

Contents

1 Overview of Phonon Raman Scattering in Solids

R. Merlin, A. Pinczuk, W.H. Weber	1
1.1 Light Scattering Mechanisms and Selection Rules	3
1.1.1 Conservation Laws	3
1.1.2 Kinematics: Wave Vector Conservation	4
1.1.3 Kinematics: Breakdown of Wave Vector Conservation	5
1.1.4 Light Scattering Susceptibilities	6
1.1.5 Enumeration of Raman Active Modes	9
1.1.6 Stokes and Anti-Stokes Scattering Intensities	11
1.2 Resonant Light Scattering and Forbidden Effects	12
1.3 Two-Phonon Scattering	15
1.4 Phonons in Semiconductor Alloys	17
1.5 Impurity Centers and Other Defects	19
1.6 Phonons in Amorphous Materials	22
1.7 Structural Phase Transitions: Effects of Temperature, Pressure and Composition	23
1.8 Conclusions	26
References	26

I The Effect of a Surface Space-Charge Electric Field on Raman Scattering by Optical Phonons

Elias Burstein	30
References	33

2 Raman Instrumentation

Sanford A. Asher, Richard Borrett	35
2.1 Raman Measurement Regime	36
2.1.1 Spontaneous, Non-resonance Raman Spectral Measurements ..	36
2.1.2 Spontaneous, Resonance Raman Spectral Measurements	37
2.1.3 Nonlinear Raman Measurements	38
2.2 Choice of Raman Excitation Wavelength	38
2.2.1 CW Lasers	38
2.2.2 Pulsed Lasers	39
2.3 Optical Methods for Rayleigh Rejection	40

VIII Contents

2.3.1 Holographic Notch Filter	41
2.3.2 Dielectric Edge Filters	41
2.3.3 Pre-monochromator Rayleigh Rejection	42
2.4 Raman Spectrometers	42
2.4.1 Dispersive Raman Spectrometers	42
2.4.2 FT-Raman Spectrometers	44
2.4.3 Detectors	44
2.4.4 Imaging Raman Spectrometers	45
2.5 Examples of New Raman Instruments for Materials Characterization	46
2.5.1 UV Raman Microspectrometer for CVD Diamond Studies	47
2.5.2 UV Raman Instrument for in situ Studies of CVD Diamond Growth	50
2.6 Conclusions	52
References	53
3 Characterization of Bulk Semiconductors Using Raman Spectroscopy	
J. Menendez	55
3.1 Inelastic Light Scattering by Phonons in Semiconductors	56
3.1.1 Phonons in Semiconductors	58
3.1.2 Anharmonic Effects	63
3.1.3 Raman Scattering by Phonons	64
3.2 Semiconductor Characterization	76
3.2.1 Crystal Orientation	76
3.2.2 Temperature Monitoring	77
3.2.3 Stress Measurements	80
3.2.4 Impurities	85
3.2.5 Alloying	90
3.3 Conclusion	99
References	99
II Finding the Stress from the Raman Shifts: A Case Study	
Ingrid de Wolf	104
References	106
III Brillouin Scattering from Semiconductors	
M. Grimsditch	107
References	108

4 Raman Scattering in Semiconductor Heterostructures	
Daniel Gammon	109
4.1 Electrons in Semiconductor Heterostructures	111
4.2 Resonant Raman Scattering	114
4.3 Kinematics	117
4.4 Vibrational Raman Scattering	
in Semiconductor Heterostructures	118
4.4.1 Phonons in Semiconductor Quantum Wells	118
4.4.2 Phonons as a Probe of Interface Roughness	
in a Quantum Well	124
4.5 Electronic Raman Scattering	
in Semiconductor Heterostructures	132
4.5.1 Shallow Impurities	133
4.5.2 Quasi-Two-Dimensional Electron Gas	137
4.6 Conclusion	144
References	144
IV Raman Scattering Enhancement by Optical Confinement in Semiconductor Planar Microcavities	
B. Jusserand, A. Fainstein	148
References	150
5 Raman Scattering in High-T_c Superconductors: Phonons, Electrons, and Magnons	
M. Cardona	151
5.1 High- T_c Superconductors: Chemical Composition and Crystal Structure	154
5.2 Raman Scattering by Phonons in High- T_c Superconductors	161
5.2.1 Vibrational Frequencies and Eigenvectors	161
5.2.2 Raman Intensities, Raman Tensors	173
5.2.3 The Phases of the Raman Tensors	173
5.3 Scattering by Intraband Electronic Excitations	176
5.3.1 Normal Metals	176
5.3.2 Scattering in the Superconducting State	184
5.4 Electron–Phonon Interaction	193
5.5 Crystal Field Transitions	
Between f -Electron Levels	199
5.6 Light Scattering by Magnons in HTSC and Their Antiferromagnetic Parent Compounds	204
5.6.1 Antiferromagnetic Structures	
in the Underdoped Parent Compounds	204
5.6.2 Introduction to Light Scattering by Magnons	
in Antiferromagnets	208

