# EEE105: Glossary of Terms

## *Roman*

A Area. In addition to its use in defining the Area of plates in a capacitor. It is regularly used to define the cross-sectional area of a conducting medium through which current flows.

a This can have two meanings in this course: its conventional "physics" meaning of acceleration of an object or particle (in the section on drift velocity); or in a field effect transistor it is used to define the absolute thickness of a piece of doped material used as the channel.

B A constant of proportionality relating the recombination rate, R to the product of the electron and hole concentrations. In other courses B is commonly used for the Magnetic Field.

b The thickness of a piece of doped material used as the channel of a field effect transistor, taking into account reductions due to depletion region thickness(es) which may be present.

C This can have two meanings. In this course it is used in its normal meaning of Capacitance, but in science it is also commonly used to indicate a constant. In this latter context it is used for the constant in the equation relating the bond breaking energy, $W_g$, and temperature to the intrinsic carrier concentration.

CB Abbreviation commonly used for "conduction band". The conduction band can also be called $E_c$, or $E_{CB}$, which strictly means the conduction band energy. [note: $W_g=E_c-E_v$, where $E_v$ is the valence band energy, see VB]

$C_j$ The junction capacitance. As the depletion region of a p-n junction can be considered as an insulating region sandwiched between two conducting regions it has a capacitance associated with it.

c the speed of light in a vacuum

D Diffusion Coefficient, a constant of proportionality relating the net flux of particles through cross-sectional area to the concentration gradient of the particles.

$D_e$ Diffusion Coefficient or diffusivity of electrons in a material.

$D_h$ Diffusion Coefficient or diffusivity of holes in a material.

d distance between two points or objects (e.g. between two plates in a capacitor). It is also used to represent the total thickness of the depletion region in a p-n junction.

$d_1$,$d_2$ two thicknesses used to represent the thickness of the depletion region on the p- and n- side of a p-n junction, or vice versa. [$d=d_1+d_2$]

$d_j$ Total depletion region thickness of a p-n junction, sometimes referred to merely as d.

$d_n$ Depletion region thickness on the n-side of the p-n junction, sometimes referred to as $d_2$ (or $d_1$).

$d_p$ Depletion region thickness on the p-side of the p-n junction, sometimes referred to as $d_1$ (or $d_2$).

E Electric Field, which is actually a vector quantity $\underline{E}$, giving both the strength and direction of the field at a point in space. In this course E can usually be treated simply as a scalar due to the 1D nature of the problems.

$E_{ph}$ Energy of a photon [$E_{ph}=hf$]

F Force, which is actually a vector quantity $\underline{F}$, giving both the strength and direction of the force at a point in space. In this course F can usually be treated simply as a scalar due to the 1D nature of the problems in this course. [$F=ma=qE$).

f frequency. In some texts the frequency of a photon may be referred to by $\nu$ ("nu")

G This variable can have two meanings. It is conventionally used to define the conductance of a piece of material [$G=1/R$] (used in the section on field effect transistors). However in this course we also use it for the generation rate: The rate of generation of free electrons and holes through the breaking of bonds, usually from thermal processes.

$G_0$ The channel conductance of a field effect transistor when the gate bias, $V_g$ =0V.

$g_m$ Transconductance of a field effect transistor [$g_m=dI_d/dV_g$]

h Planck's constant. A fundamental constant relating the frequency of a photon "electromagnetic wave" to the energy of the photon.

$h_{FE}$ The comment emitter bias current gain in a bipolar junction transistor [$h_{FE}= I_C/I_B$], see also $\beta$.

I Current

$I_0$ The so called saturation current in a p-n junction diode [$I=I_0(\exp(qV/kT)-1)$]. It is the current one would, in theory, expect as the leakage current in a reverse biased diode.

$I_B$ Base current in a bipolar junction transistor.

$I_C$ Collector current in a bipolar junction transistor.

$I_d$ Drain current flowing along the channel of a field effect transistor.

$I_{d0}$ Drain current following the channel of a field effect transistor with a gate bias, $V_g$=0V, with some potential $V_d$ between source and drain.

