Glossary

ab initio model: a type of **model** designed from "first principles"; *i.e.* knowledge of fundamental mechanisms, without adjustable parameters, in contrast to an **empirical model**. An ***ab initio*** calculation carried out from theoretical data is considered to be more predictive.

absorption lines: dark spectral lines that appear after decomposition of radiation that has travelled through a medium (**absorption spectrum**).

adsorption: the attachment of **molecules** on a solid surface by a generally passive, non-specific process (for example by **electrostatic** attraction in the gas or liquid phase).

aggregate: finely granular matter made up of a very small number of **atoms** or **molecules**, or even cells, linked together by various weak forces, generally irreversibly.

algorithm: a sequence of operations of mathematical logic necessary to perform a computation task.

allotropic: differing in **crystalline** structure but possessing constant chemical properties.

amine: the NH_2 group.

amphiphilic: comprising both **hydrophobic** and **hydrophilic** parts.

anisotropic: possessing properties that vary according to direction (*ant.* **isotropic**).

anode: a positive **electrode** in an electrical device.

aromatic: containing **atoms** of carbon arranged in one or more rings in which single and double bonds alternate, for example benzene (6 carbon atoms).

atom: the fundamental building block of ordinary matter, composed of a **nucleus** (**protons** and **neutrons**) around which **electrons** gravitate.

atomic level: energy level that an **atom** can have according to its state; *ground state or excited state*.

bacterium: a rapidly multiplying single-cell micro-organism without a distinct nucleus.

ballistic: moving solely under the effects of impetus and gravity, (ordinary meaning), *or* moving without interacting with the vibrations of a **crystal** lattice or a **molecule**, and therefore without attenuation.

bandgap, direct or indirect: a **semiconductor** has a structure of **electron bands** of different energy levels that the **electrons** in the matter can occupy. These bands arise from the periodic nature of the atomic arrangement in the **crystal** lattice and the wave properties of the electrons. The **bandgap** is located between a filled permitted band (or that is practically filled at a finite temperature), the **valence band**, and an empty (or practically empty) band, the **conduction band**. **Photons** with energy greater than the bandgap generate **charge carriers** by the transition of electrons between permitted bands. The crossing of the bandgap can occur with emission of **phonons** - this is an **indirect bandgap** (the case for **silicon**) - or without emission (**direct bandgap**).

base pair: term designating the purines and pyrimidines (a linked pair of **nucleotides** on opposite strands) in **DNA** and **RNA molecules**.

beat signal: signal whose pulse amplitude is the resultant of the different pulses of two different signals.

biochip: micro-device able to carry out analyses of a biological nature. The **DNA microarray**, for example, can be used to detect the presence of **DNA** strands by matching with their complementary strands, called **probes**, attached to the chip.

biomimetic: created by analogy with a biological substance or process.

bit: the elementary unit of information. In classical data processing it can take either of two values, generally noted 0 and 1.

black body: an ideal physical object, taken to be in perfect equilibrium with ambient electromagnetic radiation.

bond, covalent: a bond linking two **atoms** that fill their outermost orbits by sharing one or more pairs of **electrons**.

bond, hydrogen: a bond 20 times weaker than a **covalent bond** that can be formed between two **molecules** of water owing to their **polar** nature.

bond, ion-covalent: a bond that is both **ionic** (characterized by the *transfer* of **electrons** between an ion and a cation) and **covalent** (in which electrons are shared between two **atoms**).

capacitive effect: the accumulation of charges by an **electrostatic** process when a potential difference is applied to two conductors insulated one from the other. This effect is sought in capacitors (an example of a **capacitive device**), but may be unwanted, for example when charges accumulate between two conductors (**capacitive coupling**).

capacity: the ratio of the accumulated charge to the voltage applied to the terminals.

capillary forces: forces that develop at a liquid/solid interface and affect the shape of its boundary with the ambient medium. This influence is greater at smaller scales.

carbon nanotube: a **crystal** structure made up of one or more rolled-up sheets of **graphene** of **nanometric** diametre, the length of which can reach up to several hundred **micrometres**. It can be either metallic or **semiconducting**, according to how it is rolled.

