



Proceedings
of the
**13th International Symposium
on Automotive Lighting**

**Technische Universität Darmstadt
Laboratory of Lighting Technology**

Published by

Prof. Dr.-Ing. habil. Tran Quoc Khanh

in the series

Darmstädter Lichttechnik

Volume 18

ISAL 2019: Volume 18

ISBN 978-3-8316-4817-7

Bibliografische Information der Deutschen Bibliothek:

Die Deutsche Bibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über <http://dnb.ddb.de> abrufbar.

Das Werk ist urheberrechtlich geschützt. Sämtliche, auch auszugsweise Verwertungen bleiben vorbehalten.

Die Wiedergabe von Gebrauchsnamen, Handelsnamen, Warenbezeichnungen usw. in diesem Werk berechtigt auch ohne besondere Kennzeichnung nicht zu der Annahme, dass solche Namen in Sinne der Warenzeichen- und Markenschutz-Gesetzgebung als frei zu betrachten wären und daher von jedermann benutzt werden dürften.

Copyright © utzverlag GmbH · 2019

Printed in Germany

utzverlag GmbH, München

089-277791-00 · www.utzverlag.de



13th International Symposium on Automotive Lighting

Steering Board

Dr.-Ing. C. Allgeier, OSRAM Continental GmbH, GER

D. Vanderhaeghen, Lumileds, USA

G. R. Draper, GTB, UK

Prof. M. J. Flannagan, University of Michigan, USA

H. Fratty, Fratty Consulting, FRA

Dr.-Ing. M. Hamm, Audi AG, GER

Dr.-Ing. W. Huhn, Audi AG, GER

Prof. Tran Quoc Khanh, TU Darmstadt, GER

R. Klädtke, ZKW, AU

Dr. rer. nat. M. Kleinkes, Hella KGaA Hueck & Co., GER

U. Kostanzer, Daimler AG, GER

R. Krautscheid, Federal Ministry of Transport and Digital Infrastructure, GER

Dr. phil. nat. R. Neumann, Varroc Lighting Systems, GER

Dr.-Ing. J. Ripperger Valeo, FRA

Dr.-Ing. E.-O. Rosenhahn, Automotive Lighting GmbH, GER

M. Sasaki, Koito Manufacturing Co. Ltd., JPN

I. Schneider, Adam Opel GmbH, GER



Foreword

It is a pleasure to present you the proceedings of the 13th International Symposium on Automotive Lighting, which takes place in Darmstadt on September 23-25, 2019. This conference is the document of a series of successful conferences since the first PAL-conference in 1995 and shows the latest innovative potentials of the automotive industry in the application of lighting technologies.

These proceedings result from the work of a lot of experts in the automotive and optical industry, administrative bodies, research institutes and universities. It summarizes the findings of more than 200 authors and co-authors and gives a scope of their expectations for the future. In 2019, the ISAL Steering Board could identify the following focus topics:

- Light source technology generally with the latest innovations in Laser and LED modules
- High Resolution Headlamps and Digital Light
- Road Projections
- Communication between automated vehicles and other road users
- Headlamp Rating Systems

While in the last couple of years, focus was placed high-resolution headlamps and this topic still remains relevant today, the most pressing topic for this year's ISAL is the visual communication between automated vehicles and other road users. While this topic includes the general question, if communication is necessary emphasis is also placed on how, when and where communication is needed. Another strong topic for this year's symposium is the ongoing investigation on road projection and its benefit for the driver. What kind of symbols should be projected onto the road in front of the driver and what benefit do they lead to?

Similar to ISAL 2017, ISAL 2019, will host a podium discussion on the latest research regarding the communication between automated vehicles and other road users. Discussing different findings over the last two years and the consequences for automotive lighting due to that.

We wish you a very informative and successful ISAL 2019 in Darmstadt. We hope that this year's event and these proceedings will give you inspiration and motivation for your work during the next 24 months.

