APPENDIX AII

FUNDAMENTAL PHYSICAL CONSTANTS

Quantity	Symbol	Value	Unit
Electronic charge (magnitude)	q	1.60×10^{-19}	coulomb (C)
Electronic mass (magnitude)	m	9.11×10^{-28}	gram (g)
Unit nucleonic mass	m_{nucl}	1.66×10^{-24}	gram (g)
Avogadro's number	N_t	6.02×10^{23}	atoms/g-atom (mole)
Boltzmann's constant	k	1.38×10^{-23}	joule/kelvin (J/°K)
Thermal energy (300°K)	kT	0.026	electron-volt (eV)
Thermal voltage (300°K)	kT/q	0.026	volt (V)
Speed of light (vacuum)	c	3.0×10^{10}	centimeter/second (cm/sec)
Planck's constant	h	6.63×10^{-34}	joule-second (J-sec)
Frequency (cycles/sec)	Hz	1.0	hertz (Hz)
Permittivity of free space	ϵ_o	8.85×10^{-14}	farad/centimeter (F/cm)
Relative dielectric constants:			
Germanium	$(\epsilon_r)_{Ge}$	16.0	—
Silicon	$(\epsilon_r)_{Si}$	11.9	—
Gallium arsenide	$(\epsilon_r)_{GaAs}$	13.1	—
Silicon dioxide	$(\epsilon_r)_{SiO_2}$	3.9	—
Silicon nitride	$(\epsilon_r)_{Si_3N_4}$	7.5	—
Sapphire	$(\epsilon_r)_{Sapp}$	9.2	—
Thermal conductivities (300°K)	κ_{Ge}	0.6	watts/cm-°C (W/cm-°C)
	κ_{Si}	1.5	watts/cm-°C (W/cm-°C)
	κ_{GaAs}	0.46	watts/cm-°C (W/cm-°C)
Lattice constants (300°K)	a_{Ge}	5.646	angstrom (Å)
	a_{Si}	5.430	angstrom (Å)
	a_{GaAs}	5.653	angstrom (Å)
Energy gaps (300°K)	E_{gGe}	0.66	electron-volt (eV)
	E_{gSi}	1.12	electron-volt (eV)
	E_{gGaAs}	1.42	electron-volt (eV)
Intrinsic concentrations (300°K)	n_{Ge}	2.4×10^{13}	centimeter^{-3} (cm^{-3})
	n_{Si}	1.5×10^{10}	centimeter^{-3} (cm^{-3})
	n_{GaAs}	1.8×10^{6}	centimeter^{-3} (cm^{-3})
Micrometer (micron)	μm	1.0×10^{-4}	centimeter (cm)
Angstrom unit	Å	1.0×10^{-8}	centimeter (cm)
Electron-volt	eV	1.6×10^{-19}	joules (J)

Appendix B

International System of Units

Quantity	Unit	Symbol	Dimensions
Length	meter	m	
Mass	kilogram	kg	
Time	second	s	
Temperature	kelvin	K	
Current	ampere	A	
Frequency	hertz	Hz	1/s
Force	newton	N	$kg\text{-}m/s^2$
Pressure	pascal	Pa	N/m^2
Energy	joule	J	N-m
Power	watt	W	J/s
Electric charge	coulomb	C	A-s
Potential	volt	V	J/C
Conductance	siemens	S	A/V
Resistance	ohm	Ω	V/A
Capacitance	farad	F	C/V
Magnetic flux	weber	Wb	V-s
Magnetic induction	tesla	T	Wb/m^2
Inductance	henry	H	Wb/A

Appendix C

Unit Prefixes[a]

Multiple	Prefix	Symbol	Multiple	Prefix	Symbol
10^{18}	exa	E	10^{-1}	deci	d
10^{15}	peta	P	10^{-2}	centi	c
10^{12}	tera	T	10^{-3}	milli	m
10^{9}	giga	G	10^{-6}	micro	μ
10^{6}	mega	M	10^{-9}	nano	n
10^{3}	kilo	k	10^{-12}	pico	p
10^{2}	hecto	h	10^{-15}	femto	f
10	deka	da	10^{-18}	atto	a

[a]Adopted by International Committee on Weights and Measures. (Compound prefixes should not be used; e.g., not μμ but p.)