catalysis: a process involving a substance (**catalyst**) that is able to speed up a chemical reaction without itself being permanently modified.

cathode: a negative **electrode** in an electrical device.

charge carriers: electron conduction; electric current is a movement of charge carriers.

chiral: of a **molecule**, not superimposable on its in-plane mirror image.

coalescence: the coming together of particles to form larger particles.

colloid: a mixture of ultramicroscopic particles dispersed uniformly in a substance to make a suspension or **gel**.

compartment (in a living organism or an ecosystem)**:** biological space, most often virtual in nature, but of measurable volume, occupied homogeneously (concentration) by a **molecular** substance or population that behaves in a specific way and has a single physico-chemical form.

computation code: see **numerical modelling**.

conductance: a measure of the current that a given resistance will allow to flow under a given potential difference. The reciprocal of *resistance*, it is equal to the current divided by the electric potential. Unit: the siemens (S). **Transconductance** is conductance per unit length (S/m).

conjugated polymer: a **polymer** chain characterized by alternating saturated and unsaturated carbon-carbon bonds, a pattern that produces delocalized **electrons** (pi electrons).

Cooper pair: two **electrons** grouped together to form a system that behaves like a **boson**, a particle of integer **spin**, whereas isolated electrons are **fermions** (particles of half-integer spin). This pairing is, in particular, the basis of **superconductivity** and superfluidity. The two electrons have the same quantity of movement, but opposite signs.

coordination: the bonds made by an **ion** with **electron**-donor **atoms** The *coordination number* is the number of bonds that an ion is able to make with such atoms.

Coulomb attraction: force of attraction between two electric charges of opposite sign.

Coulomb blockade: **electrostatic** effect due to **Coulomb repulsion** undergone by an **electron** when it approaches a charged object. As a **quantum** dot has a very low capacitance, its total energy is essentially dominated by the charge energy, which prevents current flowing through the structure, except for **discrete** values of an external control parameter.

Coulomb interaction: the electrical interaction between two charged particles: *attraction* when the charges are of opposite sign, and *repulsion* when they are of the same sign. Its intensity is range-dependent: at short range inside the nucleus, the force of repulsion between two **protons** is of the order of a **MeV**, but it is counteracted by other stronger forces of attraction, which are responsible for the cohesion of the nucleus. At longer range the force of repulsion prevails, with an energy of the order of an **eV**.

Coulomb repulsion, Coulomb barrier: electrical force that causes two particles carrying charges of the same sign to repel each other (*e.g.*, **protons** in two **nuclei**).

covalent: characteristic of the chemical bond formed between two **atoms** by **electron** sharing.

crosslinking: the bridging of **polymer** chains.

crystal: assembly of **atoms**, **ions** or **molecules** regularly distributed in a periodic pattern in the three spatial directions.

CVD *(chemical vapour deposition)***:** method for the preparation of thin layers by a vapour phase deposit formed by a chemical reaction from a gaseous medium of different composition.

density functional theory: a theory used to calculate the energy of an *n*-particle **quantum** system from its density.

diamond: one of the three **allotropic** forms of carbon. It has a cubic **crystal** structure and a very high **refractive index**.

dielectric constant: ratio (K) between the absolute **permittivity** of a **dielectric** and the **permittivity** of a vacuum.

dielectric permittivity (or dielectric constant)**:** measure of the electrical insulating power of a material. It is expressed relative to air (equal to that of a **vacuum**) in picofarad/metre (pF/m).

dielectric: insulating substance able to store **electrostatic** energy. A dielectric is characterized by its **permittivity** or *dielectric constant*. In a **capacitor**, the dielectric is placed between two conducting plates or sheets.

diffraction: deviation of the direction of wave propagation when waves (sound, light, **X-rays**, etc.) meet an obstacle or an aperture the size of which is of the same order of magnitude as their wavelength.

diode: a one-way conducting device used in an electronic circuit (**gate**). A component formed by the junction of two **semiconductors** invented in 1904 by Flemming and called a "valve" for the detection of amplitude modulation and rectification of alternating current. The **anode** or *plate* was positioned around the cathode, which was heated by a filament, and emitted **electrons**. When there is no supply voltage, the electron cloud that forms around the cathode produces a negative charge that repels escaping electrons. The maximum current that can flow through the diode depends on the nature and temperature of the **cathode**.

discrete: discontinuous (to discretize means to separate).

dislocation: disturbance in the form of a localized slippage affecting an **atomic** row in a **crystal** lattice.

