Physical Parameters

We need models for various "constants" we left unspecified. Also, we may need to modify the semiconductor eqs. according to the physical situation.

Carrier concentrations can become dependent on background doping: bandgap narrowing effect. At very large concentrations, impurities start forming a band of their own that can merge with the conduction or valence band, or it provides additional states ("tail" states) inside the forbiden bandgap.

Quick fix: introduce "effective intrinsic concentration" n_{ie} which hides all the details of physics into simple increase of intrinsic concetration due to rigid band-edge shifts so that

$$n = n_{ie} exp\left(\frac{q(\psi - \phi_n)}{kT}\right) \tag{1}$$

The most often used model for BGN is Slotboom's, although more physically based models keeps appearing. Caution: evaluate the extraction of model parameters — does it include degeneracy or not. Also, in its most common application, it does not matter which dopand is used, which is not eniterely consistent, but it works. In other words, the bandgap change is equally divided between conduction and valance bands. This restriction can be avoided but the problem needs to be re-formulated.

Two way to approach mobility: heuristic and physics based. It can be viewed as proportionality "constant" between electric field and velocity (i.e. $v = \mu E$), or it is defined through average momentum relaxation times. The latter point of view is better suited to physical interpretation. Think of these relaxation times as average time the electrons are free to move around with thermal velocity before they are scattered.

Scattering mechanisms: thermal lattice vibrations (phonons), ionized impurities, neutral impurites, vacancies, interstitials, dislocations, surfaces and carrier-carrier scattering. The most fundamental is phonon scattering but there are several types. "Acoustic deformation potential" lattice scattering represents scattering off the acoustic waves traveling around the crystal. Two types: longitudinal and transverse. Acoustic phonons displace neighbouring atoms in the same direction; optical phonons displace them in opposite directions. The distinguishing feature: temperature dependence is $\sim T^{-3/2}$. Model:

$$\mu_n^L = \mu_n^0 \left(\frac{T}{300}\right)^{-\alpha_n} \tag{2}$$

Mathiessen's rule may be applied to sum up the individual contributions to mobility (extreme caution).

Impurity scattering: features $\sim T^{3/2}$ dependence. Complications at high doping because of "screening": Conwell and Weiskopf, Brooks-Herring, Ridley models.

How to combine phonon (L) and impurtity (i) models into one mobility? Mathiessen's rule is a poor choice. Best to resort to heuristics — Caughey-Tomas model

$$\mu_{n,p}^{LI} = \mu_{n,p}^{\min} + \frac{\mu_{n,p}^{L} - \mu_{n,p}^{I}}{1 + \left(\frac{CI}{C_{n,p}^{ref}}\right)^{\alpha_{n,p}}} \tag{3}$$

or, even simpler, Scharfetter-Gummel model

$$\mu_{n,p}^{LI} = \frac{\mu_{n,p}^{L}}{\left(1 + \frac{CI}{C_{n,p}^{ref} + \frac{CI}{S_{n,p}}}\right)^{1/2}} \tag{4}$$

Arora's model for temperature dependence of various constants in Caughey-Thomas' model.

Large scatter of experimental results!

carrier-carrier scattering difficult to model and introduces numerical problems. Likely use: high injection cases.

Experimentally we know that velocity saturates vs. electric field. This saturation needs to be modeled. Not much in terms of theory, but this one works:

$$\mu_{n,p}^{LICNE} = \frac{\mu_{n,p}^{LICN}}{\left(1 + \left(\frac{\mu_{n,p}^{LICN} E_{n,p}}{v_{n,p}^{sat}}\right)^{\beta_{n,p}}\right)^{1/\beta_{n,p}}} \tag{5}$$

Another popular choice is Scharfetter-Gummel model.

For GaAs devices there is a "hump" in v vs. E curve. In Si, velocity monotonically reaches the saturation value, but not so in GaAs. One way to include this effect is

$$\mu_{LIE} = \frac{\mu_n^{LI} + v_n^{sat} \frac{E_n^3}{\left(E_n^{crit}\right)^4}}{1 + \left(\frac{E_n}{E_n^{crit}}\right)^4} \tag{6}$$

For MOS devices surface scattering needs to be treated.