

Magnetic Field Effects on Quantum Wells

Magnetic Field Effects on Quantum Wells

Sujaul Chowdhury
Department of Physics, Shahjalal University of Science and Technology,
Sylhet 3114, Bangladesh

Chowdhury Shadman Awsaf
Department of Physics, Shahjalal University of Science and Technology,
Sylhet 3114, Bangladesh

Ponkog Kumar Das
Department of Physics, Shahjalal University of Science and Technology,
Sylhet 3114, Bangladesh



AIP Publishing Books
A publication of AIP Publishing
Melville, New York

Copyright © 2021 AIP Publishing LLC

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by law.

To obtain permission to reuse material from this title, contact AIP Publishing at rights@aip.org. Additional rights and permissions information is available at: <https://publishing.aip.org/resources/researchers/rights-and-permissions/permissions/>.

First edition, published 2021.

Library of Congress Control Number: 2021945045

ISBN: 978-0-7354-2384-8 (Softcover)

ISBN: 978-0-7354-2387-9 (Online)

ISBN: 978-0-7354-2385-5 (ePub)

ISBN: 978-0-7354-2386-2 (ePDF)

Set in 10/13pt MinionPro by Nova Techset Private Limited, Bengaluru & Chennai, India, and bound by The Sheridan Group, USA

The publisher and authors cannot guarantee the accuracy of this work. Readers of scientific texts should not rely on any third-party text, or the statements and conclusions embodied in such work, without independently confirming hypotheses, factual statements, and conclusions. The publisher does not endorse organizations, institutions, or companies that may be referenced herein.

Published by AIP Publishing

1305 Walt Whitman Road, Suite 300, Melville, NY 11747-4300, USA

PREFACE

This book, *Magnetic Field Effects on Quantum Wells*, is an in-depth analysis of the topic and the first of its kind.

The scope and intended focus of the book are as follows:

1. The book covers the physics of a semiconductor nanostructure.
2. The book contains a comprehensive theoretical account of the topic.
3. The book is aimed at providing academics and scientists complete information on the physics of a non-tunneling regime of a semiconductor nanostructure in a magnetic field.
4. This is the first comprehensive account of the topic.

The book deals with a semiconductor nanostructure called an isolated GaAs–AlGaAs quantum well (QW). The parametric variations of the transmission coefficient of the QW in a non-tunneling regime are calculated in the absence and presence of a magnetic field applied perpendicular to the GaAs–AlGaAs interfaces. Both analytical and numerical investigations are reported. The magnetic field dependence of the parametric variations is explained in a quantitatively exact manner. The book also contains a comprehensive theoretical account of the topic. Background information about microelectronics, nanostructure physics, and classical mechanics is also covered to enable readers to understand the book.

Unique features of this book include:

1. Complete calculations
2. Analytical and numerical accounts
3. Magnetic field effects brought out and explained in a quantitatively exact manner
4. A comprehensive theoretical account of the topic

