JOINT INTERNATIONAL CONFERENCE ON

UV LED Technologies & Applications ICULTA-2018

APRIL 22 – 25, 2018
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Joint International Conference on
UV LED Technologies & Applications 2018

Welcome to ICULTA-2018

April 22 - 25, 2018
MELIÃ Hotel Berlin, Germany

The “International Conference on UV LED Technologies & Applications” (ICULTA-2018) is jointly organized by the German consortium “Advanced UV for Life” and the “International Ultraviolet Association” (IUVA). “Advanced UV for Life” is a consortium of 50 German industrial and academic partners working together on the development and application of UV LEDs. The cooperation within a number of research projects is funded by the German Federal Ministry of Education and Research within the framework of the Twenty20 initiative. The IUVA is an organization of UV industry, educators, consultants, utilities, and research professionals, with a mission to make the use of ultraviolet light a leading technology for public health and environmental applications. The IUVA is the leading authority on the use of ultraviolet technology through advocacy and education to industry, research and public policy sectors world-wide.

The goal of the conference is to bring together experts from science and industry to crosslink and to discuss the state of the art of UV LED technology, integration of UV LEDs into modules and systems as well as their application in industry and research. The workshop will feature tutorial, invited, oral, and poster sessions. Sessions have been organized along key topics, including “Semiconductors & Devices”, “Water & Disinfection”, “Medical Applications”, “Plant Growth & Food”, “Spectroscopy”, “Measurement”, and “UV Curing”. We hope we have put together an interesting program for you and look forward to stimulating discussions and open exchange of ideas.

Of course this conference could not be possible without the support, dedication and hard work of a number of people involved. We would like to thank all members of the “Program Committee” and especially Markus Weyers as Program Committee Chair, for putting together an excellent program. A big thanks also goes to the sponsors, whose support is greatly appreciated. And last but not least a “Thank you” to all participants of the conference, including tutorial, invited, and contributed speakers as well as poster presenters.

Finally, a big “Thank you” to the Organizing Committee, especially Antje Mertsch, Nicolas Hübener, Klaus Jacobs, Gary Cohen, and Mickey Fortune who were instrumental in making this conference successful.

Michael Kneissl (AUVL)
TU Berlin & Ferdinand-Braun-Institute, Germany
Conference Co-Chair

Karl Linden (IUVA)
University of Colorado Boulder, USA
Conference Co-Chair

Sunday, April 22

13:00-19:00

Registration

14:00-17:30

Tutorials

Room Barcelona II

14:00-14:45 | Su-1

Selected Topics of Fronted Process Technology of UV LEDs
M. Strassburg
OSRAM OS

14:45-15:30 | Su-2
UV for Disinfection and Water Purification
K. Linden
University of Colorado Boulder

15:30-16:00

Coffee Break

15:30-16:15 | Su-3
UV LED lamp systems in UV curable industrial applications
D. Skinner
Heraeus Noblelight

16:15-17:00 | Su-4
UV LEDs in medicine - photobiological basics and future aspects
H. Meffert
Dermatologisches Zentrum Berlin

18:00-20:00

Welcome Reception

Monday, April 23

07:00-17:00

Registration

08:00-08:30

Opening

Room Barcelona I

08:30-10:00

Session: Mo-A1
Water & Disinfection I

Chair: Oluf Hoyer
Expert in UV Water Disinfection, Germany

Room Barcelona I

08:30-09:00 | Mo-A1.1 (Invited)
UV LEDs for small drinking water systems: a revolution in robust and effective disinfection
K.G. Linden[1], N.M. Hull[1], K Sholtes[1], S.E. Beck[2]
[1]Environmental Engineering, University of Colorado Boulder, USA, [2]Department of Environmental Microbiology, Eawag, Switzerland

09:00-09:30 | Mo-A1.2 (Invited)
UV LED Systems: Reflections on validation testing
J. Eggers[1], T. Schwarzenberger[1], K-H. Schön[1]
[1]TZW: DVGW – Technologiezentrum Wasser, Germany

09:30-09:45 | Mo-A1.3
Using CFD to determine performance opportunities when designing UVC LED reactors for water disinfection
S. Kaemmerer[1], M. Rapaka[2], L. Morningstar[3]
[1]Xylem Services GmbH, Germany, [2]Xylem - Wedeco, India, [3]Xylem - Wedeco, USA

09:45-10:00 | Mo-A1.4
Simulation of UV-LED Reactors for Virtual Prototyping: What are the Challenges?
F. Taghipour[1], M. Keshavarzfathy [1]
[1]Department of Chemical and Biological Engineering, The University of British Columbia, Canada

08:30-10:00

Session: Mo-B1
Medical Applications I

Chair: Jürgen Lademann
Charité - Universitätsmedizin Berlin, Germany

Room Barcelona II

08:30-09:00 | Mo-B1.1 (Invited)
Interaction between Medical and Physical Research in UV-Treatment of Skin Deseases
K. Hönle[1]
[1]Dr. Hönle Medizintechnik GmbH, Germany

09:00-09:30 | Mo-B1.2 (Invited)
Wearable LED-based device for phototherapy applications
F. Farrell[1], B. Guilhabert[1], A-M. Haughey[2], P. Connolly[3], M. D. Dawson[1], N. Laurand[1]
[1]Institute of Photonics, Department of Physics, SUPA, University of Strathclyde, UK, [2]Fraunhofer Centre for Applied Photonics, UK, [3]Department of Biomedical Engineering, University of Strathclyde, UK

09:30-09:45 | Mo-B1.3
Designing with UVC LEDs for Medical Applications
K. Kahn[1]
[1]Crystal IS, USA

09:45-10:00 | Mo-B1.4
UV LED illumination and ASIC detector unit for fluorescence lifetime determination
C. Möller[1], V. Körner[2], C. Heinze[1], H.-G. Ortlepp[1], R. Matthes[2], W. Altermann[2], T. Schildbach[2], M. Winkler[2], D. Buchweitz[2], M. Götz[2], T. Ortlepp[1]
[1]CiS Forschungsinstitut für Mikrosensori, Germany, [2]DMOS GmbH, Germany,

10:00-10:30

Coffee Break & Exhibition

10:30-12:00

Session: Mo-A2
Semiconductors & Devices I

Martin Straßburg
OSRAM Opto Semiconductors GmbH, Germany

Room Barcelona I

10:30-11:00 | Mo-A2.1 (Invited)
Prospects and challenges in the development of UV LED technology
N. Lobo Ploch[1]
[1]*UVphotonics NT GmbH, Germany*

11:00-11:30 | Mo-A2.2 (Invited)
Recent Progress and Future Prospects of AlGaN Deep-UV LEDs
H. Hirayama[1,2], M. Jo[1,2], N. Maeda[1,2]
[1]*RIKEN, Japan,* [2]*RIKEN Center for Advanced Photonics, Japan*

11:30-11:45 | Mo-A2.3
Field effect UV µ-LEDs: a new concept
J. Rottner[1], H.Haas[1], C. Largeron[1], D. Vaufrey[1], I.C. Robin[1], Q. Lalauze[1], N. Rochat[1], A. Grenier[1], G.Feuillet[1]
[1]*CEA-Leti, France*

11:45-12:00 | Mo-A2.4
LED Curable 100% Solids Very Low Viscosity Conformal Coating
A. K. Nebioglu[1], C. Morrissey[1]
[1]*Dymax Corporation, 318 Industrial Lane, Torrington, CT 06790, USA*

10:30-12:00

Session: Mo-B2
Plant Growth & Food I

Chair: Monika Schreiner
Leibniz-Institut für Gemüse- und Zierpflanzenbau Großbeeren/Erfurt e.V., Germany

Room Barcelona II

10:30-11:00 | Mo-B2.1 (Invited)
Tunable Grow Lights in Controlled Environment Agriculture (CEA) – Challenges and Opportunities
S. Olschowski[1]
[1]*OSRAM GmbH, Germany*

11:00-11:30 | Mo-B2.2 (Invited)
A new tool for the horticultural industry; UV-radiation
M. A. K. Jansen[1]
[1]*University College Cork, School of Biological, Earth and Environmental Sciences, Ireland*

11:30-11:45 | Mo-B2.3
Microbial inactivation by LED technology to improve food safety
R. M. Syamaladevi[1], A. J. Prasad[1]
[1]*University of Alberta, Canada*

11:45-12:00 | Mo-B2.4
Quantification of harmful UV LED radiation at workplaces on the examples of food packaging UV disinfection and horticultural UV lighting
G. Hopfenmüller[1], N. Papathanasiou[1], T. Weiss[1]
[1]*sglux GmbH, Germany*

12:00-13:00

Lunch Break (Buffet) & Exhibition

13:00-14:30

Session: Mo-A3
Water & Disinfection II

Chair: Kumiko Oguma
University of Tokyo, Japan

Room Barcelona I

13:00-13:30 | Mo-A3.1 (Invited)
UV LED Disinfection Systems: The last 10 years to the next 10 years
O. Lawal[1], J. Pagan[1], J. Cosman[1]
[1]AquiSense Technologies, USA

13:30-14:00 | Mo-A3.2 (Invited)
Wavelength-Specific UV Inactivation, Molecular Mechanisms, and Potential Synergie
S.E. Beck[1], K.G. Linden[2], H. Ryu[3], L. Boczek[3], J.L. Cashdollar[3], K.M. Jeanis[2], O.R. Lawal[4], P. Suwan[5], T. Koottatep[5]
[1]EAWAG, Swiss Federal Institute of Aquatic Science and Technology, Switzerland, [2]University of Colorado Boulder, USA, [3]United States Environmental Protection Agency (USEPA), USA, [4]AquiSense Technologies, USA, [5]Asian Institute of Technology, Thailand

14:00-14:15 | Mo-A3.3
UV-LED based water disinfection: Testing of synergistic and water matrix effects
D. B. Miklos[1], W.-L. Wang[1,2], K. G. Linden[3], J. E. Drewes[1], U. Hübner[1]
[1]Chair of Urban Water Systems Engineering, Technical University of Munich, Germany, [2]School of Environment, Tsinghua University Beijing, China, [3]Department of Civil, Environmental, and Architectural Engineering, University of Colorado, USA

14:15-14:30 | Mo-A3.4
Rapid measurement of UV-LEDs dose response curves and spatial irradiance distribution
Y. Gerchman[1], Y. Betzalel[2], V. Cohen-Yaniv[2], H. Mamane[2]
[1]University of Haifa and Oranim college, Israel, [2]Tel Aviv University, Israel

13:00-14:30

Session: Mo-B3
Spectroscopy I

Chair: Gerhard Wiegleb
FH Dortmund, Germany

Room Barcelona II

13:00-13:30 | Mo-B3.1 (Invited)
Broadband UV-LED light source for spectroscopic applications
T. Jenek [1], C. Soeller [1]
[1]Heraeus Noblelight GmbH, Germany

13:30 -14:00 | Mo-B3.2 (Invited)
Measuring gas concentrations with UV LED for emission and environmental monitoring applications
C. Heffels[1], B. Schmidt[1]
[1]Siemens AG, Germany

14:00-14:15 | Mo-B3.3
Online water monitoring based on UV-LEDs
A. Benz[1], B. Spigaht[1], R. Morawek[1], A. Weingartner[1]
[1]scan Messtechnik GmbH, Austria

14:15-14:30 | Mo-B3.4
Autofluorescence based rapid detection of microbial contaminations for hygiene monitoring
F. Stüpmann[1], E. Gutmann[2], M. Moschall[1], H. P. Saluz[2]
[1]Silicann Systems GmbH, Germany, [2]Leibniz Institute for Natural Product Research and Infection Biology, Germany

14:30-15:00

Coffee Break & Exhibition

15:00-16:30

Session: Mo-A4
Semiconductors & Devices II

Chair: Leo Schowalter
Crystal IS, Inc., USA

Room Barcelona I

15:00-15:30 | Mo-A4.1 (Invited)
Current Status and Future Works of High Power Deep UV LEDs
R. J. Choi[1], Y. J. Seong[1], W. S. Yum[1], J. T. Oh[1], H. H. Jeong[1], J. O. Song[1]
[1]LG Innotek, Republic of Korea

15:30-16:00 | Mo-A4.2 (Invited)
Enhancement of light extraction efficiency of DUV LEDs by high UV durable fluoro resin encapsulation and light distribution lens
Y. Sakane[1], Y. Hatanaka[1], K. Aosaki[1], Y. Nagasawa[2], A. Hirano[2], M. Ippommatsu[2],H. Amano[3,4], I. Akasaki[4,5]
[1]Asahi Glass Co., Ltd. Chiyoda, Japan, [2]UV Craftory Co., Ltd.,Japan, [3]IMaSS, Nagoya University, Japan, [4]ARC-Nagoya University, Japan, [5]Meijo University, Japan

16:00-16:15 | Mo-A4.3
Development of efficient and reliable UVB light emitting diodes for medical and material processing applications
T. Kolbe[1,2], A. Knauer[2], J. Rass[1,2], H. K. Cho[2], N. Lobo Ploch[1,2], J. Glaab[2], J. Ruschel[2], A. Andrle[2], K. Hilbrich[2], C. Stölmacker[2], M. Weyers[2], S. Einfeldt[2]
[1]UVphotonics NT GmbH, Germany, [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany

16:15-16:30 | Mo-A4.4
Narrow Band Milliwatts power operation of AlGaN based UVB LED for Medical Applications
M. A. Khan[1], Y. Itokazu [1], T. Matsumot [1], N. Maeda [1], M. Jo [1], N. Kamata [1], H. Hirayama [1]
[1]Riken, Japan

15:00-16:30

Session: Mo-B4
UV Curring I

Chair: Peter Rotsch
OSA Opto Light GmbH, Germany

Room Barcelona II

15:00-15:30 | Mo-B4.1 (Invited)
Characteristics of LED-UV lamps for curing applications and technical solutions
P. Burger[1]
[1]Dr. Hönle AG, Germany

15:30-16:00 | Mo-B4.2 (Invited)
Curing advantages with deep-UV LED below 300nm
T. Bizjak-Bayer[1], G. Yang[2], S. Kuk[2]
[1]Qioptiq Photonics GmbH & Co. KG, Germany
[2]Excelitas Technologies Corp., Canada

16:00-16:15 | Mo-B4.3
Innovations in photo-curable materials for fast curing and high quality pattering
A. Voigt[1], J. J. Klein[1], G. Grützner[1]
[1]micro resist technology GmbH, Germany

16:15-16:30 | Mo-B4.4
Status and trends of the UV LED curing industry
P.Boulay, P.Mukish
Yole Développement, France

16:30-18:30

Poster Session & Exhibition

Mo-P1

On the Temperature and Time Dependent Photoluminescence of Lu3Al5O12:Gd3+

M Laube[1,] T. Jüstel[1]
[1]*Research Group Tailored Optical Materials, University of Applied Sciences Münster, Germany*

Mo-P2

UV curable nap cores as core material for lightweight applications

K. Klauke[1], N. Gerber[1], C. Dreyer[1]
[1]*Fraunhofer-Institute for Applied Polymer Research IAP, Research Division Polymeric Materials and Composites PYCO, Germany*

Mo-P3

Design and fabrication of a microcontroller based wireless LED-research module for application in in vitro culture labs

H. Bethge[1], T. Rath[2], G. Akyazi[3], T. Winkelmann[1]
[1]*Leibniz Universität Hannover, Institute of Horticultural Production Systems, Woody Plant and Propagation Physiology Section, Germany,* [2]*University of Applied Sciences Osnabrueck, Laboratory for Biosystems Engineering), Germany,* [3]*Leibniz Universität Hannover, Institute of Horticultural Production Systems, Biosystems Engineering, Germany*

Mo-P4

AlN Growth and Characterization on Silicon Substrate for UV Applications

I. Demir[1], H. Li[2], R. McClintock[3], I. Altuntas[1], S. Elagoz[1], K. Zekentes[4], M. Razeghi[3]
[1]*Cumhuriyet University, Turkey,* [2]*University of California, USA,* [3]*Northwestern University, USA,* [4]*FORTH, Institute of Electronic Structure and Laser (IESL), Greece*

Mo-P5

UV Spectral Sensitivities of Escherichia Coli and MS2 Phage Measured with UVC LED Water Disinfection Module

N. Yabuki[1], H. Kishi[1], S. Sugiyama[1], S. Miya[1]
[1]*Asahi Kasei Corporation, UVC Project, Japan*

Mo-P6

Innovative UV LED Curable Resins for Optical Coatings for Medical Applications and Materials Processing

M. Köhler[1], C. Dreyer[1], J. Rosenkranz[2]
[1]*Fraunhofer-Institute for Applied Polymer Research IAP, Research Division Polymeric Materials and Composites PYCO, Germany,* [2]*j-fiber GmbH, Germany*

Mo-P7

Combining Fluid Simulation and Flow Visualization to predict Disinfection Reactor Performance

S. Jinno[1], S. Miya[1], S. Sugiyama[1], T. Tanaka[1], N. Ito[1], K. Uchida[1]
[1]*Asahi Kasei Corporation, UVC Project, Japan*

Mo-P8

Thermal management performance of deep UV LED sources applying thermoelectric cooler devices

P. Fredes[1,2], U. Raff [1], J. Pascal[1], E. Gramsch[2]
[1]*Electrical Engineer Department, Universidad de Santiago de Chile, Chile,* [2]*Optics and Semiconductors Lab, Physics Department, Universidad de Santiago de Chile, Chile*

Mo-P9

Improvement of light extraction efficiency in deep-UV µ-LEDs

P. Pampili[1,2], M. Akhter[1], V.Z. Zubialevich[1], P. P. Maaskant[1], B. Corbett[1], P. J. Parbrook[1,2]
[1]*Tyndall National Institute, Ireland,* [2]*School of Engineering, University College Cork, Ireland*

Mo-P10

The impact of vapor supersaturation on the growth of 260-280 nm UV-LED

M.P. Hoffmann; M. Tollabi-Mazraehno; C. Brandl; M. J. Davies; H.-J. Lugauer
OSRAM Opto Semiconductors, Germany

Mo-P11

Research on UVC LED Light Source for Portable Flow Water Sterilizer

C. C. Lu[1], M. Karthickraj [1], C. P. Hsu[1], Y.-K. Fu[1], S. Y. Wang[2]
[1]Industrial Technology Research Institute, Taiwan, [2]Food Industry Research and Development Institute, Taiwan

Mo-P12

UV LED-Based Advanced Oxidation Process for Treatment of Biomedical and Biomolecular Laboratories Wastewater

M. Malekshahi
Ferdowsi University of Mashhad, Mashhad, Iran

Mo-P13

Strongly improved UV transparency of bulk AlN crystals grown by PVT

C. Hartmann, J. Wollweber, A. Dittmar, K. Irmscher, M. Bickermann
Leibniz Institute for Crystal Growth, Germany

Mo-P14

3D Printed White Light-Emitting Diodes

G. Wang[1,3], B. Fan[2,3], Y. Wang[4], Y. Li[3], J. Li[1,3], Y. Ge[1,3]
[1]School of Electronics and Information Technology, Sun Yat-sen University, China, [2]Institute of Advanced Technology, Sun Yat-sen University, China, [3]Device and Equipment R&D Department, Foshan Institute of Sun Yat-sen University, China, [4]Pennsylvania State University, United States

Mo-P15

Electromodulated reflectance of AlGaN layers and quantum wells in the UV spectral range

E. Zdanowicz[1,2], P. Ciechanowicz[1,3], K. Opołczyńska[1,3], Ł. Janicki[2], K. Komorowska[1,] D. Hommel[1,3], R. Kudrawiec[1,2]
[1]Wroclaw Research Center EIT+, Poland [2]Faculty of Fundamental Problems of Technology, Wroclaw University of Science and Technology, Poland, [3]Faculty of Physics, University of Wroclaw, Poland

Mo-P16

Photocatalytic degradation of Imidacloprid in solar-powered UV-LED photoreactor system by TiO2-Fe3O4 nanocomposite

M. R. Eskandarian[1], M. H. Rasoulifard[1]
[1]Water and Wastewater Treatment Research Laboratory, Department of Chemistry, University of Zanjan, Iran

Mo-P17

New generation of sustainable water disinfection systems; Photovoltaic-powered UV-LED photoreactors

M. R. Eskandarian[1], M. H. Rasoulifard[1]
[1]Water and Wastewater Treatment Research Laboratory, Department of Chemistry, University of Zanjan, Iran

Mo-P18

Defect Reduction of Epitaxially Grown GaN Layer on Patterned Sapphire Substrate

I. Altuntas[1], I. Demir[1], A. Alev Kizilbulut[2], B. Bulut[2], S. Elagoz[1,2]
[1]Cumhuriyet University Nanofotonik Application and Research Center, Turkey, [2]ERMAKSAN Optoelectronics, Turkey

Mo-P19

AlGaN-based UV LEDs with emission below 230 nm

F. Mehnke[1], L. Sulmoni[1], M. Guttmann[1], T. Wernicke[1], M. Kneissl[1]
[1]Institute of Solid State Physics, Technische Universität Berlin, Germany

Mo-P20

Demands on packaging for high performance UV LEDs

S. Nieland[1], D. Mitrenga[1], M. Weizman[2], P.Rotsch[2], D. Karolewski[1], I.Kaepplinger[1], O.Brodersen[1], T.Ortlepp[1]
[1]CiS Forschungsinstitut für Mikrosensorik GmbH Erfurt, Germany, [2] Osa opto light GmbH Berlin, Germany

Mo-P21

Effect of AlN Capping on Thermal Stability of GaN Nanowires Grown on Sapphire by PAMBE Technique

S.Bhunia[1], R.Sarkar[1], D. Nag[1], S. Mahapatra[1], A. Laha[1]
[1]Indian Institute of Technology Bombay, India

Mo-P22

Al0.5Ga0.5N Nanowires Grown Directly on Sapphire Substrate by Plasma Assisted Molecular Beam Epitaxy with Minimal Compositional Inhomogeneity.