Yours sincerely,



Prof. Dr.-Ing. habil. Tran Quoc Khanh

Contents

Foreword	3
Contents	5
I. General Headlamps Topics	15
Optical Concepts with Slim Lenses for Design Driven Headlamps	17
<i>D. Brunne, HELLA GmbH & Co. KGaA, Germany</i>	
Efficacy of Headlamp Cleaning Devices and their Contribution to Road Safety	25
<i>K. Kosmas, J. Kobbert, T.Q. Khanh, Laboratory of Lighting Technology, Technische Universität Darmstadt, Germany</i>	
Opti-ADB – Study on Low Number of Segments	33
<i>J. Martoch, P. Ferbas, S. Büttgen, H. Groner, Varroc Lighting System, Czech Republic, Germany</i>	
Adaptive Driving Beam (ADB) with variable color temperature for enhanced visibility	43
<i>J. Y. Joo, IoT Lighting Research Center, Korea Photonics Technology Institute, E. J. Choi, Dept. of Optometry, Konyang University, H. S. Park, Dept. of Automotive Conversion, Youngnam University, Korea</i>	
Technical & Industrial Strategy for High Efficiency Front Lighting Modules	49
<i>A. Perrotin, F. Evanno, J.F. Doha, M. Hermitte, Y. Gromfeld, Valeo Lighting Systems Product Group, France.</i>	
II. General Topics in Automotive Lighting	65
Energy saving potential of headlights by determining the current utilization rate of headlight functions	67
<i>A. Erkan, K. Kosmas, J. Kobbert, T.Q. Khanh, Laboratory of Lighting Technology, Technische Universität Darmstadt</i>	

“Self-Healing” Measures for Matrix-LED-Headlamps	77
<i>P. Janke, J. Locher, HELLA GmbH & Co. KGaA, D. Peters, Paderborn University, T. Sapovalov, Helmut-Schmidt-University, T. Bertram, TU Dortmund University, all Germany</i>	
Democratization of Advanced Driving Beam Systems – Good light for everyone!	87
<i>C. Neitzke, Opel Automobile GmbH, Germany</i>	
Battery Electric Vehicles (BEV) versus Internal Combustion Engine Vehicles (ICEV): First Real Time Investigations on Temperature Load Differences in Headlamp Environment.	95
<i>M. Manderscheid, M. Hamm, M. Klaussner, Audi AG, Germany</i>	
Reducing Head Lighting Level on Urban Roads for Different Street Lighting Situations	105
<i>M. Wagner, A. Erkan, K. Kosmas, T.Q. Khanh, Laboratory of Lighting Technology, Technische Universität Darmstadt</i>	
Real Driving Benefits and Research Findings with Digital Light Functions	113
<i>M. Hamm, Audi AG, Germany</i>	
Safety Enhancement Effect of Back-up Guide Lamps: A Field Experiment with North American Consumers	123
<i>H. Pak, Yeungnam University, J.-W. Hwang, K.-B. Lee, SL Corporation, Korea</i>	
Potentials of Diffractive Diffuser Optics	133
<i>M. Mügge, HELLA GmbH & Co. KGaA, Germany</i>	
Micro Surface-LED Evolution of the S-LED Concept	143
<i>T. Gloss, V. Simurda, Varroc Lighting Systems, Czechia</i>	
New Trends and Functionalities in Signal Lighting	147
<i>C. Studeny, Volkswagen AG, Germany</i>	
Visibility Improvement using Guide Function of Turn Signal Lamp	157

The photo-biological safety study of phosphor converted white laser diode applied in automotive lighting 167

Ru Li^{1,2}, Qian Liu¹, Zhibin Tang^{2,3}, Jianfen Feng², Liang Deng², Jiajie Fan^{3,4}, Zhehan Zheng¹, Wei Chen^{3,4}, Dunhua Cao⁵, Zhiming, Yu²

