Howard W. Sams PUBLICATION 21099

Solid-State Components

by Rufus P. Turner

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HOWARD W. SAMS & CO., INC.
THE BOBBS-MERRILL CO., INC.
INDIANAPOLIS • KANSAS CITY • NEW YORK

FIRST EDITION

FIRST PRINTING—1974

International Standard Book Number: 0-672-21099-1
Library of Congress Catalog Card Number: 74-78357

Preface

Modern electronics is comprised largely of solid-state electronics. Although the solid-state branch of electronics originally played a minor role, it has grown to eclipse most of the other branches. As a result, solid-state components have appeared regularly and have grown in number. It is now time to devote a brief encyclopedia exclusively to these components.

This book offers brief explanatory descriptions of solid-state components. It includes not only semiconductor devices, but also a selection of other components—such as the ferroelectric cell, memory core, and piezoelectric crystal—which utilize the phenomena of polarization, magnetization, potential generation, and similar effects in solids other than semiconductors.

Although the author's objective has been conciseness, clarity has not knowingly been sacrificed anywhere for brevity. There are abundant cross references. The drawings serve in most instances as illustrations of structure and function, and do not always reproduce the exact geometries found in the equivalent manufactured devices.

We hope that this book will become a handy source of ready information on solid-state devices—how they look and how they work.

RUFUS P. TURNER

A

AF TRANSISTOR

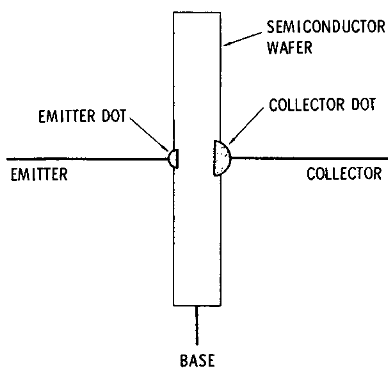
A small-signal transistor or power transistor that, because of its design and fabrication, is limited to operation at audio frequencies. A great many conventional small-signal and power transistors fall into this category. Examples: Type 2N107 (small-signal) and Type 2N3142 (25 watts). *Compare* RF Transistor. *See also* Transistor.

ALLOY DIODE

A junction diode in which the pn junction is created by alloying a suitable material part of the way into a semiconductor wafer. Thus, a p-type element, such as indium, may be alloyed a short distance into a wafer of n-type germanium. *See also* Diode *and* Junction Diode.

ALLOY-JUNCTION TRANSISTOR

A junction transistor made by alloying a small amount of p-type material into opposite faces of an n-type semiconductor wafer or by alloying n-type material into opposite faces of a p-type wafer. The alloyed regions become the



Alloy-junction transistor.

emitter and collector elements, the collector usually being the larger. An example is the pnp transistor made by alloying a small dot of indium into each face of a germanium wafer. Example: Type 2N407. *See also* Transistor.

ARC-SUPPRESSOR DIODE

See **Suppressor Diode.**

ATOMIC BATTERY

See **Solid-State Battery.**

AVALANCHE DIODE

A breakdown diode exhibiting reverse breakdown at a voltage higher than −5 volts. A breakdown diode having a breakdown voltage lower than −5 volts is properly termed a *zener diode;* however, a growing custom seems to favor the name "zener" for all breakdown diodes, including avalanche diodes. *See also* Diode, Breakdown Diode, *and* Zener Diode.

B

BACKWARD DIODE

A semiconductor component which, in structure and electrical behavior, is somewhat similar to the *tunnel diode* (which see). Unlike the conventional diode, the backward diode conducts heavily in the reverse direction and "blocks" in the forward direction. Example: Type 4JF2A-1. *See also* Diode.

BIPOLAR TRANSISTOR

A transistor in which the input signal injects minority current carriers into the transistor structure, these control-

ling the flow of majority carriers in the output circuit. This is the so-called "conventional" transistor; i.e., one having emitter, base, and collector electrodes. For further details, see the description of the bipolar transistor under Transistor. *Compare* Field-Effect Transistor.

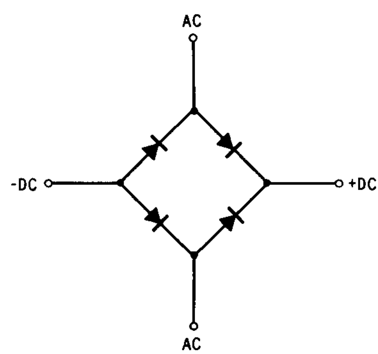
BREAKDOWN DIODE

A specially processed silicon diode whose reverse-conduction characteristic exhibits a sharp, nondestructive breakdown at a specified reverse voltage. At this breakdown-voltage point, a small change in voltage produces a large change in current, or, conversely, a large change in diode current produces a small (almost imperceptible) change in diode voltage drop. When the breakdown voltage (BV) is lower than −5 volts, the diode is called a *zener diode;* when the breakdown voltage is higher than −5 volts, the diode is called an *avalanche diode. See also* Diode *and* Zener Diode.

BRIDGE

A semiconductor rectifier assembly consisting of four diodes internally connected into a conventional bridge circuit. The advantage of the bridge circuit is full-wave operation without a center-tapped transformer winding. Disadvantages are the number of diodes required and the lack

Bridge.

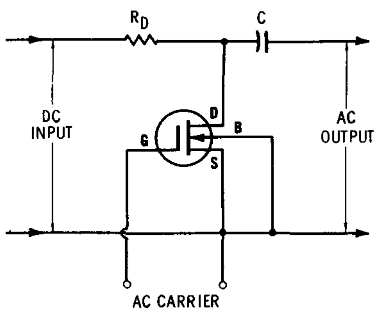


of a common ground between input and output. *Compare* Half Bridge *and* Ring Modulator. *See also* Rectifier *and* Meter Rectifier.

C

CHOPPER TRANSISTOR

A small-signal transistor intended primarily for use in the on-off operation in electronic chopper circuits, or which is supplementarily useful in choppers. Such transistors are usually characterized by low I_c and h_{fe} ratings; they usually operate at low or medium speed. Examples: Type 2N2004 (bipolar), Type 2N4856A (field-effect), Type 3N140 (MOSFET). *See also* Transistor.



Chopper transistor (MOSFET in typical circuit.)

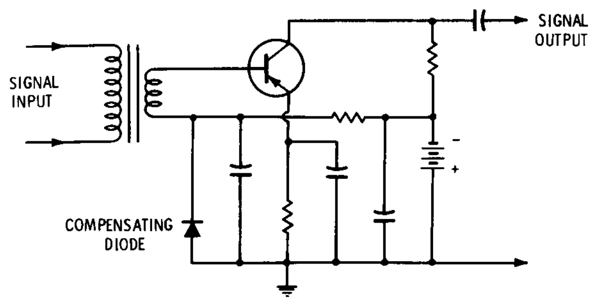
CMOS

See **Complementary Metal Oxide Semiconductor.**

COMPENSATING DIODE

A forward-biased junction diode employed to stabilize transistor currents against changes in temperature. The diode constitutes the lower leg of a voltage divider supplying dc bias to the base of the transistor. Because the diode is made of the same semiconductor used in the transistor, it

undergoes a change in resistance in the same direction and of approximately the same magnitude as the change in the internal resistance of the transistor. The base bias voltage



Compensating diode.

developed across the diode decreases with increasing temperature and thus reduces the transistor collector current, which increases with temperature. Example: Type 1N2326. *See also* Diode *and* Junction Diode.

COMPLEMENTARY METAL OXIDE SEMICONDUCTOR

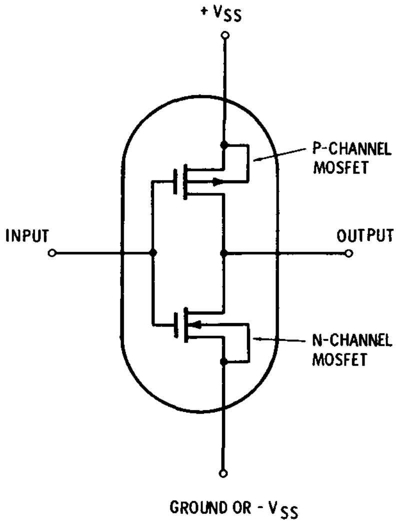
Abbreviation, *CMOS*. An integrated circuit containing two metal-oxide-semiconductor field-effect transistors (MOSFETs), one n-channel and the other p-channel, in a complementary-symmetry circuit. *See also* Integrated Circuit, Metal-Oxide-Semiconductor Field-Effect Transistor, *and* Transistor.

CONTACT PROTECTOR

See **Suppressor Diode.**

COPPER-OXIDE DIODE

A semiconductor diode in which the rectifying junction occurs between mating copper and cuprous-oxide surfaces. The oxide is in the form of a film processed onto the surface



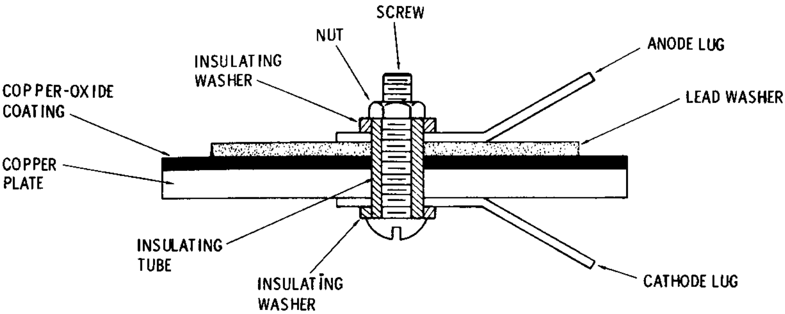
Complementary metal-oxide-semiconductor device.

of a copper disc or plate. The copper is the anode, and the oxide is the cathode.

Miniature copper-oxide diodes are widely used as meter rectifiers; larger-sized units (copper-oxide rectifiers) were once used extensively in low- and medium-power ac-to-dc power conversion, but they have been largely supplanted in this application by selenium, germanium, and silicon rectifiers. Copper-oxide diodes have also been employed, usually in bridge or ring circuits, as modulators and demodulators in sideband telephony, and as relay rectifiers. *See also* Diode *and* Junction Diode.

COPPER-OXIDE RECTIFIER

A semiconductor device utilizing the rectifying interface between copper and copper oxide. In manufacture, an oxide layer is grown on the surface of a copper disc or plate; the copper becomes the cathode and the oxide the anode. Contact is made to the oxide surface with a soft lead washer and tinned lug, and to the copper surface with a similar lug. The entire assembly is held together tightly with a screw



Copper-oxide rectifier.

that passes through a central hole in the plate and is insulated from the latter by a fiber or plastic tube. The completed unit is termed a rectifier *plate* or *cell.* Copper-oxide rectifiers fall into two categories, the power type and the low-level type.

Power Type

The copper-oxide rectifier has a long history of use in the conversion of ac power to dc power; it preceded the widespread adoption of the selenium rectifier by almost a generation. This device exhibits low forward voltage drop, but it is temperature sensitive (85°C is a typical maximum operating temperature). Its greatest limitation, however, is its low voltage rating (approximately 5 volts per plate), which requires the series connection of a large number of plates to handle useful amounts of ac voltage. However, in certain low-voltage devices, such as battery chargers and early electrodynamic loudspeakers, the copper-oxide rectifier remained unchallenged for some time until the acceptance of the selenium rectifier, and later the germanium and silicon types, all of which have supplanted the copper-oxide unit as a rectifier of useful power.

Low-Level Type

Miniature copper-oxide rectifiers (single plates or two-plate assemblies and bridge stacks) having a dc output of only a few milliamperes are still used in such applications as

meter rectification, af signal modulation and demodulation, and relay rectification. But even in these uses, small germanium and silicon diodes have superseded the copper-oxide type in many places. In the past, the miniature copper-oxide rectifier was low priced. The great disadvantage of this type has always been poor frequency response: A rectifier-type meter employing an uncompensated copper-oxide rectifier often shows error as low as 5000 Hz and is useless at radio frequencies, whereas a point-contact germanium diode in the same application may be operated at frequencies up to several megahertz.

See also Rectifier *and* Meter Rectifier.

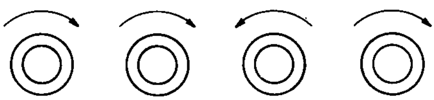
CORE MEMORY

A computer memory or calculator memory in which *ferrite cores* (which see) store the information bits. Magnetization in one direction around the ring-shaped core signifies the one state; magnetization in the opposite direction signifies the zero state (this action is illustrated in part A of the accompanying illustration). The core is magnetized by a short-duration pulse of current in the required direction through a coil wound on the core or through a wire passing through the hole of the core. The core then remains magnetized in that direction until the stored bit is later erased.

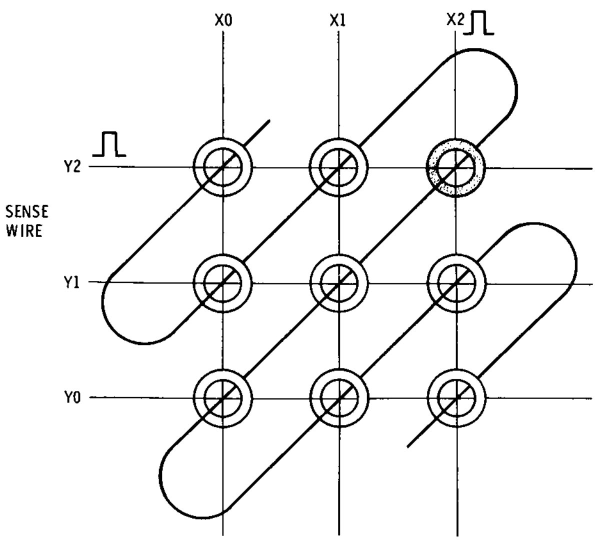
In a *memory plane* or *memory plate,* the cores are placed at the intersections of horizontal (Y) and vertical (X) wires in a matrix, as shown in part B of the accompanying illustration. These wires pass through the holes of the cores. Pulses applied to the horizontal and vertical wires perform the read-in and read-out of the memory. In part B, for example, a pulse is applied to horizontal wire Y2 at the same time that a similar pulse is applied to vertical wire X2. Each of these pulses produces half the critical value of current required to shift the magnetization of a core. A single pulse alone cannot shift the magnetization of a core, but the two together can write the information bit into the core, as indicated by the shaded core at the intersection of X2 and Y2.

For reading information out of the memory, a single lead (the *sense wire*) is threaded through all of the cores, as shown in part B. As in writing, pulses are applied to the X and Y wires for reading, but the currents are in the direction opposite that for writing. If a core at a selected intersection is storing a one, the read pulse will switch it to zero, and this shift will induce an output voltage in the sense wire. If the core is storing a zero, however, no voltage is induced in the sense wire.

The core memory may contain hundreds or thousands of cores in one or many planes. It is a nonvolatile, random-access memory with short access time, and—unlike tape, drum, and disc memories—it has no moving parts. Moreover, it is compact. While for illustration only nine cores are



(A) Cores storing bits 1101.



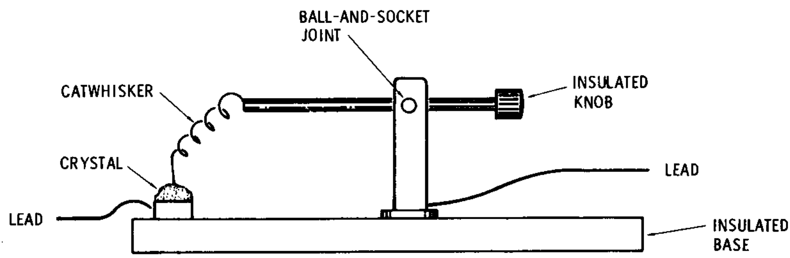
(B) Memory array.

Core memory.

shown in part B of the illustration (a three-by-three plane), practical core memories contain large numbers of cores; thus, a 32-by-32 plane contains 1024 cores.

CRYSTAL DETECTOR

The progenitor of the modern semiconductor diode, this point-contact device was introduced at the turn of the twentieth century and served as the most sensitive radio detector then known until the commercialization of the vacuum tube. (As late as 1926, the crystal detector was still used in some radio receivers, both homemade and factory-built.) Today, the crystal detector in its original form is available from some equipment manufacturers, but it is used chiefly in toy radios.



Crystal detector.

Essentially, the crystal detector consists of a mounted lump of some natural or artificial crystalline material—such as galena, silicon, or iron pyrites—whose surface is touched by the point of a springy wire (the "catwhisker"). When a good spot is found by moving the point around to different parts of the surface of the crystal, the device becomes a good low-voltage rectifier and accordingly a detector of radio signals. This detector needs frequent readjustment, however, since the lifetime of a sensitive spot is rather short. Furthermore, the spots are easily destroyed by strong signals, dust, and corrosion. These defects were overcome with the development of the modern point-contact diode—primarily for radar use—around the time of World War II.

CRYSTAL DIODE

An early name for the semiconductor diode, succeeding the term *crystal rectifier.* At some indeterminate point in the 1960s, the term "crystal diode" was replaced by more specific ones, such as *germanium diode* and *silicon diode.*

CRYSTAL MIXER

A term used occasionally for the semiconductor-diode mixer (frequency converter) stage in a radar receiver, radio receiver, or spectrum analyzer.

CRYSTAL RECTIFIER

The early proper name of the semiconductor diode. By the early 1950s, this term was being superseded by *crystal diode* (which see). Prior to circa 1940, the term "crystal rectifier" was used to denote a crystal detector (which see) employed as a meter rectifier.

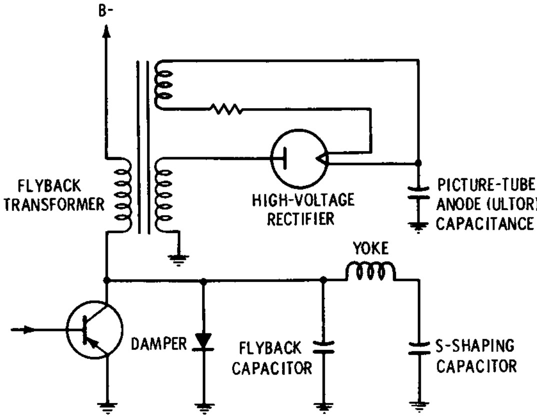
CRYSTAL TRIODE

The early proper name of the transistor. For a short time after 1948, some authors and manufacturers seemed to favor the generic term "crystal triode" for the then new device and to allow "transistor" to designate the Western Electric Co. product exclusively. After circa 1952, however, usage had given "transistor" the edge.

