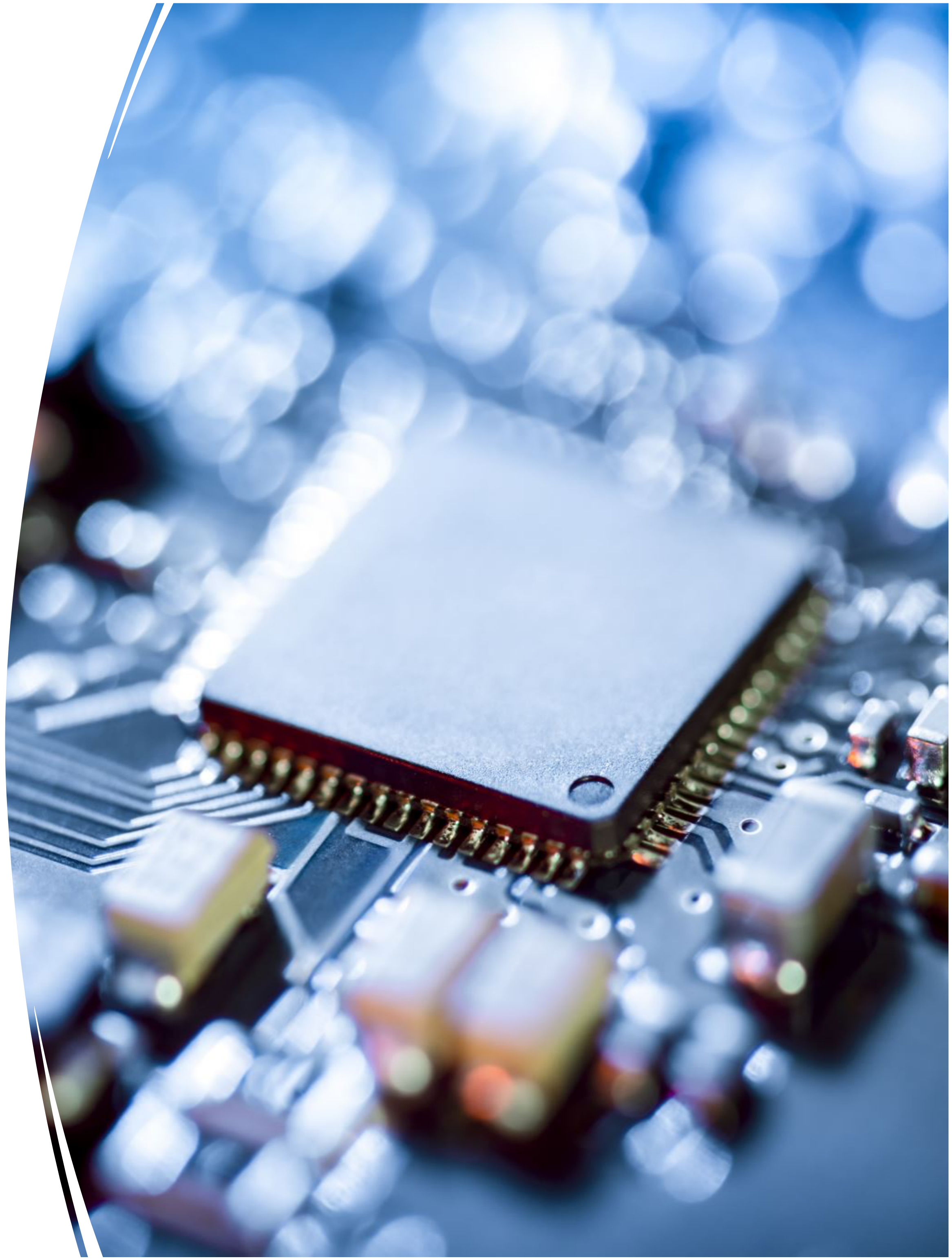
Semiconductor Device Modeling and Simulation