Digital Speedup in Simulating Complex Innovative Lighting Systems 177

J. Mepurath, S. Berlitz, AUDI AG, Germany

III. Light Distributions 187

Object and Gaze Distribution based Optimization of Low and High Beam 189

J. Kobbert, K. Kosmas, T.Q. Khanh, Laboratory of Lighting Technology, Technische Universität Darmstadt

Adverse Weather Light – New Approaches to Evaluate Adaptive Light Functions 199

A. Thoma, L-Lab, Germany, M. Vollrath, TU Braunschweig, Germany

Evaluation of the light distribution of a matrix-headlight with a Hardware-in-the-Loop-simulation 211

M. Waldner, T. Bertram, Institute of Control Theory and Systems Engineering, TU Dortmund University, Germany

DIGITAL LIGHT – The Future Light Distribution for Automated Vehicles 221

C. Gut, Z. Xilu, B. Boeke, Daimler AG, Germany

IV. High Resolution Headlamps and Digital Light 228

Real Driving Benefits and Research Findings with Digital Light Functions 229

M. Hamm, Audi AG, Germany

Traffic Safety Benefits provided by High Resolution Headlamp Systems 239

E.-O. Rosenhahn, F. Link, Automotive Lighting Reutlingen GmbH, Germany

Boost Safety & Styling – New HD-LED Systems for front and rear 249

M. Kleinkes, W. Pohlmann, C. Wilks, all HELLA GmbH & Co. KGaA, Germany

Micro-Pixel-LED-Headlights 259

<i>J. Roth, M. Thamm, Volkswagen AG, M. P. Held, R. Lachmayer, Leibniz Universität Hannover, Institut für Produktentwicklung und Gerätebau, B. Kleinert, IAV GmbH, all Germany</i>	
4K Pixel Solid State Glare Free High Beam	269
<i>S. Cladé, M. Courcier, S. Roels, M. Pellarin, Valeo Lighting Systems, France</i>	
Imaging Optics for High-Resolution Headlamps	281
<i>S. Köhler, B. Fischer, A. Klarius, HELLA GmbH & Co. KGaA, Germany</i>	
Implementation of Pixel Technology for Automotive Lighting System based on Wafer-Level Process	291
<i>Jonghun Lee, G. Ko, Junho. Lee, Samsung Electronics, Republic of Korea</i>	
The Study of Functionality for Now and Future High Definition Lighting	299
<i>H. Lee, MOBIS, South Korea</i>	
V. Road Projection	309
Success of Driver Assistance through Light Projections on the Road	311
<i>M. Budanow, C. Neumann, Karlsruhe Institute of Technology, Light Technology Department, Karlsruhe, Germany</i>	
Symbol Projections: Gain or Gadget?	321
<i>F. Kriegt, A. Thoma, Research Institute of Automotive Lighting and Mechatronics (L-LAB), Lippstadt, Germany, B. Willeke, B. Kubitzka, M. Kaup, HELLA GmbH & Co. KGaA, Lippstadt, Germany</i>	
LCoS projection system	331
<i>C. Bremer, BMW AG & B. Lewerich, BMW AG & Frank Hendricks, Opsira GmbH & C. Neumann, KIT, Germany</i>	
Road Marking Solutions with Pixelized Light Source	343
<i>B. Reiss, S. Cladé, Valeo Lighting Systems, France</i>	
Optimized ADB Symbol Projection	355

W. Gonçalves, A. Issoufou, PSA Groupe, France, U. Becherer, Opel Automobile GmbH, Germany

Requirement Performance of Road Projection Lamp in Conjunction with Turn Signal Lamp **362**

Y. Shibata, M. Kito, H. Ishida, Koito Manufacturing CO., LTD., Japan, Y. Goto, M. Kamijo, Shinshu University, Japan

Impact of Advanced Lighting Function based on Road Projection for Departing Indication in Parking Lots **375**

S. Azouigui, B. Barbedette, S. Saudrais, Y. Sortais, 1ELS – ESTACA / Institut d’Optique Graduate School, France, S. Bordel, Cerema, France, C. Neumann, P. Jahn, KIT – Light Technology Institute, Germany

