

Riga Technical University

Effective Lighting

Coordinator Leonids Ribickis

Leonids Ribickis
Ilja Galkins
Gintautas Tamulaitis
Arif Pashayev
Bahadur Tagiyev

Kerim Allahverdiyev
Igor Uteshevs
Aleksandrs Suzdalenko
Ansis Avotins
Olegs Tetervenoks

RTU Press
Riga, 2015

This document has been prepared by the financial support of European Union. Authors from Riga Technical University, National Aviation Academy and Vilnius University are responsible for the content of this document. This publication reflects the views only of the authors, and it cannot be regarded as the European Union's official position.

The book is developed in a frame of the project "Development of Training Network for Improving Education in Energy Efficiency" acronym: ENERGY, grant Nr. 530379-TEMPUS-1-2012-1- LVTEMPUS-JPCR.

The project was approved by the European Commission in frame of the Program Tempus IV – Fifth call for proposals (Programme guide EACEA/25/2011).

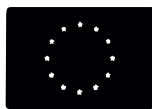
The textbook is devised for students of electrical engineering specialties, who study effective lighting technologies. The textbook can be useful for students and professionals focusing on lighting issues. The book gives overview of current lighting systems and elements, as well as explains their operating principles.

Sub-programme Joint Projects

Action Curricular Reform

Deliverable 2.1. Development and translation of study courses within the frame of direction Effective Lighting.

Reviewers: **Olga Ruban**, PhD, ass. Prof., Tallin University of Technology Virumaa College,
Jelena Armas, PhD, Elektriveli OÜ
Kristine Bērziņa, Dr.sc.ing., EEF, Riga Technical University



Tempus



Project Scientific Manager **Leonids Ribickis**
Project Manager **Anatolijs Zabasta**
Scientific Editors: **Ansis Avotins, Igors Uteshevs**
Proofreading **Anastasia Zhiravetska**
Coordinator institution **Riga Technical University**

Autors of the book are responsible for publication of illustrations.

All rights are reserved. No part of this publication may be reproduced, stored, transmitted or disseminated in any form or by any means without prior written permission from Riga Technical University represented by RTU Press to whom all requests to reproduce copyright material should be directed in writing.

© Riga Technical University, 2015

ISBN 978-9934-10-603-3

Published by RTU Press, Riga Technical University, 1 Kalku Street, Riga, LV-1658, Latvia.

Cover picture from Shutterstock.com

Printed by RTU Printing House

Contributors

Leonids Ribickis (Project Coordinator), Prof., Dr. habil.sc. ing., Riga Technical University (RTU), Faculty of Power and Electrical Engineering, Institute of Industrial Electronics and Electrical Engineering, 1, Kalku Str., Riga, LV 1658, Latvia, Leonids.Ribickis@rtu.lv

Ilja Galkins, professor, Riga Technical University, Faculty of Power and Electrical Engineering, Institute of Industrial Electronics and Electrical Engineering, 12-K1, Azenes Str., Riga, LV1050, Latvia, e-mail: gia@eef.rtu.lv

Gintautas Tamulaitis, professor and head of the Department of Semiconductor Physics at Vilnius University, Sauletekio al. 9 - III, Vilnius, LT-10222, Lithuania, e-mail: gintautas.tamulaitis@ff.vu.lt

Arif Pashayev, professor, Academician of the Azerbaijan National Academy of Sciences, Rector of the National Aviation Academy of Azerbaijan, Bina 25th km, Baku 1045, Azerbaijan.

Bahadur Tagiyev, professor, Academician of the Azerbaijan National Academy of Sciences, Director of the Scientific Research Institute for Transportation and Aviocosmic Problems, National Aviation Academy of Azerbaijan, Bina 25th km, Baku 1045, Azerbaijan, e-mail: bahadur34@mail.ru.

Kerim Allahverdiyev, professor, Member of the European Academy of Sciences, Senior Scientific Researcher, Scientific Research Institute for Transportation and Aviocosmic Problems, National Aviation Academy of Azerbaijan, Bina 25th km, Baku 1045, Azerbaijan, e-mail: kerim.allahverdi@gmail.com

Igors Uteshevs, senior researcher, Riga Technical University, Faculty of Power and Electrical Engineering, Institute of Industrial Electronics and Electrical Engineering, 12-K1, Azenes Str., Riga, LV1050, Latvia, e-mail: igors.utesevs@rtu.lv

Aleksandrs Suzdalenko, senior researcher, Riga Technical University, Faculty of Power and Electrical Engineering, Institute of Industrial Electronics and Electrical Engineering, 12-K1, Azenes Str., Riga, LV1050, Latvia, e-mail: aleksandrs.suzdalenko@rtu.lv

Ansis Avotins, researcher, Riga Technical University, Faculty of Power and Electrical Engineering, Institute of Industrial Electronics and Electrical Engineering, 12-K1, Azenes Str., Riga, LV1050, Latvia, e-mail: ansis.avotins@rtu.lv

Olegs Tetervenoks, researcher, Riga Technical University, Faculty of Power and Electrical Engineering, Institute of Industrial Electronics and Electrical Engineering, 12-K1, Azenes Str., Riga, LV1050, Latvia, e-mail: olegs.tetervenoks@rtu.lv

