

A Dictionary of

Electronics and Electrical Engineering

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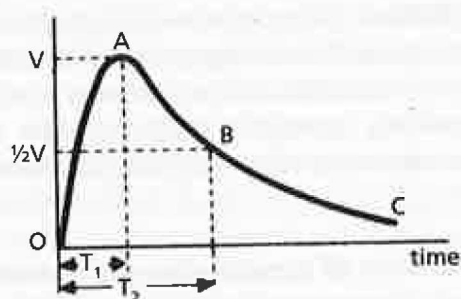
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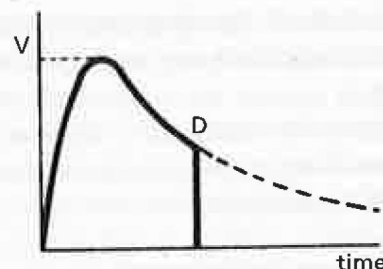
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(a) Waveshape of impulse voltage



(b) Waveshape of chopped impulse voltage

during the wavefront or during the wavetail. The actual value of the impulse voltage at which flashover or puncture occurs during the wavefront is the **impulse flashover voltage** or the **impulse puncture voltage**. If flashover or puncture occurs on the wavetail the peak value of the impulse voltage is quoted. The **time to flashover** or the **time to puncture** is the time interval between the beginning of the impulse voltage or current and the instant at which the wave is chopped (point D in Fig. b).

In an insulator used in a.c. power transmission systems, the impulse voltage at which flashover or puncture occurs in the insulator is in general different to the voltage of the a.c. power at which failure occurs. The **impulse ratio for flashover** (or **puncture**) is the ratio of the impulse flashover voltage (or puncture voltage) to the peak value of the alternating voltage at which flashover or puncture occurs. Typical values for commonly used insulators are between 1.5 and 1.2.

impurities Foreign atoms in a semiconductor that are either naturally occurring or deliberately introduced. Impurities have a fundamental effect on the type and amount of conductivity of the semiconductor. **Impurity diffusion** is the deliberate diffusion of impurities into selected regions of a semiconductor in order to produce the desired characteristics. The energy levels due to the impurities are **impurity levels**. The presence of impurities affects the mobilities (both **Hall* and **drift* mobilities) of charge carriers due to **impurity scattering** between the carriers and the impurity atoms. *See also* DIFFUSION; SEMICONDUCTOR.

IM rejection *See* IP₃.

IMU *See* INERTIAL MEASUREMENT UNIT.

inactive interval *See* SAWTOOTH WAVEFORM.

incandescence The emission of visible light from a substance at a high temperature. In the incandescent lamp, for example, when an electric current is passed through a metal or carbon filament, the temperature of the filament is raised sufficiently for incandescence to occur (*see* HEATING EFFECT OF A CURRENT). The term incandescence is also used to describe the emitted radiation itself. *Compare* LUMINESCENCE.

incident current (initial current) *See* REFLECTION COEFFICIENT.

increment The operation of adding one to the value of a variable, usually in a computer program. It is the opposite operation to **decrement*.

incremental permeability *See* PERMEABILITY.

differential resistance The resistance of a device or component part measured under small signal conditions.

differential winding Two or more coils or two windings of a single coil arranged so that when carrying a current their magnetomotive forces are in opposition.

d

differentiator (differentiating circuit) A circuit that gives an output proportional to the differential, with respect to time, of the input. *Compare* INTEGRATOR.

diffraction A phenomenon occurring when electromagnetic waves or beams of charged particles, such as electrons, encounter either an opaque object or a boundary between two media. The beams are not propagated strictly in straight lines but are bent at the discontinuity. This effect is due to the wave nature of electromagnetic radiation and the *de Broglie waves associated with the charged particles. Interference between the diffracted waves produces a **diffraction pattern** of maxima and minima of intensity; the diffraction pattern produced depends on the size and shape of the object causing the diffraction and the wavelength of the incident radiation. It can be used to investigate crystal structures or surface structures.

