Walker, Rob. "Silicon Genesis: Oral Histories of Semiconductor Industry Pioneers: Interview with Gordon E. Moore: March 3, 1995." Transcription by Dag Spicer, Department of History, Stanford University Libraries, 1996.

—*Gordon Bell*

MOS/CMOS

Metal oxide semiconductor (MOS) and complementary MOS (CMOS) refer to the technology used in the fabrication of certain **integrated circuits**. MOS and CMOS transistors are not built out of individual components—they are etched on a **silicon** plate by carving the different components out of a metallic and silicon oxide substrate. A silicon plate is used because its oxide is a good insulator.

Transistors are basic electronic elements that can be used to amplify signals, as **digital** switches, or to provide a given resistance. There are two basic types of MOS transistors: *n-doped* and *p-doped*. The first type is negatively doped at the source and drain, the second positively—hence the n and p prefixes.

A bipolar transistor is built on top of a silicon wafer by sandwiching a p-type layer between two n-type regions, or vice versa. Silicon is a crystal with a regular atomic structure. When some elements are added to the material (using diffusion, for example), electrons can be set free (n-doping) or *holes* arise, that is, positions in the atomic bindings that are more stable when an electron is captured (p-doping). Adding arsenic, for example, creates n-doped silicon and adding boron produces p-doped silicon. Figure 1 is a diagram of an n-MOS transistor. The metallic gate is not in contact with a p-doped layer. A layer of silicon dioxide isolates the metal from the p-doped semiconductor.

The purpose of the n-MOS transistor is to implement a digital switch with two states, open or closed. If the voltage at the gate is low, electrons cannot flow from the drain to the source, because the p-doped material acts as a barrier, and therefore the switch is open. But if the gate is set to a higher voltage (higher than a certain threshold), electrons are attracted to the gate, forming a conducting channel that allows electricity to flow from the n-doped drain to the n-doped source. The switch is now closed. A p-MOS transistor has a similar structure, but the n-doped and p-doped regions are interchanged, and the gate voltage must be inverted. The design with an insulated gate is called a field-effect transistor (FET).

When an n-MOS or p-MOS transistor is closed, there is a flow of electricity between source and drain. MOS transistors are fast but consume too much energy in their 1 state. CMOS components provide a solution. A CMOS switch is built out of two MOS transistors, an n-MOS and a p-MOS transistor, placed side by side. CMOS design is now the dominant technology for the implementation of **microprocessors**, memories, and other chips, because of its lower power dissipation. CMOS circuits consume energy only when they switch state, not in their static modes.

The operation of a CMOS element can be illustrated by considering a CMOS inverter. Figure 2 shows a schematic design of such a circuit. The p-type transistor has been drawn connected to the 5-V line and with a gate that receives the inverted input (the small circle means *inversion*). The n-type transistor is connected to ground. Note that there is no direct connection between the 5-V line and ground. When the input is negative, the p-type transistor closes, the n-type transistor is open, and the output line is connected to 5 V. When the input is positive (a

