Semiconductor Radiation Detectors

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Device Physics

With 167 Figures and 11 Tables

Springer

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Cover picture: A large area double sided silicon detector and several small detector and test structures fabricated on a silicon wafer of four inch diameter in the MPI Semiconductor Laboratory at Munich. (Foto Filser)

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Preface

Semiconductor detectors for nuclear radiation and particles have experienced a rather rapid development in the last few years. Although these developments have been documented in a large number of publications, it seemed useful to collect this information in the form of an introductory textbook that also includes the basic concepts behind the most recent developments.

The book is intended to serve as a basis for academic teaching as well as a guide and reference for all those active in the development or use of semiconductor detectors.

Semiconductor detectors are now used in a large variety of fields in science and technology, including nuclear physics, elementary particle physics, optical and x-ray astronomy, medicine, and materials testing – and the number of applications is growing continually. Closely related, and initiated by the application of semiconductors, is the development of low-noise low-power integrated electronics for signal readout.

The success of semiconductor detectors is due to several unique properties that are not available with other types of detectors. Examples of these properties are: the combination of extremely precise position measurement with high readout speed; direct availability of signals in electronic form; the simultaneous precise measurement of energy and position; and the possibility of integrating detector and readout electronics on a common substrate.

It is worth noting that all these developments have grown out of the need to provide investigative tools for basic research – in this case for elementary particle physics – and also that the fruits of these developments are now of benefit to other fields of science and technology.

In presenting the material, emphasis is given to the principles of physics in detection and device structures, while specific applications and detector systems are left to one side. A major part is devoted to readout electronics and considerations of noise in detector–amplifier systems.

Although detector systems per se are not covered, the demands are dealt with that are made on detector properties by the presently planned applications of tens of thousands of detectors in the harsh radiation environment of newly constructed particle colliders. The production of this large number of detectors requires a simple design that can be produced economically and that can nevertheless cope with the drastic radiation-induced changes to material properties. The field of radiation damage and device stability is therefore also given broad coverage.

There are also some aspects of semiconductor detectors that are barely covered or completely neglected. The emphasis of the book is on silicon detectors. Although other semiconductor materials (and in particular compound semiconductors) are given less prominence, a large number of the physical principles and device structures can also be applied to other detector materials. Completely missing is any reference to cryogenic detectors, which partially also use semiconductors and operate at very low temperatures.

The important subject of detector technology has been treated only in a rudimentary way because it is planned to follow up this book by several volumes from different authors treating other aspects of semiconductor detectors. The next two, already in preparation, will cover detector technology and the physical limits on the measuring precision of detectors.

I have tried to introduce subjects in an intuitive way before resorting to a more formal mathematical treatment. Understanding the physics of the devices is in my opinion not only of importance for people working in detector development but also necessary for selecting and making proper use of the detectors for specific applications. I have also tried to write in a self-contained way so that the book can be read without the need for frequent consultation of other standard literature. Therefore the book contains an introduction to basic semiconductor physics and an appreciable amount of information also available elsewhere in standard textbooks.

In writing this book I have profited from many discussions with colleagues, in particular from my coworkers at the MPI Semiconductor Laboratory. Several of them have also performed the tedious task of careful checking of part or all of the manuscript and have made valuable suggestions for improvements. I want to mention in particular E. Gatti, R. Wunstorf, R.H. Richter, J. Kemmer, L. Strüder, K. Kandiah, P.F. Manfredi, M. Doser, L. Andricek, D. Hauff, N. Hörnel, P. Holl, P. Klein, P. Lechner, H. Soltau, C.v. Zanthier, C. Fabjan, and D. Atkins.

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Munich, March 1999 Gerhard Lutz

Contents