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PHYSICS OF HEAVILY DOPED SILICON AND SOLAR-CELL PARAMETER MEASUREMENT

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CONTRACT: PHYSICS OF HEAVILY DOPED SILICON AND SOLAR-CELL PARAMETER MEASUREMENT

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GOALS: THEORY & EXPERIMENT ON ENERGY GAP (ΔE_G), LIFETIME (τ), RECOMB. VELOCITY (S), DIFFUSIVITY (D), MOBILITY IF N AND/OR P IS HIGH.

ALSO

ACCURATE DETERMINATION OF τ, S, IN QUASINEUTRAL REGIONS

REPORT DATE: 10/2/84 (3 MOS.)

Colored & Presented by C. Tang Sah

HIGH-EFFICIENCY SILICON SOLAR CELL RESEARCH

Status (Briefly)

3 Parameters: $\Delta E_G, \tau_B, S_{BSF}$

1 • 1. ENERGY-GAP MODEL DEVELOPED, COMPARED WITH PHOTOLUMINESCENT AND TRANSPORT DATA. ΔE_G

2 • 2. ELECTRICAL SHORT-CIRCUIT CURRENT DECAY (ESCCD) DEVELOPED AND IMPROVED τ_B, S_{BSF}

• 3. ESCCD AUGMENTED BY ADMITTANCE VS. ω AND V(FORWARD)

• 4. ESSCD+ADMITTANCE APPLIED TO MEASURE S AND τ FOR BASE OF MANY BSF SOLAR CELLS

Publications

2 ESSCD IN TRANS ED, Y · ESSCD BEING WRITTEN. τ_B, S_{BSF}

1 ENERGY GAP MODEL IN PHOTOVOLTAICS CONF., ALSO DETAILED VERSION UNDER REVIEW, PHYS. REV. ΔE_G

CO-WORKERS: A. NEUGROSCHEL, ALL WORK: P.T. LANDSBERG, C.T. SAH, AND NEUGROSCHEL ON ENERGY GAP.

Remarks on Energy Gap Model

- ENERGY GAP = KEY PARAMETER
- SIMPLE USEFUL FORMULA
- REPRESENTS EXPERIMENTAL FACTS
  - 5K (OPTICAL = PL)
  - 300K (TRANSPORT DATA)
- HEAVILY DOPED (LARGE N OR P)
- HIGHLY EXCITED (LARGE N AND P)
  - STRONG IRRADIATION
  - P/N TRANSITION REGION
- T DEPENDENCE
  - SOLAR CELLS AT 300K
  - EXPERIMENTS, OTHER T
- Simple understanble Theory :–
  Debye (Carrier) Screening < Electrostatic Coulombic
  - SAH (1966), Chapter 6
  - SAH, McNutt, Chan, TR28 (June 1974)
  - SAH, etal, SOLAR CELL (1978)
  - LANDSBERG, N.L.S. (1984)

HIGH-EFFICIENCY SILICON SOLAR CELL RESEARCH

TEMPERATURE DEPENDENCES OF $\sqrt{m_N m_P}/m$, E_G, n_i and L_D OF SILICON

C. T. Sah, N. J. McNutt and C. H. Chan

Technical Report No. 28

June 27, 1974

Solid State Electronics Laboratory
Technical Report No. 28
June 27, 1974

Electrical Engineering Research Laboratories
University of Illinois
Urbana, Illinois

The actual energy gap also includes the electron-hole, electron-electron and hole-hole electrostatic interaction energies which reduces the energy gap at high carrier concentrations. This effect is represented by ΔE,

$$\Delta E_G = -e/4\pi\epsilon(\lambda_D+a) \quad (4)$$

$$= -1.23\times10^{-4}/(L_D+a) \text{ Volts} \quad (5)$$

1984 Landsberg Version

EXPRESSION FOR GAP SHRINKAGE

$$(1):\quad E_G(N,P) = W + \frac{e^2}{\epsilon a}\, e^{-k_D(N,P)a}$$

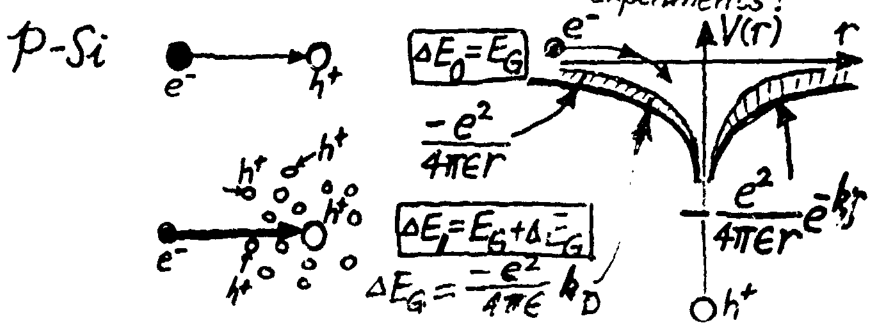
$$(2):\quad E_G = W + \frac{e^2}{\epsilon a}, \quad \text{for } N = P = 0$$