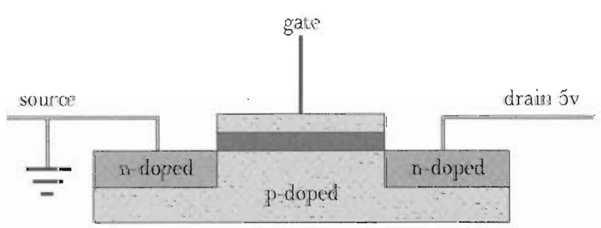

Figure 1 *n-MOS transistor.*

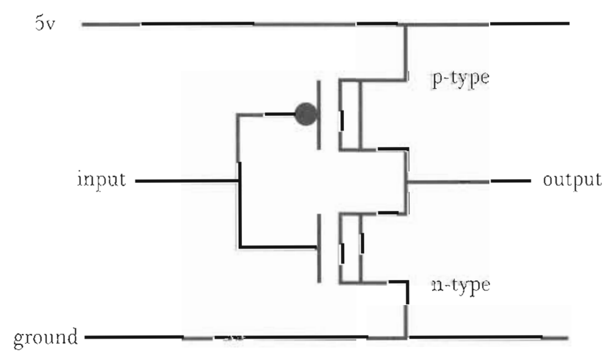

Figure 2 *CMOS design.*

	Electron-tube era	
1901	J. C. Bose	Vacuum rectifier
1902	Ambrose Fleming	Vacuum tube (diode)
1906	G. W. Pichard and L. W. Austin	Crystal detector
1907	Lee de Forest	Audion three-electrode tube (triode)
1918	Czochralski	Method of pulling crystals from the melt
1925	Julius Edgar Lilienfeld	Principle of the field-effect transistor
1934	Oskar Heil	Structure of the junction field-effect transistor
1938	W. Schottky	Schottky-barrier diode
	Bipolar transistor era	
1947	J. Bardeen, W. H. Brattain, and W. Shockley	Germanium point contact transistor
1948	W. Shockley	Germanium junction transistor
1950	W. J. Pietenpohl and R. S. Ohl	Silicon bipolar transistor
1951	G. K. Teal and E. Buehler	Germanium single crystal
1952	G. K. Teal and E. Buehler	Silicon single crystal
1952	Texas Instruments	Commercial production, silicon bipolar transistor
1953	Keck, H. C. Theuerer, and Emeis	Float-zone processing
1957	R. C. Sangster	Vapor-phase epitaxial growth
	Integration era	
1959	Jack S. Kilby	Monolithical integrated circuit
1959	Robert N. Noyce	Planar junction field-effect transistor
1958	Jean A. Hoerni	Planar surface field-effect transistor
1959	Gordon E. Moore and Robert N. Noyce	Planar technology
1960	H. C. Theuerer, J. J. Kleinach, H. H. Lour, and H. Christensen	Epitaxial diffused transistor
1960	J. A. Hoerni	Silicon planar process
1960	D. Kahny and M. M. Atalla	MOS field-effect transistor
1961	Fairchild Semiconductor	First commercial digital integrated circuit
	MOS transistor era	
1962	Fairchild Semiconductor	MOS integrated circuits
1963	Frank Wanlass, Fairchild Semiconductor	CMOS integrated circuits
	Application era	
1967	Dalbergh Hearing Aids	First hearing aid worn in the ear
1968	Hodges et al.	MOS 64-bit RAM memory
1968	Fairchild Semiconductor	µmA709 operational amplifier
1970	Dennard, IBM	One-transistor dynamic memory cell
1970	Marcian E. Hoff, Intel	1103 4-kbit DRAM
1971	Intel	4004 4-bit microprocessor
1972	Intel	8008 8-bit microprocessor
1974	Intel	8080 8-bit microprocessor
1981	J. W. Beyers et al., Hewlett-Packard	450,000-transistor microprocessor
1984	[several contributors]	Megabit memory chip
1995	[several contributors]	Experimental gigabit memory chip

Figure 3. *Timetable of the electronic era.*

1 in the input), the n-type transistor closes, the p-type transistor opens and the output line is therefore connected to ground. The circuit thus transforms a 0 into a 1 and a 1 into a 0. Many other logical operations, such as OR and AND, can be implemented using CMOS designs.

When comparing this circuit with a simple n-MOS or p-MOS transistor, the important point to notice is that the only time when there is a flow of electricity between the 5-V line and ground is when the state of the transistors is switched. This is the only moment in which energy is consumed. When the output has been set and the circuit has stabilized, there is no energy consumption except for charge leaks at the gate. In this design the gate is like a small capacitor that has to be replenished or depleted at each change of state.

In 1963, Frank Wanlass and C. T. Sah, engineers at Fairchild, applied for a patent on CMOS technology. Although CMOS electronic elements are slower than bipolar transistors, they consume 10 times less power, and many more transistors can be integrated on a chip when the power requirements are reduced. The introduction of CMOS technology therefore paved the way for VLSI (very large scale integration) chips. In 1991, Frank Wanlass received the Solid-States Circuits Award from the **Institute of Electrical and Electronics Engineers** for "pioneering contribution to high-speed dynamic memory design and cell technology."

Further Reading

Baker, Jacob, Harry Li, and David Boyce. *CMOS Circuit Design, Layout, and Simulation.* New York: IEEE Press, 1998.

Morris, P. R. *A History of the World Semiconductor Industry.* London: Peregrinus IEE, 1990.

Riordan, Michael, and Lillian Hoddeson. *Crystal Fire: The Birth of the Information Age.* New York: Norton, 1997.

—*Raúl Rojas*

Motherboard

In a **personal computer** (PC), the motherboard is the base onto which the main electronic components, such as the processor and memory, are soldered. Expansion boards are connected to the motherboard by inserting them into expansion slots. Motherboards for **IBM** PC–compatible computers are dominant in the microcomputer industry.

The figure shows an example of a commercial motherboard. The processor (a **Pentium** II) is inserted in a special slot. Having a slot for the processor is very convenient, since it can be replaced when a better model becomes available. In this way the rest of the **hardware** investment can be preserved. The DIMM sockets are used to plug-in memory chips in DIMM (dual-in-line memory module) packages. In this example there are also some connectors for floppies, hard drives, and parallel and serial ports.

The **BIOS** (basic input output software) is stored in a **ROM** (read-only memory) chip that contains the basic code to control the computer. The battery in the figure is used to keep the computer clock running. Expansion slots are quite prominent in this motherboard: three ISA (industry standard architecture) and three PCI (peripheral component interconnect) slots are present. The AGP (accelerated graphics port) chipset is used to speed up the display of computer graphics on the screen, especially three-dimensional images.

The USB (universal serial bus) is a new kind of "**plug and play**" interface that makes it possible to connect peripherals without having to add an expansion card to the motherboard. USB is a standard developed by several companies, which have made it available to other computer manufacturers free of charge. The power connector takes a set of different voltage levels from the power source and delivers them to all components using metallic lines etched on the motherboard, possibly in several layers. Other types of boards include the daughter card (those that connect to a motherboard), controller cards (used to interface a peripheral to the motherboard), a network interface card (NIC, used to connect the computer to a **local area network**), and video cards (used to control the screen).

There are many parameters that differentiate motherboards, such as the number of processors that can be plugged in, the clock speed, the maximum data transfer rate of the local bus, the BIOS used, and the amount of maximum memory that can be added to the system. Although, in theory, upgrading a computer by buying a new motherboard should be easy, in practice it can be very difficult because there are so many available options, and very detailed knowledge of all the hardware is needed.