EXHIBIT 1

United States of America

United States Patent and Trademark Office

BLUEICE

Reg. No. 4,758,185

Registered June 23, 2015

Int. Cl.: 7

TRADEMARK

PRINCIPAL REGISTER

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FOR: MACHINES FOR PROCESSING SUBSTRATE, MACHINES FOR MANUFACTURING SUBSTRATES, MACHINES FOR ETCHING SUBSTRATES, MACHINES FOR CLEANING SUBSTRATES, MACHINES FOR DRYING SUBSTRATES, MACHINES FOR PROCESSING SEMICONDUCTORS, MACHINES FOR PROCESSING SEMICONDUCTOR WAFERS, MACHINES FOR MANUFACTURING SEMICONDUCTOR WAFERS, MACHINES FOR CLEANING SEMICONDUCTOR WAFERS, MACHINES FOR ETCHING SEMICONDUCTOR WAFERS, MACHINES FOR DRYING SEMICONDUCTOR WAFERS, MACHINES FOR CLEANING PHOTOMASKS, MACHINES FOR DRYING PHOTOMASKS, IN CLASS 7 (U.S. CLS. 13, 19, 21, 23, 31, 34 AND 35).

OWNER OF REPUBLIC OF KOREA REG. NO. 40-1067516, DATED 11-3-2014, EXPIRES 11-3-2024.

THE COLOR(S) BLUE IS/ARE CLAIMED AS A FEATURE OF THE MARK.

THE MARK CONSISTS OF THE WORD "BLUEICE" IN BLUE UPPERCASE LETTERS.

SER. NO. 85-790,063, FILED 11-29-2012.

ALICIA COLLINS, EXAMINING ATTORNEY

UNITED STATES PATENT AND TRADEMARK OFFICE
DEPARTMENT OF COMMERCE

Michelle K. Lee

Director of the United States
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What and When to File:

First Filing Deadline: You must file a Declaration of Use (or Excusable Nonuse) between the 5th and 6th years after the registration date. *See* 15 U.S.C. §§1058, 1141k. If the declaration is accepted, the registration will continue in force for the remainder of the ten-year period, calculated from the registration date, unless cancelled by an order of the Commissioner for Trademarks or a federal court.

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The above documents will be accepted as timely if filed within six months after the deadlines listed above with the payment of an additional fee.

***ATTENTION MADRID PROTOCOL REGISTRANTS:** The holder of an international registration with an extension of protection to the United States under the Madrid Protocol must timely file the Declarations of Use (or Excusable Nonuse) referenced above directly with the United States Patent and Trademark Office (USPTO). The time periods for filing are based on the U.S. registration date (not the international registration date). The deadlines and grace periods for the Declarations of Use (or Excusable Nonuse) are identical to those for nationally issued registrations. *See* 15 U.S.C. §§1058, 1141k. However, owners of international registrations do not file renewal applications at the USPTO. Instead, the holder must file a renewal of the underlying international registration at the International Bureau of the World Intellectual Property Organization, under Article 7 of the Madrid Protocol, before the expiration of each ten-year term of protection, calculated from the date of the international registration. *See* 15 U.S.C. §1141j. For more information and renewal forms for the international registration, see http://www.wipo.int/madrid/en/.

NOTE: Fees and requirements for maintaining registrations are subject to change. Please check the USPTO website for further information. With the exception of renewal applications for registered extensions of protection, you can file the registration maintenance documents referenced above online at http://www.uspto.gov.

NOTE: A courtesy e-mail reminder of USPTO maintenance filing deadlines will be sent to trademark owners/holders who authorize e-mail communication and maintain a current e-mail address with the USPTO. To ensure that e-mail is authorized and your address is current, please use the Trademark Electronic Application System (TEAS) Correspondence Address and Change of Owner Address Forms available at http://www.uspto.gov.

EXHIBIT 2

Click Here for a **FREE QUOTE** or call **860-653-2573** for more information

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High-quality orbital tube and automatic pipe welding systems

Since 1971, Magnatech has manufactured orbital welding equipment for a wide range of diverse applications. As a top solution provider for tube, pipe, and pipeline markets, our range of orbital welding systems are designed to meet your specific challenges, whether minimal clearances in maintenance applications or use by lesser skilled operators in remote locations and hostile environments. Designed for reliability and simplicity in programming and operation, our orbital welding systems will improve productivity, reduce weld repair rates, and produce consistent welds meeting all code standards.

We meet the needs of our global clientele with guidance in selecting the most suitable systems to meet their specific application requirements. Our in-house support staff provide our customers with expert technical application assistance and service support.

We offer a range of equipment which utilize the following processes:

- Gas Tungsten Arc Welding (GTAW)
- Gas Metal Arc Welding (GMAW)
- Flux Core Arc Welding (FCAW)

Below are a few examples in a range of industries detailing how our products provided a solution to a customer's unique problem.

Tube Welding

Markets Include:
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The Food, Dairy & Beverage Industry
Pharmaceutical Biotechnology
Semiconductor and Related Industries
Brewery & Winery Industry

Pipe Welding

Markets Include:
Fossil Fuel Power Generation Industry
Nuclear Power Generation Industry
Petrochemical and Chemical Plants
Pressure Vessels
Process Piping
Shipbuilding

Pipeline Welding

Markets Include:
Offshore
Pipeline

Magnatech's automatic pipe and tube welding machines bring the benefits of digital technology to the orbital welding customer. These include unparalleled parameter accuracy, repeatability, and reliability. Our welding power sources operate a broad range of both enclosed and open arc weld heads. Our sales engineers can assist you in selecting the model to best meet your application requirements.

Our mission is to provide orbital welding solutions tailored to your tube and pipe application. With the ever-declining number of skilled welders worldwide, our orbital welding machines are engineered to allow a less skilled operator not only make code welds but also do it with a substantial productivity improvement. Autoprogramming for both fusion-only and multipass welding with filler wire addition eliminates the need for onsite technical specialists to laboriously develop the weld parameters by trial and error. All our orbital welding system models incorporate an intuitive user interface, simplifying operation and guaranteeing repeatable welds. Rigorous quality control of components during manufacture, followed by final calibration and weld testing, ensure trouble-free operation.

Please contact us to discuss your specific application and to learn how orbital welding can improve your bottom line.

EXHIBIT 3

PRODUCTS OVERVIEW

VIRTUALLY EVERY LEADING EDGE DEVICE HAS BEEN MADE USING OUR EQUIPMENT

Advanced microchips are in many of the familiar products we use every day – from mobile phones and computing devices to entertainment systems and increasingly "smart" cars. Electronic products are everywhere and life without them unimaginable.

Creating the tiny, complex chips used in these devices involves the repetition of a core set of processes and includes hundreds of individual steps. For successful production, semiconductor manufacturers require sophisticated processes and fabrication equipment.

Lam Research works closely with customers to deliver the products and technologies needed to enable their success. By offering critical chip-processing capabilities, our products provide a vital link between the visionary designs for the latest electronic devices and the companies that produce them.

OUR SOLUTIONS

Market demand for faster, smaller, more powerful, and energy-efficient electronics is driving the development of new fabrication strategies that enable producing advanced devices with fine, closely packed features and complex 3D structures. Creating the cutting-edge microprocessors, memory devices, and numerous other product types in demand today is extremely challenging and requires continuous innovation to deliver capable processing solutions.

Through collaboration and drawing on multiple areas of expertise, Lam continues to develop the new capabilities required to manufacture these increasingly challenging devices. Our innovative technology and productivity solutions deliver a wide range of wafer processing capabilities needed to create the latest chips and applications – from transistor, interconnect, patterning, advanced memory, and packaging to sensors and transducers, analog and mixed signal, discretes and power devices, and optoelectronics and photonics.

› SEE OUR SOLUTIONS

OUR PROCESSES

(1:37)

EXTENDING MOORE'S LAW: SELF-ALIGNED QUADRUPLE PATTERNING (SAQP)

(0:58)

Semiconductor processes used in the manufacture of today's most advanced chips are challenged to literally push the limits of physics and chemistry with their nanoscale features, novel materials, and increasingly complex 3D structures. Meeting the ever-changing fabrication demands of new chip designs requires precision control at the atomic scale.

To ensure those new process technologies are production-ready when new chips head to the fab, Lam's scientists and engineers stay abreast of our customers' manufacturing needs. Our broad portfolio of market-leading products for thin film deposition, plasma etch, photoresist strip, and wafer cleaning are complementary processing steps used throughout semiconductor manufacturing. To support advanced process monitoring and control of critical steps, our product offerings include a line of high-precision mass metrology systems.

› SEE OUR PROCESSES

OUR PRODUCTS
ENABLING CHIPMAKERS TO CREATE THE FUTURE

SEE ALL PRODUCTS

Lam Research - Where Innovation Begins and Never Ends

NOW PLAYING

LAM RESEARCH - WHERE INNOVATION BEGINS AND NEVER ENDS

(3:50)

MULTIPLE PATTERNING ENABLES FEATURE SHRINK

(2:54)

3D NAND: KEY PROCESS STEPS

EXHIBIT 4

WIKIPEDIA

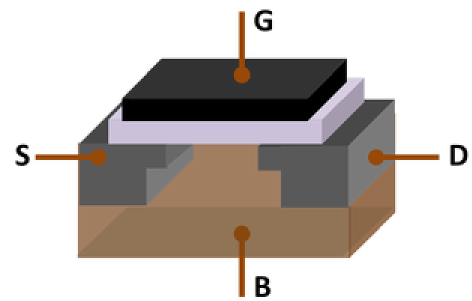
Transistor

A **transistor** is a semiconductor device used to amplify or switch electronic signals and electrical power. It is composed of semiconductor material usually with at least three terminals for connection to an external circuit. A voltage or current applied to one pair of the transistor's terminals controls the current through another pair of terminals. Because the controlled (output) power can be higher than the controlling (input) power, a transistor can amplify a signal. Today, some transistors are packaged individually, but many more are found embedded in integrated circuits.

Assorted discrete transistors. Packages in order from top to bottom: TO-3, TO-126, TO-92, SOT-23.

Austro-Hungarian physicist Julius Edgar Lilienfeld proposed the concept of a field-effect transistor in 1926, but it was not possible to actually construct a working device at that time.[1] The first working device to be built was a point-contact transistor invented in 1947 by American physicists John Bardeen and Walter Brattain while working under William Shockley at Bell Labs. They shared the 1956 Nobel Prize in Physics for their achievement.[2] The most widely used transistor is the MOSFET (metal–oxide–semiconductor field-effect transistor), also known as the MOS transistor, which was invented by Mohamed Atalla with Dawon Kahng at Bell Labs in 1959.[3][4][5] The MOSFET was the first truly compact transistor that could be miniaturised and mass-produced for a wide range of uses.[6]

Transistors revolutionized the field of electronics, and paved the way for smaller and cheaper radios, calculators, and computers, among other things. The first transistor and the MOSFET are on the list of IEEE milestones in electronics.[7][8] The MOSFET is the fundamental building block of modern electronic devices, and is ubiquitous in modern electronic systems.[9] An estimated total of 13 sextillion MOSFETs have been manufactured between 1960 and 2018 (at least 99.9% of all transistors), making the MOSFET the most widely manufactured device in history.[10]



Metal-oxide-semiconductor field-effect transistor (MOSFET), showing gate (G), body (B), source (S) and drain (D) terminals. The gate is separated from the body by an insulating layer (pink).

Most transistors are made from very pure silicon, and some from germanium, but certain other semiconductor materials are sometimes used. A transistor may have only one kind of charge carrier, in a field-effect transistor, or may have two kinds of charge carriers in bipolar junction transistor devices. Compared with the vacuum tube, transistors are generally smaller, and require less power to operate. Certain vacuum tubes have advantages over transistors at very high operating frequencies or high operating voltages. Many types of transistors are made to standardized specifications by multiple manufacturers.