$$(3):\quad \Delta E_G = \frac{e^2}{\epsilon a}\left[1 - e^{-k_D(N,P)a}\right] = \frac{e^2}{\epsilon}\, k_D(N,P)$$

$\lambda_D = \frac{1}{k_D}$ = Debye Screening Length

1966 Sah Version: Screening by Majority carriers on minority carrier ΔE_G

★ **NOTE: ΔE_G data is from** minority carriers experiments!



Screening Wave Number k_D

$$k_D^2 = \frac{e^2}{\epsilon kT}\left[N_C F_{-1/2}(\eta_F - \eta_C) + \ldots\right]$$

FOR GENERAL N AND P.

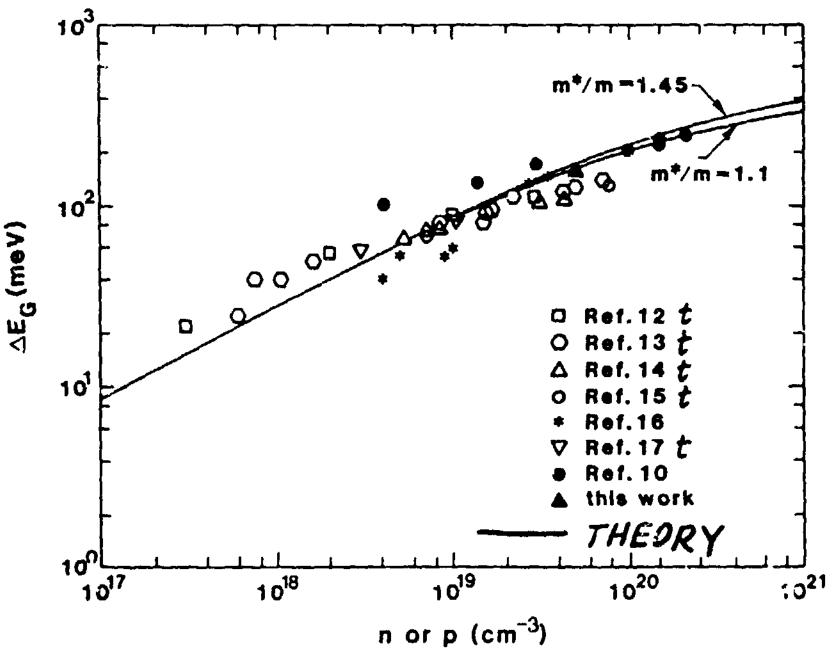
FOR LOW CONCENTRATIONS, FERMI INTEGRALS BECOME EXPONENTIALS:

