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Peter Van Zant

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A Practical Guide to Semiconductor Processing

Peter Van Zant

Fifth Edition

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Microchip Fabrication

This edition is dedicated to two exceptional women, Marilyn (Van Zant) O'Connor and Anne Miller. Marilyn is my lovely and loving sister. She is also my good friend, enthusiastic supporter, and a wise confidant. Thanks, sis.

For over twenty years Anne has been a collaborator, business partner, and friend. Her wise business counsel and contributions to this text are greatly appreciated.

Preface to the Fifth Edition

Despite recessions, the microchip industry continues its evolutionary march to the physical limits of silicon-based ICs. Fortunately, the end seems always just over the hill, and the industry keeps chugging along. Unfortunately, keeping a textbook current with the advances in microchip fabrication means frequent updates. Hence this fifth edition.

This edition follows the same chapter sequence as the previous editions. Hopefully, this will assist instructors in upgrading their course curriculums. Fortunately, the basics of semiconductor device operation and wafer processing remain the same and will be found in this edition.

My thanks go to Steve Chapman, my editor at McGraw-Hill. His guidance and patience with my writing schedule are appreciated.

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Last, but not least, thanks to my wife Mary Dewitt for enduring my 5:30 A.M. writing sessions and her unending support.

About the Author

Peter Van Zant is an internationally known semiconductor professional with an extensive background in process engineering, training, consulting, and writing. Principal of Peter Van Zant Associates, a firm that supplies writing, training, and consulting services to business and industry, he is the author of *Semiconductor Technology Glossary,* Third Edition; *Integrated Circuits Text; Safety First Manual;* and *Chip Packaging Manual.* His books and training materials are used by chip manufacturers, industry suppliers, colleges, and universities. Peter Van Zant Associates' customers include Intel, National Semiconductor, Applied Materials, Air Products and Chemicals, SCP Global Inc., and a number of educational institutions. Mr. Van Zant is also the elected District 1 Supervisor in his home county of Nevada in California.

Contents

Chapter

1

The Semiconductor Industry

Overview

In this chapter, you will be introduced to the semiconductor industry with a description of the historic product and process developments and the rise of semiconductors into a major world industry. The major manufacturing stages, from material preparation to packaged product, are introduced along with the mainstream product types, transistor building structures, and the different integration levels. Industry product and processing trends are identified.

Objectives

Upon completion of this chapter, you should be able to:

1. Describe the difference between discrete devices and integrated circuits.
2. Define the terms “solid-state, “planar processing” and “N-type” and “P-type” semiconducting materials.
3. List the four major stages of semiconductor processing.
4. Explain the integration scale and at least three of the implications of processing circuits of different levels of integration.
5. List the major process and device trends in semiconductor processing.

Birth of an Industry

The electronics industry got its jump start with the discovery of the audion vacuum tube in the 1906 by Lee Deforest.[1] It was made possible the radio, television, and other consumer electronics. It also was the brains of the world's first electronic computer, named the Electronic Numeric Integrator and Calculator (ENIAC), first demonstrated at the Moore School of Engineering in Pennsylvania in 1947.

This ENIAC hardly fits the modern picture of a computer. It occupied some 1500 square feet, weighed 30 tons, generated large quantities of heat, required the services of a small power station, and cost $400,000 in 1940 dollars. The ENIAC was based on 19,000 vacuum tubes along with thousands of resistors and capacitors (Fig. 1.1).

A vacuum tube consists of three elements: two electrodes separated by a grid in a glass enclosure (Fig. 1.2). Inside the enclosure is a vacuum, required to prevent the elements from burning up and to allow the easy transfer of electrons.

Tubes perform two important electrical functions: *switching* and *amplification*. Switching refers to the ability of an electrical device to turn a current on or off. Amplification is a little more complicated. It is the ability of a device to receive a small signal (or current) and amplify it while retaining its electrical characteristics.

