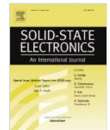
Solid-State Electronics
Volume 23, Issue 6, June 1980, Pages 519–530



On the physics and modeling of small semiconductor devices—I ☆

J.R. Barker[a, ‡], D.K. Ferry[a]

Show more

DOI: 10.1016/0038-1101(80)90033-7

Abstract

Current LSI technology has progressed rapidly and is pushing toward fabrication of sub-micron dimensioned devices. Several authors have previously used static characteristics, power dissipation, noise, and packing density to look at limiting properties of small devices, although the actual device physics was not considered in detail. As devices become smaller, we expect that the temporal and spatial scales in these devices become sufficiently small that the semi-classical approach to transport theory, as expressed by the Boltzmann transport equation, becomes of questionable validity. In this paper, we address the question of whether our physical understanding of devices and their operation can be extrapolated to small space and time scales, and to what extent the essential quantum electronics prevents a down-scaling. We attempt to lay here a conceptual framework for an ultimate physics of small devices and the modeling necessary to characterize these devices. In this first paper, we work with a dimensional scale of $l \sim 2500$ Å, the medium small device, leaving a smaller scale to a subsequent work. Although this scale is marginally in a region where the semi-classical approach is valid, extensive modifications must be made to incorporate several new physical effects, including: intra-collision field effect, retarded spatial and temporal non-local effects, two-dimensional quantization, memory effects in the transport parameters, nonlinear screening/descreening, and multiple scattering effects.

☆ Supported by U.S. Army Research Office.

‡ Permanent address: Physics Department, University of Warwick, Coventry, England.

Solid-State Electronics
Volume 23, Issue 6, June 1980, Pages 531–544

On the physics and modeling of small semiconductor devices—II ☆: The very small device

J.R. Barker[a, ‡], D.K. Ferry[a]

DOI: 10.1016/0038-1101(80)90034-9

Abstract

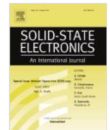
In a previous paper, we attempted to lay a conceptual framework for an ultimate physics of small semiconductor devices and concentrated on the medium small device. Here we treat the very small device (VSD), characterized by an effective channel length of 250 Å. We demonstrate how such a device could conceivably be fabricated using two side processing of the wafer. In treating the transport, however, it is found that the time and distance scales are such that the Boltzmann transport equation is completely invalidated. Here we develop the appropriate quantum transport equations based upon the density matrix for the entire system, device plus boundaries plus environment. It is found that the boundaries and environment can lead to renormalization of the energy spectrum as well as long range dissipative interactions. Two special cases of the transport equations are treated. If the transport is dominantly stochastic, an exact Langevin equation is found for the various transport parameters. In a second case, a parameterized density matrix is used in analogy to the displaced Maxwellian. In this latter case, a hierarchy of moment equations can be developed to yield, e.g. energy and momentum balance equations.

☆ Supported by the U.S. Army Research Office.

‡ Permanent address: Physics Department, University of Warwick, Coventry, England.

Solid-State Electronics

Volume 23, Issue 6, June 1980, Pages 545–549



On the physics and modeling of small semiconductor devices—III ☆: Transient response in the finite collision-duration regime

D.K. Ferry[a], J.R. Barker[a, ‡]

Show more

DOI: 10.1016/0038-1101(80)90035-0

Abstract

The role of the finite, non-zero collision duration in high electric fields is examined for its effect on transient and over-shoot response of the carrier velocity and energy. The finite collision duration introduces a temporal retardation effect on the collisional relaxation mechanisms for energy and momentum. As a consequence, the effective temperature also undergoes an overshoot behavior, which leads to a general *quickening* of the total transient response. Calculations were performed for steady, homogeneous fields utilizing a displaced Maxwellian approach. These calculations were performed for GaAs and Si and have significance for sub-micron devices in these materials. The generally faster response leads to the prospect of improved high frequency properties over what is normally expected.

☆ Work supported by the U.S. Office of Naval Research.

‡ Permanent address; Physics Department, Warwick University, Coventry, England.