R. Sarkar[1], S. Bhunia[2], D. Nag[1], A. Laha[1]
[1]Department of Electrical Engineering, Indian Institute of Technology Bombay, India, [2]Department of Physics, Indian Institute of Technology Bombay, India

Mo-P23

Modeling of nitride nanostructures with the nextnano software

S. Birner[1], Z. Jéhn[2]
[1]nextnano GmbH, Germany, [2]Xiences GmbH, Hungary

Mo-P24

Added value or operational imperative? Water disinfection in vehicular systems

R. Simons[1], J. Cosman[1], J. Pagan[1]
[1]AquiSense Technologies UK, USA, Canada

Mo-P25

Pulsed Sputter Deposition of III-Nitrides for UV Emitters

F. Steib[1,2], G. Schöttler[1], T. Remmele[4], A. Behres[3], S. Fündling[1,2], M. Albrecht[4], M. Straßburg[3], H.-J. Lugauer[3], H.-H. Wehmann[1,2], A. Waag[1,2]
[1]Institut für Halbleitertechnik and Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, Germany,[2]epitaxy competence center ec2, Germany ,[3]Osram Opto Semiconductors GmbH, Germany, [4]Leibniz Institute for Crystal Growth, Germany

Mo-P26

AlGaN-Based UV-C LEDs Emitting Near 270 nm on Low Defect Density AlN/Sapphire Templates

N. Susilo[1], L. Sulmoni[1], S. Hagedorn[2], D. Jaeger[3], H. Miyake[4], C. Kuhn[1], M. Guttmann[1], J. Enslin[1], J. Rass[2], N. Lobo-Ploch[2], C. Reich[1], B. Neuschulz[1], F. Mehnke[1], M. Reiner[2], O. Krüger[2], H. K. Cho[2], T. Wernicke[1], S. Einfeldt[2], M. Weyers[2], M. Kneissl[1,2]
[1]Technische Universität Berlin, Institute of Solid State Physics, Germany, [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany, [3]Evatec AG, Switzerland, [4]Department of Electrical and Electronic Engineering, Mie University, Japan

Mo-P27

Off-grid UV-LED Water Disinfection – Surface Water Case Study

B. Adeli[1], A. Babaie[1]
[1]Acuva Technologies, Canada

Mo-P28

p-n junction visualization and quantitative characterization of nanowire based AlxGa1-xN LEDs

A.M. Siladie[1], B. Gayral[1], F. Donatini[2], B. Daudin[1], J. Pernot[2]
[1]Univ. Grenoble Alpes, CEA, INAC, France
[2]Univ. Grenoble Alpes, CNRS, Institute Néel, France

Mo-P29

An innovative Si package for high-performance UV LEDs

I. Kaepplinger[1], R. Taeschner[1], D. Mitrenga[1], D. Karolewski[1], L. Long[1], S. Nieland[1], O. Brodersen[1], T. Ortlepp[1]
[1]CiS Forschungsinstitut für Mikrosensorik, Germany

Mo-P30

Hybrid top-down/bottom up fabrication of AlN/AlGaN core-shell nanorods for deep-UV emitting LEDs

P.M. Coulon[1], G. Kusch[2], P. Fletcher[1], P. Chausse[1], R.W. Martin[2], P.A. Shields[1]
[1]Dept. Electrical & Electronic Engineering, University of Bath, UK, [2]Department of Physics, SUPA, University of Strathclyde, UK

Mo-P31

New developments in UV LED process control – using Inline Continuous Automated Dynamic Technology (ICAD-Technology)

T. Efsen
Efsen UV & EB Technology, Denmark

Mo-P32

Extracting near- and far-field radiation patterns of AlInGaN-based UV-LEDs

M. Guttmann[1], A. Ghazaryan[1], S. Wu[1], N. Susilo[1], J. Enslin[1], F. Mehnke[1], C. Kuhn[1], L. Sulmoni[1], T. Wernicke[1], J. Rass[2], H. K. Cho[2], N. Lobo-Ploch[2], T. Kolbe[2], A. Knauer[2], S. Hagedorn[2], A. Braun[2], A. Külberg[2], M. Schmidt[2], O. Krüger[2],K. Hilbrich[2], S. Knigge[2], D. Mitrenga[3], I. Käpplinger[3], T. Ortlepp[3], S. Einfeldt[2], M. Weyers[2], M. Kneissl[1,2]
[1]Technische Universität Berlin, Institute of Solid State Physics, Germany, [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany, [3]CiS Forschungsinstitut für Mikrosensorik GmbH, Germany

Mo-P33

UVC LED disinfection of medical device tube lumen

J. Bak[1], T. Begovic[2]
[1]UVclinical aps, Denmark, [2]Aarhus University, Denmark

Mo-P34

Integrated dose simulation tool for UV-LED reactors

A. Babaie[1], A. Jalali[1], B. Adeli[1]
[1]Acuva Technologies Inc*, Canada*

18:30-21:30

Networking Dinner

Tuesday, April 24

08:00-17:00

Registration

08:30-10:00

Session: Tu-A1
Semiconductors & Devices III

Chair: Masafumi Jo
RIKEN, Japan

Room Barcelona I

08:30-09:00 | Tu-A1.1 (Invited)
Development of short wavelength UVC LEDs at 265nm and below for water disinfection and water quality monitoring
L. Schowalter[1]
[1]Crystal IS, Inc., USA, Asahi Kasei Corp, Japan

09:00-09:30 | Tu-A1.2 (Invited)
Improving the reliability of UV-B and UV-C LEDs
S. Einfeldt[1], J. Glaab[1], J. Ruschel[1], J. Rass[1,2], T. Kolbe[1,2], H. Cho[1], N. Lobo Ploch[1,2],M. Brendel[1], A. Knauer[1], I. Ostermay[1], O. Krüger[1], M. Weyers[1], C. Kuhn[3], J. Enslin[3],F. Mehnke[3], T. Wernicke[3], M. Kneissl[1,3]
[1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany, [2]UVphotonics NT GmbH, Germany, [3]Technische Universität Berlin, Institut für Festkörperphysik, Germany

09:30-09:45 | Tu-A1.3
Fabrication and long-term Stability of Aluminum Reflector-Arrays for UV-LED Modules
M. Weizman[1], P. Rotsch[1], W. Arnold[1], M. Honecker[2]
[1]OSA Opto Light GmbH, Germany, [2] Honecker GmbH, Germany

09:45-10:00 | Tu-A1.4
Miniaturized Hermetic Reflector Cavity Packaging for UV LEDs
U. Hansen[1], S. Maus[1], O. Gyenge[1], R. Abdallah[1], M. Neitz[2], S. Marx[2]
[1]MSG Lithoglas GmbH, Germany, [2]Technical University of Berlin, Germany

08:30-10:00

Session: Tu-B1
Plant Growth & Food II

Chair: Marcel Jansen
University College Cork, Ireland

Room Barcelona II

08:30-09:00 | Tu-B1.1 (Invited)
UVB radiation from LEDs impacts the formation of health-promoting secondary plant metabolites
M. Wiesner-Reinhold[1], S. Neugart[1], S. Baldermann[1], T. Filler[1], K. Czajkowski[1], J. Glaab[1], S. Einfeldt[1], C. Huber[1], M. Schreiner[1]
[1]Leibniz Institute of Vegetable and Ornamental Crops, Germany

09:00-09:30 | Tu-B1.2 (Invited)
Postharvest UV-B application on fruits. A study on nutraceutical quality, shelf life and responses to fungal infection
A. Ranieri[1,2]
[1]Department of Agriculture, Food and Environment, University of Pisa, Italy, [2]Interdepartmental Research Center Nutrafood "Nutraceuticals and Food for Health", University of Pisa, Italy

09:30-09:45 | Tu-B1.3
Application of UV LEDs for DNA analysis
C. Möller[1], M. Hentschel[2], T. Hensel[2], A. Müller[2], C. Heinze[1], O. Brodersen[1], T. Ortlepp[1]
[1]CiS Forschungsinstitut für Mikrosensorik GmbH, Germany, [2]Analytik Jena AG, German

10:00-10:30

Coffee Break & Exhibition

10:30-12:00

Session: Tu-A2
Water & Disinfection III

Chair: Sven Kaemmerer
Xylem GmbH, Germany

Room Barcelona I

10:30-11:00 | Tu-A2.1 (Invited)

Fluid Disinfection Using Light Guiding and UV Light Emitting Diodes

G. Knight[1], E. Mahoney[1]
[1]Trojan Technologies, Canada

11:00-11:30 | Tu-A2.2 (Invited)

UV-LEDs as emerging sources for UV based advanced oxidation: Opportunities and Challenges

M. Mohseni[1], A. Kheyrandish[1], S. Satyro[1],
[1]University of British Columbia, Department of Chemical & Biological Engineering, Canada

11:30-11:45 | Tu -A2.3

Irradiance-dependent UV dose response in microorganism and biomolecule inactivation

J. Pasquantonio[1], T. Thompson[1]
[1]Phoseon Technology, USA

11:45-12:00 | Tu -A2.4

Decomposition of Organic Compounds through UV-LED Advanced Oxidation Processes

B. Adeli[1], A. Babaie[1]
[1]Acuva Technologies, Canada

10:30-12:00

Session: Tu-B2
Medical Applications II

Chair: Regina Sommer
Medizinische Universität Wien

Room Barcelona II

10:30-11:00 | Tu-B2.1 (Invited)

Experiences with in-vivo and in-vitro tests of sun protection products

U. Heinrich[1], N. Braun[1], H. Tronnier[1], D. Kockott[2]
[1]Dermatronnier, Institute of Experimental Dermatology at Witten/Herdecke University, Germany, [2]UV-Technik, Germany

11:00-11:30 | Tu-B2.2 (Invited)

Non-invasive sun protection factor determination using LED light

M. C. Meinke [1], S. Schanzer [1], C. Reble [2], G. Khazaka [2], G. Wiora [2], H. Karrer [3], J. Lademann [1]
[1]Charité - Universitätsmedizin Berlin, Department of Dermatology, Germany, [2]C.-Khazaka Electronic GmbH, Germany, [3]Hans Karrer GmbH, Germany

11:30-11:45 | Tu-B2.3

Limits and Possibilities to Detect Free Radical Formation in Skin during UV-Irradiation

S. Albrecht[1], C. Kasim[1,2], A. Elpelt[3], C. Reble[1,4], L. Mundhenk[3], H. Pischon[3], S. Hedtrich[5], C. Witzel[1], J. Lademann[1], L. Zastrow[1], I. Beckers[6], M. Meinke[1]
[1]Charite – Universitatsmedizin Berlin, Germany, [2]Institute of Biotechnology, Technische Universität Berlin, Germany, [3]Institute of Veterinary Pathology, Freie Universität Berlin, Germany, [4]Courage + Khazaka Electronic GmbH, Germany, [5]Institute of Pharmacy, Freie Universität Berlin, Germany, [6]Beuth University of Applied Sciences Berlin, Germany

11:45-12:00 | Tu-B2.4

Light-initiated drug release from nanocarriers

A. Patzelt[1], T. Koburger-Janssen[2], A. Kramer[3], G. Mueller[3], K. Landfester[4], L. Busch[1], J. Lademann[1]
[1]Charité – Universitätsmedizin Berlin, corporate member of Freie Universität Berlin, Humboldt-Universität zu Berlin, and Berlin Institute of Health, Department of Dermatology, Venerology and Allergology, [2]Hygiene Nord GmbH, Germany, [3]Universitätsmedizin Greifswald, Körperschaft des öffentlichen Rechts, Institut für Hygiene und Umweltmedizin, Germany, [4] Max Planck Institute for Polymer Research, Germany

12:00-13:00

Lunch Break (Buffet) & Exhibition

13:00-14:30

Session: Tu-A3
Water & Disinfection IV

Chair: Sara Beck
EAWAG, Switzerland

Room Barcelona I

13:00-13:30 | Tu-A3.1 (Invited)

Control of water-borne infections by UV irradiation

R. Sommer[1], G. Hirschmann[2], T. Haider[3] A. Schmalwieser[4]
[1]Medical University Vienna, Institute for Hygiene and Applied Immunology, Water Hygiene, Austria, [2]Austrian Institute of Technology, Austria, [3]HAI-SO Environmental Expertise and Documentation, Austria, [4]University of Veterinary Medicine, Austria

13:30-14:00 | Tu-A3.2 (Invited)

Air disinfection with an UVC LEDs device

M. Ruffin[1], H. Van Hille[2]
[1]Excelitas Technologies, USA, [2]Excelitas Technologies, Germany

14:00-14:15 | Tu-A3.3

Efficiency of UV-LED/TiO_2/ $K_2S_2O_8$ system for photocatalytic decomposition of pharmaceutical pollutants in contaminated water

M. Rasoulifard[1], M. Eskandarian[1]
[1]Water and Wastewater Treatment Research Laboratory, Department of Chemistry, University of Zanjan, Iran

14:15-14:30 | Tu-A3.4

Ultraviolet Membrane Bioreactor for Enhancing the Removal of Organic Matter in Micro-Polluted Water

Y. Zhang; L. Zhou; Y. Wang
College of Environmental Science & Engineering, Tongji University, China

13:00-14:30

Session: Tu-B3
Spectroscopy II

Chair: Frank Stüpmann
Silican, Germany

Room Barcelona II

13:00-13:30 | Tu-B3.1 (Invited)

UV-LEDs for spectroscopic sensor application

M. Degner [1], H. Ewald [1],
[1]University of Rostock, Germany

13:30 -14:00 | Tu-B3.2 (Invited)

ULTRA.sens®: UV LEDs in industrial gas sensing applications

G. Wiegleb[1], S. Wiegleb[2]
[1]University of Applied Sciences Dortmund, Germany, [2]Wi.Tec-Sensorik GmbH, Germany

14:00-14:15 | Tu-B3.3

Development and Application of UV-LED Gas Sensing Devices

E. Espid[1], F. Taghipour[1]
[1]Department of Chemical and Biological Engineering, The University of British Columbia, Canada

14:15-14:30 | Tu-B3.4

Application of deep UV-LEDs for metrology and process control in semiconductor industry

J. Zettler[1], K. Haberland[1]
[1]LayTec AG, Germany

14:30-15:00

Coffee Break & Exhibition

15:00-16:30

Session: Tu-A4
Semiconductors & Devices IV

Chair: Neysha Lobo Ploch
UVphotonics NT GmbH, Germany

Room Barcelona I

15:00-15:30 | Tu-A4.1 (Invited)
Highly reliable package technologies for UVC LED modules
F. Gindele[1], A. Neumeier[1], R. Graf[1], C. Rakobrandt[1]
[1]SCHOTT AG, Electronic Packaging, Germany

15:30-16:00 | Tu -A4.2 (Invited)
Deep UV light source at 222 nm based on second harmonic generation of GaN high power diode lasers
B. Sumpf[1], N. Ruhnke[1], A. Müller[1], B. Eppich[1], M. Maiwald[1], G. Erbert[1], G. Tränkle[1]
[1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany

16:00 -16:15 | Tu -A4.3
Deep UV micro-LED arrays for optical communications
X. He[1], E. Xie[1], E. Gu[1], M. Dawson[1]
[1]Institute of Photonics, Department of Physics, University of Strathclyde, UK

16:15-16:30 | Tu -A4.4
MOVPE Growth of Deep Ultraviolet LEDs with Emission Wavelength below 240nm on Native AlN and Sapphire Substrates
M. Tollabi Mazraehno[1,2]; M. P. Hoffmann[2]; M. J. Davies[2]; C. Reich[1]; B. Neuschulz[1]; C. Frankerl[2]; M. G. Jama[2]; C. Brandl[2]; T. Wernicke[1]; M. Kneissl[1]; H.-J. Lugauer[2]
[1]Technische Universität Berlin, Germany, [2]Osram Opto Semiconductors GmbH, Germany

15:00-16:30

Session: Tu-B4
Measurement I

Chair: Sven Einfeldt
Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany

Room Barcelona II

15:00-15:30 | Tu-B4.1 (Invited)
Characterization and calibration of compact array spectroradiometers for spectral measurements of UV-LEDs
P. Sperfeld[1], S. Nevas[1]
[1]Physikalisch-Technische Bundesanstalt, Germany

15:30-15:45 | Tu-B4.2
Why and how to characterize UVC LEDs? Part 1: Test protocols, aging and temperature behavior
K.-H. Schoen[1], T. Schwarzenberger[1], J. Eggers[1]
[1]TZW: DVGW-Technologiezentrum Wasser, Germany

15:45-16:00 | Tu-B4.3
Why and how to characterize UVC LED? Part 2: Measurement of directivity and UVC output
T. Schwarzenberger[1], K.-H. Schön[1], J. Eggers[1]
[1]TZW: DVGW – Technologiezentrum Wasser, Germany

16:00-16:15 | Tu-B4.4
Standardization of Measurement of UV-LED Lamp Output, Feasibility and Tolerance to Error
K. Sholtes[1], J. Pagan[2], O. Lawal[2], K. Linden[1]
[1]University of Colorado Boulder, USA, [2]AquiSense Technologies, USA

16:15-16:30 | Tu-B4.5
A stray light corrected array spectroradiometer for complex high dynamic range measurements in the UV spectral range
R. Zuber[1], P. Sperfeld[2], M. Clark[1]
[1]Gigahertz-Optik GmbH, Germany, [2]Physikalisch-Technische Bundesanstalt, Germany

16:30-17:00

Closing Remarks

Room Barcelona I

17:00-18:30

Round Table on UVC LED System Standards

Room Barcelona II

17:00-18:30

optional: Guided Sightseeing | Berlin – A City in Transition

Participation in the city tour is limited. Please contact the registration counter if you would like to attend.

Wednesday, April 25

09:00-10:00

Transfer

Meeting point in the lobby of MELIÃ Hotel

10:00-12:00

Technical Tours / Visits

Use the opportunity to visit a company or research institution in and nearby Berlin.

Please contact the registration counter if you would like to attend.