$I_E$ Emitter current in a bipolar junction transistor.

$I_e$ Electron current. The current carried by free electrons as charge carriers. Note in a p-n junction this means the current due to electrons injected across the junction into the p-type material

$I_{e0}$ The saturation current contribution due to electrons [$I_0= I_{e0}+I_{h0}$]

$I_h$ Hole current. The current carried by holes as charge carriers. Note in a p-n junction this means the current due to holes injected across the junction into the n-type material

$I_{h0}$ The saturation current contribution due to holes[$I_0= I_{e0}+I_{h0}$]

$i_d$ Small signal drain current in a field effect transistor

J Current Density, equal to current divided by the cross-sectional area through which it flows. [$J=I/A$]

$J_0$ The so called saturation current density in a p-n junction diode [$J=J_0(\exp(qV/kT)-1)$]. It is the current density one would, in theory, expect as the leakage current density in a reverse biased diode.

$J_{diff}$ Current density due to diffusion of charge carriers due to a concentration gradient of them.

$J_{drift}$ Current density due to drift of charge carriers due to the presence of an electric field.

$J_e$ Electron current density. The current density carried by free electrons as charge carriers. Note in a p-n junction this means the current density due to electrons injected across the junction into the p-type material

$J_{e0}$ The saturation current contribution due to electrons [$J_0= J_{e0}+J_{h0}$]

$J_h$ Hole current density. The current density carried by holes as charge carriers. Note in a p-n junction this means the current density due to holes injected across the junction into the n-type material

$J_{h0}$ The saturation current density contribution due to holes [$J_0= J_{e0}+J_{h0}$]

k The Boltzman Constant, a fundamental constant relating thermal energy and temperature.

L Length (of a piece of material such as a conductor).

$L_e$ Minority carrier diffusion length for electrons. This is the average, or characteristic length to which excess electrons can diffuse into a p-type layer before recombining. [$L_e=(D_e\tau_e)^{1/2}$]

$L_h$ Minority carrier diffusion length for holes. This is the average, or characteristic length to which excess holes can diffuse into a n-type layer before recombining. [$L_h=(D_h\tau_h)^{1/2}$]

l Used to define the gate length in a field effect transistor.

m mass of an object or particle

$m^*$ Effective mass. The mass of a charge carrier in a solid may be different from that of the carrier in vacuum. The reasons for this are related to quantum mechanics and will not be covered until second year (EEE207). It is often expressed as a fraction of the mass of an electron in free space

$m_e$ Mass of an electron in free space, a constant

$m_e^*$ Effective mass of a free electron in a particular material

$m_h^*$ Effective mass of a hole in a particular material

$N_a$ Number density of acceptors in a piece of semiconductor material. Normally at room temperature the density of holes, p, can be assumed equal to $N_a$.

$N_d$ Number density of donors in a piece of semiconductor material. Normally at room temperature the density of free electrons, n , can be assumed equal to $N_d$.

$n$ — the number density of free electrons (electrons able to move freely -- i.e. not bound to an atom or in a bond) in a piece of material. In an n-type semiconductor this number density can also be represented as $n_{(n)}$ or $n_n$ to distinguish majority carriers from minority carriers.

$n_i$ — Intrinsic free electron concentration. The number density of free electrons generated through thermal processes in a material. If the material was perfectly pure this would be the free electron concentration in the material.

$n_{(n)}$ — The majority carrier concentration of electrons in n-type material (see also 'n')

$n_p$ — The concentration of free electrons in a p-type material. This is a so-called minority carrier concentration.

$p$ — This is another variable that has more than one conventional meaning in its use in this course. While p is used for momentum at one point (drift velocity proof) in most circumstances it represents the hole density (number of free holes per unit volume) in a piece of semiconductor. In an p-type semiconductor this number density can also be represented as $p_{(p)}$ or $p_p$ to distinguish majority carriers from minority carriers.

$p_i$ — Intrinsic hole concentration. The number density of holes generated through thermal processes in a material. If the material was perfectly pure this would be the hole concentration in the material. Note: $n_i=p_i$.

