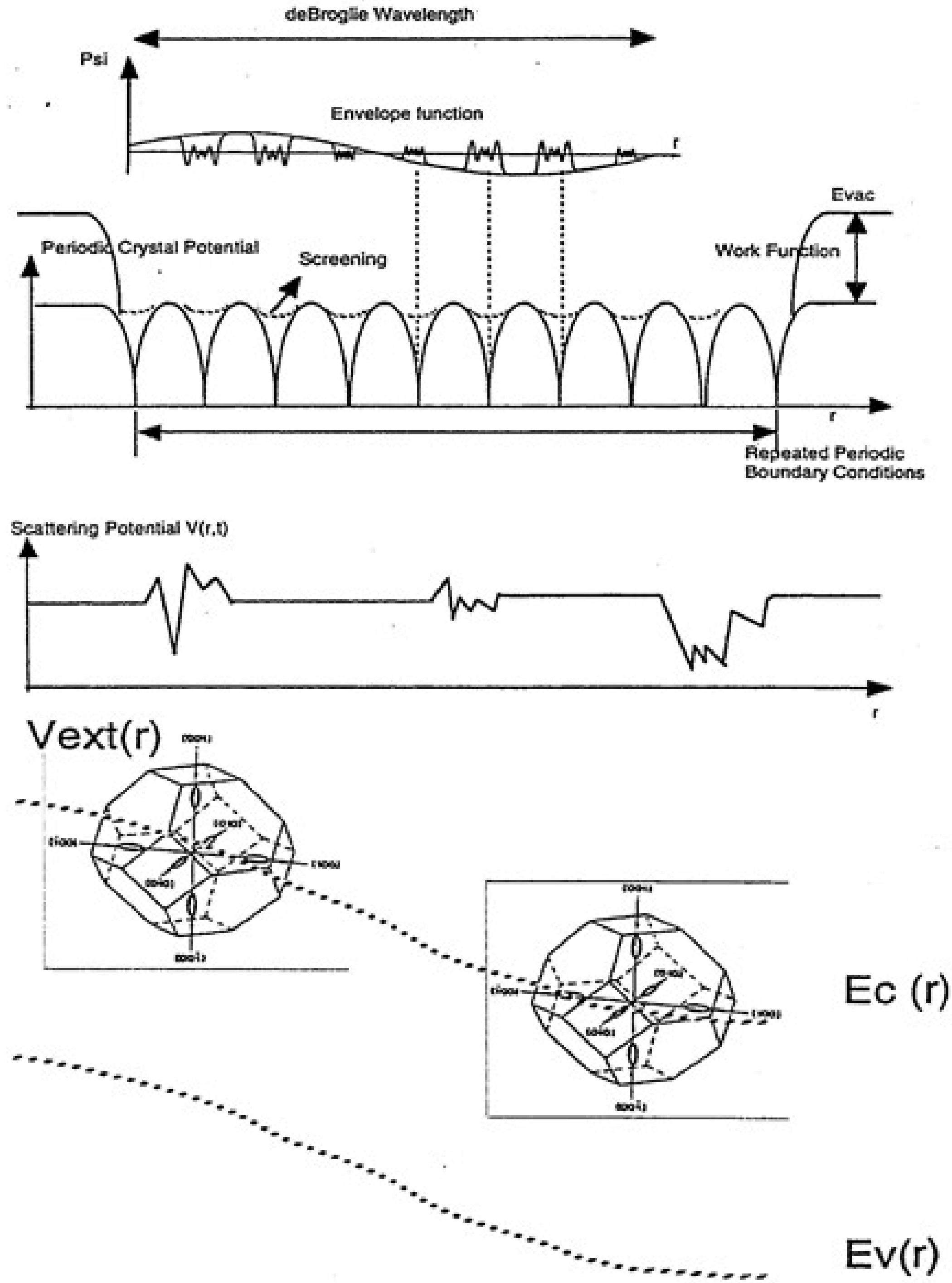
Potentials in a solid

Bloch wavefunction

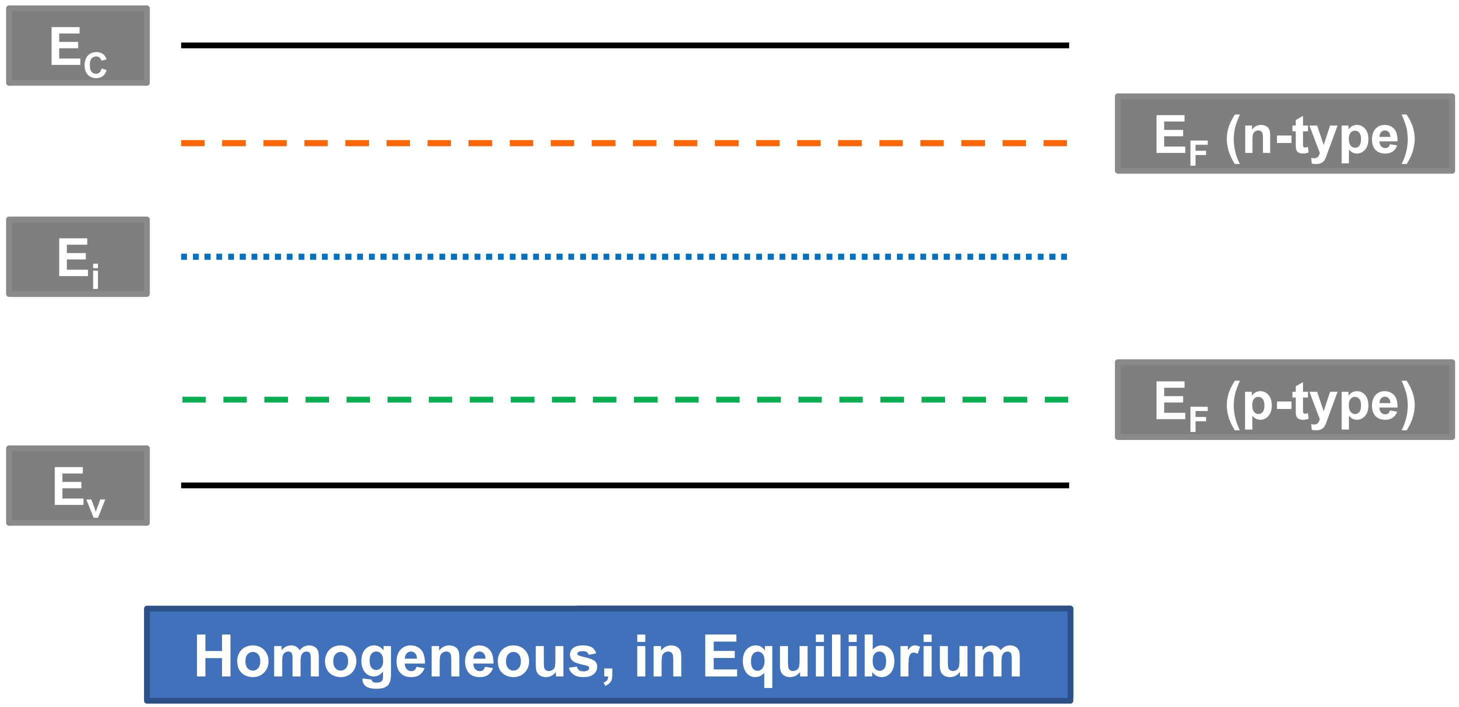
