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| 65 | <b>Transport Processes<br/>in Ion-Irradiated Polymers</b><br>By D. Fink   | 75 | <b>Wafer Bonding</b><br>Applications and Technology<br>Editors: M. Alexe and U. Gösele  |
| 66 | <b>Multiphased Ceramic Materials</b><br>Processing and Potential<br>Editors: W.-H. Tuan and J.-K. Guo   | 76 | <b>Spirally Anisotropic Composites</b><br>By G.E. Freger, V.N. Kestelman,<br>and D.G. Freger                                  |
| 67 | <b>Nondestructive<br/>Materials Characterization</b><br>With Applications to Aerospace Materials<br>Editors: N.G.H. Meyendorf, P.B. Nagy,<br>and S.I. Rokhlin | 77 | <b>Impurities Confined<br/>in Quantum Structures</b><br>By P.O. Holtz and Q.X. Zhao   |
| 68 | <b>Diffraction Analysis<br/>of the Microstructure of Materials</b><br>Editors: E.J. Mittemeijer and P. Scardi   | 78 | <b>Macromolecular Nanostructured<br/>Materials</b><br>Editors: N. Ueyama and A. Harada  |
| 69 | <b>Chemical-Mechanical Planarization<br/>of Semiconductor Materials</b><br>Editor: M.R. Oliver  | 79 | <b>Magnetism and Structure<br/>in Functional Materials</b><br>Editors: A. Planes, L. Manósa,<br>and A. Saxena                 |
| 70 | <b>Applications of the Isotopic Effect<br/>in Solids</b><br>By V.G. Plekhanov   | 80 | <b>Ion Implantation<br/>and Synthesis of Materials</b><br>By M. Nastasi and J.W. Mayer  |
| 71 | <b>Dissipative Phenomena<br/>in Condensed Matter</b><br>Some Applications<br>By S. Dattagupta and S. Puri   | 81 | <b>Metallopolymer Nanocomposites</b><br>By A.D. Pomogailo and V.N. Kestelman  |
|    |   | 82 | <b>Plastics for Corrosion Inhibition</b><br>By V.A. Goldade, L.S. Pinchuk,<br>A.V. Makarevich and V.N. Kestelman              |
|    |   | 83 | <b>Spectroscopic Properties of Rare Earths<br/>in Optical Materials</b><br>Editors: G. Liu and B. Jacquier                    |

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Volumes 10–61 are listed at the end of the book.

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# Spectroscopic Properties of Rare Earths in Optical Materials

With 194 Figures and 61 Tables



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# 《Spectroscopic Properties of Rare Earths in Optical Materials》

## Preface

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Decades of scientific research on spectroscopic properties of f-shell electrons has spawned an extensive array of applications for rare-earth activated luminescent and laser materials. From phosphors activated by  $\text{Eu}^{2+}$ ,  $\text{Eu}^{3+}$  and  $\text{Tb}^{3+}$  ions for lighting and display to crystals and glasses doped with  $\text{Er}^{3+}$  and  $\text{Yb}^{3+}$  for infrared-to-visible up-conversion, rare-earths represent a large share of the lighting materials market. Currently,  $\text{Nd}^{3+}$  doped crystals such as  $\text{Nd}^{3+} : \text{YAG}$  ( $\text{Y}_3\text{Al}_5\text{O}_{12}$ ) and  $\text{Nd}^{3+} : \text{YVO}_4$  are the dominant laser media for high power and compact solid-state lasers, while  $\text{Er}^{3+}$  doped phosphate and silicate glasses prevalent in optical fiber amplifiers and microlasers used in optical telecommunications. Thanks also to materials science development, rare-earths will receive even wider use in the future, entering in the new world of nanotechnologies for instance. In addition to rare-earth activated phosphors and solid-state lasers, optical applications of rare-earths are already an integral part of internet and data communications and are expected to be applied to information storage and processing, and organic and biological devices.

