KTH Information and Communication Technology

IH1611 Spring 2020

Material Properties and Formulas

Physical Constants

Description	Symbol	Value
Elementary charge	q	$1.60 \cdot 10^{-19}$ C
Electron volt	eV	$1.60 \cdot 10^{-19}$ J
Boltzmann's constant	k	$1.38 \cdot 10^{-23}$ J/K = $8.62 \cdot 10^{-5}$ eV/K
Free electron mass	m_0	$9.11 \cdot 10^{-31}$ kg
Permittivity of free space	ε_0	$8.85 \cdot 10^{-12}$ F/m
Planck's constant	h	$6.63 \cdot 10^{-34}$ Js
Reduced Planck's constant (h/2π)	ħ	$1.05 \cdot 10^{-34}$ Js
Speed of light in vacuum	c	$3.00 \cdot 10^{8}$ m/s
Thermal voltage at T=300 K	kT/q	0.0259 V
Wavelength of 1 eV photon	λ	1.24·μm

Unit Conversion

Quantity	Symbol	Value/Dimension
Micrometer, micron	μm	1 μm = 10^{4} Å = 10^{3} nm = 10^{-4} cm
Nanometer	nm	1 nm = 10 Å = 10^{-3} μm = 10^{-7} cm
Ångström	Å	1 Å = 10^{-4} μm = 10^{-8} cm = 10^{-10} m
Electric charge (Coulomb)	C	A·s
Current (Ampere)	A	C/s
Frequency (Hertz)	Hz	1/s
Energy (Joule)	J	N·m
Power (Watt)	W	J/s
Potential (Volt)	V	W/A
Conductance (Siemens)	S	A/V
Resistance (Ohm)	Ω	V/A
Capacitance (Farad)	F	C/V

Semiconductor Formulas

Fermi-Dirac statistics	$f(E) = \frac{1}{1 + e^{\frac{(E-E_F)}{kT}}}$	k: Boltzmann's constant [eV/K] T: Temperature [K] E_F: Fermi Level [eV]
Poisson's equation	$\frac{d^2V}{dx^2} = -\frac{dE}{dx} = -\frac{\rho}{\varepsilon_S}$	V: Potential [V] E: Electric field [V/cm] ρ: Charge density [C/cm^3] ε_S: Semiconductor permittivity [F/cm]
Continuity equation for electrons	$\frac{\partial n}{\partial t} = \frac{1}{q}\frac{\partial J_n}{\partial x} - \frac{n - n_o}{\tau_n} + G$	n: Electron carrier concentration [cm^{-3}] J_n: Electron current density [A/cm^2] τ_n: Electron recombination lifetime [s] G: External electron generation rate [cm^{-3}s^{-1}]
Continuity equation for holes	$\frac{\partial p}{\partial t} = -\frac{1}{q}\frac{\partial J_p}{\partial x} - \frac{p - p_o}{\tau_p} + G$	p: Hole carrier concentration [cm^{-3}] J_p: Hole current density [A/cm^2] τ_p: Hole recombination lifetime [s] G: External hole generation rate [cm^{-3}s^{-1}]
Einstein relationship	$D = \frac{kT}{q}\mu$	D: Diffusion coefficient of carriers[cm^2/s] μ: Mobility of carriers[cm^2/Vs]
Diffusion Length	$L = \sqrt{D\tau}$	D: Diffusion coefficient of carriers[cm^2/s] τ: Carrier recombination lifetime [s]
MOS capacitor equations	$V_g = V_{fb} + \phi_s + V_{ox}$ $V_{ox} = -\frac{Q_{sub}}{C_{ox}}$	V_g: Gate voltage [V] V_{fb}: Flatband voltage [V] ϕ_s: Surface potential [V] V_{ox}: Voltage over oxide [V] Q_{sub}: Charge in semiconductor [C/cm^2] C_{ox}: Oxide capacitance [F/cm^2]
NMOSFET	$V_t = V_{t0} + (m-1)V_{sb}$ $m = 1 + \frac{\varepsilon_s T_{oxe}}{\varepsilon_{ox} W_{dmax}}$ $I_{ds} = \frac{W}{L} C_{oxe}\mu_{ns}(V_{gs} - V_t - \frac{m}{2}V_{ds})V_{ds}$	V_t: threshold voltage [V] V_{t0}: threshold voltage at zero V_{sb} [V] m: bulk-charge factor [ ] V_{sb}: Potential between source and bulk [V] ε_s: Permittivity of semiconductor [F/cm] T_{oxe}: Effective oxide thickness [cm] ε_{ox}: Permittivity of oxide [F/cm] W_{dmax}: Maximum depletion layer width [cm] W: Gate width [cm] L: Gate length [cm] C_{oxe}: Effective oxide capacitance [F/cm^2] μ_{ns}: Electron surface mobility [cm^2/Vs] V_{gs}: Potential between gate and source [V] V_{ds}: Potential between drain and source [V]