Periodic potential

Imperfection → scattering potential

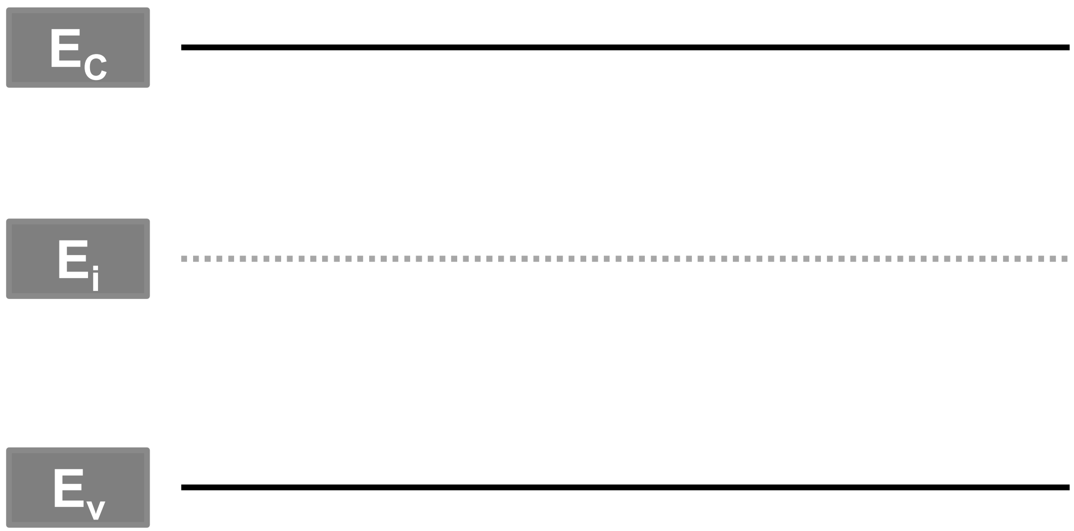