Appendix D

Greek Alphabet

Letter	Lowercase	Uppercase	Letter	Lowercase	Uppercase
Alpha	α	A	Nu	ν	N
Beta	β	B	Xi	ξ	Ξ
Gamma	γ	Γ	Omicron	o	O
Delta	δ	Δ	Pi	π	Π
Epsilon	ϵ	E	Rho	ρ	P
Zeta	ζ	Z	Sigma	σ	Σ
Eta	η	H	Tau	τ	T
Theta	θ	Θ	Upsilon	υ	Υ
Iota	ι	I	Phi	ϕ	Φ
Kappa	κ	K	Chi	χ	X
Lambda	λ	Λ	Psi	ψ	Ψ
Mu	μ	M	Omega	ω	Ω

Appendix E

Physical Constants

Quantity	Symbol	Value
Angstrom unit	Å	$1\ Å = 10^{-4}\ \mu m = 10^{-8}$ cm
Avogadro constant	N_{AVO}	$6.02204 \times 10^{23}\ mol^{-1}$
Bohr radius	a_B	0.52917 Å
Boltzmann constant	k	1.38066×10^{-23} J/K (R/N_{AVO})
Elementary charge	q	1.60218×10^{-19} C
Electron rest mass	m_0	0.91095×10^{-30} kg
Electron volt	eV	$1\ eV = 1.60218 \times 10^{-19}$ J $= 23.053$ kcal/mol
Gas constant	R	1.98719 cal $mol^{-1}\ K^{-1}$
Permeability in vacuum	μ_0	1.25663×10^{-8} H/cm $(4\pi \times 10^{-9})$
Permittivity in vacuum	ϵ_0	8.85418×10^{-14} F/cm $(1/\mu_0 c^2)$
Planck constant	h	6.62617×10^{-34} J-s
Reduced Planck constant	$\hbar$	1.05458×10^{-34} J-s $(h/2\pi)$
Proton rest mass	M_p	1.67264×10^{-27} kg
Speed of light in vacuum	c	2.99792×10^{10} cm/s
Standard atmosphere		$1.01325 \times 10^5\ N/m^2$
Thermal voltage at 300 K	kT/q	0.0259 V
Wavelength of 1-eV quantum	λ	1.23977 μm

Appendix F

Lattice Constants

	Element or Compound	Name	Crystal[a] Structure	Lattice Constant at 300 K (Å)
Element	C	Carbon (diamond)	D	3.56683
	Ge	Germanium	D	5.64613
	Si	Silicon	D	5.43095
	Sn	Grey Tin	D	6.48920
IV–IV	SiC	Silicon carbide	W	$a = 3.086$, $c = 15.117$
III–V	AlAs	Aluminum arsenide	Z	5.6605
	AlP	Aluminum phosphide	Z	5.4510
	AlSb	Aluminum antimonide	Z	6.1355
	BN	Boron nitride	Z	3.6150
	BP	Boron phosphide	Z	4.5380
	GaAs	Gallium arsenide	Z	5.6533
	GaN	Gallium nitride	W	$a = 3.189$, $c = 5.185$
	GaP	Gallium phosphide	Z	5.4512
	GaSb	Gallium antimonide	Z	6.0959
	InAs	Indium arsenide	Z	6.0584
	InP	Indium phosphide	Z	5.8686
	InSb	Indium antimonide	Z	6.4794
II–VI	CdS	Cadmium sulfide	Z	5.8320
	CdS	Cadmium sulfide	W	$a = 4.16$, $c = 6.756$
	CdSe	Cadmium selenide	Z	6.050
	CdTe	Cadmium telluride	Z	6.482
	ZnO	Zinc oxide	R	4.580
	ZnS	Zinc sulfide	Z	5.420
	ZnS	Zinc sulfide	W	$a = 3.82$, $c = 6.26$
IV–VI	PbS	Lead sulfide	R	5.9362
	PbTe	Lead telluride	R	6.4620

[a] D = Diamond, W = Wurtzite, Z = Zincblende, R = Rock salt.

Appendix G

Properties of Important Semiconductors

Semiconductor		Bandgap (eV) 300 K	Bandgap (eV) 0 K	Mobility at 300 K (cm^2/V-s)[a] Elec.	Mobility at 300 K (cm^2/V-s)[a] Holes	Band[b]	Effective Mass m^*/m_0 Elec.	Effective Mass m^*/m_0 Holes	ϵ_s/ϵ_0
Element	C	5.47	5.48	1800	1200	I	0.2	0.25	5.7
	Ge	0.66	0.74	3900	1900	I	1.64[c] 0.082[d]	0.04[e] 0.28[f]	16.0
	Si	1.12	1.17	1500	450	I	0.98[c] 0.19[d]	0.16[e] 0.49[f]	11.9
	Sn		0.082	1400	1200	D			
IV–IV	α-SiC	2.996	3.03	400	50	I	0.60	1.00	10.0
III–V	AlSb	1.58	1.68	200	420	I	0.12	0.98	14.4
	BN	~7.5				I			7.1
	BP	2.0							
	GaN	3.36	3.50	380			0.19	0.60	12.2
	GaSb	0.72	0.81	5000	850	D	0.042	0.40	15.7
	GaAs	1.42	1.52	8500	400	D	0.067	0.082	13.1
	GaP	2.26	2.34	110	75	I	0.82	0.60	11.1
	InSb	0.17	0.23	80000	1250	D	0.0145	0.40	17.7
	InAs	0.36	0.42	33000	460	D	0.023	0.40	14.6
	InP	1.35	1.42	4600	150	D	0.077	0.64	12.4
II–VI	CdS	2.42	2.56	340	50	D	0.21	0.80	5.4
	CdSe	1.70	1.85	800		D	0.13	0.45	10.0
	CdTe	1.56		1050	100	D			10.2
	ZnO	3.35	3.42	200	180	D	0.27		9.0
	ZnS	3.68	3.84	165	5	D	0.40		5.2
IV–VI	PbS	0.41	0.286	600	700	I	0.25	0.25	17.0
	PbTe	0.31	0.19	6000	4000	I	0.17	0.20	30.0

