abhaltet

LUMINESCENT MATERIALS

Springer-Verlag

G. Blasse, B. C. Grabmaier

Luminescent Materials

With 171 Figures and 31 Tables

Springer-Verlag
Berlin Heidelberg New York
London Paris Tokyo
Hong Kong Barcelona Budapest

Prof. Dr. G. Blasse

Debye Institute
University Utrecht
Postbox 80.000
3508 TA Utrecht
The Netherlands

Prof. Dr. B. C. Grabmaier

Siemens Research Laboratories
ZFE BT MR 22
D-81730 München
Germany

also with Debye Institute
University Utrecht

ISBN 3-540-58019-0 Springer-Verlag Berlin Heidelberg New York
ISBN 0-387-58019-0 Springer-Verlag New York Berlin Heidelberg

Library of Congress Cataloging-in-Publication Data
Blasse, G. Luminescent materials / G. Blasse, B.C. Grabmaier. p. cm.
Includes bibliographical references and index.
ISBN 3-540-58019-0. -- ISBN 0-387-58019-0 (U.S.)
1. Phosphors. 2. Luminescence. I. Grabmaier, B. C., 1935- II. Title.
QC476.7.B53 1994 620.1'1295--dc20 94-20336 CIP

Typesetting with TEX: Data conversion by Lewis & Leins, Berlin
SPIN: 10187460 02/3020 - 5 4 3 2 1 0 - Printed on acid-free paper

no patiently typed the
er correction appeared
drawing some of the
disposal.
s with and inspiration
acts, some oral, some
. In the preparation of
, A. Bril, C.W.E. van
ry useful.
minescence. We hope
phenomena, to design
on in doing so.

G. Blasse, Utrecht
Grabmaier, München

Table of Contents

Chapter 1 A General Introduction to Luminescent Materials
Chapter 2 How Does a Luminescent Material Absorb Its Excitation Energy?

2.1 General Considerations 10
2.2 The Influence of the Host Lattice 16
2.3 The Energy Level Diagrams of Individual Ions 20
2.3.1 The Transition Metal Ions (d^n) 20
2.3.2 The Transition Metal Ions with d^0 Configuration 25
2.3.3 The Rare Earth Ions ($4f^n$) 25
2.3.4 The Rare Earth Ions ($4f$-$5d$ and Charge-Transfer Transitions) 27
2.3.5 Ions with s^2 Configuration 28
2.3.6 Ions with d^{10} Configuration 29
2.3.7 Other Charge-Transfer Transitions 30
2.3.8 Color Centers 30
2.4 Host Lattice Absorption 30
References 31

Chapter 3 Radiative Return to the Ground State: Emission

3.1 Introduction 33
3.2 General Discussion of Emission from a Luminescent Center 33
3.3 Some Special Classes of Luminescent Centers 38
3.3.1 Exciton Emission from Alkali Halides 38
3.3.2 Rare Earth Ions (Line Emission) 40
3.3.3 Rare Earth Ions (Band Emission) 45
3.3.4 Transition Metal Ions 50
3.3.5 d^0 Complex Ions 52
3.3.6 d^{10} Ions 53
3.3.7 s^2 Ions 55
3.3.8 The U^{6+} ion 59
3.3.9 Semiconductors 60
3.3.10 Cross-Luminescence 64
3.4 Afterglow 65
3.5 Thermoluminescence 66
3.6. Stimulated emission 67
References 70

Chapter 4 Nonradiative Transitions

4.1 Introduction 71
4.2 Nonradiative Transitions in an Isolated Luminescent Centre 72
4.2.1 The Weak-Coupling Case 74
4.2.2 The Intermediate- and Strong-Coupling Cases 77
4.3 Efficiency 84
4.4 Maximum Efficiency for High Energy Excitation [13] 85
4.5 Photoionization and Electron-Transfer Quenching 86
4.6 Nonradiative Transitions in Semiconductors 88
References 89

Chapter 5 Energy Transfer

5.1 Introduction 91
5.2 Energy Transfer Between Unlike Luminescent Centers 91
5.3 Energy Transfer Between Identical Luminescent Centers 95
5.3.1 Weak-Coupling Scheme Ions 95
5.3.2 Intermediate- and strong-coupling scheme ions 103
5.4 Energy Transfer in Semiconductors 106
References 106

Chapter 6 Lamp Phosphors

6.1 Introduction 108
6.2 Luminescent Lighting [1-3] 108
6.3 The Preparation of Lamp Phosphors 111
6.4 Photoluminescent Materials 112
6.4.1. Lamp Phosphors for Lighting 112
6.4.2 Phosphors for Other Lamp Applications 126
6.4.3 Phosphors for High-Pressure Mercury Vapour Lamps 127
6.4.4 Phosphors with Two-Photon Emission 130
6.5 Outlook 130
References 133

Chapter 7 Cathode-Ray Phosphors

7.1 Cathode-Ray Tubes: Principles and Display 134
7.2 Preparation of Cathode-Ray Phosphors 136
7.3 Cathode-Ray Phosphors 137
7.3.1 Some General Remarks 137
7.3.2 Phosphors for Black-and-White Television 138
7.3.3 Phosphors for Color Television 138
7.3.4 Phosphors for Projection Television 141
7.3.5 Other Cathode-Ray Phosphors 143
7.4 Outlook 145
References 145

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS
Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS
Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS
Sync your system to PACER to automate legal marketing.