External potential



Band diagram

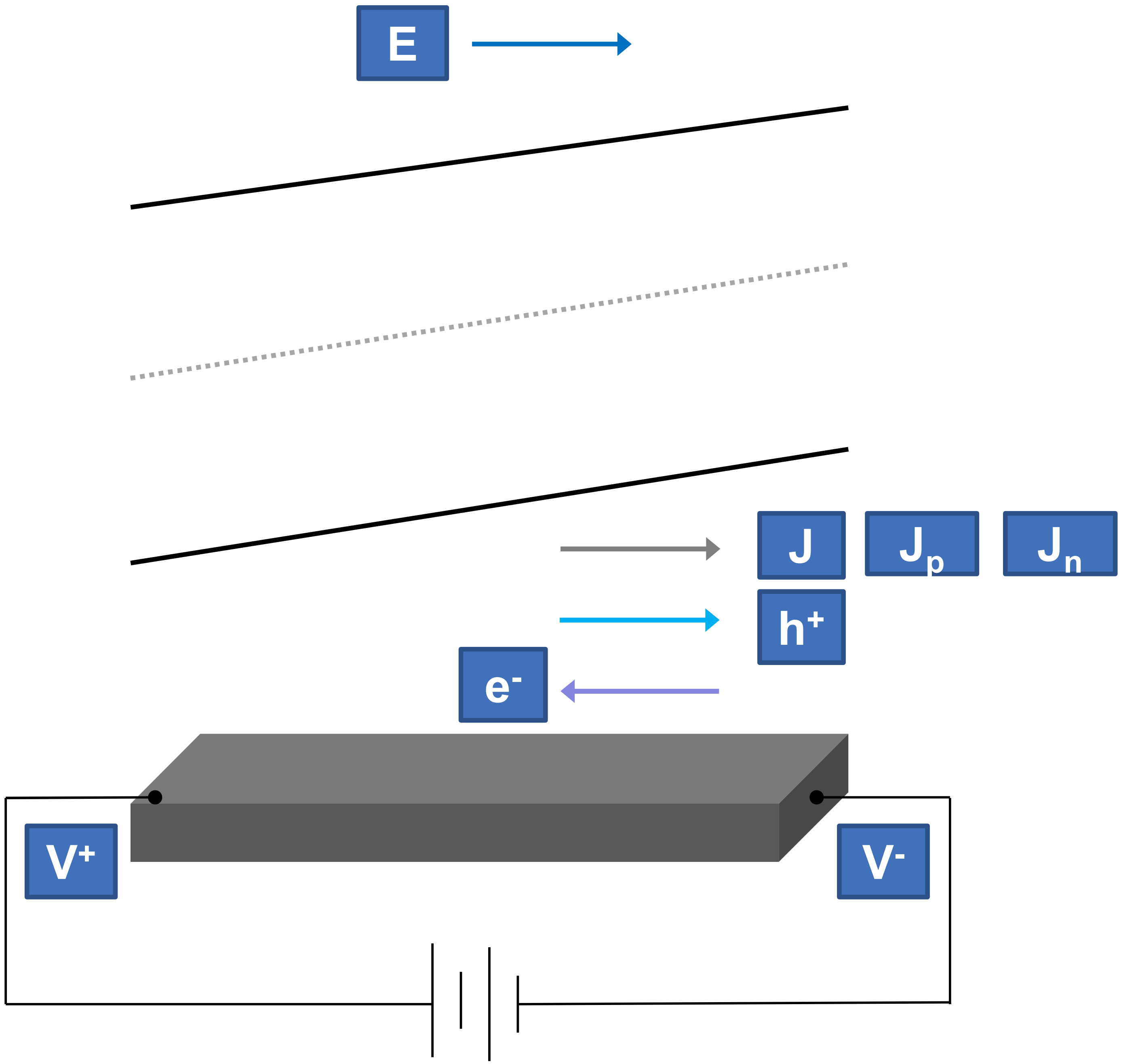


Band diagram



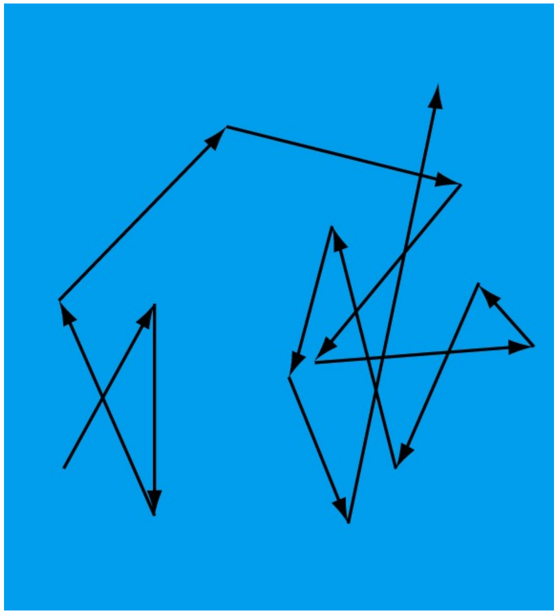
What happens if there is an electric field (due to inhomogeneity OR due to non-equilibrium)?

