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Introduction to Space Charge Effects in Semiconductors

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Preface

This short *Introduction into Space Charge Effects in Semiconductors* is designed for teaching the basics to undergraduates and show how space charges are created in semiconductors and what effect they have on the electric field and the energy band distribution in such materials, and consequently on the current–voltage characteristics in semiconducting devices.

Such space charge effects were described previously in numerous books, from the classics of Spenke and Shockley to the more recent ones of Seeger and others. But many more detailed information were only available in the original literature and some of them not at all. It seems to be important to collect all in a comprehensive Text that can be presented to students in Physics, Electrical Engineering, and Material Science to create the fundamental knowledge that is now essential for further development of more sophisticated semiconductor devices and solar cells.

This book will go through every aspect of space charge effects and describe them from simple elementaries to the basics of semiconductor devices, systematically and in progressing detail.

For simplicity we have chosen this description for a one-dimensional semiconductor that permits a simple demonstration of the results graphically without requiring sometimes confusing perspective rendering.

In order to clarify the principles involved, the book starts with a hypothetical model, by assuming simple space charge distributions and deriving their effects on field and potential distributions, using the Poisson equation. It emphasizes the important sign relations of the interreacting variables, space charge, field, and potential (band edges).

It then expands into simple semiconductor models that contain an abrupt nn-junction and gives an example of important space charge limited currents, as observed in nn^+-junctions.

In the following chapters, the developing of space charges in more realistic semiconductors are discussed. For this discussion it is assumed that the student is already familiar with the energy band model in solids, knows the difference between electron and hole transport and understands the basics of the transport equations, including the carrier mobility and the action of an (external) electric field. It is also assumed that he is familiar with the basic thermodynamics of solids, including the concept of Fermi levels, as well as of nonequilibrium conditions when external excitations, e.g., optical excitations are present. We will, therefore, refer in the following presentation only briefly to the concept of quasi-Fermi levels which then will be used extensively here.

Such space charges will be first discussed in simple Schottky barriers, where these processes are most easily understood. The book will begin in a simple n-type semiconductor with one type of donors that can trap charges and are the principle facilitators of space charges when the conditions at the semiconductor surface are fixed and are different from the volume. The book then proceeds to include multiple trap levels at different energies and discusses in more detail the shape of current–voltage characteristics.

It then includes optical excitation and its influence on the space charge, and gives as a practical example a Schottky barrier description as part of an abrupt heterojunction.

The book proceeds with including electrons and holes In the next chapters. It expands the discussion to include minority carriers, carrier generation, recombination, and trapping, and uses quasi-Fermi and demarcation levels to distinguish between traps and recombination centers and their relevance to optical excitation and carrier transport. Here the differences between thermal equilibrium and steady state are explained and current continuity equations are introduced. The effect of carrier lifetimes on currents is described. Minority carrier currents and their interrelation with majority carrier currents are discussed and generation–recombination currents are analyzed under a variety of conditions, including surface recombination.

The concepts of diffusion velocity and drift-assisted diffusion, as well as drift-assisted generation–recombination currents are discussed.

Here it becomes important to distinguish between different types of fields, the built-in fields as they occur in space charge regions, and the external fields created by an applied voltage.

Now the book proceeds to a more comprehensive discussion of a variety of pn-junctions, their behavior with and without light in a number of typical devices. The analytical description, presenting solution curves of the complete set of transport – Poisson and continuity equations is divided into thin devices and thick devices in which two parts of the devices have different dominant transport properties.

All chapters are appended with a brief Summary and Emphasis section and with a number of Exercise Problems for students to familiarize themselves with the important findings discussed in the preceding chapter.

The book contains two chapters as appendix that may be added to the curriculum, depending on the background of the students, dealing with the basic carrier transport equations.

I would like to thank my friend Professor Dieter Bimberg for reminding me that my material he had on his desk needs some upgrading and editing to make it available to future generations of students as a text.

I would like to acknowledge the dedicated help I received from Ms. Anita Schwartz of the Information Technology Department of the University of Delaware to assist me in composing the text of this book.

My special thanks goes to Renate, my wife, who expected me to be truly retired and spend more time relaxing with her, while I was most of the days in my office, trying to find the proper way to explain in writing to future students and colleagues the intricacy of the field of space charges in semiconductors.

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