

C. Blasse P. G. Schubmeyer

UTS LIBRARY



39339037982730

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.)
I. Phosphors. 2. Luminescence. I. Grabmaier, B. C., 1935- II. Title.
QC476.7.B53 1994 620.1'1295--dc20 94-20336 CIP

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, re-use of illustrations, recitation, broadcasting, reproduction on microfilms or in other ways, and storage in data banks. Duplication of this publication or parts thereof is only permitted under the provisions of the German Copyright Law of September 9, 1965, in its current version, and a copyright fee must always be paid.

© Springer-Verlag Berlin Heidelberg 1994
Printed in Germany

The use of registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

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

so patiently typed the
correction appeared
drawing some of the
disposal.

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 ($4f\text{-}5d$ 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

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.