Since the 1960s, several classic books on spectroscopy of rare-earth ions in solids have been published, including those by Wybourne (1965) and Hüfner (1978). More recent advances in spectroscopic theory and laser experiments involving rare-earth ions in solids were also reviewed, for example, in the book edited by Kaplyanskii and Macfarlane (1987). However, in the f-elements research community, we feel the need of a book that updates the information of recent progresses in the field and facilitates understanding and applications of the principles and concepts that are required in rare-earth optical materials characterization and development. The goal of this book is to provide a connection between basic research and materials science through analysis of fundamental spectroscopic properties of rare-earth activated luminescent and laser optical materials. In addition, this book will serve as an updated reference for materials research by covering a number of currently active topics in the field of rare-earth photo-physics and photo-chemistry. Fundamental topics of optical

spectroscopy are addressed with an emphasis on the physical interactions that determine the primary optical properties, including energy level schemes, transitions intensities, line broadening, mechanisms of non-radiative relaxation and energy transfer. Topics of applied research are selected from recent advances in concepts and techniques that created significant opportunities for present and future applications of rare-earth optical materials.

An international collaboration, which includes contributions from authors with both experimental and theoretical expertise, enables us to offer the reader a systematic review of fundamental aspects and to provide a wide coverage on new applications that utilize the electronic transitions of rare-earth ions in solid-state materials. From free-ion and crystal-field energy level structures to transition intensities and line broadening induced by ion-ion and ion-phonon interactions, the first four chapters survey the fundamentals of f-element photo-physics and spectroscopy, and provide a theoretical framework for the subjects that are discussed in the rest of the book. From Chapter 5 onwards, each chapter is devoted to a particular area of importance in new materials characterization or technology development. From up-conversion phenomena, to materials requirements for frequency-domain and time-domain optical memory, to current progress in rare-earth laser materials and phosphors, the concepts and principles discussed in this book were taken directly from the forefront of research in rare-earth optical materials. Moreover, illustration of current progress in fundamental aspects of quantum confinement and quantum electrodynamics is also discussed. To make it easier to read, and also to avoid cluttering up Chapters 1, 2 and 3, the more theoretical derivations of these chapters are given in Appendices A and B. We hope that this book will provide useful information to researchers and students in the field of f-element spectroscopy and materials development.

Although chapters in this book are written independently by individual authors, significant efforts have been made to achieve a coherent connection and systematic balance for the book as a whole. We are grateful to all authors of this book for their excellent contributions.

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# Contents

<b>1</b>	<b>Electronic Energy Level Structure</b>	<b>1</b>
1.1	Introduction	1
1.2	Electronic States and Coupling Schemes	4
1.2.1	Central Field Approximation	4
1.2.2	<i>LS</i> Coupling and Intermediate Coupling	7
1.3	Free-ion Interactions	11
1.3.1	Coulomb Interaction	11
1.3.2	Spin-orbit Interaction	14
1.3.3	Corrections to Free-ion Hamiltonian	15
1.3.4	Reduced Matrices and Free-ion State Representation	17
1.3.5	Parameterization of the Free-ion Interactions	18
1.3.6	Energy Levels of $4f^N$ Configurations and Binding Energies Relative to Host Band	23
1.4	Crystal-field Interaction	26
1.4.1	Crystal-field Hamiltonian and Matrix Element Evaluation	28
1.4.2	Symmetry Rules	32
1.4.3	Empirical Evaluation of Crystal-field Parameters	37
1.4.4	Theoretical Evaluation of Crystal-field Parameters	39
1.4.5	Corrections to the Crystal-field Hamiltonian	46
1.5	Analysis of Crystal-field Spectra	50
1.5.1	Experimental Data	51
1.5.2	Computational Modeling	54
1.6	Modeling of $4f^N - 4f^{N-1} 5d$ Spectra	57
1.6.1	Energy Gaps Between the $4f^N$ and Excited Configurations	57
1.6.2	Hamiltonian for $4f^{N-1} 5d$ Configurations	59
1.6.3	Determination of Hamiltonian Parameters	60
1.7	Magnetic and Hyperfine Interactions	64
1.7.1	Zeeman Effect	65
1.7.2	Magnetic Hyperfine Interaction	67
1.7.3	Nuclear Electric Quadrupole Interaction	69
1.7.4	Ion-ligand Hyperfine Interaction	72
1.7.5	$\text{Pr}^{3+}$	73
1.7.6	$\text{Eu}^{3+}$	76