Work function and Schottky barrier heights of metals and silicides to Si

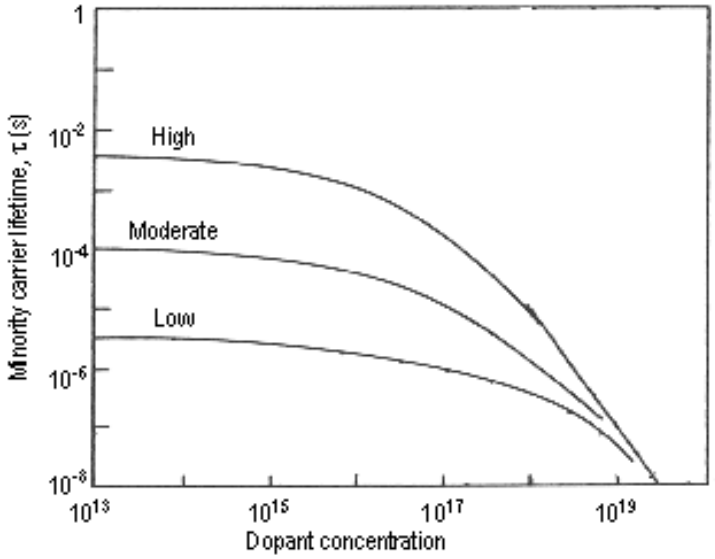
Metal	Mg	Ti	Cr	W	Mo	Pd	Au	Pt
ϕ_{Bn} (V)	0.4	0.5	0.61	0.67	0.68	0.77	0.8	0.9
ϕ_{Bp} (V)		0.61	0.50		0.42		0.3	
Work Function ψ_M (V)	3.7	4.3	4.5	4.6	4.6	5.1	5.1	5.7

Silicide	$ErSi_{1.7}$	HfSi	$MoSi_2$	$ZrSi_2$	$TiSi_2$	$CoSi_2$	WSi_2	$NiSi_2$	Pd_2Si	PtSi
ϕ_{Bn} (V)	0.28	0.45	0.55	0.55	0.61	0.65	0.67	0.67	0.75	0.87
ϕ_{Bp} (V)			0.55	0.55	0.49	0.45	0.43	0.43	0.35	0.23

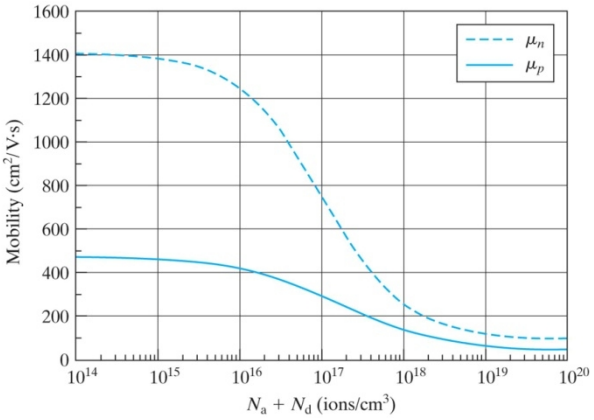
Properties of Si (T=300 K)

QUANTITY	SYMBOL	VALUE/DIMENSION
Bandgap	E_g	1.12 eV, indirect
Intrinsic carrier concentration	n_i	10^{10} cm^{-3}
Effectiv Density of states in E_C	N_c	$2.8 \cdot 10^{19}$ cm^{-3}
Effectiv Density of states in E_v	N_v	$1.0 \cdot 10^{19}$ cm^{-3}
Electron effective mass	m_n/m_0	0.26
Hole effective mass	m_p/m_0	0.39
Electron/Hole thermal velocity	v_{th}^e/v_{th}^h	$2.3 \cdot 10^7$ / $1.7 \cdot 10^7$ cm/s
Electron affinity	χ	4.05 eV
Relative permittivity	ε_r	11.9
Electric breakdown field	$\mathcal{E}_{crit}$	~$4 \cdot 10^5$ V/cm