Charité - Universitätsmedizin Berlin

Physical method for the non-invasive determination of the sun protection factor of sunscreens by LED techniques
Address: Charité - Universitätsmedizin Berlin | CCP | Charitéplatz 1 | 10117 Berlin | Germany

CrysTec GmbH

Single crystal processing for electronics research
Address: CrysTec GmbH | Köpenicker Str. 325 | 12555 Berlin | Germany

Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik

Fabrication of UV LEDs – semiconductor epitaxy and chip processing
Address: Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik | Gustav-Kirchhoff-Str. 4 | 12489 Berlin | Germany

Fraunhofer IAP, Research Division Polymeric Materials and Composites PYCO

Thermoset-based composites – from monomers to components
Address: Research division Polymeric Materials and Composites PYCO | Technical Center 1 | Freiheitstraße 124-126 | 15745 Wildau | Germany

LayTec AG

Integrated Metrology
Address: LayTec AG | Seesener Str. 10-13 | 10709 Berlin | Germany

Leibniz Institute for Crystal Growth

Growth of semiconductor crystals at the IKZ
Address: Leibniz Institute for Crystal Growth | Max-Born-Str. 2 | 12489 Berlin | Germany

SENTECH Instruments GmbH

Plasma process technology and thin film metrology for small scale production
Address: SENTECH Instruments GmbH | Schwarzschildstr. 2 | 12489 Berlin | Germany

sglux SolGel Technologies GmbH

UV sensors and metrology
Address: sglux GmbH | Richard-Willstätter-Str. 8 | 12489 Berlin | Germany

Technische Universität Berlin – Institute of Solid State Physics

Deep UV LED fabrication and testing at Technische Universität Berlin
Address: Technische Universität Berlin | Institute of Solid State Physics | Hardenbergstr. 36 | 10623 Berlin

Sunday, April 22

13:00 - 19:00 | Registration	
14:00 - 17:30 | Tutorials (Barcelona II)	**14:00 - 14:45 | Su-1 Selected Topics of Frontend Process Technology of UV LEDs** M. Strassburg
	14:45 - 15:30 | Su-2 UV for Disinfection and Water Purification K. Linden
	15:30 - 16:00 | Coffee Break
	16:00 - 16:45 | Su-3 UV LED lamp systems in UV curable industrial applications D. Skinner
	16:45 - 17:30 | Su-4 UV LEDs in medicine - photobiological basics and future aspects H. Meffert
18:00 - 20:00 | Welcome Reception	

Tutorial
Selected Topics of Frontend Process Technology of UV LEDs

Martin Strassburg, Marc Patrick Hoffmann, and Hans-Jürgen Lugauer
OSRAM Opto Semiconductors GmbH, Leibnizstr. 4, 93055 Regensburg, Germany

LEDs emitting in the wavelength range below 400 nm (UV) are gaining more and more interest in academia and industry, due to numerous of possible applications and benefits over existing conventional lamp technologies. In contrast, conventional technologies have limited lifetimes and can contain toxic materials like Mercury. Ultraviolet LEDs can be used for numerous applications like curing, ink drying, disinfection purposes, for environmental and medical applications, but also for gas sensors.

The semiconductor material used for UV-LEDs depends on the specific UV wavelength range addressed. From 400nm to 365nm, the well-known InGaN material system is applied, while for shorter wavelengths LEDs AlGaN with high Aluminum content is used. In this case, the frontend processes needed differ significantly in comparison to the well-known processes applied to visible or UV-A LEDs.

Generally, the efficiencies of AlGaN based Deep UV (DUV) LEDs are low in comparison to InGaN based LEDs. All the different parts of the frontend process, the epitaxy via Metal Organic Vapor Phase Epitaxy (MOVPE), the chip processing and even the characterization of DUV LEDs pose their unique challenges. In case of AlGaN epitaxy for UV-devices for instance, the incorporation of point defects, impurities and dislocations have to be controlled since they can impact drastically the efficiency of the LEDs. High strain in the epitaxial layers, due to the high Al-content AlGaN, leads to relaxation and cracking reducing efficiency and yield of these devices. Furthermore, doped AlGaN layers suffer from low conductivities due to difficulties in doping with increasing Al content.

In case of the DUV chip process, DUV LED structures suffer from bad n- and p-type contacts. New contacts on AlGaN have to be developed for an Ohmic behavior and the chip process has to be optimized for a high temperature contact annealing. Especially the p-GaN quality has to be improved and matched to the DUV chip processing. Generally, novel p-type contacting schemes have to be investigated to reduce the absorption in the DUV. In addition, due to the unique problem of low light extraction efficiencies of deep UV optical devices, additional efforts for improved light extraction have to be developed. These processes are largely unknown compared to all experiences from visible LEDs.

In summary, the most common challenges for UV frontend process are discussed, and the state of the art solutions and future approaches are presented in this tutorial.

Tutorial
UV for disinfection and water purification

Karl G. Linden
Environmental Engineering, University of Colorado Boulder, Boulder CO 80303, USA

The tutorial will introduce the audience to the use of ultraviolet radiation for water disinfection and purification. Topics to be covered will include:

- Fundamentals of UV for disinfection of pathogens in water
  - Important UV wavelengths for inactivation of microorganisms
  - Mechanisms of UV disinfection – why UV works
- Review of the major types of UV systems and their emission spectra, including UV LEDs and non-mercury lamps
- Advantages and disadvantages of UV treatment for water
- Examples of UV systems in practice: Municipal and household scales
- Overview of regulations for use of UV in water treatment
- Validation methods for UV disinfection systems
- Water quality factors to consider in design of UV disinfection systems
- UV applications for purification of water from chemical pollutants
  - UV photolysis and advanced oxidation
- Role of UV LEDs in the future of UV water treatment

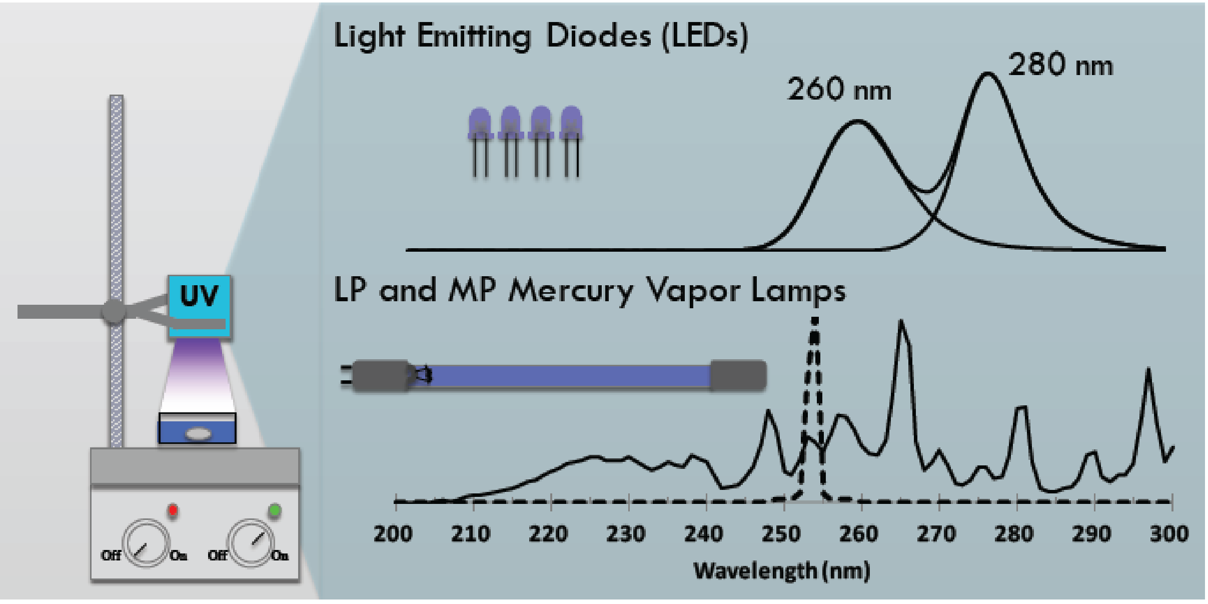

Figure 1. Emission spectra for traditional UV sources compared to UV LEDs. Credit: S.E. Beck, 2017

Tutorial
UV LED lamp systems in UV curable industrial applications: achievements and challenges

Dawn Skinner
Heraeus Noblelight Ltd, UK

UV curing is a technology that has grown and diversified widely since it was introduced into manufacturing process in the early 1970s. From its early use in printing and wood coating through to applications in coating industrial plastic components, bonding and coating applications in medical devices, glass decorating, composite manufacturing, protective coatings for optical fibres and specialised coatings on flexible films, just as examples

Its success has been driven by improved coating performance, fast cure speed, small compact units, economical use of energy and low heat impact on the coating and substrate and, the potential for 100% solid coatings and adhesives.

In recent years there has been increasing interest and adoption of UV LED technology in various application fields. This has been driven by the advantages offered by an LED-based UV curing system over the established broad band medium pressure Hg UV lamp systems such as, lower heat output, longer life, lower energy consumption and flexibility in design of the equipment.

However, some significant challenges remain before UV LED curing can be used in all of the existing UV curing applications. Currently, the UV LED lamp systems used in industrial curing applications have emissions in the UVA range, typically 365, 385 or 395nm. This is driven by the need for high output power combined with long life-times and commercially acceptable costs of the UV LED lamp system. This brings challenges around the restricted range of photoinitiators at this these wavelengths, yellowing of coatings and poor surface cure because of the lack of shorter wavelength output which is a specific requirement for many industrial UV curing applications.

This tutorial will introduce the principle of the UV curing process, review the successes of UV LED lamps in current applications and the challenges and prospects for future successes.

Tutorial
UV LEDs in medicine - photobiological basics and future aspects

H. Piazena[1], H. Meffert[2]
[1]*Charité - Universitätsmedizin Berlin, Medical Photobiology Group, Germany*
[2]*Dermatologisches Zentrum Berlin, Potsdamer Chaussee 80, 14129 Berlin, Germany*

UV radiation covers a wavelength range between 100 - 380 nm and is divided into the sub-ranges UV-C (100 - 280 nm), UV-B (280-320 nm) and UV-A (320-380 nm). Photon energies range from 12.40 eV at 100 nm to 3.26 eV at 380 nm. Therefore UV radiation may cause photochemical processes in the tissue which depend however on the wavelength, on irradiance, on exposure time, on the geometry and on frequency of exposure.

Medical and cosmetic use of UV radiation is restricted to the sub-ranges of UV-B and of UV-A, as well as to exposures of the skin. Action spectra of wanted (beneficial) UV effects and of unwanted (damaging) UV effects in skin show a partial overlapping. Thus, spectral optimization of the irradiation units is needed to maximize spectral effectiveness for the selected wanted effect and to minimize the risk of possible damages.

Therefore, a photobiologically based set of measures was defined in order to evaluate spectral properties of UV devices for therapeutic and for cosmetic purposes in terms of the spectral benefit/risk ratio. Main characteristics of this evaluation system are: the sun/effect factor, the effect/erythema ratio and the beneficial/damaging effect ratio.

Photobiological effectiveness of radiation emitted by LEDs is comparable to the effectiveness of other conventional (non-coherent) UV sources such as fluorescent or high pressure discharge lamps if the exposure conditions are equivalently in terms of wavelength, radiance, irradiance and dose.

LEDs show a number of advantages as compared with conventional UV sources, such as: straightforward realization of spectrally optimized narrow band UV sources without additional filtering, development of double band, multi band or broad band devices to stimulate wanted synergistic effects, small design (probes, spot-radiators), high values of irradiance and radiance, straightforward geometric adaptation of emitted radiation to curved skin areas and local exposures limited to the lesions only without unnecessary stress of healthy skin as well, and last but not least improved efficiency of using electric energy..

Most LEDs show a strong forward direction of emitted radiation which could cause unwanted hot spots and local in-homogeneities of irradiance in the area of use as well. This disadvantage has to be solved by technical measures.

In conclusion of these aspects, LED based technology enables the development of a new generation of UV irradiation units which are superior to conventional UV devices as currently used in dermatology, in internal medicine, in cosmetics and for health prevention as well. Moreover, highly precise spectral selection and geometric adaptation of exposure enable to include new indications into UV therapy, and results in increased therapeutic success of treatment in the case of currently included indications due to the restriction of UV exposure to the therapeutically effective range.

Monday, April 23

Room Barcelona I	Room Barcelona II
7:00 - 17:00 Registration	
8:00 - 8:30 | Opening (Barcelona I)	
8:30 - 10:00 | Mo-A1 **Water & Disinfection I** *Chair: O. Hoyer* K. Linden (invited) J. Eggers (invited) S. Kaemmerer F. Taghipour	**8:30 - 10:00 | Mo-B1** **Medical Applications I** *Chair: J. Lademann* K. Hönle (invited) F. Farrell (invited) K. Kahn C. Möller
10:00 - 10:30 | Coffee Break & Exhibition	
10:30 - 12:00 | Mo-A2 **Semiconductors & Devices I** *Chair: M. Straßburg* N. Lobo Ploch (invited) M. Jo (invited) J. Rottner A. Nebioglu	**10:30 - 12:00 | Mo-B2** **Plant Growth & Food I** *Chair: M. Schreiner* S. Olschowski (invited) M. Jansen (invited) R. Syamaladevi G. Hopfenmüller
12:00 - 13:00 | Lunch Break (Buffet) & Exhibition	
13:00 - 14:30 | Mo-A3 **Water & Disinfection II** *Chair: K. Oguma* O. Lawal (invited) S. Beck (invited) D. Miklos Y. Gerchman	**13:00 - 14:30 | Mo-B3** **Spectroscopy I** *Chair: G. Wiegleb* T. Jenek (invited) C. Heffels (invited) A. Benz F. Stüpmann

14:30 - 15:00 | Coffee Break & Exhibition	
15:00 - 16:30 | Mo-A4 **Semiconductors & Devices II** *Chair: L. Schowalter* R. J. Choi (invited) Y. Sakane (invited) T. Kolbe M. Khan	**15:00 - 16:30 | Mo-B4** **UV Curing I** *Chair: P. Rotsch* P. Burger (invited) T. Bizjak-Bayer (invited) A.Voigt P. Boulay
16:30 - 18:30 | Poster Session, Exhibition	
18:30 - 21:30 | Networking Dinner (MELIÃ Hotel Restaurant)	

UV LEDs for small drinking water systems: a revolution in robust and effective disinfection?

K.G. Linden[1], N.M. Hull[1], K Sholtes[1], S.E. Beck[2]
[1] *Environmental Engineering, University of Colorado Boulder, Boulder CO 80303, USA*
[2] *Department of Environmental Microbiology, Eawag, Duberdorf, Switzerland*

Recent advances in UVLED technology now offer the opportunity to create a tailored wavelength-specific disinfection system, with potential improved efficiencies over medium pressure UV systems (Lawal, 2012) and no use of mercury in the lamp. Improved efficiency is due to better power conversion to light emission, emission targeted to the action spectra of pathogens, and potential for improved architecture in UV system design. UVLEDs are now available in wavelengths below 250 nm and gains in efficiency are increasing, expecting to follow trends of visible light LEDs. For small system disinfection, UVLEDs offer the potential for a low-power, high efficiency, robust, pathogen targeted disinfection system. The first flow-through UVLED system, the UV Pearl (Aquisense, Earlanger, KY), is commercially available. The objectives of this work were to evaluate the use of UVLEDs for disinfection of pathogens and their potential to create a new paradigm for UV-based water treatment.

One area of potential innovation for UVLEDs is in combinations of wavelengths to enhance disinfection or create synergistic disinfection. Recent work combining wavelengths for disinfection based on pathogen action spectra will be presented focusing on *E. coli*, MS2 coliphage, adenovirus and LEDs with output at 265 and 280 nm, compared to conventional mercury vapor (low and medium pressure) UV sources. In addition, studies combining UV output from these LEDs with emission at 222 nm from an excimer source will be presented to illustrate the potential synergy, should LEDs be viable at those low wavelengths in the future. Figure 1 illustrates the emission spectra of the LEDs and mercury lamps. Another area where LEDs can be a game changer is in performance resilience. The disinfection performance of a flow-through UV-LED (285 nm LEDs, 0.5 liters per minute) reactor was evaluated over a year of operation at a small system water utility employing slow sand filtration, in Colorado (USA). Performance curves for various flowrates and UV transmittance levels were developed in the lab to predict reduction equivalent dose (RED) for comparison to field data. In the field, spiked MS2 disinfection was measured quarterly in slow sand filter effluent water over the course of a year, with total coliform, *E. coli*, and TOC measured bi-weekly, and UVT, temperature, turbidity, and pH measured daily. The system performed as well as the existing conventional chlorine disinfection process for total coliform inactivation through varying water quality, and required no maintenance over the year-long trial, with a yearly electricity cost of $25 USD. These findings as well as efforts to develop standardized protocols for measurement and performance of UVLED systems will be evaluated in considering if we are truly experiencing a revolution in disinfection opportunities for water supply.

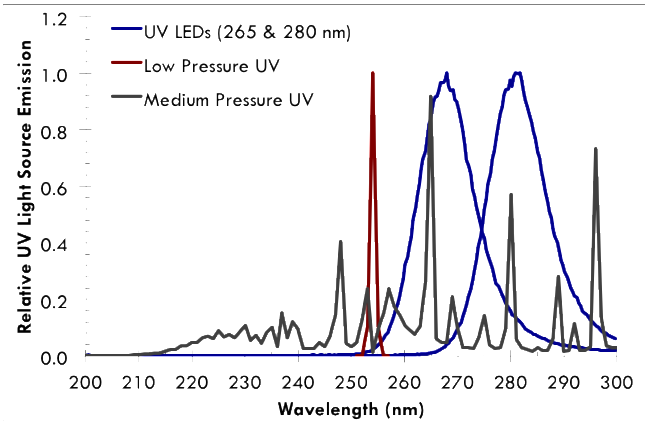

Figure 1. Emission of two common UV LEDs in comparison to LP and MP mercury vapor lamps.

UV LED Systems: Reflections on validation testing

J. Eggers[1], T. Schwarzenberger[1], K-H. Schön[1]
[1]*TZW: DVGW – Technologiezentrum Wasser, Karlsruher Straße 84, 76139 Karlsruhe, Germany*

UV disinfection is enabling a wide range of applications e.g. municipal drinking water and waste water treatment, as well as industrial applications such as food and beverage industry, pool water and ballast water treatment.

At present, low-pressure (LP) and medium-pressure (MP) mercury vapor lamps are used almost exclusively for disinfection purposes. However, before the disinfection devices are introduced into the market they typically undergo comprehensive validation testing [1, 2]. This includes determination of disinfection efficacy at different test conditions and, in addition, characterization of components used in UV disinfection devices such as UV lamps and UV sensors.

The commercial relevance of UV LEDs is growing rapidly and with increasing maturity of LED based systems they become more and more attractive for broad industrial applications, in particular disinfection purposes [3]. Yet, up to now no functional and technical requirements have been established for LED based disinfection devices. The need for a standardized and internationally accepted test protocol, as well as harmonized operation and monitoring guidelines for such systems, is generally agreed.

Starting with an overview on existing test protocols developed for plasma lamp systems for various applications, this presentation will focus on whether and to which extend these requirements can be transferred to LED based disinfection systems. In conclusion the need for adaptions will be identified, taking into consideration different characteristics of plasma lamps and UV LEDs. This includes for example differences in aging behavior, directivity and spectral output.

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[2] DVGW (2006). UV Devices for the Disinfection for Drinking Water Supply – Worksheet W 294: Parts 1, 2 and 3. Deutsche Vereinigung des Gas und Wassserfaches, Bonn, Germany.

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Using CFD to determine performance opportunities when designing UVC LED reactors for water disinfection

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Designing UV reactors for water disinfection is a mix of hydraulics, lamp design, lamp array layout, materials and added performance features. Adding UVC LED's to this mix also adds additional difficulties to the design process. The spot beam light output of UVC LED's can produce a wide variety of arrays and output profiles. Developing a system with the least number of LED's to produce a good light pattern and to achieve an adequate disinfection can be difficult. Due to the limited efficiencies of UVC LED's, reactor efficiency is critical. Principle consideration of different reactor geometries is paramount in determining an efficient reactor design.

The findings discussed are the CFD modelling and post processing requirements to achieve a good simulation using ANSYS Fluent software. In addition, model configurations to determine an efficient reactor design and the simulation results of such models are reviewed. Finally, the performance of the simulated UVC LED reactor models are compared to that of the conventional mercury amalgam lamp reactors.

Simulation of UV-LED Reactors for Virtual Prototyping: What are the Challenges?

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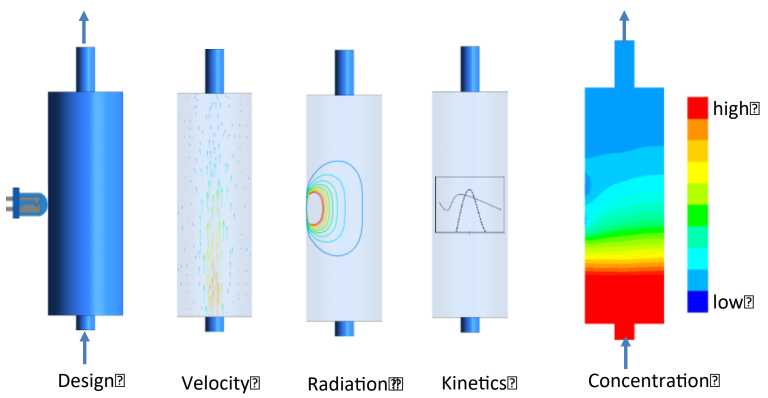
Computational models simulating the behavior of ultraviolet (UV) reactors for water purification have been developed and evaluated experimentally in the past decade. While these models are very helpful for providing insight into the performance of the UV reactor as well as their design and optimization, special attention must be devoted to modeling setup and experimental evaluation. This is particularly important for the newly emerging ultraviolet light emitting diode (UV-LED) reactors. Given their special characteristics and distinct operation modes, UV-LEDs offer a higher degree of freedom in reactor design and manufacturing compared to UV lamps. As a result, a successful model for simulating and predicting the performance of UV-LED reactors could be a crucial tool for virtual prototyping and optimization.

