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

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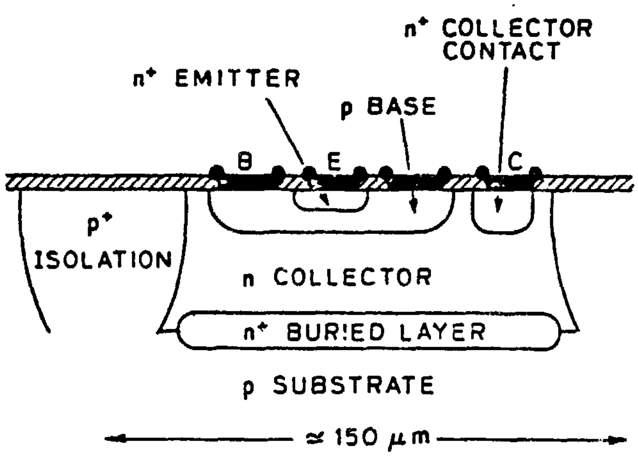
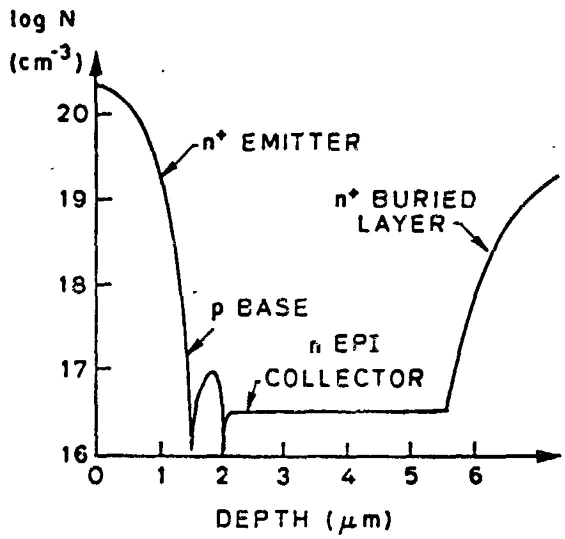
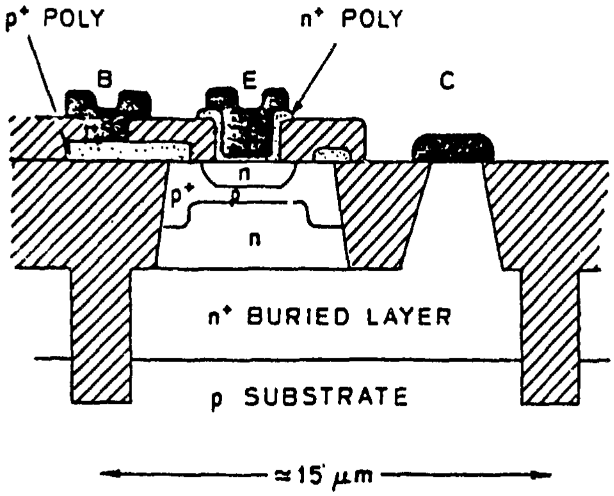
Scaled Bipolar Devices

