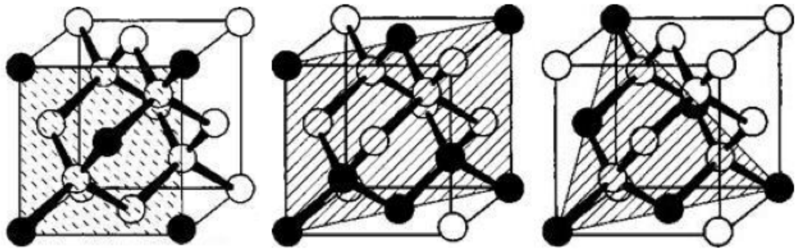
MATERIALS SCIENCE 122 MIDTERM FORMULA SHEET SPENSER TALKINGTON

Condensed Periodic Table

H 1							He 4
Li 7	Be 9	B 11	C 12	N 14	O 16	F 19	Ne 20
Na 23	Mg 24	Al 27	Si 28	P 31	S 32	Cl 35	Ar 40
K 39	Ca 40	Ga 70	Ge 73	As 75	Se 78	Br 80	Kr 84

Diamond	C, Si, Ge, α-Sn
Zincblende	GaAs, InSb, β-SiC, β-BN

Diamond cubic structure. Three crystallographic planes are shown. Switching alternate atoms in diamond structure makes zincblende.



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Units

Unit		Value
Joule	J	N m
Electronvolt	eV	1.60218×10^{-19} J
Calorie	cal	4.18400 J
Micron	μm	10^{-4} cm
Nanometer	nm	10^{-7} cm
Angstrom	Å	10^{-8} cm
Newton	N	kg m s^{-2}
Pascal	Pa	N m^{-2}
Volt	V	J C^{-1}
Ampere	A	C s^{-1}

Physical Constants

Constant		Value
Atmosphere	Atm	1.01325×10^{5} Pa
Atomic mass	u	1.66054×10^{-27} kg
Avogadro's number	N_A	6.02214×10^{23} mol^{-1}
Boltzmann's constant	k_B	8.61733×10^{-5} eV K^{-1}
Electron mass	m_e	9.10938×10^{-31} kg
Fundamental charge	e	1.60218×10^{-19} C
Gravity on earth	g	9.80665 m s^{-2}
Light speed	c	2.99792×10^{10} cm s^{-1}
Plank's constant	h	4.13567×10^{-15} eV s
Vacuum permittivity	ε_0	8.85419×10^{-14} F cm^{-2}

Prefixes

peta	P	^{15}
tera	T	^{12}
giga	G	^{9}
mega	M	^{6}
kilo	k	^{3}
		^{0}
milli	m	$^{-3}$
micro	μ	$^{-6}$
nano	n	$^{-9}$
pico	p	$^{-12}$
femto	f	$^{-15}$

Variables and Units

Quantity		Units
Energy	E	eV
Force	F	N
Mass	m	kg
Concentration	N, C	cm^{-3}
Dose	Q_0, ϕ	cm^{-2}
Length	a, d, l, r, δ	cm
Position	x, z	cm
Area	A	cm^2
Volume	V	cm^3
Temperature	T	K
Thermal Conductivity	α, k	W m^{-1} K^{-1}
Velocity	v	m s^{-1}
Flux	J	kg m^{-2} s^{-1}
Frequency	ν	s^{-1}
Voltage	V	N m C^{-1}
Current	I	C s^{-1}
Resistance	R	Ω
Power	P	J s^{-1}
Charge	q	C
Resistivity	ρ	Ω cm
Conductivity	σ	Ω^{-1} cm^{-1}
Mobility	μ	cm^2 V^{-1} s^{-1}
Permittivity	ε	F cm^{-2}
Electric Field	E	N C^{-1}
Magnetic Field	B	T

Properties (at 300K)

Property		Si	GaAs
Lattice parameter	Å	5.431	4.653
Atomic density	cm^{-3}	4.994×10^{22}	2.21×10^{22}
Density	g cm^{-3}	2.328	5.317
Thermal expansion	K^{-1}	2.33×10^{-6}	5.69×10^{-6}
Melting point	K	1709	1535
Permittivity	F cm^{-2}	11.68	12.4
Band gap	eV	1.17	1.519
Electron mobility	cm^2 V^{-1} s^{-1}	1350	8500
Hole mobility	cm^2 V^{-1} s^{-1}	490	400

