

ULSI Technology

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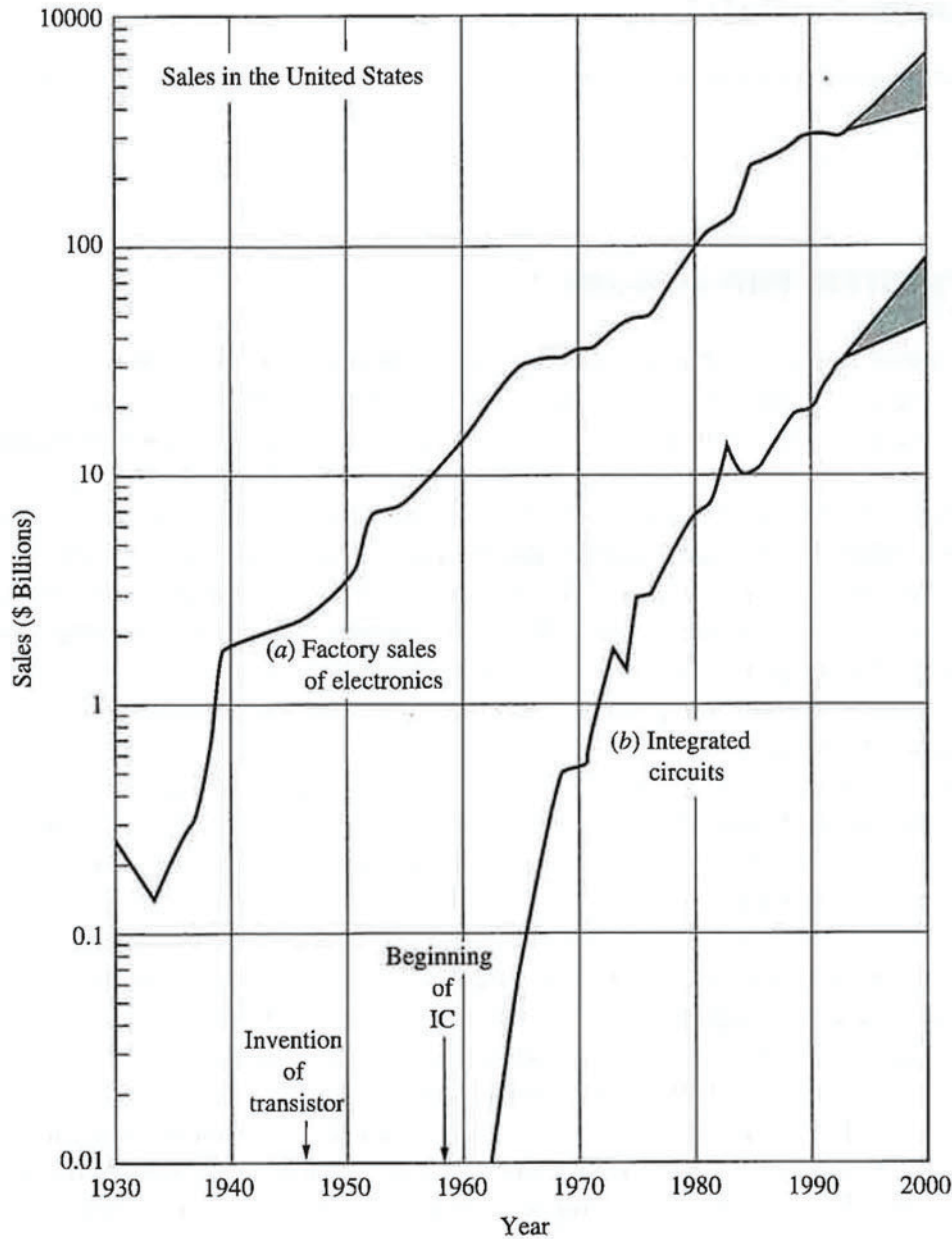
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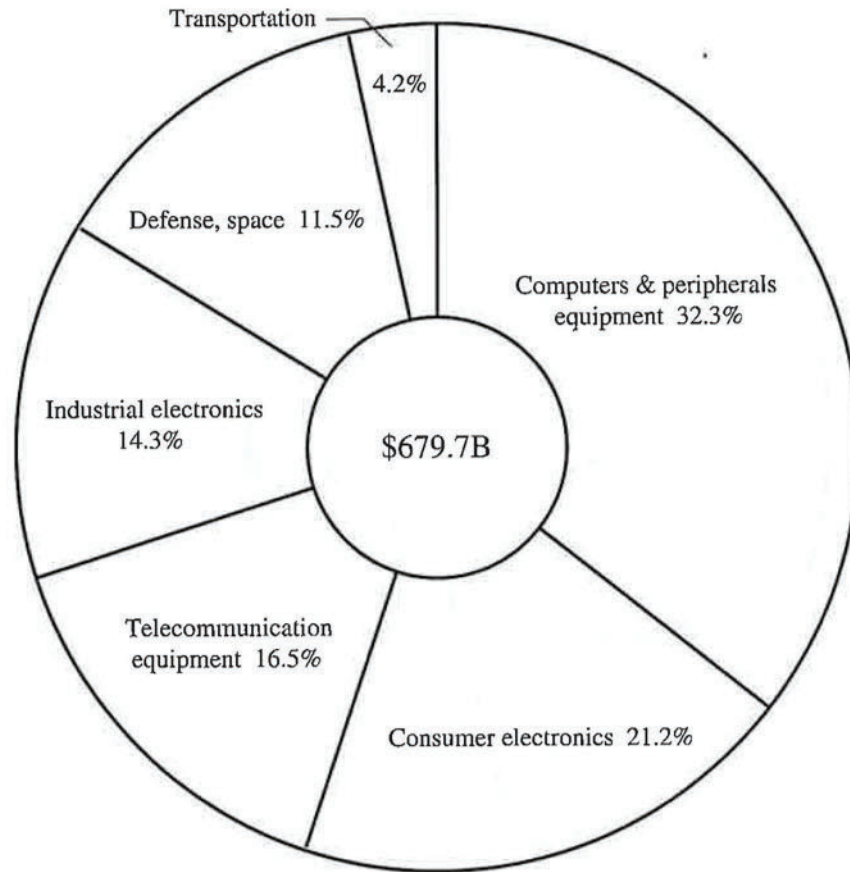
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**FIGURE 1**