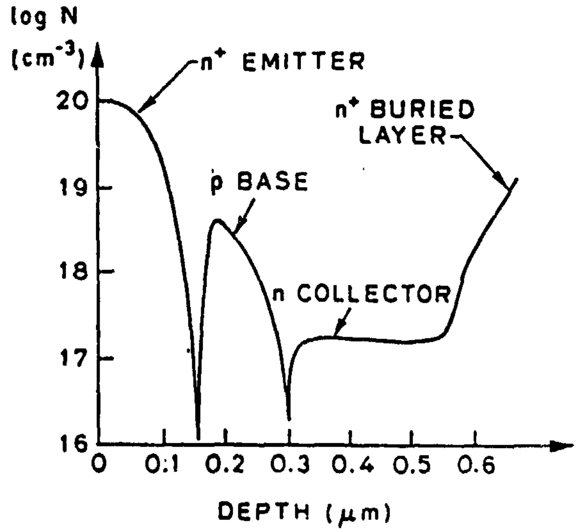
1970's

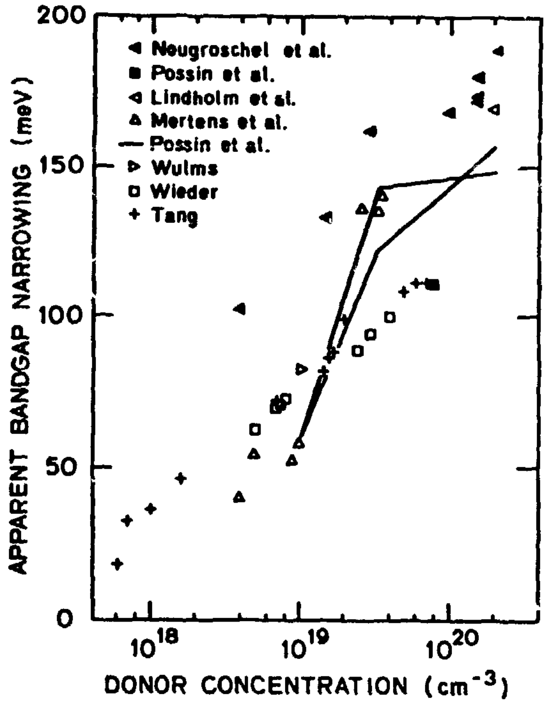




1980's







Basic Transport Equations

Assumptions:

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

1. Hole current equation:

$$J_p = p\mu_p \frac{dF_{fp}}{dx}$$

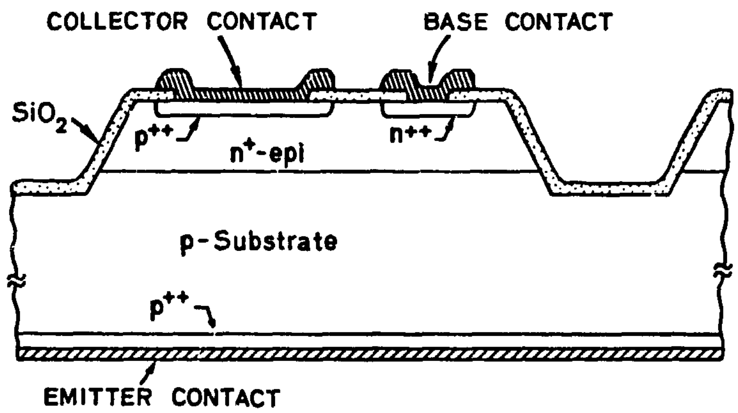
2. Hole continuity equation:

$$\frac{1}{q}\frac{dJ_p}{dx} = -R = -\frac{p - p_o}{\tau_p}$$

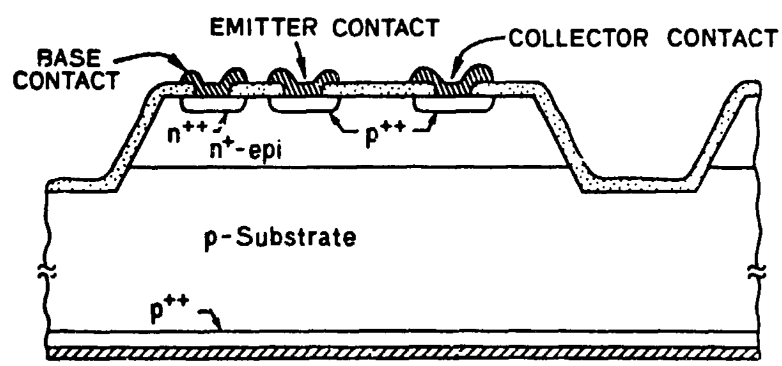
3. Hole density equation:

$$p = \int_{-\infty}^{\infty} \rho_v(E)[1 - f(E)]dE = p_o exp \frac{E_F - E_{fp}}{kT}$$