D

DAMPER DIODE

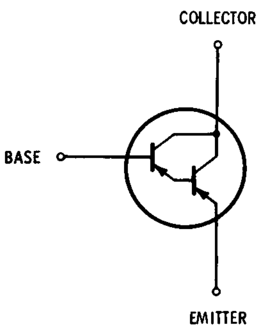
A semiconductor diode employed as the damper in the horizontal-deflection section of a television circuit. Typical maximum peak reverse voltage of such a device is 320 volts. Example: Type 1N4785 (germanium diffused-junction type). *See also* Diode *and* Junction Diode.



Damper diode.

DARLINGTON

A semiconductor device consisting of two transistors direct-coupled in a single envelope. This arrangement provides high current amplification, the complete device be-



Darlington.

having as a single transistor with extremely high beta. Also called *Darlington pair* and *Darlington amplifier*. Example: Type 2N999 ($h_{FE} = 70{,}000$ maximum at $I_c = 100$ mA).

DAT

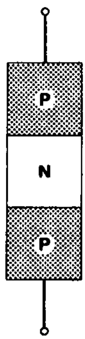
See **Diffused Alloy Transistor.**

DEMODULATOR PROBE

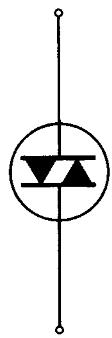
See under **Diode Probe.**

DIAC

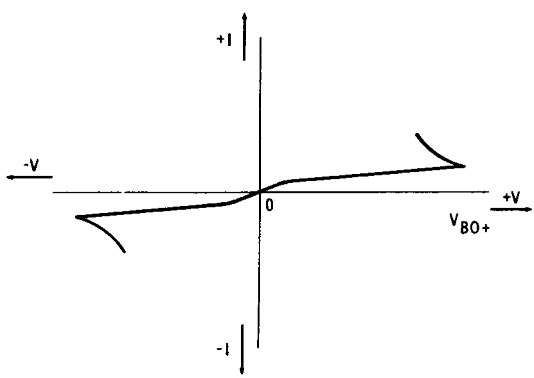
A two-terminal, three-layer, bidirectional, silicon, switching device. This device may be operated on either ac or dc, conducting heavily (the on state) after the applied positive or negative voltage reaches a certain critical value (V_{BO+} or V_{BO-}). Until the voltage reaches this value, only a tiny leakage current flows through the diac (the off state). The



(A) Structure.



(B) Symbol.



(C) Typical performance.

Diac.

response of the device is shown in part C of the accompanying illustration. The switching on is an avalanche breakdown action.

Diacs are employed in comparatively simple circuits to switch power, dim lights, control heaters, and control the speed of universal motors. Example: Type 1N5411.

DIFFUSED ALLOY TRANSISTOR

Abbreviation, *DAT*. An alloy transistor in which a graded base has been produced by diffusion. Also called *drift-field transistor* (which see). Example: 2N1179. *See also* Transistor.

DIFFUSED DIODE

A junction diode in which the pn junction is created by diffusing a gaseous dopant part of the way into the semiconductor wafer. A p-type (acceptor) material is diffused into an n-type wafer; an n-type (donor) material is diffused into a p-type wafer. *See also* Diode *and* Junction Diode.

DIFFUSED TRANSISTOR

A transistor in which one or more of the n or p regions have been created by diffusing a suitable material (usually in gaseous form) into the semiconductor wafer. Because diffusion is a slow process, it affords close control of transistor geometry and electrical characteristics, and at the time of this writing it is the preferred method of manufacturing transistors. For more detail, see Single-Diffused Transistor, Double-Diffused Transistor, and Triple-Diffused Transistor. *See also* Transistor.

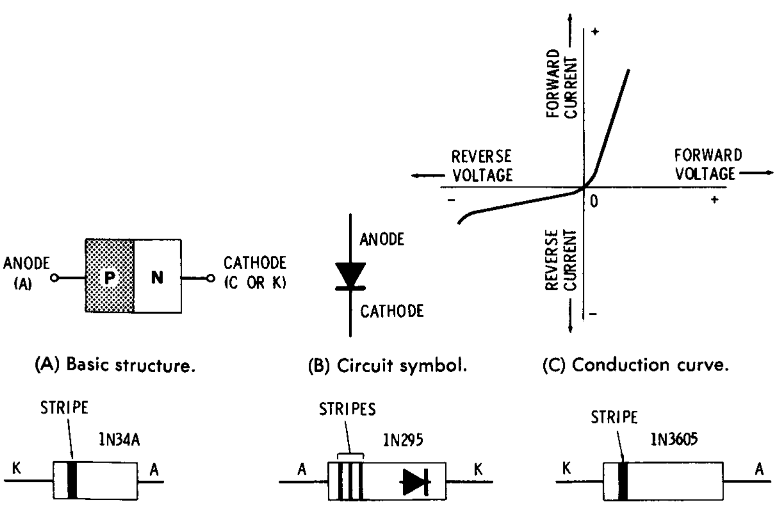
DIGITAL IC

An integrated circuit designed for the on-off type of operation common to trigger and switching systems. Integrated circuits of this type contain such circuits as adders,

decoders, flip-flops, gates, inverters, and shift registers, and they are used extensively in computers and calculators. Like linear ICs, digital ICs can readily be adapted to numerous applications other than those for which they were intended. Examples: Type MC54L42 (BCD-to-decimal decoder), Type MC5470 (single edge-triggered JK flip-flop). *Compare* Linear IC. *See also* Integrated Circuit.

DIODE

A semiconductor device (usually with two elements and two terminals) containing a pn junction and exhibiting asymmetrical conduction. The p region is the anode, and the n region is the cathode of the diode. The diode conducts with very little resistance when a positive voltage (*forward voltage*) is applied to its anode, but it offers very high resistance when a negative voltage (*reverse voltage*) is applied to the anode. Consequently, a relatively high current (*forward current*) flows in response to the positive bias, and a small (sometimes infinitesimal) current (*reverse current*) flows



(A) Basic structure. (B) Circuit symbol. (C) Conduction curve.

(D) Typical packages.

Diode.

in response to the negative bias. This asymmetrical conductivity suits the diode to ac rectification, electronic switching, signal detection, modulation, demodulation, and kindred applications. Diodes are made from all semiconductors, common examples being germanium, silicon, gallium arsenide, selenium, and copper oxide.

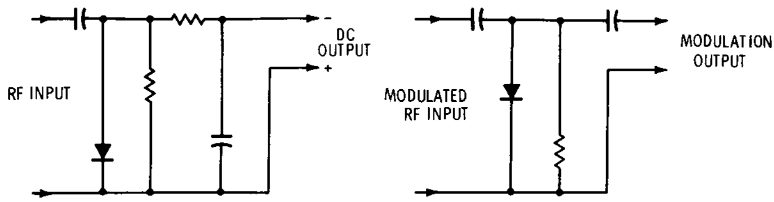
Diodes are classified according to their semiconductor base (germanium, silicon, etc.), structure (junction, point-contact, planar, etc.), power capability (small-signal, medium-power, high-power, etc.), circuit function (signal diode, clamping diode, switching diode, etc.), voltage or current rating (high-forward-current type, high-reverse-voltage type, etc.), response characteristics (high-speed, short storage time, etc.), and other such categories. They are made in a variety of shapes and sizes.

In the family of diodes, the *four-layer diode* (which see) is a notable exception, for this diode contains three pn junctions and is actually a thyristor. It was given the name diode because it is a two-terminal device.

See also Alloy Diode, Avalanche Diode, Backward Diode, Breakdown Diode, Compensating Diode, Copper-Oxide Diode, Damper Diode, Diffused Diode, Double-Base Diode, Esaki Diode, Four-Layer Diode, Gallium-Arsenide Diode, Germanium Diode, Gold-Bonded Diode, Grown Diode, Hot-Carrier Diode, Junction Diode, Laser Diode, Light-Emitting Diode, Photodiode, PIN Diode, Planar Diode, Planar Passivated Diode, Point-Contact Diode, Reference Diode, Selenium Diode, Silicon Diode, Snap Diode, Stabistor, Switching Diode, Trigger Diode, Tunnel Diode, *and* Voltage-Variable-Capacitor Diode.

DIODE PROBE

An instrument probe containing a diode (usually a point-contact diode). There are two general types, the *rectifier type* and the *demodulator type.* The rectifier type, also called the *rf type,* rectifies an ac voltage (usually at radio frequency) to deflect a dc electronic voltmeter, the deflection being proportional to the peak value of the ac. The demodu-



(A) Rf type. (B) Demodulator type.

Diode probe.

lator type demodulates a signal, such as a television wave, and delivers the modulation envelope for viewing on an oscilloscope screen. Both types of diode probe are supplied by meter manufacturers and accessories manufacturers.

DOUBLE-BASE DIODE

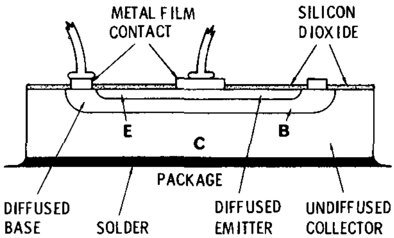
A name sometimes applied to the *unijunction transistor* (which see). This term, which was the early official name of the unijunction device, arose from the fact that the device contains only one pn junction, like the conventional diode, but is provided with two bases.

DOUBLE-DIFFUSED TRANSISTOR

A *diffused transistor* (which see) in which two separate diffusions are performed, both from the top face of the semiconductor wafer. The first diffusion creates the base in the wafer; the next diffusion, on top of the first one, creates the emitter. The bottom region of the wafer then becomes the undiffused collector. Example: Type 2N5179. *Compare* Single-Diffused Transistor *and* Triple-Diffused Transistor. *See also* Diffused Transistor.

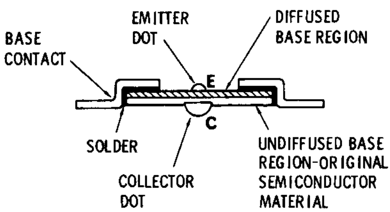
DRIFT-FIELD TRANSISTOR

An alloy-type, bipolar, junction transistor that utilizes an internal drift field to achieve radio-frequency operation. This field is obtained by grading the concentration of an impurity in the semiconductor wafer (base element of the



Double-diffused transistor.

transistor) in such a way that the concentration is high on the emitter side of the wafer and gradually becomes lower across the thickness of the wafer to the collector side. The high-frequency operation of the transistor results from acceleration of current carriers by the drift field. Example: Type 2N370. *See also* Alloy-Junction Transistor.



Drift-field transistor.

DUO

Two matched components, usually diodes or transistors, housed in a single case.

E

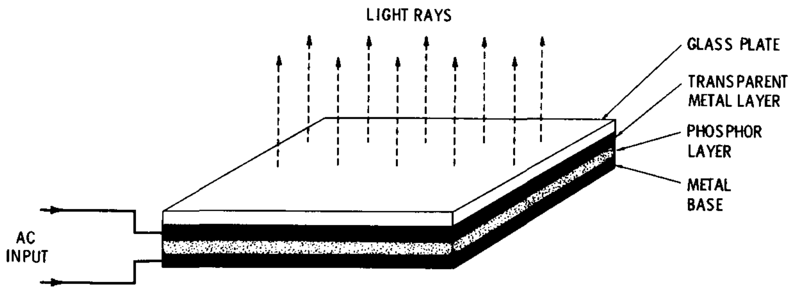
ELECTRET

A plate or disc of wax, ceramic, or plastic that in processing has been heated (or melted) and allowed to cool slowly in a high-voltage electrostatic field. This technique causes the body to become permanently polarized, a voltage being available between its faces. In this respect, the electret is the counterpart of the permanent magnet.

A great many uses have been suggested for the electret. One present commercial application is the electret microphone.

ELECTROLUMINESCENT CELL

A light source utilizing the principle of electroluminescence, the ability of certain materials to glow when a voltage is applied to them. In a typical cell (see accompanying illustration), a sensitive phosphor is coated on a metal backplate, or base, which serves as one electrode. A thin, transparent layer of metal is evaporated on top of the phosphor layer to serve as the other electrode. Finally, a protective glass plate covers this transparent metal layer.



Electroluminescent cell.

An ac voltage (115 to several thousand volts, depending on the size of the cell, type of phosphor, and desired illumination) causes the phosphor layer to glow, the light rays passing through the transparent metal layer and the glass cover. The cell will not glow continuously when the voltage is dc; only a single flash occurs when the dc voltage is applied.

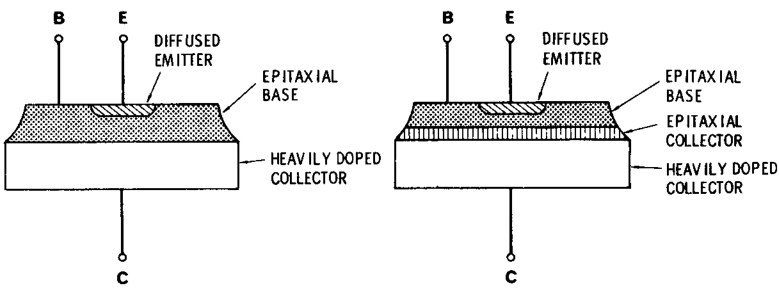
Electroluminescent elements of this type have been used in night lights, some space lighters, and optical couplers. Some thought has been given to their potentialities as flat television picture tubes.

ELECTROSTRICTIVE CERAMIC

A ceramic compound, such as barium titanate, specially processed to exhibit electrostriction, the tendency of certain materials to shrink under the influence of an electric field. Discs or strips of the material are metal plated, and an operating voltage is applied between the metal surfaces to obtain twisting or shrinking of the body. The resulting movement is used to close a pair of contacts (electrostrictive relay), interrupt a circuit intermittently (electrostrictive chopper), transform a voltage into a pressure (electrostrictive voltage-to-pressure transducer), and perform kindred functions. An ac voltage will cause the body to vibrate, and this action suggests possible applications in loudspeakers, hydrophones, and ultrasonic transducers. Electrostriction may be regarded as the electric counterpart of magnetostriction.

EPITAXIAL TRANSISTOR

A transistor in which one or more elements are grown by the epitaxial process (that is, atom by atom on top of the semiconductor wafer at high temperature). Thus, in the *epitaxial-base-type* transistor, an epitaxial base is grown on the wafer (the collector), and then the emitter is diffused into this base. In the *dual-epitaxial-layer* transistor, first an epitaxial collector is grown on the wafer (the heavily doped



(A) Epitaxial-base type. (B) Dual-epitaxial-layer type.

Epitaxial transistor.

collector), and then an epitaxial base is grown on the first epitaxial layer. Finally, an emitter is diffused into the epitaxial base. Since epitaxial growth is atomic, it extends almost perfectly the crystal lattice of the semiconductor material on which the growth occurs. Examples: Type 2N3241A, Type 2N5183 (double-diffused epitaxial type). *See also* Transistor *and* Diffused Transistor.

ESAKI DIODE

Another name for *tunnel diode* (which see). This name honors Dr. Leo Esaki, inventor of the tunnel diode.

F

FERRITE CORE

A small ring made from a suitable sintered and compressed mixture of iron oxide and other metallic oxides (such as those of cobalt, nickel, manganese, and magnesium) and valued for its high retentivity and high resistivity. Such a core is easily magnetized and will retain its magnetization indefinitely; moreover, its high resistivity ensures low eddy-current losses. The ferrite core exhibits a rectangular hysteresis loop. The ring-type ferrite core is of particular importance in computer memories and miniature toroidal coils and transformers. Other shapes are available for antenna rods, transformer cores, and so on.

Small ferrite cores make possible large-scale, low-volume, static magnetic memories for computers and calculators. They are useful also in experimental magnetic amplifiers and control systems. *See also* Core Memory.

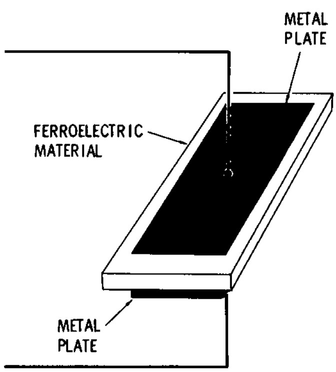
FERRITE ISOLATOR

An isolator—that is, a device having higher loss in one direction than in another—made of ferrite (some mixture of the oxides of iron and other metals) and inserted into a

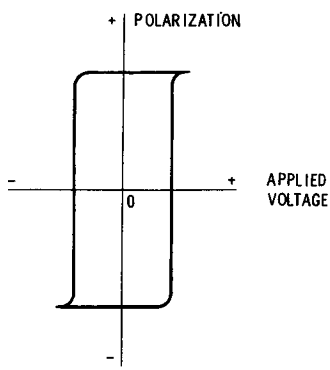
short section of waveguide. Microwave energy passes readily through the isolator in one direction, but is largely absorbed when attempting to pass in the opposite direction. In one version, the isolator section is inserted between two waveguides rotated 45° with respect to each other. The isolator then rotates a signal in the "forward" direction 45° for transmission through the output waveguide, but rotates a "backward" signal 45° the other way to exclude it from the output waveguide.

FERROELECTRIC CELL

A plate or disc of crystalline material—such as barium titanate, guanidine aluminum sulfate hexahydrate, or triglycene sulfate—with its parallel faces metallized or otherwise provided with contact plates. The cell becomes polarized electrically when a voltage is applied to its faces, and



(A) Structure.



(B) Idealized response.

Ferroelectric cell.

this polarization is retained until suitably switched in direction. The cell exhibits a rectangular hysteresis loop and accordingly is analogous to a *ferrite core* (which see).