We will discuss a set of general guidelines for the simulation of UV-LED reactors for water treatment. We will present a method for determining accurate microorganism inactivation rate constants irradiated by UV-LEDs taking into account the characteristics of the radiation source, action spectra of microorganism, and the optical properties of the medium. Further, we will describe a UV-LED radiation model that takes into account not only refraction, reflection, and absorption of the medium, but also any modification of UV-LED radiation pattern through optical lenses, to compute the UV fluence rate. Furthermore, we will discuss the selection of appropriate turbulence model for the accurate prediction of the reactor hydrodynamics. Finally, an integrated model of simulating the behavior of UV-LED reactors developed in our research group will be presented. We will explain how the reactor performance model could enable UV-LED reactor optimization through fast virtual prototyping and the performance evaluation of different creative design options.



The integration of three complex phenomena: hydrodynamics, radiation distribution, and kinetics can lead to the predication of the performance of any UV-LED reactor design concept through virtual prototyping.

Prospects and challenges in the development of UV LED technology

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Ultraviolet (UV) radiation has a broad range of commercial applications, ranging from disinfection of water, air and surfaces to health care and even industrial production. In 2016 the UV lamp market was estimated to be a USD 628 million business [1] and is expected to increase with the introduction of new applications. This large market has provided a tremendous push in the development of sources in the UVA (320–400 nm), UVB (290–320 nm) and UV-C (200–290 nm) wavelength regions. Recently, many research efforts are being directed towards developing group III-nitride based UV light emitting diodes (LEDs) due to their distinct advantages over traditional UV sources such as a pre-tunable and nearly monochromatic emission spectrum, high power conversion efficiencies, compact size and environmentally friendliness. These advantages have led to an estimated UV LED market size of USD 288 million in 2017 [2]. The UV LED market is expected to continue growing, to USD 526 million in 2020 [2], by not only substituting conventional lamps but also by generating new application fields. Nonetheless, dramatic improvements in the efficiency and reliability of the LEDs are required for the rapid adoption of UV LED technology in a variety of applications especially in the UVB and UVC regions.

This presentation will provide an overview of the current status of the UV LED device technology and market. From the substrate up to the device packaging, the challenges in improving the power conversion efficiencies and the reliability of the UVB and UVC LEDs will be presented and the techniques currently being investigated to overcome them will be discussed. Due to efficiencies still being lower than the visible LEDs, methods to increase the internal quantum efficiencies as well as the light extraction efficiencies of the UVB and UVC LEDs continue to remain the main focus of research. Simultaneously new packages and encapsulants, designed especially for UV LEDs, need to be developed. Finally, the specific requirements of the LEDs for use in different applications need to be identified and realized.

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[2] LEDinside, “UV LED vs. UV LED Module Market Report.” http://www.ledinside.com, April 2017.

Recent Progress and Future Prospects of AlGaN Deep-UV LEDs

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AlGaN deep ultraviolet light-emitting diodes (DUV-LEDs) are attracting a great deal of attention, since they have the potential to be used in a wide variety of applications, such as for sterilization, water purification, UV curing, and in the medical and biochemistry fields. As a result of recent developments in AlGaN DUV LEDs, high internal quantum efficiencies (IQE) of more than 60-80% have been achieved by reducing the threading dislocation density (TDD) of the AlN, and/or by the introduction of AlN single crystal wafers. However, the wall-plug efficiency (WPE) of AlGaN DUV-LEDs still remains below 2%. The target for the efficiency of AlGaN DUV-LEDs is to go beyond an efficiency of 20%, which would make them comparable to low-pressure mercury lamps. A significant problem is that the light-extraction efficiency (LEE) is still quite low because of heavy UV absorption through the p-GaN contact-layer. Usual LEE is still below 10%.

In this work, we demonstrate an external quantum efficiency (EQE) of over 20% and WPE over 10% in an AlGaN DUV-LEDs by increasing LEE. In order to increase LEE of DUV LEDs, we introduced a transparent p-AlGaN contact layer, a highly reflective p-type electrode and AlN template buffer fabricated on patterned sapphire substrate (PSS). We used high-Al-content (Al=70%) p-AlGaN contact layers for 270 nm UVC LEDs. The transparency of the p-AlGaN contact layer was more than 97%. As a highly-reflective p-type electrode, we used Rh. By introducing a transparent contact layer and a highly-reflective electrode, EQE was increased by approximately 3 times. We also observed the efficiency increase by about 1.7 times by introducing AlN template fabricated on PSS and by conducting encapsulation with resin. Maximum EQE was 20.3 % for a 275 nm UVC LED measured under room temperature DC current condition. The UV output power with 50 mW current was 44 mW. Recently we also succeeded in reducing an applying voltage and obtained the record WPE of 10.8% from the DUV LED with lens. We also demonstrated the increase of LEE by introducing highly-reflective photonic crystal fabricated on the p-AlGaN transparent contact layer.

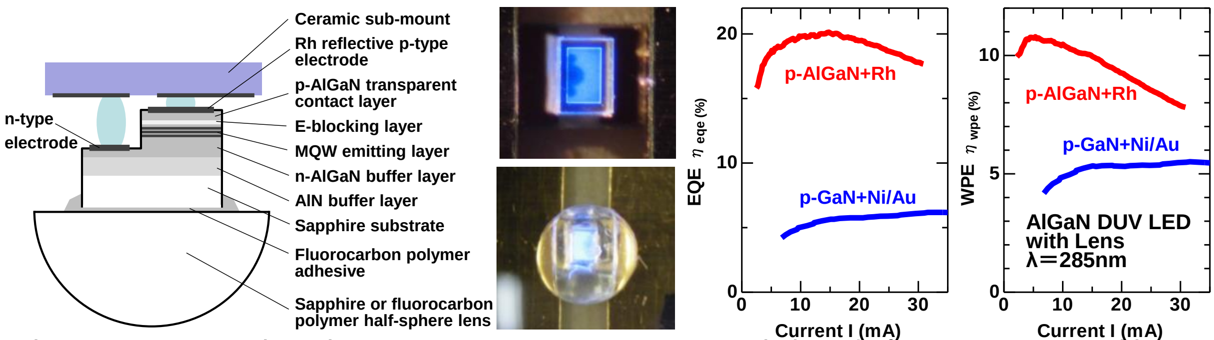

Fig. 1: Structure, photo images, EQE [illegible]racteristics of AlGaN DUV LED with lens. (The samples were supplied by DOWA Electronics Materials Co. Ltd.)

Field effect UV µ-LEDs: a new concept

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In their most classical form, deep UV LEDs require the use of highly p-doped AlGaN epilayers. But as the Al content in the alloy increases, the activation energy for the Mg-dopants increases as well, leading to very low acceptor ionization levels.

To bypass the inefficiency of p-doping, our proposal consists in using a geometry whereby the electric field below a MOS capacitor is combined with an UV µ-LED. The process consists in first designing µm size mesa structures from a UV epitaxial stack and subsequently depositing a gate (insulator + metal) along the sides of the mesa. When applying an appropriate negative voltage to this "side-gate", the electric field below the gate induces a hole accumulation channel around the mesa. The holes will use this channel to go into the quantum well active region, diffuse along the length of the wells and finally recombine with electrons.

In order to check for the validity of the approach, we shall first dwell on the simulation results using the Silvaco Atlas software. The simulations were carried out for µm size mesa structure encompassing an Al0.5Ga0.5N/Al0.7Ga0.3N Multiple Quantum Wells (MQW) active region emitting around 265 nm, with or without a surrounding gate on the sidewalls of the mesa. Varying gate and diode voltages, and assuming perfect light extraction and electrical contacts, the use of a side gate in a µ-LED geometry allows the WPE to be theoretically increased by a factor of about 3.

Obviously, one of the main challenges of this approach lies in avoiding any interface trap and Fermi level pinning on the sidewalls of the µ-mesa. This requires optimizing the etching process used for creating the µ-mesa. We shall comment this point both through simulations and through the ongoing experimental determinations of the damage induced by the etching process.

LED Curable 100% Solids Very Low Viscosity Conformal Coating

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Conformal coatings are thin, polymeric coatings that are used to provide environmental protection and electrical insulation of printed circuit boards (PCBs). Typically applied at a 50-225µm thickness, these coatings are designed to 'conform' to the board without adding excessive cost or weight. The excellent coverage extends the life of PCBs. Very low viscosity formulations are often required for very thin conformal coating applications. Solvents are most often used to reduce viscosity of the formulations and to accommodate dispensing needs. Solvent-free coatings are attractive due to their environmental friendliness and ability to offer faster processing for coating lines. Until recently, efforts in developing very low viscosity 100% solids coatings were not successful due to performance requirements such as chemical, heat, and humidity resistance. We have developed a technology that results in 20-30 cP viscosity 100% solids light curable coatings. We will discuss the performance in reliability tests such as heat and humidity resistance as well as corrosion resistance (flowers of sulfur resistance and salt spray resistance). Any change in physical appearance, formation of oxidation spots, and insulation performance were checked on PCBs after reliability tests. In addition to LED cure optimization, the new coating can also be cured with broad spectrum UV light and secondary heat for shadow areas.

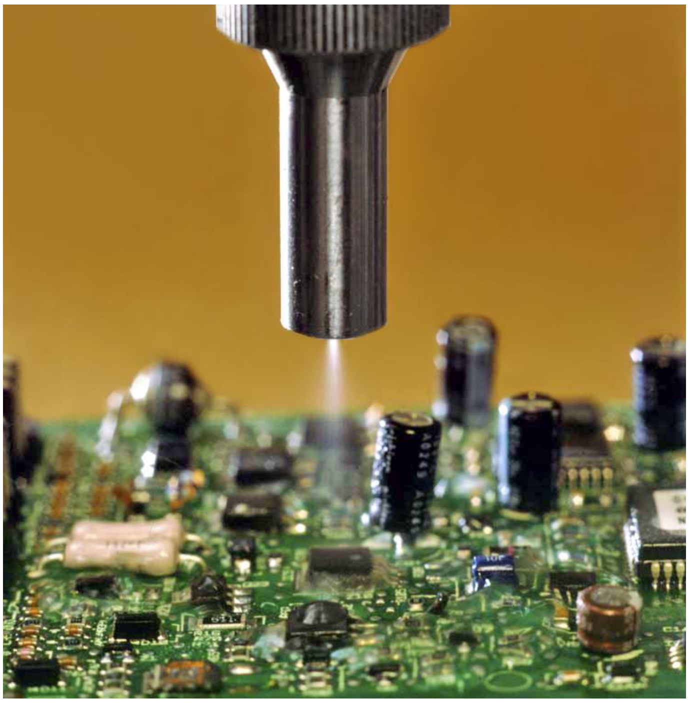

Fig. 1: Spraying of LED curable 100% solid very low viscosity conformal coating

UV LED Disinfection Systems: The last 10 years to the next 10 years

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UV-C LEDs were once considered an embryonic technology suitable only for research and decades away from commercial implementation. We are now at a tipping point where are being applied to commercial products. This time goes on, these devices will revolutionize infection prevention strategies for water, air, and surface disinfection.

This presentation will provide an overview of applied UV-C LED technology. The discussion will focus on the progression of the devices themselves, the systems built around them and the application of those systems. Specifically, how those systems differ from 'traditional' UV systems. Current commercial case studies will be included in commercial, residential and space applications.

A discussion related to the unique attributes that allow LED technology to be applied where traditional UV technology cannot be applied. In addition to the broader scale application into very high-volume markets in developing countries. This will show a new technology that is partly disruptive and partly constructive.

In addition to the current state of UV-C LED technology, the fast approaching future will be explored. One intriguing aspect is what impact LEDs will have on future system development. This technology will be suitable for future municipal systems, with full-scale pilot systems already being tested in Europe and Asia.

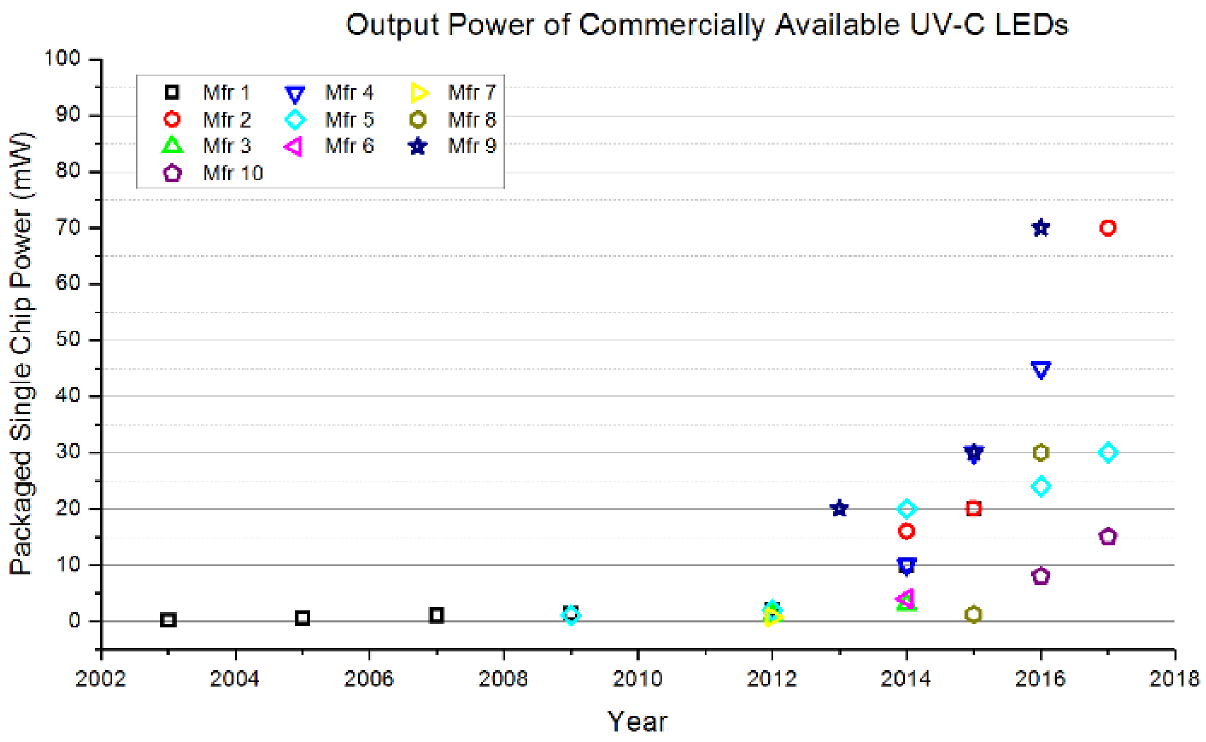

Fig. 1: Output Power of Commercially Available UV-C LEDs

Wavelength-Specific UV Inactivation, Molecular Mechanisms, and Potential Synergies

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This research assessed the wavelength-specific effects of germicidal ultraviolet (UV) irradiation on microorganisms including bacteria, viruses, and helminth eggs. Every organism has a unique spectral sensitivity to UV irradiation. In many cases, the sensitivity of bacteria strongly correlates with their DNA or RNA absorbance. For many viruses, however, the sensitivity deviates from the UV absorbance of their DNA or RNA because mechanisms other than nucleic acid damage are contributing to their UV inactivation. This is especially important for disinfection with UV light emitting diodes (LEDs), which emit across the germicidal wavelength range depending on their substrates and coatings.

This work evaluated UV LEDs emitting at 260 nm, 280 nm, and the combination of 260|280 nm together for their efficacy in inactivating a common fecal indicator, *E. coli*, as well as human enteric viruses on the United States Environmental Protection Agency's contaminant candidate list (adenovirus 2 and four enteroviruses including coxsackievirus A10, echovirus 30, enterovirus 70, and poliovirus 1), and surrogate microorganisms used for validating UV reactors, MS2 coliphage and *Bacillus pumilus* spores. When possible, inactivation by LEDs was compared with the efficacy of low-pressure (LP) UV irradiation emitted at 254 nm as well as that of another common polychromatic UV source, the medium-pressure (MP) UV lamp.

For some microorganisms, exposure to two UV LED wavelengths simultaneously was evaluated for potential synergistic effects. No dual-wavelength synergy was detected for bacterial and viral inactivation nor for DNA and RNA damage. Some scenarios were also compared for electrical energy per order of log reduction. These showed that in order for UV-C LEDs to match the electrical efficiency per order of log reduction of conventional LP UV sources, they must reach efficiencies of 25-39% or be improved by smart reactor design.

Follow-on research evaluated UV LEDs emitting at 280 nm and LP UV for their efficacy at inactivating *Ascaris lumbricoides*, an intestinal parasite common in low- to middle-income countries, responsible for roundworm infections in 1.4 billion people worldwide. Both UV sources were effective at very high doses with sufficient mixing: approximately 100 mJ/cm^2 of LP UV irradiation and 250 mJ/cm^2 of irradiation from a 280 nm UV LED were required for 1-log reduction of *Ascaris lumbricoides*.

This wavelength-specific research will be discussed within the broader context of UV LED disinfection.

UV-LED based water disinfection:

Testing of synergistic and water matrix effects

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Recently, sequential managed aquifer recharge technology (SMART) has been proposed as an innovative multi-barrier treatment concept for indirect potable water reuse. This concept utilizes modified engineered natural treatment systems including multiple barriers to deliver a water quality that is suitable for drinking water augmentation, while offering a high degree of groundwater protection. One stage of this multi barrier system is UV-disinfection which is investigated using Ultraviolet (UV) light emitting diodes (LEDs). UV-LEDs are an emerging technology for water and wastewater disinfection and have proven effective in inactivating various bacterial, viral and protozoan pathogens. Moreover, UV-C LEDs have shown high potential since they are smaller, lighter, and less fragile than traditional mercury vapor lamps.

Fundamental laboratory-scale investigations were conducted using a triple-wavelength UV-C LED system (HYTECON, Germany) with a PTFE reflector tube emitting at peaks of 265, 275 and 285 nm for inactivation of MS_2 coliphages. UV-irradiance was determined using KI/KIO_3 actinometry and a UV-C broadband radiometer (sglux, Germany). Besides single peak-wavelength effects, the combination of two and three different LEDs was investigated to test the presence of synergistic effects. Furthermore, water matrix effects were investigated using a phosphate buffer solution as a pure reference system and different spiked real water matrices including municipal wastewater treatment plant effluent as well as effluent from a pilot-scale SMART system.

Intensive testing of irradiance measurements shows discrepancies in between radiometer and actinometer results due to diffuse reflections of the PTFE tube. Preliminary results from disinfection experiments reveal highest dose response for LED 265 with an inactivation of 5 log followed by LED 275 with 4.2 log and LED 285 with 2.8 log inactivation at 60 mJ/cm^2, respectively. Combinations of different peak wavelengths LEDs did not result in synergistic effects.

Rapid measurement of UV-LEDs dose response curves and spatial irradiance distribution

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UV-Light Emitting Diodes (UV-LEDs) are a promising technology for water–borne pathogens inactivation; nevertheless, as always, new technologies bring in new challenges. Classical mercury vapor based UV lamps have long and narrow geometry, limiting reactor shape accordingly, but UV LEDs allow for much more flexible geometrical design, resulting the need for new testing tools. We present the use of multiwall microtiter plates for rapid determination of dose response curves and irradiation surface geometry (e.g. "Petri factor") of collimated UV-LED systems. Such plates come in many forms, containing from 6 to 1536 "wells", with different spatial organization (2x3 for 6 well to 32X48 for 1536 well plate), allowing for high spatial resolution and/or the possibility for simultaneous testing of multiple repeats and conditions. Together with Aquisense Technologies we designed a wide rectangular multi-wavelength UV-LED apparatus that irradiates the area of a microtiter plate. Using microtitter plates we tested this array for photon flux, spatial uniformity and bio- and chemical-dosimetry, dose-response for the different UV-LEDs. This approach allowed for simultaneous measurement of multiple samples and/or repeats and can be useful for rapidly identifying disinfection conditions (e.g. UV wavelengths, doses, environmental conditions) that will be effective for inactivation. This method may also be implemented for low volume samples or for determining concurrently absorbance and UV exposures for many samples.