Contents

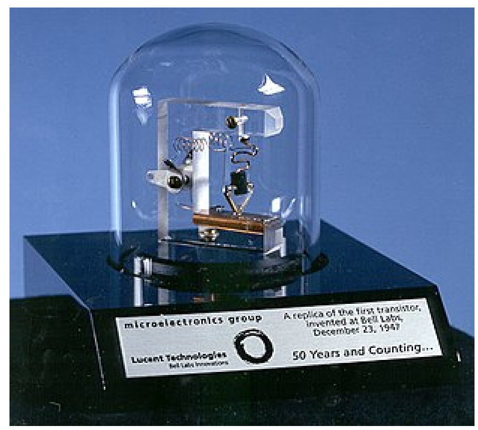
History

Julius Edgar Lilienfeld proposed the concept of a field-effect transistor in 1925.

The thermionic triode, a vacuum tube invented in 1907, enabled amplified radio technology and long-distance telephony. The triode, however, was a fragile device that consumed a substantial amount of power. In 1909, physicist William Eccles discovered the crystal diode oscillator.[11] Austro-Hungarian physicist Julius Edgar Lilienfeld filed a patent for a field-effect transistor (FET) in Canada in 1925,[12] which was intended to be a solid-state replacement for the triode.[13][14] Lilienfeld also filed identical patents in the United States in 1926[15] and 1928.[16][17] However, Lilienfeld did not publish any research articles about his devices nor did his patents cite any specific examples of a working prototype. Because the production of high-quality semiconductor materials was still decades away, Lilienfeld's solid-state amplifier ideas would not have found practical use in the 1920s and 1930s, even if such a device had been built.[18] In 1934, German inventor Oskar Heil patented a similar device in Europe.[19]

Bipolar transistors

John Bardeen, William Shockley and Walter Brattain at Bell Labs in 1948. They invented the point-contact transistor in 1947 and bipolar junction transistor in 1948.



A replica of the first working transistor, a point-contact transistor invented in 1947.

From November 17, 1947, to December 23, 1947, John Bardeen and Walter Brattain at AT&T's Bell Labs in Murray Hill, New Jersey, performed experiments and observed that when two gold point contacts were applied to a crystal of germanium, a signal was produced with the output power greater than the input.[20] Solid State Physics Group leader William Shockley saw the potential in this, and over the next few months worked to greatly expand the knowledge of semiconductors. The term *transistor* was coined by John R. Pierce as a contraction of the term *transresistance*.[21][22][23] According to Lillian Hoddeson and Vicki Daitch, authors of a biography of John Bardeen, Shockley had proposed that Bell Labs' first patent for a transistor should be based on the field-effect and that he be named as the inventor. Having unearthed Lilienfeld's patents that went into obscurity years earlier, lawyers at Bell Labs advised against Shockley's proposal because the idea of a field-effect transistor that used an electric field as a "grid" was not new. Instead, what Bardeen, Brattain, and Shockley invented in 1947 was the first point-contact transistor.[18] In acknowledgement of this accomplishment, Shockley, Bardeen, and Brattain were jointly awarded the 1956 Nobel Prize in Physics "for their researches on semiconductors and their discovery of the transistor effect".[24][25]

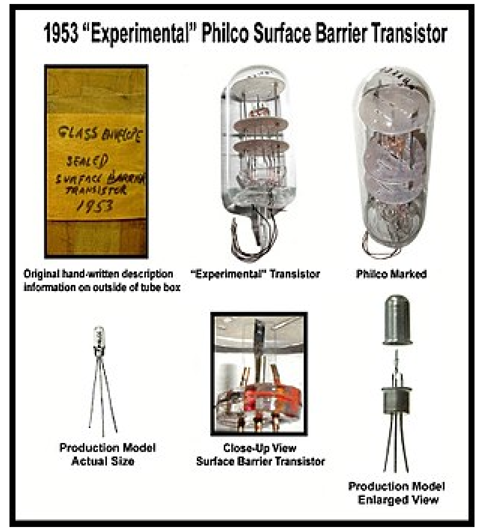
Shockley's research team initially attempted to build a field-effect transistor (FET), by trying to modulate the conductivity of a semiconductor, but was unsuccessful, mainly due to problems with the surface states, the dangling bond, and the germanium and copper compound materials. In the course of trying to understand the mysterious reasons behind their failure to build a working FET, this led them instead to invent the bipolar point-contact and junction transistors.[26][27]

In 1948, the point-contact transistor was independently invented by German physicists Herbert Mataré and Heinrich Welker while working at the *Compagnie des Freins et Signaux*, a Westinghouse subsidiary located in Paris. Mataré had previous experience in developing crystal rectifiers from silicon and germanium in the German radar effort during World War II. Using this knowledge, he began researching the phenomenon of "interference" in 1947. By June 1948, witnessing currents flowing through point-contacts, Mataré produced consistent results using samples of germanium produced by Welker, similar to what Bardeen and Brattain had accomplished earlier in December 1947. Realizing that Bell Labs' scientists had already invented the transistor before them, the company rushed to get its "transistron" into production for amplified use in France's telephone network and filed his first transistor patent application on August 13, 1948.[28][29][30]

The first bipolar junction transistors were invented by Bell Labs' William Shockley, which applied for patent (2,569,347) on June 26, 1948. On April 12, 1950, Bell Labs chemists Gordon Teal and Morgan Sparks had successfully produced a working bipolar NPN junction amplifying germanium transistor. Bell Labs had announced the discovery of this new "sandwich" transistor in a press release on July 4, 1951.[31][32]

Herbert Mataré in 1950. He independently invented a point-contact transistor in June 1948.

The first high-frequency transistor was the surface-barrier germanium transistor developed by Philco in 1953, capable of operating up to 60 MHz.[33] These were made by etching depressions into an N-type germanium base from both sides with jets of Indium(III) sulfate until it was a few ten-thousandths of an inch thick. Indium electroplated into the depressions formed the collector and emitter.[34][35]



Philco surface-barrier transistor developed and produced in 1953

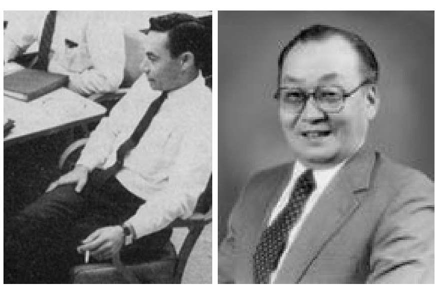
The first "prototype" pocket transistor radio was shown by INTERMETALL (a company founded by Herbert Mataré in 1952) at the *Internationale Funkausstellung Düsseldorf* between August 29, 1953 and September 6, 1953.[36][37] The first "production" pocket transistor radio was the Regency TR-1, released in October 1954.[25] Produced as a joint venture between the Regency Division of Industrial Development Engineering Associates, I.D.E.A. and Texas Instruments of Dallas Texas, the TR-1 was manufactured in Indianapolis, Indiana. It was a near pocket-sized radio featuring 4 transistors and one germanium diode. The industrial design was outsourced to the Chicago firm of Painter, Teague and Petertil. It was initially released in one of six different colours: black, ivory, mandarin red, cloud grey, mahogany and olive green. Other colours were to shortly follow.[38][39][40]

The first "production" all-transistor car radio was developed by Chrysler and Philco corporations and it was announced in the April 28, 1955 edition of the Wall Street Journal. Chrysler had made the all-transistor car radio, Mopar model 914HR, available as an option starting in fall 1955 for its new line of 1956 Chrysler and Imperial cars which first hit the dealership showroom floors on October 21, 1955.[41][42][43]

The Sony TR-63, released in 1957, was the first mass-produced transistor radio, leading to the mass-market penetration of transistor radios.[44] The TR-63 went on to sell seven million units worldwide by the mid-1960s.[45] Sony's success with transistor radios led to transistors replacing vacuum tubes as the dominant electronic technology in the late 1950s.[46]

The first working silicon transistor was developed at Bell Labs on January 26, 1954 by Morris Tanenbaum. The first commercial silicon transistor was produced by Texas Instruments in 1954. This was the work of Gordon Teal, an expert in growing crystals of high purity, who had previously worked at Bell Labs.[47][48][49]

MOSFET (MOS transistor)



Mohamed Atalla (left) and Dawon Kahng (right) invented the MOSFET (MOS transistor) at Bell Labs in 1959.

Semiconductor companies initially focused on junction transistors in the early years of the semiconductor industry. However, the junction transistor was a relatively bulky device that was difficult to manufacture on a mass-production basis, which limited it to a number of specialised applications. Field-effect transistors (FETs) were theorized as potential alternatives to junction transistors, but researchers could not get FETs to work properly, largely due to the troublesome surface state barrier that prevented the external electric field from penetrating into the material.[6]

In the 1950s, Egyptian engineer Mohamed Atalla investigated the surface properties of silicon semiconductors at Bell Labs, where he proposed a new method of semiconductor device fabrication, coating a silicon wafer with an insulating layer of silicon oxide so that electricity could reliably penetrate to the conducting silicon below, overcoming the surface states that prevented electricity from reaching the semiconducting layer. This is known as surface passivation, a method that became critical to the semiconductor industry as it later made possible the mass-production of silicon integrated circuits.[50][51] He presented his findings in 1957.[52] Building on his surface passivation method, he developed the metal–oxide–semiconductor (MOS) process.[50] He proposed the MOS process could be used to build the first working silicon FET, which he began working on building with the help of his Korean colleague Dawon Kahng.[50]

The metal–oxide–semiconductor field-effect transistor (MOSFET), also known as the MOS transistor, was invented by Mohamed Atalla and Dawon Kahng in 1959.[3][4] The MOSFET was the first truly compact transistor that could be miniaturised and mass-produced for a wide range of uses.[6] With its high scalability,[53] and much lower power consumption and higher density than bipolar junction transistors,[54] the MOSFET made it possible to build high-density integrated circuits,[5] allowing the integration of more than 10,000 transistors in a single IC.[55]

CMOS (complementary MOS) was invented by Chih-Tang Sah and Frank Wanlass at Fairchild Semiconductor in 1963.[56] The first report of a floating-gate MOSFET was made by Dawon Kahng and Simon Sze in 1967.[57] A double-gate MOSFET was first demonstrated in 1984 by Electrotechnical Laboratory researchers Toshihiro Sekigawa and Yutaka Hayashi.[58][59] FinFET (fin field-effect transistor), a type of 3D non-planar multi-gate MOSFET, originated from the research of Digh Hisamoto and his team at Hitachi Central Research Laboratory in 1989.[60][61]

Importance

Transistors are the key active components in practically all modern electronics. Many thus consider the transistor to be one of the greatest inventions of the 20th century.[62]

The MOSFET (metal–oxide–semiconductor field-effect transistor), also known as the MOS transistor, is by far the most widely used transistor, used in applications ranging from computers and electronics[51] to communications technology such as smartphones.[63] The MOSFET has been considered to be the most important transistor,[64] possibly the most important invention in electronics,[65] and the birth of modern electronics.[66] The MOS transistor has been the fundamental building block of modern digital electronics since the late 20th century, paving the way for the digital age.[9] The US Patent and Trademark Office calls it a "groundbreaking invention that transformed life and culture around the world".[63] Its importance in today's society rests on its ability to be mass-produced using a highly automated process (semiconductor device fabrication) that achieves astonishingly low per-transistor costs.

