SEMICONDUCTORS

By Helmut Wolf

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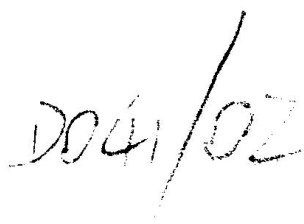

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Preface

For the last few years the market for integrated circuits has grown at a more rapid rate than the gross national product. Compared to 1966, the GNP in 1970 has increased by 32%, whereas the semiconductor IC market has increased by 254%. The worldwide market for semiconductor products will increase from 2.5 billion dollars in 1970 to 4.0 billion dollars annually in 1980. These figures indicate the importance and the impact of the semiconductor industry, although the integrated circuit sector represents only 0.02% of the GNP.

The basis for the generation and fabrication of integrated circuits and other semiconductor products lies in an advanced semiconductor technology. Since the advent of the transistor in 1948, semiconductor technology has progressed at a very rapid rate. In part this has been made possible by solving the problem of obtaining hyperpure semiconductor materials. Silicon continues to be the dominant material used for discrete devices and integrated circuits. Other semiconductors, notably germanium and gallium arsenide, have established themselves as significant materials, although their percental usage is relatively small.

The purpose of this book is to give in concise form the most significant information on most semiconductors of practical interest, mainly in semiconductor technology and semiconductor device fabrication. In its organization it falls almost exactly in the middle between a handbook and a textbook, although the distinction usually is rather fundamental. It is certainly intended for reference use and should serve as a useful handbook for people involved in semiconductor research and development. On the other hand, it can serve as a brief text since it has more or less complete continuity and can be read completely. It does not try to be all-exhaustive or all-inclusive but attempts to be a practical book which gives answers to the every-day questions of semiconductor workers.

The purpose of the book is twofold. First, it summarizes the theoretical aspects of semiconductor behavior, generally without resorting to derivations of equations; for deeper background information the reader is referred to the various available textbooks. Second, it gives a selection of experimental and other data necessary for the design and understanding of the operation of semiconductor devices. However, a detailed discussion of semiconductor devices is not given here, except for simple *p-n* junctions, mainly because

these are special cases of *p-n* junctions, surface or bulk structures, whereas the topics selected for this book have been of more fundamental and general nature. It is intended to complement the author's book "Silicon Semiconductor Data"* where the emphasis has been on a graphical presentation of mostly experimental data on silicon. In this book the emphasis is on an understanding of the nature of semiconductor phenomena and related subjects.

Structurally the book starts with a discussion of general semiconductor properties including a review of crystals as far as necessary for an understanding of semiconductor behavior, the energy band structure, and characteristics of degenerate and nondegenerate semiconductors. Then the properties of various semiconductors are compared. Thermal, optical, and etching characteristics of semiconductors are then discussed. Doping techniques are described in the second chapter which treats ion implantion as an alternative to solid-state diffusion. It includes also the growth of epitaxial films. In the third chapter the electrical behavior of semiconductors is reviewed. Since the properties of semiconductors change with the addition of foreign atoms, their effect on carrier density, mobility, resistivity, and others is discussed. The properties of silicon dioxide, still the most widely used insulator in semiconductor technology, are given in the fourth chapter. This includes the oxidation of silicon surfaces, impurity redistribution at the semiconductor surface during thermal oxidation, diffusion of impurities in silicon dioxide, and its masking capabilities. Chapter five gives the properties of semiconductor surfaces and of metal-semiconductor interfaces and discusses the formation of barriers at the interfaces. The sixth chapter describes the properties of *p-n* junctions, i.e., depletion layer, avalanche breakdown, capacitance, electric field, and others. In the seventh chapter a few common semiconductor measurement techniques are discussed.

The numerical values of properties given in this book do not necessarily represent the most accurate or the most complete values obtained, although every effort has been made to include the latest available figures. For more extensive information the reader is referred to the excellent compilation of data on various semiconductors by Mrs. Meta Neuberger at the Electronic Properties Information Center (EPIC), Hughes Aircraft Company.

The critical review of the manuscript by Dr. A. Ballonoff and the constructive criticism of the chapter on Metal-Semiconductor Contacts by Dr. A. N. Saxena are greatly appreciated.

Sunnyvale, California
August 1971

HELMUT F. WOLF

* Published by Pergamon Press, Oxford, 1969.

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