[a] The values are for drift mobilities obtained in the purest and most perfect materials available to date.
[b] I = indirect, D = direct.
[c] Longitudinal effective mass.
[d] Transverse effective mass.
[e] Light-hole effective mass.
[f] Heavy-hole effective mass.

Appendix H

Properties of Ge, Si, and GaAs at 300 K

Properties	Ge	Si	GaAs
Atoms/cm^3	4.42×10^{22}	5.0×10^{22}	4.42×10^{22}
Atomic weight	72.60	28.09	144.63
Breakdown field(V/cm)	$\sim 10^5$	$\sim 3 \times 10^5$	$\sim 4 \times 10^5$
Crystal structure	Diamond	Diamond	Zincblende
Density (g/cm^3)	5.3267	2.328	5.32
Dielectric constant	16.0	11.9	13.1
Effective density of states in conduction band, N_C (cm^{-3})	1.04×10^{19}	2.8×10^{19}	4.7×10^{17}
Effective density of states in valence band, N_V (cm^{-3})	6.0×10^{18}	1.04×10^{19}	7.0×10^{18}
Effective Mass, m^*/m_0			
Electrons	$m^*_l = 1.64$ $m^*_t = 0.082$	$m^*_l = 0.98$ $m^*_t = 0.19$	0.067
Holes	$m^*_{lh} = 0.044$ $m^*_{hh} = 0.28$	$m^*_{lh} = 0.16$ $m^*_{hh} = 0.49$	$m^*_{lh} = 0.082$ $m^*_{hh} = 0.45$
Electron affinity, χ(V)	4.0	4.05	4.07
Energy gap (eV) at 300 K	0.66	1.12	1.424
Intrinsic carrier concentration (cm^{-3})	2.4×10^{13}	1.45×10^{10}	1.79×10^6
Intrinsic Debye length (μm)	0.68	24	2250
Intrinsic resistivity (Ω-cm)	47	2.3×10^5	10^8
Lattice constant (Å)	5.64613	5.43095	5.6533
Linear coefficient of thermal expansion, $\Delta L/L\Delta T$ (°C^{-1})	5.8×10^{-6}	2.6×10^{-6}	6.86×10^{-6}
Melting point (°C)	937	1415	1238
Minority carrier lifetime (s)	10^{-3}	2.5×10^{-3}	$\sim 10^{-8}$
Mobility (drift) (cm^2/V-s)			
	3900 1900	1500 450	8500 400
Optical-phonon energy (eV)	0.037	0.063	0.035
Phonon mean free path λ_0 (Å)	105	76 (electron) 55 (hole)	58
Specific heat (J/g-°C)	0.31	0.7	0.35
Thermal conductivity at 300 K (W/cm-°C)	0.6	1.5	0.46
Thermal diffusivity (cm^2/s)	0.36	0.9	0.24
Vapor pressure (Pa)	1 at 1330°C 10^{-6} at 760°C	1 at 1650°C 10^{-6} at 900°C	100 at 1050°C 1 at 900°C

Appendix I

Properties of SiO_2 and Si_3N_4 at 300 K

Insulator:	SiO_2	Si_3N_4
Structure	Amorphous	Amorphous
Melting point (°C)	~1600	—
Density (g/cm^3)	2.2	3.1
Refractive index	1.46	2.05
Dielectric constant	3.9	7.5
Dielectric strength (V/cm)	10^7	10^7
Infrared absorption band (μm)	9.3	11.5–12.0
Energy gap (eV)	9	~5.0
Thermal-expansion coefficient ($°C^{-1}$)	5×10^{-7}	—
Thermal conductivity (W/cm-K)	0.014	—
dc resistivity (Ω-cm)		
at 25°C	10^{14}–10^{16}	~10^{14}
at 500°C	—	~2×10^{13}
Etch rate in buffered HF[a] (Å/min)	1000	5-10

[a] Buffered HF: 34.6% (wt.) NH_4F, 6.8% (wt.) HF, 58.6% H_2O.