(a) Factory sales of electronics in the United States for the 64 years between 1930 and 1993 and projected to 2000. (b) Integrated circuit market in the United States for 32 years between 1962 and 1993 and projected to 2000. (After Refs. 1 and 2.)

DEVICE MINIATURIZATION

Figure 5, curve (a), shows the rapid growth in the number of components per MOS memory chip.^{4,5} Note that the MOS IC complexity has advanced from small-scale integration (SSI), to medium-scale integration (MSI), to large-scale integration (LSI), to very-large-scale integration (VLSI), and finally to ultralarge-scale integration (ULSI), which has 10^7 or more components per chip. We note that since 1975 the growth has been maintained at a rate of about 40% annually; in other words, the

**FIGURE 2**

1993 world electronics industry. (After Dataquest, 1994.)

number of components has doubled every two years. At this rate, over 100 million components per chip will be available before the year 2000; in the early 21st century we will move into the gigabit range, with IC chips having more than one billion components.^{6,7} Also shown in Fig. 5 is the growth of the number of components for bipolar, MESFET, and MODFET ICs. They are about two orders of magnitude lower in complexity compared with MOS-based ICs.

The most important factor in achieving the ULSI complexity is the continued reduction of the minimum device-feature length [see Fig. 6, curve (a)]. Since 1960, the annual rate of reduction has been 13%, which corresponds to a reduction by a factor of two every six years. At this rate, the minimum feature length will shrink from its present length of 0.5 μm to 0.2 μm in the year 2000. The junction depth of the source and drain junctions, and the gate oxide thickness are also being reduced at a similar rate as shown in curves (b) and (c) of Fig. 6, respectively.

The reduction of the device feature length and related dimensions has resulted in reduced overall device size and unit price per function. Figure 7 shows the relative price and size reductions.⁸ In the past fifty years, prices have gone down by 100 million times, and the size has been reduced by a factor of one billion. By 2000 the price per bit is expected to be less than 0.1 millicent for a 64-megabit memory chip. Similar price reductions are expected for logic ICs. Additional benefits from device