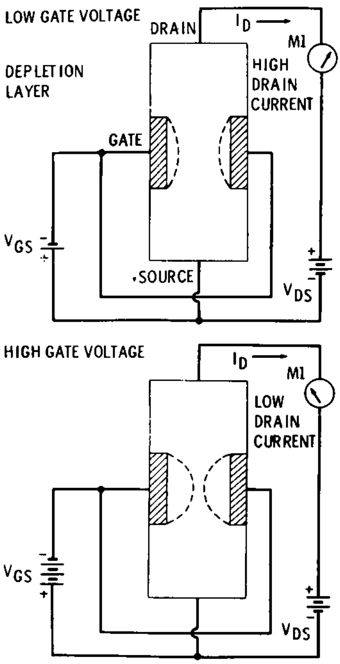
The response of the cell (see part B of the accompanying illustration) suggests use of this device in electrostatic memories, flip-flops, multivibrators, switches, and similar applications.

FET

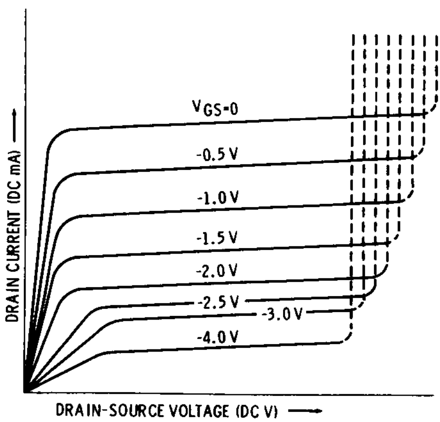
See Field-Effect Transistor.

FIELD-EFFECT TRANSISTOR

Abbreviation, *FET*. A transistor in which the input signal produces an electric field inside the transistor structure, this field controlling the flow of current carriers in the output circuit of the device. For further details, see the description of the field-effect transistor under Transistor.



(A) Structure and action.

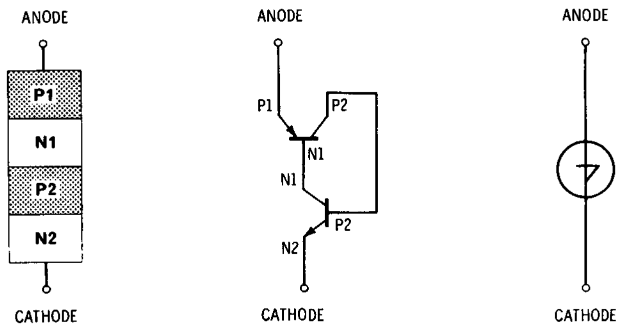


(B) Performance.

Field-effect transistor.

FOUR-LAYER DIODE

A two-terminal, active, semiconductor device; this device is not a true diode, but instead a two-terminal thyristor. It consists of four layers—arranged p, n, p, and n—alternately processed in a silicon bar or chip. This arrangement results in the equivalent of a pnp transistor direct coupled to an npn transistor. The end p layer is simultaneously the anode of the device and the emitter of the equivalent pnp transistor, and the end n layer is simultaneously the cathode of the device and the emitter of the equivalent npn transistor.



(A) Structure. (B) Equivalent circuit. (C) Symbol.

Four-layer diode.

When a forward voltage is applied to the four-layer diode, the device conducts (switches on) only when the voltage reaches a certain critical value. Current is then initiated and continues to flow even if the voltage is reduced. Current stops (the device switches off) only when the voltage is interrupted or reversed in polarity. This action suits the four-layer diode for use in switching circuits, control circuits, relaxation oscillators, pulse generators, and inverters. Example: Type 1N3304. *See also* Diode *and* Junction Diode.

G

GaAs DIODE

See **Gallium-Arsenide Diode.**

GALLIUM-ARSENIDE DIODE

A diode employing processed gallium arsenide (GaAs) as the semiconductor material. *See also* Diode.

Ge DIODE

See **Germanium Diode.**

GENERAL-PURPOSE TRANSISTOR

A small-signal bipolar transistor whose electrical characteristics suit it for a range of applications—such as amplification and oscillation at audio and low or medium radio frequencies—that usually call for special transistors. General-purpose transistors are usually inexpensive and appeal especially to hobbyists, experimenters, and others who cannot stock a large supply of special-purpose types. Example: Type 2N170. *See also* Transistor.

GERMANIUM DIODE

A diode employing processed germanium as the semiconductor material. The germanium type was the second of the modern semiconductor diodes, the first being the silicon diode; it was the first to permit high reverse voltage. Germanium diodes are manufactured in both the junction type and point-contact type. The junction type exhibits a poorer front-to-back resistance ratio than the equivalent silicon diode does, a poorer temperature coefficient, and a lower value of maximum permissible reverse voltage. *Compare* Silicon Diode. *See also* Diode, Junction Diode, *and* Point-Contact Diode.

GERMANIUM JUNCTION DIODE

A semiconductor diode employing the rectifying barrier between an n layer and a p layer in a single germanium wafer. This type is employed chiefly as a power rectifier. Example: Type 1N91. *Compare* Germanium Point-Contact Diode. *See also* Diode *and* Germanium Diode.

GERMANIUM POINT-CONTACT DIODE

A semiconductor diode employing the rectifying contact between a metal (usually tungsten) catwhisker and a wafer of specially processed germanium. Example: Type 1N34A. *Compare* Germanium Junction Diode. *See also* Diode, Germanium Diode, Gold-Bonded Diode, *and* Point-Contact Diode.

GERMANIUM RECTIFIER

A power rectifier utilizing a pn junction in germanium. This device is essentially a heavy-duty junction diode. The germanium rectifier exhibits lower forward voltage drop than the selenium rectifier does, but it suffers from significant temperature sensitivity, which limits its use in some applications unless it is air cooled or liquid cooled for 80°C maximum junction temperature. Some liquid-cooled germanium rectifiers can handle up to 6000 amperes at 26 to 66 volts. This rectifier is short-circuit sensitive. Germanium rectifiers may be connected in series for high-voltage service. Example: Type 1N91. *Compare* Silicon Rectifier. *See also* Rectifier.

GERMANIUM TRANSISTOR

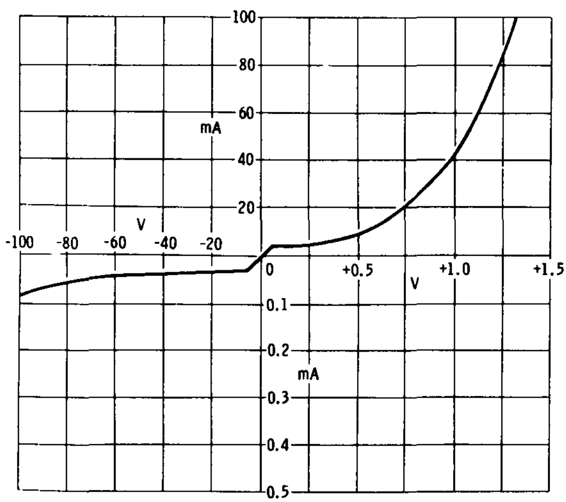
A transistor employing germanium as the semiconductor material. The first transistors were point-contact germanium units. The point-contact type is no longer manufactured, but germanium junction transistors are available in many models. *Compare* Silicon Transistor. *See also* Transistor.

Ge TRANSISTOR

See **Germanium Transistor.**

GOLD-BONDED DIODE

A germanium point-contact diode having a gold catwhisker whose point is bonded to the germanium wafer. Particular features of this type of diode are (1) high forward current, (2) almost constant low reverse current up to a high value of reverse voltage (typically −60 to −80 volts), and (3) notable stability of operation. Disadvantages of this diode in some applications are (1) almost equal forward and reverse currents at applied voltages of a few millivolts and (2) the significant capacitance of the comparatively large contact area, limiting operation to frequencies under 1 MHz. Example: Type 1N96A.



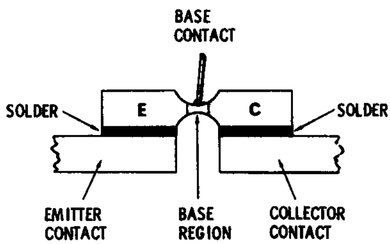
Gold-bonded diode (typical response).

GROWN DIODE

A junction diode in which the pn junction is created by growing an n layer and then a p layer, or vice versa, in a single crystal of semiconductor material while this crystal is being pulled from a melt. *See also* Diode *and* Junction Diode.

GROWN-JUNCTION TRANSISTOR

A junction transistor in which the alternate n and p regions are formed by adding impurities, and/or controlling the rate of growth, at the proper points in a molten crystal of semiconductor material as it is pulled from the melt. A number of complete transistor wafers may be made from a finished crystal of this type, and the emitter, base, and collector leads attached to them. Example: Type 2N348. *See also* Transistor *and* Rate-Grown Transistor.

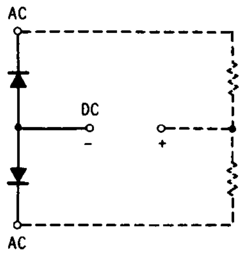


Grown-junction transistor.

H

HALF BRIDGE

A semiconductor rectifier assembly consisting of two diodes connected so as to form two arms of a conventional bridge circuit. For a complete bridge circuit, two external diodes or two resistors may be added, as shown by the dashed lines in the accompanying illustration; for other applications, the two-diode circuit is sufficient, as supplied. *Compare* Bridge. *See also* Rectifier *and* Meter Rectifier.

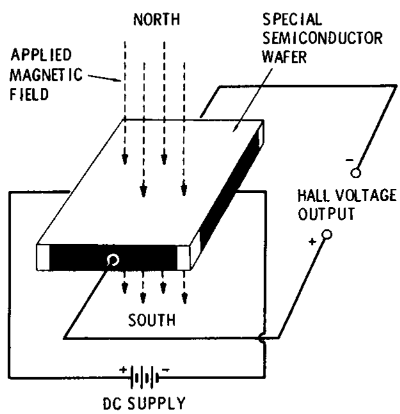


Half bridge.

HALL GENERATOR

A four-terminal semiconductor device whose operation is based on the Hall effect. In one form of this device, ohmic contacts are made at each of the four edges of a thin wafer of suitable semiconductor material, such as indium antimonide or indium arsenide. A dc supply voltage is applied between two opposite edges of the wafer, as shown in the accompanying illustration, and output terminals are connected to the other two opposite edges.

Normally, no voltage appears at the output terminals. However, when a transverse magnetic field is applied to the wafer in the direction shown, a voltage proportional to the strength of the field appears, with the upper output terminal negative and the lower output terminal positive. This action (Hall effect) results from the crowding of current carriers



Hall generator.

(provided by the supply voltage) to the edges of the wafer by the magnetic field.

Hall generators are used principally in magnetic field sensing and instrumentation (such as electric power meters and analog-type multipliers) involving two inputs, one of which may be converted into a magnetic field or which is itself such a field.

HIGH-SPEED DIODE

See **Switching Diode.**

HIGH-SPEED TRANSISTOR

See **Switching Transistor.**

HOT-CARRIER DIODE

A semiconductor diode in which hot carriers (that is, electrons or holes having higher energy than that of the majority carriers common to the semiconductor material used) are emitted from a layer of the semiconductor into a metal base. The fast-switching ability of this diode results from the almost total absence of minority carriers. Example: Type MBD101. *See also* Diode *and* Junction Diode.

HYBRID IC

A type of integrated circuit which combines features of both the monolithic type and the thin-film type. Sometimes, the term "hybrid IC" is applied to a unit that contains two or more interconnected IC chips or wafers. *Compare* Monolithic IC *and* Thin-Film IC. *See also* Integrated Circuit.

I

IC

See **Integrated Circuit.**

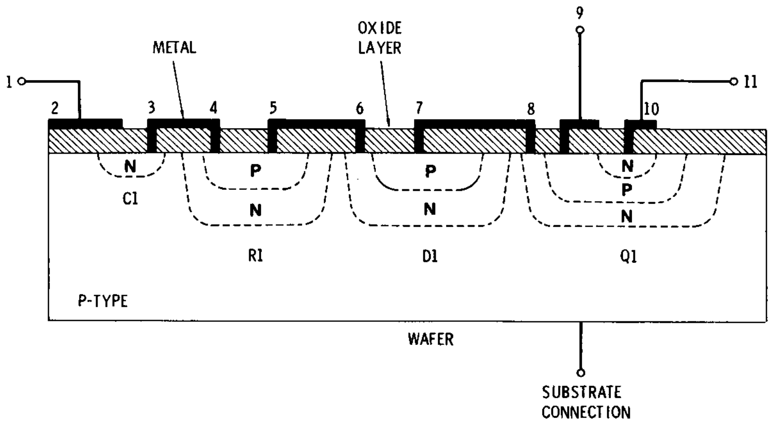
INTEGRATED CIRCUIT

Abbreviation, *IC.* A semiconductor device incorporating a complete circuit (or a partial circuit, such as a pair of components) in which the components (transistors, diodes, resistors, capacitors) and the interconnections between them are created in a wafer of suitably processed silicon by means of some combination of diffusion, metallizing, and photolithography. The IC fabrication technique allows a complicated multistage circuit to be contained in a small transistor-type case; the Type CA3030 integrated circuit, for example, is an operational amplifier containing 10 transistors, 2 diodes, and 18 resistors and is housed in a TO-5, 12-lead case. Integrated circuits have greatly simplified the building of electronic equipment and have dramatically reduced the size of complex electronic systems.

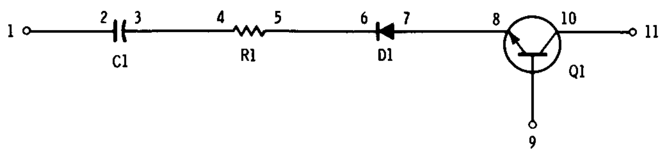
Part A of the accompanying illustration shows the cross section of an integrated circuit—consisting of a capacitor (C1), resistor (R1), diode (D1), and transistor (Q1)—created in a p-type wafer. The solid black portions represent thin metal film, the shaded portion is an insulating (passivating) layer of silicon dioxide, and the dashed lines represent n and p regions that are diffused into the p-type silicon substrate. The diffusions are completed first. Next, the insulating layer is grown on top of the wafer. Then, windows are etched into the insulation at the proper places (such as 3 and 4) for the metal (to be applied later) to extend through and make contact with the diffused regions. Finally, a metal film is deposited in sections on top of the insulating layer to provide contact with the integrated components and connections between them. A second insulating layer may then be applied to protect the metal sections from short circuit.

The capacitor is formed by the metal-film section, underlying n region, and intervening oxide film. The resistor is formed by the p region whose ends are contacted by points 4 and 5 of the metal film. The n region under this p region provides a high reverse resistance preventing a short circuit to other components through the p wafer. The diode is

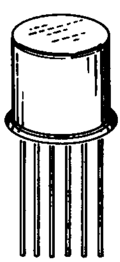
formed by the n region contacted by 6 and the p region contacted by 7. The npn transistor is formed by the n region contacted by 8, p region contacted by 9, and n region contacted by 10. While this is not necessarily a standard circuit, it serves to show how four components and the inter-



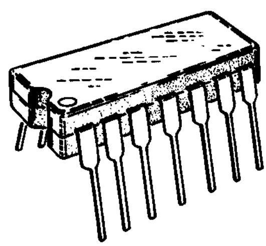
(A) Illustrative structure.



(B) Equivalent circuit.



(C) TO-5 case.



(D) Dual in-line case.

Integrated circuit.

connecting "wiring" can be fabricated in a wafer to yield an IC.

See also Digital IC, Hybrid IC, Linear IC, Monolithic IC, *and* Thin-Film IC.

J

JUNCTION DIODE

A diode made by forming a pn junction in a wafer or disc of semiconductor material, such as germanium, silicon, or gallium arsenide. Thus, part of a wafer of n-type material may be converted to p type to provide the required junction, or, conversely, part of a wafer of p-type material may be converted to n type. The p region is the anode, and the n region is the cathode of the diode.

Junction diodes are available in a variety of sizes and ratings and are usually of the germanium and silicon types. A junction diode may be fabricated by means of any of the processes for forming pn junctions: alloying, growing, diffusion, etc. Junction diodes are more rugged than their point-contact counterparts; however, the maximum operating frequency of the junction diode is much lower, largely owing to the comparatively high capacitance of the junction. *Compare* Point-Contact Diode. *See also* Diode.

JUNCTION PHOTOCELL

A light-sensitive device utilizing a pn junction. This may be either a *junction diode* (which see) arranged so that light falls on its junction or a *silicon photocell,* which is a junction-type device. *See also* Photocell.

JUNCTION TRANSISTOR

Any transistor in which the required p and n regions have been formed in a single wafer of semiconductor material. Included in this category are junction-type bipolar transis-

tors and junction-type field-effect transistors. The p and n regions are created by means of various processes: alloying, growing, diffusion. *Compare* Point-Contact Transistor. *See also* Transistor.

L

LASER DIODE

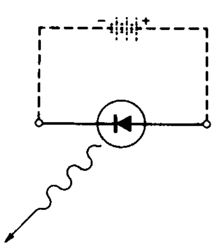
A light-emitting diode (which see) that generates coherent light.

LED

See **Light-Emitting Diode.**

LIGHT-EMITTING DIODE

Abbreviation, *LED*. A semiconductor diode (usually a gallium-arsenide or gallium-phosphide type) that emits light when energized by a low voltage. Such diodes are widely used in readout devices and optical couplers, and to some extent as pilot lights in low-drain, portable, solid-state equipment. There are two main types: *visible-light-emitting* and *infrared-light-emitting*. Example: Type 40598A. *See also* Diode.



Light-emitting diode.

LINEAR IC

An *integrated circuit* (which see) designed for conventional applications, such as amplification or oscillation, in which the output signal is continuous, rather than broken, and in the amplifier is a replica of the input signal. These ICs contain such circuits as af amplifiers, i-f amplifiers, operational amplifiers, rf amplifiers, and video amplifiers, and can be readily adapted to numerous applications other than those for which the ICs were designed. Examples: Type CA3007 af amplifier, Type CA3010 operational amplifier. *Compare* Digital IC. *See also* Integrated Circuit.

LIQUID CRYSTAL

The seeming lack of logic in including something called "liquid" in a book on solid-state components may be explained by revealing that a piece of liquid-crystal material may be thought of as a liquid in somewhat the same way that glass is considered a congealed liquid. Thus, a piece of liquid-crystal material, such as is used to form the numbers in the readout of an electronic calculator, resembles a piece of transparent or translucent plastic.