Si carrier lifetime τ in low, moderate and high quality Si crystals



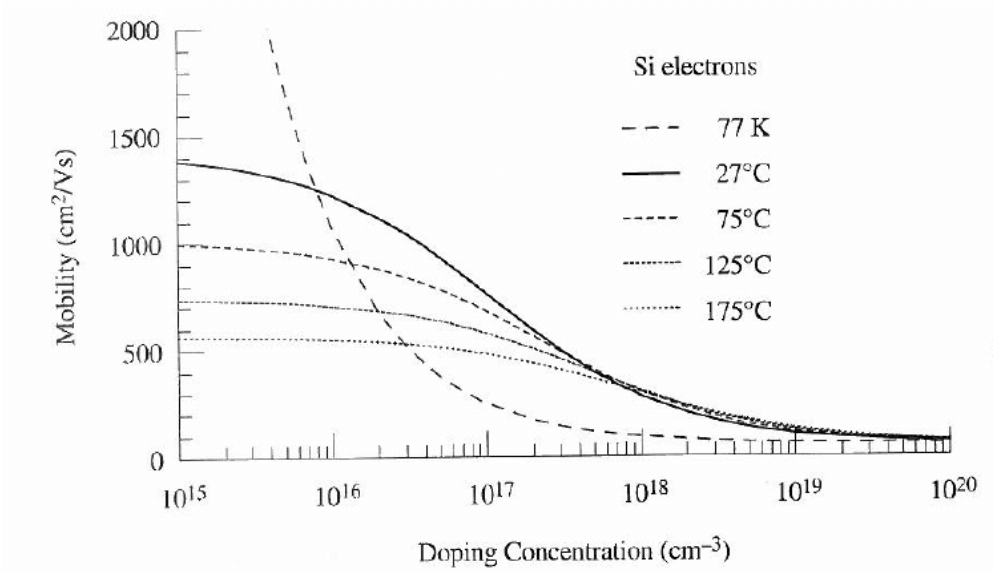
Si electron and hole mobility at T=300 K [cm²/Vs]