Bands in an electric field

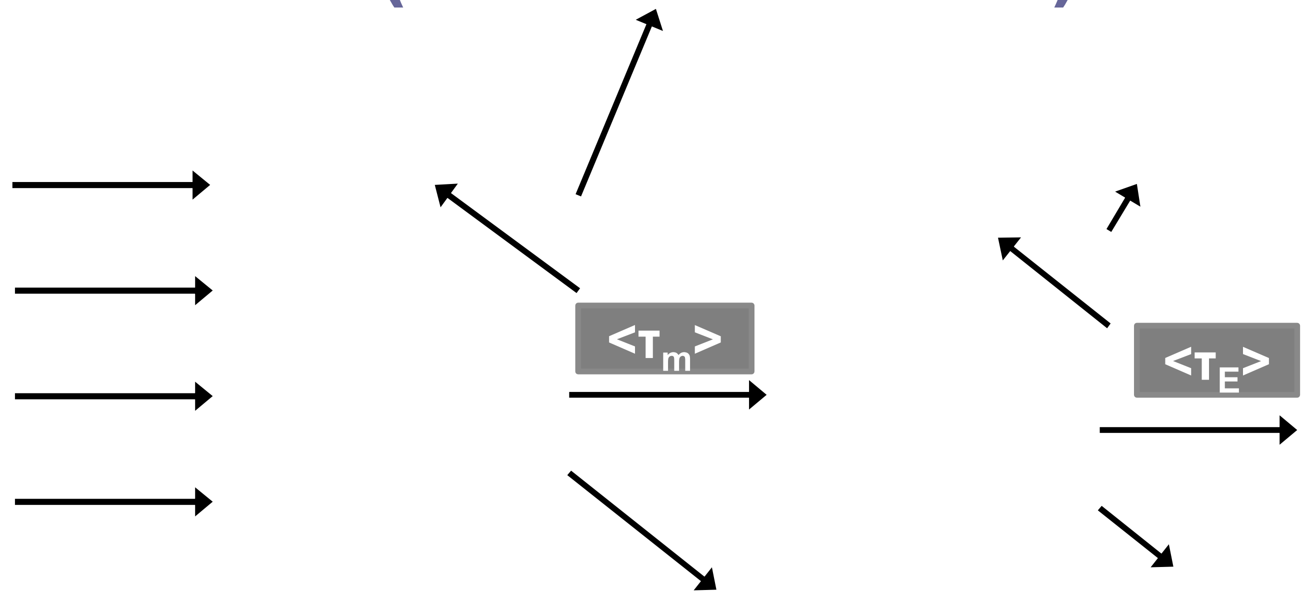


Electrons in a band (with collisions)

No longer semi-classical motion



Collisions → Brownian motion



Drift

Momentum relaxation

Energy relaxation

$$\frac{1}{\tau} = S_1\left(k,k'\right) + S_2\left(k,k'\right) + \ldots = \frac{1}{\tau_1} + \frac{1}{\tau_2} + \ldots$$

Mean time between collisions

S_j: Scattering rate due to j-th mechanism (ionized impurity, acoustic phonon, …)

Mattheisen's Rule?

Mobility and drift current

Charged particle in electric field → acceleration

$$\frac{dv}{dt} = \frac{q\mathcal{E}}{m^*}$$

'Friction' due to scattering

$$\frac{dv}{dt} + \frac{v}{\tau_m} = \frac{q\mathcal{E}}{m^*}$$

Steady-state drift

$$\frac{v_d}{\tau_m} = \frac{q\mathcal{E}}{m^*} \Rightarrow v_d = \left(\frac{q\tau_m}{m^*}\right)\mathcal{E} = \mu \cdot \mathcal{E}$$