The invention of the first transistor at Bell Labs was named an IEEE Milestone in 2009.[67] The list of IEEE Milestones also includes the inventions of the junction transistor in 1948 and the MOSFET in 1959.[68]

Although several companies each produce over a billion individually packaged (known as *discrete*) MOS transistors every year,[69] the vast majority of transistors are now produced in integrated circuits (often shortened to *IC*, *microchips* or simply *chips*), along with diodes, resistors, capacitors and other electronic components, to produce complete electronic circuits. A logic gate consists of up to about twenty transistors whereas an advanced microprocessor, as of 2009, can use as many as 3 billion transistors (MOSFETs).[70] "About 60 million transistors were built in 2002… for [each] man, woman, and child on Earth."[71]

The MOS transistor is the most widely manufactured device in history.[10] As of 2013, billions of transistors are manufactured every day, nearly all of which are MOSFET devices.[5] Between 1960 and 2018, an estimated total of 13 sextillion MOS transistors have been manufactured, accounting for at least 99.9% of all transistors.[10]

The transistor's low cost, flexibility, and reliability have made it a ubiquitous device. Transistorized mechatronic circuits have replaced electromechanical devices in controlling appliances and machinery. It is often easier and cheaper to use a standard microcontroller and write a computer program to carry out a control function than to design an equivalent mechanical system to control that same function.

Simplified operation

A Darlington transistor opened up so the actual transistor chip (the small square) can be seen inside. A Darlington transistor is effectively two transistors on the same chip. One transistor is much larger than the other, but both are large in comparison to transistors in large-scale integration because this particular example is intended for power applications.

A transistor can use a small signal applied between one pair of its terminals to control a much larger signal at another pair of terminals. This property is called gain. It can produce a stronger output signal, a voltage or current, which is proportional to a weaker input signal and thus, it can act as an amplifier. Alternatively, the transistor can be used to turn current on or off in a circuit as an electrically controlled switch, where the amount of current is determined by other circuit elements.[72]

There are two types of transistors, which have slight differences in how they are used in a circuit. A *bipolar transistor* has terminals labeled **base**, **collector**, and **emitter**. A small current at the base terminal (that is, flowing between the base and the emitter) can control or switch a much larger current between the collector and emitter terminals. For a *field-effect transistor*, the terminals are labeled **gate**, **source**, and **drain**, and a voltage at the gate can control a current between source and drain.[73]

The image represents a typical bipolar transistor in a circuit. Charge will flow between emitter and collector terminals depending on the current in the base. Because internally the base and emitter connections behave like a semiconductor diode, a voltage drop develops between base and emitter while the base current exists. The amount of this voltage depends on the material the transistor is made from, and is referred to as V_{BE}.[73]

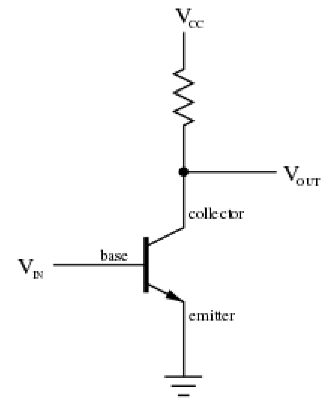
Transistor as a switch

Transistors are commonly used in digital circuits as electronic switches which can be either in an "on" or "off" state, both for high-power applications such as switched-mode power supplies and for low-power applications such as logic gates. Important parameters for this application include the current switched, the voltage handled, and the switching speed, characterised by the rise and fall times.[73]

In a grounded-emitter transistor circuit, such as the light-switch circuit shown, as the base voltage rises, the emitter and collector currents rise exponentially. The collector voltage drops because of reduced resistance from collector to emitter. If the voltage difference between the collector and emitter were zero (or near zero), the collector current would be limited only by the load resistance (light bulb) and the supply voltage. This is called *saturation* because current is flowing from collector to emitter freely. When saturated, the switch is said to be *on*.[74]

Providing sufficient base drive current is a key problem in the use of bipolar transistors as switches. The transistor provides current gain, allowing a relatively large current in the collector to be switched by a much smaller current into the base terminal. The ratio of these currents varies depending on the type of transistor, and even for a particular type, varies depending on the collector current. In the example light-switch circuit shown, the resistor is chosen to provide enough base current to ensure the transistor will be saturated.[73]

In a switching circuit, the idea is to simulate, as near as possible, the ideal switch having the properties of open circuit when off, short circuit when on, and an instantaneous transition between the two states. Parameters are chosen such that the "off" output is limited to leakage currents too small to affect connected circuitry, the resistance of the transistor in the "on" state is too small to affect circuitry, and the transition between the two states is fast enough not to have a detrimental effect.[73]



A simple circuit diagram to show the labels of a n–p–n bipolar transistor.

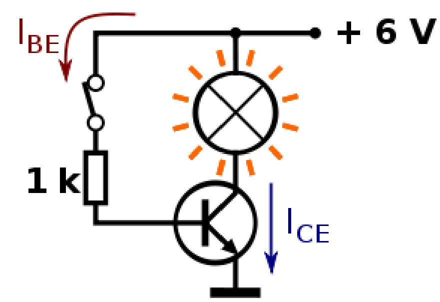
Transistor as an amplifier

The common-emitter amplifier is designed so that a small change in voltage (V_{in}) changes the small current through the base of the transistor whose current amplification combined with the properties of the circuit means that small swings in V_{in} produce large changes in V_{out}.[73]

Various configurations of single transistor amplifier are possible, with some providing current gain, some voltage gain, and some both.

From mobile phones to televisions, vast numbers of products include amplifiers for sound reproduction, radio transmission, and signal processing. The first discrete-transistor audio amplifiers barely supplied a few hundred milliwatts, but power and audio fidelity gradually increased as better transistors became available and amplifier architecture evolved.[73]

Modern transistor audio amplifiers of up to a few hundred watts are common and relatively inexpensive.



BJT used as an electronic switch, in grounded-emitter configuration.

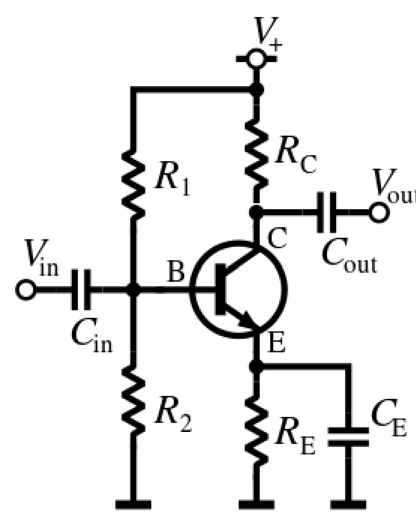
Comparison with vacuum tubes

Before transistors were developed, vacuum (electron) tubes (or in the UK "thermionic valves" or just "valves") were the main active components in electronic equipment.

Advantages

The key advantages that have allowed transistors to replace vacuum tubes in most applications are

- No cathode heater (which produces the characteristic orange glow of tubes), reducing power consumption, eliminating delay as tube heaters warm up, and immune from cathode poisoning and depletion.
- Very small size and weight, reducing equipment size.
- Large numbers of extremely small transistors can be manufactured as a single integrated circuit.
- Low operating voltages compatible with batteries of only a few cells.
- Circuits with greater energy efficiency are usually possible. For low-power applications (for example, voltage amplification) in particular, energy consumption can be very much less than for tubes.
- Complementary devices available, providing design flexibility including complementary-symmetry circuits, not possible with vacuum tubes.
- Very low sensitivity to mechanical shock and vibration, providing physical ruggedness and virtually eliminating shock-induced spurious signals (for example, microphonics in audio applications).
- Not susceptible to breakage of a glass envelope, leakage, outgassing, and other physical damage.



Amplifier circuit, common-emitter configuration with a voltage-divider bias circuit.

Limitations

Transistors have the following limitations:

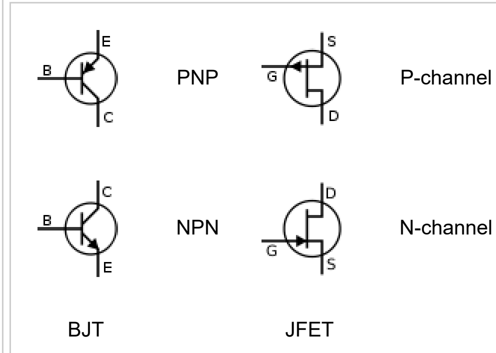
- They lack the higher electron mobility afforded by the vacuum of vacuum tubes, which is desirable for high-power, high-frequency operation — such as that used in over-the-air television broadcasting.
- Transistors and other solid-state devices are susceptible to damage from very brief electrical and thermal events, including electrostatic discharge in handling. Vacuum tubes are electrically much more rugged.
- They are sensitive to radiation and cosmic rays (special radiation-hardened chips are used for spacecraft devices).

- In audio applications, transistors lack the lower-harmonic distortion — the so-called tube sound — which is characteristic of vacuum tubes, and is preferred by some.[75]

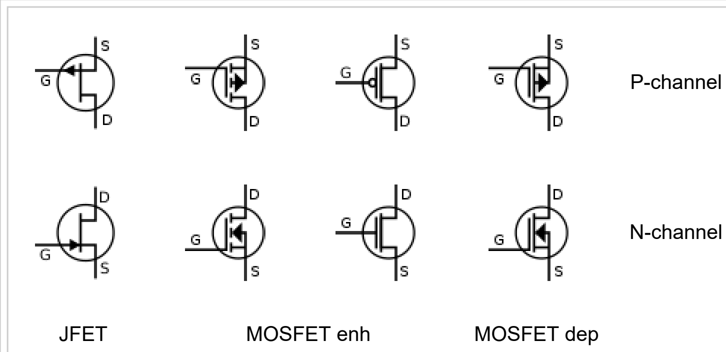
Types

Transistors are categorized by

- Structure: MOSFET (IGFET), BJT, JFET, insulated-gate bipolar transistor (IGBT), "other types".
- semiconductor material: the metalloids germanium (first used in 1947) and silicon (first used in 1954)—in amorphous, polycrystalline and monocrystalline form—, the compounds gallium arsenide (1966) and silicon carbide (1997), the alloy silicon-germanium (1989), the allotrope of carbon graphene (research ongoing since 2004), etc. (see Semiconductor material).
- Electrical polarity (positive and negative): n–p–n, p–n–p (BJTs), n-channel, p-channel (FETs).
- Maximum power rating: low, medium, high.
- Maximum operating frequency: low, medium, high, radio (RF), microwave frequency (the maximum effective frequency of a transistor in a common-emitter or common-source circuit is denoted by the term f_T, an abbreviation for transition frequency—the frequency of transition is the frequency at which the transistor yields unity voltage gain)
- Application: switch, general purpose, audio, high voltage, super-beta, matched pair.
- Physical packaging: through-hole metal, through-hole plastic, surface mount, ball grid array, power modules (see Packaging).
- Amplification factor h_{FE}, β_F (transistor beta)[76] or g_m (transconductance).
- temperature: Extreme temperature transistors and traditional temperature transistors (−55°C to +150°C). Extreme temperature transistors include high-temperature transistors (above +150°C) and low-temperature transistors (below −55°C). The high-temperature transistors that operate thermally stable up to 220°C, can be developed by a general strategy of blending interpenetrating semi-crystalline conjugated polymers and high glass-transition temperature insulating polymers.[77]



BJT and JFET symbols



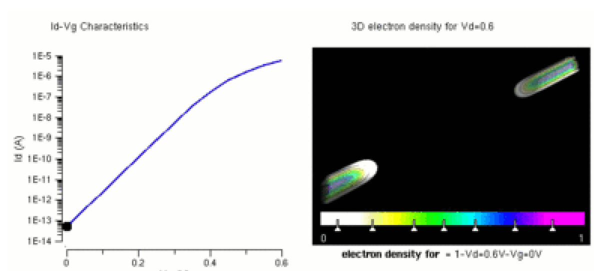
JFET and MOSFET symbols

Hence, a particular transistor may be described as *silicon, surface-mount, BJT, n–p–n, low-power, high-frequency switch*.