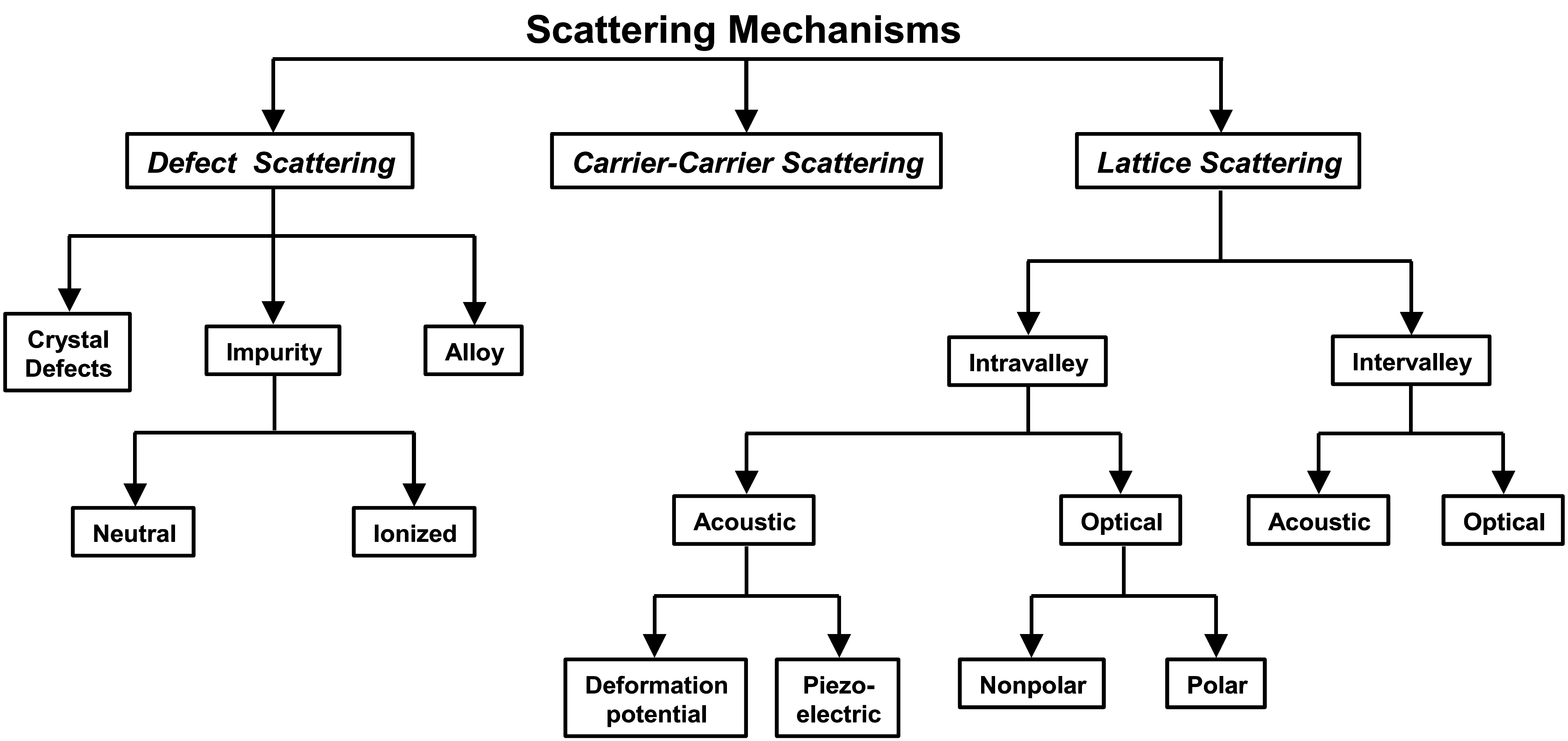
L4.03 Mobility Modeling

Dragica Vasileska
Arizona State University



National Nanotechnology Coordinated Infrastructure

Mobility Limiting Scattering Mechanisms



Mobility Modeling – Bulk Materials

- Characterization of μ_0 as a function of doping and lattice scattering
- Characterization of v_{sat} as a function of lattice temperature
- Describing the transition between the low-field and the saturation velocity region