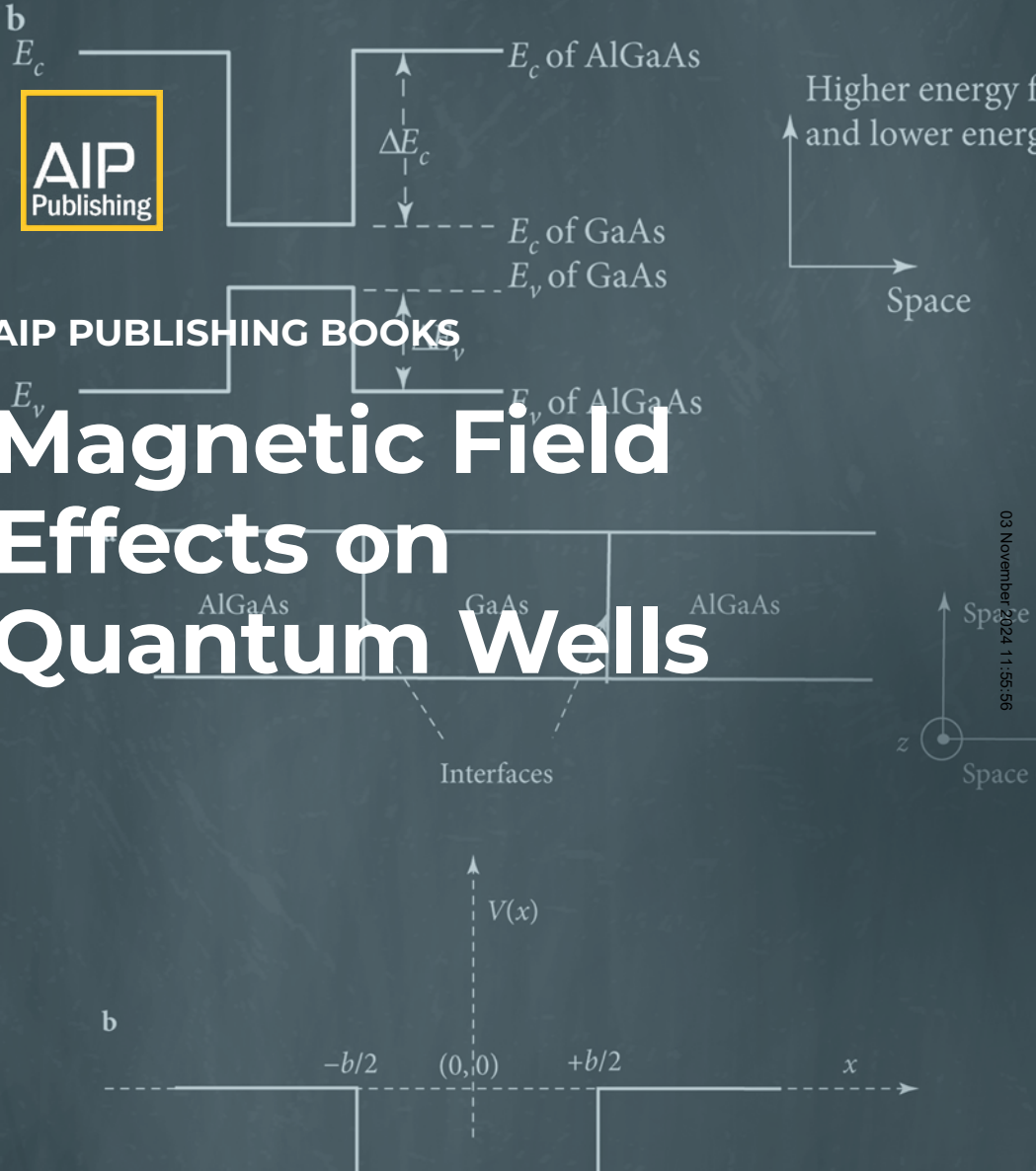
Benefits of this book for the reader include:

1. Backgrounds on microelectronics, nanostructure physics, and classical mechanics
2. Complete acquaintance with the physics of the topic

Audiences of the book are graduate students and academics of physics and electrical and electronic engineering.

The organization of chapters is as follows. After a necessary introduction to the backgrounds of microelectronics and nanostructure physics in the first two chapters, Chap. 3 solves the 1D problem in zero magnetic field and reveals the analytical expression for the transmission coefficient. In Chap. 4, the classical Hamiltonian function of a charged particle in an electric and a magnetic field is calculated,

which is used in Chap. 5 to obtain the corresponding Hamiltonian operator. In Chap. 5, the problem is resolved by reducing the 3D problem to a 1D problem. In Chap. 6, the analytical expression of the magnetic-field-dependent transmission coefficient is obtained. Chapter 7 carries out numerical investigations to reveal the effects of the magnetic field on the transmission coefficient. We find that a larger magnetic field reduces the effective depth of the quantum well.