The nematic type of liquid crystal is normally transparent, but it is made turbulent by the application of a voltage to it. The turbulence disappears when the voltage is removed. This action enables the crystal material to pass or obstruct light from a source, such as a lamp. It also enables light to be either reflected through the material from a shiny backplate, or obstructed.

M

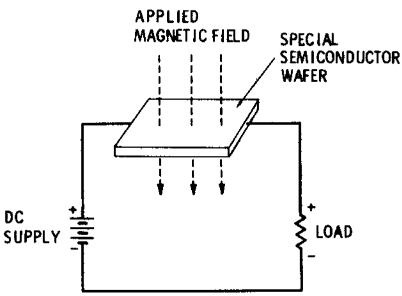
MADT

***See* Microalloy Diffused Transistor.**

MAGNETORESISTOR

A two-terminal semiconductor device whose operation is based on the ability of some materials to change their resistance in a magnetic field. In one form of this device, ohmic contacts are applied to each end of a wafer of suitable semiconductor material, such as indium arsenide or indium antimonide. A dc supply voltage then is applied to the wafer, and a desired load device is connected in series, as shown in the accompanying illustration.

Normally, the resistance of the wafer is very low, so current passes readily from the battery through the wafer to the load. However, when a transverse magnetic field is applied to the wafer, the resistance of the wafer increases in proportion to the strength of the field, and the current through the wafer and the voltage across the load decrease. In one type of magnetoresistor, a field-strength increase from 0 to 10 kilogauss increases the wafer resistance from 1 ohm to 10 ohms. Magnetoresistors are employed as magnetic sensors, control devices, and rudimentary amplifiers. Example: Type MS-41. *Compare* Hall Generator.



Magnetoresistor.

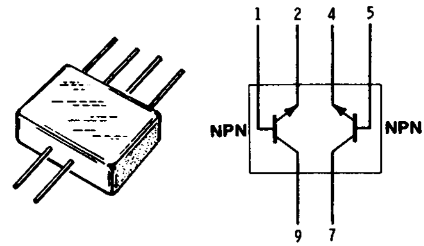
MAT

See **Microalloy Transistor.**

MATCHED PAIR

Two closely matched diodes or transistors enclosed in a single case or supplied separately.

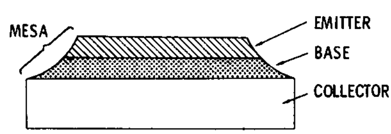
Matched pair.



MESA TRANSISTOR

A type of transistor characterized by a small-area emitter and base occupying a plateau ("mesa") on top of a larger-area collector, the entire structure being obtained from a single wafer of semiconductor material. In its simplest form, the structure is obtained by diffusing a base and then an emitter into the top face of the wafer (as explained in the description of the double-diffused transistor) and then etching away a part of the sides of the emitter and base layers to establish the mesa. As a result, the larger area is devoted to the collector, which needs this increased size for power dissipation. Many diffused transistors now employ the mesa structure. *See also* Diffused Transistor.

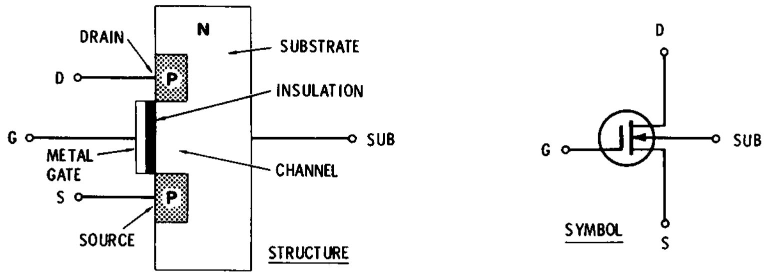
Mesa transistor.



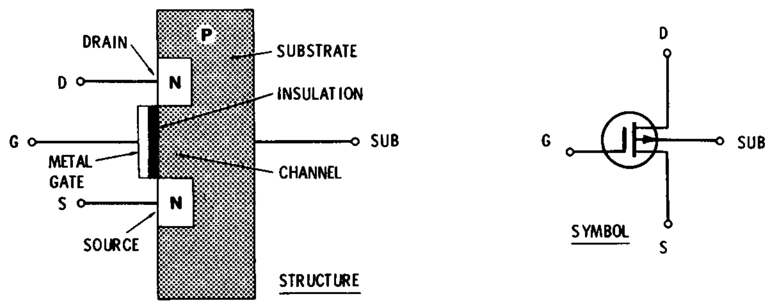
METAL-OXIDE-SEMICONDUCTOR FIELD-EFFECT TRANSISTOR

Abbreviation, *MOSFET*, occasionally *MOST*. An insulated-gate field-effect transistor; its name, metal-oxide-semi-

conductor field-effect transistor, denotes the sequence of layers—metal-film gate, oxide insulation, and semiconductor wafer—in the cross section of the device. (See the description of the insulated-gate field-effect transistor—IGFET—under Transistor.)



(A) N-channel.



(B) P-channel.

Metal-oxide-semiconductor field-effect transistor.

The MOSFET operates on the principle that the flow of current carriers in a path (the *channel*) through a semiconductor wafer may be controlled by means of an electric field produced by an input-signal voltage applied to the gate electrode and penetrating into the channel. The wafer is n-type silicon in an n-channel MOSFET, and it is p-type silicon in a p-channel MOSFET. Current from an external dc supply flows through the channel from the *source* electrode to the *drain* electrode of the MOSFET. These two electrodes consist of diffused p-type regions in an n-channel MOSFET, and of n-type regions in a p-channel MOSFET. The gate

is situated between the source and drain on the surface of the wafer and is insulated from the latter.

There are three types of MOSFETs and modes of operation: *depletion type, enhancement type,* and *depletion/enhancement type.* Each may be either n channel or p channel.

In the depletion type, an applied negative gate-to-source voltage narrows ("depletes") the channel, reducing the output current. A sufficiently high value of this voltage completely constricts ("pinches off") the channel, reducing the output current to zero. The depletion-type MOSFET normally operates with negative gate bias.

In the enhancement type, an applied positive gate-to-source voltage widens ("enhances") the channel, increasing the output current. The enhancement-type MOSFET normally operates with positive gate bias.

In the depletion/enhancement type, the gate bias is zero. A positive gate voltage then swings the device into enhancement-type operation (that is, a positive increase in gate voltage causes an increase in output current), whereas a negative gate voltage swings the device into depletion-type operation (that is, a negative increase in gate voltage causes a decrease in output current).

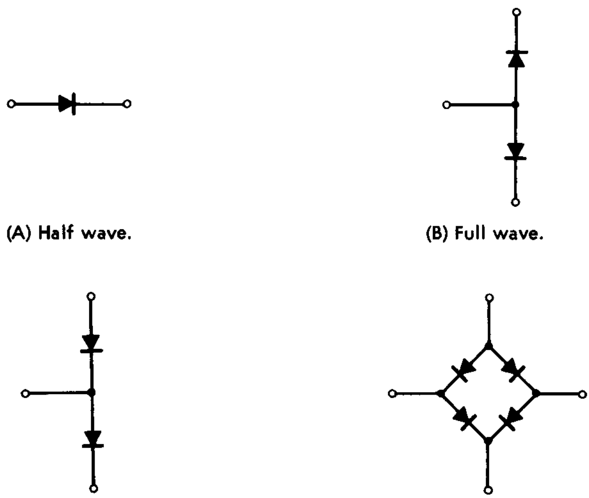
MOSFETs are supplied in either single-gate or dual-gate types. In each type, the gate insulation is extremely high in resistance, making the input of this device resemble that of a vacuum tube. However, the insulating layer is extremely thin and may easily be punctured by excessive signals and by static charges accumulated by the gate-to-wafer capacitance. To prevent such damage, manufacturers supply some MOSFETs (such as Type 3N187) containing internal, back-to-back zener diodes that short-circuit damaging voltages and protect the insulation.

See also Transistor.

METER RECTIFIER

A miniature diode or assembly of diodes used to change an ac voltage into dc to deflect a dc current meter (usually

a milliameter or microammeter) and thus to convert the latter into a simple ac meter. Meter rectifiers usually consist of copper-oxide diodes or germanium point-contact diodes (silicon point-contact diodes for microwave frequencies), and they are available in half-wave, full-wave, half-bridge, and full-bridge types. *See also* Bridge, Copper-Oxide Diode, Copper-Oxide Rectifier, Half Bridge, Point-Contact Diode, *and* Rectifier.



(A) Half wave. (B) Full wave.

(C) Half bridge. (D) Full bridge.

Meter rectifier.

MICROALLOY DIFFUSED TRANSISTOR

Abbreviation, *MADT*. A type of microalloy transistor in the manufacture of which a controlled amount of a suitable dopant is diffused into the semiconductor wafer before the emitter and collector dots are plated into the etched pits. This technique allows closer control of the transistor parameters than is afforded in the microalloy transistor (MAT) itself. *See also* Microalloy Transistor.

MICROALLOY TRANSISTOR

Abbreviation, *MAT*. A high-frequency transistor fabricated by means of etching and plating in the same manner as the surface barrier transistor and then heat-treating the structure to alloy the emitter dot and collector dot with the semiconductor wafer. *See also* Surface Barrier Transistor.

MONOLITHIC IC

The most common type of integrated circuit. All of its components and interconnections are formed in a single chip or wafer of semiconductor material (the *substrate*). Throughout its body, the chip is one material, various small areas of it having been processed to yield diode, transistor, capacitor, or resistor action. It is this feature that suggests the term "monolithic" (from the Greek *monolithos,* "made from one stone"). Because of this one-material/single-block construction, high uniformity and reliability are obtainable (for example, matched diodes and matched transistors are easily guaranteed). *Compare* Hybrid IC *and* Thin-Film IC. *See also* Integrated Circuit.

MOSFET

***See* Metal-Oxide-Semiconductor Field-Effect Transistor.**

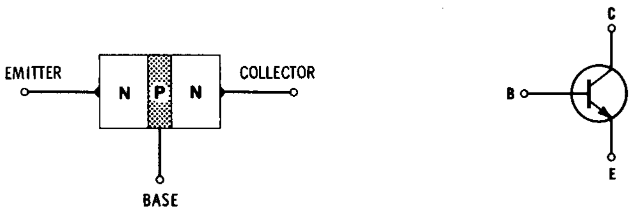
MOST

Metal-oxide-semiconductor transistor. An occasional term and abbreviation for the metal-oxide-semiconductor field-effect transistor (which see).

N

NPN TRANSISTOR

A junction transistor having an n-type emitter, a p-type base, and an n-type collector. This unit requires a negative emitter voltage and a positive collector voltage. Examples: Type 2N5180 (small-signal), Type 2N3439 (power). *Compare* PNP Transistor. *See also* Junction Transistor.



(A) Structure. (B) Symbol.

Npn transistor.

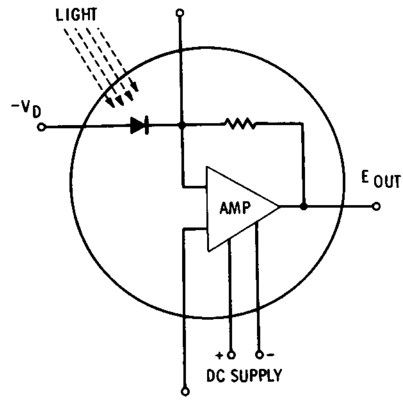
O

OPTICAL COUPLER

See **Optoelectronic Coupler.**

OPTICAL DETECTOR

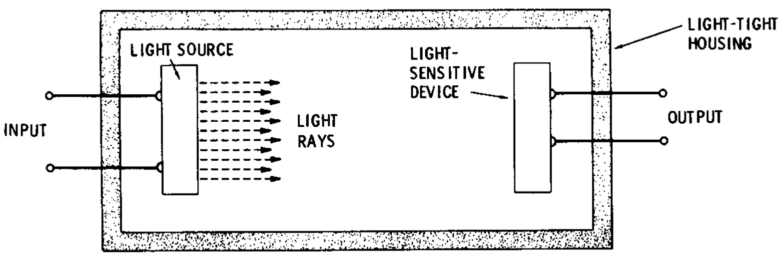
A light-to-voltage converter consisting of a silicon pin photodiode, integrated operational amplifier, and gain-determining network, all contained in a transistor-type case. Bias voltages (dc) are applied to the device, which delivers a dc output voltage proportional to the illumination of the photodiode surface. Example: Type 509.



Optical detector.

OPTOELECTRONIC COUPLER

Also called *optical coupler*. A signal-coupling device that consists essentially of a light-emitting device enclosed in a light-tight housing with a light-sensitive device. The former is either an incandescent lamp, neon lamp, light-emitting diode, or electroluminescent cell; the latter is either a photocell (photovoltaic or photoconductive), photodiode, or phototransistor.



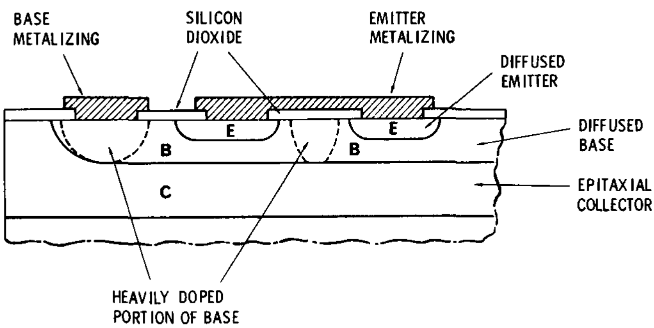
Optoelectronic coupler.

The input signal activates or modulates the light source so that the light output is proportional to the input-signal voltage or current or is a replica of the modulation. The light rays then actuate the light-sensitive device, whose output signal likewise is proportional to the input signal or reproduces the input waveform. Under some conditions, the

optoelectronic coupler will provide signal amplification. This device gives almost perfect input/output isolation because of the extremely low capacitance between the light-emitting component and the light-sensitive component.

OVERLAY TRANSISTOR

A double-diffused epitaxial transistor having numerous separate diffused emitters, which are interconnected by means of metallizing and diffusion. This structure ensures reduced charging time constants at no sacrifice of current or power ratio by increasing the emitter edge-to-edge ratio. Example: Type 2N5996. *See also* Epitaxial Transistor.



Overlay transistor.

P

PARAMETRIC AMPLIFIER DIODE

Another name for voltage-variable-capacitor diode (which see).

PC

See **Photocell.**

PC DIODE

See Point-Contact Diode.

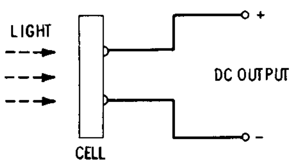
PC TRANSISTOR

See Point-Contact Transistor.

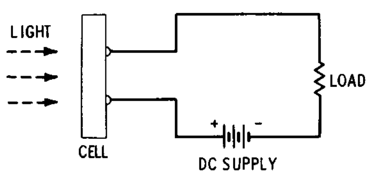
PHOTOCELL

Abbreviation, pc. Also called *photoelectric cell.* A device for converting luminous energy into electrical energy or for using luminous energy to control an electric current. A *photovoltaic cell* (also called *self-generating photocell*) produces a dc voltage that is proportional to incident light; a *photoconductive cell* (also called *photoresistive cell*) changes its resistance inversely with the intensity of incident light and accordingly can vary an electric current.

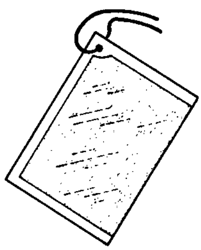
Photocells employing selenium or silicon as the light-sensitive material can function as either photovoltaic or photoconductive types; however, the silicon type is used almost exclusively in the photovoltaic mode, owing to its higher output voltage for a given illumination. An early



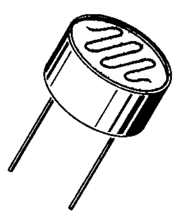
(A) Photovoltaic.



(B) Photoconductive.



(C) Selenium.



(D) Cadmium sulfide.

Photocell.

photocell employing copper oxide as the light-sensitive material was supplanted by the selenium cell. Light-sensitive materials employed in photoconductive cells include cadmium selenide, cadmium sulfide, indium antimonide, and lead sulfide.

Most photocells employ a layer of light-sensitive material on a metal plate, the latter constituting one electrode of the cell. The second electrode consists of a metal ring in contact with the exposed surface of the material or is a transparent layer of metal evaporated on the surface of the material. These cells can be made in any desired shape or size.

Largely because of their usually flat-plate type of construction, many photocells exhibit significant amounts of shunting capacitance, and this limits their frequency response unless the cell is quite small. The spectral response of the selenium cell peaks at approximately 0.555 micron, that of the silicon cell at approximately 0.8 micron; both of these are superior to the human eye.

Compare Photodiode *and* Phototransistor. *See also* Selenium Photocell *and* Silicon Photocell.

PHOTOCONDUCTIVE CELL

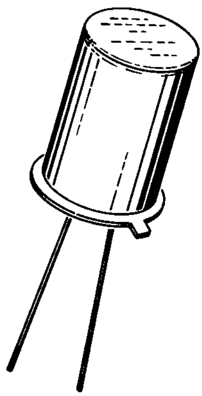
Also called *photoresistive cell.* A photocell (which see) in which the light-sensitive material lowers its resistance (increases its conductance) in proportion to incident light. When such a cell is operated with a voltage source, it acts as a light-variable resistor, the current flowing into the circuit increasing with illumination, and vice versa. Examples are cadmium selenide, cadmium sulfide, and lead sulfide photocells. Selenium photocells and silicon photocells also are photoconductive, but they are valued more for their photovoltaic properties. *Compare* Photovoltaic Cell.

PHOTODIODE

A special fabrication of semiconductor diode employed as a photoelectric cell. Either the junction-type or the point-

contact-type structure is used. The device is arranged so that light falls on the junction in the junction type, or on the point of contact between the catwhisker and the wafer in the point-contact type. The photodiode is usually operated as a photoconductive (photoresistive) cell dc-biased in the reverse direction; however, it may operate also as a low-output self-generating cell. Examples: Type 1N77 (point-contact type), Type 1N77A (junction type). *See also* Diode, Junction Diode, Photocell, *and* Point-Contact Diode.

Photodiode.



PHOTOFET

Trade name (Siliconix, Inc.) for a field-effect type of phototransistor (which see) with built-in lens. Example: Type P-102.

