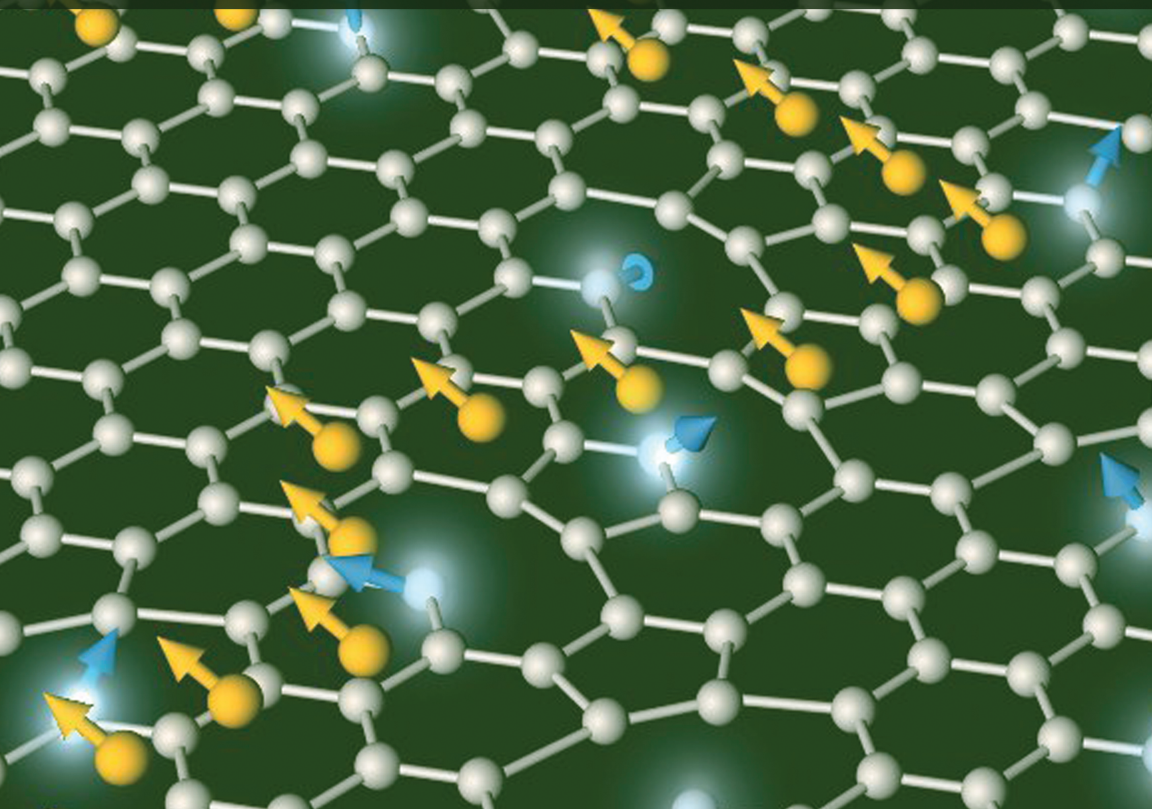
Wide Bandgap Semiconductor Spintronics

Vladimir Litvinov



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To my wife, Valeria, and
my children, Natasha and Vlady

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Preface

The field of spintronics is currently being explored in various directions. One of them, semiconductor spintronics, is of particular recent interest since materials developed for electronics and optoelectronics are gradually becoming available for spin-manipulation-related applications, e.g., spin-transistors and quantum logic devices allowing the integration of electronic and magnetic functionalities on a common semiconductor template.

The scope of this book is largely concerned with the spintronic properties of III-V Nitride semiconductors. As wide bandgap III-Nitride nanostructures are relatively new materials, particular attention is paid to the comparison between zinc-blende GaAs- and wurtzite GaN-based structures where the Rashba spin-orbit interaction plays a crucial role in voltage-controlled spin engineering.

The book also deals with topological insulators, a new class of materials that could deliver sizeable Rashba spin splitting in the surface electron spectrum when implemented into a gated device structure. Electrically driven zero-magnetic-field spin-splitting of surface electrons is discussed with respect to the specifics of electron-localized spin interaction and voltage-controlled ferromagnetism.

Semiconductor spintronics has been explored and actively discussed and various device implementations have been proposed along the way. Writings on this topic appear in the current literature. This book is focused on the materials science side of the question, providing a theoretical background for the most common concepts of spin-electron physics. The book is intended for graduate students and may serve as an introductory course in this specific field of solid state theory and applications. The book covers generic topics in spintronics without entering into device specifics since the overall goal of the enterprise is to give instructions to be used in solving problems of a general and specific nature.

Chapter 1 deals with the electron spectrum in bulk wurtzite GaN and the origin of linear terms in energy dispersion. Attention is paid to the symmetry and features of wurtzite spintronic materials which differentiate them from their cubic GaInAs-based counterparts.

Rashba and Dresselhaus spin-orbit terms in heterostructures with one-dimensional confinement are considered in Chapter 2, where typical spin textures are discussed in relation to in-plane electron momentum. This chapter also presents the microscopic derivation of the Rashba interaction in wurtzite quantum wells that allows electron spin-splitting to be related to the material and geometrical parameters of the structure. In particular, we discuss Rashba spin splitting in a structurally symmetric wurtzite quantum well to focus on the polarization-field induced Rashba interaction.

Vertical tunneling through a single barrier and a polarization-field distorted Al(In)GaN/GaN quantum well, as a possible spin-injection mechanism, is considered in Chapter 4.

Chapters 5 and 6 are devoted to a detailed theoretical description of mechanisms of ferromagnetism in magnetically doped semiconductors, specifically in the III-V Nitrides. These chapters discuss the indirect exchange interaction in metals of any dimension and in semiconductors. Emphasis is placed on the specific feature of the indirect exchange interaction in a one-dimensional metal. Also, the standard mean-field approach to ferromagnetic phase transition is described, as is the percolation picture of phase transition in certain systems, for example, wide bandgap semiconductors, for which mean-field theory breaks down.

The electronic properties of topological Bi_2Te_3 insulators are discussed in Chapter 7, where the semiconductor is taken as an example. Topological insulator film biased with a vertical voltage presents a system with voltage-controlled Rashba interaction and it is of interest in relation to possible spintronic applications. Surface electrons in the biased topological insulator are spin-split and this affects the indirect exchange interaction between magnetic atoms adsorbed onto a surface. The calculation of indirect exchange in a topological insulator is given in Chapter 8.

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