Contents

Contributors	3
Introduction	7
1. Terms in Lighting	9
1.1. <i>Terms of photometry</i>	10
1.1.1. Luminous flux.....	10
1.1.2. Luminous intensity.....	11
1.1.3. Illuminance.....	12
1.1.4. Luminance.....	13
1.1.5. Luminous efficacy.....	14
1.1.6. Colour temperature.....	15
1.1.7. Colour rendering index.....	16
1.1.8. Lifetime.....	17
1.2. <i>Normative aspects</i>	17
1.2.1. Optics for street profile.....	17
1.2.2. Body of luminaire.....	18
1.2.3. PSU quality and Dimming.....	19
2. Fundamentals of LEDs	21
2.1. <i>History of LEDs</i>	22
2.2. <i>Basics of LEDs</i>	23
2.3. <i>Materials for LED</i>	37
2.4. <i>Efficiency of LEDs</i>	47
2.5. <i>White LEDs</i>	54
3. Application of LEDs	57
3.1. <i>Introduction</i>	58
3.2. <i>Street lighting</i>	62
3.3. <i>LED-based lighting in remote areas</i>	66
3.4. <i>Emergency lights and signage</i>	73
3.5. <i>LEDs in traffic lights and automotive industry</i>	74
3.6. <i>Displays and panels</i>	78
3.7. <i>Medical applications</i>	80
3.8. <i>Plant cultivation</i>	83

4. Power Supplies and Circuits for LED Driving	85
4.1. <i>Important features of LED applications</i>	86
4.1.1. LED applications.....	86
4.1.2. Electrical properties of LED.....	87
4.1.3. Light amount produced by LED.....	88
4.1.4. LED junction temperature.....	89
4.2. <i>Configurations of LED light sources</i>	92
4.3. <i>Light regulation techniques</i>	96
4.3.1. Light patterns in time domain.....	96
4.3.2. Methodology for comparosion of driver’s control perfomance.....	96
4.3.3. Fluent mode light regulation.....	100
4.3.4. Pulse mode light regulation.....	102
4.3.5. Step mode light regulation.....	103
4.3.6. Controllability in fluent mode.....	105
4.3.7. Controllability in pulse mode.....	106
4.3.8. Controllability in the step mode.....	106
4.3.9. Comparison of light regulation techniques.....	106
4.4. <i>Basics of LED power supplies</i>	109
4.5. <i>Dimmable LED drivers with linearised regulation curve</i>	111
4.5.1. Introduction – possible ways of obtaining of linear curve.....	111
4.5.2. LED Drivers with linear regulation curve (or Close to that).....	112
4.5.3. Compensation of nonlinearities of LED’s VA curve with tapped inductors.....	118
4.5.4. Compensation of nonlinearities of LED’s VA curve with FM.....	123
4.5.5. Overall conclusions.....	126
4.6. Typical LED drivers with ICs available on market.....	126
4.6.1. Classification of LED driver ICs.....	126
4.6.2. Examples of linear LED driver ICs.....	127
4.6.3. Examples of switch mode LED driver ICs.....	129
4.7. Protection of LEDs and their power supplies.....	146
4.7.1. Electrical overstress protection.....	146
5. Devices and Systems for LED Lighting Control	149
5.1. <i>Dimmers</i>	150
5.1.1. Dimmers preface.....	150
5.1.2. How modern lght dimmers work.....	150
5.1.3. 0-10 V dimming.....	152
5.2. <i>Sensors</i>	152
5.2.1. Sensors preface.....	152
5.2.2. Classification of sensors.....	157
5.2.3. Sensor properties.....	159
5.2.4. Signal types.....	160
5.2.5. Sensing elements types.....	161

6. Inorganic Materials for LED Applications – II – III2 – VI4 – (II – Ca, Sr, Ba; III – Ga, In, Al; VI – S, Se, O) Luminophors	174
6.1. <i>Rear Earth ions in the II – III2 – VI4 (II – Ca, Sr, Ba; III – Ga, In, Al; VI – S, Se, O) compounds</i>	178
6.2. <i>Growth of II – III 2 – VI4 compounds investigation their luminescence and optical properties</i> ...	187
6.2.1. <i>Synthesis and growth of II – III2 – VI4 single crystals</i>	187
6.2.2. <i>Effects affecting radiative characteristics of ternary II – III2 – VI4 phosphors</i>	191
6.2.3. <i>X-ray analysis of II – III2 – VI4 single crystals</i>	193
6.2.4. <i>Measurement procedure of the luminescence properties in the visible and infrared region and diffusion reflection</i>	198
6.2.5. <i>Measurement procedure of streamer discharge of II – III2 – VI4 compounds</i>	198
6.2.6. <i>The method of X-ray analysis and Raman spectra measurements</i>	200
6.3. <i>Radlative properties of II – III2 – VI4 compounds activated by ions (REI)</i>	202
6.3.1. <i>Luminescent properties of the calcium thiogallate doped by Eu²⁺ ions</i>	202
6.3.2. <i>Ellipsometric investigations of CaGa₂S₄</i>	216
7. Technology of Visualisation and Illumination	223
7.1. <i>The properties necessary for effective visualization</i>	224
7.1.1. <i>Basics of colorimetry</i>	227
7.1.2. <i>Application of II – III2 – VI4 : REE luminophors in the liquid crystals technology</i>	235
7.1.3. <i>Application of II – III2 – VI4 : REE luminophors in the EL devices</i>	237
7.1.4. <i>Application of II – III2 – VI4 : Eu²⁺ luminophors in the light-emitting diode (LED) technologies</i>	241
7.2. <i>Laboratory work No.1</i>	244
7.2.1. <i>Determination of the optical characteristics of collecting and diverging lenses</i>	244
7.3. <i>Laboratory work No.2</i>	254
7.3.1. <i>Measurement of the laser excitation wavelength</i>	254
7.3.2. <i>Devices and accessories</i>	254
7.3.3. <i>Theoretical justification</i>	255
7.3.4. <i>How to perform laboratory work</i>	261
7.3.5. <i>Control questions</i>	262
8. References	263