

Appendix 1: List of symbols

Symbol	Description	MKS Units
a	Acceleration	m/s^2
a_0	Bohr radius	m
A	Area	m^2
A^*	Richardson constant	m/s
A_C	Collector area	m^2
A_E	Emitter area	m^2
b	Bimolecular recombination constant	m^3/s
c	Speed of light in vacuum	m/s
C	Capacitance per unit area	F/m^2
C_D	Diffusion capacitance per unit area	F/m^2
C_{DS}	Drain-source capacitance	F
C_{FB}	Flatband capacitance per unit area of a MOS structure	F/m^2
C_G	Gate capacitance	F
C_{GS}	Gate-source capacitance	F
C_{GD}	Gate-drain capacitance	F
C_{HF}	High-frequency capacitance per unit area of a MOS structure	F/m^2
C_j	Junction capacitance per unit area	F/m^2
C_{LF}	Low-frequency (quasi-static) capacitance per unit area of a MOS structure	F/m^2
C_M	Miller capacitance	F
C_{ox}	Oxide capacitance per unit area	F/m^2
C_s	Semiconductor capacitance per unit area	F/m^2
D_n	Electron diffusion constant	m^2/s
D_p	Hole diffusion constant	m^2/s
E	Energy	Joule

E	Electric field	V/m
E_0	Lowest energy in a one-dimensional quantum well	Joule
E_a	Acceptor energy	Joule
E_{br}	Breakdown field	V/m
E_c	Conduction band energy of a semiconductor	Joule
E_d	Donor energy	Joule
E_F	Fermi energy (thermal equilibrium)	Joule
$E_{F,n}$	Fermi energy in an n-type semiconductor	Joule
$E_{F,p}$	Fermi energy in a p-type semiconductor	Joule
E_g	Energy bandgap of a semiconductor	Joule
E_i	Intrinsic Fermi energy	Joule
E_n	n^{th} quantized energy	Joule
E_{ph}	Photon energy	Joule
E_t	Trap energy	Joule
E_v	Valence band energy of a semiconductor	Joule
E_{vacuum}	Electron energy in vacuum	Joule
$F(E)$	Distribution function (probability density function)	
$f_{BE}(E)$	Bose-Einstein distribution function	
$f_{FD}(E)$	Fermi-Dirac distribution function	
$f_{MB}(E)$	Maxwell-Boltzmann distribution function	
F	Force	Newton
F_n	Quasi-Fermi energy of electrons	Joule
F_p	Quasi-Fermi energy of holes	Joule
$g(E)$	Density of states per unit energy and per unit volume	$\text{m}^{-3}\text{J}^{-1}$
$g(E)$	Density of states in the conduction band per unit energy and per unit volume	$\text{m}^{-3}\text{J}^{-1}$
$g(E)$	Density of states in the valence band per unit energy and per unit volume	$\text{m}^{-3}\text{J}^{-1}$
g_d	Output conductance of a MOSFET	S

g_m	Transconductance of a MOSFET	S
G	Carrier generation rate	$\text{m}^{-3}\text{s}^{-1}$
G_n	Electron generation rate	$\text{m}^{-3}\text{s}^{-1}$
G_p	Hole generation rate	$\text{m}^{-3}\text{s}^{-1}$
h	Plank's constant	J s
$\hbar$	Reduced Plank's ($= h / 2\pi$)	J s
I	Current	A
I_B	Base current of a bipolar transistor	A
I_C	Collector current of a bipolar transistor	A
I_D	Drain current of a MOSFET	A
I_E	Emitter current of a bipolar transistor	A
I_F	Forward active current of a bipolar transistor	A
$I_{D,sat}$	Drain current of a MOSFET in saturation	A
I_{ph}	Photo current	A
I_r	Recombination current	A
I_R	Reverse active current of a bipolar transistor	A
I_s	Saturation current	A
I_{sc}	Short circuit current of a solar cell	A
J	Current density	A/m^2
J_n	Electron current density	A/m^2
J_p	Hole current density	A/m^2
k	Boltzmann's constant wavenumber	J/K m^{-1}
l	Mean free path	m
L	Length	m
L_D	Debye length	m
L_n	Electron diffusion length	m

