fused later with the Professional Group on Electronic Computers of the IRE. The **Association for Computing Machinery** (ACM) was formed at around the same time as the subcommittee within the AIEE.

The IEEE organizes hundreds of technical conferences every year and publishes proceedings volumes and many high-quality journals. Eight of the most important journals in electrical and electronic engineering are from the IEEE, as are seven of the most important journals in telecommunications, and seven more in computer hardware and architecture. IEEE journals are now available online, so that researchers all over the world have ready access to them; past issues are sold scanned in **CD-ROM**. In fact, the IEEE produces 30 percent of the technical literature about electronics and computers published in the world.

The IEEE is governed by a board of directors and an executive committee. The president is elected for one year and presides over 10 regions and 36 technical societies (the Computer Society being only one of them). The board of directors decides on the recipients of annual awards given to distinguished scientists. Included are the Internet Award, the Andrew Grove Award, and the Undergraduate Teaching Award, established to promote high-quality teaching standards at U.S. universities.

Education is a major concern of the IEEE, which has always fostered the establishment of student chapters at universities. Students can take part in the main conferences and organize many special activities for other students. For a low fee, students can have an electronic subscription to all IEEE journals in a certain field, for example computing.

The IEEE logo shows an arrow within a rhombus, representing the direction of an electric field, with the circle around the arrow representing the magnetic field. The rhombus, taken from the logo of the AIEE, represents Benjamin Franklin's kite, used in his famous experiment on the electric nature of thunderstorms.

—Raúl Rojas

Instruction Set

The collection of basic commands that can be executed directly by the processor of a computer is called the *instruction set*. It can consist of just a few basic commands or hundreds of instructions. The instruction set delimits the capabilities of the machine; from the viewpoint of the programmer, it represents the machine.

The first programmable computer, the **Z1** built by **Konrad Zuse** (1910–95) from 1936 to 1938, had an instruction set of just eight instructions: addition, subtraction, multiplication, and division of two numbers, load from memory and store to memory, as well as reading a decimal number from the keyboard and displaying a decimal result in a panel. Curiously, the first large-scale electronic computer, the **ENIAC**, which was officially presented in 1945, had no instruction set; the ENIAC was programmed by running wires from one unit to another, replicating in this way the **data flow** of the computation.

Modern **microprocessors** are produced in families that are downward compatible at the object code level—that is, the programs compiled for one member of the family can be run by a newer processor. This means that the instruction set can only be expanded, not reduced. One current example is the **Pentium** family of microprocessors, which have added some instructions from generation to generation while preserving compatibility with old programs.

Sometimes a distinction is made between complex instruction set computers (CISC) and **reduced instruction set computers** (RISC). CISCs were produced in the 1970s and 1980s. The CISC instruction sets was optimized in relation to the size of the code, and this favored complex and powerful primitive instructions. RISC machines, in contrast, use simpler instructions but more of them in a single program. Since the individual instructions are simpler, they can be executed in parallel or overlapped, saving time and resources.

An important question in computer architecture is: Which minimal instruction set will still allow the programmer to write any conceivable program? **Alan Turing** (1912–54) designed a computer in the late 1940s that could actually work using a single command: The MOVE A B instruction would only transport a number from memory register A to register B. But every register (and there were several of them) performed a different computation on arrival of each number: One

register added the new number to its old contents, another subtracted, another was cleared, and so on. In this way any computation can be performed by moving information around in these special machine registers.