Basic Formulae

$$V_{\text{sphere}} = \frac{4}{3}\pi r^3 \qquad A_{\text{sphere}} = 4\pi r^2 \qquad V_{\text{cone}} = \pi r^2 \frac{h}{3}$$

$$A_{\text{cone}} = \pi r(r + \sqrt{r^2 + h^2}) \quad A_{\text{circle}} = \pi r^2 \quad C_{\text{circle}} = 2\pi r$$

$$I = \frac{dq}{dt} \qquad V = IR \qquad P = I^2 R \qquad \rho = \frac{RA}{l} \qquad \sigma = \frac{1}{\rho}$$

$$E_{\text{photon}} = \frac{hc}{\lambda} = \frac{1240\ \text{eV nm}}{\lambda} \qquad E_{\text{ionize}} = \left(\frac{m}{m_e}\right)\left(\frac{\varepsilon_0}{\varepsilon}\right)^2$$

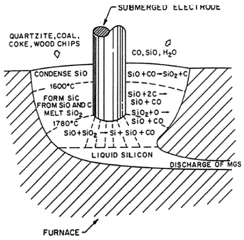
$$N_{\text{state}} = N_{\text{total}}\, e^{-\frac{E_{A,\text{state}}}{k_B T}} \qquad \sigma = e\,(n_h \mu_h + n_e \mu_e)$$

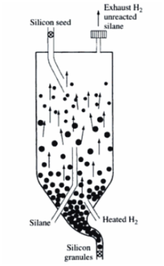
$$F_E = q\,E \qquad A \cdot B = AB\ \cos\theta$$

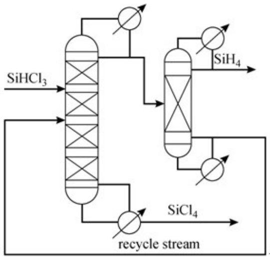
$$F_B = q\, v \times B \qquad A \times B = AB\ \sin\theta$$

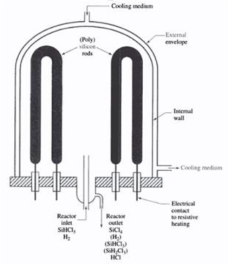
Purification

(1) Electric arc furnace → (2) Fluidized bed reactor → (3) Distillation tower → (4) Siemens deposition reactor









(1) Reduction	15 kWh/kg	1700 ˚C	SiO2 (s) + 2 C (s)	→	Si (l) + 2 CO (g)	then crush
(2) Dissolution	1.2 kWh/kg	300 ˚C	Si (s) + 3 HCl (g)	→	SiHCl3 (g) + H2 (g)	to tower
(3) Distillation	150 kWh/kg	70 ˚C	SiHCl3 (g) →→→→→→→	→	SiHCl3 (l)	to reactor
(4) Deposition	150 kWh/kg	1100°C	SiHCl3 (g) + H2 (g)	→	Si (s) + 3 HCl (g)	then crush

Czochralski Bulk Growth

(1) melt → (2) dope → (3) crystallize

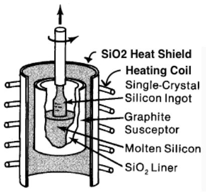
(For GaAs: BN crucible, B2O3 encapsulant)

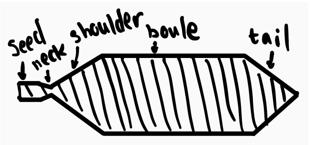
$$C_m = C_{melt}$$
$$C_l = C_{liquid}$$
$$C_s = C_{solid}$$

$$\int_0^l C_s A dx = C_m V$$
$$v_{max} = \frac{k}{\rho L}\frac{dT_l}{dx_l}$$
$$k_0 = \frac{C_s}{C_l}$$

NFT/Scheil Equation:

$$C_s(x) = k_0 C_m (1-x)^{k_0-1}$$
$$k_{eff} = \frac{k_0}{k_0 + (1-k_0)e^{-\frac{v\delta}{D}}}$$

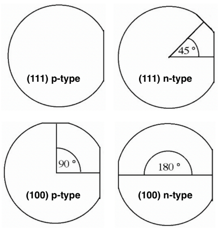




Wafering

(1) Shape (2) section (3) test (4) wafer (5) lapp (6) dremel (7) etch (8) polish (9) clean (10) inspect (11) pack