$$k_D^2 = \left[e^2 (N + P)/\epsilon kT\right]$$

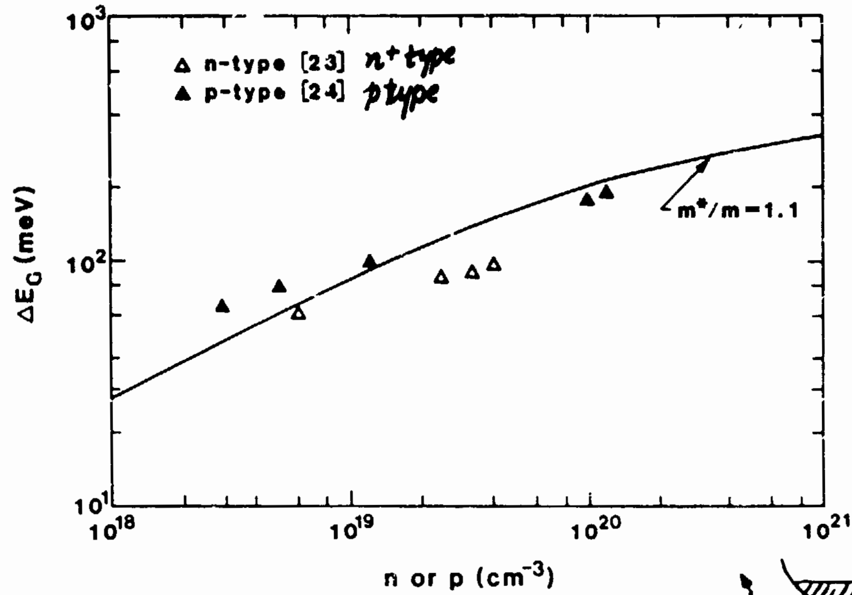
OR, FOR DEGENERATE DENSITY N,

$$k_D^2 = (3/\pi)^{1/3} \left(e^2 m_n^* / \pi \epsilon h^2\right) N^{1/3}$$

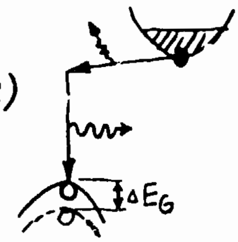
MKS unit
(4π of CGS taken out)

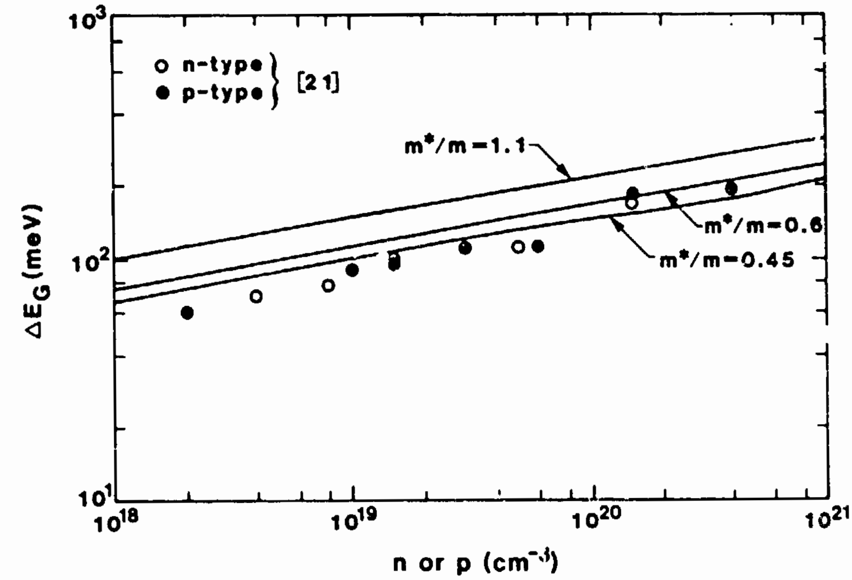


Comparison with minority carrier transport or 'pn' product measurements in bipolar devices: diodes, transistors.



Luminescence data (Dumke)
at 300K
23. Dumke, APL 42, 196 (1983)
24. Dumke, JAP 54, 3200 (1983)





5K Photoluminescence and exitation data
Wagner PR B29, 2002 (1984)

2. MEASUREMENT OF S AND τ IN QUASINEUTRAL BASE OF BSF CELLS

S_{BSF} τ_B

ESSCD ↔ slope & intercept

ESSCD

- 1. REPORT IMPROVED ESSCD: ELECTRICAL SHORT-CIRCUIT CURRENT DECAY BY USE OF

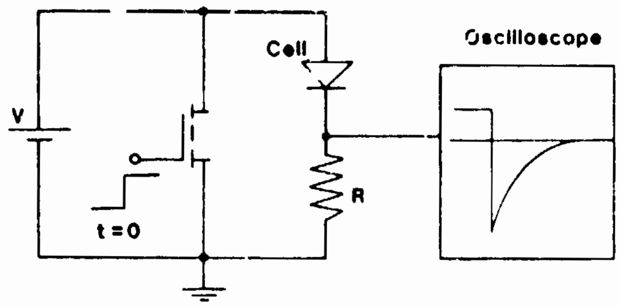
  FAST MOS TRANSISTOR SWITCH (10 ns.).
- 2. ADVANTAGE OF ESSCD VS OPEN-CIRCUIT VOLTAGE DECAY, REVERSE STEP RECOVERY, ETC. IT AVOIDS INFLUENCE OF HOLES & ELECTRONS IN P/N SCR BY FORCING DENSITIES TO EQUILIBRIUM VALUES IN 10 ps.