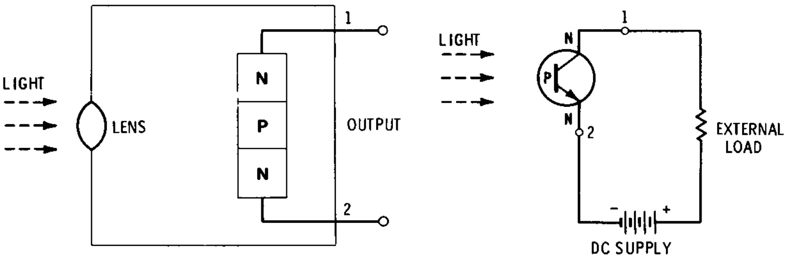
PHOTORESISTIVE CELL

See Photoconductive Cell.

PHOTOTRANSISTOR

A light-sensitive device employing a transistor structure and so arranged that light can fall on a sensitive part, such as one of the junctions, preferably the emitter-base junction. Incident light energy causes current carriers to be released

in the semiconductor, and these act in the same way as a dc input signal applied to a conventional transistor; that is, they enter the emitter-base circuit of the transistor and give rise to an amplified current in the collector circuit. The result is higher output current for a given illumination than



(A) Structure. (B) Typical circuit.

Phototransistor.

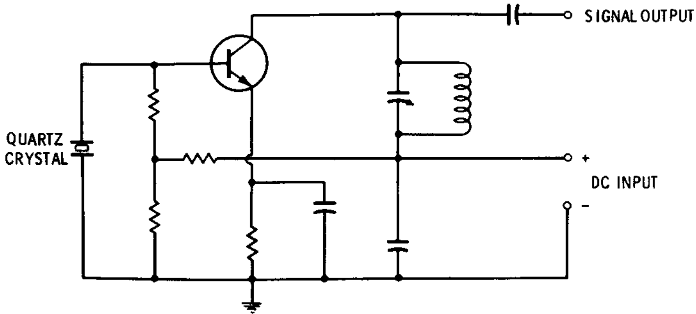
that afforded by a similar photodiode (which see). The accompanying illustration shows an npn phototransistor; the pnp type and the field-effect type also are available. Example: Type 2N5777.

PHOTOVOLTAIC CELL

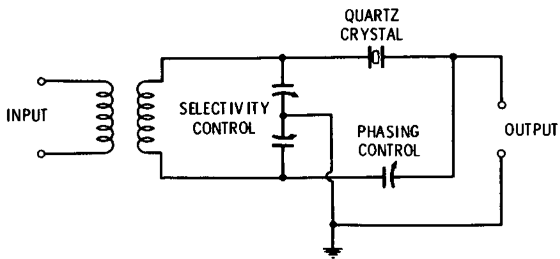
Also called *self-generating cell.* A photocell (which see) that requires no power supply and that delivers an output voltage proportional to incident light. Examples: Type 1B30 (selenium), Type S1M (silicon). *Compare* Photoconductive Cell. *See also* Selenium Photocell *and* Silicon Photocell.

PIEZOELECTRIC CRYSTAL

A plate, disc, bar, or rod of crystalline material, such as quartz or Rochelle salt, that exhibits the piezoelectric effect; that is, mechanical deformation of the plate (pressure, bending, twisting—depending on the type of material) causes a voltage to appear between opposite faces, and, conversely, application of voltage between opposite faces causes the plate to change shape.



(A) Crystal oscillator.



(B) Crystal filter.

Piezoelectric crystal in typical circuits.

The vibration frequency of a quartz crystal depends on the dimensions of the crystal, particularly thickness, which can be held very closely. In some crystal cuts, this frequency is only slightly affected by temperature. Accordingly, the frequency of an electronic oscillator can be precisely controlled by including a quartz crystal in the circuit. The *crystal oscillator* is the basis of transmitter and instrument circuits. The quartz crystal is useful also as a highly selective filter (called either *crystal filter* or *crystal resonator*), the crystal passing or rejecting signals at its natural frequency, depending on the kind of circuit in which it is used. For either the oscillator or the filter application, contact is made with the crystal by means of metal plates pressed against the opposite faces or by means of electrodes plated on the faces.

The relatively high output voltage versus pressure of such crystals as Rochelle salt suits this type for use in ac-

celerometers, microphones, phonograph pickups, vibration pickups, and similar transducers. The opposite effect—conversion of ac voltage to mechanical vibration—suits this crystal also for use in earphones, loudspeakers and ultrasonic transducers.

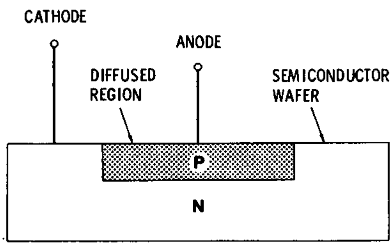
Some ceramic materials also are piezoelectric and are employed in pickups and microphones. Some—such as lead zirconate titanate—are employed, like quartz, in selective filters.

PIN DIODE

A silicon diode in which a lightly doped layer of intrinsic silicon separates the n and p layers. (The name is an abbreviation of *p-type, intrinsic-type, n-type.*) Example: Type MPN3401. *See also* Diode *and* Junction Diode.

PLANAR DIODE

A junction diode so constructed that both the n layer and the p layer are available for external connection at the same face of the semiconductor wafer. This structure is



Planar diode.

achieved by diffusing a p-type dopant into an n-type wafer, or an n-type dopant into a p-type wafer. *See also* Diffused Diode, Diode, *and* Junction Diode.

PLANAR PASSIVATED DIODE

A *planar diode* (which see) on whose surface an oxide film has been grown to protect the otherwise exposed pn

junction from short circuits and contamination. Tiny holes (*windows*) in the film admit the anode and cathode leads.

A special type is the planar epitaxial passivated (PEP) diode, which is made from expitaxial silicon and accordingly provides low forward resistance. Example: Type 1N3605. *See also* Diode, Junction Diode, *and* Planar Diode.

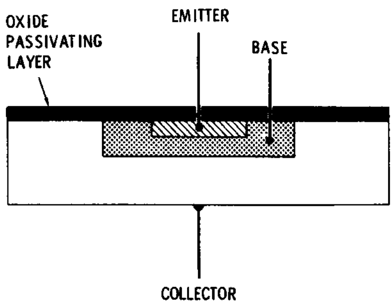
PLANAR PASSIVATED TRANSISTOR

See under Planar Transistor.

PLANAR TRANSISTOR

A transistor in which all of the pn junctions edge along the top face of the semiconductor wafer. This structure results from diffusing impurity materials into the face. After the junctions are formed, an insulating layer of silicon dioxide (the *passivating layer*) is grown on the face of the

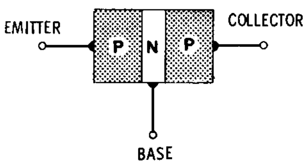
Planar transistor.



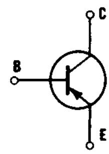
wafer to protect the exposed junctions against contamination and short circuit. (This arrangement gives rise to the term *planar passivated transistor.*) Planar transistors may be of either the single-diffused, double-diffused, or triple-diffused type. Examples: Type 40244 (single-diffused), Type 2N2857 (double-diffused), Type 2N5415 (triple-diffused). *See also* Diffused Transistor.

PNP TRANSISTOR

A junction transistor having a p-type emitter, an n-type base, and a p-type collector. This unit requires a positive emitter voltage and a negative collector voltage. Examples: Type 2N591 (small-signal), Type 40022 (power). *Compare* NPN Transistor. *See also* Junction Transistor.



(A) Structure.

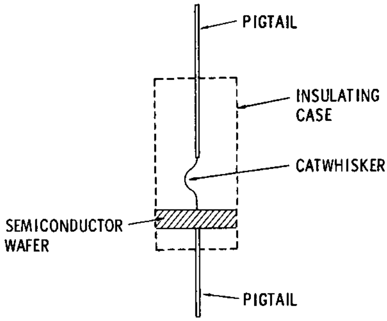


(B) Symbol.

Pnp transistor.

POINT-CONTACT DIODE

Also called *pc diode*. A diode employing the rectifying contact between the sharp point of a fine wire (the *catwhisker*) and a small wafer of semiconductor material (the *crystal*), such as germanium or silicon. It is believed that this device really functions as a junction diode, since after assembly it is electroformed by means of a pulse of current, and this operation creates a small spot of the opposite kind of semiconductor around the contact between whisker and crystal (a p-type spot is formed in an n-type wafer, and vice versa).



Point-contact diode.

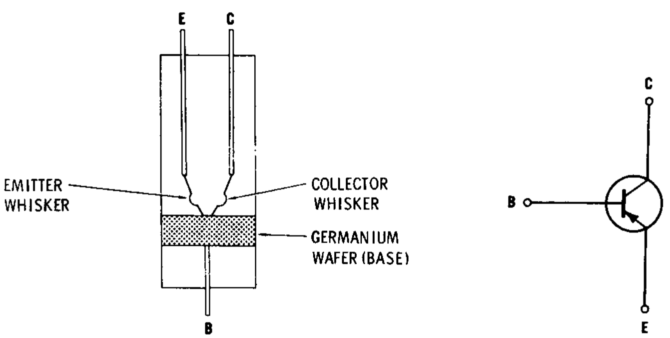
The point-contact diode is limited in power dissipation, but it has superior high-frequency characteristics, owing to its low shunt capacitance (1 pF or less) ; some point-contact diodes (such as Type 1N21) operate into microwave frequencies. Examples: Type 1N34A (germanium), Type 1N21B (silicon). *Compare* Junction Diode. *See also* Diode.

POINT-CONTACT TRANSISTOR

Also called *pc transistor.* An early type of transistor in which two pointed metal wires (*catwhiskers*) touch the face of a semiconductor wafer a few thousandths of an inch from each other. One whisker is forward biased with respect to the wafer, and the other is reverse biased with respect to the wafer. The forward-biased one serves as the emitter of this transistor, and the reverse-biased one serves as the collector; the wafer is the base.

The point-contact transistor is difficult to manufacture as a carefully controlled device. Furthermore, it exhibits a current amplification ratio (*alpha*) greater than 1, and this latter feature makes the point-contact transistor prone to oscillate in such circuits as the common-emitter amplifier and quickly destroy itself. It also is not so rugged as the junction transistor, which has supplanted it.

It is thought that the point-contact transistor is itself a special junction-type device since after assembly of the



(A) Structure. (B) Symbol.

Point-contact transistor.

unit, a pulse of current is passed between each whisker and the wafer to electroform the contact areas, an operation that produces a tiny p-type spot in an n-type wafer. The result is, of course, a pnp structure. Additional complications attendant to the same process, however, result in the higher-than-unity alpha and the resulting notorious instability of the point-contact transistor.

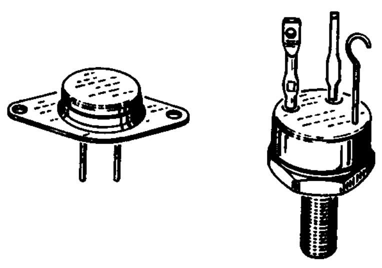
Point-contact transistors are curiosities when they are found today. A typical example is Type 2N33. *Compare* Junction Transistor. *See also* Transistor.

POWER DIODE

Another name for *rectifier* (which see).

POWER TRANSISTOR

A transistor designed for high power output and high power dissipation. It is hard to identify the line separating power transistors from small-signal transistors. Some authorities designate a 100-milliwatt unit as a power transistor, whereas others would have the power group start



Power transistors.

at ½ watt. Suffice it to say that a power transistor should be capable of delivering a substantial amount of useful power, rather than a few tens of milliwatts in a given application. Examples: Type 2N71 (1 watt), Type 2N2739 (200 watts). *Compare* Small-Signal Transistor. *See also* Transistor.

Q

QUAD

A group of four matched components, usually diodes or transistors, housed in a single case. *Compare* Matched Pair.

R

RATE-GROWN TRANSISTOR

A *grown-junction transistor* (which see) in which n and p layers result from properly changing the rate at which a single crystal is pulled from a melt of n- and p-doped semiconductor material. At the correct temperatures, a fast rate produces an n region, and a slow rate produces a p region. *See also* Transistor.

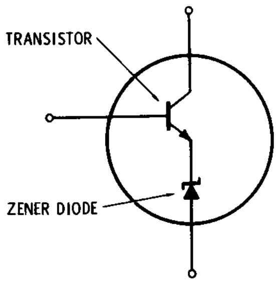
RECTIFIER

Broadly, any semiconductor device that changes ac into dc. Thus, any diode is a rectifier. Customarily, however, the term is applied to those diodes, or combinations of diodes, that rectify relatively large amounts of energy. Exceptions are found in such low-power devices as *meter rectifiers, avc rectifiers,* and *relay rectifiers.* For obvious reasons, rectifiers are sometimes called *power diodes,* and to distinguish them from meter rectifiers and signal rectifiers they are sometimes called *power rectifiers.* Examples: Type 1N1189A (silicon), Type 1N91 (germanium), Type V10HF (selenium).

See also Copper-Oxide Rectifier, Germanium Rectifier, Meter Rectifier, Selenium Rectifier, Silicon Controlled Rectifier, *and* Silicon Rectifier.

REFERENCE AMPLIFIER

A combination of transistor and zener diode direct coupled in a single envelope. This device simplifies the design and construction of a voltage-regulated power supply by



Reference amplifier.

combining in one component the reference diode and the error amplifier needed in such supplies. Example: Type RA-1.

REFERENCE DIODE

A special zener diode, usually internally temperature-compensated, which exhibits a very stable voltage drop for large changes in reverse current. Because of its stability, this device is sometimes used in place of a standard cell as a source of accurate dc calibration voltage, when it is operated in series with a battery and suitable limiting resistor. It is also employed in voltage regulators that require an accurate and stable reference-voltage source. A typical example is the Type 1N4295, 10-volt diode. This unit has a zener current rating of 10 mA and a temperature coefficient of 0.012%/°C (−55 to + 150°C). *See also* Diode *and* Zener Diode.

RF PROBE

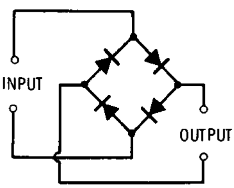
See under **Diode Probe.**

RF TRANSISTOR

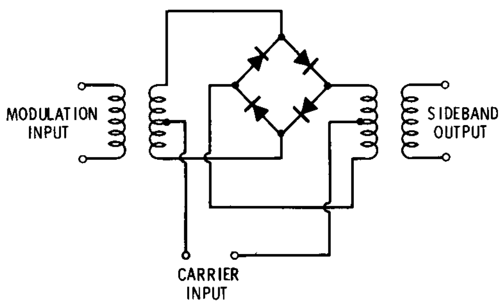
A small-signal transistor or power transistor designed and fabricated for operation into the radio-frequency spectrum. (Most conventional junction transistors have cutoff frequencies in the high audio-frequency region.) Examples: small-signal Type 2N1179 (f = 100 MHz), power Type 2N5921 (f = 2 GHz, P = 6 W). *Compare* AF Transistor. *See also* Transistor.

RING MODULATOR

A four-diode, bridge-like arrangement employed in sideband circuits to modulate a carrier with a selected modulation signal. Unlike the bridge-type rectifier (*see* Bridge), this device has its diodes connected in simple series in a ring or diamond. The ring modulator is supplied as a self-contained unit (*see* Quad) and usually employs copper-oxide or germanium diodes. *See also* Diode.



(A) Symbol.



(B) Typical circuit.

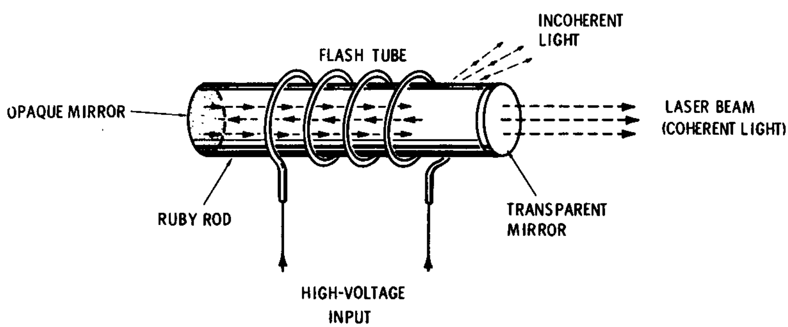
Ring modulator.

RUBY LASER

A device that generates intense coherent light as a result of pulsing the atoms in a ruby rod. The accompanying illustration shows a simplified version of this type of laser. Here, the ruby rod (natural or artificial) is silvered at each of its optically flat ends; the back end is completely silvered so

that no light can pass through the mirror it forms, but the front end is only lightly silvered and forms a transparent mirror through which some light can pass and from which some can be reflected within the rod. The rod is surrounded by a coiled flash tube.

When a high-voltage pulse is applied to the flash tube, the resulting intense flash of light forces electrons in the atoms of the ruby rod to a higher energy level. When the flash ends, the electrons fall back to their original energy level and in so doing emit energy in the form of visible light. A small amount of this light escapes as random incoherent light, but that which moves down the rod excites other atoms on the way, cumulatively increasing the amount of light. This light is reflected by the opaque mirror back down the rod to the transparent mirror which reflects it. The two mirrors reflect the light back and forth between the ends of the rod, more atoms being excited and the intensity increasing with each trip. Finally, a highly intense coherent (single wavelength and phase) beam of light passes through the transparent mirror and out of the end of the rod.



Ruby laser.

RUBY MASER

A maser in which the stimulated body is a ruby rod. This device produces low-noise amplification of microwaves in the following manner: Atoms in the ruby rod are raised to a high energy level. A microwave input signal then pulses

them to a lower energy level, and in keeping with quantum theory, this falling to a lower energy level is accompanied by the emission of energy. Since this output energy is greater than that of the input-signal energy which triggered it, amplification is achieved. The frequency of the input signal is chosen equal to the frequency that normally is generated by the atoms when they lapse to the lower energy level.