Vertical Transistor



Lateral Transistor



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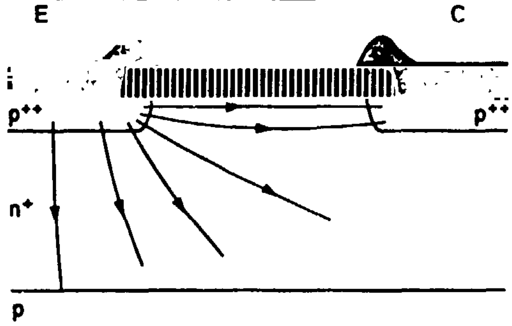
Lateral Transistors

Extraction of diffusion length



Collector current:

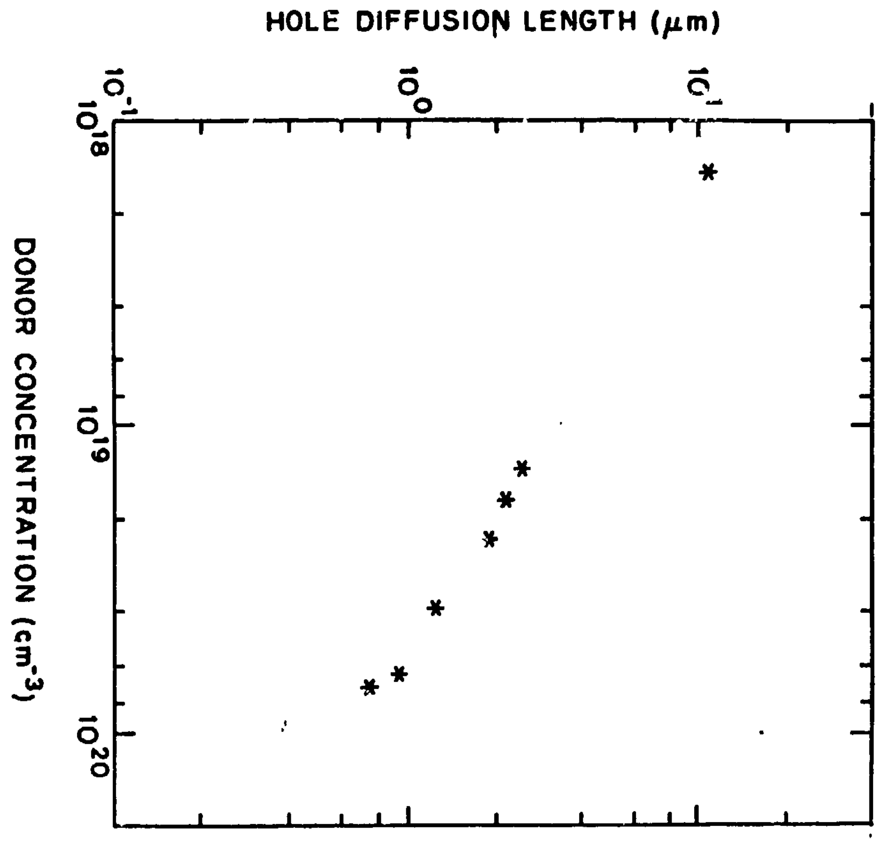
$$I_{oci} = qAF_L(p_oD_p)(\frac{1}{L_p})\frac{1}{sinh(\frac{W_{Bi}}{L_p})}$$