Vacuum tubes suffer from a number of drawbacks. They are bulky and prone to loose connections and vacuum leaks, they are fragile, they

Size, ft	30 × 50
Weight, tons	30
Vacuum Tubes	18,000
Resistors	70,000
Capacitors	10,000
Switches	6000
Power Requirements, W	150,000
Cost (in 1940)	$400,000

Figure 1.1 ENIAC statistics. *(Source:* Foundations of Computector Technology, *J. G. Giarratano, Howard W. Sams & Co., Indianapolis, IN, 1983.)*

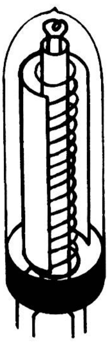


Figure 1.2 Vacuum tube.

require relatively large amounts of power to operate, and their elements deteriorate rather rapidly. One of the major drawbacks to the ENIAC and other tube-based computers was a limited operating time due to tube burn-out. However, the world did not recognize the potential of computers early on. IBM Chairman, Thomas Watson, in 1943, ventured that, “I think there is a worldwide market for maybe five computers.”

These problems were the impetus leading many laboratories around the country to seek a replacement for the vacuum tube. That effort came to fruition on December 23, 1947, when three Bell Lab scientists demonstrated an electrical amplifier formed from the semiconducting material germanium (Fig. 1.3).

This device offered the electrical functioning of a vacuum tube but added the advantages of being solid state (no vacuum), being small and lightweight, and having low power requirements and long lifetime. First named a *transfer resistor,* the new device soon became known as the *transistor.*

The three scientists, John Bardeen, Walter Brattin, and William Shockley were awarded the 1956 Nobel Prize in physics for their invention.

The Solid-State Era

That first transistor was a far distance from the high-density integrated circuits of today. But it was the component that gave birth to the solid-state electronics era with all its famous progeny. Besides transistors, solid-state technology is also used to create diodes, resistors, and capacitors. Diodes are two-element devices that function in a circuit as an on/off switch. Resistors are monoelements devices that serve to limit current flow. Capacitors are two-element devices that store charge in a circuit. In some integrated circuits, the technology is used to create fuses. Refer to Chapter 14 for an explanation of these concepts and an explanation of how these devices work.

Figure 1.3 The first transistor.

These devices, containing only one device per chip, are called *discrete* devices (Fig. 1.4). Most discrete devices have less-demanding operational and fabrication requirements than integrated circuits. In general, discrete devices are not considered leading-edge products. Yet, they are required in most sophisticated electronic systems. In 1998, they accounted for 12 percent of the dollar volume of all semiconductor devices sold.[2] The semiconductor industry was in full swing by the early 1950s, supplying devices for transistor radios and transistor based computers.

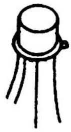
Integrated Circuits (ICs)

The dominance of discrete devices in solid-state circuits came to an end in 1959. In that year, Jack Kilby, a new engineer at Texas Instruments in Dallas, Texas, formed a complete circuit on a single piece of the semiconducting material germanium. His invention combined several transistors, diodes, and capacitors (five components total) and used the natural resistance of the germanium chip (called a *bar* by Texas Instruments) as a circuit resistor. This invention was the *integrated circuit*, the first successful integration of a complete circuit in and on the same piece of a semiconducting substrate.

The Kilby circuit did not have the form that is prevalent today. It took Robert Noyce, then at Fairchild Camera, to furnish the final piece of the puzzle. In Fig. 1.5 is a drawing of the Kilby circuit. Note that the devices are connected with individual wires.

Earlier, Jean Horni, also at Fairchild Camera, had developed a process of forming electrical junctions in the surface of a chip to create a solid-state transistor with a flat profile (Fig. 1.6). The flattened profile was the outcome of taking advantage of the easily formed natural oxide of silicon, which also happened to be a dielectric (electrical insulator). Horni's transistor used a layer of evaporated aluminum, that was patterned into the proper shape, to serve as wiring for the device. This technique is called *planar technology*. Noyce applied this technique to

- Transistors
- Diodes
- Capacitors
- Resistors



Discrete Diode Package

Figure 1.4 Solid-state discrete devices.