A popular way to remember which symbol represents which type of transistor is to look at the arrow and how it is arranged. Within an NPN transistor symbol, the arrow will Not Point iN. Conversely, within the PNP symbol you see that the arrow Points iN Proudly.

Field-effect transistor (FET)

The *field-effect transistor*, sometimes called a *unipolar transistor*, uses either electrons (in *n-channel FET*) or holes (in *p-channel FET*) for conduction. The four terminals of the FET are named *source*, *gate*, *drain*, and *body* (*substrate*). On most FETs, the body is connected to the source inside the package, and this will be assumed for the following description.



Operation of a FET and its Id-Vg curve. At first, when no gate voltage is applied, there are no inversion electrons in the channel, so the device is turned off. As gate voltage increases, the inversion electron density in the channel increases, current increases, and thus the device turns on.

In a FET, the drain-to-source current flows via a conducting channel that connects the *source* region to the *drain* region. The conductivity is varied by the electric field that is produced when a voltage is applied between the gate and source terminals, hence the current flowing between the drain and source is controlled by the voltage applied between the gate and source. As the gate–source voltage (V_{GS}) is increased, the drain–source current (I_{DS}) increases exponentially for V_{GS} below threshold, and then at a roughly quadratic rate ($I_{DS} \propto (V_{GS} - V_T)^2$) (where V_T is the threshold voltage at which drain current begins)[78] in the "space-charge-limited" region above threshold. A quadratic behavior is not observed in modern devices, for example, at the 65 nm technology node.[79]

For low noise at narrow bandwidth the higher input resistance of the FET is advantageous.

FETs are divided into two families: *junction FET* (JFET) and *insulated gate FET* (IGFET). The IGFET is more commonly known as a *metal–oxide–semiconductor FET* (MOSFET), reflecting its original construction from layers of metal (the gate), oxide (the insulation), and semiconductor. Unlike IGFETs, the JFET gate forms a p–n diode with the channel which lies between the source and drain. Functionally, this makes the n-channel JFET the solid-state equivalent of the vacuum tube triode which, similarly, forms a diode between its grid and cathode. Also, both devices operate in the *depletion mode*, they both have a high input impedance, and they both conduct current under the control of an input voltage.

Metal–semiconductor FETs (MESFETs) are JFETs in which the reverse biased p–n junction is replaced by a metal–semiconductor junction. These, and the HEMTs (high-electron-mobility transistors, or HFETs), in which a two-dimensional electron gas with very high carrier mobility is used for charge transport, are especially suitable for use at very high frequencies (several GHz).

FETs are further divided into *depletion-mode* and *enhancement-mode* types, depending on whether the channel is turned on or off with zero gate-to-source voltage. For enhancement mode, the channel is off at zero bias, and a gate potential can "enhance" the conduction. For the depletion mode, the channel is on at zero bias, and a gate potential (of the opposite polarity) can "deplete" the channel, reducing conduction. For either mode, a more positive gate voltage corresponds to a higher current for n-channel devices and a lower current for p-channel devices. Nearly all JFETs are depletion-mode because the diode junctions would forward bias and conduct if they were enhancement-mode devices, while most IGFETs are enhancement-mode types.

Metal-oxide-semiconductor FET (MOSFET)

The metal–oxide–semiconductor field-effect transistor (MOSFET, MOS-FET, or MOS FET), also known as the metal–oxide–silicon transistor (MOS transistor, or MOS),[5] is a type of field-effect transistor that is fabricated by the controlled oxidation of a semiconductor, typically silicon. It has an insulated gate, whose voltage determines the conductivity of the device. This ability to change conductivity with the amount of applied voltage can be used for amplifying or switching electronic signals. The MOSFET is by far the most common transistor, and the basic building block of most modern electronics.[9] The MOSFET accounts for 99.9% of all transistors in the world.[10]

Bipolar junction transistor (BJT)

Bipolar transistors are so named because they conduct by using both majority and minority carriers. The bipolar junction transistor, the first type of transistor to be mass-produced, is a combination of two junction diodes, and is formed of either a thin layer of p-type semiconductor sandwiched between two n-type semiconductors (an n–p–n transistor), or a thin layer of n-type semiconductor sandwiched between two p-type semiconductors (a p–n–p transistor). This construction produces two p–n junctions: a base–emitter junction and a base–collector junction, separated by a thin region of semiconductor known as the base region. (Two junction diodes wired together without sharing an intervening semiconducting region will not make a transistor).

BJTs have three terminals, corresponding to the three layers of semiconductor—an *emitter*, a *base*, and a *collector*. They are useful in amplifiers because the currents at the emitter and collector are controllable by a relatively small base current.[80] In an n–p–n transistor operating in the active region, the emitter–base junction is forward biased (electrons and holes recombine at the junction), and the base-collector junction is reverse biased (electrons and holes are formed at, and move away from the junction), and electrons are injected into the base region. Because the base is narrow, most of these electrons will diffuse into the reverse-biased base–collector junction and be swept into the collector; perhaps one-hundredth of the electrons will recombine in the base, which is the dominant mechanism in the base current. As well, as the base is lightly doped (in comparison to the emitter and collector regions), recombination rates are low, permitting more carriers to diffuse across the base region. By controlling the number of electrons that can leave the base, the number of electrons entering the collector can be controlled.[80] Collector current is approximately β (common-emitter current gain) times the base current. It is typically greater than 100 for small-signal transistors but can be smaller in transistors designed for high-power applications.

Unlike the field-effect transistor (see below), the BJT is a low-input-impedance device. Also, as the base–emitter voltage (V_{BE}) is increased the base–emitter current and hence the collector–emitter current (I_{CE}) increase exponentially according to the Shockley diode model and the Ebers-Moll model. Because of this exponential relationship, the BJT has a higher transconductance than the FET.

Bipolar transistors can be made to conduct by exposure to light, because absorption of photons in the base region generates a photocurrent that acts as a base current; the collector current is approximately β times the photocurrent. Devices designed for this purpose have a transparent window in the package and are called phototransistors.

Usage of MOSFETs and BJTs

The MOSFET is by far the most widely used transistor for both digital circuits as well as analog circuits,[81] accounting for 99.9% of all transistors in the world.[10] The bipolar junction transistor (BJT) was previously the most commonly used transistor during the 1950s to 1960s. Even after MOSFETs became widely available in the 1970s, the BJT remained the transistor of choice for many analog circuits such as amplifiers because of their greater linearity, up until MOSFET devices (such as power MOSFETs, LDMOS and RF CMOS) replaced them for most power electronic applications in the 1980s. In integrated circuits, the desirable properties of MOSFETs allowed them to capture nearly all market share for digital circuits in the 1970s. Discrete MOSFETs (typically power MOSFETs) can be applied in transistor applications, including analog circuits, voltage regulators, amplifiers, power transmitters and motor drivers.

Other transistor types

- Field-effect transistor (FET):
  - Metal–oxide–semiconductor field-effect transistor (MOSFET), where the gate is insulated by a shallow layer of insulator
    - p-type MOS (PMOS)
    - n-type MOS (NMOS)
    - complementary MOS (CMOS)
      - RF CMOS, for power electronics
    - Multi-gate field-effect transistor (MuGFET)
      - Fin field-effect transistor (FinFET), source/drain region shapes fins on the silicon surface
      - GAAFET,Similar to FinFET but nanowires are used instead of fins, the nanowires are stacked vertically and are surrounded on 4 sides by the gate
      - MBCFET, variant of GAAFET that uses nanosheets instead of nanowires, made by Samsung
    - Thin-film transistor, used in LCD and OLED displays
    - Floating-gate MOSFET (FGMOS), for non-volatile storage
    - Power MOSFET, for power electronics
      - lateral diffused MOS (LDMOS)
  - Carbon nanotube field-effect transistor (CNFET), where the channel material is replaced by a carbon nanotube
  - Junction gate field-effect transistor (JFET), where the gate is insulated by a reverse-biased p–n junction
  - Metal–semiconductor field-effect transistor (MESFET), similar to JFET with a Schottky junction instead of a p–n junction
    - High-electron-mobility transistor (HEMT)
  - Inverted-T field-effect transistor (ITFET)
  - Fast-reverse epitaxial diode field-effect transistor (FREDFET)
  - Organic field-effect transistor (OFET), in which the semiconductor is an organic compound
  - Ballistic transistor (disambiguation)
  - FETs used to sense environment
    - Ion-sensitive field-effect transistor (IFSET), to measure ion concentrations in solution,
    - Electrolyte–oxide–semiconductor field-effect transistor (EOSFET), neurochip,
    - Deoxyribonucleic acid field-effect transistor (DNAFET).

Transistor symbol created on Portuguese pavement in the University of Aveiro.

- Bipolar junction transistor (BJT):
  - Heterojunction bipolar transistor, up to several hundred GHz, common in modern ultrafast and RF circuits
  - Schottky transistor
  - avalanche transistor
  - Darlington transistors are two BJTs connected together to provide a high current gain equal to the product of the current gains of the two transistors
  - Insulated-gate bipolar transistors (IGBTs) use a medium-power IGFET, similarly connected to a power BJT, to give a high input impedance. Power diodes are often connected between certain terminals depending on specific use. IGBTs are particularly suitable for heavy-duty industrial applications. The ASEA Brown Boveri (ABB) *5SNA2400E170100* ,[82] intended for three-phase power supplies, houses three n–p–n IGBTs in a case measuring 38 by 140 by 190 mm and weighing 1.5 kg. Each IGBT is rated at 1,700 volts and can handle 2,400 amperes
  - Phototransistor.
  - Emitter-switched bipolar transistor (ESBT) is a monolithic configuration of a high-voltage bipolar transistor and a low-voltage power MOSFET in cascode topology. It was introduced by STMicroelectronics in the 2000s,[83] and abandoned a few years later around 2012.[84]
  - Multiple-emitter transistor, used in transistor–transistor logic and integrated current mirrors
  - Multiple-base transistor, used to amplify very-low-level signals in noisy environments such as the pickup of a record player or radio front ends. Effectively, it is a very large number of transistors in parallel where, at the output, the signal is added constructively, but random noise is added only stochastically.[85]
- Tunnel field-effect transistor, where it switches by modulating quantum tunnelling through a barrier.
- Diffusion transistor, formed by diffusing dopants into semiconductor substrate; can be both BJT and FET.
- Unijunction transistor, can be used as simple pulse generators. It comprise a main body of either P-type or N-type semiconductor with ohmic contacts at each end (terminals *Base1* and *Base2*). A junction with the opposite semiconductor type is formed at a point along the length of the body for the third terminal (*Emitter*).
- Single-electron transistors (SET), consist of a gate island between two tunneling junctions. The tunneling current is controlled by a voltage applied to the gate through a capacitor.[86]
- Nanofluidic transistor, controls the movement of ions through sub-microscopic, water-filled channels.[87]
- Multigate devices:

  - Tetrode transistor
  - Pentode transistor
  - Trigate transistor (prototype by Intel)
  - Dual-gate field-effect transistors have a single channel with two gates in cascode, a configuration optimized for *high-frequency amplifiers*, *mixers*, and oscillators.
- Junctionless nanowire transistor (JNT), uses a simple nanowire of silicon surrounded by an electrically isolated "wedding ring" that acts to gate the flow of electrons through the wire.
- Vacuum-channel transistor, when in 2012, NASA and the National Nanofab Center in South Korea were reported to have built a prototype vacuum-channel transistor in only 150 nanometers in size, can be manufactured cheaply using standard silicon semiconductor processing, can operate at high speeds even in hostile environments, and could consume just as much power as a standard transistor.[88]
- Organic electrochemical transistor.
- Solaristor (from solar cell transistor), a two-terminal gate-less self-powered phototransistor.

Part numbering standards/specifications

The types of some transistors can be parsed from the part number. There are three major semiconductor naming standards. In each, the alphanumeric prefix provides clues to type of the device.