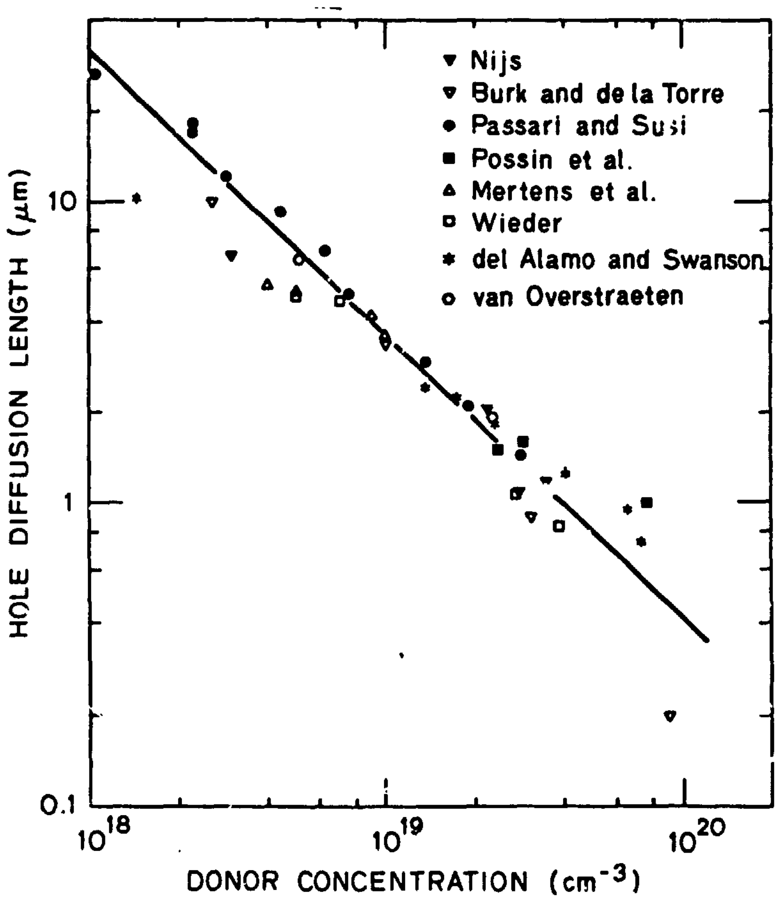
If $W_{Bi} \gg L_p$

$$I_{oci} = qAF_L(p_oD_p)(\frac{2}{L_p})exp-(\frac{W_{Bi}}{L_p})$$

Then

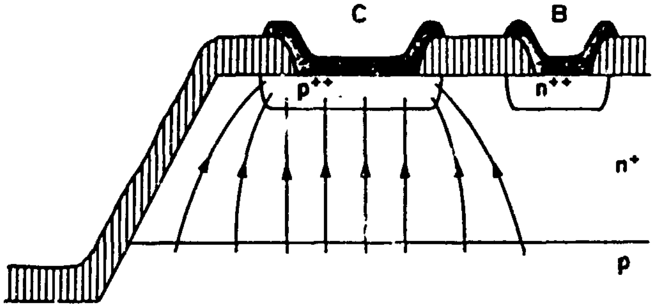
$$\frac{I_{oci}}{I_{oc1}} = exp-(\frac{W_{Bi}-W_{B1}}{L_p})$$


HOLE DIFFUSION LENGTH (μm)
10^-1
10^0
10^1
10^18
10^19
10^20
DONOR CONCENTRATION (cm^-3)


Nijs
Burk and de la Torre
Passari and Susi
Possin et al.
Mertens et al.
Wieder
del Alamo and Swanson
van Overstraeten
HOLE DIFFUSION LENGTH (μm)
10
1
0.1
10^18
10^19
10^20
DONOR CONCENTRATION (cm^-3)

Vertical Transistors

Measurement of $p_o D_p$



Collector current:

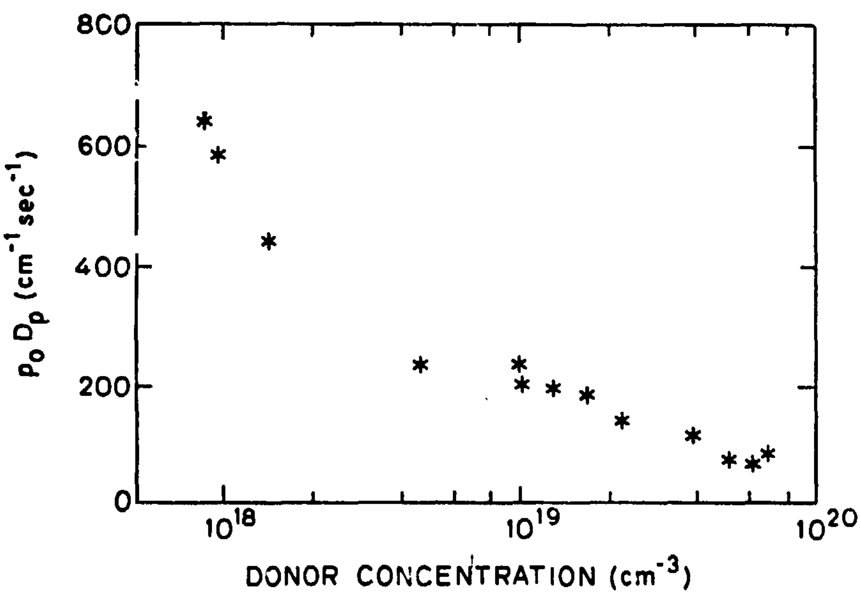
$$J_{oc} = p_o D_p \left(\frac{1}{L_p}\right) \frac{1}{\sinh\left(\frac{W_B}{L_p}\right)}$$

