HIGH-EFFICIENCY SOLAR CELLS

N87-16415

MEASUREMENT OF MINORITY CARRIER LIFETIME, MOBILITY AND DIFFUSION LENGTH IN HEAVILY DOPED SILICON

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Outline

Introduction

Measurement of Minority Carrier Lifetimes in p^+ and n^+ Si

- photoluminescence decay technique

- data reduction

- fits of lifetime vs. doping data (p^+ and n^+)

Measurement of Diffusion Length and Mobility in p^+ and n^+ Si

- lateral transistor test structure

- typical diffusion length data

- diffusion length vs. doping in p^+ Si

- electron (minority carrier) mobility vs. doping

- hole (minority carrier) mobility vs. doping

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Minority Carrier Lifetime in n^+ and p^+ Silicon
Recombination Paths

- Shockley-Read-Hall Recombination

$$\tau_p = (N_t v \sigma)^{-1}$$

  – lifetime independent of doping, dependent on N_t

- Auger Recombination: Trap Assisted

$$\tau_p = (T_n n N_t)^{-1}$$

  – lifetime dependent on doping, N_t

- Auger Recombination: Band to Band

$$\tau_p = (C_n n^2)^{-1}$$

  – lifetime dependent on doping only

Photoluminescence Lifetime Decay

- short (200 ps) laser pulse generates minority carriers
- monitor decay of luminescence radiation

Photoluminescence Decay Lifetime Measurement Apparatus

647 nm MODE LOCKED Kr⁺ LASER

SINGLE PULSE SELECTION ELECTRONICS

BRAGG CELL

HEAVILY DOPED Si SAMPLE

INFRARED MONOCHROMATOR

LIQUID N₂ COOLED Si PHOTOMULTIPLIER

VARIABLE DELAY

PULSE AMPLITUDE DISCRIMINATOR

TIME TO PULSE HEIGHT CONVERTER   STOP   START

PULSE AMPLITUDE DISCRIMINATOR

WIDEBAND LOW-NOISE AMPLIFIER

MULTI-CHANNEL ANALYZER

LABORATORY COMPUTER DATA STORAGE

Photoluminescence Decay
Si:Sb $4.2 \cdot 10^{18}$
$\tau = 160$ ns $\pm$ 10%

when τ long compard to 'instrumental' pulse width decay rate of photoluminescence yeilds τ

CHANNEL NUMBER (1.01 ns/ch)
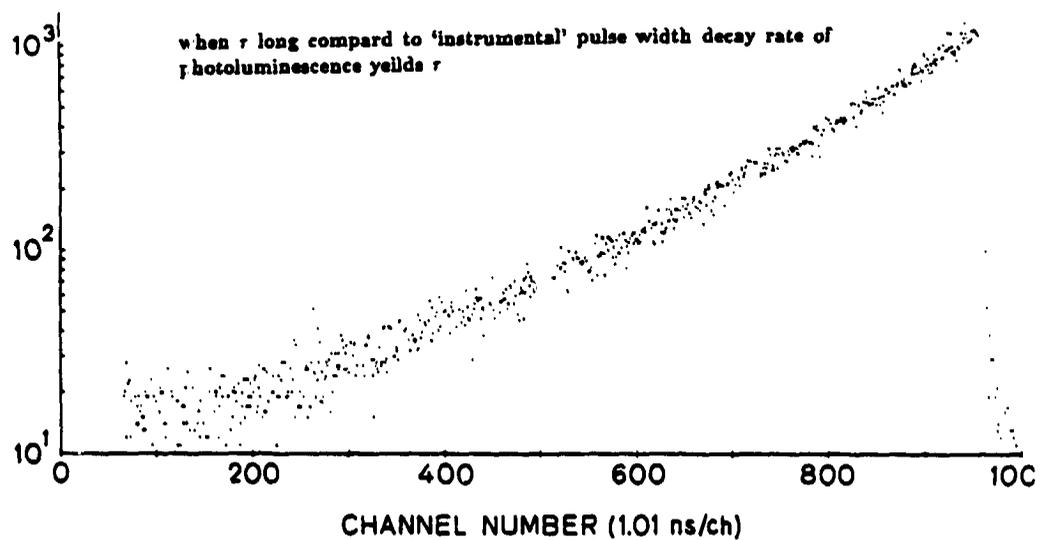
Photoluminescence Decay
Si:Ph 9.2 · 10^{19}
$\tau = 880$ ps $\pm$ 20%

