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Springer Science+Business Media, LLC

Library of Congress Cataloging in Publication Data

Ferry, David K.
Physics of submicron devices / David K. Ferry and Robert O. Grondin.
p. cm. – (Microdevices)
Includes bibliographical references and index.
ISBN 978-1-4613-6444-3 ISBN 978-1-4615-3284-2 (eBook)
DOI 10.1007/978-1-4615-3284-2
1. Semiconductors. 2. Solid state physics. 3. Electronics – Materials. 4. Electron transport. 5. Microstructure. I. Grondin, Robert Oscar. II. Title. III. Series.
QC611.F42 1991 91-31155
537.6′22 – dc20 CIP

ISBN 978-1-4613-6444-3

Originally published by Plenum Press, New York in 1991

Preface

The purposes of this book are many. First, we must point out that it is not a device book, as a proper treatment of the range of important devices would require a much larger volume even without treating the important physics for submicron devices. Rather, the book is written principally to pull together and present in a single place, and in a (hopefully) uniform treatment, much of the understanding on relevant physics for submicron devices. Indeed, the understanding that we are trying to convey through this work has existed in the literature for quite some time, but has not been brought to the full attention of those whose business is the making of submicron devices.

It should be remarked that much of the important physics that is discussed here may not be found readily in devices at the 1.0-μm level, but will be found to be dominant at the 0.1-μm level. The range between these two is rapidly being covered as technology moves from the 256K RAM to the 16M RAM chips. Indeed, devices can be made much smaller, as Si MOSFETs have been made by IBM and MIT with effective gate lengths as short as 70 nm, while MESFETs and HEMTs have been made at Arizona State University and in Japan with gate lengths as short as 25 nm. Whether devices with these gate lengths will ever make it into production in VLSI chips is problematical. It is far more important to note that these devices will provide windows into the relevant physics that will set the ultimate limits on downscaling of semiconductor devices. As much as the minimum feature size (usually the gate length) on VLSI chips has shrunk, the *predicted* limit to down-scaling has shrunk, often at the same rate. Less than two decades ago, it was stated by one knowledgeable individual (whose identity shall remain unknown to the reader) that MOSFETs could never be made (in integrated circuits) with gate lengths less than 10 μm. We clearly do much better. We illustrate in Figure P1 how this predicted limit to down-scaling has progressed through the recent decades.

The current "projected" minimum feature size (indicated by the symbol next to the question mark in Figure P1) is based upon the observation in 20–25-μm HEMTs that tunneling through the depletion region prevents the devices from being "pinched off" and therefore greatly reduces the transconductance. It is not at all sure that this will be a limitation on downsizing, as clever engineers find

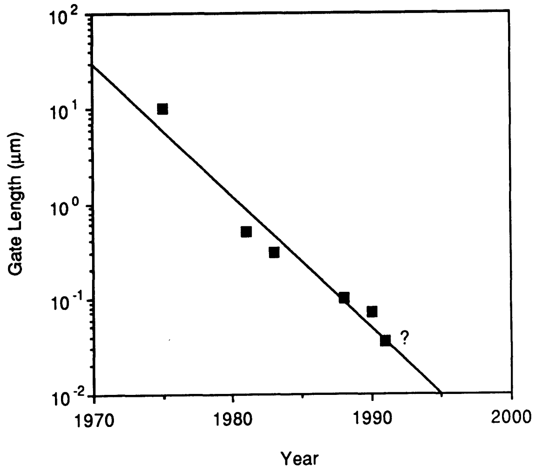

FIGURE P1. Projected minimum feature size.

other ways to introduce devices. However, the downsizing arguments point out the need to understand much physics, which has been ignored as "... second- and third-order effects, ..." in current devices. If for no other reason, it is important to understand the physics that becomes important in submicron (and ultrasubmicron) devices just as it is important to understand the circuit interaction effects.

In the process above, we try to provide a good summary of a widely scattered literature. The focus is generally on physics instead of devices, but even then the physics is not usually discussed in a conventional solid-state or semiconductor physics book. Here, rather than greatly worry over band structure and phonon spectra calculations, we instead employ the physical pictures produced by such calculations in a detailed study of electric current flow in submicron systems.

Chapter 1 reviews the material usually found in a conventional solid-state physics book, but we try to illustrate certain critical assumptions (e.g., treating scattering processes as being independent) and the weakness of certain commonly discussed ideas (e.g., tunneling times). Chapter 2, on the other hand, reviews a number of important technological processes involved in the preparation of submicron structures. Then in Chapter 3 the important properties of interfaces, whether heterojunctions between semiconductors or between an insulator and a semiconductor, are discussed. We also introduce simple models of the operation of the common devices.

Chapter 4 begins, and Chapter 5 finishes, a detailed tutorial overview of semiclassical transport theory. All commonly used, and some rarely used, schemes are discussed and their interrelationship explored. The central theme that develops is that the ensemble Monte Carlo technique is for a variety of good reasons the workhorse technique of hot-carrier transport calculations. What may not be as obvious is that many of the supposedly computationally simpler approaches may not be computationally simpler. These approaches often look simple, but when one starts asking about performing calculations in two or three spatial dimensions one finds that the equation sets grow rapidly in complexity. Such an extension, however, is basically quite trivial for Monte Carlo models. The boundary conditions also are not simplified when compared to Monte Carlo cases, and in small devices this can be quite important. Last, and often overlooked, since people usually do not publish numerical methods that fail, is the issue of numerical stability. While the Monte Carlo approach is inherently stable, the coupled sets of nonlinear partial differential equations produced in other approaches often pose formidable problems in a numerical implementation.

Chapter 5 concludes with a review of numerous attempts at experimentally seeing the effects of transient hot-carrier transport effects. The holy grail is to somehow see a velocity overshoot. We hope that this review will illustrate that while it seems clear from a variety of experiments that a velocity overshoot is occurring, a quantitative experimental observation has not yet been produced.

Chapter 6 discusses the important materials area of alloys between different semiconductors. These are both useful and interesting, but it is important to know that some "warts" appear in the simple theories that have been formulated. Then, in Chapter 7 the important electron–electron interaction and the screening effects introduced by this process are discussed. This is followed in Chapter 8 by a discussion of the relatively new area of surface superlattices.

We end the book in Chapters 9 and 10 with a discussion of quantum transport and of noise in submicron devices. These are areas in which very few experiments have been performed and relatively few calculations done. Perhaps the most important observation there is that some of the guesses that one is tempted to make about the spatial and temporal correlations seen in hot-carrier transport are not only wrong but in some cases predict trends opposite to the correct ones. We suspect that a detailed understanding of the noise limits faced in submillimeter-wave systems still lies outside the limits of our theories.

It is assumed that the reader has a basic understanding of solid state physics and electronics, at least to the level of a text such as Kittel's or Ashcroft and Mermin's. This also assumes that the reader has had an introductory course in quantum mechanics, although such important topics as tunneling and time-dependent perturbation theory are reviewed in Chapter 9, where they are important for very small devices and very high electric fields.

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