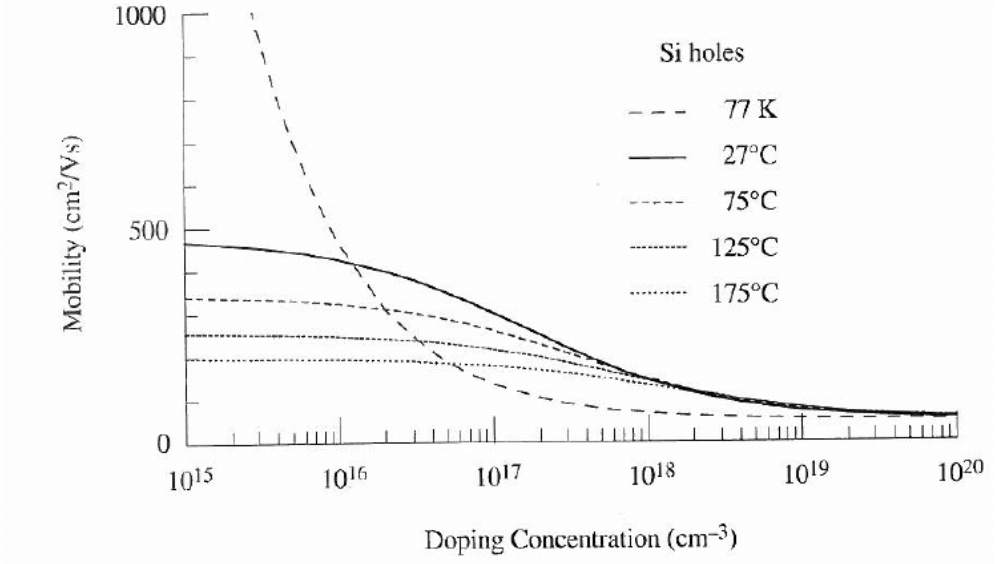


$$\mu_n = \frac{1318}{1+\left(\frac{N_a+N_d}{10^{17}}\right)^{0.85}} + 92$$

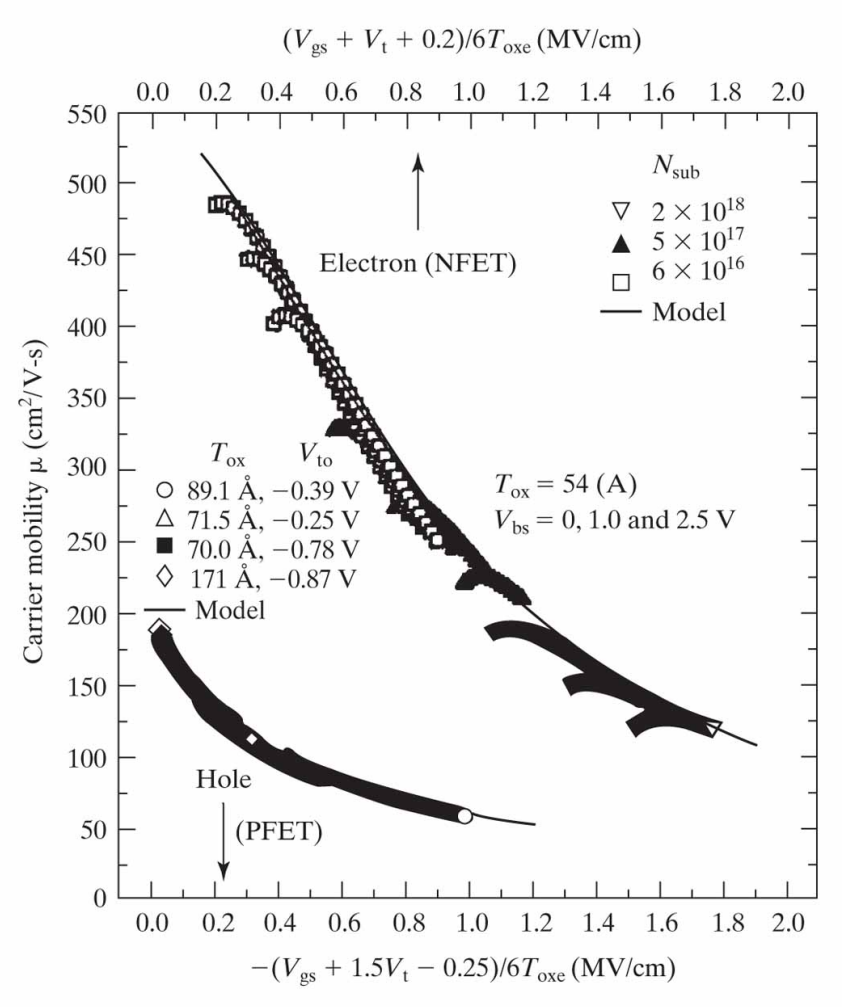
$$\mu_p = \frac{420}{1+\left(\frac{N_a+N_d}{1.6\cdot 10^{17}}\right)^{0.7}} + 50$$

Si electron and hole mobility a various temperatures





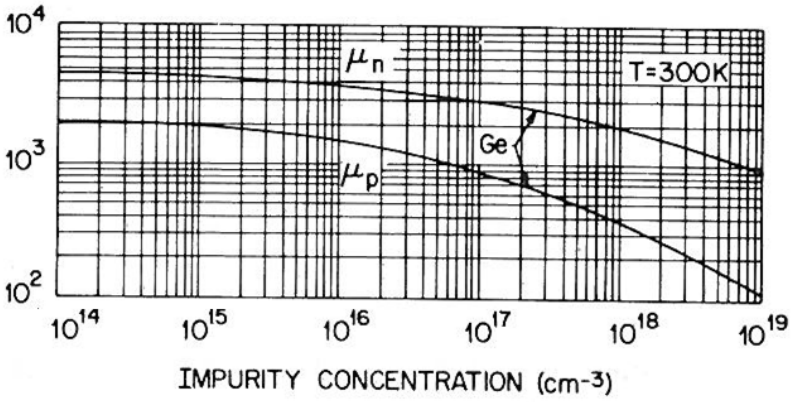
Silicon electron and hole surface mobility