1. 7. 7	Tb <sup>3+</sup> .....	85
1. 7. 8	Other Ions .....	88
	References .....	89
<b>2</b>	<b>Transition Intensities</b> .....	95
2. 1	Introduction .....	95
2. 2	Basic Equations .....	96
2. 2. 1	Electric and Magnetic Dipole Operators .....	96
2. 2. 2	Polarization Selection Rules .....	98
2. 2. 3	Vibronic Transitions .....	100
2. 3	One Photon Transitions Within the 4f <sup>N</sup> Configuration .....	102
2. 3. 1	General Theory .....	103
2. 3. 2	Transitions Between Crystal-field Levels .....	104
2. 3. 3	Transitions Between <i>J</i> Multiplets .....	108
2. 3. 4	Selection Rules .....	109
2. 3. 5	Vibronic Transitions .....	109
2. 3. 6	Circular Dichroism .....	110
2. 3. 7	Parameter Fits .....	111
2. 3. 8	Comparison with First-principles Calculations .....	117
2. 3. 9	Extensions to the Models .....	121
2. 4	Higher-energy Transitions .....	122
2. 4. 1	4f <sup>N</sup> ↔ 4f <sup>N-1</sup> 5d Transitions .....	122
2. 4. 2	Charge Transfer .....	123
2. 5	Two-photon Processes .....	124
2. 5. 1	f <sup>N</sup> ↔ f <sup>N</sup> Transitions .....	124
2. 5. 2	4f <sup>N</sup> ↔ 4f <sup>N-1</sup> 5d Transitions .....	126
2. 6	Conclusions .....	126
	References .....	126
<b>3</b>	<b>Ion-phonon Interactions</b> .....	130
3. 1	Introduction .....	130
3. 2	Basic Concepts: Hamiltonian of the Ion-phonon Interaction, Adiabatic and Nonadiabatic Terms .....	131
3. 3	Coupling Constants .....	139
3. 4	Density Matrix Formalism in the Quantum Theory of Relaxation .....	145
3. 5	Thermal Shifts of Zero-phonon Line Positions .....	151
3. 6	Non-radiative Transitions Between Crystal Field Energy Levels .....	153
3. 6. 1	One- and Two-phonon Transition Rates .....	153
3. 6. 2	Phonon Contributions to Linewidths .....	155
3. 6. 3	Multiphonon Relaxation .....	158



3.7	Vibrational Structure of the Optical Spectra .....	166
3.8	Simulations of the Ion-phonon Interaction Effects .....	170
3.8.1	Impurity Rare Earth Single Ion Centers in the LiYF <sub>4</sub> Crystal .....	171
3.8.2	Relaxation Broadening of Optical Transitions in Pr <sup>3+</sup> Dimer Centers in CsCdBr <sub>3</sub> .....	182
3.9	Conclusions .....	185
	References .....	186
<b>4</b>	<b>Line Broadening Mechanisms and Their Measurement .....</b>	<b>191</b>
4.1	Introduction .....	191
4.2	Inhomogeneous Broadening .....	194
4.2.1	Zero-phonon Linewidths of 4f→4f and 4f→5d Transitions .....	194
4.2.2	Line Broadening from Defects and Disorder .....	195
4.2.3	Site-selective Spectroscopy .....	197
4.2.4	Ultrannarrow Inhomogeneous Linewidths .....	201
4.3	Non-inhomogeneous Sources of Line Structure .....	202
4.3.1	Hyperfine Structure and Isotope Shifts .....	202
4.3.2	Vibronic Sidebands .....	203
4.4	Homogeneous Broadening .....	204
4.4.1	Ion-phonon Interactions .....	205
4.4.2	Ion-ion Interactions .....	208
4.4.3	Ion-nuclear Spin-spin Interactions .....	213
4.5	Measurement of Line Broadening and Examples .....	214
4.5.1	Fluorescence Line-narrowing .....	215
4.5.2	Spectral Hole Burning .....	218
4.5.3	Coherent Transient Spectroscopy .....	227
4.6	Disordered, Low-dimensional and Nanostructure Crystalline Materials .....	238
4.6.1	Disordered Materials .....	239
4.6.2	Low Dimensional Systems .....	246
4.6.3	Nanocrystalline Materials .....	251
4.7	Conclusions .....	257
	References .....	257
<b>5</b>	<b>Up-conversion in RE-doped Solids .....</b>	<b>266</b>
5.1	Introduction and Historical Background .....	267
5.2	Energy Transfers Between RE Ions; Role of Energy Diffusion in Up- and Down-conversion .....	268
5.2.1	Recall of Basics of Energy Transfer with	