L_p	Hole diffusion length	m
L_x	Hole diffusion length	m
m	Mass	kg
m^*	Effective mass	kg
m_A	Atomic mass	kg
m_0	Free electron mass	kg
m_e^*	Effective mass of electrons	kg
m_h^*	Effective mass of holes	kg
M	Proton mass	kg
	Multiplication factor	
	Electron density	m^{-3}
	Integer	
n	Refractive index	
	Ideality factor	
n_i	Intrinsic carrier density	m^{-3}
$n(E)$	Electron density per unit energy and per unit volume	m^{-3}
n_0	Electron density in thermal equilibrium	m^{-3}
n_i	Intrinsic carrier density	m^{-3}
n_n	Electron density in an n-type semiconductor	m^{-3}
n_{n0}	Thermal equilibrium electron density in an n-type semiconductor	m^{-3}
n_p	Electron density in a p-type semiconductor	m^{-3}
n_{p0}	Thermal equilibrium electron density in a p-type semiconductor	m^{-3}
	Number of particles	
N	Doping density	
N_a	Acceptor doping density	m^{-3}
N_a^-	Ionized acceptor density	m^{-3}
N_A	Avogadro's number	

N_B	Base doping density	m^{-3}
N_c	Effective density of states in the conduction band	m^{-3}
N_C	Collector doping density	m^{-3}
N_d	Donor doping density	m^{-3}
N_d^+	Ionized donor density	m^{-3}
N_E	Emitter doping density	m^{-3}
N_{ss}	Surface state density	m^{-2}
N_t	Recombination trap density	m^{-2}
N_v	Effective density of states in the valence band	m^{-3}
	Hole density	m^{-3}
p	Particle momentum	kgm/s
	Pressure	Nm^{-2}
$p(E)$	Hole density per unit energy	m^{-3}
p_0	Hole density in thermal equilibrium	m^{-3}
p_n	Hole density in an n-type semiconductor	m^{-3}
p_{n0}	Thermal equilibrium hole density in an n-type semiconductor	m^{-3}
p_p	Hole density in a p-type semiconductor	m^{-3}
p_{p0}	Thermal equilibrium hole density in a p-type semiconductor	m^{-3}
q	electronic charge	C
	Heat	Joule
Q	Charge	C
Q_B	Majority carrier charge density in the base	C/m^2
Q_d	Charge density per unit area in the depletion layer of an MOS structure	C/m^2
$Q_{d,T}$	Charge density per unit area at threshold in the depletion layer of an MOS structure	C/m^2
Q_i	Interface charge density per unit area	C/m^2
Q_{inv}	Inversion layer charge density per unit area	C/m^2

Q_M	Charge density per unit area in a metal	C/m^2
Q_n	Charge density per unit area in the depletion layer of an n-type region	C/m^2
Q_p	Charge density per unit area in the depletion layer of a p-type region	C/m^2
Q_{ss}	Surface state charge density per unit area	C/m^2
r_e	Emitter resistance	Ohm
r_p	Base resistance	Ohm
R	The Rydberg constant	J
	Resistance	Ohm
R_n	Electron recombination rate	$m^{-3}s^{-1}$
R_p	Hole recombination rate	$m^{-3}s^{-1}$
R_s	Sheet resistance	Ohm
s	Spin	
S	Entropy	J/K
t	Thickness	m
t_{ox}	Oxide thickness	m
T	Temperature	Kelvin
	Kinetic energy	Joule
u_w	Spectral density	$Jm^{-3}s^{-1}$
U	Total energy	Joule
U_A	Auger recombination rate	$m^{-3}s^{-1}$
U_{b-b}	Band-to-band recombination rate	$m^{-3}s^{-1}$
U_n	Net recombination rate of electrons	$m^{-3}s^{-1}$
U_p	Net recombination rate of holes	$m^{-3}s^{-1}$
U_{SHR}	Shockley-Read-Hall recombination rate	$m^{-3}s^{-1}$
v	Velocity	m/s
v_R	Richardson velocity	m/s
v_{sat}	Saturation velocity	m/s