Japanese Industrial Standard (JIS)

The *JIS-C-7012* specification for transistor part numbers starts with "2S",[89] e.g. 2SD965, but sometimes the "2S" prefix is not marked on the package – a 2SD965 might only be marked "D965"; a 2SC1815 might be listed by a supplier as simply "C1815". This series sometimes has suffixes (such as "R", "O", "BL", standing for "red", "orange", "blue", etc.) to denote variants, such as tighter h_{FE} (gain) groupings.

JIS transistor prefix table

Prefix	Type of transistor
2SA	high-frequency p–n–p BJT
2SB	audio-frequency p–n–p BJT
2SC	high-frequency n–p–n BJT
2SD	audio-frequency n–p–n BJT
2SJ	P-channel FET (both JFET and MOSFET)
2SK	N-channel FET (both JFET and MOSFET)

European Electronic Component Manufacturers Association (EECA)

The Pro Electron standard, the European Electronic Component Manufacturers Association part numbering scheme, begins with two letters: the first gives the semiconductor type (A for germanium, B for silicon, and C for materials like GaAs); the second letter denotes the intended use (A for diode, C for general-purpose transistor, etc.). A 3-digit sequence number (or one letter then two digits, for industrial types) follows. With early devices this indicated the case type. Suffixes may be used, with a letter (e.g. "C" often means high h_{FE}, such as in: BC549C[90]) or other codes may follow to show gain (e.g. BC327-25) or voltage rating (e.g. BUK854-800A[91]). The more common prefixes are:

Pro Electron / EECA transistor prefix table

Prefix class	Type and usage	Example	Equivalent	Reference
AC	Germanium small-signal AF transistor	AC126	NTE102A	Datasheet (http://www.weisd.com/store2/NTE102A.pdf)
AD	Germanium AF power transistor	AD133	NTE179	Datasheet (http://www.weisd.com/store2/nte179.pdf)
AF	Germanium small-signal RF transistor	AF117	NTE160	Datasheet (http://www.weisd.com/store2/nte160.pdf)
AL	Germanium RF power transistor	ALZ10	NTE100	Datasheet (http://www.weisd.com/store2/nte100.pdf)
AS	Germanium switching transistor	ASY28	NTE101	Datasheet (http://www.weisd.com/store2/NTE101.pdf)
AU	Germanium power switching transistor	AU103	NTE127	Datasheet (http://www.weisd.com/store2/nte127.pdf)
BC	Silicon, small-signal transistor ("general purpose")	BC548	2N3904	Datasheet (https://www.mccsemi.com/pdf/Products/2N3904(TO-92).pdf)
BD	Silicon, power transistor	BD139	NTE375	Datasheet (http://www.fairchildsemi.com/ds/BD/BD135.pdf)
BF	Silicon, RF (high frequency) BJT or FET	BF245	NTE133	Datasheet (http://www.onsemi.com/pub_link/Collateral/BF245A-D.PDF)
BS	Silicon, switching transistor (BJT or MOSFET)	BS170	2N7000	Datasheet (http://www.fairchildsemi.com/ds/BS/BS170.pdf)
BL	Silicon, high frequency, high power (for transmitters)	BLW60	NTE325	Datasheet (http://www.datasheetcatalog.org/datasheet/philips/BLW60.pdf)
BU	Silicon, high voltage (for CRT horizontal deflection circuits)	BU2520A	NTE2354	Datasheet (http://www.datasheetcatalog.org/datasheet/philips/BU2520A.pdf)
CF	Gallium arsenide small-signal microwave transistor (MESFET)	CF739	—	Datasheet (https://web.archive.org/web/20150109012745/http://www.kesun.com/pdf/rf%20transistor/CF739.pdf)
CL	Gallium arsenide microwave power transistor (FET)	CLY10	—	Datasheet (http://www.datasheetcatalog.org/datasheet/siemens/CLY10.pdf)

Joint Electron Device Engineering Council (JEDEC)

The JEDEC *EIA370* transistor device numbers usually start with "2N", indicating a three-terminal device (dual-gate field-effect transistors are four-terminal devices, so begin with 3N), then a 2, 3 or 4-digit sequential number with no significance as to device properties (although early devices with low numbers tend to be germanium). For example, 2N3055 is a silicon n–p–n power transistor, 2N1301 is a p–n–p germanium switching transistor. A letter suffix (such as "A") is sometimes used to indicate a newer variant, but rarely gain groupings.

Proprietary

Manufacturers of devices may have their own proprietary numbering system, for example CK722. Since devices are second-sourced, a manufacturer's prefix (like "MPF" in MPF102, which originally would denote a Motorola FET) now is an unreliable indicator of who made the device. Some proprietary naming schemes adopt parts of other naming schemes, for example a PN2222A is a (possibly Fairchild Semiconductor) 2N2222A in a plastic case (but a PN108 is a plastic version of a BC108, not a 2N108, while the PN100 is unrelated to other xx100 devices).

Military part numbers sometimes are assigned their own codes, such as the British Military CV Naming System.

Manufacturers buying large numbers of similar parts may have them supplied with "house numbers", identifying a particular purchasing specification and not necessarily a device with a standardized registered number. For example, an HP part 1854,0053 is a (JEDEC) 2N2218 transistor[92][93] which is also assigned the CV number: CV7763[94]

Naming problems

With so many independent naming schemes, and the abbreviation of part numbers when printed on the devices, ambiguity sometimes occurs. For example, two different devices may be marked "J176" (one the J176 low-power JFET, the other the higher-powered MOSFET 2SJ176).

As older "through-hole" transistors are given surface-mount packaged counterparts, they tend to be assigned many different part numbers because manufacturers have their own systems to cope with the variety in pinout arrangements and options for dual or matched n–p–n + p–n–p devices in one pack. So even when the original device (such as a 2N3904) may have been assigned by a standards authority, and well known by engineers over the years, the new versions are far from standardized in their naming.

Construction

Semiconductor material

The first BJTs were made from germanium (Ge). Silicon (Si) types currently predominate but certain advanced microwave and high-performance versions now employ the *compound semiconductor* material gallium arsenide (GaAs) and the *semiconductor alloy* silicon germanium (SiGe). Single element semiconductor material (Ge and Si) is described as *elemental*.

Semiconductor material characteristics

Semiconductor material	Junction forward voltage V @ 25 °C	Electron mobility $m^2/(V·s)$ @ 25 °C	Hole mobility $m^2/(V·s)$ @ 25 °C	Max. junction temp. °C
Ge	0.27	0.39	0.19	70 to 100
Si	0.71	0.14	0.05	150 to 200
GaAs	1.03	0.85	0.05	150 to 200
Al-Si junction	0.3	—	—	150 to 200

Rough parameters for the most common semiconductor materials used to make transistors are given in the adjacent table. These parameters will vary with increase in temperature, electric field, impurity level, strain, and sundry other factors.

The *junction forward voltage* is the voltage applied to the emitter–base junction of a BJT in order to make the base conduct a specified current. The current increases exponentially as the junction forward voltage is increased. The values given in the table are typical for a current of 1 mA (the same values apply to semiconductor diodes). The lower the junction forward voltage the better, as this means that less power is required to "drive" the transistor. The junction forward voltage for a given current decreases with increase in temperature. For a typical silicon junction the change is −2.1 mV/°C.[95] In some circuits special compensating elements (sensistors) must be used to compensate for such changes.

The density of mobile carriers in the channel of a MOSFET is a function of the electric field forming the channel and of various other phenomena such as the impurity level in the channel. Some impurities, called dopants, are introduced deliberately in making a MOSFET, to control the MOSFET electrical behavior.

The *electron mobility* and *hole mobility* columns show the average speed that electrons and holes diffuse through the semiconductor material with an electric field of 1 volt per meter applied across the material. In general, the higher the electron mobility the faster the transistor can operate. The table indicates that Ge is a better material than Si in this respect. However, Ge has four major shortcomings compared to silicon and gallium arsenide:

1. Its maximum temperature is limited.
2. It has relatively high leakage current.
3. It cannot withstand high voltages.
4. It is less suitable for fabricating integrated circuits.

Because the electron mobility is higher than the hole mobility for all semiconductor materials, a given bipolar n–p–n transistor tends to be swifter than an equivalent p–n–p transistor. GaAs has the highest electron mobility of the three semiconductors. It is for this reason that GaAs is used in high-frequency applications. A relatively recent FET development, the *high-electron-mobility transistor* (HEMT), has a heterostructure (junction between different semiconductor materials) of aluminium gallium arsenide (AlGaAs)-gallium arsenide (GaAs) which has twice the electron mobility of a GaAs-metal barrier junction. Because of their high speed and low noise, HEMTs are used in satellite receivers working at frequencies around 12 GHz. HEMTs based on gallium nitride and aluminium gallium nitride (AlGaN/GaN HEMTs) provide a still higher electron mobility and are being developed for various applications.

'Max. junction temperature' values represent a cross section taken from various manufacturers' data sheets. This temperature should not be exceeded or the transistor may be damaged.

'Al–Si junction' refers to the high-speed (aluminum–silicon) metal–semiconductor barrier diode, commonly known as a Schottky diode. This is included in the table because some silicon power IGFETs have a parasitic reverse Schottky diode formed between the source and drain as part of the fabrication process. This diode can be a nuisance, but sometimes it is used in the circuit.

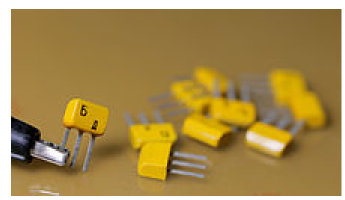
Packaging

Discrete transistors can be individually packaged transistors or unpackaged transistor chips (dice).

Assorted discrete transistors

Transistors come in many different semiconductor packages (see image). The two main categories are *through-hole* (or *leaded*), and *surface-mount*, also known as *surface-mount device* (SMD). The *ball grid array* (BGA) is the latest surface-mount package (currently only for large integrated circuits). It has solder "balls" on the underside in place of leads. Because they are smaller and have shorter interconnections, SMDs have better high-frequency characteristics but lower power rating.

Transistor packages are made of glass, metal, ceramic, or plastic. The package often dictates the power rating and frequency characteristics. Power transistors have larger packages that can be clamped to heat sinks for enhanced cooling. Additionally, most power transistors have the collector or drain physically connected to the metal enclosure. At the other extreme, some surface-mount *microwave* transistors are as small as grains of sand.


Soviet KT315b transistors

Often a given transistor type is available in several packages. Transistor packages are mainly standardized, but the assignment of a transistor's functions to the terminals is not: other transistor types can assign other functions to the package's terminals. Even for the same transistor type the terminal assignment can vary (normally indicated by a suffix letter to the part number, q.e. BC212L and BC212K).

Nowadays most transistors come in a wide range of SMT packages, in comparison the list of available through-hole packages is relatively small, here is a short list of the most common through-hole transistors packages in alphabetical order: ATV, E-line, MRT, HRT, SC-43, SC-72, TO-3, TO-18, TO-39, TO-92, TO-126, TO220, TO247, TO251, TO262, ZTX851.

Unpackaged transistor chips (die) may be assembled into hybrid devices.[96] The IBM SLT module of the 1960s is one example of such a hybrid circuit module using glass passivated transistor (and diode) die. Other packaging techniques for discrete transistors as chips include Direct Chip Attach (DCA) and Chip On Board (COB).[96]

Flexible transistors

Researchers have made several kinds of flexible transistors, including organic field-effect transistors.[97][98][99] Flexible transistors are useful in some kinds of flexible displays and other flexible electronics.