	Activator in Its Ground State .....	268
5.2.2	Up-conversion Processes by Sequential Energy Transfers; Comparison with ESA and Typical Examples .....	276
5.3	Up-conversion in Single-ion and Pair-level Level Description; Theoretical and Experimental Discrimination .....	279
5.3.1	Application of Cooperative Luminescence; Theory and Examples .....	284
5.3.2	Some Experimental Results for APTE Effect and Their Implications in Various Field .....	286
5.4	Cross-relaxation and the Photon Avalanche Effect .....	296
5.4.1	The Avalanche Process as a Positive Feedback System .....	298
5.4.2	Conditions for Observing an Avalanche Threshold .....	300
5.4.3	$\text{Er}^{3+}$ ; $\text{LiYF}_4$ as an Avalanche Model Experiment .....	302
5.4.4	Photon Avalanche in $\text{Er}^{3+}$ -doped Fluoride Glasses in Fibre and Bulk Shape .....	306
5.4.5	Avalanche in Co-doped Systems .....	309
5.4.6	Up-conversion Laser with Multiphonon-assisted Pumping Scheme and Photon Avalanche .....	310
5.5	Perspectives and Future Advances .....	311
5.5.1	Up-conversion UV Tunable Lasers .....	311
5.5.2	New Materials for Low-intensity IR Imaging .....	312
5.5.3	Up-conversion Material Intrinsic Bistability .....	312
5.6	Conclusions .....	314
	References .....	315
<b>6</b>	<b>Current Topics in Rare-earth Lasers .....</b>	<b>320</b>
6.1	Introduction .....	320
6.2	Spectroscopic and Laser Parameters .....	321
6.2.1	Basic Laser Parameters .....	322
6.2.2	Determination of Absorption Cross Sections .....	328
6.2.3	Determination of Emission Cross Sections .....	329
6.2.4	Determination of Radiative Lifetimes and Branching Ratios .....	336
6.3	UV-visible Laser Sources .....	340
6.3.1	Compact and Tunable UV Lasers Based on $\text{Ce}^{3+}$ Doped Crystals; Prospects with Other Ions .....	340
6.3.2	Lasers Based on $\text{Nd}^{3+}$ and $\text{Yb}^{3+}$ Doped Nonlinear Crystals .....	345
6.4	Near- and Mid-infrared Laser Sources .....	349
6.4.1	High-power and Ultrafast Lasers Based on $\text{Yb}^{3+}$ Doped Materials .....	349

6.4.2	Rare-earth Doped Crystals for Telecommunications and Eyesafe Laser Applications .....	355
6.4.3	Low-frequency Phonon Materials for Mid-infrared Lasers .....	364
6.5	Conclusions .....	369
Appendix .....		370
6.A	Laser Threshold Condition .....	370
6.B	Minimum Fraction of Excited Population $\beta_{\min}$ .....	371
6.C	Energy Transfer Rates .....	371
6.D	Einstein Coefficients .....	372
6.E	List of Acronyms .....	372
References .....		373