Electron and X-ray diffraction are employed to investigate crystal structures, the diffraction pattern produced being dependent on the spacing of the crystal planes. Electron diffraction is used to assess the structure of a crystalline semiconductor material near the surface. **Low-energy electron diffraction** uses a beam of low-energy electrons incident normal to the surface and the diffraction patterns from the back-scattered electrons are detected. **Reflection high-energy electron diffraction** uses a high-energy electron beam at a very small grazing angle of incidence. In this case the forward-scattered electrons produce the diffraction pattern. Electron diffraction patterns obtained from transmission *electron microscopy can be used to provide information about crystalline materials throughout their bulk but this latter is a time-consuming method and very difficult to interpret.

X-ray diffraction is employed to detect imperfections in semiconductor crystals by means of **X-ray topography**, using a slit and photographic plate to record a 'map' of the slice on a photographic film. Although lateral resolution is of the order of several micrometres the technique is rapid and nondestructive.

diffused junction A junction between two different conductivity regions within a semiconductor formed by *diffusion of the appropriate impurity atoms into the material.

diffusion 1. The movement of charge carriers in a semiconductor. *See* FICK'S LAW. 2. The process of introducing selected impurity atoms into designated areas of a *semiconductor in order to modify the properties of that area. The semiconductor is heated to a predetermined temperature in a gaseous atmosphere of the desired impurity. Impurity atoms that condense on the surface diffuse into the semiconductor material in both the vertical and horizontal directions. The numbers of impurity atoms and distance travelled at any given temperature is well-defined according to *Fick's law. The interface between two different conductivity regions within a semiconductor is known as a **diffused junction**.

Early diffused devices were formed by performing nonselective diffusions over the entire semiconductor surface; any unwanted regions of the semiconductor were etched away (as in *mesa transistors) and the junctions were formed below the surface and parallel to it. Modern techniques use the *planar process of selective diffusion into

well-defined areas of semiconductor. The edge of the junction is perpendicular to the surface and the device may be formed along the surface of the material.

Double diffusion is a method of forming diffused junctions in which successive diffusions of different impurity types are made into the same well-defined region of semiconductor. The temperature and diffusion time are adjusted to produce the desired impurity concentration. This technique is used if very precise distances between junctions are required, as in *DMOS circuits, since the geometry is defined by the diffusion process itself and errors caused by misalignment of successive photographic masks are eliminated.

diffusion constant (diffusivity) See DIFFUSION CURRENT; FICK'S LAW.

diffusion current A flow of charge carriers from a region of higher concentration or density to a region of lower concentration, due to the diffusion process described by *Fick's law. This flow of charge results in a corresponding electrical current:

$$J_{\text{diffusion}} = eD \left(\frac{\partial n}{\partial x} \right)$$

where D is the **diffusion constant** or **diffusivity** of the charge carriers in the material and $\partial n / \partial x$ is the concentration gradient.

diffusion potential (built-in field) See P-N JUNCTION.

digital ammeter An *ammeter that displays the values of the current as numbers. The input is usually supplied as an analogue signal and this is repetitively sampled by the ammeter, which displays the instantaneous values. The instrument thus functions as a type of *analogue-to-digital converter.

digital audio broadcasting (DAB) A system for the transmission of *digital radio.

digital audio tape See DAT.

digital camera A camera that records its image directly into digital memory using either a *CCD sensor or a *CMOS sensor. Both still and video images can be recorded, often by the same camera. Advanced digital cameras take still pictures by collecting a video stream while waiting for the shutter button to be pressed, and then use image processing techniques on frames from just before to just after the button press to produce the best possible image. All *smartphone and most commercial and consumer-oriented cameras are digital. See also SOLID-STATE CAMERA.

digital circuit A circuit that responds to discrete values of input voltage and produces discrete values of output voltage. Usually two voltage levels only are recognized, as in binary *logic circuits. Compare LINEAR CIRCUIT.

digital codes In *digital communications, the representation of a signal for transmission down a communications channel. **Coding**, the process of transforming the input message or signal into digital form, follows a defined set of rules; these rules form the codes. Most digital codes result in a signal having two levels – binary one and binary zero. Once coded, the signal is transmitted across the channel, and when received it is decoded to restore the original message or signal. The general process of coding as it relates to digital communication is shown in Fig. *a* (see also ENCRYPTION; MULTIPLEX OPERATION; MODULATION).