See also

- Band gap
- Digital electronics
- Diffused junction transistor
- Moore's law
- Optical transistor
- Semiconductor device modeling
- Transistor count
- Transistor model
- Transresistance
- Very-large-scale integration

References

1. "1926 – Field Effect Semiconductor Device Concepts Patented" (http://www.computerhistory.org/siliconengine/field-effect-semico

nductor-device-concepts-patented/). Computer History Museum. Archived (https://web.archive.org/web/20160322023120/http://www.computerhistory.org/siliconengine/field-effect-semiconductor-device-concepts-patented/) from the original on March 22, 2016. Retrieved March 25, 2016.
2. "The Nobel Prize in Physics 1956" (https://www.nobelprize.org/nobel_prizes/physics/laureates/1956/). *Nobelprize.org*. Nobel Media AB. Archived (https://web.archive.org/web/20141216204332/http://www.nobelprize.org/nobel_prizes/physics/laureates/1956/) from the original on December 16, 2014. Retrieved December 7, 2014.
3. "1960 - Metal Oxide Semiconductor (MOS) Transistor Demonstrated" (https://www.computerhistory.org/siliconengine/metal-oxide-semiconductor-mos-transistor-demonstrated/). *The Silicon Engine*. Computer History Museum.
4. Lojek, Bo (2007). *History of Semiconductor Engineering* (https://archive.org/details/historysemicondu00loje_697). Springer Science & Business Media. pp. 321 (https://archive.org/details/historysemicondu00loje_697/page/n327)–3. ISBN 9783540342588.
5. "Who Invented the Transistor?" (https://www.computerhistory.org/atchm/who-invented-the-transistor/). *Computer History Museum*. December 4, 2013. Retrieved July 20, 2019.
6. Moskowitz, Sanford L. (2016). *Advanced Materials Innovation: Managing Global Technology in the 21st century* (https://books.google.com/books?id=2STRDAAAQBAJ&pg=PA168). John Wiley & Sons. p. 168. ISBN 9780470508923.
7. "Milestones:Invention of the First Transistor at Bell Telephone Laboratories, Inc., 1947" (http://www.ieeeghn.org/wiki/index.php/Milestones:Invention_of_the_First_Transistor_at_Bell_Telephone_Laboratories,_Inc.,_1947). *IEEE Global History Network*. IEEE. Archived (https://web.archive.org/web/20141121055308/http://ieeghn.org/wiki/index.php/Milestones:Invention_of_the_First_Transistor_at_Bell_Telephone_Laboratories,_Inc.,_1947) from the original on November 21, 2014. Retrieved December 7, 2014.
8. "Milestones:List of IEEE Milestones" (http://ethw.org/Milestones:List_of_IEEE_Milestones). Institute of Electrical and Electronics Engineers. Retrieved July 25, 2019.
9. "Triumph of the MOS Transistor" (https://www.youtube.com/watch?v=q6fBEjf9WPw). *YouTube*. Computer History Museum. August 6, 2010. Retrieved July 21, 2019.
10. "13 Sextillion & Counting: The Long & Winding Road to the Most Frequently Manufactured Human Artifact in History" (https://www.computerhistory.org/atchm/13-sextillion-counting-the-long-winding-road-to-the-most-frequently-manufactured-human-artifact-in-history/). *Computer History Museum*. April 2, 2018. Retrieved July 28, 2019.
11. Moavenzadeh, Fred (1990). *Concise Encyclopedia of Building and Construction Materials* (https://books.google.com/?id=YiJaEAUj258C&pg=PA430&dq=Eccles+Oscillator+Galena#v=onepage&q=Eccles%20Oscillator%20Galena&f=false). ISBN 9780262132480.
12. Lilienfeld, Julius Edgar (1927). *Specification of electric current control mechanism patent application* (https://worldwide.espacenet.com/publicationDetails/originalDocument?FT=D&date=19270719&DB=&CC=CA&NR=272437A&KC=A&locale=en_EP#).
13. Vardalas, John (May 2003) Twists and Turns in the Development of the Transistor (http://www.todaysengineer.org/2003/May/history.asp) Archived (https://web.archive.org/web/20150108082709/http://www.todaysengineer.org/2003/May/history.asp) January 8, 2015, at the Wayback Machine *IEEE-USA Today's Engineer*.
14. Lilienfeld, Julius Edgar, "Method and apparatus for controlling electric current" U.S. Patent 1,745,175 (https://www.google.com/patents/US1745175) January 28, 1930 (filed in Canada 1925-10-22, in US October 8, 1926).
15. "Method And Apparatus For Controlling Electric Currents" (http://www.google.com/patents?id=uBFMAAAAEBAJ&printsec=abstract#v=onepage&q&f=false). United States Patent and Trademark Office.
16. "Amplifier For Electric Currents" (http://www.google.com/patents?id=jvhAAAAAEBAJ&printsec=abstract#v=onepage&q&f=false). United States Patent and Trademark Office.
17. "Device For Controlling Electric Current" (http://www.google.com/patents?id=52BQAAAAEBAJ&printsec=abstract#v=onepage&q&f=false). United States Patent and Trademark Office.
18. "Twists and Turns in the Development of the Transistor" (https://web.archive.org/web/20150108082709/http://www.todaysengineer.org/2003/May/history.asp). Institute of Electrical and Electronics Engineers, Inc. Archived from the original (http://www.todaysengineer.org/2003/May/history.asp) on January 8, 2015.
19. Heil, Oskar, "Improvements in or relating to electrical amplifiers and other control arrangements and devices" (http://v3.espacenet.com/publicationDetails/biblio?CC=GB&NR=439457&KC=&FT=E), Patent No. GB439457, European Patent Office, filed in Great Britain 1934-03-02, published December 6, 1935 (originally filed in Germany March 2, 1934).
20. "November 17 – December 23, 1947: Invention of the First Transistor" (http://www.aps.org/publications/apsnews/200011/history.cfm). American Physical Society. Archived (https://web.archive.org/web/20130120065607/http://www.aps.org/publications/apsnews/200011/history.cfm) from the original on January 20, 2013.
21. Millman, S., ed. (1983). *A History of Engineering and Science in the Bell System, Physical Science (1925–1980)*. AT&T Bell Laboratories. p. 102.
22. Bodanis, David (2005). *Electric Universe*. Crown Publishers, New York. ISBN 978-0-7394-5670-5.
23. "transistor". *American Heritage Dictionary* (3rd ed.). Boston: Houghton Mifflin. 1992.
24. "The Nobel Prize in Physics 1956" (http://nobelprize.org/nobel_prizes/physics/laureates/1956/). nobelprize.org. Archived (https://web.archive.org/web/20070312091604/http://nobelprize.org/nobel_prizes/physics/laureates/1956/) from the original on March 12, 2007.
25. Guarnieri, M. (2017). "Seventy Years of Getting Transistorized". *IEEE Industrial Electronics Magazine*. **11** (4): 33–37. doi:10.1109/MIE.2017.2757775 (https://doi.org/10.1109%2FMIE.2017.2757775).
26. Lee, Thomas H. (2003). *The Design of CMOS Radio-Frequency Integrated Circuits* (https://web.stanford.edu/class/archive/ee/ee214/ee214.1032/Handouts/HO2.pdf) (PDF). Cambridge University Press. ISBN 9781139643771.
27. Puers, Robert; Baldi, Livio; Voorde, Marcel Van de; Nooten, Sebastiaan E. van (2017). *Nanoelectronics: Materials, Devices, Applications, 2 Volumes* (https://books.google.com/books?id=JOqVDgAAQBAJ&pg=PA14). John Wiley & Sons. p. 14. ISBN 9783527340538.
28. FR 1010427 (https://worldwide.espacenet.com/textdoc?DB=EPODOC&IDX=FR1010427) H. F. Mataré / H. Welker / Westinghouse: "Nouveau sytème cristallin à plusieurs électrodes réalisant des relais de effects électroniques" filed on August 13, 1948
29. US 2673948 (https://worldwide.espacenet.com/textdoc?DB=EPODOC&IDX=US2673948) H. F. Mataré / H. Welker / Westinghouse, "Crystal device for controlling electric currents by means of a solid semiconductor" French priority August 13, 1948
30. "1948, The European Transistor Invention" (http://www.computerhistory.org/semiconductor/timeline/1948-European.html). Computer History Museum. Archived (https://web.archive.org/web/20120929202704/http://www.computerhistory.org/semiconductor/timeline/1948-European.html) from the original on September 29, 2012.