when τ is short compared to 'instrumental' pulse width must deconvolve τ

COUNTS

10^4

10^3

10^2

10^1

0   200   400   600   800   1000

CHANNEL NUMBER (49.8 ps/ch)
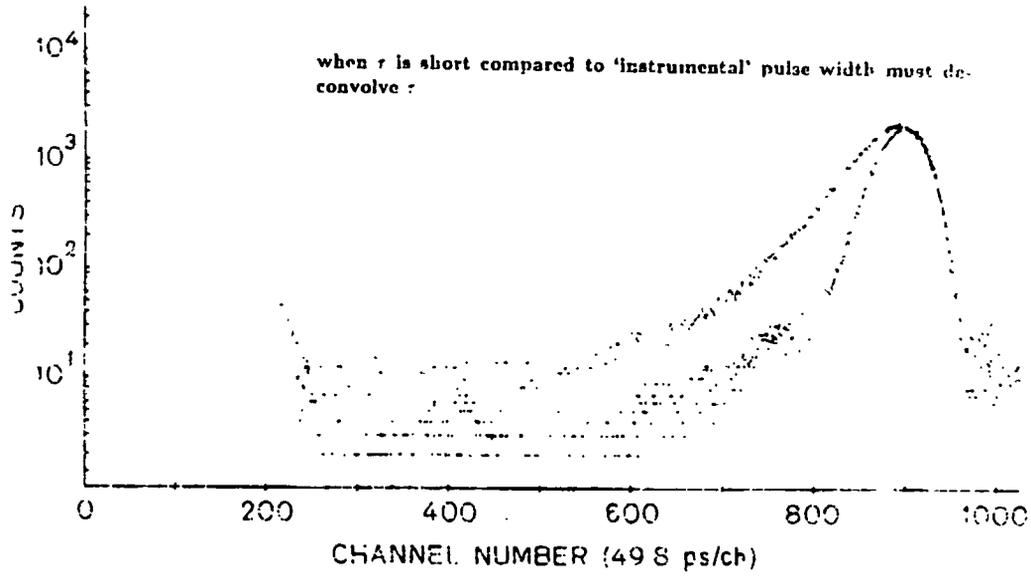
Electron Lifetime in p-Type Silicon

- This Data
- Dziewior/Schmid

ELECTRON LIFETIME (s)

10^{-4}

10^{-5}

10^{-6}

10^{-7}

10^{-8}

10^{-9}

10^{-10}

$\tau_n \sim p^{-1}$

$\tau_n \sim p^{-2}$

10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21}

p-TYPE DOPING (cm^{-3})