SEM (scanning electron microscope) See ELECTRON MICROSCOPE.

semianechoic chamber See ANECHOIC CHAMBER.

semiconductor A (usually) crystalline solid that in pure form exhibits a *conductivity midway between that of metals and insulators, typically 1–1000 siemens per metre. A pure, or *intrinsic semiconductor has an electron *energy band structure of the form shown schematically in Fig. *a*. The *valence band contains electrons that are used in bonding the atoms of the crystal together; at *absolute zero of temperature ($T = 0$ K) this band is completely filled. The next highest allowed band of energies is the *conduction band, which in semiconductors is separated from the valence band by an energy band gap of about one electronvolt. At absolute zero the conduction band is completely empty, and the material behaves like an insulator.

At room temperature (about 300 K), some electrons in the valence band gain enough thermal energy from their surroundings to cross the band gap and appear in the conduction band. The two bands are now partially filled and the possibility of electrical conduction exists; conduction is by electrons in the conduction band and *holes in the valence band. The conductivity is still low compared to metals because of the relatively small numbers of carriers involved in conduction. The *number density of electrons (n) in the conduction band equals the number density of holes (p) in the valence band, which in turn equals the **intrinsic density** (n_i):

$$n = p = n_i$$

The *Fermi energy level E_F in an intrinsic semiconductor lies halfway between the conduction and valence band edges. The following expressions for n and p also hold:

$$n = N_c \exp \left[-\frac{(E_c - E_F)}{kT} \right] = N_c \exp \left[-\frac{E_g}{2kT} \right]$$

$$p = N_v \exp \left[-\frac{(E_F - E_v)}{kT} \right] = N_v \exp \left[-\frac{E_g}{2kT} \right]$$

Hence,

$$n_i = \sqrt{\left\{ (N_c N_v) \exp \left[-\frac{E_g}{2kT} \right] \right\}}$$

where N_c , N_v are the equivalent density of states in the conduction and valence bands, respectively, E_g is the energy gap, k the Boltzmann constant, and T the thermodynamic temperature. The intrinsic density, and hence conductivity, therefore has a strong temperature dependence.

The intrinsic conductivity is generally too low and too temperature dependent to be of practical use for electrical components. The *carrier density can, however, be controlled by the careful introduction of **donor** and **acceptor impurities** into the semiconductor; this creates an *extrinsic semiconductor. The *impurities have the following specific properties.

A donor impurity

- replaces a host atom in the crystal;
- has one more valence electron than the atom it replaces;
- after bonding into the crystal, the extra valence electron can be easily lost;
- the free electron is in the conduction band, able to contribute to conduction;
- the donor atom becomes a positive ion, a +ve charge fixed in place in the crystal.

An acceptor impurity

replaces a host atom in the crystal;

has one fewer valence electrons than the atom it replaces;

after bonding into the crystal, the vacant space is easily replaced by an electron from the valence band;

this leaves a hole in the valence band, able to contribute to conduction;

the acceptor atom becomes a negative ion, a -ve charge fixed in place in the crystal.

The addition of impurities to a semiconductor is known as *doping*. The impurity densities are chosen to be much greater than the intrinsic density, so that the temperature variation of carriers is overwhelmed, and the material conductivity is independent of temperature. The electron and hole densities in doped semiconductors are as follows:

In an **n-type semiconductor**:

donor density $N_D >$ acceptor density $N_A \gg$ intrinsic density n_i

electron density $n = N_D - N_A$, so electrons are *majority carriers*,

hole density $p = n_i^2/n$, so holes are *minority carriers*,

the Fermi energy is in upper half of band gap.

In a **p-type semiconductor**:

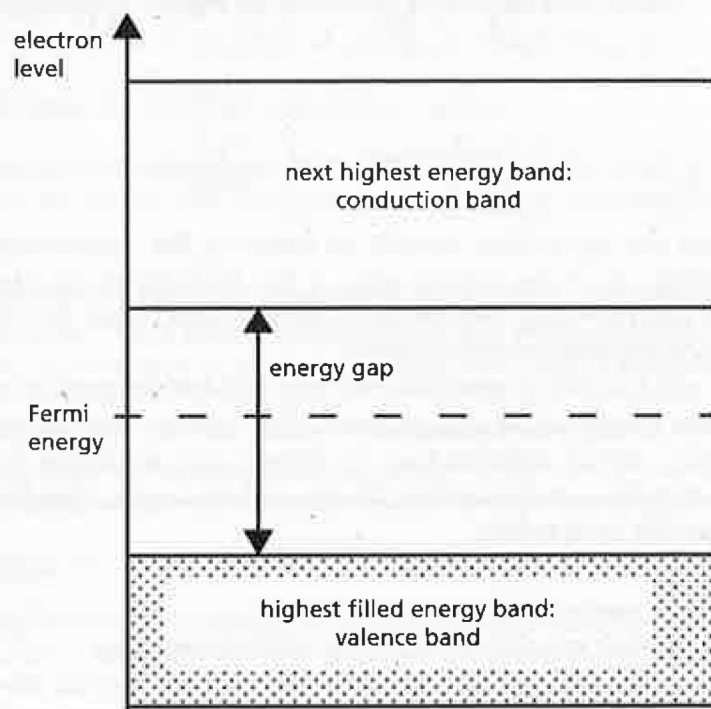
acceptor density $N_A >$ donor density $N_D \gg$ intrinsic density n_i