Drift current

$$J = q\eta v_d = \left(q\eta\mu\right)\mathcal{E}$$

$$\mu = \frac{q\langle\tau_m\rangle}{m^*}$$

Mobility

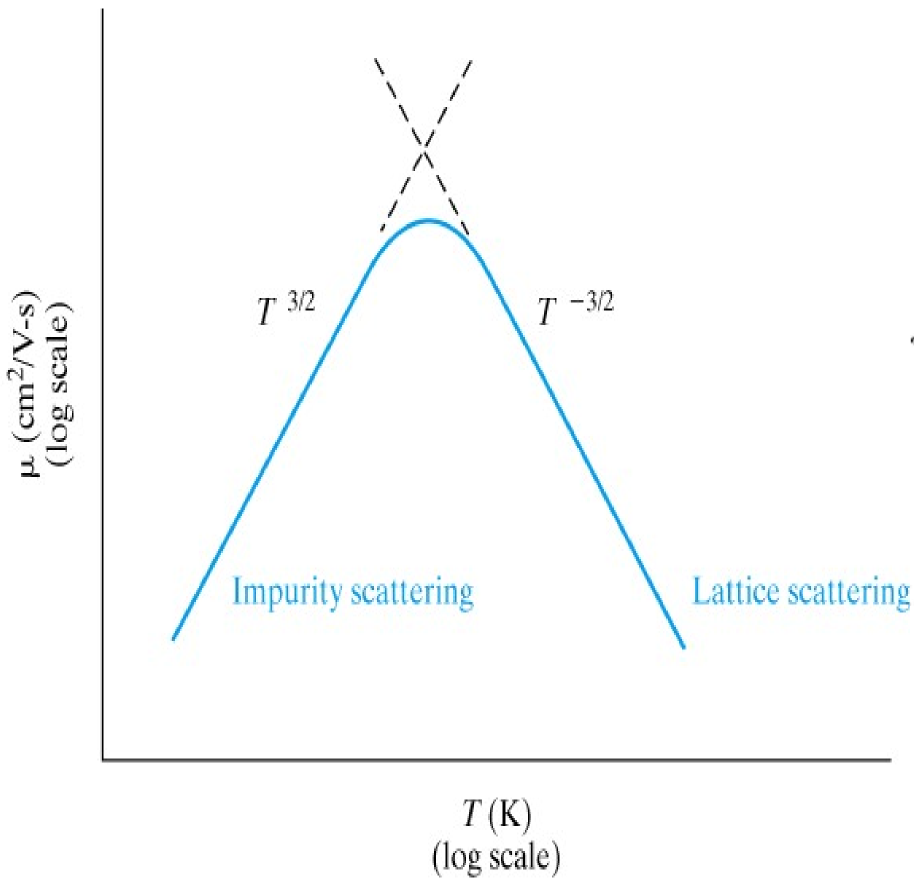
Ohm's Law

Electron & hole drift

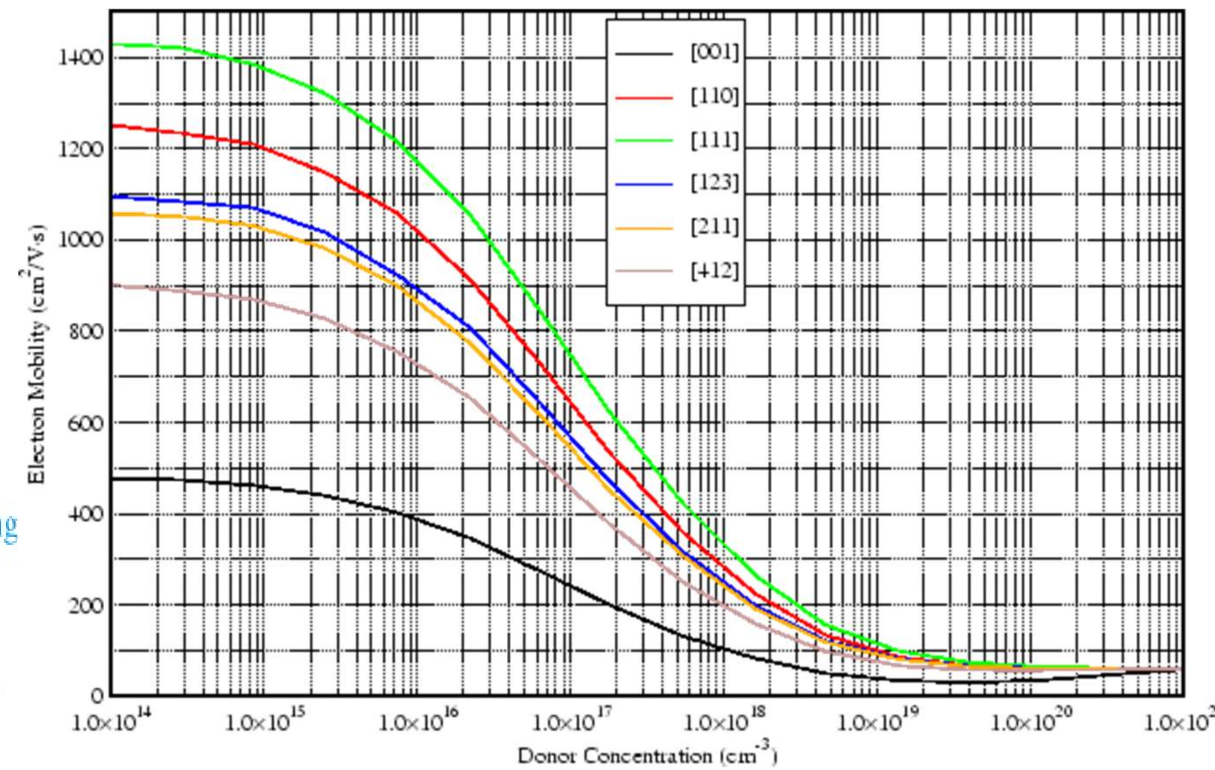
$$J = J_n + J_p = nev_n + pev_p = \left(ne\mu_n + pe\mu_p\right)\cdot\mathcal{E}$$

