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Maurizio Dapor

Transport of Energetic Electrons in Solids

Computer Simulation with Applications to Materials Analysis and Characterization

Third Edition

Springer

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To my dearest father, always alive in my mind and in my heart

Preface to the Third Edition

This volume is an extended edition of a book published in 2014 (first edition) and 2017 (second edition). It provides all the information necessary to the reader to write his/her own Monte Carlo code. The possibility to compare the obtained results with the many numerical and experimental examples presented through the text can help the reader to better describe and understand the processes and the phenomena concerning the transport of electrons and positrons in solid targets.

The updated content of this third edition includes the theory of the spin-polarized electron beams, the study of elastic scattering by molecules, a simple derivation of the Bethe-Bloch stopping power formula, the f-sum rule and the ps-sum rule, the Vicanek and Urbassek formula for the calculation of the backscattering coefficient, and the Wolff theory of the secondary electron spectra.

A new chapter is devoted to the basic concepts of computational physics. Another chapter is dedicated to the elementary aspects of the interaction of beams of electrons and positrons with thin solid films (the so-called multiple reflection method).

Further comparisons between theory and experimental data are presented here as well.

Villazzano, Italy — Maurizio Dapor

Preface to the Second Edition

This book describes all the mechanisms of scattering (elastic and inelastic) of electrons with the atoms of the target in the simplest possible way. The use of techniques of quantum mechanics is described in detail for the investigation of interaction processes of electrons with matter. The book presents the strategies of the Monte Carlo method, as well as numerous comparisons among the results of the simulations with the experimental data available in the literature. The new content of this extended and updated second edition includes the derivation of the Rutherford formula, details about the calculation of the phase shifts that are used in the relativistic partial wave expansion method, and the description of the Mermin theory. The role of secondary electrons in the proton cancer therapy is discussed as well in the chapter devoted to applications: in this context, Monte Carlo results about the radial distribution of the energy deposited in solids by secondary electrons generated by energetic proton beams are presented.

Povo, Italy — Maurizio Dapor
August 2016

Preface to the First Edition

In modern physics, we are interested in systems with many degrees of freedom. Let us consider, for example, the number of atoms in a solid, the number of electrons in an atom, or the number of electrons of a beam interacting with the many atoms and electrons of a solid.

In many situations, these systems can be described by the calculations of definite integrals of very high dimension. An example is the evaluation of the classical partition function for a gas of many atoms at a temperature T. The Monte Carlo method gives us a very accurate way to calculate high-dimensional definite integrals: it evaluates the integrand at a random sampling of abscissa.

The Monte Carlo method is also used for evaluating many physical quantities necessary for the study of the interactions of particle beams with solid targets. The simulation of the involved physical processes, by random sampling, allows to solve many particle transport problems. Letting the particles carry out an artificial, random walk—taking into account the effect of the single collisions—it is possible to accurately evaluate the diffusion process.

This book is devoted to the electron beam interactions with the solid targets. As a researcher in this field, I am persuaded that a book on kV electron transport in solids can be very useful. It is difficult, for the newcomer, to find this topic exhaustively treated; and it is not easy for the beginner to sort out the importance of the great number of published papers.

The Monte Carlo simulation is the most powerful theoretical method for evaluating the physical quantities related to the interaction of electrons with a solid target. A Monte Carlo simulation can be considered as an idealized experiment. The simulation does not investigate the fundamental principles of the interaction. It is necessary to know them—in particular the energy loss and angular deflection phenomena—to produce a good simulation.

This book is complementary with respect to many other texts dedicated to similar subjects (including my book entitled Electron-Beam Interactions with Solids, published by Springer-Verlag in 2003) for the following two aspects.

1. I have, on the one hand, systematically minimized the mathematical contents of the more difficult theoretical parts. Since the essential concept to digest is the meaning of the various cross sections, the mathematical details, for the sake of clarity, have been deliberately avoided. I have reduced the theoretical part to the presentation of the energy loss and the angular deflections, providing simple recipes to calculate the stopping power, the differential inverse inelastic mean free path, and the differential elastic scattering cross section. This allowed me to avoid to describe in depth quantum theory. Mathematical contents and details can be found in the Appendices, in my previous book, and in many other books dedicated to modern physics and quantum mechanics.
2. In the derivation and use of the simpler theoretical transport models, I have, on the other hand, included many details. I think, indeed, there is a need for a basic physical picture in order to provide the beginner with a solid background about electron transport in solids. This can be only achieved by a step-by-step derivation of the analytical formulas.

Comparing available experimental data with simulation results is a fundamental step in evaluating the quality of the Monte Carlo codes. Selected applications of the Monte Carlo method to kV electron transport in solids are presented in the second part of this book. The book compares computational simulations and experimental data in order to offer a more global vision.

Povo, Italy Maurizio Dapor
October 2013

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