hole density $p = N_A - N_D$, so holes are *majority carriers*,

electron density $n = n_i^2/p$, so electrons are *minority carriers*,

the Fermi energy is in lower half of band gap.

At thermal equilibrium a dynamic equilibrium exists in a semiconductor. Mobile charges move around the crystal in a random manner due to scattering by the nuclei in the crystal lattice. The crystal retains overall charge neutrality and the number of charge carriers remains essentially constant. A continuous process of regeneration and recombination occurs, however, as thermally excited electrons enter the conduction band and other electrons return to the valence band and there combine with holes (*see also RECOMBINATION PROCESSES*).



Energy band diagram of an intrinsic semiconductor

If an electric field is applied to the semiconductor, charge carriers move under the influence of the field but still undergo scattering processes. The result of the field is to impose a drift in one direction onto the random motion of the carriers (*see also* DRIFT MOBILITY; CONTINUITY EQUATION).

Extrinsic semiconductors are used for making *diodes, *transistors, and *integrated circuits (*see also* P-N JUNCTION; METAL-SEMICONDUCTOR CONTACT). The most common semiconductor material is silicon, which is used for around 99% of commercial semiconductor products. *Compound semiconductors, such as *gallium arsenide, are used in specialist applications such as microwave devices and optoelectronics.

SEE WEB LINKS

- 'How Semiconductors Work', on the howstuffworks website
- An introduction to semiconductors, from the University of Cambridge

semiconductor device Any electronic circuit or device that depends for its operation on the flow of charge *carriers within a *semiconductor.

semiconductor diode A *diode constructed from semiconducting material.

semiconductor laser (diode laser) A *laser that uses a *p-n junction diode made from a *direct-gap semiconductor material such as *gallium arsenide, GaAs. When a p-n junction is operated in forward bias, majority carriers are injected across the junction and appear as excess minority carriers on the other side of the junction. In normal p-n junction operation these excess carriers would recombine with the majority carriers, and constitute the current flow across the junction. In a direct-gap semiconductor this *recombination process can be radiative: the band-gap energy E_g that is released during recombination is given up as light, which has a wavelength $\lambda = hc/E_g$ and is thus *monochromatic (h is the Planck constant and c the speed of light).

Stimulated emission of *coherent radiation is arranged by cutting the semiconductor laser die so that the two end faces are parallel and reflective, and the radiated photons pass through the *active region or optical cavity of the laser, causing further stimulated emission of photons. The light in the optical cavity is confined by the *active area of the p-n junction contacts.

In a **heterostructure laser**, greater optical confinement is obtained by surrounding the active p-n junction region by semiconductor material of a slightly different dielectric constant and hence refractive index. This causes internal reflections of the photons at the interface between the active region and this confining layer, resulting in a higher photon density in the light beam and hence a higher intensity of light. An example of a heterostructure laser would use a GaAs p-n junction active region, sandwiched between layers of lattice-matched AlGaAs, which has a slightly higher dielectric constant. Variations on this theme can include further heterostructure layers to confine the laser active region and the optical cavity independently, a device known as a **separate confinement heterostructure (SCH)** laser.

In the above examples, reflective facets are used to provide the optical feedback necessary for stimulated emission to occur. In a **distributed feedback (DFB)** laser, the feedback is generated by corrugating the interface between the active and confining layers with a specific periodicity; this causes the emitted light to be scattered back into the optical cavity to interfere constructively with the light reflecting from the two facets. The optical feedback and hence the laser output is thereby increased.