$p_n$ — The concentration of holes in a n-type material. This is a so-called minority carrier concentration.

$p_{(p)}$ — The majority carrier concentration of holes in p-type material (see also 'p')

$Q$ — Total Charge on some object

$Q_B$ — The charge stored in the base of a bipolar junction transistor.

$q$ — A single charge, used extensively in the course to represent the magnitude of the charge on either electron (or hole). In some books and other courses you may find "e" used for this latter purpose.

$R$ — This variable normally means Resistance. [$R=\rho L/A$]. However in this course it can also be used to represent the recombination rate of electrons and holes.

$R_L$ — Resistance of a load resistor in for example an amplifier circuit.

$r$ — the distance between to points or particles. Many problems in this couse can be reduced to one dimension (1D) so "x" is often used instead.

$T$ — Temperature. (Remember to convert temperatures into Kelvin before use!)

$t$ — time

$V$ — Normally represents the difference in potential between two points (the potential difference or voltage). It is also be used at the beginning of the course to define the absolute potential which is the potential difference at that position compared to a point at infinity.

$V_0$ — The built-in potential opposing current flow in a p-n junction. It is a barrier that can be overcome by applying a sufficiently high forward bias to the structure.

VB — Abbreviation commonly used for "valence band". The valence band can also be called $E_v$, or $E_{VB}$, which strictly means the conduction band energy. [note: $W_g=E_c-E_v$, where $E_c$ is the valence band energy, see CB]

$V_{BE}$ — Base-Emitter voltage in a bipolar junction transistor. (Also can be written $V_{be}$)

$V_{CB}$ — Collector-Base voltage in a bipolar junction transistor. (Also can be written $V_{cb}$)

$V_{CE}$ — Collector-Emitter voltage in a bipolar junction transistor. (Also can be written $V_{ce}$)

$V_d$ — The voltage drop between source and drain in a field effect transistor (can be called $V_{ds}$)

$V_g$ — The voltage drop between source and gate in a field effect transistor, or the gate voltage (can be called $V_{gs}$)

$V_j$ — The junction potential. The modified potential barrier for a p-n junction in the presence of bias. [in forward bias: $V_j=V_0-V$; in reverse bias: $V_j=V_0+V$]

$V_p$ — The pinch-off voltage in a field effect transistor.

$V_T$ — Threshold Voltage: minimum value of $V_g$ to induce a channel in an enhancement mode MOSFET.

$v$ — velocity of a particle

$v_d$ Drift velocity. The average velocity of a charged particle as is moves through a solid. In the ID problems we consider in this course the average velocity is only in the x direction, even though the instantaneous velocity of a particular particle could be in any direction. The drift velocity of charge carriers in a material in an E-field depends on how long on average they can be accelerated in the field before undergoing a scattering event. Can be formally written as $\langle v_d \rangle$ to show that it is an average quantity.

$v_{gs}$ Small signal gate voltage in a field effect transistor (may also be written as $v_g$)

$v_p$ Peak velocity reached by an electron before a particular scattering event.

$W_g$ The energy required to break an electron out of its bond creating an electron hole pair. In some books/ other courses you may find this written as $E_g$. You may find it called the ionisation energy, or more correctly the bandgap energy.

w Used to define the gate width in a field effect transistor.

$w_B$ Width of the base in a bipolar junction transistor.

x distance along x-axis.

## *Greek*

$\alpha$ "alpha". Base transport factor in a bipolar junction transistor, defined as the fraction of the electron current that reaches the collector in an npn device.

$\alpha_B$ "alpha B". Common base current gain in a bipolar junction transistor [$\alpha_B=\Delta I_C/\Delta I_E$]

$\beta$ "beta". The common emitter current gain in a bipolar junction transistor [$\beta=\Delta I_C/\Delta I_B$]

$\Delta I_C$ "delta I C". Change in collector current in a bipolar junction transistor.

$\Delta I_E$ "delta I E". Change in emitter current in a bipolar junction transistor.