## 7 Rare Earth Materials in Optical Storage

<b>and Data Processing Applications .....</b>		<b>379</b>
7.1	Introduction .....	379
7.1.1	Equivalence of Holeburning and Photon Echoes in Storage and Signal Processing Applications .....	381
7.1.2	Material Parameters for Optical Data Storage .....	382
7.1.3	Dephasing and Spectral Diffusion .....	382
7.2	Eu <sup>3+</sup> Materials .....	384
7.2.1	Properties of Y <sub>2</sub> SiO <sub>5</sub> .....	385
7.2.2	Eu <sup>3+</sup> : Y <sub>2</sub> SiO <sub>5</sub> .....	386
7.2.3	Other Experiments in Eu <sup>3+</sup> : Y <sub>2</sub> SiO <sub>5</sub> .....	391
7.2.4	Eu <sup>3+</sup> : Y <sub>2</sub> O <sub>3</sub> .....	391
7.2.5	Eu <sup>3+</sup> : YAlO <sub>3</sub> .....	393
7.3	Pr <sup>3+</sup> Materials .....	394
7.3.1	Pr <sup>3+</sup> : Y <sub>2</sub> SiO <sub>5</sub> .....	394
7.3.2	Pr <sup>3+</sup> : YAlO <sub>3</sub> .....	397
7.3.3	Pr <sup>3+</sup> : Y <sub>3</sub> Al <sub>5</sub> O <sub>12</sub> .....	398
7.3.4	Pr <sup>3+</sup> : LaF <sub>3</sub> .....	399
7.4	Tm <sup>3+</sup> Materials .....	399
7.4.1	Tm <sup>3+</sup> : Y <sub>3</sub> Al <sub>5</sub> O <sub>12</sub> .....	401
7.4.2	Tm <sup>3+</sup> : Lu <sub>3</sub> Al <sub>5</sub> O <sub>12</sub> .....	404
7.4.3	Tm <sup>3+</sup> : Y <sub>1.5</sub> Lu <sub>1.5</sub> Al <sub>5</sub> O <sub>12</sub> .....	405
7.4.4	Tm <sup>3+</sup> : Y <sub>3</sub> Ga <sub>5</sub> O <sub>12</sub> .....	406
7.4.5	Tm <sup>3+</sup> : LaF <sub>3</sub> .....	407
7.4.6	Tm <sup>3+</sup> : Y <sub>2</sub> SiO <sub>5</sub> .....	407
7.4.7	Tm <sup>3+</sup> : Y <sub>2</sub> Si <sub>2</sub> O <sub>7</sub> .....	408
7.4.8	Tm <sup>3+</sup> : Y <sub>2</sub> O <sub>3</sub> .....	409
7.4.9	Tm <sup>3+</sup> : YAlO <sub>3</sub> .....	409
7.4.10	Tm <sup>3+</sup> Materials Summary .....	410

7.5	Er <sup>3+</sup> Materials	411
7.5.1	Properties of Er <sup>3+</sup> :Y <sub>2</sub> SiO <sub>5</sub>	412
7.5.2	Properties of Er <sup>3+</sup> :Y <sub>2</sub> O <sub>3</sub>	416
7.5.3	Properties of Er <sup>3+</sup> :LiNbO <sub>3</sub>	416
7.5.4	Properties of Er <sup>3+</sup> :YAlO <sub>3</sub>	417
7.5.5	Properties of Er <sup>3+</sup> :Y <sub>3</sub> Al <sub>5</sub> O <sub>12</sub>	419
7.5.6	Properties of Er <sup>3+</sup> Doped Tungstates	420
7.5.7	Er <sup>3+</sup> Materials Summary	420
7.6	Other Materials	421
7.6.1	Eu <sup>2+</sup> Materials	422
7.6.2	Deuterated Fluorides	423
7.6.3	Eu <sup>3+</sup> Persistence	424
7.6.4	Nd <sup>3+</sup> Systems	424
7.7	Conclusions	426
	References	426
<b>8</b>	<b>Rare Earth Doped Confined Structures for Lasers and Amplifiers</b>	<b>430</b>
8.1	Introduction	430
8.2	Propagation and Amplification; the Key Parameters	432
8.2.1	Opto-geometrical Parameters	432
8.2.2	Spectroscopic Parameters	433
8.2.3	Amplification into a Waveguide	438
8.2.4	Material Requirements for Fabrication of Waveguide	441
8.2.5	Other Specific Properties; Photosensitivity and Photorefractivity	442
8.3	Waveguide Amplifiers and Lasers	443
8.3.1	Erbium-doped Fiber Amplifier	444
8.3.2	Praseodymium-doped Fiber Amplifier	449
8.3.3	Thulium-doped Fiber Amplifier	450
8.3.4	Fiber Lasers	452
8.3.5	Optical Integrated Amplifiers and Lasers	453
8.4	Optical Microcavities and Nanoconfinement	454
8.4.1	Optical Confinement	455
8.4.2	Experimental Evidences	456
8.4.3	Various Devices	457
8.5	Conclusions	458
	References	458
<b>9</b>	<b>Rare Earth Luminescent Centers in Organic and Biochemical Compounds</b>	<b>462</b>
9.1	Introduction	462