360
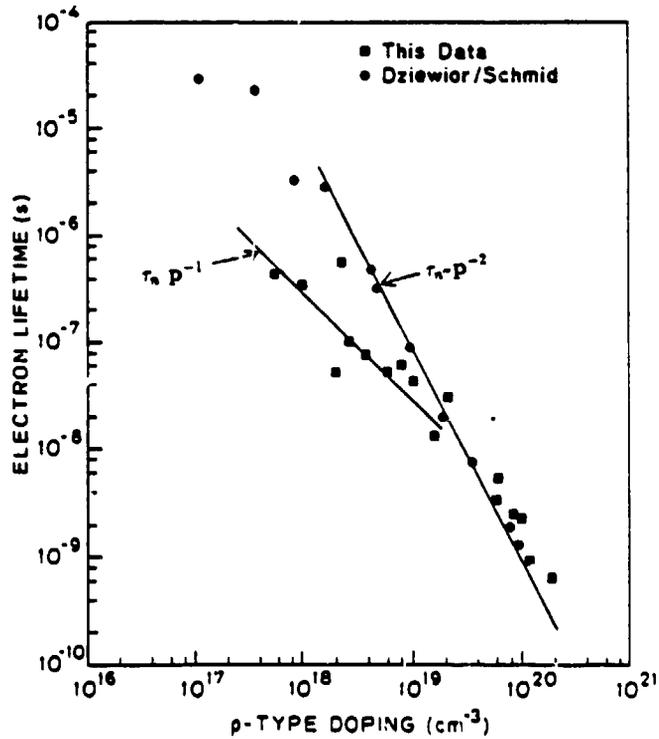
Hole Lifetime in n-Type Silicon
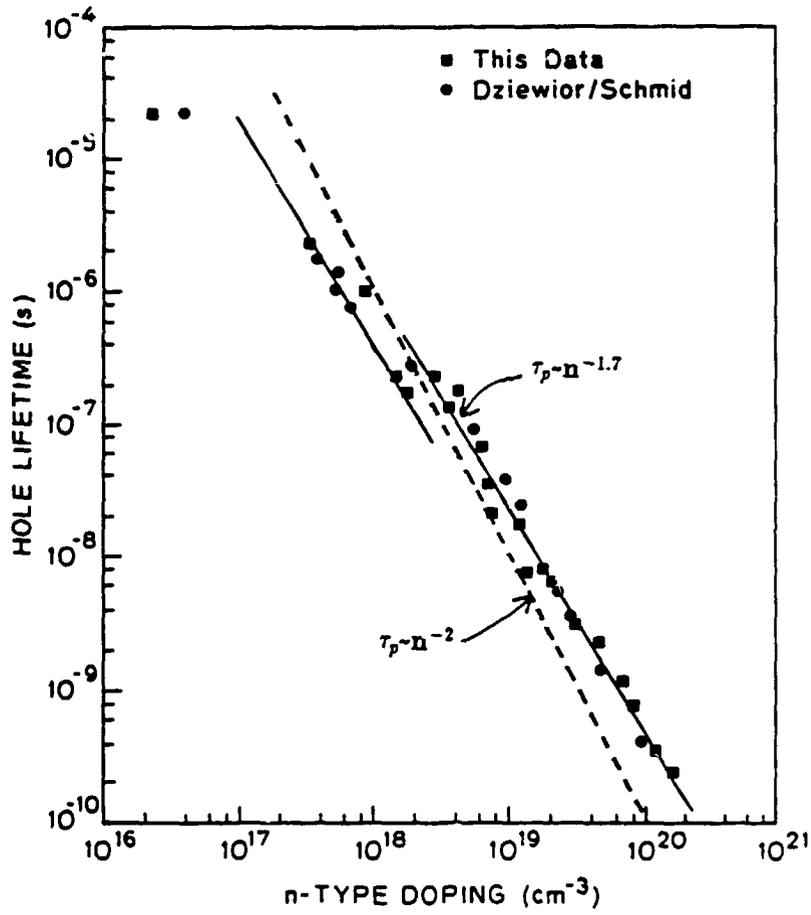
Measurement of Diffusion Length and Mobility

