# Preface

In this book, we present a comprehensive survey of the thermoballistic approach to charge carrier transport in semiconductors. This semiclassical approach, which we have developed over the past decade, bridges the gap between the opposing drift-diffusion and ballistic ("thermionic") models of carrier transport, whose validity is limited to values of the carrier mean free path that are very small and very large, respectively, compared with typical length scales in a semiconducting sample.

The physical concept underlying the thermoballistic approach, while incorporating basic features of the drift-diffusion and ballistic descriptions, constitutes a novel, unifying scheme. It is based on the introduction of "ballistic configurations" arising from a random partitioning of the length of a semiconducting sample into ballistic transport intervals across which the carriers move without collisions (for simplicity, we consider one-dimensional transport). These intervals are linked to one another at points of local thermodynamic equilibrium, where the carriers are, at the same time, both emitted and absorbed. [The joint appearance of thermal and ballistic attributes has led us to call our approach "thermoballistic".] During their transmission across the ballistic intervals, the carriers encounter, in general, potential energy barriers generated by a combination of internal and external electrostatic potentials in the sample, and concurrently undergo spin relaxation. The lengths of the ballistic intervals are stochastic variables, which are contingent upon the probabilities for carriers to traverse an interval without collisions with the scattering centers randomly distributed over the sample. These probabilities are controlled by the carrier mean free path, whose magnitude is arbitrary. By averaging the ballistic total and spin-polarized carrier currents as well as the associated densities over all ballistic configurations, position-dependent thermoballistic currents and densities are derived, which are expressed in terms of two dynamical functions, *viz.*, an average chemical potential and a spin accumulation function. Algorithms to determine these functions are set up by appropriately connecting the thermoballistic total and spin-polarized currents with the total physical current and the spin polarizations in the contacts. The thermoballistic currents form the point of departure for the calculation of all relevant transport quantities.

In our original publications, we developed the thermoballistic concept gradually, starting from what we called the "generalized Drude model". In this model, the averaging over ballistic configurations was introduced, and the current-voltage characteristic was obtained by assuming current conservation from one ballistic interval to the next. Relaxing this assumption, we were led to the construction of a position-dependent total thermoballistic current, which is expressed in terms of a local chemical potential. Spin-dependent thermoballistic currents and densities were introduced in conjunction with applications to spin-polarized transport in ferromagnet/semiconductor heterostructures and structures involving diluted magnetic semiconductors.

While in these publications the essence of the thermoballistic concept has been outlined, none of them affords a complete, systematic elaboration of this concept and its implementation. We, therefore, believe that a comprehensive survey of the thermoballistic approach is called for, with emphasis on a self-contained and coherent presentation based on a consistent set of physical assumptions. This includes a recollection of early attempts to describe carrier transport in semiconductors and a transparent, step-by-step derivation of the formalism. Presenting such a kind of survey is the aim of this book.

The book starts with an account of Drude's model of carrier transport, which is at the root of all classical and semiclassical transport models. This is followed by a survey of the standard drift-diffusion and ballistic descriptions, forming the cornerstones of the thermoballistic approach. Thereupon, to pave the way for the fully developed form of the thermoballistic concept, we present a "prototype thermoballistic model". This model, while based on the assumptions underlying our "generalized Drude model", revises and refines that model. In the central part of the book, a coherent exposition of the thermoballistic approach proper is presented within a general formulation that takes into account arbitrarily shaped, spin-split potential energy profiles as well as spin relaxation during the carrier motion across ballistic intervals. The physical conditions underlying the implementation of the thermoballistic concept are established, and explicit equations governing the average chemical potential and the spin accumulation function are derived.

The relevance of the work presented in this book lies in providing a unified understanding of semiclassical carrier transport, which, we believe, constitutes a valuable contribution to present-day semiconductor physics and spintronics. Moreover, by presenting explicit equations for the calculation of transport quantities and working out various examples, we supply tools for future, systematic analyses of experimental data.

Being originally non-specialists in the field of solid-state physics, we were motivated to embark on theoretical studies of carrier transport in semiconductors by our experimental colleagues in the (then) Hahn-Meitner-Institut Berlin, who had asked for theoretical support in interpreting their data on carrier transport in poly- and microcrystalline photovoltaic materials. Having entered deeper into the field, we perceived the challenge to fill, by unifying drift-diffusion and ballistic transport within a physically consistent approach, a long-standing gap in the theory of carrier transport in semiconductors. Moreover, we realized that recent progress in device physics, spintronics, and photovoltaics called for an extension of the theoretical framework hitherto available for the semiclassical analysis of experimental data in these fields.

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Reinhard Lipperheide
Uwe Wille

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