9.2	Sensitizing the Luminescence of Trivalent Lanthanide Ions .....	464
9.2.1	Establishing the Importance of the Triplet State .....	464
9.2.2	Mechanisms of Energy Transfer .....	467
9.3	Preventing Nonradiative Deactivation of the Metal Ion Luminescent States .....	469
9.3.1	Vibrational Deactivation Processes .....	469
9.3.2	Electronic Deactivation Processes .....	472
9.4	Designing a Luminescent Probe .....	476
9.4.1	Qualitative Rules .....	476
9.4.2	Quantitative Estimates .....	477
9.5	Luminescent Lanthanide Complexes with Organic Ligands .....	481
9.6	Applications in Biomedical Analyses .....	486
9.6.1	Fluoroimmunoassays .....	486
9.6.2	Responsive Systems .....	489
9.7	Conclusions .....	491
Appendix	.....	491
9. A	Chemical Formulae of Compounds Cited in the Text .....	491
9. B	Glossary and Chemical Formulae .....	496
References	.....	497
<b>10</b>	<b>Rare Earth Ions in Advanced X-ray Imaging Materials .....</b>	<b>500</b>
10.1	X-ray Phosphors .....	500
10.2	X-ray Phosphors Used for Intensifying Screens .....	502
10.2.1	Calcium Tungstate .....	503
10.2.2	Rare Earth Tantalate Based Phosphors .....	504
10.2.3	Europium Activated Barium Fluoro-chloride Phosphors .....	509
10.2.4	Tb- and Tm-activated Lanthanum Oxybromides .....	511
10.2.5	Tb <sup>3+</sup> -activated Gadolinium Oxysulfide .....	513
10.3	X-ray Storage Phosphors and Their Applications .....	514
10.3.1	Physical Mechanism of Photostimulated Luminescence .....	515
10.4	X-ray Phosphors for Computed Tomography .....	518
10.4.1	Scintillators for X-ray Computed Tomography .....	521
10.5	Scintillators for Electromagnetic Calorimetric Detection .....	524
10.5.1	Cerium Fluoride .....	525

10.5.2	Ce <sup>3+</sup> -activated Gd <sub>2</sub> SiO <sub>5</sub> and Lu <sub>2</sub> SiO <sub>5</sub> .....	526
10.6	Conclusions .....	527
	References .....	527
<b>Appendix A</b>	<b>Effective Operator Calculations</b> .....	<b>530</b>
A.1	Effective Hamiltonians and Effective Operators .....	530
A.2	Perturbation Expansions .....	531
A.3	Symmetries and Selection Rules .....	534
A.4	Implications .....	535
	References .....	536
<b>Appendix B</b>	<b>Matrix Elements of Tensor Operators</b> .....	<b>537</b>
B.1	Angular Momentum States and Operators .....	537
B.2	Clebsh-Gordan Coefficients and 3-j Symbols .....	537
B.3	Tensor Operators and the Wigner-Eckart Theorem .....	538
B.4	More Complex Situations .....	539
	References .....	540
<b>Keywords Index</b>	.....	<b>541</b>
<b>Materials Index</b>	.....	<b>545</b>

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