DNA microrarray: device used to detect the presence of a **DNA** strand by pairing it with its complementary strand fixed on the chip, called a **probe**, at **hybridization** sites using the principle of the DNA double helix. This technique makes it possible, for example, to analyze the overall **gene** expression of a cell.

dopant: foreign **atom** introduced into a **crystal** lattice to modify its properties. For example, a **semiconductor** can be doped to modify its electrical properties by inserting a **discrete** *allowed* energy level in the **bandgap** near the **valence band** or the **conduction band**. The added atom thus supplies a mobile **electron** or **hole** to one or the other of the allowed bands, which increases the **electrical conductivity** of the materials.

DRAM: dynamic random access memory.

electrical conductivity: the electrical **conduction** capacity of a material, expressed in siemens per unit length.

electrode: an electrical conductor that serves to emit, receive or control, by means of an electric field, a flow of **electrons** or **ions** (it can be an **anode** or a **cathode**).

electrolysis: decomposition caused by the displacement of **ions**, under the influence of an electrical potential difference, towards positive and negative **electrodes**.

electronvolt (eV): unit of energy equal to 1.6×10^{-19} joules. This is the energy acquired by an electron accelerated by a voltage of one volt (multiple: the **keV** equal to 10^3 eV).

electron: negatively-charged elementary particle.

electron-hole pair (or **exciton**): a pair of **carriers** not linked to an **atom** and therefore able to move throughout the **crystal** where they have appeared. One is negative (**electron** in the **conduction band**) and the other positive (no electron in the **valence band**).

electronic or ionic conduction: process whereby an **electron** or **ion** moves in a material.

electrophoresis: a method for separating constituents of a mixture according to the speed with which they migrate in an electric field. **Molecules** are separated according to their charge and their molecular weight.

electrostatic: based on electric charges that do not move (constant electric field).

emission lines: bright spectral lines that appear when the radiation emitted from a body heated to a high temperature is decomposed (**emission spectrum**).

Glossary

energy band: an energy interval available for occupation by **electrons** in matter.

enzyme: a **protein** macro**molecule** that activates a biochemical reaction by **catalysis**.

excimer laser: laser in which the resonance cavity contains a halogen gas (for example, an argon-fluorine mixture) and which delivers **UV** light pulses with durations in the nanosecond range and energies of the order of a few hundred millijoules.

exciton: an **electron-hole** pair.

Fabry-Perot (cavity, interferometer)**:** an instrument for optical analysis composed of two moveable partially reflective mirrors mounted face to face. One of the mirrors can be tracked and the other rotated. The device is placed in front of the light source to be studied, which produces interference fringes. The incident beam is split up into a multitude of secondary beams of low amplitude. When they are parallel, their amplitudes combine and interfere. The Fabry-Perot interferometer lets through only certain wavelengths from the source, depending on the distance between the mirrors, which is inversely proportional to the width of the transmission peaks observed.

Fermi level: energy level representing a particular equilibrium point (given by the Fermi function) between the number of **electrons** in the **conduction band** and the number of **holes** in the **valence band**. In an intrinsic **semiconductor**, it is located in the middle of the **bandgap**. In an ***n*-doped** material , the Fermi level is situated slightly below the conduction band minimum, and in a ***p*-doped** material it is slightly above the valance band maximum.

field effect (or **cold emission**)**:** force due to **electrostatic** pressure, always directed outwards, which can eject the surface charges of a positively-charged conductor. This force is used in field-effect emission microscopes.

fluorescence: light emission caused by the absorption by a substance of an incident energy flux (of light, electromagnetic radiation, **X-rays** or **electrons**) followed by rapid re-emission of electromagnetic radiation as the excited electrons in the outer **atomic** layers relax to their ground state. If the wavelength of the emitted radiation lies in the visible spectrum, **luminescence** occurs.