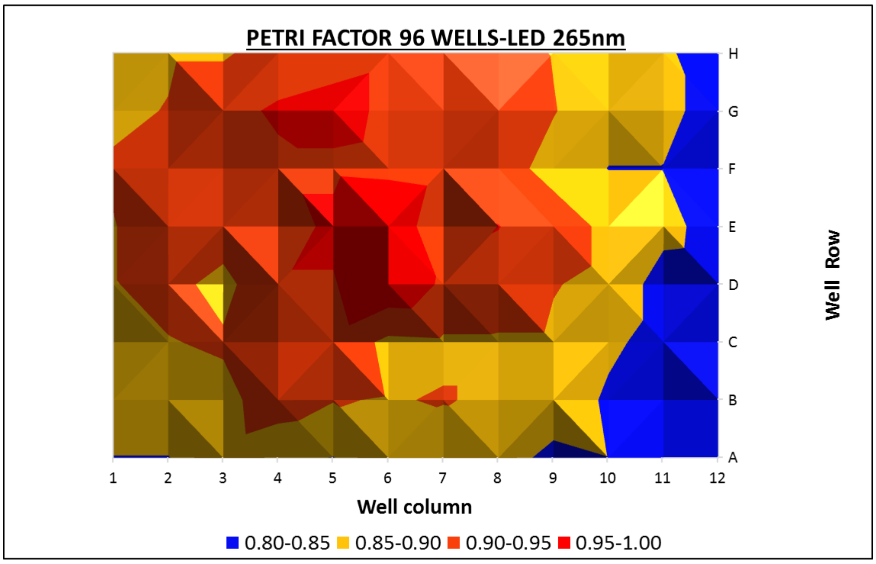

Fig. 1: 96-multititter plate petri factor measurement

Current Status and Future Works of High Power Deep UV LEDs

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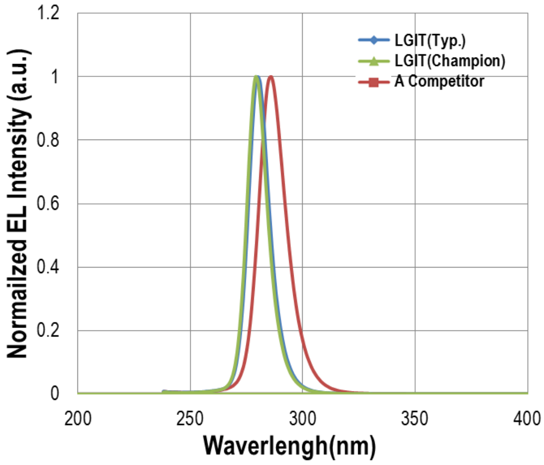
Deep ultraviolet light emitting diodes (UV-C LEDs) are taking significant interest in varying applications such as disinfection and purification for water, air, and surface. Therefore, many reports have been published regarding the development and applications of UV-C LEDs, which have been also adopted a home appliances recently. However, UV-C LEDs still have a number of challenges such as output power, cost, reliability, and manufacturability. In this talk, recent advances (output power above 120mW and wall-plug efficiency above 5% in single device) in epitaxial quality, device design, and reliability for high current driven UV-C LEDs will be presented. We expect this performance to be used in the flow system for disinfection and purification of water and air in the near future.



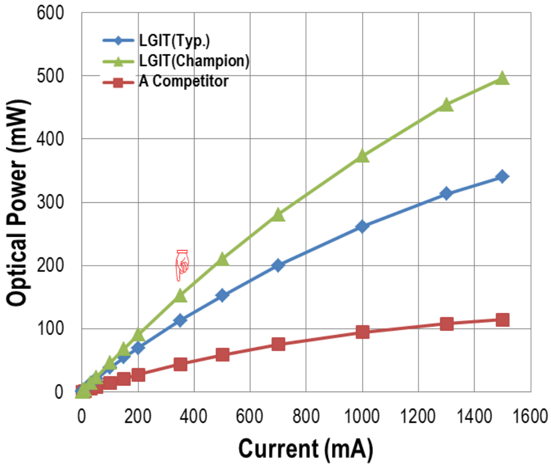


Fig. 1: The EL Spectra of 280nm and Output power vs. Injection current, respectively.

Enhancement of light extraction efficiency of DUV LEDs by high UV durable fluoro resin encapsulation and light distribution lens

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AlGaN-based deep-ultraviolet (DUV) (λ < 300 nm) LEDs are expected to be useful for many applications such as sterilization, deodorizing, and ultraviolet curing, and so on. The bare dies of AlGaN-based deep-ultraviolet (DUV) LEDs on sapphire substrate achieved the external quantum efficiency (EQE) of greater than 6% at 280-300 nm, 5% at 270 nm, and 4% at 260 nm, respectively, using p-GaN contact layer.[1] Thus, a DUV-transparent resin encapsulation is considered as the solution of increasing in light extraction efficiency (LEE) for DUV-LEDs, because any silicone resin suffer from fatal damage due to photolysis caused by DUV light.[4] For encapsulating DUV-LED dies, the optically isotropic amorphous perfluoro-resins with DUV-transmittance and robustness against DUV region was indispensable.[3,4,5] Poly-(perfluoro-4-vinyloxy-1-butene) terminated with $-CF_3$ (p-BVE-S) showed no damage on electrode and the resin for over 6000 h, demonstrating1.5-fold LEE using hemispherical encapsulation for single-chip and 3×4 array. On the other hand, the terminal ends of -COOH and $-COOCH_3$ were decomposed by DUV light, resulting in electrode damage and seriously increased leakage.
Another commercially available amorphous fluorine resin having a DUV transmittance was also investigated, which is, perfluoro-2,2-dimethyl-1,3 dioxole (PDD) copolymerized with tetrafluoroethylene (TFE-co-PDD) with different main chain structure.[5] A reliability test showed that the decomposition of the PDD caused an increase in the leakage for both 262 and 289nm LEDs. In contrast, samples with p-BVE-S did not show any damage. Therefore the molecular structure of the encapsulation material for DUV LEDs has been clarified.
Furthermore, the demonstration of mass producing chip-on-board (COB) packaging using p-BVE-S resin was succeeded using a transfer molding of 12 concave depressions. [4] Detailed procedure of the encapsulations of fabricating array semispherical lens by using poly-BVE-S will be presented.

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Development of efficient and reliable UVB light emitting diodes for medical and material processing applications

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The development of efficient (In)AlGaN-based light emitting diodes (LEDs) emitting in the ultraviolet B (UVB) spectral region (280 nm – 320 nm) is essential due to their vast commercial potential. UVB LEDs are expected to not only replace traditional mercury lamps in applications such as curing of polymers and phototherapy but also to establish new applications in the fields of plant growth and sensing. Although a lot of progress has been made on the performance of the UVB LEDs, the efficiency of the devices as well as their lifetime still needs to be improved. In this study the influence of the design of the semiconductor layer structure, the chip processing technology and the package on the efficiency and lifetime of UVB LEDs, grown by metalorganic vapor phase epitaxy on c-plane sapphire substrates, will be presented.

Firstly, the performance of UVB (In)AlGaN-based multiple quantum well LEDs were studied and the influence of the material composition and p-type doping on the emission characteristics and lifetime was analyzed. Therefore, LEDs with different electron blocking layer (EBL) designs and doping concentrations (Fig. 1) were compared. The highest internal quantum efficiency, emission power and lifetime were obtained for LEDs with a gradient-like EBL, with decreasing aluminum content in direction to the p-side of the LED. Secondly, investigations on the influence of the metal contacts, and insulator material as well as contact geometries and the device packaging on the performance and lifetime of UVB LEDs will be presented. Based on these optimizations, LEDs emitting at 315 nm with output powers up to 30 mW at 350 mA and a L70/ L50 lifetime of larger than 3000/ 8000 hours after a burn in phase of 100 hours were realized. Current lifetime measurements have shown that these values can be further improved by larger p-contact areas and therefore lower current densities.

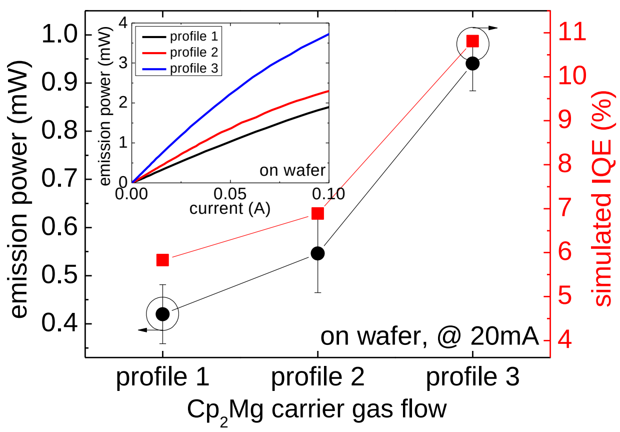

Fig. 1: Measured average emission power as well as simulated internal quantum efficiency (IQE) of 310 nm LEDs with different temporal Cp_2Mg carrier gas flow profiles (p-doping profiles) in the EBL. Inset: Typical emission power vs. current characteristics of 310 nm LEDs with different temporal Cp_2Mg carrier gas flow profiles in the EBL.

Narrow Band Milliwatts power operation of AlGaN based UVB LED for Medical Applications

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Smart and high-power UVB LEDs/LDs (280-320nm) light sources are strongly demanded for wide range of applications like immunotherapy, agriculture, UV cure, skin care treatment, wound healing, Vitamin D3 and many other medical applications[1-5]. Torii et al., raise a question, “Which UVB wavelengths induce HMGB1 expression and whether the 310 nm wavelength, which is used therapeutically, induces HMGB1 secretion without inducing apoptosis?“[4]. At last Torii et al., concluded that NB-310nm UVB, induces the secretion of high-mobility group box-1(HMGB1) without inducing the apoptosis (death of cells). It is also known that the NB UVB LED can generate phytochemicals in the plants [1]. Based on this motivation, we attempted to grow and characterize AlGaN based UVB LED using MOCVD. Recently we got high EQE around 3.8% with max output power around 14mW for the upper bound (280-300nm) UVB LED devices for producing Vitamin D3 in human body [5]. Thanks to the graded n-AlGaN buffers, AlGaN MQWs on AlN template, blessed us with high IQE (35%). Subsequently, the PL/EL emission peaks between 300nm and 310nm were successfully tune by compositional variation of Al and Ga in the n-AlGaN buffer layer as well as in the MQWs for the desired target of medical applications. As a result NB UVB LED light emitter around 310 nm with max output power of 7.1 mW for lower bound were successfully realized. The low EQE around 0.9% might be caused by the weak performance of EBL. We struggling to resolve this issue of current injection in the near future.

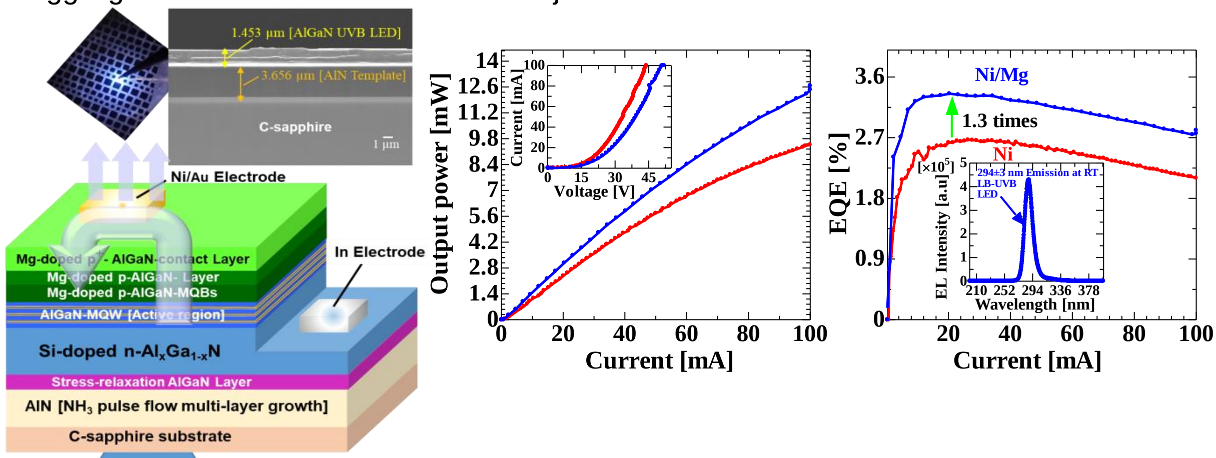

Figure 2 (a) Schematic structure of the AlGaN UVB LED grown on AlN template (b) I-L (in the inset I-V) and (c) I-EQE (in the inset EL Vs

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[3]. William et al., Clinical Dermatology. Saunders Elsevier. p. 335 ISBN 0-7216-2921- 0(2006).
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[5]. Kalajian et al., Scientific Reports 7, 11489 (2017).

Interaction between Medical and Physical Research in UV-Treatment of Skin Deseases

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The first User of UV-Radiation for dermatological application was Niels Ryberg Finsen at the End of the 19th century. For his first treatments he had only sunlight. It was his idea to construct special irradiation equipment (optical components) to concentrate the radiation on the skin of his patients, later on with a artificial UV source: the electric arc between coal electrodes, enriched with iron compounds. His work was continued by Ernst Kromayer, who improved the Finsen Lamp by using water cooling for the electrodes and found an industrial manufacturer for his then called Kromayer Lamp. These lamps were emitting both UV A- and UV B-radiation. The main application field was Lupus Vulgaris, at that time a very serious skin desease. In the 1920th other skin deeases have been treated: Psoriasis, Vitiligo, Atopic Dermatite. In the 2nd half of the 20th century some dematoligists found, that the healing success for different skin deseases depends from the used part of the total UV range. After exploring the response functions they defined special methods of treatment according to these functions.For example Psoriasis should be treated either with UV B (SUP) Phototherapy or with UV A Radiation combined with application of Psoralene (PUVA). The manufcturer of medical equipment could deliver the different spectral ranges by two kinds of radiation sources:

the low pressure fluorescence tube with various spectra and the high pressure metal halide discharge lamp with a broad spectral emission, from which special regions could be selected. There was a hard fight between the suppliers of these two kinds of radiation sources for about 30 years. The further developpment brouht the narrow band tube (311 nm) and the excimer laser (308 nm),

which both fit the response function of Psoriasis quite well. More suitable for some appplications should be the new UV radiation source LED, which has some advantages due to its small size.

Wearable LED-based device for phototherapy applications

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Phototherapy with UVA/B or visible wavelengths is used to treat skin disorders such as psoriasis, eczema and vitiligo. Traditionally, phototherapy is carried out in a clinical environment and utilises large fluorescent lamps. These are now being replaced with more efficient and compact light-emitting diodes (LEDs), a trend that is set to continue thanks to the progress of UV LED technology. LEDs are also facilitating the emergence of at-home devices to improve patient convenience and decrease demand on the healthcare system [1]. Current at-home devices consist of rigid LED arrays, which limits their conformability and produces non-uniform light distribution over the treatment area, in turn limiting their efficacy and wearability [2].

As a solution to this problem, we are engineering a flexible light therapy device that combines LEDs and a sub-mm-thick polydimethylsiloxane (PDMS) light sheet in an edge-lit configuration. PDMS has previously been shown as an effective flexible light guide [3]; its high transparency from 290 nm upwards and its biocompatibility make it an ideal substrate for a wearable phototherapy device. The PDMS sheet acts as a waveguide and the light diffused through the top surface is measured as irradiance (µW/cm^2). Furthermore, the change in irradiance by embedding scattering particles has been demonstrated (*fig. 1*) utilising a UV LED (385 nm) at an optical power of 25 mW. This approach produces a uniform emission of 140 µW/cm^2 over a treatment area of 2.25 cm^2, an increase from 1.5 µW/cm^2 with the PDMS sheet alone. We will describe the effect of coupling LEDs to our PDMS sheet, discuss design strategies for efficient and uniform light extraction to the treatment area and explore micro-transfer printing as a method of integrating bespoke LEDs.

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[3] J-H. Lee et al, Journal of the SID, 2008, **16**, 329-335.

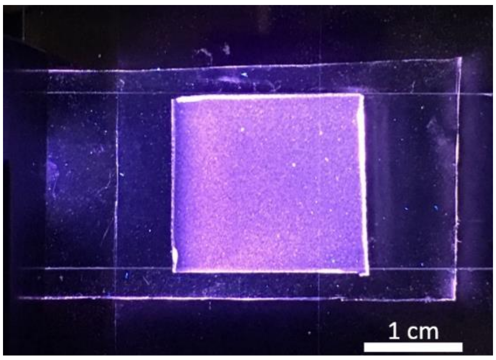

Fig. 1. Light sheet with embedded scattering particles coupled to a UV LED (385 nm) in an edge-lit configuration from the left side

Designing with UVC LEDs for Medical Applications

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Deep UV (UVC) LEDs are gaining traction in the fight against healthcare acquired infections (HAIs). UVC is a proven effective method to fight target microbes like Clostridium Difficile (c. diff), which are not impacted by alcohol-based disinfection protocols. With UVC LEDs, medical device and equipment manufacturers can cost-effectively integrate on-demand disinfection into common point of care products to reduce HAIs and improve patient outcomes. Such devices can readily be connected to IT systems to quantify disinfection activities and establish a clear connection with incidence of HAI.
In addition, UVC LEDs offer considerable design advantages over other traditional disinfection methods thanks to their small footprint, low power consumption, and lack of toxic byproducts or hazardous materials.

To successfully incorporate UVC LED-based disinfection into new or existing point of care medical devices and equipment requires an understanding of the relationships between spectral sensitivity, UV dose, irradiance, exposure time, useful lifetime and material properties. This talk will discuss these considerations, with a focus on designing for end-of-life and worst-case-scenario, which is required to ensure efficacy of disinfection over the life of the product. The variables affecting operation and performance and tools to help design and prevent failure mechanisms will be presented, complemented by examples from the field where innovation was driven by successful integration of UVC LEDs.

UV LED illumination and ASIC detector unit for fluorescence lifetime determination

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Fluorescence lifetime determination is widely utilized for bioscience research and analysis. The fluorescence stimulation in conventional systems is usually done with expensive picosecond laser systems. We present a cost-effective 370 nm LED based excitation module with a pulse FWHM of 1 ns and a beam diameter of 4 mm. The functionality of the excitation module was demonstrated with the fluorescence dye ATTO 390 with a fluorescence lifetime of 5 ns. The width of 8 mm of the excitation module enables the parallel measurement of adjacent sample chambers of a well plate. Further, a silicon UV-photodiode is designated to monitor the output power of the LED.

For a fast analysis of the fluorescence signal, we developed an ASIC for fluorescence histogram recording. The ASIC determines the time between excitation pulse and incoming fluorescence photon with an accuracy of about 80 ps. The ASIC blind time after the excitation pulse is configurable. The determined time is saved in bins. The width of the bins is programmable. For fluorescence light detection a silicon photomultiplier (SiPM) is used. Output of the ASIC is a histogram with the counted amount of photons at the different times after excitation. This histogram equals the fluorescence response of the dye. The fluorescence lifetime can be calculated out of this histogram. We demonstrate first proof of concept measurements with the ASIC.

Tunable Grow Lights in Controlled Environment Agriculture (CEA) – Challenges and Opportunities

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It is well known that light intensity and light quality affects next to photosynthesis, plant morphology, as well as the synthesis of secondary metabolites. In controlled environment, agriculture (CEA) light is one of the limiting parameters, therefore, it is also one of the key factors, with which we can manipulate plant development without using GMOs. The globally increasing community, working with different spectral qualities, is mainly using the photosynthetic active radiation (PAR). However, the interest in growing plants with spectra like UV and Far-Red is increasing rapidly.
For that, special equipment like tunable light sources, which can provide narrow band spectra of different wavelengths and also mimic a broad spectrum, could be beneficial. In the recent years, light-emitting diodes (LED) enabled us to provide exact spectral ranges we want to expose plants to, without the heat radiation in their direction. In comparison to the usage of high-pressure sodium (HPS) light sources, which only provides a fix spectrum.
Especially for research institutes, breeders and growers it is interesting to accelerate the development of different light treatments and enhance plant morphology, plant health and the content of secondary metabolites (e.g. antioxidants, vitamins and glucosinolates).
The rapid developing LED-technique gives us many different opportunities like, growth control, adaption to supply chains, mitigation of fungi diseases and other pests, decrease the usage of chemicals and much more.
Generically this presentation shows some exciting results, how a tunable light source can encourage scientists, growers and their plants with dynamic light treatments.