v_{th}	Thermal velocity	m/s
V	Potential energy	Joule
	Volume	m ³
V_a	Applied voltage	V
V_A	Early voltage	V
V_{br}	Breakdown voltage	V
V_B	Base voltage	V
V_{BE}	Base-emitter voltage	V
V_{BC}	Base-collector voltage	V
V_C	Collector voltage	V
V_{CE}	Collector-emitter voltage	V
V_D	Drain voltage	V
V_{DS}	Drain-source voltage	V
$V_{DS,sat}$	Drain-source saturation voltage	V
V_E	Emitter voltage	V
V_{FB}	Flatband voltage	V
V_G	Gate voltage	V
V_{GS}	Gate-source voltage	V
V_{oc}	Open circuit voltage of a solar cell	V
V_t	Thermal voltage	V
V_T	Threshold voltage of an MOS structure	V
w	Depletion layer width	m
w_B	Base width	m
w_C	Collector width	m
w_E	Emitter width	m
w_n	Width of an n-type region	m
w_p	Width of a p-type region	m

W	Work	Joule
x	Position	m
x_d	Depletion layer width in an MOS structure	m
$x_{d,T}$	Depletion layer width in an MOS structure at threshold	m
x_j	Junction depth	m
x_n	Depletion layer width in an n-type semiconductor	m
x_p	Depletion layer width in a p-type semiconductor	m
a	Absorption coefficient	m^{-1}
a	Transport factor	
a_F	Forward active transport factor	
a_n	Ionization rate coefficient for electrons	m^{-1}
a_R	Reverse active transport factor	
a_T	Base transport factor	
b	Current gain	
g	Body effect parameter	$\text{V}^{1/2}$
g_E	Emitter efficiency	
G_n	Auger coefficient for electrons	m^6s^{-1}
G_p	Auger coefficient for holes	m^6s^{-1}
d_n	Excess electron density	m^{-3}
d_p	Excess hole density	m^{-3}
d_R	Depletion layer recombination factor	
$DQ_{n,B}$	Excess electron charge density in the base	C/m^2
e	Dielectric constant	F/m
e_0	Permittivity of vacuum	F/m
e_{ox}	Dielectric constant of the oxide	F/m

ϵ_s	Dielectric constant of the semiconductor	F/m
μ_0	Permeability of vacuum	H/m
Q	Tunnel probability	
λ	Wavelength	m
μ	Electro-chemical potential	Joule
μ_n	Electron mobility	m ² /V-s
μ_p	Hole mobility	m ² /V-s
ν	Frequency	Hz
ρ	Charge density per unit volume	C/m ³
ρ	Resistivity	Ωm
ρ_{ox}	Charge density per unit volume in the oxide	C/m ³
σ	Conductivity	$\Omega^{-1}\text{m}^{-1}$
τ	Scattering time	s
τ_n	Electron lifetime	s
τ_p	Hole lifetime	s
ϕ	Potential	V
ϕ_B	Barrier height	V
ϕ_F	Bulk potential	V
ϕ_i	Built-in potential of a p-n diode or Schottky diode	V
ϕ_s	Potential at the semiconductor surface	V
F	Flux	m ⁻² s ⁻¹
F_M	Workfunction of the metal	V
F_{MS}	Workfunction difference between the metal and the semiconductor	V
F_S	Workfunction of the semiconductor	V
χ	Electron affinity of the semiconductor	V
Ψ	Wavefunction	

ω Radial frequency

rad/s