$\Delta I_B$ "delta I B". Change in base current in a bipolar junction transistor.

$\delta n$ "delta n" this is the concentration of excess electrons, induced through injection of the charge carriers by either electrical or optical means. It can be represented as a function of x (distance) or t (time)

$\delta n_0$ "delta n nought " this is a boundary condition giving the concentration of excess electrons, induced through injection of the charge carriers by either electrical or optical means at x=0, or at some interface (e.g. between semiconductor and air, or between p-type material and the depletion region etc.)

$\delta p$ "delta p" this is the concentration of excess holes, induced through injection of the charge carriers by either electrical or optical means.

$\delta p_0$ "delta p nought " this is a boundary condition giving the concentration of excess holes, induced through injection of the charge carriers by either electrical or optical means at x=0, or at some interface (e.g. between semiconductor and air, or between n-type material and the depletion region etc.)

$\varepsilon$ "epsilon" the pemittivity, giving the strength of interation between charged particles in a particular medium. [$\varepsilon=\varepsilon_0\varepsilon_r$]

$\varepsilon_0$ "epsilon nought" the pemittivity of free space. A fundamental constant used in defining the strength of interaction between charged particles in a vacuum.

$\varepsilon_r$ "epsilon r" the relative pemittivity, a term modifying the free space constant, $\varepsilon_0$, to account for the change of strength of the interaction between charges in a material.

$\gamma_E$ "gamma E". Emitter injection efficiency in a bipolar junction transistor, defined as the fraction of extra emitter current due to electrons in an npn device.

$\lambda$ "lambda", the wavelength of a photon "electromagnetic wave"

$\mu$ "mu" mobility. This represents the ease with which charge carriers can move in a particular material. It depends on both the mass of the charge carrier and its drift velocity.

$\mu_e$ "mu e" mobility of (free) electrons in a material.

$\mu_h$ "mu h" mobility of holes in a material.

$\rho$ "rho". Unfortunately this is a symbol that is conventionally used for a number of different meanings and so once again care must be taken in this course to examine the context in which it is being used. It is used in this course to:

1. represent the density of charge in a particular volume. It will equal the number of charged particles in a volume times the charge on one particle divided by the volume.
2. represent the resistivity of a material.
(N.B. In other courses or in books you may find it used to represent the density of mass in a particular volume.)

$\rho_n$ "rho n", the density of charge in the n-type side of the depletion region of a p-n junction. It is possible that in books and other courses that $\rho_n$ could represent the resistivity of a n-type layer (i.e. $1/\sigma_n$), so care needs to be taken.

$\rho_p$ "rho p", the density of charge in the p-type side of the depletion region of a p-n junction. It is possible that in books and other courses that $\rho_n$ could represent the resistivity of a p-type layer (i.e. $1/\sigma_p$), so care needs to be taken.

$\sigma$ "sigma", conductivity. This is the reciprocal of resistivity, $\rho$ [$\sigma=1/\rho$] in a material where the only charge carriers present a electrons then $\sigma=nq\mu$.

$\sigma_n$ "sigma n", conductivity in a piece of n-type material, for example the n-type side of a p-n junction.

$\sigma_p$ "sigma p", conductivity in a piece of p-type material, for example the p-type side of a p-n junction.

$\tau$ "tau" the average, or characteristic, time between events, or for an event to occur in a random process. e.g. the time between scattering events for charged particles in a conductor, or the time for a minority carrier to recombine.

$\tau_B$ "tau B". The base transit time the time taken for the base charge to be changed in a bipolar junction transistor

$\tau_e$ "tau e" the average, or characteristic for minority carrier electrons to recombine in p-type material. Called the minority carrier lifetime for electrons. [$\tau_e=1/(Bp)$]

$\tau_h$ "tau h" the average, or characteristic for minority carrier holes to recombine in n-type material. Called the minority carrier lifetime for holes. [$\tau_h=1/(Bn)$]

## *Other*

$\equiv^m$ Abbreviation used to mean the word "equilibrium".