A. Low-Field Mobility for Bulk Materials

Phonon scattering only:

- Simple power-law dependence of the temperature
- Sah *et al*. model: acoustic + optical and intervalley phonons combined via Mathiessen's rule

Ionized impurity scattering only:

- Concentration dependent mobility model: valid for Si and GaAs only
  - To enable this model, specify CONMOB on the MODELS statement
- Conwell-Weiskopf model
  - To enable the model for both electrons and holes, specify CONWELL on the MODELS statement. Alternatively, N.CONWELL on the MOBILITY statement enables it for electron mobility. P.CONWELL on the MOBILITY statement enables it for hole mobility.
- Brooks-Herring model
  - To enable the model for both electrons and holes, specify BROOKS on the MODELS statement. Alternatively, N.BROOKS on the MOBILITY statement enables it for electron mobility. P.BROOKS on the MOBILITY statement enables it for hole mobility.

A. Low-Field Mobility for Bulk Materials

Combined phonon and ionized impurity scattering:

- Caughey and Thomas model: temperature dependent phonon scattering + ionized impurity scattering.
  - This model is called in using ANALYTIC in the MODELS statement. The parameters of this model are specified in the MOBILITY statement.
- Arora model: similar to Caughey and Thomas model.
  - This model is activated by specifying ARORA in the MODELS statement. The parameters of the model are specified in the MOBILITY statement.

A. Low-Field Mobility for Bulk Materials

Carrier-carrier scattering

- Dorkel and Leturg model: temperature-dependent phonon scattering + ionized impurity scattering + carrier-carrier interactions
  - This model is activated using the CCSMOB parameter of the MODELS statement. The parameters of the model are specified in the MOBILITY statement
- Klaassen model: includes the effects of lattice scattering, impurity scattering (with screening from charged carriers), carrier-carrier scattering, and impurity clustering effects at high concentration.
  - One can enable or disable the model by using the KLA parameter in the MODELS statement, or independently for electrons and holes by the KLA.N and KLA.P parameters of the MOBILITY statement.

B. Field-Dependent Mobility

The field-dependent mobility model provides smooth transition between low-field and high-field behavior:

$$\mu(E) = \frac{\mu_0}{\left[1 + \left(\frac{\mu_0 E}{\text{VSATN(P)}}\right)^{\text{BETAN(P)}}\right]^{1/\text{BETAN(P)}}}$$

Default:
BETAN = 2 for electrons
BETAP = 1 for holes

v_{sat} is modeled as a temperature-dependent quantity:

$$\text{VSATN} = \frac{\text{ALPHAN.FLD}}{1 + \text{THETAN.FLD}\, exp\left(\frac{T_L}{\text{TNOMN.FLD}}\right)} \ [\text{cm/s}]$$

$$\text{VSATP} = \frac{\text{ALPHAP.FLD}}{1 + \text{THETAP.FLD}\, exp\left(\frac{T_L}{\text{TNOMP.FLD}}\right)} \ [\text{cm/s}]$$

Mobility Modeling – Inversion Layers

- Characterization of μ_0 as a function of doping, lattice scattering, perpendicular field dependence
- Characterization of v_{sat} as a function of lattice temperature
- Describing the transition between the low-field and the saturation velocity region

Inversion Layer Mobility Models

- Lombardi CVT model: combines acoustic phonon, non-polar optical phonon and surface-roughness scattering (as an inverse square dependence of the perpendicular electric field) via Mathiessen's rule
  - The model is selected by setting CVT on the MODELS statement. This model overrides any other mobility models which may be specified on the MODELS statement.
- Darwish CVT model: (a) bulk mobility is calculated using Klaassen's model to take into account Coulomb screening effects; (b) new expression for surface roughness is used.
  - One can enable the Darwish model for electrons and holes by specifying NEWCVT.N or NEWCVT.P on the MOBILITY statement.
- Yamaguchi model: (a) low-field part combines lattice, ionized impurity and surface-roughness scattering. (b) there is also a parametric dependence on the in-plane field (high-field component)
  - Selected by setting YAMAGUCHI in the MODELS statement. This model overrides any mobility model specifications other than the CVT model.