S

SBDT

See **Surface Barrier Diffused Transistor.**

SBT

See **Surface Barrier Transistor.**

SCINTILLATING CRYSTAL

A plate, disc, or film of crystalline material, such as sodium iodide or phosphorescent zinc sulfide, which emits flashes of light when exposed to radioactive energy. Such a crystal is the heart of the scintillation counter, a sensitive radioactivity-detecting instrument in which a photosensitive device (particularly a photomultiplier tube) picks up the flashes and delivers equivalent electrical pulses to an amplifier/counter circuit.

SCR

See **Silicon Controlled Rectifier.**

SCS

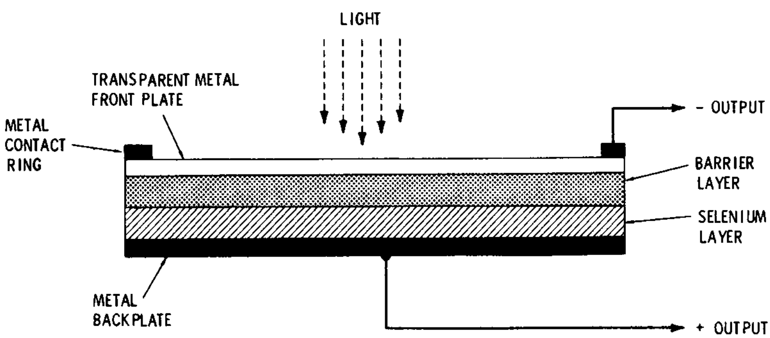
See **Silicon Controlled Switch.**

SELENIUM DIODE

A junction diode in which processed selenium is the semiconductor material. In this diode, a thin layer of selenium is deposited on a small aluminum or iron disc or wafer. The metal serves as the anode, and the selenium as the cathode. Example: Type 1N1625. *See also* Diode *and* Junction Diode.

SELENIUM PHOTOCELL

A photocell (which see) in which specially processed selenium is the light-sensitive material. The cross section of a selenium photocell resembles that of a selenium rectifier plate, except that the front electrode in the cell is a *transparent* deposit of metal on the face of the selenium layer which, in turn, has been applied to a metal base plate. The base plate and the transparent front plate constitute the electrodes of the photocell.



Selenium photocell.

Incident light passes through the transparent front plate and impinges upon the selenium, from which electrons are released by the light energy. These electrons pass from the selenium, across the barrier layer, to the front plate and are trapped there, making the front plate negative. The resulting dc output voltage, therefore, is negative at the front plate and positive at the back plate. At 2000 foot-candles, the average open-circuit output voltage of the

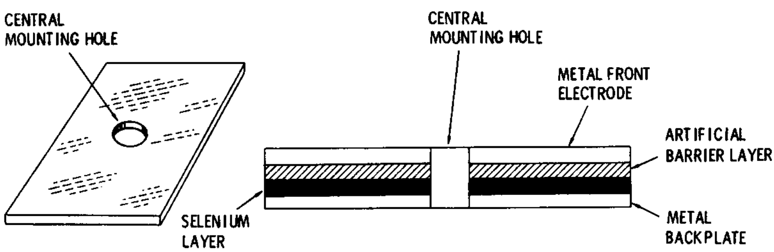
selenium photocell is 0.45 volt. Example: Type DP5. *Compare* Silicon Photocell. *See also* Photocell.

SELENIUM RECTIFIER

A power rectifier in which the semiconductor material is specially processed selenium. A relatively thin layer of the prepared selenium is applied to a nickel-plated and etched aluminum plate or disc (*backplate* or *base*). On top of the selenium layer, a thin film of proprietary lacquer is applied (*artificial barrier layer*). On top of the barrier layer, a metal layer (*front electrode* or *counter electrode*), usually a cadmium alloy, is applied either by spraying or by evaporation. The finished unit is termed a rectifier *plate, disc,* or *cell.* The backplate is the anode, and the front electrode is the cathode.

The selenium rectifier cell is a relatively low-voltage device (for example, 20 volts rms). A number of them must be stacked in series, by means of a central mounting hole, for higher-voltage service. Selenium rectifiers are very familiar in this form, resembling an assembly of parallel heat fins.

Selenium rectifiers are supplied in a variety of current and voltage ratings (for example, up to 30 kilovolts and 50,000 amperes) and in several configurations (single-phase, voltage doubler, bridge, etc.). *See also* Rectifier.



Selenium rectifier.

SELF-GENERATING PHOTOCELL

Also called *photovoltaic cell.* A photocell (which see) that delivers an output voltage that is proportional to incident

light. No external battery or other power supply is required. *Compare* Photoconductive Cell. *See also* Selenium Photocell *and* Silicon Photocell.

SEMICAP

Trade name (International Rectifier Corp.) for *voltage-variable-capacitor diode* (which see).

SHOCKLEY DIODE

Another name for *four-layer diode* (which see). The name honors the inventor of this device, Dr. William Shockley, one of the inventors of the transistor.

Si DIODE

***See* Silicon Diode.**

SILICON CAPACITOR

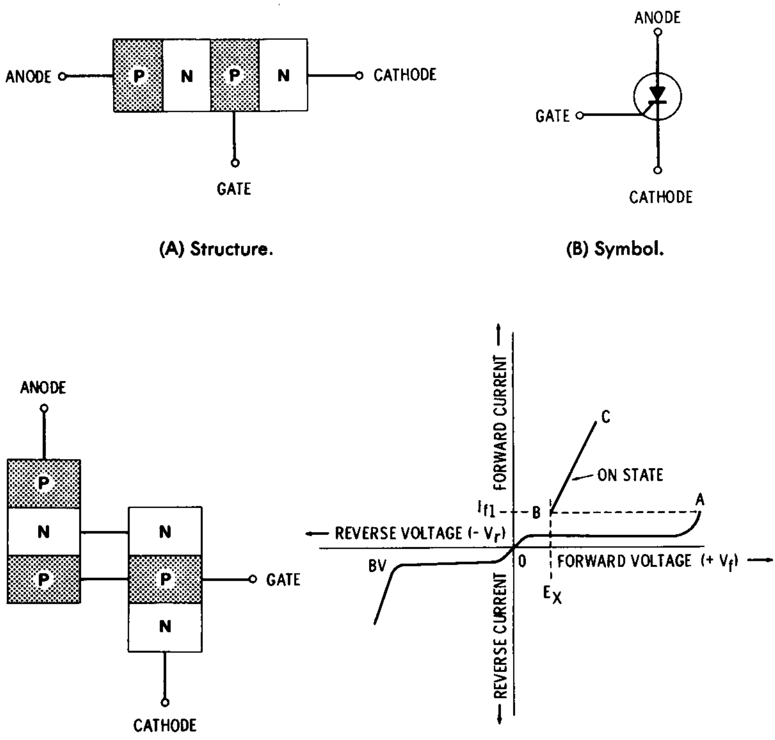
Another name for *voltage-variable-capacitor diode* (which see).

SILICON CONTROLLED RECTIFIER

Abbreviation, *SCR.* Although this device takes its name from the fact that it is a controllable rectifier of alternating current, it is generically a thyristor and as such may be employed for a number of functions other than rectification.

The SCR is a pnpn (four-layer) device; the endmost p layer is the anode, the endmost n layer is the cathode, and the p layer nearest the cathode is the gate (control electrode)—see part A of the accompanying illustration. This structure is equivalent to a pnp transistor direct coupled internally to an npn transistor (part C of the illustration). Because of the equivalent two-transistor structure of the SCR, this device blocks current in both directions when the gate voltage is zero. But when a positive voltage (with re-

spect to the cathode) is applied to the gate, the SCR performs in the manner shown in part D of the illustration. When the anode is negative ($-V_r$), only a small reverse current flows unless $-V_r$ inadvertently reaches the breakdown point, BV. Thus, the SCR is effectively an open switch when the anode is negative; this is the off state of the device. When the anode is positive ($+V_f$), the forward current is first insignificant (from zero to point A). When the forward voltage reaches point A (*forward breakover voltage*), however, an avalanche breakdown occurs and the forward current increases sharply, as from point B to point C. This is the on state of the device.



(A) Structure.

(B) Symbol.

(C) Equivalent structure.

(D) Performance.

Silicon controlled rectifier.

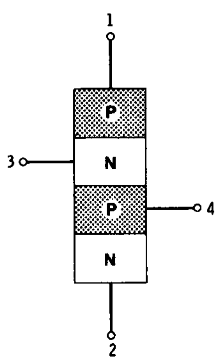
Once the SCR switches on, the gate—like the grid in a thyratron tube—has no further control of the current; it regains control only after the anode voltage switches to zero or becomes negative. In this way, the SCR can rectify an alternating current, under the control of gate voltage. This control action also suits the SCR to many applications formerly preempted by the thyratron tube. Some of these include dc-to-ac inversion, power switching, welder timing, phase control of power supplies, and motor speed control.

Silicon controlled rectifiers are available in a number of shapes and sizes with a variety of electrical ratings. Representative units are Type 2N3528 (2 amperes, 200 volts) and Type 2N3899 (35 amperes, 600 volts).

See also Rectifier *and* Thyristor.

SILICON CONTROLLED SWITCH

Abbreviation, *SCS.* A pnpn device in which each layer is connected to a separate terminal. This arrangement permits considerable versatility of application, since a number of external connections may be made. For example, using terminals 1 and 2 gives a four-layer diode (which see); using terminal 1 as the anode, 2 as the cathode, and 4 as the gate gives a silicon controlled rectifier (which see); using terminals 1 and 4 gives a diac (which see). Other selections (top to bottom) yield a diode in series with a transistor, a transistor in series with a diode, and so on. The circuit



Silicon controlled switch.

symbol depends on the choice of terminals and interconnections. Example: Type 3N59.

SILICON DIODE

A diode employing processed silicon as the semiconductor material. The silicon diode was the first of the modern semiconductor diodes, its point-contact version having been developed for World War II radar. Silicon diodes are manufactured both in the junction type and the point-contact type. The junction-type unit exhibits a front-to-back resistance ratio superior to that of its germanium counterpart, a superior temperature coefficient, and a higher value of maximum permissible reverse voltage. Examples: Type 1N21B (point-contact), Type 1N300 (junction).

Silicon point-contact diodes provide superior high-frequency operation; typical design frequencies are 3000 MHz for Type 1N21A, 10,000 MHz for Type 1N23B, 25,000 MHz for Type 1N26, and over 30,000 MHz for Type 1N53.

Compare Germanium Diode. *See also* Diode, Junction Diode, *and* Point-Contact Diode.

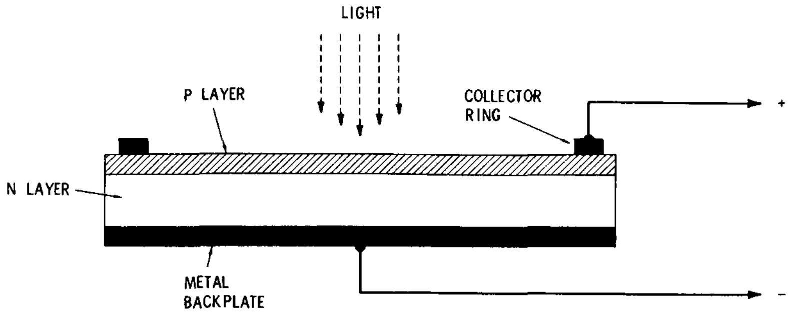
SILICON JUNCTION DIODE

See under **SILICON DIODE.**

SILICON PHOTOCELL

A photocell (which see) in which specially processed silicon is the light-sensitive material. In this device, an n-type silicon layer is applied to a metal backplate which becomes one output electrode. A thin p layer is then formed on, or diffused into, the exposed face of the n layer. Finally, a metal collector ring (or a transparent metal layer) is applied to the p layer and constitutes the other output electrode.

The n and p layers form a large-area pn junction across which there is a natural electric field. Light energy impinging upon the p layer generates electron-hole pairs and minority carriers (electrons in the p layer and holes in the



Silicon photocell.

n layer), and electrons are swept from p to n, and holes from n to p. This action produces the output voltage of the cell, with the collector ring or transparent front electrode positive and the backplate negative. At 2000 footcandles, the average open-circuit output of the silicon photocell is 0.3 to 0.6 volt.

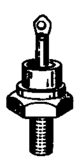
Compare Selenium Photocell.

SILICON POINT-CONTACT DIODE

See under **Silicon Diode.**

SILICON RECTIFIER

A power rectifier utilizing a pn junction in silicon. This device is essentially a heavy-duty junction diode. The silicon rectifier is characterized by a very high front-to-back current ratio (for example, greater than 12,000,000 to 1), excellent rectification efficiency (for example, greater than 99%), low forward voltage drop, high peak inverse voltage (for example, 1000 volts), and high temperature rating (for



Silicon rectifier.

example, 200°C ambient). Silicon rectifiers are supplied in a number of configurations, from single-junction units to stacks (including polyphase bridge arrangements). Silicon rectifiers may be connected in series for high-voltage service. Example: Type 1N1186A. *Compare* Germanium Rectifier. *See also* Rectifier.

SILICON TRANSISTOR

A transistor employing processed silicon as the semiconductor material. The silicon transistor followed the germanium type in commercial introduction and has supplanted the latter in many applications that demand the superior temperature and voltage ratings of the silicon unit. *Compare* Germanium Transistor. *See also* Transistor.

SINGLE-DIFFUSED TRANSISTOR

A diffused transistor in which a suitable impurity material is simultaneously diffused through the opposite faces of a semiconductor wafer. This process creates an emitter at one face and a collector at the opposite one; the intervening undiffused region in the wafer is the base. Example: Type 2N1300. *Compare* Double-Diffused Transistor *and* Triple-Diffused Transistor. *See also* Diffused Transistor.

Si TRANSISTOR

***See* Silicon Transistor.**

SMALL-SIGNAL TRANSISTOR

A transistor designed for voltage amplification, low-level current amplification, low-level switching, and similar applications. Such a transistor delivers no substantial power output (at most a few tens of milliwatts) and has a lower power-dissipation rating than does a power transistor. Example: Type 2N3242A. *Compare* Power Transistor. *See also* Transistor.

SNAP DIODE

A diode that provides rapid switch-off after post-forward-conduction carrier storage. The snap-off time is less than 1 nanosecond in some types. (In a conventional diode, the stored carriers leak off much more slowly.) Example: Type SSA-550. *See also* Diode *and* Junction Diode.

SOLAR BATTERY

A dc source made up of several self-generating photocells, particularly silicon photocells (which see), connected in series for useful output voltage when illuminated by sunlight. Such batteries are used in space satellites, control devices, emergency telephone power supplies, and portable radios.

SOLAR CELL

A silicon photocell (which see). It is often so called because of its characteristically high output voltage when exposed to sunlight. *See, for example,* Solar Battery.

SOLID-STATE BATTERY

A direct-current source consisting of a photovoltaic cell (which see) mounted close to a body of suitable radioactive material, the two being contained in a radiation-confining and light-tight housing. Energy radiated by the material excites the photocell, causing the latter to generate a dc voltage. This arrangement provides a dc source of extreme simplicity and very long life. Also called *atomic battery.*

SOLID-STATE LAMP

A light-emitting diode, liquid crystal, or electroluminescent cell (all of which see) employed as a pilot light.

SOLID-STATE MASER

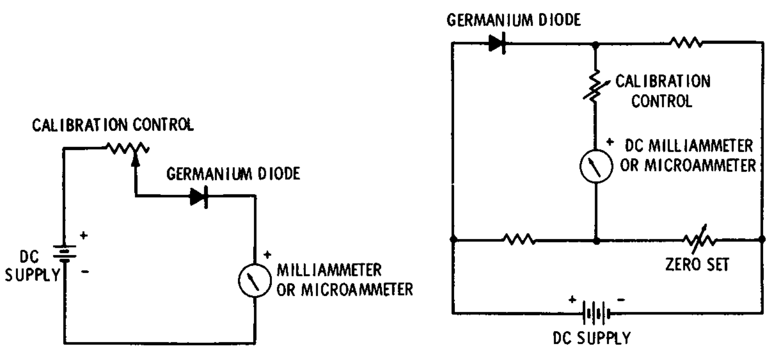
A maser in which the stimulated material (usually in a resonant chamber) is a solid substance. *See, for example,* Ruby Maser.

SOLID-STATE RELAY

A completely transistorized circuit in which the output stage, containing a power-type switching transistor, is preceded by one or more low-level switching stages. A small input signal applied to the low-level input of the circuit switches the output transistor in and/or out of its conducting state, switching power in an external circuit without the intermediary of an electromechanical relay.

SOLID-STATE THERMOMETER

An electronic thermometer circuit in which the sensor exploits the temperature-dependent resistance of a semi-



(A) Series circuit. (B) Bridge type.

Solid-state thermometer.

conductor, such as germanium. In its simplest form, this instrument employs a foward-biased germanium diode as the temperature sensor (see part A of the accompanying illustration). The sensor may also be connected in a bridge

circuit (part B) for improved sensitivity. In either circuit, a *thermistor* (which see) may be used in place of the diode.

SOLID-STATE THYRATRON

A term used sometimes to denote the silicon controlled rectifier and arising from the similarity between the behavior of the SCR and that of the thyratron tube. *See also* Silicon Controlled Rectifier.

SOLID-STATE TUBE

A semiconductor diode, rectifier, or transistor supplied in a housing having a plug base for insertion into the socket of an electron tube which it replaces. Example: Type 1N2632, which replaces the Type 5R4 rectifier tube.

SPARK-SUPPRESSOR DIODE

See **Suppressor Diode.**

STABISTOR

A type of forward-biased reference diode, often containing two or more diode elements, having closely controlled forward voltage characteristics. Such diodes are employed as low-voltage regulators, nonlinear bias units, and level shifters (in diode-transistor logic circuits). Example: Type 1N4156. *See also* Diode *and* Reference Diode.

SUN BATTERY

Another name for *solar battery* (which see).

SUPERBETA TRANSISTOR

A bipolar transistor having a very high common-emitter current amplification ratio (β, or h_{fe}). The designation is somewhat hazy, but in the superbeta device, beta can be

taken as 500 or higher (this corresponds to an alpha of 0.998 or higher). Example: Type 2N3230 (minimum $\beta = 1000$). *See also* Bipolar Transistor.