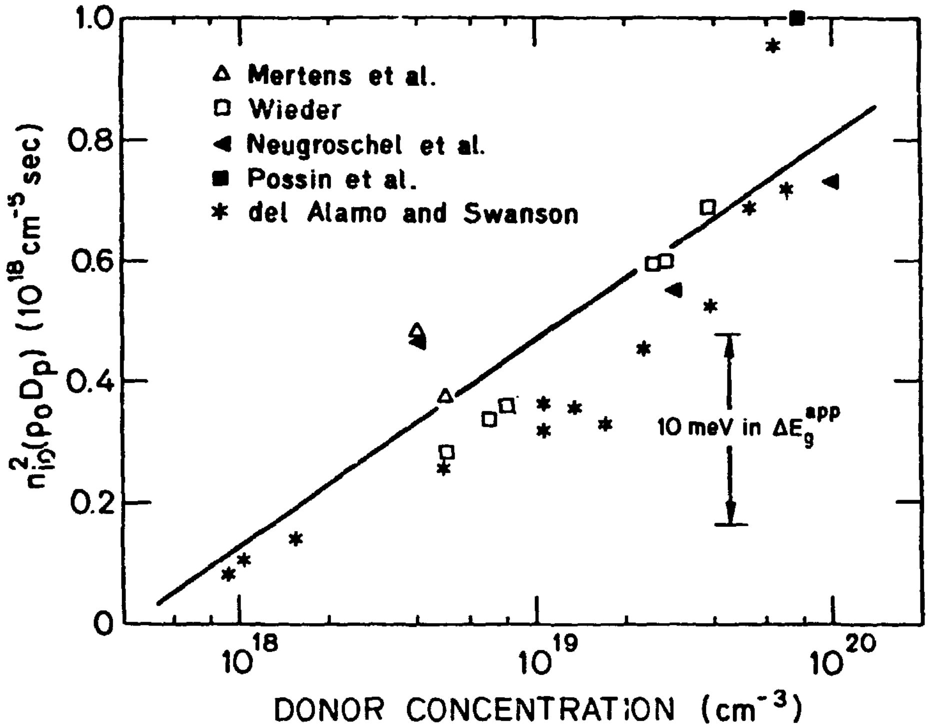
If $W_B \ll L_p$

$$J_{oc} \simeq p_o D_p \frac{1}{W_B}$$

If $W_B \gg L_p$

$$J_{oc} \simeq p_o D_p \frac{2}{L_p} exp - \frac{W_B}{L_p}$$





Authors	$N_s(cm^{-3})$	$x_j(\mu m)$	J_o (A/cm^2) measured	calculated
Kwark and Swanson	3.3×10^{19}	1.0	8.3×10^{-13}	1.1×10^{-12}
Kwark and Swanson	4.6×10^{19}	0.66	1.1×10^{-12}	1.5×10^{-12}
Ning and Isaac	1.2×10^{20}	0.20	2.8×10^{-12}	2.8×10^{-12}
Patton and Plummer	2.1×10^{19}	0.20	3.2×10^{-12}	3.6×10^{-12}
Patton and Plummer	4.4×10^{19}	0.23	2.6×10^{-12}	2.6×10^{-12}

Conclusions

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