Contents

1 Introduction **1**
- 1.1 The Integer Quantum Hall Effect . . . 1
- 1.2 The Fractional Quantum Hall Effect . . . 2
- 1.3 High Landau Levels . . . 9
- 1.4 This Thesis . . . 11

2 Microwave-Induced Zero Resistance States **15**
- 2.1 Zero Resistance States and Microwave-Induced Resistance Oscillations . . . 15
- 2.2 Theoretical Explanation of ZRS . . . 17
  - 2.2.1 Instability of the Zero-Current State . . . 18
  - 2.2.2 Microscopic Mechanisms leading to Absolute Negative Conductivity . . . 20
    - Displacement Mechanism (DP) . . . 21
    - Distribution Function Mechanism (DF) . . . 23

3 Classical Model for a Microwave-Irradiated 2DEG in the Presence of Bichromatic Irradiation **27**
- 3.1 Monochromatic Irradiation . . . 28
- 3.2 Bichromatic Irradiation . . . 31
  - 3.2.1 Weak Detuning . . . 33
    - Calculation of the Diagonal Conductivity . . . 33
    - Numerical Results: Multistability . . . 35
    - Stability of Different Branches . . . 39
  - 3.2.2 Strong Detuning . . . 40
    - Parametric Instability at $(\omega_1 + \omega_2) \simeq 2\omega_c$ . . . 41
    - Parametric Instability at $|\omega_1 - \omega_2| \simeq 2\omega_c$ . . . 42
    - Saturation of Parametric Resonance . . . 43
    - Implications for dc Transport . . . 44
- 3.3 Bichromatic Irradiation and Absolute Negative Conductivity . . . 45
- 3.4 Discussion . . . 46

4 Microwave Photoconductivity due to Intra-Landau-Level Transitions **49**
- 4.1 Experiment . . . 50
- 4.2 Model . . . 51
  - 4.2.1 Two-Dimensional Electron Gas in a Modulation Potential 52
  - 4.2.2 Electrons in High Landau Levels . . . 53
  - 4.2.3 Electronic States in the Absence of a Modulation Potential 54

4.2.4 Spectrum and Matrix Elements in the Presence of the Modulation Potential . . . 55
4.2.5 Density of States in the Modulation Potential . . . 57
4.2.6 Regimes . . . 59
4.3 Mechanisms . . . 60
4.3.1 General Expression for the Current . . . 60
4.3.2 Kinetic Equation . . . 61
4.3.3 T-Matrix . . . 62
4.3.4 Intra-LL-Transition Matrix Elements . . . 63
4.3.5 Transport and Single-Particle Time . . . 65
4.4 Dark Current . . . 66
4.4.1 Longitudinal Dark Current . . . 66
4.4.2 Transverse Dark Current . . . 67
4.5 Photocurrent . . . 68
4.5.1 Longitudinal Photocurrent . . . 70
Distribution Function Mechanism . . . 70
Displacement Mechanism . . . 74
4.5.2 Transverse Photocurrent . . . 76
Distribution Function Mechanism . . . 76
Displacement Mechanism . . . 77
4.6 Comparison with Experiment . . . 77
4.7 Polarization Dependence . . . 79
4.8 Discussion . . . 80

5 In-Plane Magnetic Field 83
5.1 Theory . . . 84
5.1.1 Without Spin Splitting . . . 86
5.1.2 With Spin Splitting . . . 88
5.2 Results . . . 92
5.2.1 Oscillatory Photoconductivity . . . 92
5.2.2 Limiting Cases . . . 94
5.3 Discussion . . . 94

6 Drag in Double-Layer Systems 97
6.1 Conventions . . . 98
6.2 Coulomb Drag . . . 100
6.3 Phonon Drag . . . 102
6.4 Linear Response Theory of Drag . . . 104
6.4.1 Drag Conductivity . . . 104
6.4.2 Triangle Vertex . . . 104
6.4.3 Triangle Vertex in the Low Temperature Limit . . . 105

7 Phonon Drag in High Landau Levels 109
7.1 Linear Response Theory of Phonon Drag: Triangle Vertex and Polarization Function . . . 109
7.1.1 Relevant Momentum Range and Regime of Interest . . . 109
7.1.2 Triangle Vertex: Dominant Contribution $\mathbf{\Gamma}^{(q/k_F)}$ . . . 110

7.1.3 The Polarization Function in the Ballistic Regime 112
Real Part of the Polarization Function 113
Imaginary Part of the Polarization Function 114
Connection between Triangle Vertex and Polarization Function 114
7.1.4 Triangle Vertex: Additional Contributions 115
The Contribution $\mathbf{\Gamma}^{(1/qR_c)}$ 115
The Contribution $\mathbf{\Gamma}^{(\Delta/\omega_c)}$ 116
7.2 Interaction of 2D Electrons with Bulk Phonons in the Bilayer System 117
7.2.1 Model 117
7.2.2 Phonon-Mediated Electron-Electron Interaction 120
7.2.3 Anisotropy Factors 121
7.2.4 Phonon-Mediated Interlayer Interaction 123
7.3 Analytical Results 124
7.3.1 Unscreened Interlayer Interaction 125
7.3.2 Screened Interlayer Interaction 125
7.3.3 Phonon Drag Conductivity 128
7.4 Numerical Results 131
7.4.1 Finite Phonon Mean Free Path 133
7.4.2 Temperature Dependence 134
7.4.3 Dependence on Landau Level Broadening 136
7.4.4 Dependence on Interlayer Separation 137
7.4.5 Filling Factor Dependence: Equal Filling Factors 138
7.4.6 Filling Factor Dependence: Different Filling Factors . . . 139
7.5 Discussion 139

8 Conclusions **141**

Appendix **145**
A Drag Conductivity 145
B Analytical Continuation of the Drag Conductivity 149
C Analytical Continuation of the Triangle Vertex 151
D Impurity Diagram Technique in High Landau Levels: SCBA . . . 155
E The Electron-Phonon Interaction in Bulk GaAs 159
E.1 Phonon Modes 160
E.2 Deformation Potential Interaction 160
Displacement Field 160
Solution of the Equation of Motion 162
Creation and Annihilation Operators 162
Deformation Potential Approximation 162
DP Interaction Matrix Elements 163
E.3 Piezoelectric Interaction 164
Piezoelectricity 164
The PE Tensor of Gallium Arsenide 165
Piezoelectric Coupling 167
PE Interaction Matrix Elements 168

E.4 Long Wavelength Limit and Isotropic Debye Approximation 168
F Laguerre Polynomials and Vertex Overlaps 171
F.1 Asymptotic Expansions of the Generalized Laguerre Polynomials 171
F.2 Evaluation of the Difference of Vertex Overlaps 172

Acknowledgments **175**

Curriculum Vitae **177**

Bibliography **179**