Fourier transform: a complex mathematical formula whereby the relative weight of each frequency in a temporal signal is determined in order to produce a spectral representation.

fullerene: the third **allotropic** form of carbon after **graphite** and **diamond**. It forms closed cages (**C_{60}**), the shape of which is reminiscent of a football.

functionalization: in its broad meaning, the tailoring of a chemical, physical or biological entity to lend it desired functions. In a narrower meaning, the attachment of certain chemical functional groups on the surface of a material.

gene: DNA sequence on a chromosome forming a unit of hereditary information that directs the formation of a **phenotypic** characteristic through the production of one or more **proteins**.

genome: the entire **genetic** material of a living organism.

granulometry: the measure of the dimensions and shapes of particles and their distribution in powders and suspensions.

graphite: one of the three **allotropic** forms of carbon. It has a **crystalline** structure made up of sheets of **graphene** in which each carbon **atom** is linked to three neighbours.

hybridization: the ability of the **bases** in a strand of **nucleic acid** to spontaneously recognize and match up with complementary bases.

hydrocarbon: a chemical **molecule** composed solely of carbon and hydrogen.

hydrolysis: decomposition of a chemical species (**molecule** or **ion**) by the action of water.

hydrophilic / hydrophobic: water-attracting/water-repelling.

in vitro (Latin '"in glass")**:** carried out in laboratory glassware, outside the living organism, *e.g.*, laboratory analysis or manipulation of biological systems. The opposite of ***in vivo*** ("in living organisms").

inductance: the induced potential generated in a circuit by current flowing through it per unit rate of change of the current. Its unit is the henry.

infrared (**IR**) **radiation:** the part of the electromagnetic spectrum covering radiation of wavelength between 760-780 **nm** and 1 mm. It breaks down into ***near IR*** (760 nm - 4 **µm**), *mid-IR* (4 - 14 µm), *far IR* (14 µm - 100 µm) and *sub-millimetric IR* (100 µm –1 mm).

interstitial: characteristic of a supernumerary **atom** located between the planes of a **crystal** lattice.

ion: atom (or **molecule**) that has lost or gained one or more **electrons** and therefore carries an electric charge.

Josephson junction: a junction between two **superconducting electrodes** made by inserting between them an insulating layer that is sufficiently thin for the **electrons** to be able to cross it by **tunnelling**.

Joule effect: production of heat due to the resistance of a conductor to the flow of an electric current.

***lab-on-chip*:** a device incorporating a large number of basic analytical functions normally conducted in a laboratory.

laser diode: source of coherent light, the beam intensity of which can be varied by applying a variable voltage.

lattice (crystal)**:** the elementary structural pattern of a **crystal**.

leakage current: the current that leaks through the **gate** insulator by **tunnelling**.

ligand: any **molecule** that can bond to another one, in particular an organic molecule able to bond selectively and with high affinity to a biological *receptor*. A molecule or **ion** attached to the central **atom** of a **complex** by a **coordination** bond.

lipid: a substance containing a fatty acid or a derivative thereof.

logic gate: an **integrated circuit** capable of processing logic states (existence of a constant positive voltage (noted 1) or a zero voltage (state noted 0)).

luminescence: light emission resulting from excitation by radiation (**photoluminescence**), electric current, chemical reaction, etc.

magnetic flux: measure of magnetic induction (number of magnetic lines), expressed in webers (Wb).

mass spectrometry: a method for determining the composition of a sample by studying **ion** fragments obtained by electron bombardment of a sample and separated by magnetic or electric means. The ion fragments form a *mass spectrum* that can be interpreted and used to identify the **molecular** structure.