Contemporary computer architects develop the instruction set for a computer by simulating the microprocessor first. They write a compiler for the first draft of the instruction set, let some benchmark programs run, and then tune the instruction set, adding or deleting instructions, until they get the fastest machine. Only then is the actual hardware design begun.
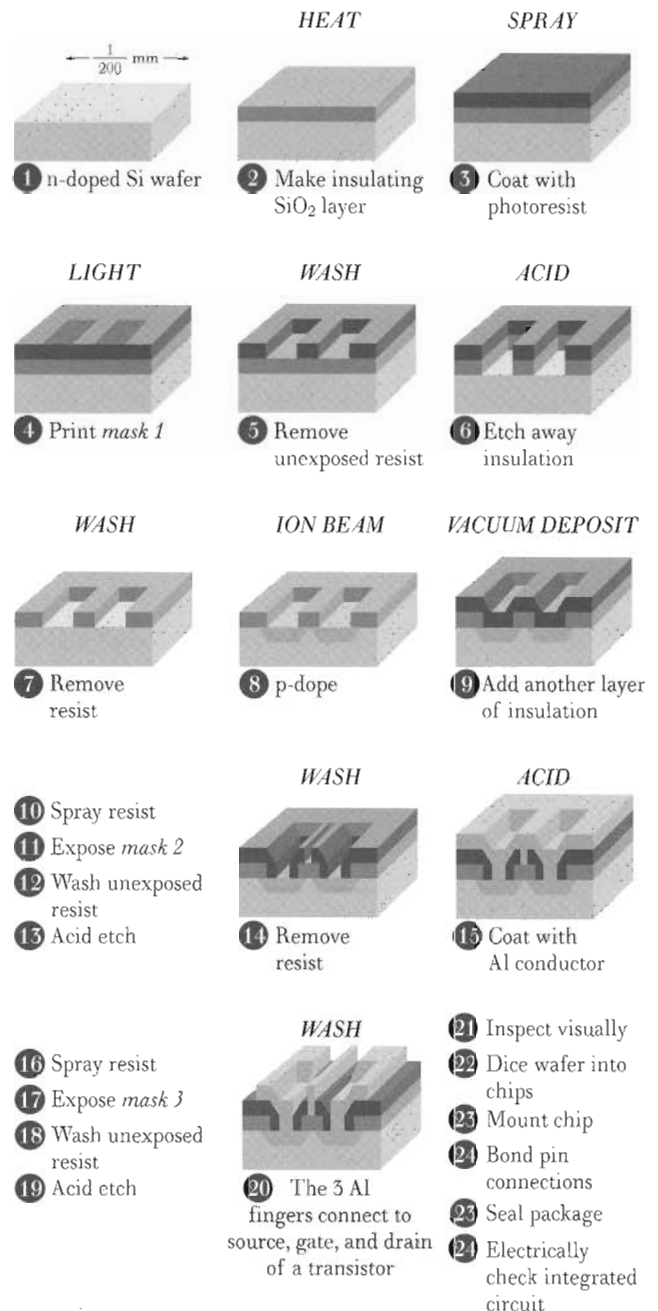
—*Raúl Rojas*

Integrated Circuit

An integrated circuit is a device in which all **transistors** and other logical and electronic components are manufactured in a single multistep process. Today's integrated circuits usually consist of a **silicon** base on which millions of components can be etched.

In the early 1950s, Geoffrey Dummer (1909–) was developing and testing radar units in the United Kingdom. He observed that the smaller and simpler a unit was, the better it stood up to stress tests. He reasoned that the unit did not need to be functionally simpler, but that a smaller number of separate components improved reliability. At a U.S. conference in 1952 he clearly described a solid block of interconnected components based on the **semiconductor** materials in use for transistors and arranged a small research project with Plessey, a European company. By 1957 they showed an unsuccessful device 4 millimeters (mm) square, but funding was not available to pursue the idea. There were no problems constructing a number of transistors on a block of treated silicon, but electrically isolating parts of them and connecting other regions to form circuits proved difficult.

Dummer's vision was well understood in the United States, and it was **Jack Kilby** (1923–) at **Texas Instruments** (TI) who produced the first working device, an oscillator, in mid-1958. He had experience with chemically treated (or *doped*) ceramics and with shaping them precisely by coating the surface with a light-sensitive paint (*photoresist*), reducing a pattern

(or *mask*) photographically to expose the regions he wanted to preserve, chemically removing the unexposed regions of photoresist, etching these regions with acid, then chemically removing the photoresist mask (overall, this is *photolithography*). The components in Kilby's device were shaped for isolation and interconnected manually using tiny wires soldered under a microscope. Texas Instruments coined the term *inte-*

1. n-doped Si wafer
2. Make insulating SiO$_2$ layer — *HEAT*
3. Coat with photoresist — *SPRAY*
4. Print *mask 1* — *LIGHT*
5. Remove unexposed resist — *WASH*
6. Etch away insulation — *ACID*
7. Remove resist — *WASH*
8. p-dope — *ION BEAM*
9. Add another layer of insulation — *VACUUM DEPOSIT*
10. Spray resist
11. Expose *mask 2*
12. Wash unexposed resist
13. Acid etch — *WASH*
14. Remove resist
15. Coat with Al conductor — *ACID*
16. Spray resist
17. Expose *mask 3*
18. Wash unexposed resist
19. Acid etch
20. The 3 Al fingers connect to source, gate, and drain of a transistor — *WASH*
21. Inspect visually
22. Dice wafer into chips
23. Mount chip
24. Bond pin connections
25. Seal package
26. Electrically check integrated circuit

Fabrication sequence for one transistor on an integrated circuit.