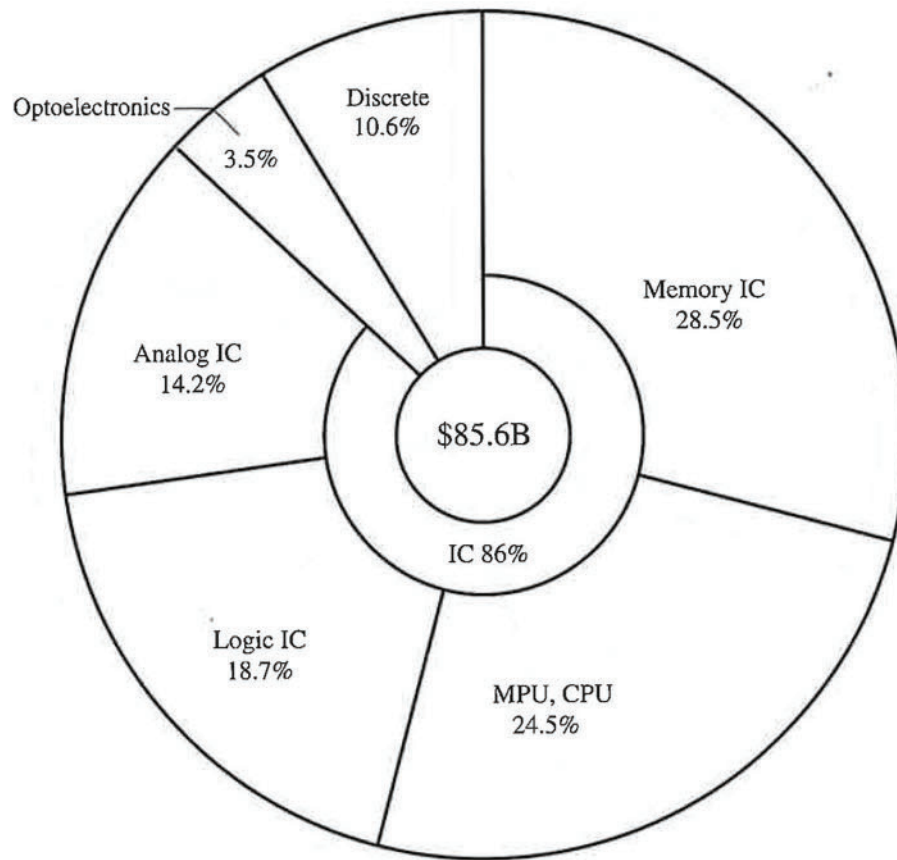


FIGURE 3
1993 world semiconductor industry. (After Dataquest, 1994.)

