MEASUREMENT OF MINORITY CARRIER TRANSPORT PARAMETERS IN HEAVILY DOPED n-TYPE SILICON

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Scaled Bipolar Devices

1970's

1980's
Basic Transport Equations

Assumptions:

- n-type silicon
- steady state
- quasi-neutrality
- low injection
- 1-D

1. Hole current equation:
   \[ J_p = \mu_p \frac{dF_{fp}}{dx} \]

2. Hole continuity equation:
   \[ \frac{1}{q} \frac{dJ_p}{dx} = -R = -\frac{p - p_o}{\tau_p} \]

3. Hole density equation:
   \[ p = \int_{-\infty}^{\infty} \rho_p(E)[1 - f(E)]dE = p_o \exp \frac{E_F - E_{fp}}{kT} \]
HIGH-EFFICIENCY DEVICE RESEARCH

Vertical Transistor

Lateral Transistor

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Lateral Transistors

**Extraction of diffusion length**

Collector current:

\[ I_{oci} = qAF_L(p_0D_p)\left(\frac{1}{L_p}\right)\frac{1}{\sinh\left(\frac{W_{Bi}}{L_p}\right)} \]

If \( W_{Bi} \gg L_p \)

\[ I_{oci} = qAF_L(p_0D_p)\left(\frac{2}{L_p}\right)e^x - \left(\frac{W_{Bi}}{L_p}\right) \]

Then

\[ \frac{I_{oci}}{I_{oc1}} = e^x - \left(\frac{W_{Bi} - W_{B1}}{L_p}\right) \]
HIGH-EFFICIENCY DEVICE RESEARCH

HOLE DIFFUSION LENGTH (μm)

DONOR CONCENTRATION (cm⁻³)

- Log-log plot showing the relationship between hole diffusion length and donor concentration.
HIGH-EFFICIENCY DEVICE RESEARCH

![Graph showing the relationship between hole diffusion length and donor concentration. The graph includes data from various researchers: Nijs, Burk and de la Torre, Possin et al., Passari and Sussi, Mertens et al., Wieder, del Alamo and Swanson, and van Overstraeten. The x-axis represents donor concentration (cm^-3), and the y-axis represents hole diffusion length (μm).]
Vertical Transistors

Measurement of \( p_o D_p \)

Collector current:

\[
J_{oc} = p_o D_p \left( \frac{1}{L_p} \right) \frac{1}{\sinh \left( \frac{W_B}{L_p} \right)}
\]

If \( W_B \ll L_p \)

\[
J_{oc} \approx p_o D_p \frac{1}{W_B}
\]

If \( W_B \gg L_p \)

\[
J_{oc} \approx p_o D_p \frac{2 \exp \left( - \frac{W_B}{L_p} \right)}{L_p}
\]

Graph: Donor concentration vs. \( p_o D_p \)
Conclusions

1. There are only two independent parameters that control minority carrier transport and recombination in heavily doped silicon: $p_D$ and $L_P$.

2. These parameters have been measured in heavily phosphorus doped silicon.

3. With the use of these measured parameters, accurate prediction of the emitter saturation current of bipolar transistors has been demonstrated.