VI. Glare, Rear and Interior Lighting **385**

Quantifying the safety effects of headlamp glare using crash data **387**

Michael J. Flannagan, John M. Sullivan, The University of Michigan, USA

New adaptive light signalling functions for reducing glare and reaction time **397**

M. Vollmer, L. Schwenkschuster, J. Wild, T. Hornung, odelo GmbH, Germany J. Kobbert, J. Simon, Technische Universität Darmstadt, Laboratory of Lighting Technology, Germany

Integration of a melanopic-light-unit into a passenger car – initial results from a field study **407**

S. Schüler, D. Betz, Daimler AG, Germany, R. Popp, University of Regensburg, Germany

Boosting Human Performance: Human Subject Research on Energizing Effects by Overhead Light Panels for Interior Lighting **419**

A. Niemeyer, Audi AG, C. Neumann, Light Technology Institute Karlsruhe, Germany

Measuring method to evaluate transient dynamic glare situations **429**

Rear Lamps Luminance homogeneity evaluation: validation of a new analytical method based on eye perception 440

S. Paroni, A. Londero, M. Svetini, Automotive Lighting, Tolmezzo, Italy

VII. Light Sources and Sensors 451

Frontiers in LED and Micro-LED Technology 453

Oleg Shchekin, Benno Spinger, Norbert Lesch, Dirk Vanderhaeghen, James Tarne, Lumileds LLC, USA, Lumileds Germany GmbH

Challenges of the illumination of holograms with narrow-band LEDs in automotive applications 463

D. Karthaus, C. Bungenstock, HELLA GmbH & Co. KGaA, M. Giehl, L-LAB – Research institute for automotive lighting and mechatronics, Germany

Automotive Illumination Using Micro-Optics 473

P. Schreiber, Ch. Wächter, Ch. Li, D. Michaelis, St. Fischer, R. Leitel, P. Dannberg, M. Stumpf, R. Rosenberger, Fraunhofer IOF, Germany

Durable functional coatings for advanced cleaning of automotive sensors and headlamps 484

S. Wölper, I. Savych, T. Schmidt, GXC Coatings GmbH, Goslar, Germany

Heatsink-Less Economic LED Headlamp Approach 495

S. Groetsch, M. Kiessling, A. Guenther, N. Haefner, R. Huber, Osram Opto Semiconductors GmbH, Regensburg, Germany

Sensor fusion for dynamic high-resolution lighting 505

M. Austerer, M. Holzbauer, C. Künzel, M. Rosenauer, OSRAM Continental GmbH, A. Jachens, Continental Automotive GmbH

Development of Laser Scanning Headlamps using MEMS Mirror Device 515

M. Miyachi, H. Kurosu, M. Sakurai, M. Tani, Y. Yasuda, Stanley Electric, Japan

DIGITAL OLED for Taillighting – Most Efficient, Homogeneous, and Flexible Display Technology 525

M. Kruppa, W. Thomas, Audi AG, Germany

Integration of sensors in headlamps, leading to a multifunctional component for environmental perception. 535

P. Hartmann, S. Weissensteiner, ZKW Group GmbH, Austria

VIII. Automated Vehicles: Signalling 545

Customizable Pixel Signal Lighting 547

S. Knoop, M. Mügge, D. Mundt, C. Hohmann, J. Spiegel, A. Schellbach, HELLA GmbH & Co. KGaA, Germany

Investigation and comparison of pedestrian behavior in different encounter scenarios with automated vehicles 557

T. Singer, D. Polin, B. Zandi, J. Kobbert, T. Q. Khanh, Laboratory of Lighting Technology, Technische Universität Darmstadt, Germany

Light-Based Communication of Automated Vehicles with other Traffic Participants – A Usability Study in a Virtual Reality Environment 567

C. Kettwich, Carmen, J. Dodiya, M. Wilbrink, A. Schieben, German Aerospace Center (DLR), Germany

‘I have detected you’ – Perception-based Interaction Strategy for Automated Vehicles 577

