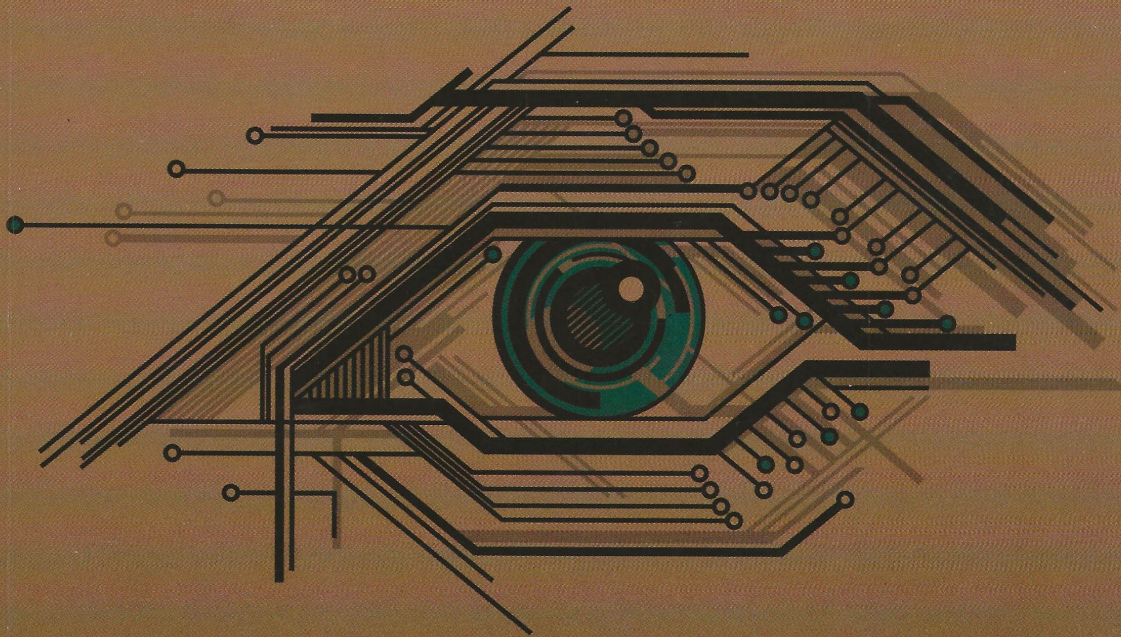


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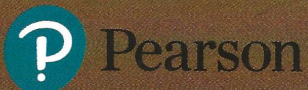
SEVENTH EDITION

SOLID STATE ELECTRONIC DEVICES



BEN G. STREETMAN

SANJAY KUMAR BANERJEE



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growth rate of these markets. If one were to plot IC sales as a function of time, one again finds a more-or-less exponential increase in sales with time over three decades. Of great importance to the consumer, the cost per electronic function has dropped dramatically over the same period. For example, the cost per bit of semiconductor memory (DRAM) has dropped from about 1 cent/bit in 1970 to about 10^{-5} cent per bit today, an improvement of five orders of magnitude in 45 years. There are no parallels in any other industry for this consistent improvement in functionality with such a lowered cost.

Although ICs started with bipolar processes in the 1960s, they were gradually supplanted by MOS and then by CMOS devices, for reasons discussed in Chapters 6 and 7. Currently, about 90% of the IC market is MOS based and about 8% BJT based. Optoelectronic devices based on compound semiconductors are still a relatively small component of the semiconductor market (about 4%), but are expected to grow in the future. Of the MOS ICs, the bulk are digital ICs. Of the entire semiconductor industry, only about 14% are analog ICs. Semiconductor memories such as DRAMs, SRAMs, and non-volatile flash memories make up approximately 25% of the market, microprocessors about 25%, and other application-specific ICs (ASICs) about 20%.

Now we shall consider the various elements that make up an integrated circuit, and some of the steps in their fabrication. The basic elements are fairly easy to name—transistors, resistors, capacitors, and some form of interconnection. There are some elements in integrated circuits, however, which do not have simple counterparts in discrete devices. We shall consider one of these, charge transfer devices, in Section 9.4. Discussion of fabrication technology is difficult in a book of this type, since device fabrication engineers seem to make changes faster than typesetters do! Since this important and fascinating field is changing so rapidly, the reader should obtain a basic understanding of device design and processing from this discussion and then search out new innovations in the current literature.

9.3 MONOLITHIC DEVICE ELEMENTS

9.3.1 CMOS Process Integration

A particularly useful device for digital applications is a combination of n-channel and p-channel MOS transistors on adjacent regions of the chip. This *complementary MOS* (commonly called *CMOS*) combination is

illustrated in the basic inverter circuit of Fig. 9-4a. In this circuit the drains of the two transistors are connected together and form the output, while the input terminal is the common connection to the transistor gates. The p-channel device has a negative threshold voltage, and the n-channel transistor has a positive threshold voltage. Therefore, a zero voltage input ($V_{in} = 0$) gives zero gate voltage for the n-channel device, but the voltage between the gate and source of the p-channel device is $-V_{DD}$. Thus the p-channel device is on, the n-channel device is off, and the full voltage V_{DD} is measured at V_{out} (i.e., V_{DD} appears across the nonconducting n-channel transistor). Alternatively, a positive value of V_{in} turns the n-channel transistor on, and the p-channel off. The output voltage measured across the "on" n-channel device is essentially zero. Thus, the circuit operates as an inverter—with a binary "1" at the input, the output is in the "0" state, whereas a "0" input produces a "1" output. The beauty of this circuit is that one of the devices is turned off for either condition. Since the devices are connected in series, no drain current flows, except for a small charging current during the switching process from one state to the other. Since the CMOS inverter uses ultra little power, it is particularly useful in applications such as electronic watch circuits that depend on very low power consumption. CMOS is also advantageous in ultra large-scale integrated circuits (Section 9.5), since even small power

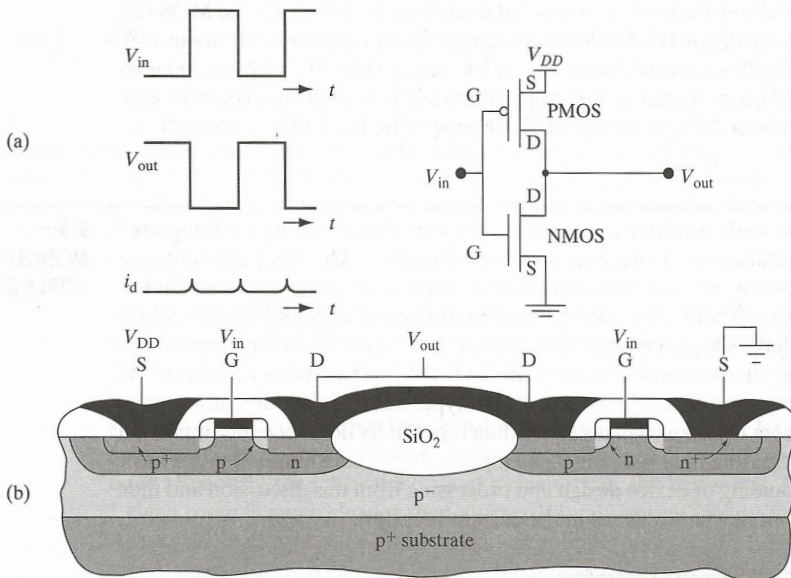


Figure 9-4

Complementary MOS structure: (a) CMOS inverter; (b) formation of p-channel and n-channel devices together.