D The transistor, fundamental component of integrated circuits

The first transistor was made in germanium by John Bardeen and Walter H. Brattain, in December 1947. The year after, along with William B. Shockley at **Bell Laboratories**, they developed the bipolar transistor and the associated theory. During the 1950s, transistors were made with **silicon** (Si), which to this day remains the most widely-used **semiconductor** due to the exceptional quality of the interface created by silicon and silicon oxide (SiO_2), which serves as an insulator. In 1958, Jack Kilby invented the **integrated circuit** by manufacturing 5 components on the same **substrate**. The 1970s saw the advent of the first microprocessor, produced by Intel and incorporating 2,250 transistors, and the first memory. The complexity of integrated circuits has grown exponentially (doubling every 2 to 3 years according to "Moore's law") as transistors continue to become increasingly miniaturized.

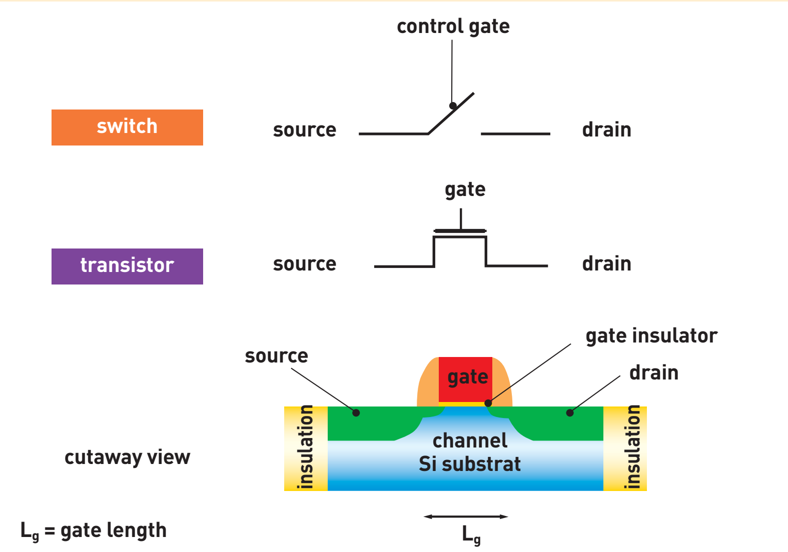


Figure.
A MOS transistor is a switching device for controlling the passage of an electric current from the source (S) to the drain (D) via a gate (G) that is electrically insulated from the conducting channel. The silicon substrate is marked B for Bulk.

The transistor, a name derived from *trans*fer and res*istor*, is a fundamental component of microelectronic integrated circuits, and is set to remain so with the necessary changes at the nanoelectronics scale: also well-suited to amplification, among other functions, it performs one essential basic function which is to open or close a current as required, like a switching device (Figure). Its basic working principle therefore applies directly to processing binary code (0, the current is blocked, 1 it goes through) in logic circuits (inverters, gates, adders, and memory cells).

The transistor, which is based on the transport of **electrons** in a solid and not in a vacuum, as in the electron tubes of the old **triodes**, comprises three **electrodes** (*anode, cathode* and *gate*), two of which serve as an electron *reservoir*: the **source**, which acts as the emitter filament of an electron tube, the **drain**, which acts as the collector plate, with the gate as "controller". These elements work differently in the two main types of transistor used today: *bipolar junction transistors*, which came first, and *field effect transistors* (**FET**).

Bipolar transistors use two types of **charge carriers**, electrons (negative charge) and **holes** (positive charge), and are comprised of identically **doped** (p or n) semiconductor substrate parts

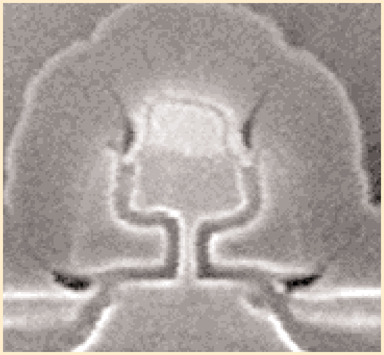
D (next)

separated by a thin layer of inversely-doped semiconductor. By assembling two semiconductors of opposite types (a p-n junction), the current can be made to pass through in only one direction. Bipolar transistors, whether n-p-n type or p-n-p type, are all basically current amplifier controlled by a gate current[1]: thus, in an n-p-n transistor, the voltage applied to the p part controls the flow of current between the two n regions. Logic circuits that use bipolar transistors, which are called TTL (for transistor-transistor logic), consume more energy than field effect transistors which present a zero gate current in off-state and are voltage-controlled.