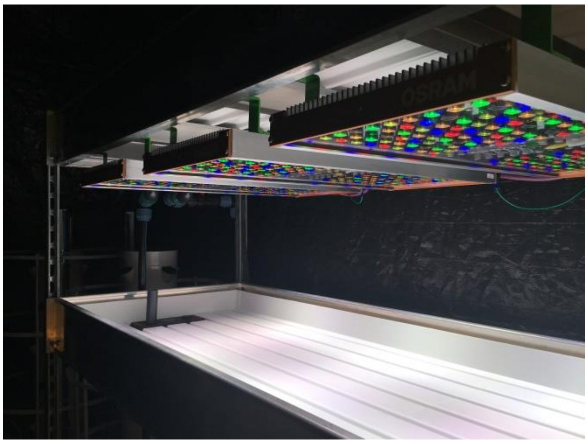

Fig. 1: Innovative tunable light source

Fig. 2: UV-A for Horticulture

A new tool for the horticultural industry; UV-radiation

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Advances in LED technology are having a profound impact on the horticultural (glasshouse) industry. Energy-efficient LEDs are replacing traditional light sources such as sodium halide lamps. Apart from gains in energy-efficiency, a major advantage of LED-technology is the capability to accurately control the light spectrum, and hence manipulate plant responses. By varying the proportions of Red, Blue and Green, processes as diverse as rooting, flowering and fruit-set can be controlled. “Light-recipes” have become available to instruct growers about crop manipulation. Thus, precision manipulation of light is rapidly becoming routine, with both the technology, and the knowledge of plant responses supporting this process. Given the scale of the industry (>200,000 acres protected-cropping in Europe, producing €150 billion worth of produce, and employing 3 million workers), novel technologies have very substantial impact.

Thus far, the commercial use of LED-technology is limited to the visible part of the spectrum. However, there is substantial potential to use ultraviolet (UV) wavelengths to manipulate crops. Specifically, UV-B wavelengths can be used to enhance levels of various bioactive compounds in crops. This may increase nutritional benefits for human consumers, and/or enhance flavour and colouration, especially in the northern European winter season. Incidentally, many of the induced bio-actives, such as flavonoids, are associated with pest and disease resistance. Therefore, UV-B wavelengths can potentially contribute to a more sustainable horticulture. UV-B wavelengths can also be used to generate a more compact, stocky plant that is more suitable for international transport, between different growers (sometimes located on different continents) and to retailers, a normal component of modern horticulture. Thus, UV-B can potentially replace hormone-like mixtures that are currently used for this purpose, again emphasizing the potential of UV-B to enhance sustainability of the horticultural industry. Nevertheless, it should be stressed that UV-C and short UV-B wavelengths can also be damaging to plants.

Current UV-technology (mainly broad band UV tubes) can simultaneously induce a multitude a plant beneficial and damaging UV responses. Work at University College Cork explores how specific UV-wavelengths, generated by narrow-band UV-emitting LEDs, can be used to selectively induce desirable plant responses, thus facilitating precision manipulation of crops.

Microbial inactivation by LED technology to improve food safety

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The application of Light Emitting Diodes (LED) for microbial inactivation in food products is an emerging research topic. High intensity pulsed light emitted by LEDs have the potential to reduce foodborne pathogenic microorganisms. Our research at University of Alberta focuses on understanding the microbial inactivation potential of lights with specific wavelengths emitted by LEDs, for example, Ultraviolet-A (UV-A, 365 nm), Near UV-Visible (NUV, 395 nm) and Blue (455 nm) lights with different power levels in wet and dry food systems. We treated wet *Escherichia coli* AW 1.7 and dry *Salmonella enterica* serovar Typhimurium using UV-A, NUV-Vis and Blue LEDs (100 Hz, 6 millisecond pulses) at selected power levels for specific time periods. Temperature of the bacterial samples increased considerably from 23^{o}C to 35, 51.5, and 30^{o}C during UV-A, NUV-Vis, and Blue LED treatments. Significant weight losses in bacterial samples due to moisture transfer during LED treatments was observed. Cell counts of *E. coli* were reduced to levels below the detection limit (~8 log CFU/ml reduction) after UV-A LED treatment with dosage of 78.2 J/cm^2 (45 min treatment) and NUV-Vis LED treatment with dosage of 280 J/cm^2 (20 min treatment). Pathogenic microorganisms generally exhibit significantly greater resistance to antimicrobial treatments in dry systems compared to wet systems. We observed reductions of 1.5, 2.8, and 2.1 log CFU/ml in dry *Salmonella* population (at a water activity of 0.75) after UV-A, NUV-Vis, and Blue LED treatments for 60, 60 and 40 min, respectively. This study shows the potential of pulsed UV-A, NUV-Vis, and Blue LED treatments to inactivate the *E. coli* and *S*. Typhimurium in wet and dry conditions. Knowledge obtained through this project will help us to select appropriate treatment conditions to reduce *E. coli* and *Salmonella* population in various food and bioproducts.

Quantification of harmful UV LED radiation at workplaces on the examples of food packaging UV disinfection and horticultural UV lighting

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Artificial UV radiation is applied in many processes such as UV disinfection, UV curing or biological activation. Besides discharge tubes, LEDs are becoming more important for a rising number of applications in particular UV curing or medical treatment. In general, exposure to UV radiation may cause health problems such as skin aging, eye damage or skin cancer. For system manufacturers, maintenance personnel and operators a precise evaluation and control of the workplace safety is essential. The potential danger varies with the irradiated wavelengths and the exposure time. The limits and the spectral weighting function of the UV irradiance are given in the directive 2006/25/EC published by the European Commission. The directive obligates employers to prepare a metrological hazard assessment. Using the necessary metrological instruments correctly is not trivial. This lecture explains the radiometric quantification method on the examples of UV disinfection of food packaging materials and horticultural UV lighting. The importance of the knowledge about spectral distribution is shown and how different calibrations and sensors are used.

[1] European Commission, Directive 2006/25/EC on the minimum health and safety requirements regarding the exposure of workers to risks arising from physical agents (artificial optical radiation)

Broadband UV-LED light source for spectroscopic applications

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[1]*Heraeus Noblelight GmbH, Hanau, Germany*

UV-LEDs are transforming light sources in spectroscopy applications in terms of size and power consumption. Small and low power LED light sources enable miniaturisation of instrumentation and pave the way towards more cost efficient analysis. Due to their robustness and their low power consumption of only a few Watts, they are also an enabler for portable measurements in the field ensuring long battery life. On the other hand LEDs cover only a very narrow spectral range of typically 10 – 15 nm (FWHM). Therefore, the LED chip needs to be chosen to match the absorption spectrum of the analyte, which limits the flexibility of the instrument. Combining multiple LED chips in one light source often results in an optical design challenge that increases complexity and cost. Hence, LED based spectrometers are typically application specific. These limitations can be overcome by generation of a broadband continuous spectrum that allows for the detection of various analytes with a single light source. Generation of a broadband continuum from 250 – 450 nm based on an UV-LED has been demonstrated that overcomes the limitations of narrowband single chip LED light sources. The presented concept can be utilized in different applications of UV spectroscopy. It offers a flexible platform for various industries where small footprint and long lifetimes are needed. This includes applications in life science, gas measurement and water monitoring.

Measuring gas concentrations with UV LED for emission and environmental monitoring applications

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Environmental regulations require the measurement of hazardous gas components emitted into the atmosphere by industries and local polluters in urban areas to monitor limiting values of gas components such as ozone, nitrogen oxides, sulfur dioxide and carbon monoxide. The first three molecules mentioned show strong absorption bands in the ultraviolet spectral range accessible with LED sources. Especially nitrogen oxides and sulfur dioxide emission measurements are gaining more importance both in stationary and mobile applications burning coal and heavy fuel oil.
In this contribution a commercial continuous gas analyzer is presented. The photometer principle is based on a double-beam setup using an absorption path and a reference path for monitoring the LED intensity. The ultraviolet radiation is collimated and passed through a beam splitter. The beam splitter additionally allows the use of two alternating LED. The one is based on AlGaN semiconductors for measuring sulfur dioxide the other on InGaN for measuring nitrogen dioxide. To improve the signal evaluation, the LEDs are operated in a pulse mode. The absorbed radiation is recorded by a photodiode collecting the light after the absorption path. Likewise, the reference radiation is recorded by a second photodiode. The ratio of both signals is used to calculate the concentration of the gas component according to Lambert-Beer's law. Both components are measured in a flow cell using a sensor electronics board producing continuous concentration values. Other applications are possible through a suitable selection of LEDs even in case of overlapping spectral absorption bands by applying a cross-interference calculation. Accurate temperature control of the photometer allows installations in process industry without individual temperature compensation.

Online water monitoring based on UV-LEDs

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Due to constant technological progress UV-LEDs are nowadays a mature product that can be found in a variety of industrial applications. Low spectral drift combined with the possibility to tune the emission wavelength via crystal growth makes UV-LEDs ideal light sources for measurement instruments.
Here, we present the realization of the i::scan (schematically shown in Fig. 1), a real-time, online sensor capturing water quality parameters, and its operation in real-world application. The measurement principle is based on the absorption of light by molecules. Through the combination of multiple emission wavelengths in the UV and visible spectral region we can distinguish between different substances that are present in water (suspended or dissolved) and measure multiple parameters simultaneously. The careful selection of the emission wavelengths minimizes the cross-sensitivity between the individual substances.
Exemplarily we present here three real-world applications for the i::scan: drinking water monitoring, river monitoring and industrial waste water analysis. We developed robust algorithms that allow us to determine the concentration of total organic carbon in the entire UVC spectral region, color, turbidity and UV254 absorption in all those application using the same measurement device. Furthermore, our algorithms can remove the effect of suspended (non-dissolved) solids yielding identical results to lab analysis after an additional sample filtration is performed. Since the i::scan does not rely on any consumable such as chemical reagents it can be operated virtually maintenance-free for multiple years.
In summary, we demonstrated an online, multi-parameter water sensor that is perfectly suited for real-time and continuous monitoring of water quality parameters. Through our algorithms we can utilize the same device in a variety of application ranging from drinking water to industrial waste water.

Fig. 1: Illustration of the i::scan. Transmitted and scattered light are measured simultaneously using two independent detectors.

Autofluorescence based rapid detection of microbial contaminations for hygiene monitoring

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Microbial contaminations in food industry and health care are implicating an acute health risk for consumer and patients. To maintain product safety and to prevent infections hygiene control is of great importance. Actual standard methods for detecting microbial contaminations are mainly based on sampling, culturing and colony counting which usually comes with a costly waiting time of several days. We have developed a rapid and reagent free method for the detection of microbial contaminations which uses the intrinsic fluorescence of microbes as a measure. For fluorescence excitation of the microbial fluorophores, namely Tryptophan, NAD(P)H and flavines, UV and also VIS LEDs are used, allowing for a compact design of the device. With optical filters and a custom made spectrometer module a sensitive detection of the emitted fluorescence is achieved. The overall performance of a first demonstrator device has been tested using standard solutions of biological fluorophores. As model contamination *E.coli* was chosen and examined in suspension and spotted on surfaces. At the moment the limit of detection is about 1-2 orders of magnitude higher compared to the ATP bioluminescence method, a swab based enzymatic hygiene test established on the market. The method holds the potential to serve as a reagent free and even online method for monitoring the hygienic status of surfaces in food processing and health care facilities.

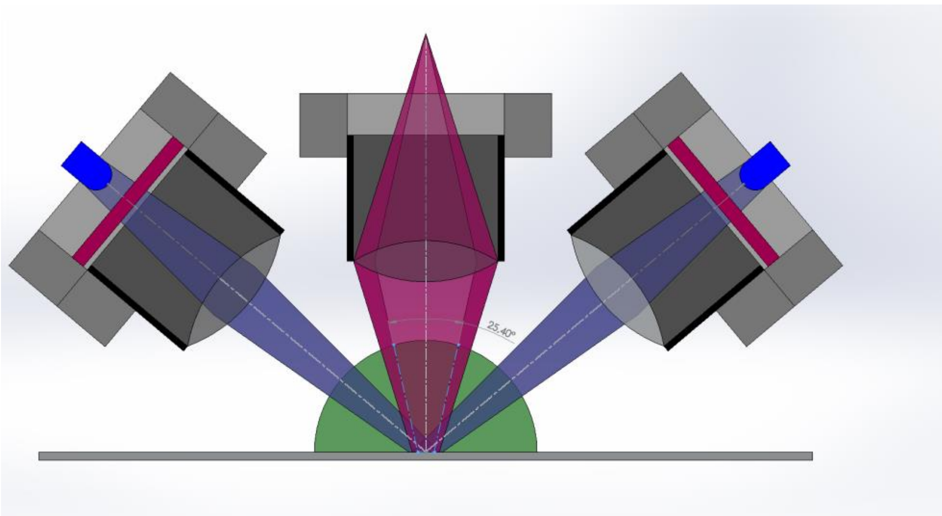

Fig. 1: Design of optical path of the experimental model of an autofluorescence based rapid detection of microbial contaminations

Characteristics of LED-UV lamps for curing applications and technical solutions

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During the last years some completely new branches of UV curing technology have found their way in the adhesive, printing and coating industry. As an alternative to conventional UV curing through medium pressure lamps we can now make use of UV-LEDs. Dr.Hönle AG started developing and manufacturing of UV-LED systems 10 years ago. Since then this rather young technology has widely established in the adhesives industry and also it has become a serious alternative to conventional UV printing applications. But UV-LEDs are based on a completely new technology, which poses challenges to the curing mechanism especially for the printing industry. This paper explains the properties of UV-LEDs for curing applications and explains technical solutions to meet and master these challenges.

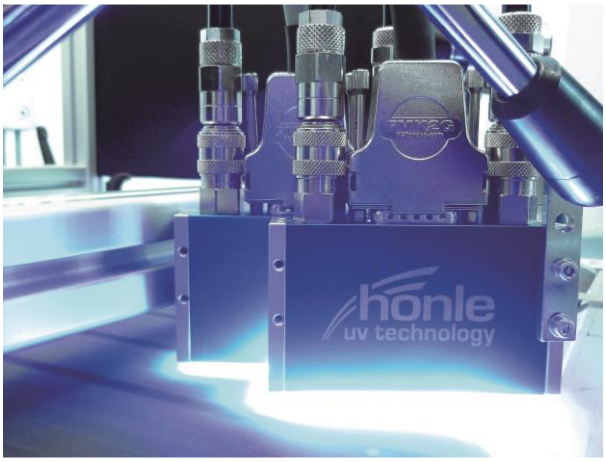

Fig. 1: LED Powerline for inkjet curing

Curing advantages with deep-UV LED below 300nm

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UV LED solutions gain more and more importance for the world environment as they demonstrated the ability to successfully replace older mercury lamp solutions in a number of curing applications [1]. UV LEDs provide reduced operational costs through longer lifespans, reduced electrical consumption, higher reliability and reduced heating of substrates. At the same time, formulation modification has enabled the use of an increasing number of UV LED curable adhesives, inks, and coatings for commercial applications.

The wide commercial adoption of today commercially available UV LED solutions is prevented because of their limitations due to the missing wavelengths range below 300nm. In a number of applications such as UV curable coatings where surface cure remains the biggest challenge to overcome with LED curing [2]. When using LED based light sources, additional exposure to deep-UV irradiation or curing under inert-gas blanketing is most often required to achieve a tack-free surface. Post exposure to deep-UV LEDs is an attractive solution that is investigated in greater depth to explore irradiance, dose and wavelength requirements for industrial curing solutions. In addition, the feasibility of adding deep-UV LEDs into a commercial LED curing system is discussed and a practical approach of such UVC LED lamp is shown. During the first experimental trials with various partners, we have achieved or overachieved the expectation with the following formulations: clear coatings on metal packages (tubes, cans, etc); pigmented inks and white colors for printing (Flexo, Offset); overprint varnishes for Flexo- and Offset print; glossy surface at Inkjet print; wood coatings and various mixture of Resins and PI for different applications.

Reference:

[1] P. Lee, UV+EV Technology, Issue 1 (2015) 50.
[2] T. Bizjak, Radtech Europe Conference Proceedings (2015)

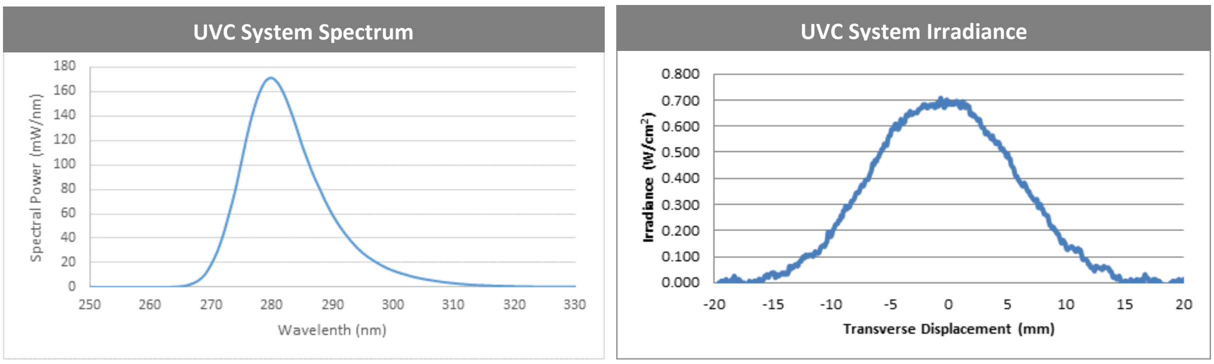

Fig. 1: UVC system with its spectrum (left side) and its irradiance (right side)

Innovations in photo-curable materials for fast curing and high quality pattering

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Until recently, high pressure mercury lamps were widely-used as UV light sources for patterning conventional photoresists and photopolymers. Due to the improvements in the development and cost-effective manufacture of LEDs their application in UV photolithography and related applications becomes a very attractive and environmentally friendly alternative to the energy-consuming mercury lamps.

In this context, the development and adaption of photoresist and photopolymer materials and their curing and patterning behavior as well the design and engineering of an UV-LED exposure tool will be presented.

The designed UV-LED equipment consists of three separate UV-LED modules, emitting monochromatic light at wavelengths of 365 nm, 390 nm and 410 nm, and is implementable for substrates of up to 4 inch diameter with a very homogeneous light intensity distribution.

The general UV-LED curing behavior of generic photoresist materials compared to mask aligner exposure and – for some materials – laser direct writing, and the manufacture of excellent 2D patterns will be demonstrated. Furthermore, developments of new UV-LED curable materials for inkjet printing as emerging direct patterning method will be shown, as well as the development of innovative UV-LED curable waveguide materials exhibiting a tunable refractive index and an excellent thermal stability.

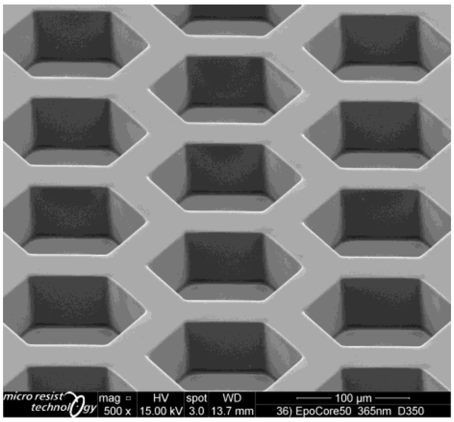

Fig. 1: EpoCore layer, 50 µm thick, exposed with UV-LED @ 365 nm

Status and trends of the UV LED curing industry

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UVA LEDs continue to progress in the UV curing space. Continuous improvement of device performance coupled with price reduction has allowed the technology to be increasingly adopted in UV curing applications. Penetration of UV LEDs is increasing but we observe differences in adoption rates depending on application. Small size and low speed applications like spot adhesive and digital inkjets have the highest adoption rate, and most new developments use UV LEDs. This is due to the small module size and low irradiance level needed that limits the extra cost of integrating UV LEDs compared to the total price of systems like inkjet printers. On the other hand, applications that need high speed processes and/or high levels of irradiance such as screen printing or coating applications have lower adoption rates. This is because UV LED performance is not yet good enough to fully replace traditional mercury lamps. To improve performance of UV LED curing systems, new UV LED devices with higher irradiance and longer lifetimes must be developed.
However, a few players involved in the UV curing industry are developing their activity towards UVC and water disinfection and/or life science applications. For these players, the UVC industry could represent a new relay of growth. Indeed, the UVC LED industry is still small but strong growth is expected in the next 12 months due to dramatic price reductions. With most of the industry believing that $1-$4/mW is the price that would trigger mass market adoption we are getting close to a UVC LED market boom. As a result, the industry related to water disinfection is still small but an increasing number of player are entering the market.

