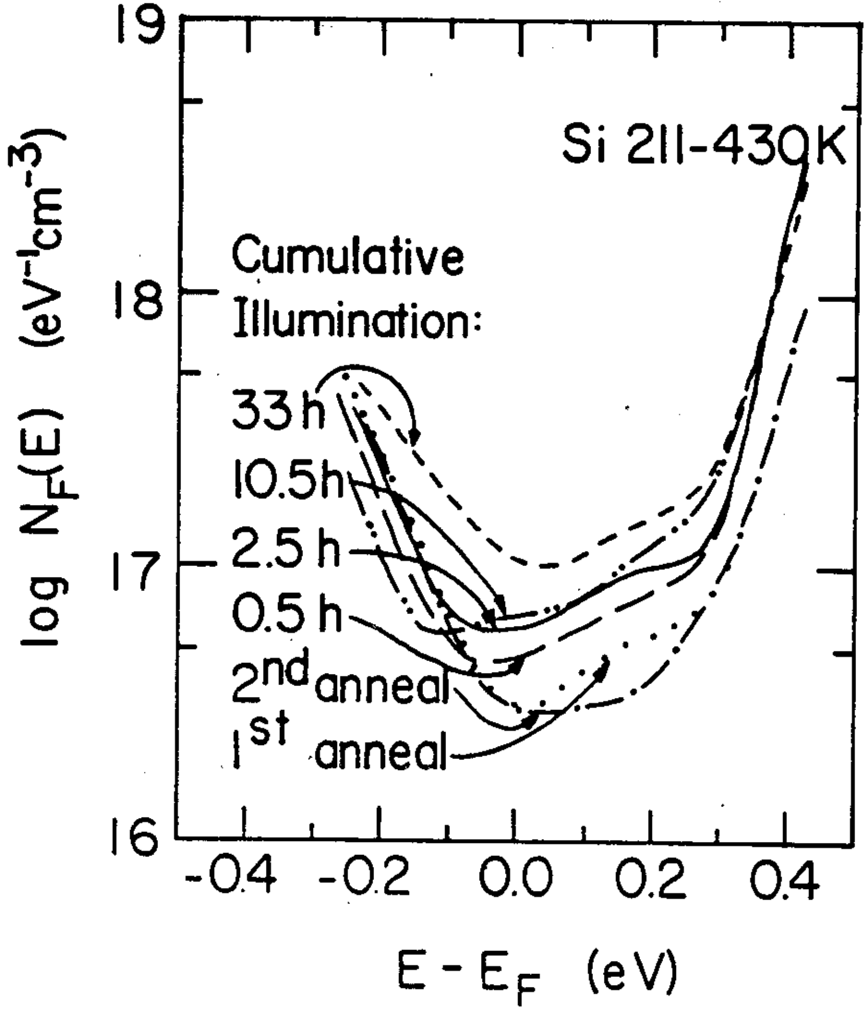
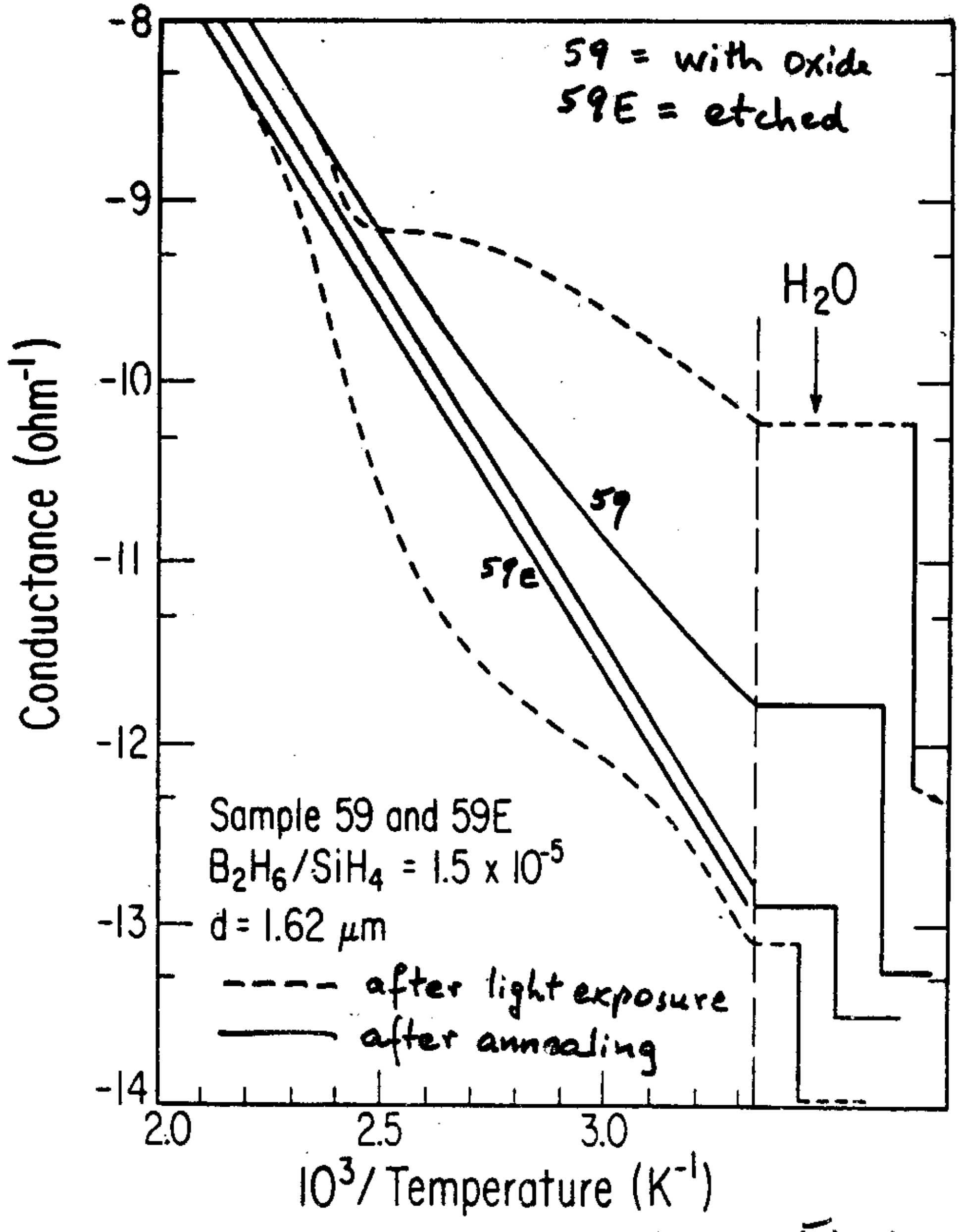


Fig. 13

-19-



-20-

Fig 14