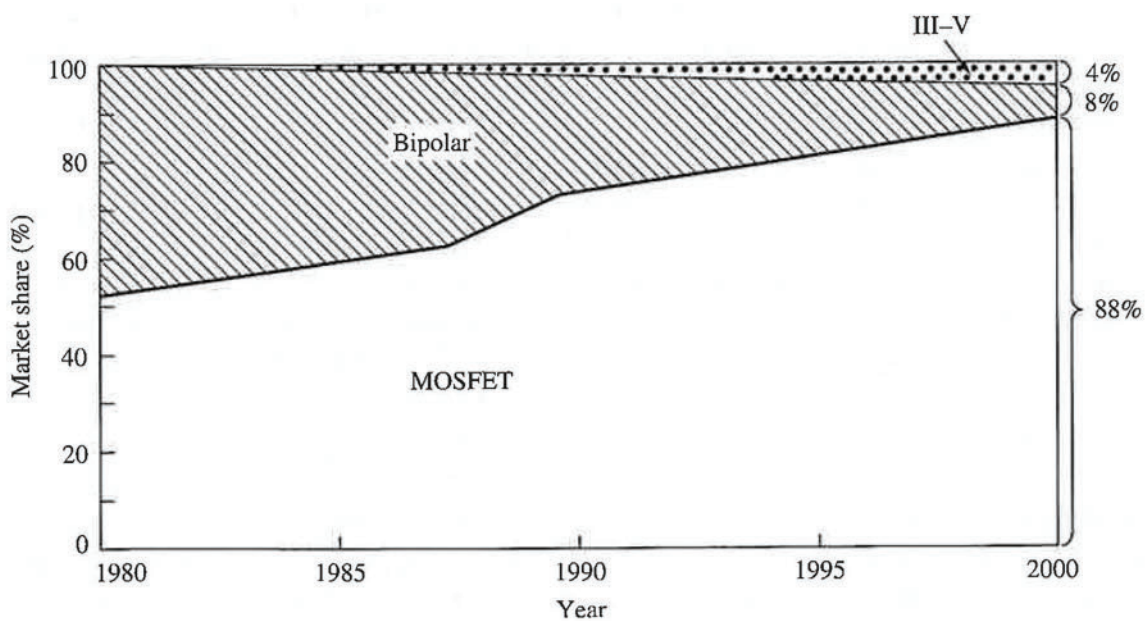
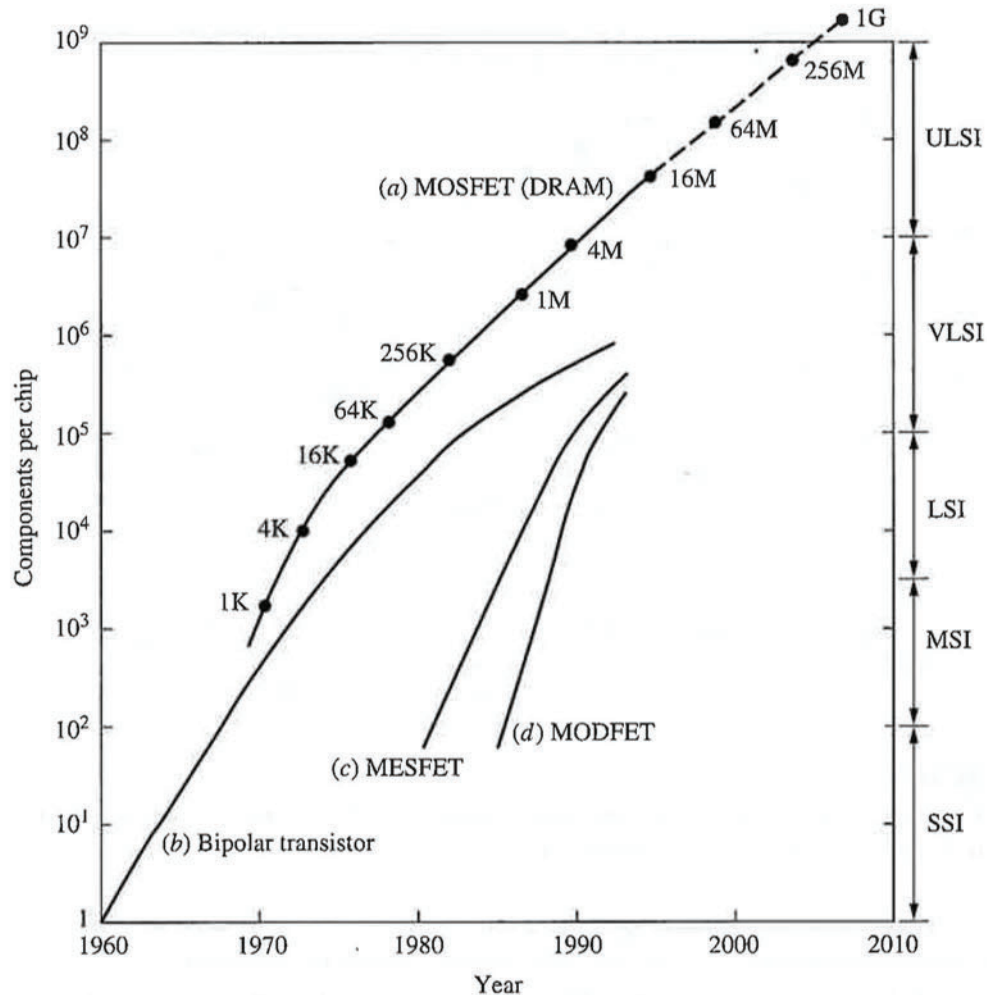


FIGURE 4
World IC market (1980–2000). (After Zdebel, Ref.3.)

**FIGURE 5**

(a) Exponential growth of the number of components per MOS IC chip. (After Moore, Ref. 4, and Myers, Ref. 5.) (b), (c), and (d) Components per chip versus year for bipolar, MESFET, and MODFET ICs, respectively.

miniaturization include improvement of device speed (which varies inversely with the device feature length) and reduction of power consumption (which varies approximately with the square of the feature length). Higher speeds lead to expanded IC functional throughput rates, so that future ICs can perform data processing, numerical computation, and signal conditioning at 100 and higher gigabit-per-second rates.⁹ Reduced power consumption results in lowering the energy required for each switching operation. Since 1960 the required energy, called the *power-delay product*, has decreased by six orders of magnitude.¹⁰

ORGANIZATION OF THE BOOK

Figure 8 shows how the 12 chapters of this book are organized. Chapter 1 considers cleanroom technology. The continued miniaturization in ULSI devices implies more