- Diffusion Length (electrons in p$^+$ Si) $L_n = \sqrt{D_n \tau_n}$

- Mobility (electrons in p$^+$ Si) $\mu_n = q/kT \; D_n$

### Lateral Transistor to Measure L_n
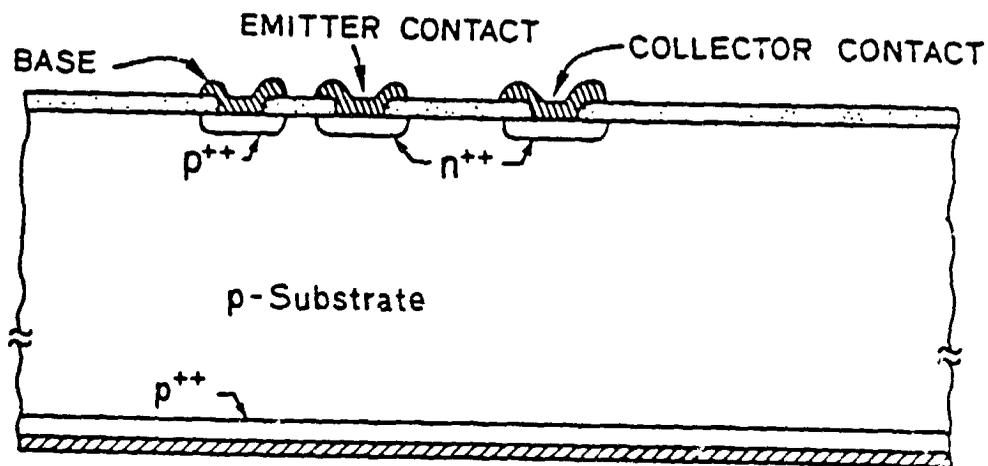
$$I_c = I_{c0}(e^{(qV_{bc}/kT)} - 1)$$

$$I_{c0} = \frac{qAn_0 D_n}{L_n} e^{-(W_b/L_n)} \qquad \text{when } W_b >> L_n$$

use similar structures v 'th varying W_b to obtain L_n

Gummel Plot of Lateral Bipolar Transistors

$W_b = 1.25 \mu m$

$W_b = 10.0 \mu m$

I_b

I_c

Base-Emitter voltage V_{be} (V)
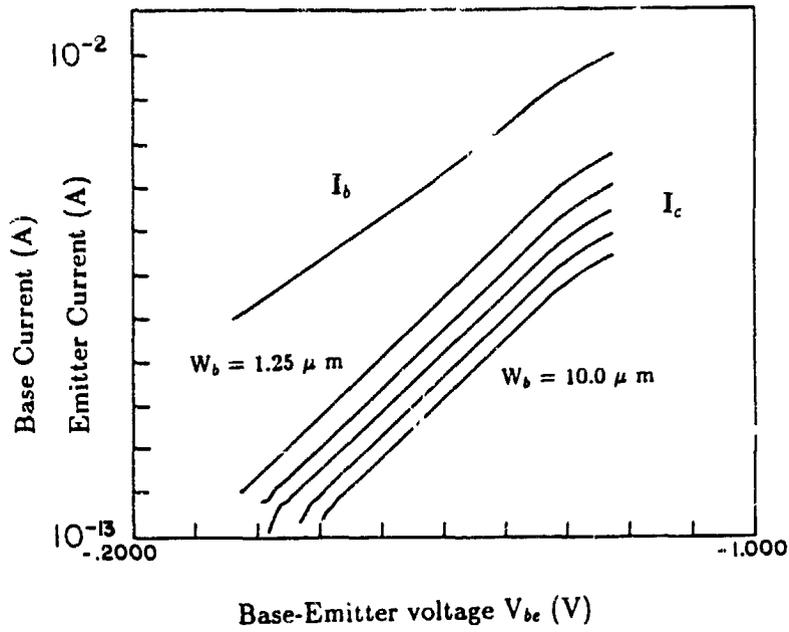
Electron Lifetimes of L_n Samples