In this presentation, we are going to highlight the status of the UV LED industry and discussing recent technology and market trends in both UVA and UVC fields.

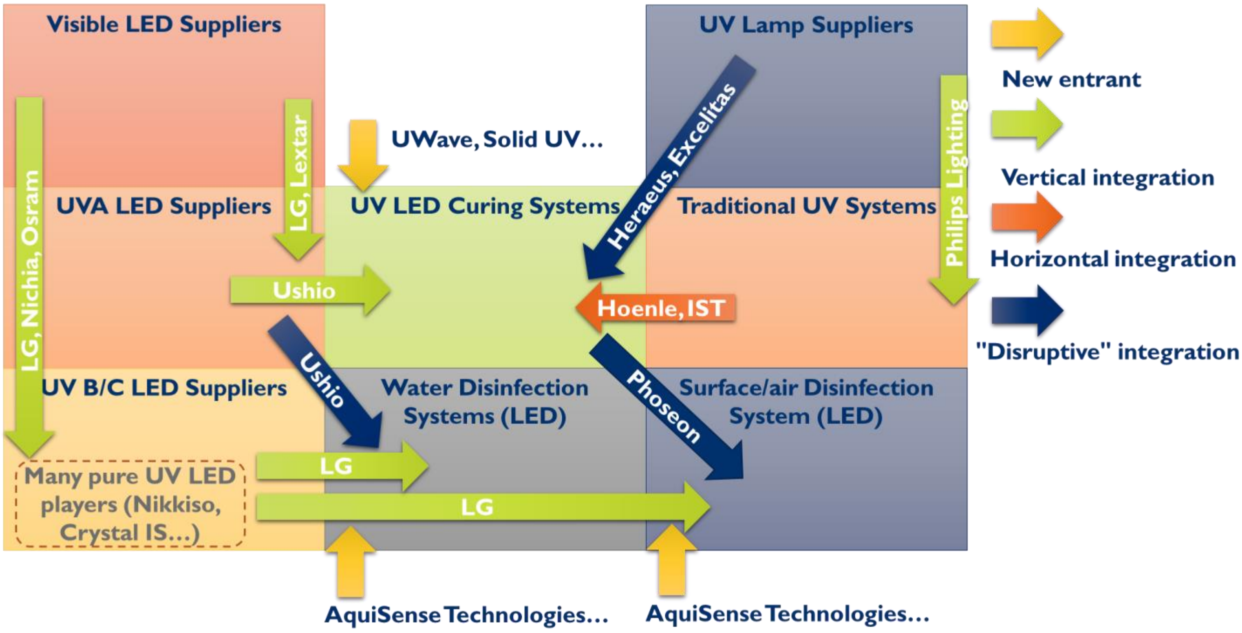

Fig. 1: Evolution of the UV LED Industry

On the Temperature and Time Dependent Photoluminescence of $Lu_3Al_5O_{12}:Gd^{3+}$

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Light emitting diodes (LEDs) have been developed to an impressive maturity level over the last decades and are thus nowadays a major product of our daily life. Nevertheless, UV-B emitting LEDs with a sufficiently high operational lifetime and wall plug efficiency lack broad commercial availability yet. Consequently, mercury-vapor discharge lamps are still in use for applications which require UV-B radiation such as medical skin treatment, UV polymer curing, or cosmetic purposes.

An alternative lamp technology is based on the Xe excimer discharge, which shows mainly VUV emission peaking at 172 nm. By the application of a luminescent screen, the emission spectrum can be completely shifted towards the UV-B range. To this end, we applied a $Lu_3Al_5O_{12}$ (LuAG) type solid state material, which is a very radiation-hard host. Herein, lutetium can be easily replaced by the well-known UV-B emitting activator Gd^{3+}. Therefore, this work deals with the efficient and long-term stable UV-B phosphor LuAG:Gd^{3+} upon VUV excitation. Photoluminescence and reflection spectra will be shown and discussed. Moreover, we provide new data concerning the temperature dependent emission of LuAG:Gd^{3+} as well as the temperature dependence of the decay curves. Both were measured in the range from 77 to 800 K in 25 K steps. Due to the linear decrease of the decay times with increasing temperature we suggest that LuAG:Gd^{3+} could also be used for temperature sensing applications under VUV excitation.

In brief summary, the present work demonstrates that LuAG:Gd^{3+} is an efficient UV-B emitting conversion material exhibiting very little thermal quenching. Therefore, it is suitable for the use in Xe excimer lamps, also at elevated temperature. Fluorescent Xe excimer lamps comprising LuAG:Gd^{3+} can be regarded as an alternative to mercury low-pressure lamps or UV-B emitting LEDs.

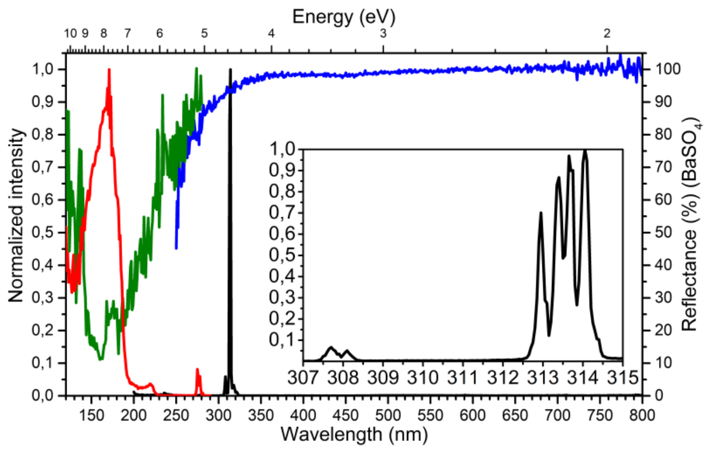

Fig. 1: The normalized excitation- (λ_{em} = 314 nm, red line), normalized emission- (λ_{ex} = 160 nm, black line), VUV-reflection- (green line) and reflection-spectra (blue line) of $(Lu_{2,85}Gd_{0,15})Al_5O_{12}$ are shown. The inset shows the sample emission from 307 to 315 nm in higher resolution (0.05 nm steps and emission slit).

UV curable nap cores as core material for lightweight applications

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Textile reinforced nap cores represent an interesting alternative to established core materials for sandwich structures in lightweight applications. For that reason, the materials were subject of several research projects [1, 2]. The material consists of a two-dimensional impregnated knitted fabric shaped into a three-dimensional structure in a first step followed by stabilization via curing of the matrix resin. In addition to a variety of thermoplastic fibers, textiles made from aramide-, glass- or hybrid fibers can be processed.

Established manufacturing processes are based on thermal curing at temperatures between 130 °C and 180 °C and require a considerable amount of energy [3, 4]. Depending on the resin formulation, the curing time varies between 5 and 60 min, which limits the production speed.

Significantly faster and more energy efficient curing can be realized by UV irradiation. The development of UV LEDs with increasing power and efficiency over the last years provides new opportunities in this field of application. The ongoing project *UV-Endlos* (Grant No. 03ZZ0133C) focuses on the development and adaption of the existing thermal curing production process towards UV LED curing.

The impregnated fabric is formed between metal cylinders and a metallic mesh, cured subsequently by UV irradiation. The described setup can be adapted to a continuous process. The impregnated textile is brought into shape between the tool belt and the rotating mesh drum (Figure 1). A combination of two UV LED-systems with 410 nm and 385 nm wavelengths was used to cure the matrix resin. Currently, systematic research using various resins at different production speeds is being done. Nap cores made from glass fabric in combination with an unsaturated polyester resin are manufactured in a continuous process in lab plant scale and mechanical tests are carried out.

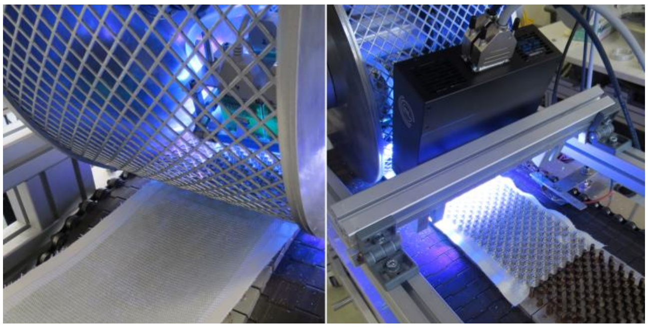

Figure 1: Test plant for nap-core manufacturing

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Design and fabrication of a microcontroller based wireless LED-research module for application in *in vitro* culture labs

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With the development and progress in LED technology, it is meanwhile possible to apply narrow-band light to plants. Nowadays LEDs are available in almost every desired wavelength. In most *in vitro* culture laboratories, fluorescent tubes are still predominantly used, although they emit only a constant light spectrum and account for approximately 65% of the total electricity used in tissue culture labs [1]. The combination of different LEDs enables the user to apply different light qualities in order to specifically control growth and developmental processes of *in vitro* cultured cells and plants or to increase the production of secondary metabolites in tissue cultures.

In this project we designed a novel microcontroller based lighting system to investigate photomorphogenetic effects in different propagation phases of plant *in vitro* cultures. We developed a web interface to adjust and visualize program settings of the LED research module. Communicating through a webpage the LED research module allows a wireless control of light intensity, light quality, photoperiod and frequency of the pulse-width-modulated LEDs. The six emitted wavelengths (UVB 300 nm, blue 440 nm, green 520 nm, red 660 nm, far red 730 nm, white 6500 K) were selected based on the absorption maxima of the major plant photoreceptors. Furthermore with a pre-simulated arrangement of the LEDs, which are mounted on a printed circuit board and exhibit different beam angles, it was possible to achieve a homogeneous light distribution pattern within the experimental area of one shelve (~4% coefficient of variation). Additionally, the bottom-cooling system commonly used in tissue culture labs is applied as an active water-cooling system of the LEDs in order to minimize temperature variations due to different emitted energies for the different light variants and also to prevent an accumulation of condensation water in the *in vitro* culture vessels. For the regulation of the active water-cooling system each LED-research-module is equipped with ball valves to control the water flow and four temperature sensors to monitor the capacity of the cooling system.

In further research studies the module will be used to investigate the effects of intensity, photoperiod, wavelength, frequency as well as pulsed compared to continuous light on plant *in vitro* cultures. To our knowledge, this is the first report of a lighting system especially designed for plant tissue culture labs, which is capable to emit wavelengths in the visible region as well as in the UVB region of the electromagnetic spectrum.

Reference:

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AlN Growth and Characterization on Silicon Substrate for UV Applications

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The growth of thick, high surface and crystalline quality of AlN films on Si substrate is highly desired for a number of applications like the development of micro and nano electromechanical system (MEMS and NEMS) technologies and particularly for fabricating AlGaN based UV-LEDs. UV-LEDs are very attractive since they are applied in many areas, such as air and water sterilization, efficient white lighting, high-density optical data storage, and military applications such as biological agent detection and non-line-of-sight communication. However, the development of UV-LEDs on Si substrates is highly desired for a series of reasons like the availability of cheap, large-diameter silicon wafers, the much lower device processing costs, and the possibility of monolithical integration of the UV-LEDs with Si circuitry. In addition, efficient AlGaN based deep UV-LEDs require layers and substrates which are transparent in UV light. So, it is preferable to grow the AlGaN based deep UV-LEDs active layers on Si substrates as the Si can be removed by chemical treatment to allow back illumination and avoid the generation and reabsorption of UV light by backside emission. These advantages make silicon an attractive substrate for AlN-AlGaN based UV devices. In this study, we will present the growth and characterization results of MOVPE grown AlN layers on Si substrate and UV-LED applications.

UV Spectral Sensitivities of Escherichia Coli and MS2 Phage Measured with UVC LED Water Disinfection Module

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As deep UV (UVC) LEDs achieve the economic and performance levels for practical application in Point of Use (POU) water disinfection, many of their unique properties are being assessed for the potential to offer new degrees of design freedom and performance optimization.

While previous POU system were limited to the use of low pressure mercury lamps, with a fixed peak output at 253.7 nm, UVC LEDs can be produced within a range of UVC wavelengths. Guided by published data on UV spectral sensitivity of common pathogenic organisms or surrogates, (E. Coli and MS2, respectively) effective inactivation of microorganisms occurs across a range of 250-280 nm yet exhibits peak absorption within 260-270 nm. The experiment utilizes a standardized flow cell design and tests for inactivation of E. Coli and MS2 within cultured water with UV LEDs at different peak wavelengths of 264, 271, 278, and 284 nm. Experimental results are analyzed for log reduction performance per LED power at selected wavelengths and compared to published UV spectral sensitivity data.

Fig. 1 shows the actual spectral sensitivities of E. Coli and MS2 phase with curves from previous works. It is revealed that shorter wavelengths are suitable for disinfection, with the most effective wavelength range being 260 – 265 nm. In the poster session, the cause of the gaps between actual results and published spectral data is discussed.

Experimental microbial test results demonstrate the modeled reactor performance confirming the feasibility and enhanced benefits inherent and accessible with the use of UVC LEDs for water disinfection.

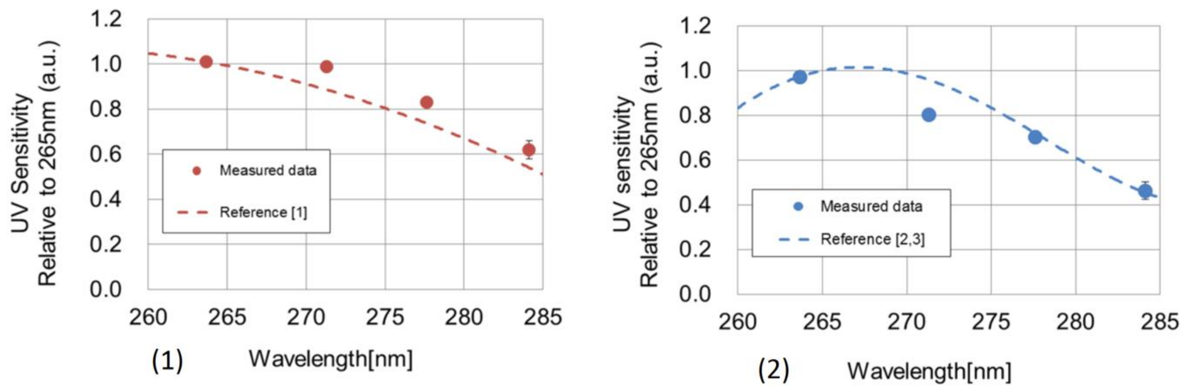

Fig. 1: Spectral sensitivities of (1) Escherichia coli and (2) MS2 phage.

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Innovative UV LED Curable Resins for Optical Coatings for Medical Applications and Materials Processing

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UV curable resins for optical coatings are of special interest, since the fast curing of resins by UV LEDs allow fast processing of the materials and short production times.[1,2] Beside the processing properties of the resins also thermal and mechanical properties have to fulfill increasing requirements, such as thermal stability, low optical propagation loss and high mechanical stability. Fluorinated polymers, especially acrylates and methacrylates, with low refractive index (n < 1.39 at 1550 nm) were investigated and the development of a modular system of resins was necessary in order to achieve these properties.[3] The studied thermosetting polymers provide an excellent curing behavior especially for UV LED cure. It was found that the resins cure very fast and completely by irradiation with 390 nm UV LEDs, figure 1. The glass transition temperature as well as the curve of the loss factor and the modulus were determined by dynamic mechanical analysis. A broad peak between 0 °C and 150 °C was observed at the curve of the loss factor. This indicates a large glass transition state of the thermosetting polymer. Additionally the modulus decreased slowly but steadily over this large range.

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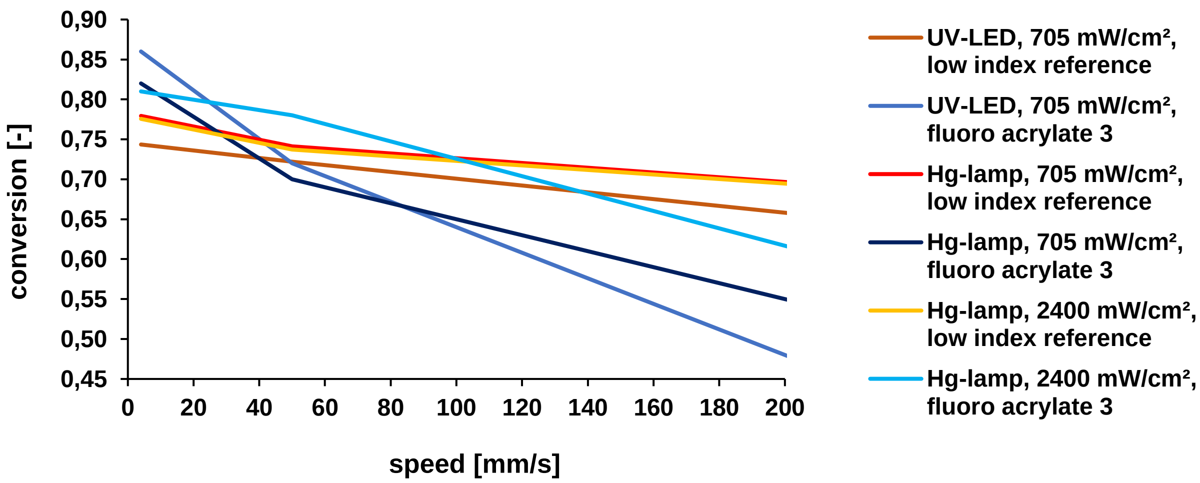

Figure 1. Conversion of low index reference material and developed fluoro acrylate 3 in dependence of irradiation speed and light source (UV-LED 390 nm/ Hg-lamp).

Combining Fluid Simulation and Flow Visualization to predict Disinfection Reactor Performance

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The application of UVC LEDs to the disinfection of water offers whole new degrees of freedom in terms of physical reactor design and performance. While straight forward, design engineers need to ensure they address the differences inherent with LED based designs while still achieving functional disinfection requirements.

In this poster session Asahi Kasei and Crystal IS engineers show how disinfection performance is simulated, for multiple conditions, using common optical and fluid models then correlated to experimental microbiological performance of a physical module confirming agreement between simulation methods and performance of the physical module.

The experiment uses UV intensity distribution simulation and Open FOAM (Field Operation And Manipulation) to simulate three conditions of a compact sterilization module utilizing Aluminum Nitride UVC LEDs. The simulated model is sized as a 20mm diameter and 40mm length cylinder, intentioned for point of use water applications at flow rates up to 0.5 liters per minute. Analytical models are compared to experimental observed internal flow of physical modules using PIV (Particle Image Velocimetry). As a result, a conditional model is shown to be most accurate in flow simulation.

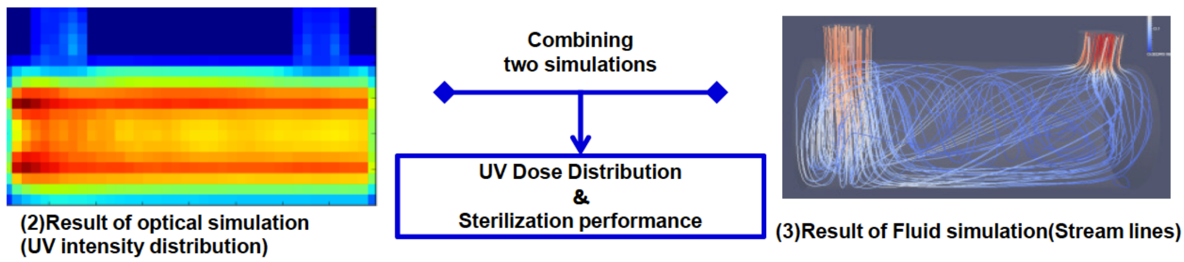

Fig. 1: Combining optical and flow simulations to predict disinfection performance in UVC LED-based water disinfection modules.