(1) Shape	unify diameter
(2) Section	saw into sections for application ranges
(4) Wafer	saw with taught, thin diamond-coated-wires
(5) Lapp	flatten with SiC/oil slurry
(7) Etch	hard oxidizer: Si (s) + HNO3 (aq) → SiO2 (s), SiO2 (s) + HF (aq) → SiO2 (aq)
(8) Polish	soft oxidizer: Si (s) + NaOH (aq) → SiO2 (s), SiO2 (s) + SiOX (s) → SiO2 (col)



Diffusion

(1) Insert → (2) dope → (3) ramp → (4) anneal → (5) cool

(2) Dope with solgel: AsH3 (g), B2H6 (l), PH3 (g)

	D_0	E_D
B	10.5	3.69
Al	8	3.47
Ga	3.6	3.57
In	16.	53.9
P	10.5	3.69
As	0.32	3.56
Sb	5.6	3.95

$$C_{diffusant}(x_j) = C_{dopant}(x_j) \qquad p \times n = n_i^2 \qquad R_S = \frac{1}{q\,\mu\,Q_0} \qquad D = D_0 e^{-\frac{E_D}{k_B T}}$$

$$E_D = E_V + E_m \approx 3.5 \text{ eV} \qquad \text{erfc}(u) = 1 - \text{erf}(u) \qquad \text{erf}(u) \approx u \text{ from 0.0 to 0.7}$$

Frequency and Velocity

$$\nu_0 = \#\text{ tries} \times \text{probability success}$$

$$v_i = 4\,\nu_0 e^{-\frac{E_m}{k_B T}} \qquad v_s = \nu_0 e^{-\frac{E_D}{k_B T}}$$

Fick's Laws

Fick I

$$J = -D\,\frac{\partial C(x,t)}{\partial x}$$

Fick II

$$\frac{dC(x,t)}{dt} = D\,\frac{\partial^2 C(x,t)}{\partial x^2}$$

Fick I + II

$$\frac{\partial J}{\partial x} = -\,\frac{\partial C(x,t)}{\partial t}$$

Field Enhancement

$$D_{eff} = hD \qquad 1 < h < 2$$

$$h = 1 + \frac{C}{2n_i}\left(1 + \left(\frac{C}{2n_i}\right)^2\right)^{-\frac{1}{2}}$$

Finite Source

$$C(x,t) = \frac{Q_0}{\sqrt{\pi D t}}\, e^{-\frac{x^2}{4Dt}}$$

Infinite Source

$$C(x,t) = C_S\, \text{erfc}\left(\frac{x}{2\sqrt{Dt}}\right)$$

Pre-deposition and Drive-in (if $10\, D_1 t_1 < D_2 t_2$)

$$Q_0(t) = \int_0^\infty C(x,t)\,dx = \frac{2}{\sqrt{\pi}} C(0,t)\sqrt{D_1 t_1}$$

$$C(x,t_1,t_2) = \frac{2C_{S,init}}{\pi}\sqrt{\frac{D_1 t_1}{D_2 t_2}}\, e^{-\frac{x^2}{4D_2 t_2}}$$

Corrections

$$(Dt)_{eff} = \sum_{i=1}^{n} D_i t_i$$

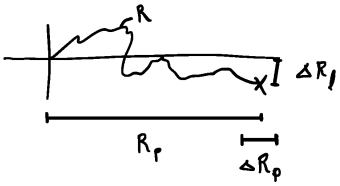
$$(Dt)_{eff} = \int_0^t D(t) t\, dt = D(T_0)\left(\frac{k_B T_0^2}{C E_m}\right)$$

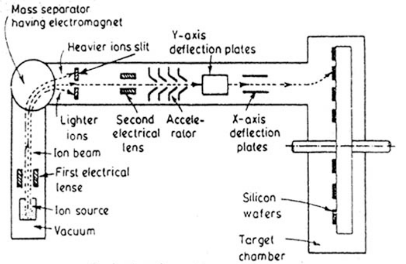
(see Field Enhancement)

Ion Implantation

$$I = \frac{dq}{dt} = \frac{n_i q}{t} \qquad Q_0 = \frac{I}{q\,r}\, t\, \frac{1}{A} \qquad r = \frac{1}{B}\sqrt{2v}\sqrt{\frac{m}{q}}$$

$$C(x) = \frac{Q_0}{\sqrt{2\pi}\Delta R_p}\, e^{-\frac{(x-R_p)^2}{2\,\Delta R_p^2}} \qquad C_{crit} = 3.75 \times 10^{24}\, \frac{\Delta R_p}{E_0}$$





Ion implantation system.