31. 1951: First Grown-Junction Transistors Fabricated (http://www.computerhistory.org/siliconengine/first-grown-junction-transistors-fabricated/) Archived (https://web.archive.org/web/20170404035446/http://www.computerhistory.org/siliconengine/first-grown-junction-transistors-fabricated/) April 4, 2017, at the Wayback Machine
32. "A Working Junction Transistor" (https://www.pbs.org/transistor/science/info/junctw.html). Archived (https://web.archive.org/web/20170703002246/http://www.pbs.org/transistor/science/info/junctw.html) from the original on July 3, 2017. Retrieved September 17, 2017.
33. Bradley, W.E. (December 1953). "The Surface-Barrier Transistor: Part I-Principles of the Surface-Barrier Transistor". *Proceedings of the IRE*. **41** (12): 1702–1706. doi:10.1109/JRPROC.1953.274351 (https://doi.org/10.1109%2FJRPROC.1953.274351).
34. Wall Street Journal, December 4, 1953, page 4, Article "Philco Claims Its Transistor Outperforms Others Now In Use"
35. Electronics magazine, January 1954, Article "Electroplated Transistors Announced"
36. 1953 Foreign Commerce Weekly; Volume 49; pp.23
37. "*Der deutsche Erfinder des Transistors – Nachrichten Welt Print – DIE WELT*" (https://www.welt.de/welt_print/article2721871/Der-deutsche-Erfinder-des-Transistors.html). *Die Welt*. Welt.de. November 23, 2011. Archived (https://web.archive.org/web/20160515182422/http://www.welt.de/welt_print/article2721871/Der-deutsche-Erfinder-des-Transistors.html) from the original on May 15, 2016. Retrieved May 1, 2016.
38. "Regency TR-1 Transistor Radio History" (http://www.regencytr1.com/). Archived (https://web.archive.org/web/20041021040145/http://www.regencytr1.com/) from the original on October 21, 2004. Retrieved April 10, 2006.
39. "The Regency TR-1 Family" (http://www.ericwrobbel.com/books/regency.htm). Archived (https://web.archive.org/web/20170427155821/http://www.ericwrobbel.com/books/regency.htm) from the original on April 27, 2017. Retrieved April 10, 2017.
40. "Regency manufacturer in USA, radio technology from United St" (http://www.radiomuseum.org/dsp_hersteller_detail.cfm?company_id=3886). Archived (https://web.archive.org/web/20170410214244/http://www.radiomuseum.org/dsp_hersteller_detail.cfm?company_id=3886) from the original on April 10, 2017. Retrieved April 10, 2017.
41. Wall Street Journal, "Chrysler Promises Car Radio With Transistors Instead of Tubes in '56", April 28, 1955, page 1
42. Hirsh, Rick. "Philco's All-Transistor Mopar Car Radio" (http://www.allpar.com/stereo/Philco/index.html). Allpar.com. Retrieved February 18, 2015.
43. "FCA North America - Historical Timeline 1950-1959" (http://www.fcanorthamerica.com/company/Heritage/Pages/Chrysler-Heritage-1950.aspx). *www.fcanorthamerica.com*.
44. Skrabec, Quentin R., Jr. (2012). *The 100 Most Significant Events in American Business: An Encyclopedia* (https://books.google.com/books?id=2kc69qrid9oC&pg=PA195). ABC-CLIO. pp. 195–7. ISBN 978-0313398636.
45. Snook, Chris J. (November 29, 2017). "The 7 Step Formula Sony Used to Get Back On Top After a Lost Decade" (https://www.inc.com/chris-j-snook/sonys-7-step-formula-for-entrepreneurial-success-business-longevity.html). *Inc.*
46. Kozinsky, Sieva (January 8, 2014). "Education and the Innovator's Dilemma" (https://www.wired.com/insights/2014/01/education-innovators-dilemma/). *Wired*. Retrieved October 14, 2019.
47. Riordan, Michael (May 2004). "The Lost History of the Transistor" (https://spectrum.ieee.org/biomedical/devices/the-lost-history-of-the-transistor). *IEEE Spectrum*: 48–49. Archived (https://web.archive.org/web/20150531113132/https://spectrum.ieee.org/biomedical/devices/the-lost-history-of-the-transistor) from the original on May 31, 2015.
48. Chelikowski, J. (2004) "Introduction: Silicon in all its Forms", p. 1 in *Silicon: evolution and future of a technology*. P. Siffert and E. F. Krimmel (eds.). Springer, ISBN 3-540-40546-1.
49. McFarland, Grant (2006) *Microprocessor design: a practical guide from design planning to manufacturing*. McGraw-Hill Professional. p. 10. ISBN 0-07-145951-0.
50. "Martin Atalla in Inventors Hall of Fame, 2009" (https://www.invent.org/inductees/martin-john-m-atalla). Retrieved June 21, 2013.
51. "Dawon Kahng" (https://www.invent.org/inductees/dawon-kahng). *National Inventors Hall of Fame*. Retrieved June 27, 2019.
52. Lojek, Bo (2007). *History of Semiconductor Engineering* (https://archive.org/details/historysemicondu00loje_697). Springer Science & Business Media. p. 120 (https://archive.org/details/historysemicondu00loje_697/page/n128). ISBN 9783540342588.
53. Motoyoshi, M. (2009). "Through-Silicon Via (TSV)" (https://pdfs.semanticscholar.org/8a44/93b535463daa7d7317b08d8900a33b8cbaf4.pdf) (PDF). *Proceedings of the IEEE*. **97** (1): 43–48. doi:10.1109/JPROC.2008.2007462 (https://doi.org/10.1109%2FJPROC.2008.2007462). ISSN 0018-9219 (https://www.worldcat.org/issn/0018-9219).
54. "Transistors Keep Moore's Law Alive" (https://www.eetimes.com/author.asp?section_id=36&doc_id=1334068). *EETimes*. December 12, 2018. Retrieved July 18, 2019.
55. Hittinger, William C. (1973). "Metal-Oxide-Semiconductor Technology". *Scientific American*. **229** (2): 48–59. Bibcode:1973SciAm.229b..48H (https://ui.adsabs.harvard.edu/abs/1973SciAm.229b..48H). doi:10.1038/scientificamerican0873-48 (https://doi.org/10.1038%2Fscientificamerican0873-48). ISSN 0036-8733 (https://www.worldcat.org/issn/0036-8733). JSTOR 24923169 (https://www.jstor.org/stable/24923169).
56. "1963: Complementary MOS Circuit Configuration is Invented" (https://www.computerhistory.org/siliconengine/complementary-mos-circuit-configuration-is-invented/). *Computer History Museum*. Retrieved July 6, 2019.
57. D. Kahng and S. M. Sze, "A floating gate and its application to memory devices", *The Bell System Technical Journal*, vol. 46, no. 4, 1967, pp. 1288–1295
58. Colinge, J.P. (2008). *FinFETs and Other Multi-Gate Transistors* (https://books.google.com/books?id=t1ojkCdTGEEC&pg=PA11). Springer Science & Business Media. p. 11. ISBN 9780387717517.
59. Sekigawa, Toshihiro; Hayashi, Yutaka (August 1, 1984). "Calculated threshold-voltage characteristics of an XMOS transistor having an additional bottom gate". *Solid-State Electronics*. **27** (8): 827–828. Bibcode:1984SSEle..27..827S (https://ui.adsabs.harvard.edu/abs/1984SSEle..27..827S). doi:10.1016/0038-1101(84)90036-4 (https://doi.org/10.1016%2F0038-1101%2884%2990036-4). ISSN 0038-1101 (https://www.worldcat.org/issn/0038-1101).
60. "IEEE Andrew S. Grove Award Recipients" (https://www.ieee.org/about/awards/bios/grove-recipients.html). *IEEE Andrew S. Grove Award*. Institute of Electrical and Electronics Engineers. Retrieved July 4, 2019.
61. "The Breakthrough Advantage for FPGAs with Tri-Gate Technology" (https://www.intel.com/content/dam/www/programmable/us/en/pdfs/literature/wp/wp-01201-fpga-tri-gate-technology.pdf) (PDF). Intel. 2014. Retrieved July 4, 2019.
62. Price, Robert W. (2004). *Roadmap to Entrepreneurial Success* (https://books.google.com/?id=q7UzNoWdGAkC&pg=PA42&dq=transistor+inventions-of-the-twentieth-century). AMACOM Div American Mgmt Assn. p. 42. ISBN 978-0-8144-7190-6.
63. "Remarks by Director Iancu at the 2019 International Intellectual Property Conference" (https://www.uspto.gov/about-us/news-updates/remarks-director-iancu-2019-international-intellectual-property-conference). *United States Patent and Trademark Office*. June 10, 2019. Retrieved July 20, 2019.

64. Ashley, Kenneth L. (2002). *Analog Electronics with LabVIEW* (https://books.google.com/books?id=0qkc2f6EXnQC&pg=PA10). Prentice Hall Professional. p. 10. ISBN 9780130470652.
65. Thompson, S. E.; Chau, R. S.; Ghani, T.; Mistry, K.; Tyagi, S.; Bohr, M. T. (2005). "In search of "Forever," continued transistor scaling one new material at a time". *IEEE Transactions on Semiconductor Manufacturing*. **18** (1): 26–36. doi:10.1109/TSM.2004.841816 (https://doi.org/10.1109%2FTSM.2004.841816). ISSN 0894-6507 (https://www.worldcat.org/issn/0894-6507). "In the field of electronics, the planar Si metal–oxide–semiconductor field-effect transistor (MOSFET) is perhaps the most important invention."
66. Kubozono, Yoshihiro; He, Xuexia; Hamao, Shino; Uesugi, Eri; Shimo, Yuma; Mikami, Takahiro; Goto, Hidenori; Kambe, Takashi (2015). "Application of Organic Semiconductors toward Transistors" (https://books.google.com/books?id=8wdCCwAAQBAJ&pg=PA355). *Nanodevices for Photonics and Electronics: Advances and Applications*. CRC Press. p. 355. ISBN 9789814613750.
67. "Milestones:Invention of the First Transistor at Bell Telephone Laboratories, Inc., 1947" (http://www.ieeeghn.org/wiki/index.php/Milestones:Invention_of_the_First_Transistor_at_Bell_Telephone_Laboratories,_Inc.,_1947). *IEEE Global History Network*. IEEE. Archived (https://web.archive.org/web/20111008193522/http://www.ieeeghn.org/wiki/index.php/Milestones:Invention_of_the_First_Transistor_at_Bell_Telephone_Laboratories,_Inc.,_1947) from the original on October 8, 2011. Retrieved August 3, 2011.
68. List of IEEE Milestones (http://ethw.org/Milestones:List_of_IEEE_Milestones)
69. FETs/MOSFETs: Smaller apps push up surface-mount supply (https://web.archive.org/web/20081206043949/http://www.globalsources.com/gsol/I/FET-MOSFET/a/9000000085806.htm). globalsources.com (April 18, 2007)
70. "ATI and Nvidia face off (http://news.cnet.com/8301-13512_3-10369441-23.html) Archived (https://web.archive.org/web/20130523063418/http://news.cnet.com/8301-13512_3-10369441-23.html) May 23, 2013, at the Wayback Machine." CNET (October 7, 2009). Retrieved on February 2, 2011.
71. Turley, Jim (December 18, 2002). "The Two Percent Solution" (http://www.embedded.com/electronics-blogs/significant-bits/4024488/The-Two-Percent-Solution) Archived (https://web.archive.org/web/20160304083348/http://www.embedded.com/electronics-blogs/significant-bits/4024488/The-Two-Percent-Solution) March 4, 2016, at the Wayback Machine. embedded.com
72. Roland, James (August 1, 2016). *How Transistors Work* (https://books.google.com/books?id=g2qsDAAAQBAJ&printsec=frontcover&dq=how+do+transistors+work&hl=en&newbks=1&newbks_redir=0&sa=X&ved=2ahUKEwjpzPbJsejoAhUKhXIEHU8oDssQ6AEwAHoECAYQAg#v=onepage&q=how%20do%20transistors%20work&f=false). Lerner Publications ™. ISBN 978-1-5124-2146-0.
73. Pulfrey, David L. (January 28, 2010). *Understanding Modern Transistors and Diodes* (https://books.google.com/books?id=y9dYENs2SVUC&printsec=frontcover&dq=how+do+transistors+work&hl=en&newbks=1&newbks_redir=0&sa=X&ved=2ahUKEwjF86zfsejoAhWShHIEHTXKBlgQ6AEwBnoECAgQAg#v=onepage&q=how%20do%20transistors%20work&f=false). Cambridge University Press. ISBN 978-1-139-48467-1.
74. Kaplan, Daniel (2003). *Hands-On Electronics*. pp. 47–54, 60–61. Bibcode:2003hoe..book.....K (https://ui.adsabs.harvard.edu/abs/2003hoe..book.....K). doi:10.2277/0521815363 (https://doi.org/10.2277%2F0521815363). ISBN 978-0-511-07668-8.
75. van der Veen, M. (2005). "Universal system and output transformer for valve amplifiers" (http://www.mennovanderveen.nl/nl/download/download_3.pdf) (PDF). *118th AES Convention, Barcelona, Spain*. Archived (https://web.archive.org/web/20091229114846/http://www.mennovanderveen.nl/nl/download/download_3.pdf) (PDF) from the original on December 29, 2009.
76. "Transistor Example" (http://www.bcae1.com/transres.htm). Archived (https://web.archive.org/web/20080208150020/http://www.bcae1.com/transres.htm) from the original on February 8, 2008. 071003 bcae1.com
77. Gumyusenge, Aristide; Tran, Dung T.; Luo, Xuyi; Pitch, Gregory M.; Zhao, Yan; Jenkins, Kaelon A.; Dunn, Tim J.; Ayzner, Alexander L.; Savoie, Brett M.; Mei, Jianguo (December 7, 2018). "Semiconducting polymer blends that exhibit stable charge transport at high temperatures". *Science*. **362** (6419): 1131–1134. Bibcode:2018Sci...362.1131G (https://ui.adsabs.harvard.edu/abs/2018Sci...362.1131G). doi:10.1126/science.aau0759 (https://doi.org/10.1126%2Fscience.aau0759). ISSN 0036-8075 (https://www.worldcat.org/issn/0036-8075). PMID 30523104 (https://pubmed.ncbi.nlm.nih.gov/30523104).
78. Horowitz, Paul; Winfield Hill (1989). *The Art of Electronics* (2nd ed.). Cambridge University Press. p. 115 (https://archive.org/details/artofelectronics00horo/page/115). ISBN 978-0-521-37095-0.
79. Sansen, W. M. C. (2006). *Analog design essentials*. New York, Berlin: Springer. p. §0152, p. 28. ISBN 978-0-387-25746-4.
80. Streetman, Ben (1992). *Solid State Electronic Devices*. Englewood Cliffs, NJ: Prentice-Hall. pp. 301–305. ISBN 978-0-13-822023-5.
81. "MOSFET DIFFERENTIAL AMPLIFIER" (http://sites.bu.edu/engcourses/files/2016/08/mosfet-differential-amplifier.pdf) (PDF). *Boston University*. Retrieved August 10, 2019.
82. "IGBT Module 5SNA 2400E170100" (https://web.archive.org/web/20120426020121/http://library.abb.com/GLOBAL/SCOT/scot256.nsf/VerityDisplay/E700072B04381DD9C12571FF002D2CFE/$File/5SNA%202400E170100_5SYA1555-03Oct%2006.pdf) (PDF). Archived from the original (http://library.abb.com/GLOBAL/SCOT/scot256.nsf/VerityDisplay/E700072B04381DD9C12571FF002D2CFE/$File/5SNA%202400E170100_5SYA1555-03Oct%2006.pdf) (PDF) on April 26, 2012. Retrieved June 30, 2012.
83. Buonomo, S.; Ronsisvalle, C.; Scollo, R.; STMicroelectronics; Musumeci, S.; Pagano, R.; Raciti, A.; University of Catania Italy (October 16, 2003). IEEE (ed.). *A new monolithic emitter-switching bipolar transistor (ESBT) in high-voltage converter applications*. 38th IAS annual Meeting on Conference Record of the Industry Applications Conference. Vol. 3 of 3. Salt Lake City. pp. 1810–1817. doi:10.1109/IAS.2003.1257745 (https://doi.org/10.1109%2FIAS.2003.1257745).
84. STMicroelectronics. "ESBTs" (https://www.st.com/en/power-transistors/esbts.html?querycriteria=productId=SC1775). *www.st.com*. Retrieved February 17, 2019. "ST no longer offers these components, this web page is empty, and datasheets are obsoletes"
85. Zhong Yuan Chang, Willy M. C. Sansen, *Low-Noise Wide-Band Amplifiers in Bipolar and CMOS Technologies*, page 31, Springer, 1991 ISBN 0792390962.
86. "Single Electron Transistors" (https://web.archive.org/web/20120426015942/http://snow.stanford.edu/~shimbo/set.html). Snow.stanford.edu. Archived from the original (http://snow.stanford.edu/~shimbo/set.html) on April 26, 2012. Retrieved June 30, 2012.
87. Sanders, Robert (June 28, 2005). "Nanofluidic transistor, the basis of future chemical processors" (http://www.berkeley.edu/news/media/releases/2005/06/28_transistor.shtml). Berkeley.edu. Archived (https://web.archive.org/web/20120702182324/http://www.berkeley.edu/news/media/releases/2005/06/28_transistor.shtml) from the original on July 2, 2012. Retrieved June 30, 2012.
88. "The return of the vacuum tube?" (http://www.gizmag.com/nasa-vacuum-channel-transistor/22626/). Gizmag.com. May 28, 2012. Archived (https://web.archive.org/web/20160414122940/http://www.gizmag.com/nasa-vacuum-channel-transistor/22626/) from the original on April 14, 2016. Retrieved May 1, 2016.