G_{QN} vs ω
$C_{HF}-C_{LF} \rightarrow \tau_B$

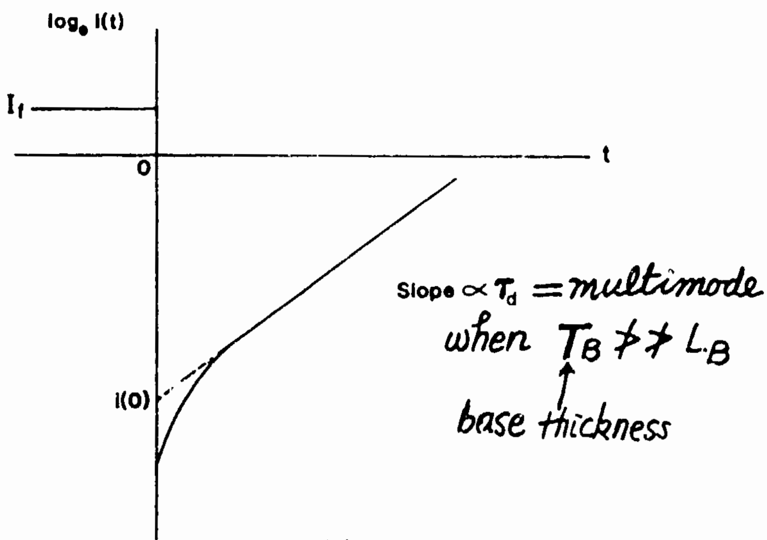
- 3. TO MEASURE S AND τ IN BASE YOU NEED SLOPE OF LOG V(t) AND ONE OTHER PIECE OF DATA. THIS IS BEST PROVIDED BY Y(jω,V)= ADMITTANCE MEASURED ON BRIDGE. Y PROVIDES TWO THINGS:
  (A) SEPARATION OF QNE I FROM QNB I BY CHANGING ω.
  (B) CONFINEMENT OF Y RESPONSE TO VOLUME (NOT SURFACE) FOR LARGE ω; THUS CAN GET τ EVEN IF DIFF. LENGTH > BASE THICKNESS.