Properties of Ge (T=300 K)

QUANTITY	SYMBOL	VALUE/DIMENSION
Bandgap	E_g	0.67 eV, indirect
Intrinsic carrier concentration	n_i	$2.4 \cdot 10^{13}$ cm^{-3}
Effectiv Density of states in E_C	N_c	$1.0 \cdot 10^{19}$ cm^{-3}
Effectiv Density of states in E_v	N_v	$6.0 \cdot 10^{18}$ cm^{-3}
Electron effective mass	m_n/m_0	0.12
Hole effective mass	m_p/m_0	0.21
Electron/Hole thermal velocity	v_{th}^e/v_{th}^h	$3.1 \cdot 10^7$ / $1.9 \cdot 10^7$ cm/s
Electron affinity	χ	4.0 eV
Relative permittivity	ε_r	16
Electric breakdown field	$\mathcal{E}_{crit}$	~ $2 \cdot 10^5$ V/cm

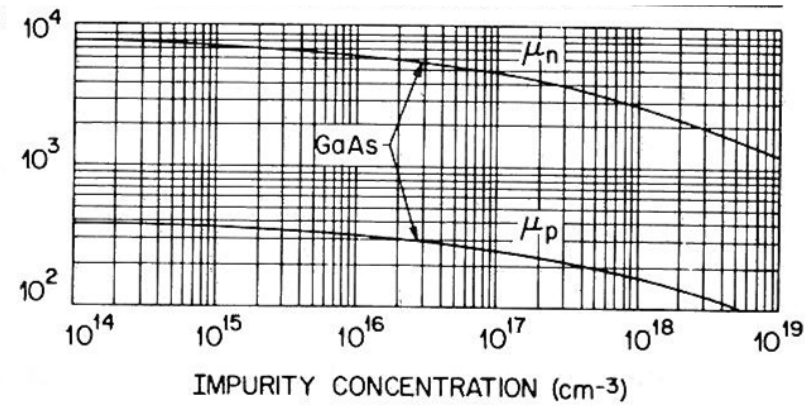
Ge electron and hole mobility at T=300 K [cm²/Vs]



Properties of GaAs (T=300 K)

QUANTITY	SYMBOL	VALUE/DIMENSION
Bandgap	E_g	1.42 eV, direct
Intrinsic carrier concentration	n_i	$9 \cdot 10^6$ cm^{-3}
Effectiv Density of states in E_C	N_c	$4.7 \cdot 10^{17}$ cm^{-3}
Effectiv Density of states in E_v	N_v	$7.0 \cdot 10^{18}$ cm^{-3}
Electron effective mass	m_n/m_0	0.067
Hole effective mass	m_p/m_0	0.34
Electron/Hole thermal velocity	v_{th}^e/v_{th}^h	$4.4 \cdot 10^7$ / $1.8 \cdot 10^7$ cm/s
Electron affinity	χ	4.07 eV
Relative permittivity	ε_r	13.1
Electric breakdown field	$\mathcal{E}_{crit}$	~8 10^5 V/cm

GaAs electron and hole mobility at T=300 K [cm²/Vs]



Properties of SiC (4H) (T=300 K)

QUANTITY	SYMBOL	VALUE/DIMENSION
Bandgap	$\mathbf{E_g}$	3.2 eV, indirect
Intrinsic carrier concentration	$\mathbf{n_i}$	-
Effectiv Density of states in E_C	$\mathbf{N_c}$	$1.7 \cdot 10^{19}$ cm^{-3}
Effectiv Density of states in E_v	$\mathbf{N_v}$	$2.5 \cdot 10^{19}$ cm^{-3}
Electron effective mass	$\mathbf{m_n/m_0}$	0.39
Hole effective mass	$\mathbf{m_p/m_0}$	0.82
Electron/Hole thermal velocity	$\boldsymbol{v_{th}^e/v_{th}^h}$	$1.9 \cdot 10^7$ / $1.2 \cdot 10^7$ cm/s
Electron affinity	$\boldsymbol{\chi}$	3.91
Relative permittivity	$\boldsymbol{\varepsilon_r}$	10
Electric breakdown field	$\mathcal{E}_{crit}$	$2.2 \cdot 10^6$ V/cm