89. "Transistor Data" (http://www.clivetec.0catch.com/Transistors.htm#JIS). Clivetec.0catch.com. Archived (https://web.archive.org/web/20160426190413/http://www.clivetec.0catch.com/Transistors.htm#JIS) from the original on April 26, 2016. Retrieved May 1, 2016.
90. "Datasheet for BC549, with A, B and C gain groupings" (http://www.fairchildsemi.com/ds/BC/BC549.pdf) (PDF). *Fairchild Semiconductor*. Archived (https://web.archive.org/web/20120407001013/http://www.fairchildsemi.com/ds/BC/BC549.pdf) (PDF) from the original on April 7, 2012. Retrieved June 30, 2012.
91. "Datasheet for BUK854-800A (800volt IGBT)" (http://www.datasheetcatalog.org/datasheet/philips/BUK854-800A.pdf) (PDF). Archived (https://web.archive.org/web/20120415132635/http://www.datasheetcatalog.org/datasheet/philips/BUK854-800A.pdf) (PDF) from the original on April 15, 2012. Retrieved June 30, 2012.
92. "Richard Freeman's HP Part numbers Crossreference" (http://www.hpmuseum.org/cgi-sys/cgiwrap/hpmuseum/archv010.cgi?read=27258). Hpmuseum.org. Archived (https://web.archive.org/web/20120605183505/http://www.hpmuseum.org/cgi-sys/cgiwrap/hpmuseum/archv010.cgi?read=27258) from the original on June 5, 2012. Retrieved June 30, 2012.
93. "Transistor–Diode Cross Reference – H.P. Part Numbers to JEDEC (pdf)" (http://www.sphere.bc.ca/test/hp-parts/300-hpxref.pdf) (PDF). Archived (https://web.archive.org/web/20160508135527/http://www.sphere.bc.ca/test/hp-parts/300-hpxref.pdf) (PDF) from the original on May 8, 2016. Retrieved May 1, 2016.
94. "CV Device Cross-reference by Andy Lake" (http://www.qsl.net/g8yoa/cv_table.html). Qsl.net. Archived (https://web.archive.org/web/20120121111531/http://www.qsl.net/g8yoa/cv_table.html) from the original on January 21, 2012. Retrieved June 30, 2012.
95. Sedra, A.S. & Smith, K.C. (2004). *Microelectronic circuits* (https://archive.org/details/microelectronicc00sedr_571) (Fifth ed.). New York: Oxford University Press. p. 397 (https://archive.org/details/microelectronicc00sedr_571/page/n426) and Figure 5.17. ISBN 978-0-19-514251-8.
96. Greig, William (April 24, 2007). *Integrated Circuit Packaging, Assembly and Interconnections* (https://books.google.com/?id=g29xoTAyAMgC&pg=PA63&dq=hybrid+integrated+circuit#v=onepage&q=hybrid%20&f=false). p. 63. ISBN 9780387339139. "A hybrid circuit is defined as an assembly containing both active semiconductor devices (packaged and unpackaged)"
97. Rojas, Jhonathan P.; Torres Sevilla, Galo A.; Hussain, Muhammad M. (2013). "Can We Build a Truly High Performance Computer Which is Flexible and Transparent?" (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3767948). *Scientific Reports*. **3**: 2609. Bibcode:2013NatSR...3E2609R (https://ui.adsabs.harvard.edu/abs/2013NatSR...3E2609R). doi:10.1038/srep02609 (https://doi.org/10.1038%2Fsrep02609). PMC 3767948 (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3767948). PMID 24018904 (https://pubmed.ncbi.nlm.nih.gov/24018904).
98. Zhang, Kan; Seo, Jung-Hun; Zhou, Weidong; Ma, Zhenqiang (2012). "Fast flexible electronics using transferrable [*sic*] silicon nanomembranes" (https://semanticscholar.org/paper/fa3acea94e990fc456c40b81f00bf8568619eb21). *Journal of Physics D: Applied Physics*. **45** (14): 143001. Bibcode:2012JPhD...45n3001Z (https://ui.adsabs.harvard.edu/abs/2012JPhD...45n3001Z). doi:10.1088/0022-3727/45/14/143001 (https://doi.org/10.1088%2F0022-3727%2F45%2F14%2F143001).
99. Sun, Dong-Ming; Timmermans, Marina Y.; Tian, Ying; Nasibulin, Albert G.; Kauppinen, Esko I.; Kishimoto, Shigeru; Mizutani, Takashi; Ohno, Yutaka (2011). "Flexible high-performance carbon nanotube integrated circuits" (https://semanticscholar.org/paper/85ac1c54477bc6bdee2fca496470c662051657dd). *Nature Nanotechnology*. **6** (3): 156–61. Bibcode:2011NatNa...6..156S (https://ui.adsabs.harvard.edu/abs/2011NatNa...6..156S). doi:10.1038/NNANO.2011.1 (https://doi.org/10.1038%2FNNANO.2011.1). PMID 21297625 (https://pubmed.ncbi.nlm.nih.gov/21297625).

Further reading

Books

- Horowitz, Paul & Hill, Winfield (2015). *The Art of Electronics* (3 ed.). Cambridge University Press. ISBN 978-0521809269.
- Amos SW, James MR (1999). *Principles of Transistor Circuits*. Butterworth-Heinemann. ISBN 978-0-7506-4427-3.
- Riordan, Michael & Hoddeson, Lillian (1998). *Crystal Fire*. W.W Norton & Company Limited. ISBN 978-0-393-31851-7. The invention of the transistor & the birth of the information age
- Warnes, Lionel (1998). *Analogue and Digital Electronics*. Macmillan Press Ltd. ISBN 978-0-333-65820-8.
- *The Power Transistor - Temperature and Heat Transfer*; 1st Ed; John McWane, Dana Roberts, Malcom Smith; McGraw-Hill; 82 pages; 1975; ISBN 978-0-07-001729-0. (archive) (https://archive.org/details/ThePowerTransistor/)
- *Transistor Circuit Analysis - Theory and Solutions to 235 Problems*; 2nd Ed; Alfred Gronner; Simon and Schuster; 244 pages; 1970. (archive) (https://archive.org/details/TransistorCircuitAnalysis/)
- *Transistor Physics and Circuits*; R.L. Riddle and M.P. Ristenbatt; Prentice-Hall; 1957.

Periodicals

- Michael Riordan (2005). "How Europe Missed the Transistor" (https://web.archive.org/web/20080214002109/http://www.spectrum.ieee.org/print/2155). *IEEE Spectrum*. **42** (11): 52–57. doi:10.1109/MSPEC.2005.1526906 (https://doi.org/10.1109%2FMSPEC.2005.1526906). Archived from the original (https://spectrum.ieee.org/print/2155) on February 14, 2008.
- "Herbert F. Mataré, An Inventor of the Transistor has his moment" (https://web.archive.org/web/20090623050755/http://www.mindfully.org/Technology/2003/Transistor-Matare-Inventor24feb03.htm). *The New York Times*. February 24, 2003. Archived from the original (http://www.mindfully.org/Technology/2003/Transistor-Matare-Inventor24feb03.htm) on June 23, 2009.
- Bacon, W. Stevenson (1968). "The Transistor's 20th Anniversary: How Germanium And A Bit of Wire Changed The World" (https://books.google.com/?id=mykDAAAAMBAJ&printsec=frontcover). *Bonnier Corp.: Popular Science, Retrieved from Google Books 2009-03-22*. **192** (6): 80–84. ISSN 0161-7370 (https://www.worldcat.org/issn/0161-7370).

Databooks

- Discrete Databook (https://archive.org/details/bitsavers_fairchilddldDiscreteDataBook_35122751); 1985; Fairchild (now ON Semiconductor)

- Small-Signal Transistor Databook (https://archive.org/details/MotorolaSmallSignalTransistorDataBook1984); 1984; Motorola (now ON Semiconductor)
- Discrete Databook (https://archive.org/details/bitsavers_sgsdataBooDevices5ed_46325378); 1982; SGS (now STMicroelectronics)
- Discrete Databook (https://archive.org/details/NationalSemiconductorDiscreteDatabook1978); 1978; National Semiconductor (now Texas Instruments)

External links

- BBC: Building the digital age (http://news.bbc.co.uk/2/hi/technology/7091190.stm) photo history of transistors
- The Bell Systems Memorial on Transistors (https://web.archive.org/web/20070928041118/http://www.porticus.org/bell/belllabs_transistor.html)
- *IEEE Global History Network, The Transistor and Portable Electronics* (http://www.ieeeghn.org/wiki/index.php/The_Transistor_and_Portable_Electronics). All about the history of transistors and integrated circuits.
- *Transistorized* (https://www.pbs.org/transistor/)*. Historical and technical information from the Public Broadcasting Service*
- *This Month in Physics History: November 17 to December 23, 1947: Invention of the First Transistor* (http://www.aps.org/publications/apsnews/200011/history.cfm). From the American Physical Society
- *50 Years of the Transistor* (https://web.archive.org/web/20070714010051/http://www.sciencefriday.com/pages/1997/Dec/hour1_121297.html). From Science Friday, December 12, 1997

Pinouts

- Common transistor pinouts (https://web.archive.org/web/20141030170632/http://hamradio.lakki.iki.fi/new/Datasheets/transistor_pinouts/)