SUPPRESSOR DIODE

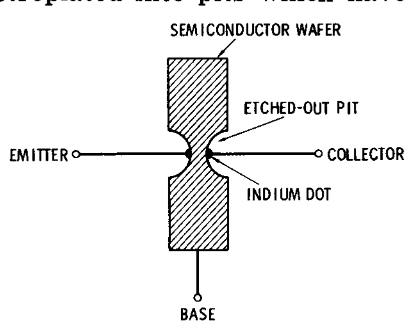
A zener diode or conventional diode used to suppress transients in an inductive circuit. The diode is connected so that it is reverse biased at normal circuit voltage and therefore offers virtually no load. A transient forward-biases the diode, however, and the diode conducts heavily, short-circuiting the high transient voltage that otherwise would damage switch or relay contacts or other circuit elements. The ideal suppressor diode is rated at low reverse leakage current, low forward resistance, and high instantaneous forward current and voltage. Also called *arc-suppressor diode, spark-suppressor diode,* and *contact protector.*

SURFACE BARRIER DIFFUSED TRANSISTOR

Abbreviation, *SBDT*. Another name for *microalloy diffused transistor* (which see).

SURFACE BARRIER TRANSISTOR

Abbreviation, *SBT*. A high-frequency transistor in which both the emitter and the collector are tiny dots (typically 0.003 inch in diameter) electroplated into pits which have

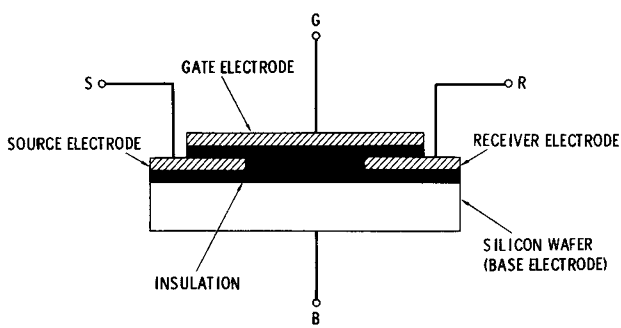


Surface barrier transistor.

been etched into the face of a semiconductor wafer. The two dots face each other across the thickness of the etched-out portion of the wafer. The extremely thin base layer and the small-area emitter and collector are responsible for the high-frequency capability of this transistor. In a typical unit, indium dots are plated onto a germanium wafer. Example: Type SB100. *See also* Transistor.

SURFACE-CHARGE TRANSISTOR

An experimental, transistor-like device utilizing the transfer of electric charges from input to output sections. In this device, the input electrode (the *source*) is a small metallic plate or deposit on top of a silicon-dioxide insulating film on one end of a silicon wafer (the *base* or *substrate*). The output electrode (the *receiver*) is a similar plate at the other end of the wafer. The control electrode (the *gate*) is a metal plate or deposit that overlaps the source and receiver, but is insulated from them by a continuation of the oxide film. A capacitor (the *input capacitor*) is formed by the source plate and the wafer, and a similar capacitor (the *output capacitor*) is formed by the receiver plate and the wafer. An input signal applied to the source charges the input capacitor. When a control signal is then applied to the gate, this signal moves the charge from the input capacitor to the output capacitor. The transferred charge then constitutes the output signal of the device and



Surface-charge transistor.

can under some circumstances produce a larger voltage than that of the input signal, thus exhibiting amplification. *See also* Transistor.

SURFACE-WAVE AMPLIFIER

An experimental, gain-producing device based upon the surface-wave filter (which see). An additional element in the amplifier is an electrode made of n-type silicon and isolated from the silicon substrate by means of a thin film of silicon dioxide. A dc bias is applied to this electrode, and the input signal is applied in series with the bias. Electron current in the silicon electrode interacts with the piezoelectric field of the filter and produces amplification in the output signal.

SURFACE-WAVE FILTER

An experimental, highly selective pass-type filter, which consists of a piezoelectric-crystal plate with a metallized electrode on each end. When an ac input signal of the proper frequency (determined by the dimensions of the plate) is applied to one of these electrodes, sound waves are produced in the plate, and these travel along the surface to the other electrode where an ac output signal is generated by piezoelectric action.

SWITCHING DIODE

A semiconductor diode exhibiting high forward current and characteristics, such as short recovery time and high-frequency cutoff, which ensure rapid, clean on-off operation. Such diodes are invaluable in computer and control circuits. Example: Type 1N777. Also called *high-speed diode*. *See also* Diode.

SWITCHING TRANSISTOR

A transistor (usually silicon) exhibiting low reverse leakage current, high switched-on current, and fast response—characteristics which ensure rapid, clean on-off operation. Such transistors are invaluable in computer and control circuits. Example: Type 2N2710. Also called *high-speed transistor*. *See also* Transistor.

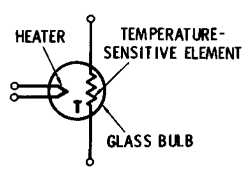
T

THERMISTOR

A specially fabricated temperature-sensitive resistor. A number of mixtures have been used in the bodies of thermistors, frequently encountered ones being oxides of cobalt, magnesium, manganese, and nickel. In some types, the thermistor differs in configuration from a conventional resistor only in the composition of its body. The temperature coefficient of a thermistor (in ohms/ohm/°C) may be specified closely and may be either positive or negative.

Thermistors are available in two principal classes: *directly heated* and *indirectly heated.* The directly heated type is exposed simply to the surrounding temperature or to the temperature of an object to which it is fastened. The indirectly heated type is supplied in a case with a nearby filament, and a control current is used to heat this filament and thereby to vary the resistance of the thermistor material. All thermistor response curves are nonlinear, and some reveal negative resistance.

(A) Directly heated.



(B) Indirectly heated.

Thermistor.

Thermistors are manufactured in a variety of shapes and sizes. The most common form resembles the conventional rod-type resistor, with axial or radial leads; other forms are washer, cylinder, disc, rectangular plate, doughnut, and bead. Thermistors are used in altimeters, anemometers, flowmeters, gas analyzers and alarms, heat sensors, and fire alarms. They also find use in some electronic circuits where their nonlinear conduction characteristic is desired and in electronic thermometers (*see* Solid-State Thermometer), radio-frequency wattmeters, temperature controllers, and vacuum gauges.

THIN-FILM IC

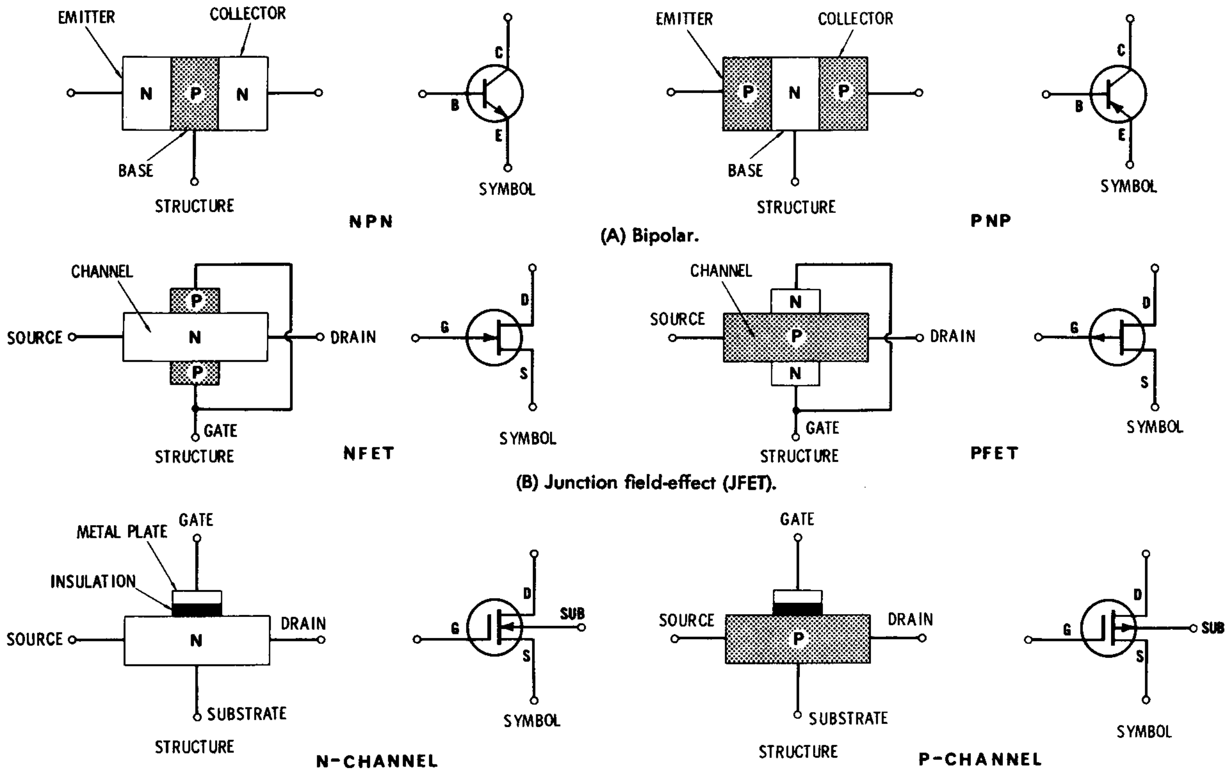
A type of integrated circuit in which suitable materials (such as semiconductors and metals) are deposited in a thin film on the semiconductor chip or wafer (substrate). Then, the resulting special areas are processed, as needed, to achieve complete integration and the desired electrical characteristics. It is somewhat as if the circuit, components, and interconnections were printed on the substrate and then blended into the latter. Transistors are not usually formed in this manner in integrated circuits, however. *Compare* Hybrid IC *and* Monolithic IC. *See also* Integrated Circuit.

THYRISTOR

Any one of a class of semiconductor devices providing thyratron-like on-off, phase-controlled, or triggered operation. For specific examples, *see* Diac, Four-Layer Diode, Silicon Controlled Rectifier, Silicon Controlled Switch, *and* Triac.

TRANSISTOR

A semiconductor amplifying device, usually with three elements. All transistors operate on the principle that under specified conditions an input signal (current or voltage, depending on the type of transistor) can control the flow of



(A) Bipolar.

(B) Junction field-effect (JFET).

(C) Insulated-gate field effect (IGFET).

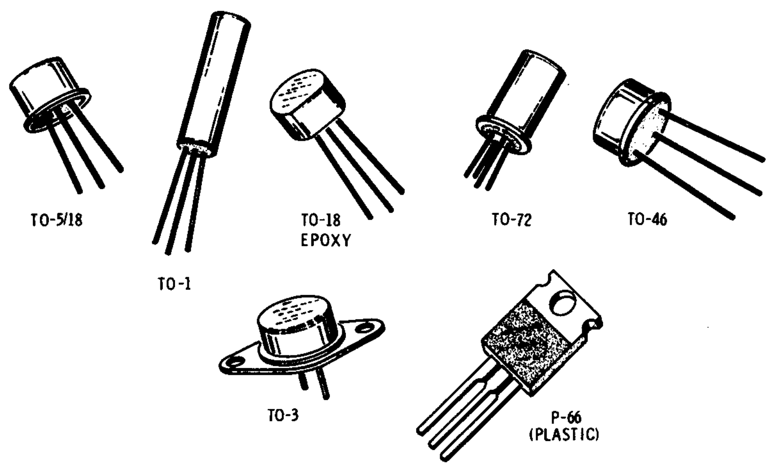
Transistor.

Transistor

output current carriers through a semiconductor. Amplification results from the greater-than-unity ratio of output signal to input signal.

Transistors may be classified broadly as *bipolar transistors* and *field-effect transistors*. In the bipolar type, the input signal is a current composed of minority carriers, whereas the output signal is a current composed of majority carriers. The bipolar transistor thus is a current-actuated device, and its effectiveness as an amplifier may be expressed as the ratio of output-current change to input-current change: *alpha* (α) or *beta* (β). In the field-effect transistor, the input signal is a voltage, and the electric field resulting from this voltage modulates the flow of current carriers through the semiconductor. The field-effect transistor thus is a voltage actuated device similar to the vacuum tube, and its effectiveness as an amplifier may be expressed as the ratio of output-current change to input-voltage change: *transconductance* (g_m).

The common bipolar transistor is a junction-type device that consists essentially of a wafer of semiconductor material (usually germanium or silicon) which has been processed



(D) Case styles.

Transistor.

to yield three layers, alternately n-type and p-type semiconductor (see part A of the accompanying illustration). A lead is attached to each of these layers. Depending on the sequence of the layers, a bipolar transistor is designated either npn or pnp. One endmost layer is termed the *emitter,* and the other endmost one the *collector;* the central layer is the *base.* (Roughly, the emitter corresponds to the cathode of a vacuum tube, the base to the grid, and the collector to the plate.) These layers are produced in a semiconductor wafer, disc, or chip by means of alloying, diffusing, or growing. The junctions between adjacent layers are essential to operation of the bipolar transistor.

There are two general types of field-effect transistor (abbreviated FET), *junction* type and *insulated-gate* type, depending on the nature of the gate electrodes. These types are described separately below.

Junction FET (JFET)

In its rudimentary form, this type consists of a thin bar of silicon with an ohmic (nonrectifying) connection made to each end. On each opposite face of the bar, a controlled amount of dopant is diffused in to create two parallel, facing strips or dots of the opposite kind of silicon. Thus, two p-type strips would be created in a bar of n-type silicon, or two n-type strips would be created in a bar of p-type silicon. Accordingly, a pn or np junction is formed between each strip and the bar, and this accounts for the name *junction FET* or *JFET.* The two strips are wired together externally and serve as the *gate* electrode; one bar-end connection is the *source* electrode, and the other bar-end connection is the *drain* electrode. (Roughly, the source corresponds to the cathode of a vacuum tube, the gate to the grid, and the drain to the plate.) In operation, the gate junction is reverse biased, and this accounts for the high input resistance and resulting voltage-actuated operation of the JFET.

Output current flows through the bar from source to drain (the passageway of this current through the semiconductor is termed the *channel*), and is controlled by the input-signal voltage applied to the gate, this voltage nar-

rowing or widening the channel. Depending on whether the channel is n-type or p-type silicon, the JFET may be called an *NFET* or *PFET*.

Insulated-Gate FET (IGFET)

In this type, the gate junction is dispensed with, and the input signal is applied to a small metal plate that is insulated from the semiconductor bar and is located where the junction would have been. (The plate is electrodeposited on top of a thin, insulating film of silicon dioxide that has been grown on the face of the bar.) This gate electrode accounts for the name *insulated-gate FET* or *IGFET*. When the input signal is applied to the insulated gate electrode, the resulting electric field penetrates into the channel, narrowing or widening the latter and accordingly controlling the flow of output current through it. Since the only input *current* that can flow is the infinitesimal leakage current of the gate insulation, the IGFET is even more a voltage-actuated device than is the JFET; consequently, the IGFET—like the vacuum tube—causes virtually no circuit loading. Depending on whether the channel is n-type or p-type silicon, the IGFET may be called an *n-channel IGFET* or *p-channel IGFET*.

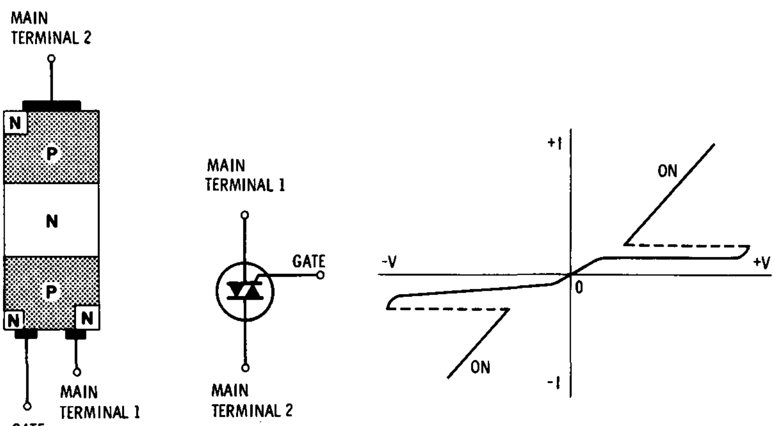
Transistor Types

Aside from their broad classification as either bipolar or field-effect, transistors (which are manufactured in a host of sizes, shapes, and ratings) are categorized in various other ways. For example, there are *small-signal transistors* and *power transistors*. According to principal application, there are *audio-frequency transistors, radio-frequency transistors, switching transistors,* and *general-purpose transistors*. According to semiconductor material employed, there are *germanium transistors* and *silicon transistors*. A transistor is *discrete* when it exists as a separate, individual component in the manner that a resistor or capacitor does; a transistor is *integrated* when it occurs within the structure of an integrated circuit as a result of the fabrication of the IC.

See also AF Transistor, Alloy-Junction Transistor, Chopper Transistor, Diffused Alloy Transistor, Diffused Transistor, Double-Diffused Transistor, Drift-Field Transistor, Epitaxial Transistor, Field-Effect Transistor, General-Purpose Transistor, Grown-Junction Transistor, Junction Transistor, Mesa Transistor, Metal-Oxide-Semiconductor Field-Effect Transistor, Microalloy Diffused Transistor, Microalloy Transistor, NPN Transistor, Overlay Transistor, Planar Transistor, PNP Transistor, Point-Contact Transistor, Power Transistor, Rate-Grown Transistor, RF Transistor, Single-Diffused Transistor, Small-Signal Transistor, Superbeta Transistor, Surface Barrier Diffused Transistor, Surface Barrier Transistor, Surface-Charge Transistor, Switching Transistor, Triple-Diffused Transistor, *and* Unijunction Transistor.

TRIAC

A three-terminal, five-layer, bidirectional, silicon switching device whose on-off switching action is similar to that of the silicon controlled rectifier (which see), except that the triac operates with either polarity of applied voltage and accordingly can switch either ac or dc. Examples: Type



(A) Structure. (B) Symbol. (C) Performance.

Triac.

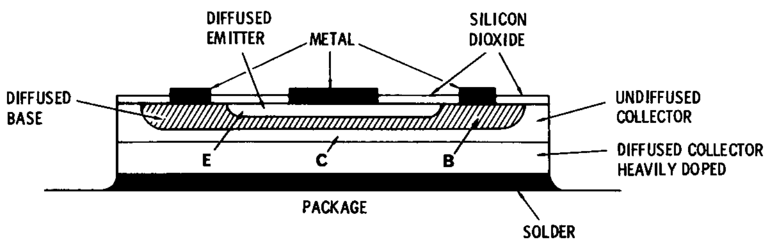
2N5567 (10 amperes, 200 volts), Type 40807 (30 amperes, 600 volts).

