Preface

Multilayered nanostructures and thin films form the building blocks of most of the devices employed in electronics, ranging from semiconductor transistors and laser heterostructures, to Josephson junctions and magnetic tunnel junctions. Recently, there has been an interest in examining new classes of these devices that employ strongly correlated electron materials, where the electron-electron interaction cannot be treated in an average way. This text is designed to train graduate students, postdoctoral fellows, or researchers (who have mastered first-year graduate-level quantum mechanics and undergraduate-level solid state physics) in how to solve inhomogeneous many-body-physics problems with the dynamical mean-field approximation. The formalism is developed from an equation-of-motion technique, and much attention is paid to discussing computational algorithms that solve the resulting nonlinear equations. The dynamical mean-field approximation assumes that the self-energy is local (although it can vary from site to site due to the inhomogeneity), which becomes exact in the limit of large spatial dimensions and is an accurate approximation for three-dimensional systems. Dynamical mean-field theory was introduced in 1989 and has revolutionized the many-body-physics community, solving a number of the classical problems of strong electron correlations, and being employed in real materials calculations that do not yield to the density functional theory in the local density approximation or the generalized gradient expansion.

This book starts with an introduction to devices, strongly correlated electrons and multilayered nanostructures. Next the dynamical mean-field theory is developed for bulk systems, including discussions of how to calculate the electronic Green's functions and the linear-response transport. This is generalized to multilayered nanostructures with inhomogeneous dynamical mean-field theory in Chapter 3. Transport is analyzed in the context of a generalized Thouless energy, which can be thought of as an energy that is extracted from the resistance of a device, in Chapter 4. The theory is applied to Josephson junctions in Chapter 5 and thermoelectric devices in Chapter 6. Chapter 7 provides concluding remarks that briefly discuss extensions to different types of devices (spintronics) and to the nonlinear and nonequilibrium response. A set of thirty-seven problems is included in the Appendix. Readers who can master the material in the Appendix will have developed a set of tools that will enable them to contribute to current research in the field. Indeed, it is the hope that this book will help train people in the dynamical mean-field theory approach to multilayered nanostructures.

The material in this text is suitable for a one-semester advanced graduate course. A subset of the material (most of Chapter 2 and 3) was taught at Georgetown University in a one-half semester short course in the Fall of 2002. The class was composed of two graduate students, one postdoctoral fellow, and one senior researcher. Within six months of completing the course all participants published refereed journal articles based on extensions of material learned in the course. A full semester course should be able to achieve similar results.

Finally, a comment on what is not in this book. Because many-body physics is treated using exact methods that are evaluated numerically, we do not include any perturbation theory or Feynman diagrams. Also there is no proof of Wick's theorem, no derivation of the linked-cluster expansion, and so on. Similarly, there is no treatment of path integrals, as all of our formalism is developed from equations of motion. This choice has been made to find a "path of least resistance" for preparing the reader to contribute to research in dynamical mean-field theory.

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