Y(ω) actually $-C_{HF}+C_{LF}=C_{QN}$ vs ω

G_{QN} vs ω

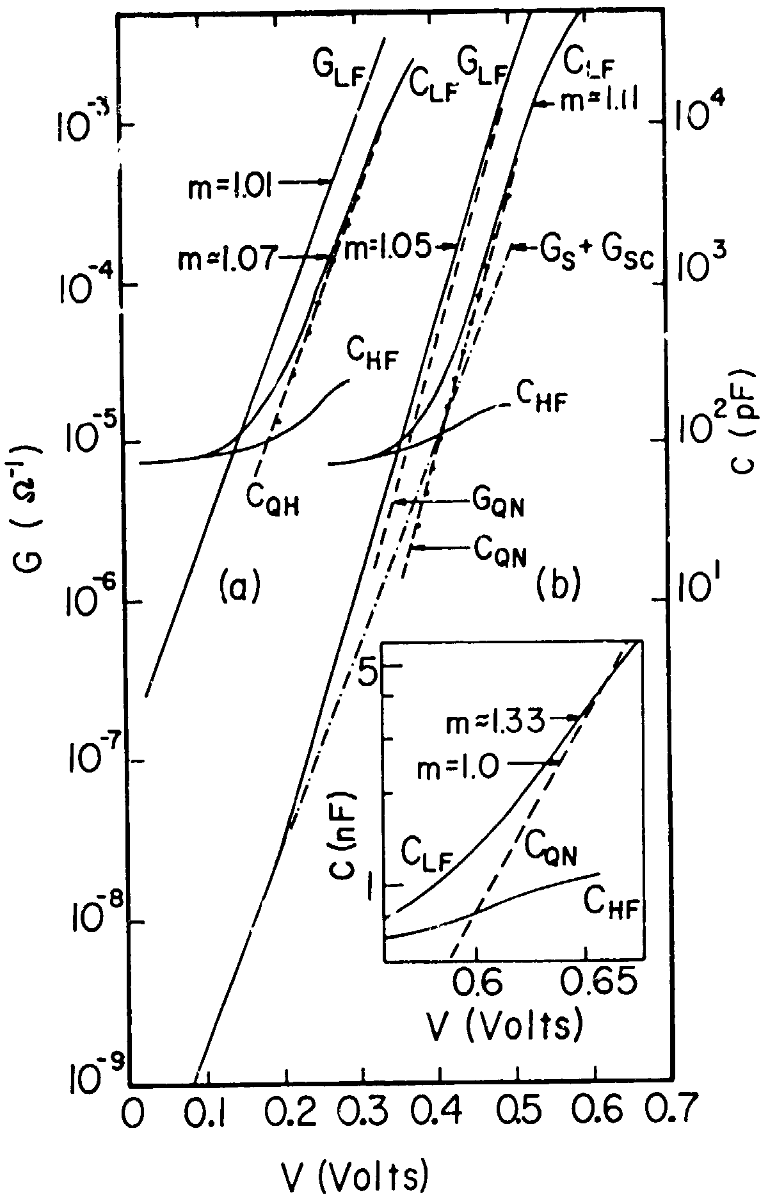


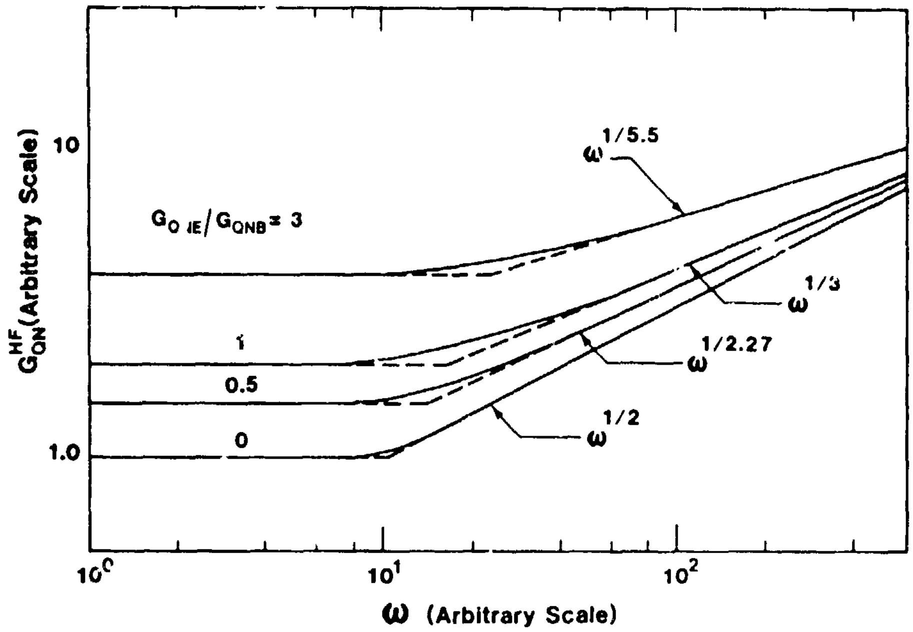
(a)



(b)

τ_d → multi-mode


G_LF
C_LF
G_LF
C_LF
m=1.11
m=1.01
m≈1.07
m=1.05
G_S + G_SC
C_HF
C_HF
C_QH
G_QN
C_QN
(a)
(b)
G (Ω⁻¹)
C (pF)
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁴
10³
10²
10¹
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
V (Volts)
5
m≈1.33
m=1.0
C (nF)
1
C_LF
C_QN
C_HF
0.6 0.65
V (Volts)



Recommendations

- 1. USE ~~NEW~~ OLD-RENEWED ENERGY GAP MODEL IN COMPUTER SIMULATION. ΔE_G
- 2. USE ESSCD + Y(jω,V) FOR τ_B AND S OF BACK SURFACE FIELD. S_{BSF}

NEAR TERM EFFORTS:

- 1. NEW EXPERIMENTS TO EXPLORE ENERGY GAP MODEL FURTHER. ΔE_G
- 2. ADAPT S_E AND τ_E MEASUREMENTS TO EMITTER, USING Y(jω).
- 3. THEORY TO ACCOUNT FOR ΔE_D & ΔE_A IMPURITY BAND INFLUENCE FOR MODERATELY HIGH DENSITIES: 10
- 4. ACCOUNT FOR HOLES AND AND ELECTRONS IN SCR TO IMPROVE ACCURACY OF OPEN-CIRCUIT VOLTAGE DECAY C_{SCR} G_{SCR}

- 1. ΔE_G, ⊕ ΔE_D & ΔE_A
- 2. S_{BSF}, τ_B, ⊕ S_E, τ_E