Inversion Layer Mobility Models

- Shirahata model: (a) uses Klaassen's low-field mobility model, (b) takes into account screening effects into the inversion layer, (c) has improved perpendicular field dependence for thin gate oxides.
  - To enable the Shirahata Mobility Model, use the SHI parameter of the MODELS statement. One can also enable it individually for electrons and holes using the SHI.N and SHI.P parameters of the MOBILITY statement.
- Tasch model: the best model for modeling the mobility in MOS inversion layers; uses universal mobility behavior. It defines the mobility as a function of the perpendicular and parallel electric fields, the interface charge, the lattice temperature and the doping concentration.
  - This model, is activated using the TASCH parameter on the MODELS statement.

Summary of Mobility Models

Model	Syntax	Notes
Concentration Dependent	CONMOB	Lookup table valid at 300K for Si and GaAs only. Uses simple power law temperature dependence.
Concentration and Temperature Dependent	ANALYTIC	Caughey-Thomas formula. Tuned for 77-450K.
Arora's Model	ARORA	Alternative to ANALYTIC for Si.
Carrier-Carrier Scattering	CCSMOB	Dorkel-Leturq Model. Includes n, N and T dependence. Important when carrier concentration is high (e.g., forward bias power devices).
Parallel Electric Field Dependence	FLDMOB	Si and GaAs models. Required to model any type of velocity saturation effect.
Tasch Model	TASCH	Includes transverse field dependence. Only for planar devices. Needs very fine grid.
Watt Model	WATT	Transverse field model applied to surface nodes only.
Klaassen Model	KLA	Includes N, T, and n dependence. Applies separate mobility to majority and minority carriers. Recommended for bipolar devices
Shirahata Model	SHI	Includes N, $E_{\perp}$. An alternative surface mobility model that can be combined with KLA.
Modified Watt	MOD.WATT	Extension of WATT model to non-surface nodes. Applies constant $E_{\perp}$effects. Best model for planar MOS devices
Lombardi (CVT) Model	CVT	Complete model including N, T, E// and $E_{\perp}$ effects. Good for non-planar devices.
Yamaguchi Model	YAMAGUCHI	Includes N, E// and $E_{\perp}$ effects. Only for 300K.

Model Usage

Table 3-75 Mobility Models Summary

	CONMOB	FLDMOB	TFLDMB2	YAMAGUCHI	CVT	ARORA	ANALYTIC	CCSMOB	SURFACE	LATTICE H	E.BALANCE
CONMOB [CM]	—	OK	OK	YA	CV	AR	AN	CC	OK	OK	OK
FLDMOB [FM]	OK	—	TF[1]	YA	CV	OK	OK	OK	OK	OK	OK
TFLDMB2 [TF]	OK	TF[1]	—	YA	CV	OK	OK	TF	TF	OK	OK
YAMAGUCHI [YA]	YA	YA	YA	—	CV	YA	YA	YA	YA	NO	NO
CVT [CV]	CV	CV	CV	CV	—	CV	CV	CV	CV	OK	OK
ARORA [AR]	AR	OK	OK	YA	CV	—	AR	CC	OK	OK	OK
ANALYTIC [AN]	AN	OK	OK	YA	OK		—	CC	OK	OK	OK
CCSMOB [CC]	CC	OK	TF	YA	CV	CC	CC	—	OK	OK	OK
SURFMOB [SF]	OK	OK	TF	YA	CV	OK	OK	OK	—	OK	OK
LATTICE H [LH]	OK	OK	OK	NO	OK	OK	OK	OK	OK	—	OK
E.BALANCE [EB]	OK	OK	OK	NO	OK	OK	OK	OK	OK	OK	[2]

(*) More details on the models can be found in the Silvaco ATLAS Manual.