TRIGGER DIODE

A name sometimes given to the diac and four-layer diode (both of which see).

TRIPLE-DIFFUSED TRANSISTOR

A diffused transistor in which three separate diffusions are performed. Two of these are made at the top face of the semiconductor wafer and produce the base and emitter, as explained under Double-Diffused Transistor. The third is made through the bottom face of the wafer (which is the collector) and extends partway into the wafer, producing a diffused collector directly beneath an undiffused collector region. Example: Type 2N718A. *Compare* Single-Diffused Transistor *and* Double-Diffused Transistor. *See also* Diffused Transistor.



Triple-diffused transistor.

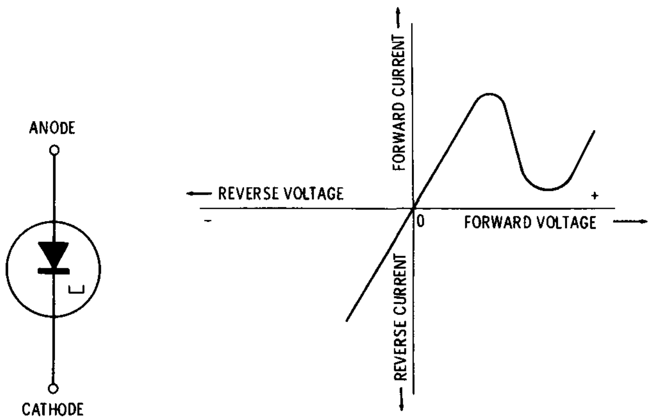
TUNING DIODE

A voltage-variable capacitor diode (which see) employed specifically as the variable capacitor in a tuned circuit.

TUNNEL DIODE

A heavily doped junction diode whose static conduction is characterized by a low front-to-back resistance ratio and

by a negative-resistance region in the forward portion of the curve. The unusual forward characteristic results from the phenomenon of *tunneling,* whereby low-energy carriers are able to tunnel under the barrier, as it were; this characteristic is completely explainable only in the complex ideas of quantum mechanics. The tunnel current flows immediately upon application of forward voltage and increases to a peak



(A) Symbol. (B) Conduction characteristic.

Tunnel diode.

(see part B of the accompanying illustration). It then decreases to a valley point as the forward voltage is increased (this resulting in the negative slope). Conventional diode forward current then flows, the current again rising as the forward voltage is further increased. The negative resistance of the tunnel diode suits this device to use in simple oscillators, amplifiers, switches, and gates. *See also* Diode *and* Junction Diode.

U

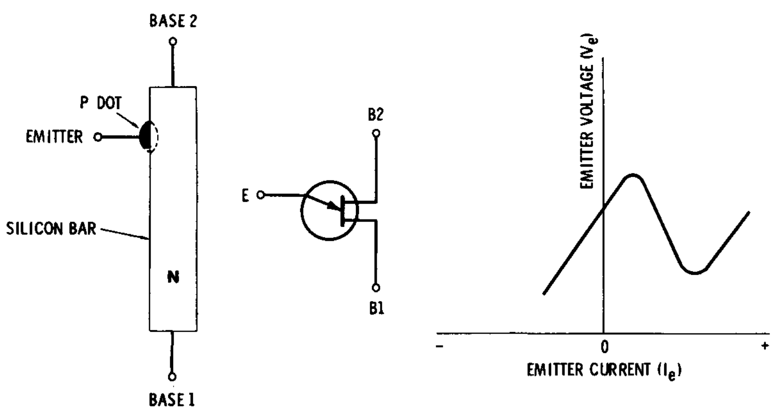
UJT

See **Unijunction Transistor.**

UNIJUNCTION TRANSISTOR

Abbreviation, *UJT*. A semiconductor device consisting essentially of a slender bar of n-type silicon having a single pn junction formed approximately one-quarter of the way down from the top end. Ohmic connections (*base 1* and *base 2*, respectively) are made to the top and bottom ends of the bar, and another connection is made to the p spot (the *emitter*). Typically, base 1 is grounded, base 2 is biased positive with respect to base 1, and a positive (emitter) signal voltage is applied to the p spot. Under these conditions, the lower half of the bar functions as an emitter and the upper half as a collector.

As the emitter current (I_e) of the unijunction transistor is increased, the emitter-to-base-1 voltage drop (V_e) increases to a peak point, then decreases to a valley point, and finally increases again (see part C of the accompanying illustration). The falling portion of the conduction curve—between the peak point and the valley point—indicates negative resistance, and it is this characteristic which suits the unijunction transistor to such applications as simple relaxation oscillators, pulse generators, trigger circuits, single-device multivibrators, frequency dividers, pulse amplifiers and the like. Example: Type 2N1671A. *See also* Transistor.



(A) Structure. (B) Symbol. (C) Performance.

Unijunction transistor.

V

VARACTOR

Another name for *voltage-variable capacitor diode* (which see).

VARICAP

Trade name (TRW Semiconductors) for *voltage-variable capacitor diode* (which see).

VARISTOR

Another name for *voltage-dependent resistor* (which see).

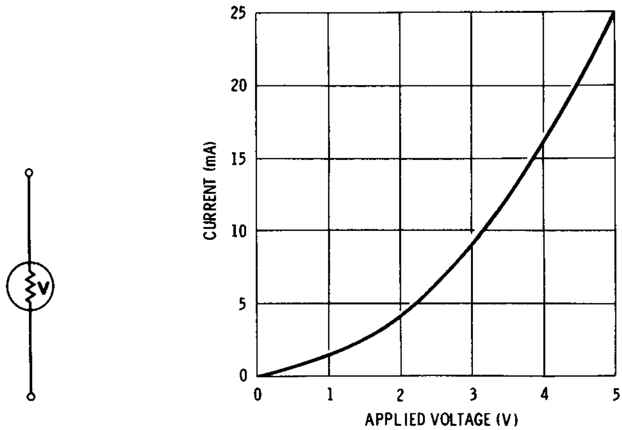
VDR

See **Voltage-Dependent Resistor.**

VOLTAGE-DEPENDENT RESISTOR

A specially fabricated two-terminal resistor whose resistance changes with applied voltage in a predictable manner. Several materials have been used in the bodies of voltage-dependent resistors, the most common being silicon carbide (Carborundum). In many models, the configuration of the voltage-dependent resistor differs from that of the conventional resistor only in the composition of its body. However, the response of the voltage-dependent resistor, unlike that of the conventional resistor, is nonohmic: For example, a 2-to-1 increase in applied voltage results in more than a 2-to-1 increase in current.

Voltage-dependent resistors are manufactured in a variety of shapes, sizes, and ratings. The most common form resembles the conventional rod resistor, with axial or radial leads. Other forms are bar, cylinder, disc, doughnut, flat



(A) Symbol. (B) Typical performance.

Voltage-dependent resistor.

plate, and washer. Voltage-dependent resistors are also called by the names *VDR, ceramic resistor, nonlinear resistor,* and *thyrite resistor.*

Applications of voltage-dependent resistors include color-tv degausser, curve changer, equipment protector, harmonic generator, lightning arrester, telephone-line bridge, transient suppressor, tv automatic height control, tv damper, tv horizontal-output regulator, and voltage regulator.

VOLTAGE-REFERENCE DIODE

Another name for *reference diode* (which see).

VOLTAGE-REGULATOR DIODE

Another name for *zener diode* (which see).

VOLTAGE-VARIABLE CAPACITOR DIODE

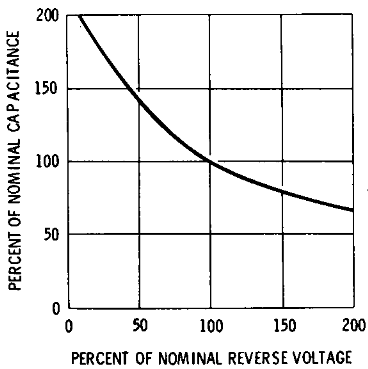
Abbreviation, *VVCD.* A specially processed silicon diode that exploits the voltage-variable capacitance of the reverse-biased pn junction. The capacitance is inversely proportional to the applied voltage and a capacitance change of 2 to 1

for a prescribed voltage change is common. Such diodes are employed extensively as tuning capacitors, frequency multipliers, dielectric amplifiers, parametric amplifiers, capacitive potentiometers, and kindred applications.

As a frequency multiplier, especially at microwave frequencies, the voltage-variable capacitor diode is well known by the name *varactor*. The VVCD also goes under various trade names, some of them being *Capsil, Epicap, paramp diode, Semicap, silicon capacitor, Varicap,* and *Voltacap.*

See also Diode *and* Junction Diode.

(A) Symbol.



(B) Approximate performance.

Voltage-variable capacitor diode.

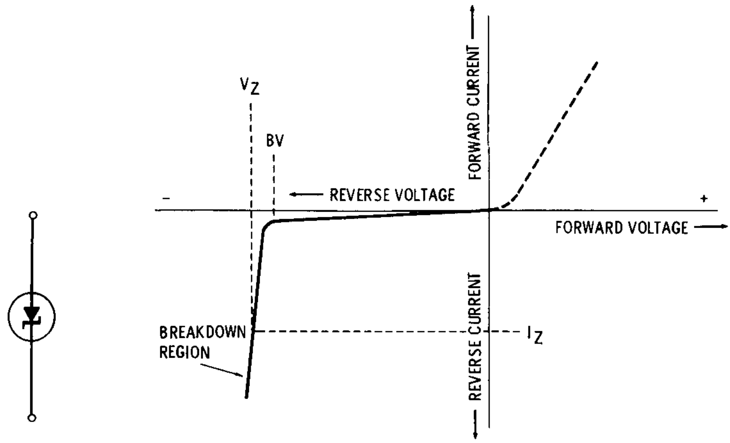
VVCD

See **Voltage-Variable Capacitor Diode.**

Z

ZENER DIODE

A specially processed silicon diode whose reverse volt/ampere characteristic exhibits a sharp, nondestructive breakdown at a predetermined reverse voltage. In the breakdown region, a small reverse-voltage increment produces a large reverse-current increment. An operating point within



(A) Symbol. (B) Conduction characteristic.

Zener diode.

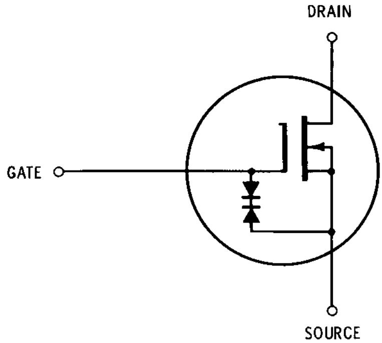
the breakdown region corresponds to the rated *zener voltage* (V_Z) and *zener current* (I_Z) of a given diode. The host of such diodes now available offer zener voltages from 0.77 volt (for example, Type 1N3896) to 580 volts (for example, Type 1N580) and zener currents from 0.1 milliampere (for example, Type 1N1946) to 3.2 amperes (for example, Type 1N4557B).

The breakdown characteristic of the zener diode suits this device to such applications as voltage regulation, limiting, signal compression, overvoltage protection, clamping, and voltage standardization. In the steep-sloped breakdown region, the voltage drop across the diode (zener voltage) is substantially constant for large changes in diode current. In the forward direction, the conductive curve of the zener diode is similar to that of the conventional semiconductor diode.

See also Diode *and* Junction Diode.

ZENER-PROTECTED MOSFET

A metal-oxide-semiconductor field-effect transistor in which the gates are protected by means of back-to-back



Zener-protected MOSFET.

zener diodes. When the gate signal is excessive or when a potentially damaging static charge has accumulated on the gate electrodes, the diodes break down and conduct heavily, short-circuiting this voltage and protecting the thin gate insulation from puncture. Example: Type 3N187.

See also Metal-Oxide-Semiconductor Field-Effect Transistor *and* Zener Diode.

Symbols and Abbreviations Used With Solid-State Devices

A—Ampere(s), area
A_i—Current amplification
A_p—Power amplification
A_v—Voltage amplification
B—Base, battery
$BaTiO_3$—Barium titanate
BV—Breakdown voltage
BW—Bandwidth
C—Capacitance, capacitor, collector, Celsius (temperature)
CdS—Cadmium sulfide
C_J—Junction capacitance
C_t—Total capacitance
D—Diameter, drain, diode
d—Thickness
E, e—Voltage, emitter
E_f—Feedback voltage
E_i—Input voltage
E_L—Load voltage
E_o—Output voltage
E_p—Peak voltage
f—Frequency, fundamental
f_c—Center frequency, cutoff frequency
f_{co}—Cutoff frequency
FET—Field-effect transistor
f_{in}—Input frequency
FL—Full load
f_o—Center frequency, initial frequency
f_r—Resonant frequency
G—Gate, conductance
GaAs—Gallium arsenide
GaP—Gallium phosphide
Ge—Germanium
g_{fs}—Common-source forward transconductance
G_m, g_m—Transconductance
g_{oss}—Common-source output conductance
h—Harmonic
h_{fe}—Common-emitter forward current transfer ratio
h_{ie}—Common-emitter input impedance
h_{oe}—Common-emitter output admittance
h_{re}—Common-emitter reverse voltage transfer ratio
h_{11}—Input impedance
h_{12}—Reverse transfer voltage ratio
h_{21}—Forward transfer current ratio
h_{22}—Output admittance
I, i—Current

I_b—Base current
IC—Integrated circuit
I_c—Collector current
I_{co}—Cutoff current
I_D—Drain current
I_e—Emitter current
I_F—Forward current
I_f—Feedback current
I_G—Gate current
IGFET—Insulated-gate field-effect transistor
I_L—Load current, inductive current
I_R—Reverse current
I_S—Source current
I_s—Current source
I_t—Total current
I_Z—Zener current
JFET—Junction field-effect transistor
K—A constant depending on the kind of semiconductor and its processing. Boltzmann's constant.
k—Dielectric constant
LED—Light-emitting diode
mA—Milliampere(s)
MADT—Microalloy diffused transistor
MAT—Microalloy transistor
MOS—Metal-oxide-semiconductor (same as MOSFET)
MOSFET—Metal-oxide-semiconductor field-effect transistor
MOST—Metal-oxide-semiconductor transistor (same as MOSFET)
n—Electron-rich semiconductor
N_D—Noise density
NF—Noise figure
nF—Nanofarad(s)
NFET—N-channel field-effect transistor
nH—Nanohenry(s)
NL—No load
np—Two-layer structure in semiconductor
npn—Transistor structure with n-type emitter and collector and p-type base
npnp—Four-layer semiconductor structure
ns—Nanosecond(s)
NTC—Negative temperature coefficient
P—Power
p—Hole-rich semiconductor
pA—Picoampere(s)
PbS—Lead sulfide
PC—Photocell, point-contact
P_c—Collector power
P_D—Power dissipation
P_{DM}—Maximum allowable power dissipation
P_e—Emitter power
PEP—Planar transistor structure employing epitaxial crystal growth and protective passivation
P_F—Forward power
P_f—Feedback power
pF—Picofarad(s)

PFET—P-channel field-effect transistor
PG—Power gain
P_i—Input power
pin—Semiconductor structure consisting of consecutive p-type, intrinsic-type, and n-type layers
pn—Two-layer structure in semiconductor
pnp—Transistor structure with p-type emitter and collector and n-type base
P_o—Power output
ps—Picosecond (s)
PTC—Positive temperature coefficient
P_Z—Zener power
Q—Quantity of electricity, transistor symbol, figure of merit ($Q = X/R$)
R, r—Resistance, resistor
R_b—Base resistance
R_c—Collector resistance
R_D—Drain resistance
R_e—Emitter resistance
R_F—Forward resistance
R_f—Feedback resistance
R_G—Gate resistance
R_i—Input resistance
R_L—Load resistance
rms—Root-mean-square value
R_o—Output resistance
R_p—Parallel resistance
R_R—Reverse resistance
R_S—Source resistance
R_t—Total resistance
R_Z—Zener resistance
S—Source
SBDT—Surface-barrier diffused transistor
SBT—Surface barrier transistor
SCR—Silicon controlled rectifier
SCS—Silicon controlled switch
Se—Selenium
Si—Silicon
SS—Solid state
Sub—Substrate
T—Thermistor, temperature, transformer
t—Time, time constant
T_b—Body temperature
TC—Temperature coefficient, thermocouple
TD—Tunnel diode
TiO_2—Titanium dioxide
UJT—Unijunction transistor
V—Varistor (voltage-dependent resistor), volt (s), voltage
VA—Volt-ampere (s)
V_b—Base voltage
V_c—Collector voltage
V_D—Drain voltage
VDR—Voltage-dependent resistor
V_e—Emitter voltage

V_F—Forward voltage
V_G—Gate voltage
V_N—Noise voltage
V_P—Gate-source pinchoff voltage
V_p—Peak voltage, pump voltage
VR—Voltage regulator
V_R—Reverse voltage
V_S—Source voltage
V_s—Voltage at the source (generator)
VVCD—Voltage-variable-capacitor diode
V_Z—Zener voltage
W—Watt(s), energy, work
X_c—Capacitive reactance
X_L—Inductive reactance
X_t—Total reactance
Y—Admittance
Z_b—Base impedance
Z_c—Collector impedance
Z_D—Drain impedance
Z_e—Emitter impedance
Z_F—Forward impedance
Z_G—Gate impedance
Z_g—Generator impedance
Z_i—Input impedance
Z_o—Output impedance
Z_p—Parallel impedance
Z_S—Source impedance
Z_s—Source (generator) impedance, series impedance
Z_Z—Zener impedance

SYMBOLS AND ABBREVIATIONS INVOLVING GREEK LETTERS

α—Current amplification factor of common-base-connected transistor. Temperature coefficient of resistance.
β—Current amplification factor of common-emitter-connected transistor
Δ—Increment
δ—Dissipation constant
η—Rectification efficiency
θ—Angle, temperature coefficient
τ—Thermal time constant
ϕ—Contact potential
Ω—Ohm(s)
ω—$2\pi f$, megohms