Field effect transistors, most commonly of **MOS** (metal oxide semiconductor) type, are used in the majority of today's **CMOS** (C for complementary) logic circuits[2]. Two n-type regions are created on a p-type silicon crystal by doping the surface. These two regions, also called drain and source, are thus separated by a very narrow p-type space called the **channel**. The effect of a positive current on the control electrode, naturally called the **gate**, positioned over the semiconductor forces the holes to the surface, where they attract the few mobile electrons of the semiconductor. This forms a conducting channel between source and drain (Figure). When a negative voltage is applied to the gate, which is electrically insulated by an oxide layer, the electrons are forced out of the channel. As the positive voltage increases, the channel resistance decreases, letting progressively more current through.

In an integrated circuit, transistors together with the other components (**diodes**, condensers, resistances) are initially incorporated into a "chip" with more or less complex functions. The circuit is built by "sandwiching" layer upon layer of conducting materials and insulators formed by **lithography** (Box D, ***Lithography, the key to miniaturization***). By far the most classic application of this is the microprocessor at the heart of our computers, which contains several hundred million transistors (whose size has been reduced 10,000-fold since the 1960s), soon a billion. This has led to industrial manufacturers splitting the core of the processors into several subunits working in parallel!

The very first transistor.



8 nanometre transistor developed by the Crolles2 Alliance bringing together STMicroelectronics, Philips and Freescale Semiconductor.

(1) This category includes **Schottky transistors** or **Schottky barrier transistors** which are field effect transistors with a metal/semiconductor control gate that, while more complex, gives improved charge-carrier mobility and response times.

(2) Giving **MOSFET** transistor (for Metal Oxide Semiconductor Field Effect Transistor).

G The tunnel effect, a quantum phenomenon

Quantum physics predicts unexpected behaviour that defies ordinary intuition. The tunnel effect is an example. Take the case of a marble that rolls over a bump. Classical physics predicts that unless the marble has enough kinetic energy it will not reach the top of the bump, and will roll back towards its starting point. In quantum physics, a particle (proton, electron) can get past the bump even if its initial energy is insufficient, by "tunnelling" through. The tunnel effect makes it possible for two protons to overcome their mutual electrical repulsion at lower relative velocities than those predicted by classical calculations.

Tunnel effect microscopy is based on the fact that there is a finite probability that a particle with energy lower than the height of a potential barrier (the bump) can still jump over it. The particles are electrons travelling through the space between two electrodes. These electrodes are a fine metal tip terminating in a single atom, and the metal or semiconductor surface of the sample. In classical physics a solid surface is considered as a well-defined boundary with electrons confined inside the solid. By contrast, in quantum physics each electron has wave properties that make its location uncertain. It can be visualized as an electron cloud located close to the surface. The density of this cloud falls off exponentially with increasing distance from the solid surface. There is thus a certain probability that an electron will be located "outside" the solid at a given time. When the fine metal tip is brought near the surface at a distance of less than a nanometre, the wave function associated with the electron is non-null on the other side of the potential barrier and so electrons can travel from the surface to the tip, and *vice versa*, by the tunnel effect. The potential barrier crossed by the electron is called the tunnel barrier. When a low potential is applied between the tip and the surface, a tunnel current can be detected. The tip and the surface being studied together form a local tunnel junction. The tunnel effect is also at work in Josephson junctions where a direct current can flow through a narrow discontinuity between two superconductors.

In a transistor, an unwanted tunnel effect can appear when the insulator or grid is very thin (nanometre scale). Conversely, the effect is put to use in novel devices such as Schottky barrier tunnel transistors and carbon nanotube assemblies.