CONTENTS

Chapter 1	Background on Microelectronics	1-1
1.1	Introduction	1-1
1.2	Intrinsic Semiconductors	1-1
1.3	Semiconductors: Elemental and Binary	1-2
1.4	Alloy Semiconductors (Ternary and Quaternary)	1-4
1.5	Bandgap Engineering	1-4
1.6	Semiconductor Heterojunctions and Heterostructures	1-6
1.7	Effective Mass	1-7
	Reference	1-8
Chapter 2	Background on Nanostructure Physics	2-1
2.1	Introduction	2-1
2.2	Single Rectangular Tunnel Barrier	2-1
2.3	Transmission Coefficient of a Single Rectangular Tunnel Barrier	2-2
2.4	Quantum Well (QW)	2-7
2.5	Double Potential Barrier	2-10
2.6	Transmission Coefficient of the Double Potential Barrier	2-11
2.7	Transmission Coefficient of Double Barrier if Two Barriers are Identical	2-12
2.8	Profile of the Transmission Peak	2-13
2.9	T vs E Curve of a Symmetric Rectangular Double Barrier	2-15
2.10	Tunneling and Non-Tunneling Regimes	2-19
	References	2-20
Chapter 3	The 1D Problem in a Zero Magnetic Field: Analytical Calculations	3-1
3.1	Introduction	3-1
3.2	Description of the Problem	3-1

3.3	Calculation of Transfer Matrix of Isolated Quantum Well for Non-Tunneling Regime	3-2
3.4	Calculation of Transmission Coefficient of Isolated Quantum Well for Non-Tunneling Regime	3-7
	References	3-10
Chapter 4	Construction of a Classical Hamiltonian Function of a Charged Particle in an Electric and a Magnetic Field	4-1
4.1	Introduction	4-1
4.2	Lagrange's Equation, Lagrangian Function, and Generalized Potential	4-1
4.3	Construction of Lagrangian Function for a Charged Particle in an Electric Field and a Magnetic Field	4-4
4.4	Construction of Hamiltonian Function for a Charged Particle in an Electric Field and a Magnetic Field	4-7
	References	4-9
Chapter 5	Reducing the 3D Problem to a 1D Problem	5-1
5.1	Introduction	5-1
5.2	Description of the Problem	5-1
5.3	The General Eigenvalue Equation of Energy	5-2
5.4	Simplification of the General Eigenvalue Equation of Energy	5-3
5.5	Adapting the General Eigenvalue Equation of Energy to Our Problem	5-3
5.6	$P_{x_{op}}$ and $P_{z_{op}}$ Commute with Hamiltonian Operator in each Region	5-5
5.7	Eigenvalue Spectrum of Energy of Electrons Inside Barrier Regions	5-7
5.8	Eigenvalue Spectrum of Energy of Electrons Outside Barrier Regions	5-9

5.9	Landau Level Index n is a Constant of Motion	5-11
5.10	Identification of Different Parts of the Energy Spectrum: Inside Barrier Regions	5-13
5.11	Identification of Different Parts of the Energy Spectrum: Outside Barrier Regions	5-14
5.12	Construction of Differential Equation for Motion of Electrons Perpendicular to Interfaces: Inside Barrier Regions	5-16
5.13	Construction of Differential Equation for Motion of Electrons Perpendicular to Interfaces: Outside Barrier Regions	5-19
	References	5-22

Chapter 6	Obtaining Analytical Expression of the Longitudinal Magnetic-Field-Dependent Transmission Coefficient of an Isolated Quantum Well in a Non-Tunneling Regime	6-1
6.1	Introduction	6-1
6.2	Conservation of Probability and Probability Current Density at Zero Magnetic Field	6-1
6.3	Free Particle: Eigenfunctions and Probability Current Density	6-3
6.4	Probability Current Density and Transmission Coefficient in Presence of Longitudinal Magnetic Field	6-4
6.5	Obtaining the Analytical Expression of the Longitudinal Magnetic-Field-Dependent Transmission Coefficient of a Quantum Well: Direct Method	6-8
6.6	Obtaining the Analytical Expression of the Longitudinal Magnetic-Field-Dependent Transmission Coefficient of a Quantum Well: Effective Potential Method	6-11
	References	6-13

Chapter 7	Numerical Investigation of Effects of a Longitudinal Magnetic Field on the Transmission Coefficient of a Quantum Well in a Non-Tunneling Regime	7-1
7.1	Introduction	7-1
7.2	Transmission Coefficient of Quantum Well in <i>Absence</i> of Magnetic Field	7-1
7.3	Transmission Coefficient of Quantum Well in <i>Presence</i> of Magnetic Field	7-8
7.4	Concluding Remarks	7-12
	References	7-13
Index		I-1