M. Kaup, HELLA GmbH & Co. KGaA, Lippstadt, Germany.

How important is communication between automated vehicles and other road users? 585

B. Zandi, J. Scheer, T. Singer, D. Polin, T. Q. Khanh, Laboratory of Lighting Technology, Technische Universität Darmstadt,

How Vehicles Learn to Display Symbols to Pedestrians 590

J. Reschke, T. Höß, B. Schleyer, S. Berlitz, AUDI AG, C. Neumann, KIT, Germany

Insights on Exterior Lighting for Autonomous Vehicles from Recent News Media 600

J. D. Bullough, Lighting Research Center, Rensselaer Polytechnic Institute, USA

Study on requirements of exterior display for V2X communication according to realizing functions 611

G.-D. Kim, N. Kwak, D.-H. Kim, Samsung Electronics, Republic of Korea

LightCom – Autonomous Vehicle’s Communication with Pedestrians 619

Nejc Jezeršek, Mag. Inž. Str., Hella Saturnus Slovenija, Slovenia

Assist. Dr. Boštjan Bajec, University of Ljubljana – Faculty of Arts, Slovenia

Assoc. Prof. Mag. Jure Miklavc, Studio Miklavc, Slovenia

Prof. Dr. Jernej Klemenc, University of Ljubljana – Faculty of Mechanical Engineering, Slovenia

Analysis and classification of road user behavior patterns in megacities and suggestions for additional light signals for automated vehicles in future mixed traffic scenarios 629

A. Stuckert, T. Singer, T. Q. Khanh, Laboratory of Lighting Technology Technische Universität Darmstadt,

The Communication Signal Lighting Systems for Automated Vehicles 639

K. G. Min, J. Y. Kim, H. M. Lee, B. S. Choi, S. W. Beak, J. H. Cha, E. J. Lee, Hyundai Mobis, Republic of Korea

“Ford becomes a software company in Lighting” – Application of new development and verification methods to develop autonomous Exterior Light Features 647

M. Schumacher, Ford Motor Company, Cologne, Germany

IX. Regulations, Rating Systems and Simulation in

Automotive Lighting 657

Ideas for including ADB Functionality into the TC4-45 Assessment System 659

G. Langhammer, E.-O. Rosenhahn, F. Freytag, Automotive Lighting Reutlingen GmbH, Germany

Virtual Night Drive Methods for Adaptive Lighting Systems Evaluation 671

P. Hartman, Skoda Auto a.s., Czech Republic

Simulation-Based Lighting Function Development of High-Definition Headlamps 677

*N. Rüddenklau, P. Biemelt, S. Henning, S. Gausemeier, A. Trächtler, Heinz Nixdorf
Institute, University of Paderborn, Germany*

x. Future of Automotive Lighting 687**High Resolution Pixel Lamp 689**

H.-D. Kim, J.-U. Kim, SL Corporation, Korea

**Exterior Surround Lighting – From Static Logo Projection to 360° Dynamic Content
Visualization 699**

*M. Rosenauer, S. Khrushchev, H.F. Gasser, S. Holzinger, M. Austerer, OSRAM
Continental GmbH*

Artificial Intelligence in Validation of Ford’s Predictive Lighting ADAS features 709

*A. Spychala, F. Aust, F. Sepcke, L. Junker, M. Schumacher, Ford Motor Company,
Cologne, Germany*

Revolution Behind the Lights: From Hardware to Software 719

A. Blondel, F. Bedu, Groupe RENAULT, France

**Future Automotive Lighting: Way to a Simplified, Automatic Controlled Light
Philosophy 727**

R. Neumann, Varroc Lighting Systems, Czech Republic

Future of Automotive Headlamps – Light for Sensors 737

G. Böhm, ZKW Group GmbH, Austria

From Best-Cost to High Resolution: LED Matrix technology future 747

D. Wiedmaier, A. Austerschulte, Automotive Lighting, Germany