

Tobias Ruf

# Phonon Raman Scattering in Semiconductors, Quantum Wells and Superlattices

Basic Results and Applications

With 143 Figures



Springer

# Contents

<b>1. Introduction</b> .....	1
1.1 General Features of Inelastic Light Scattering .....	1
1.2 Overview of Topics .....	4
<b>2. Raman Scattering in Semiconductor Superlattices</b> .....	9
2.1 Basic Properties .....	9
2.1.1 Raman Scattering .....	9
2.1.2 Electronic Structure .....	12
2.1.3 Superlattice Phonons .....	14
2.2 Optic Phonons in Ultra-Short-Period GaAs/AlAs Superlattices .....	27
2.2.1 Confined Phonons in Very Thin Layers .....	27
2.2.2 Real Superlattices: Interface Phenomena .....	30
2.3 Optic Phonons in Isotopic Superlattices .....	33
2.3.1 Stable Isotopes in Semiconductor Physics .....	33
2.3.2 Symmetric Superlattices .....	38
2.3.3 Asymmetric Superlattices .....	44
2.3.4 Compound Semiconductors .....	46
2.4 Acoustic Phonons in GaAs/AlAs Superlattices Grown along High-Index Directions .....	49
2.4.1 Dispersions and Raman Intensities .....	50
2.4.2 Experimental Results .....	55
<b>3. Continuous Emission of Acoustic Phonons</b> .....	63
3.1 Phenomenology of the Continuous Emission .....	63
3.2 Single-Quantum-Well Effects .....	68
3.2.1 Continuous Emission in a Single Quantum Well .....	69
3.2.2 Continuous Emission in Multiple Quantum Wells .....	74
3.3 Structures at Phonon Dispersion Gaps .....	77
3.3.1 Types of Intensity Anomalies .....	77
3.3.2 Mini-Brillouin Zone Edge and Center .....	79
3.3.3 Internal Gaps .....	81
3.4 Interface Roughness .....	86

3.4.1	The Model .....	86
3.4.2	Comparison to the Experiment .....	88
3.4.3	Other Methods .....	90
3.5	Homogeneous and Inhomogeneous Linewidths .....	91
3.5.1	Model Calculations .....	92
3.5.2	Indirect-Gap Superlattices .....	94
3.5.3	Direct-Gap Samples .....	98
3.6	Continuous Emission and Electron-Phonon Interaction .....	100
3.6.1	Temperature Dependence of the Homogeneous Linewidth .....	100
3.6.2	Electron-Phonon Interaction in Quantum Wells .....	101
3.6.3	Short-Period Superlattices .....	108
3.7	Magneto-Raman Spectroscopy with the Continuous Emission .....	112
<b>4.</b>	<b>Optic-Phonon Magneto-Raman Scattering .....</b>	<b>123</b>
4.1	Introduction to Magneto-Raman Scattering .....	123
4.1.1	Resonant Raman Scattering at Landau Levels .....	124
4.1.2	Electronic Structure in a Magnetic Field .....	125
4.1.3	Magneto-Raman Processes and Selection Rules .....	129
4.2	Magneto-Raman Scattering in Bulk Semiconductors .....	133
4.2.1	Magneto-Raman Scattering in GaAs .....	133
4.2.2	Resonant Magneto-Polarons in InP .....	143
4.2.3	Double Resonances in $\text{Cd}_{0.95}\text{Mn}_{0.05}\text{Te}$ .....	149
4.3	Magneto-Raman Scattering in Quantum Wells .....	153
<b>5.</b>	<b>Resonant Magneto-Luminescence .....</b>	<b>163</b>
5.1	Bulk Semiconductors .....	163
5.1.1	Landau Level Fine Structure in GaAs .....	163
5.1.2	Magneto-Luminescence in the Quasi-Classical Limit ..	168
5.2	Inter-Landau-Level Scattering in Quantum Wells .....	175
<b>6.</b>	<b>Applications and Trends .....</b>	<b>185</b>
6.1	Raman Scattering in Applied Semiconductor Research .....	185
6.1.1	Materials Characterization .....	186
6.1.2	In-Situ Monitoring of Epitaxial Growth .....	203
6.2	Recent and Future Developments .....	207
6.2.1	Near-Field and Nano-Raman Scattering .....	208
6.2.2	Raman Instrumentation .....	219
	<b>References .....</b>	<b>225</b>
	<b>Index .....</b>	<b>244</b>