

Contents

1	Introduction	1
2	Electronic and Vibrational Properties of Zincblende and Wurtzite GaAs	7
2.1	Crystal Structure	7
2.2	Electronic Band Structure	8
2.2.1	Band Structure of Zincblende GaAs	10
2.2.2	Band Structure of Wurtzite GaAs	12
2.3	Phonons and Vibrational Modes	14
2.3.1	Lattice Vibrations in GaAs Zincblende Crystals	15
2.3.2	Lattice Vibrations in GaAs Wurtzite Crystals	18
3	Strain Effects in Semiconductors	23
3.1	Mechanical Properties of Zincblende and Wurtzite Crystals	23
3.1.1	Stress Tensor	24
3.1.2	Strain Tensor	25
3.1.3	Compliance and Stiffness Tensor	25
3.1.4	Piezoelectricity	27
3.1.5	Uniaxial Stress and Strain Decomposition	28
3.2	Strain Effects on the Electronic Band Structure	31
3.2.1	Strain Effect on the Brillouin Zone	31
3.2.2	$\mathbf{k} \cdot \mathbf{p}$ Hamiltonian in GaAs Zincblende	32
3.2.3	$\mathbf{k} \cdot \mathbf{p}$ Hamiltonian in GaAs Wurtzite	37
3.3	Strain Effects on the Lattice Vibrations	44
3.3.1	Uniaxial Stress Effects on the Optical Phonons of Zincblende Crystals	45
3.3.2	Uniaxial Stress Effects on the Optical Phonons of Wurtzite Crystals	46
4	Optical Spectroscopy	49
4.1	The Fermi Golden Rule	49
4.2	Selection Rules in Wurtzite and Zincblende Crystals	52
4.3	Modeling the Photoluminescence Line-shape	57
4.4	Raman Scattering	60

4.4.1	Scattering Geometry	62
4.4.2	Raman Scattering Selection Rules in Zincblende Crystals	63
4.4.3	Raman Scattering Selection Rules in Wurtzite Crystals	66
5	Uniaxial Stress Effects on Nanowires: Experimental Methods	69
5.1	How to Apply Uniaxial Stress to a Nanowire	70
5.2	Nanowire Growth and Characterization	71
5.2.1	MOCVD Growth of Zincblende Nanowires	72
5.2.2	MBE Growth of Wurtzite Nanowires	75
5.3	Sample Nanofabrication	77
5.3.1	Flexible Substrate Design and Fabrication	77
5.3.2	Nanowire Strain Device: Design and Fabrication . . .	80
5.4	Three-point Bending Mechanism	87
5.5	Optical Spectrometer	89
5.5.1	Design of the Polarization Control Units	91
5.5.2	Characterization of the Polarization Control Units . .	95
5.6	Size Effects on Mechanical, Optical and Vibrational Properties	102
5.6.1	Size Effects on the Mechanical Properties	102
5.6.2	Size Effects on the Band Structure	103
5.6.3	Size Effects on the Lattice Dynamics	104
5.6.4	Size Effects on the Optical Coupling: the Dielectric Mismatch Effect	105
6	Uniaxial Stress Effects in GaAs Zincblende Nanowires	107
6.1	Motivation	107
6.2	Experiment	108
6.3	Optical Spectroscopy on Unstrained Nanowires	109
6.4	Strain Effects on Photoluminescence and Raman Spectra . .	113
6.5	Resolving the Phonon Contributions	116
6.6	Axial Strain and Poisson-ratio Estimation	117
6.7	Band Structure Modification with Strain	119
6.8	Maximum Strain and Photoluminescence Shift	124
6.9	Conclusion	126
7	Uniaxial Stress Effects in GaAs Wurtzite Nanowires	127
7.1	Motivation	128
7.2	Experiment	130
7.3	Optical Spectroscopy on Unstrained Wurtzite Nanowires . . .	130
7.4	Strain Effects on Raman and Photoluminescence Spectra . .	133
7.5	Reversibility of the Photoluminescence Quenching	138
7.6	Modeling the Effect of Strain on the Band Structure	139
7.7	Fingerprint of the Dark Transitions	141

7.8	Inferring Strain and Bandstructure Parameters	143
7.9	Split-off Hole Transitions: a Consistency Check of the $\mathbf{k} \cdot \mathbf{p}$ Model	145
7.10	Determination of the Phonon Deformation Potentials	147
7.11	Conclusions	152
8	Conclusions and Outlook	155
A	Crystal Structure of Zincblende and Wurtzite Crystals	173
B	Basics Concepts of Continuum Mechanics	177
B.1	Direction Cosines and Tensor Transformation	177
B.2	Einstein Notation	178
B.3	Voigt Notation	178
B.3.1	Strain Tensor in Zincblende Nanowires	179
B.3.2	Strain Tensor in Wurtzite Nanowires	181
C	Phonons and Vibrational Modes	183
C.1	Lattice Dynamics in III-V Semiconductors	183
C.1.1	Homogeneous Problem	185
C.1.2	Inhomogeneous Problem	186
C.2	Strain Effects on the Lattice Vibrations	188
C.2.1	Uniaxial Stress Effects on the Zone-center Phonons of Zincblende Crystals	191
C.2.2	Uniaxial Stress Effects on the Zone-center Phonons of Wurtzite Crystals	192
D	Continuum Mechanics of a Doubly-clamped Beam	197
	Acknowledgements	201
	Publications and Presentations	203