Acceptor Doping N_A (cm^{-3})
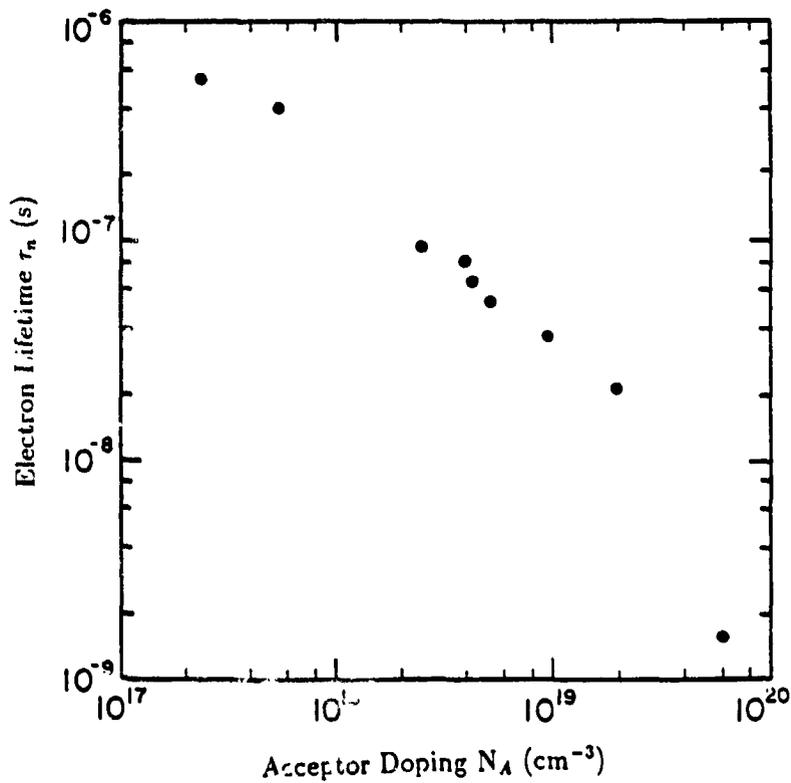
Extracted Electron Diffusion Lengths
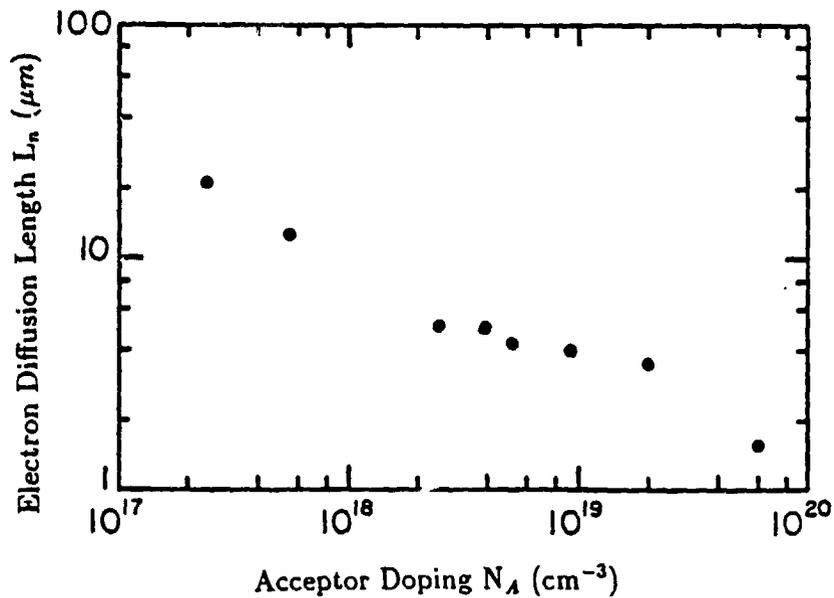
## Electron Mobility at 300°K
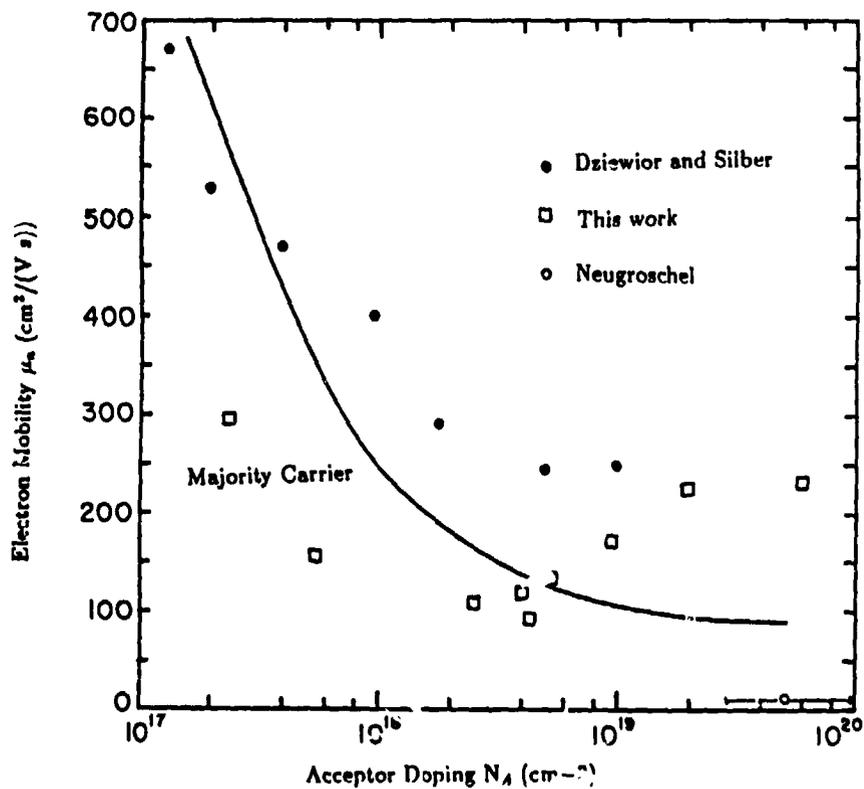
Lp and τp in Heavily Doped Epitaxial Silicon
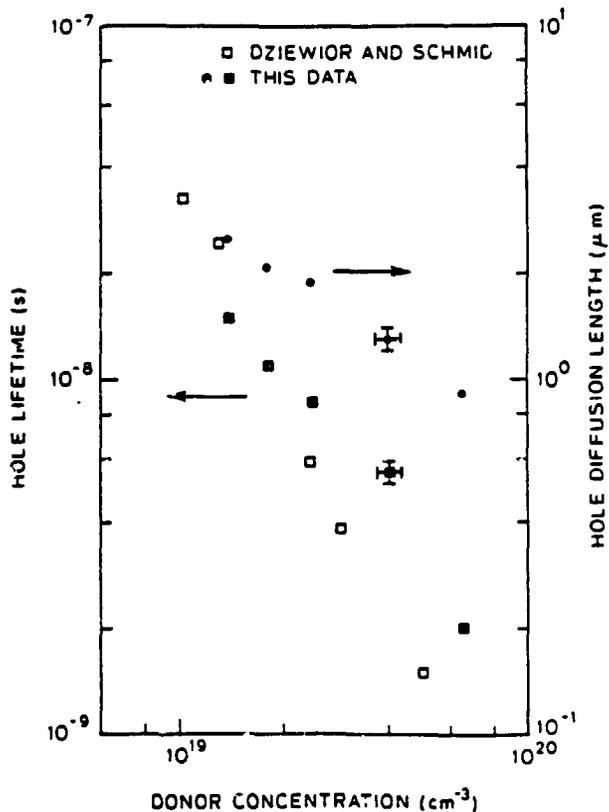
Hole Mobility in P epi Silicon
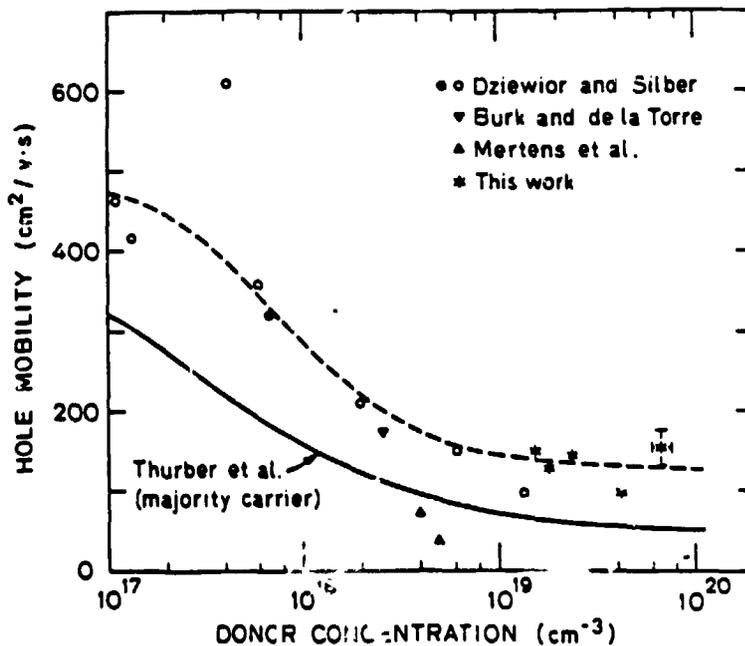
Conclusions

Lifetime in heavily doped Si

- first comprehensive measurements of τ_n, τ_p in *processed* heavily doped Si

- τ measurements extended into 10^{20} cm^{-3} doping range

- photoluminescence decay technique suitable and accurate

- τ_n in p$^+$ Si

    'standard' τ_n dependence with N_A^{-2} accurate in very limited range

    - lifetime modeled best by sum of inverse plus inverse square dependence on N_A

- τ_p in n$^+$ Si

    - previously observed τ_p dependence verified

    - use of N_D^{-2} dependence inadequate for wide doping range

    - data suggests better fit lifetime dependence of approximately $N_{\nu}^{-1.7}$

Diffusion Length and Mobility Measurement

- lateral transistor test structure used to measure L_n, L_p

- measurement of lifetimes allows extraction of μ_n, μ_p

- extraction of μ_n, μ_p in 10^{19} range shows that minority carrier mobilities exceed majority carrier mobilities