5.6.3 Electronic Structure of the CuO ₂ Antiferromagnetic Insulator and the Mechanism of Scattering by Two Magnons.....	210
5.6.4 Lineshape of Two-Magnon Raman Scattering in the Insulating HTSC Phases	214
5.6.5 Resonant Raman Scattering by Magnons	216
5.6.6 Scattering by Magnetic Fluctuations in Doped (Superconducting) Cuprates	217
References	219
V Thoughts About Raman Scattering from Superconductors	
Miles V. Klein	226
References	228
VI Two-Magnon Inelastic Light Scattering	
David J. Lockwood.....	230
References	232
6 Raman Applications in Catalysts for Exhaust-Gas Treatment	
Willes H. Weber	233
6.1 Supports and Substrates	235
6.2 Oxides of the Pt-Group Metals	239
6.2.1 Platinum Oxides.....	239
6.2.2 Iridium and Osmium Oxides	243
6.2.3 Palladium Oxide.....	243
6.2.4 Rhodium Oxides.....	246
6.2.5 Ruthenium Oxide.....	246
6.2.6 Mixed Oxides	248
6.3 Oxygen Storage Materials	249
6.4 Adsorbed Species.....	252
6.4.1 Oxides of Nitrogen	253
6.4.2 Oxides of Sulfur	257
6.5 Particle-Size Effects	259
6.6 Quantitative Analyses	261
6.7 Summary and Outlook	265
References	266
VII Historical Perspective of Raman Spectroscopy in Catalysis	
Israel E. Wachs	271
References	272

7 Raman Scattering Spectroscopy and Analyses of III-V Nitride-Based Materials

Leah Bergman, Mitra Dutta, Robert J. Nemanich	273
7.1 Experimental Considerations for Raman Scattering of Wide Band-Gap Semiconductors	274
7.2 Raman Scattering of GaN, AlN, and InN Films and Crystallites	275
7.2.1 Raman Tensors and Structure Identification of GaN, AlN, and InN	275
7.2.2 Wurtzite and Zincblende Phases of GaN	279
7.2.3 Wurtzite and Zincblende Structure of AlN and InN	284
7.3 Stress Analysis and Substrate Issues for Epitaxial Growth	287
7.3.1 Stress Analysis of GaN Films	287
7.3.2 Stress Analysis in WZ-AlN	290
7.4 Raman Analysis of the Quasi-Modes in AlN	292
7.5 Phonon–Plasmon Interaction in GaN Films and Crystallites	296
7.6 Isotopic Effects and Phonon Lifetimes in the Wurtzite Materials	301
7.7 Wide Band-Gap Alloys	303
7.8 Concluding Remarks	309
References	310

8 Raman Scattering in Fullerenes and Related Carbon-Based Materials

M.S. Dresselhaus, M.A. Pimenta, P.C. Eklund, G. Dresselhaus	314
8.1 Graphite Related Materials	316
8.1.1 Single Crystal Graphite and 2D Graphene Layers	317
8.1.2 Raman Spectra of Disordered sp^2 Carbons	319
8.2 Introduction to Fullerene Materials	326
8.2.1 Mode Classification in Fullerene Molecules	327
8.2.2 C_{60} Intra-Molecular Modes	329
8.2.3 Higher-Order Raman Modes in C_{60}	332
8.2.4 Perturbations to the Raman Spectra	333
8.2.5 Vibrational Spectra for Phototransformed Fullerenes	333
8.2.6 Inter-Molecular Modes	335
8.2.7 Vibrational Modes in Doped C_{60} -based Solids	335
8.2.8 Vibrational Spectra for C_{70} and Higher Fullerenes	337
8.3 Raman Scattering in Carbon Nanotubes	337
8.3.1 Structure of Carbon Nanotubes	338
8.3.2 Nanotube Phonon Modes	340
8.3.3 Raman Spectra of Single-Walled Carbon Nanotubes	343
8.3.4 Raman Scattering Studies at High Pressure	352
8.3.5 Charge Transfer Effects in Single-Wall Carbon Nanotubes	354

8.4 Summary	358
References	359
VIII A Case History in Raman and Brillouin Scattering: Lattice Vibrations and Electronic Excitations in Diamond	
A.K. Ramdas	365
References	368
9 Raman Spectroscopic Studies of Polymer Structure	
Shaw Ling Hsu	369
9.1 Overview of Structural Characterization	375
9.1.1 Amorphous Polymers: Low Frequency Observations	379
9.1.2 Solid State Properties	382
9.2 Polymer Anisotropy	385
9.2.1 Motivation	385
9.2.2 Partially Oriented Systems	389
9.2.3 Definition of Orientation Function	394
9.3 Long-Range Order and Disorder in Polymers	396
9.3.1 Initial Observations Made for Models and Polymers	396
9.3.2 Other LAM Observations	397
9.3.3 Applications of LAM to Polymer Structural Characterization	400
9.4 Fermi Resonance Interaction and Its Application to Structural Analysis	411
9.5 Disordered States	418
9.5.1 Normal Coordinate Approach	419
9.5.2 Molecular Dynamics Approach	421
9.5.3 Examples	423
References	438
IX C.V. Raman: A Personal Note	
Samuel Krimm	446
References	447
10 Raman Scattering in Perovskite Manganites	
V.B. Podobedov, A. Weber	448
10.1 Manganite Structure and Selection Rules for Optical Vibrational Modes	451
10.2 Doped Crystals ($x > 0$)	453
10.3 Undoped Crystals ($x = 0$)	463
10.4 Films	467
10.5 Summary	475
References	476

X Raman Scattering from Perovskite Ferroelectrics	
R.S. Katiyar	479
References	481
Index	483