Mobility dependencies

Temperature dependence

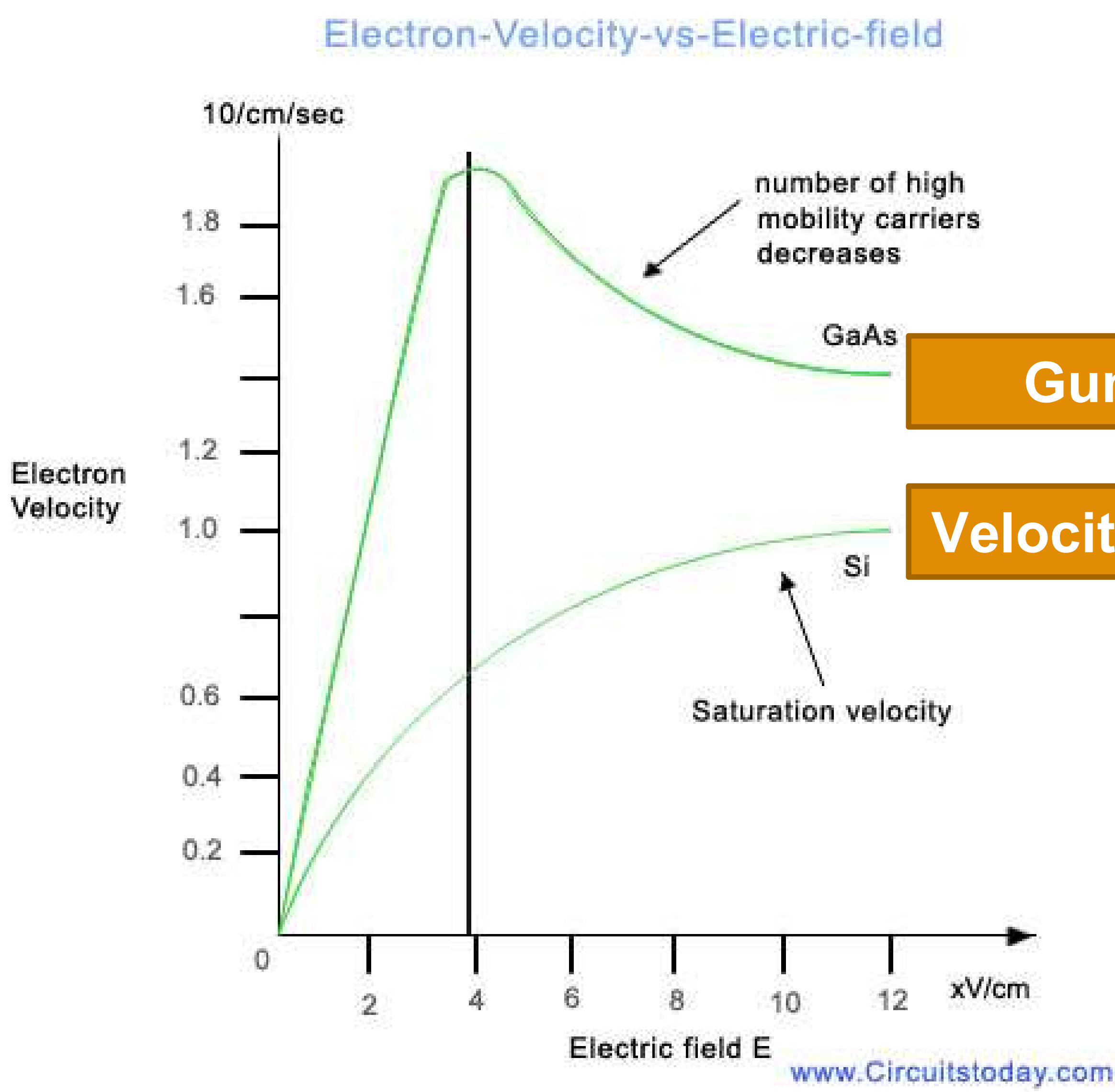


Doping & orientation dependence



Why orientation?

Mobility limits: high-fields, small dimensions



Gunn Effect

Velocity saturation

$$v(\varepsilon) = \frac{\mu\varepsilon}{1 + \mu\varepsilon / v_{sat}}$$

Velocity overshoot

Ballistic transport

Finis

Artwork Sources:

1. Prof. Sanjay Banerjee
2. electrons.wikidot.com
3. iue.tuwien.ac.at