Thermal management performance of deep UV LED sources applying thermoelectric cooler devices

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Deep UV Light Emitting Diodes (UV-C LEDs) are the current competitive new solid state lighting ultraviolet sources emitting radiation in the [200-300] nm range. The complexity of a reliable UV-C LEDs performance depends upon optical efficiency, adequate lifetime and wavelength accuracy that all concern technological applications such as disinfection processes, biomedical instrumentation and biophotochemical research. Thermal management is fundamental for optimal deep UV LEDs applications. Junction Temperature (T_J) control is mandatory to improve the optical efficiency, lifetime and the wavelength accuracy of the UV-C LED light sources. High current (100 mA - 350 mA) increase junction temperatures which needs to be controlled. Thermoelectric cooler (TEC) devices allow a critical control of the Junction Temperature, based on direct measurement of the solder point temperature. Thermoelectric modules can convert voltages (VTEC) into a temperature gradient based on a phenomenon discovered by Peltier. The solder temperature T_S dynamics which can be modeled with Newton's law of cooling depends upon the heat extraction properties of the system, i.e. the total thermal resistivity including the TEC. The cooling curves are empirical and befitting each system. As temperature increases optical efficiency of the LEDs decreases and vice versa. Using the Newton´s cooling Law and the experimental data, a PID control strategy was developed and implemented to restrict the voltage in the TEC devices and therefore the desired range of Junction Temperatures. The PID parameters are obtained with computational simulations based on physical models and experimental recordings of the solder temperature dynamics. The basic model is based on heat transfer mechanisms from junction point to solder point through the LED package. Finally we conclude that decreasing the temperature of the UV-C light source using a PID controlled TEC, the optical performance can be considerably improved.

Improvement of light extraction efficiency in deep-UV µ-LEDs

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Compared with standard visible devices, deep-UV LEDs suffer from much reduced light extraction, which severely limits their overall efficiency. This problem, due to poor UV-transparency, becomes even more important in devices that use aluminium-rich AlGaN alloys as active materials, whereby a significant amount of the light is emitted in-plane because of its TM polarisation and hence cannot escape from the semiconductor [1]. A possible way to mitigate this problem, based on our µ-LED approach, was investigated and preliminary results are here reported.

In the last few years our group has developed a special implementation of the µ-LED concept, in which the final device consists of a cluster of closely-packed µ-LEDs whose sidewalls are quasi-parabolically shaped. This configuration allows the light emitted at larger angles to be reflected back, at almost perpendicular angles, towards the sapphire substrate. This approach, which has already been demonstrated both for visible [2] and UV [3] devices, proved to be particularly beneficial in applications in which coupling with optical fibres and fast optical commutations are critical, such as e.g. in the charge management system of the LISA space mission [4]. However, its features might prove particularly beneficial also to address the light extraction efficiency droop due to increased TM polarization.

In order to prove that, two sets of devices, i.e. with and without the quasi-parabolic shaping, were fabricated from our previously grown multiple-quantum-well material emitting at 250 nm, and subsequently tested and compared. The devices were initially probed on-chip with the UV light collected by a large-core optical fibre placed in close contact with the sapphire substrate underneath the µ-LED cluster. Although some scatter was present in the data collected from different devices, the integrated power in the 240–270 nm emission range was, on average, four times larger than for the case of non-shaped devices, and this improvement remained fairly constant across the whole range of current density explored. To further understand the emission characteristics of our devices, the spectral far field patterns of a few packaged devices were also examined. The laterally elongated patterns collected from the non-shaped devices were compared with the ones simulated for different dipole orientations, and proved to be consistent with the presence of a high degree of TM polarization in the radiation emitted by our active regions. In addition to that, the shaped µ-LED clusters showed a significant increase in the deep-UV intensity in the front direction, with a maximum at around 35° from the normal, and no reduction at larger angles. This latter fact proves that the four-fold power increase in the first experiment was not due to a better coupling with the optical fibre (although this would also be possible by further optimizing the shaping), but is the result of the extraction of part of the in-plane-emitted radiation that would have otherwise been lost.

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The impact of vapor supersaturation on the growth of 260-280 nm UV-LEDs

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Deep ultraviolet (DUV) light emitting diodes in the 260 – 280 nm emission wavelength range are grown by MOCVD for various applications like disinfection purposes, water sterilization and for environmental and medical applications. However, quantum efficiencies of such AlGaN-based LEDs are quite low when compared to well-established blue light emitting diodes. For DUV LED structures several epitaxial challenges have to be addressed, since they can drastically impact the quality of these LEDs. The incorporation of defects have to be minimized in AlGaN layers of the active region to reduce non-radiative losses in the multi quantum wells. In addition, the surface morphology of AlGaN, including a high compositional homogeneity, has to be controlled at the same time. Island growth, macro stepping, H_2-etching and spiral growth of AlGaN layers with high Ga-content on sapphire have to be suppressed as possible.

Growth conditions have been examined to reduce compensation in doped layers, reduce point defects in active layers and to control the surface morphology of AlGaN on sapphire. In particular, two extreme growth conditions have been examined to control the spiral growth of AlGaN: 1) A very high vapor supersaturation condition in the gas phase, where the size of spirals can be scaled down and a low point defect incorporation can be found, and 2) a very low supersaturation condition, where spiral growth is significantly increased in a way that the spirals are overgrowing one another, effectively reducing the peak to valley height of spirals and therefore improving the surface roughness considerably. In contrast, this condition was found to lead to a high point defect incorporation. Thus, by controlling growth parameters, like V/III-ratio, temperature and H_2/N_2 ratio in the gas phase, a trade-off supersaturation condition was optimized for the achievement of both low point defects and a relative smooth surface roughness of the AlGaN.

Research on UVC LED Light Source for Portable Flow Water Sterilizer

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With the increase of UV LED efficiency, the application of UV LED is more popular. The advantages of UV LED light source are small size, strong and no pollution. It can solve the problem of environmental pollution caused by mercury lamp used in the current light source. In the design of the system, LED can design a miniature system.

In recent years, Taiwan Industrial Technology Research Institute (ITRI) is committed to the development of deep UV LED application, has developed a number of applications, including UVC LED portable disinfection cups, portable chopsticks sterilizer, portable UV LED phototherapy instrument. It can be seen that the products designed by UVC LED are easier to meet the needs of people to carry.

At this seminar, we will show the concept of UVC LED for portable flow water sterilizer. The current concept of flow water sterilizer is mostly used for home use, mostly for sufficient power supply. Using UVC LED light source design portable flow water sterilizer, with small size, low energy consumption and can use the solar charging, more suitable for the use of power shortage areas, such as disaster areas and developing countries use.

First of all, we will show ITRI's development of UVC LED portable flow water sterilizer and analysis of optical, electrical and thermal characteristics. Second, the bactericidal test of the device was carried out to study the inactivation of E. coli. The bactericidal efficiency was up to 99.99% when the water flow rate was 2 liter/min. Finally, a comprehensive discussion will be conducted to explore possible future goals and directions.

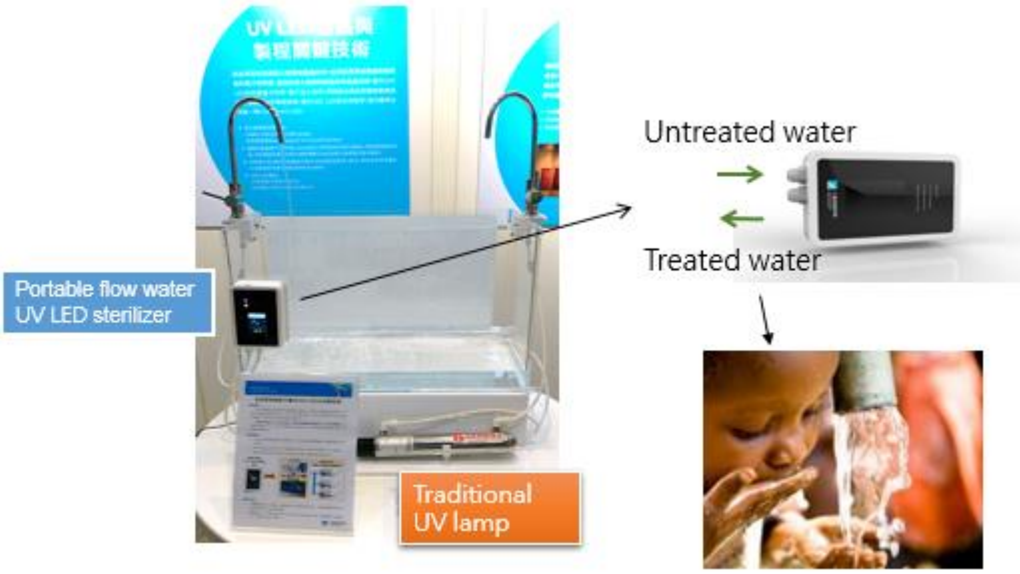

Fig. 1: UVC LED portable flow water sterilizer

UV LED-Based Advanced Oxidation Process for Treatment of Biomedical and Biomolecular Laboratories Wastewater

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Ethidium bromide (EtBr) is a hazardous mutagenic agent which is used in laboratories for visualization of nucleic acids of DNA, thus the purification of wastewaters containing this agent must be taken into serious consideration. For this aim photocatalytic degradation based on ultraviolet (UV LED) is used for EtBr photodestruction. A commercial micro sized as well as two different types of nanosized titanium dioxide (TiO2- Hombikat UV 100 and Degussa P25) and also commercial sized zinc oxide particlesare selected as photocatalyst. Photocatalyst dosages, pH, and initial hydrogen peroxide (H2O2) concentration as oxidant and electron acceptor in presence of constant rate of atmospheric oxygen are selected as variables. The photocatalysts are characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM), BET surface area and for pollutant detection UV-Vis spectroscopy is applied. The results of photodestruction rates of EtBr have shown that AOP based on UV can be a promising method for the treatment of wastewater containing EtBr generated in biomedical and biomolecular laboratories.

Strongly improved UV transparency of bulk AlN crystals grown by PVT

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Deep UV transparent bulk AlN crystals with high crystalline perfection are considered as the most promising substrate material for UVC LEDs based on $Al_xGa_{1-x}N$ layers with high Al content. In order to exploit the potential of AlN substrates the absorption coefficients at the emission wavelength of $\alpha < 15\ cm^{-1}$ are highly desirable since the light is extracted through the AlN substrate.

Bulk AlN crystals are grown by PVT at temperatures > 2000 °C. Impurities such as oxygen and carbon as well as compensating intrinsic defects lead to optical transitions within the wide band-gap. The carbon related absorption around 265 nm can be quenched for [O] >> [C], due to the shift of the Fermi level. Furthermore, significant absorption tailing off from the band edge into the UV range of interest is presumably caused by oxygen. We will show that the following conditions must fulfilled in order to achieve $\alpha(265nm) < 15\ cm^{-1}$:

$$[O] < 3\ [C]$$

$$[C] + [O] < 10^{19}\ cm^{-3}$$

These conditions can be reached using getter materials for carbon and oxygen. TaC has proven to be highly efficient by converting $Al_2O(g)$ to CO(g) by the following reaction:

$$2TaC + Al_2O(g) + N_2(g) \dashrightarrow Ta_2C + CO(g)\uparrow + 2AlN$$

Remaining volatile carbon species can be efficiently gettered by adding tungsten which reacts partially to W_2C during the growth:

$$2W + C \dashrightarrow W_2C$$

Best values of $\alpha(265nm) = 14\ cm^{-1}$ are achieved at $[O] = 6.4x10^{18}\ cm^{-3}$ and $[C] = 1.8x10^{18}\ cm^{-3}$. Entire AlN wafers (Ø ≥ 10 mm) with $\alpha(265nm) = 25\text{-}28\ cm^{-1}$ can be grown in a reproducible manner.

The combination of the high deep UV transparency with the high structural quality of the grown AlN crystals grown by our PVT growth technology (rocking curve FWHM = 11-18 arcsec) will provide all requirements necessary for the preparation of highly efficient $Al_xGa_{1-x}N$ UVC LEDs on AlN substrate wafers.

3D Printed White Light-Emitting Diodes

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With the development of lighting technology, white LEDs as an energy-saving light source, has a huge market and bright prospects. The improvement of white LEDs has become a hot research direction among the scientists. Meanwhile, as a new type rapid manufacturing technology, 3D printing possesses the merits of digitization and personalization. DLP (Digital Light Processing) UV curing 3D printing technology, one of the 3D printing technology, with its high precision and high-speed molding is increasingly the focus of international attention. This paper applied 3D printing to the phosphor coating of white LEDs, trying to develop a new manufacturing technique. In this letter, firstly, we described the basic theories of 3D printing and white LEDs, and the use of 3D printing in the field of electronic devices fabrication were investigated. We demonstrated the light-emitting mechanism of white LEDs and the existing coating process. The transmission model of light in the white LEDs is also established based on Mie scattering theory, which describes the absorption, excitation and scattering process of light in the phosphor layer. The possible problems in the printing of the phosphor layer were analyzed. Moreover, a model was designed to measure the dimensional resolution and distance resolution of the printing model under different parameters. To optimize the printing system, we added a one-way transmission film, reducing the effect of edge-curing. Experiments showed that with the increase in the exposure time or decrease in print layer thickness, the dimensional resolution would rise while the distance resolution would reduce, causing the augment of edge-curing effect. At last, we applied 3D printing technology to print the phosphor layer on a blue LED chip, as shown in figure 1. The optical properties of two samples with different layer thickness were measured. As a result, with the increase in layer thickness, the luminous efficiency of LED increased while the optical power decreased, and the yellow light components in the spectrum increased, making the emergent light closer to white light.

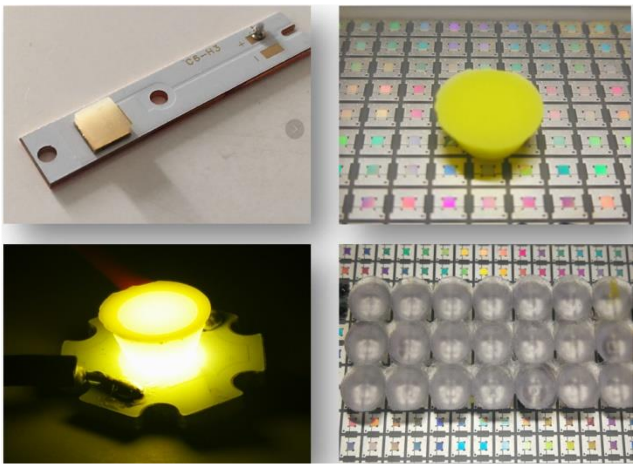

Fig. 1: 3D printed CSP white LED packaging device

Electromodulated reflectance of AlGaN layers and quantum wells in the UV spectral range

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Electromodulated reflectance [i.e., photoreflectance (PR) and contactless electroreflectance (CER)] is known as a nondestructive and very sensitive absorption-like technique to investigate the optical transitions between the ground and excited states in various semiconductor structures including bulk-like layers, quantum wells (QW) and quantum dots. Due to the Franz-Keldysh effect this method can be also applied to investigate the built-in electric field in semiconductor structures as well as the Fermi level position on the surface of semiconductor structures. However the application of PR and CER in the UV spectral range is still a challenge. In this presentation we will present our recent progress in the application of PR and CER techniques to study AlGaN layers and QWs dedicated for UV emitters. Two kind of samples will be shown and discussed. The first samples are AlGaN layers where we focus on studies of built-in electric field and the Fermi level position at the surface. The second samples are AlGaN QWs where we focus on studies of the optical transitions between the ground and excited states as well as optical transitions in QW barriers and the built-in electric field in these barriers. In case of both AlGaN layers and QWs CER spectra are compared with PL spectra in order to determine the Stokes shift. Obtained results will be discussed in the context of polarization effects in III-nitrides and their screening by the intentional and unintentional doping. In addition the carrier localization phenomenon induced by alloy content fluctuations and QW width fluctuations will be discussed for proper interpretation of CER and PL data.

Photocatalytic degradation of Imidacloprid in solar-powered UV-LED photoreactor system by TiO_2-Fe_3O_4 nanocomposite

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Photocatalytic decomposition of organic contaminants has been regarded as one of the most gorgeous concerns among environmentalist chemists. Organic pollutants containing insecticides have been considered as one of the emerging impurities of environmental resources particularly soil and water. Advanced oxidation processes (AOPs), as one of the most imperative techniques for destruction of pollutants from environments have been conducted. In spite of its ability, few surveys involving the utilization of photochemical methods to decomposition of refractory organic pollutants have been reported. The use of Ultraviolet (UV) light has become progressively more fashionable because comprise no-known disinfection by-products formation. Most of mentioned surveys relied on usual photochemical methods such as conventional UV (low- and medium pressure) lamps. Herein, set of experiments considering impact of different structure of UV photoreactors has been conducted due to study the photocatalytic decomposition of Imidacloprid as target organic pollutant, under illumination of UV light and TiO_2 photocatalysis. The synergistic impacts of Fe_3O_4 as co-catalyst in destruction process have been also probed. Photovoltaic-powered UV-light emitting diodes (UVLEDs) have been utilized as UV light sources in present work. UV-LEDs offer potential advantages over traditional UV lamps such as a better efficiency in converting electricity into light, lower power requirements, compactness and robustness, no warm-up time, no disposal problems, environmentally friend approach and longer operational life and also, design flexibility due to their small size. Results showed the proper capability of photocatalytic decomposition of Imidacloprid.

Reference

[1] Eskandarian, M.R., Choi, H., Fazli, M., Rasoulifard, M.H., 2016. Effect of UV-LED wavelengths on direct photolytic and TiO_2 photocatalytic degradation of emerging contaminants in water. Chem. Eng. J. 300, 414-422.
[2] Eskandarian, M.R., Fazli, M., Rasoulifard, M.H., Choi, H., 2016. Decomposition of organic chemicals by zeolite-TiO_2 nanocomposite supported onto low density polyethylene film under UV-LED powered by solar radiation. Appl. Catal. B Environ. 183, 407-416.
[3] Lui, G.Y., Roser, D., Corkish, R., Ashbolt, N., Jagals, P., Stuetz, R., 2014., Photovoltaic powered ultraviolet and visible light-emitting diodes for sustainable point-of-use disinfection of drinking waters, Sci. Total Environ. 493, 185–196.

New generation of sustainable water disinfection systems; Photovoltaic-powered UV-LED photoreactors

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Unquestionably, in today's energy-hungry world, the appliances which are too wasteful definitely will diminish from the stage of affordable energy technologies. One of the most accessible arenas can be addressed light sources. In this address, some 98% of the energy input ends up as heat instead of light. Halogen lamps, which look more high-tech, are not any better. There is a same story about the other kinds of traditional light irradiators. The issue would be the more challengeable obstacle whether the light defines for special approaches like water treatment issues. Compared to alternatives, ultraviolet (UV) light disinfection is very attractive because of its efficacy against all pathogen groups and minimal operational consumables. Though mercury arc lamp technology is very efficient, it requires frequent lamp replacement, involves a toxic heavy metal, and their quartz envelopes and sleeves are expensive, fragile and require regular cleaning. Perhaps the most widely anticipated of the technologies vying for center stage is the light emitting diode (LED), an emerging alternative which is semiconductor-based technology. LEDs are long-lived, robust and roughly twice as efficient as fluorescents. In fact, they are already widely used in electrical appliances. UV light emitting diodes (UVLEDs) recently have been conducted for water decontamination purposes. The new types of UV light sources provide improvements over traditional UV lamps such as better efficiency in converting electricity into light (high quantum yields), lower power requirements, compactness and robustness, no warm-up time, no disposal problems, environmentally-friend and longer operational life and also, design flexibility due to their small size. Furthermore, coupling the newly investigated UVLEDs with other cutting edge technologies like photovoltaic and solar energy clearly shows the effectiveness of UVLEDs especially when they utilize for point-of-use, in-situ, and remote zones disinfection and water treatment.

Reference

[1] Lui, G.Y., Roser, D., Corkish, R., Ashbolt, N., Jagals, P., Stuetz, R., 2014., Photovoltaic powered ultraviolet and visible light-emitting diodes for sustainable point-of-use disinfection of drinking waters, Sci. Total Environ. 493, 185–196.
[2] Eskandarian, M.R., Fazli, M., Rasoulifard, M.H., Choi, H., 2016. Decomposition of organic chemicals by zeolite-TiO_2 nanocomposite supported onto low density polyethylene film under UV-LED powered by solar radiation. Appl. Catal. B Environ. 183, 407-416.
[3] Eskandarian, M.R., Choi, H., Fazli, M., Rasoulifard, M.H., 2016. Effect of UV-LED wavelengths on direct photolytic and TiO_2 photocatalytic degradation of emerging contaminants in water. Chem. Eng. J. 300, 414-422.

Defect Reduction of Epitaxially Grown GaN Layer on Patterned Sapphire Substrate

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The great potential of wide-band-gap group III nitrides has been limited in many applications by the very high density 10^9–10^{11} cm^{-2} of threading dislocations TDs that form when the nitride materials are grown on lattice mismatched substrates. The GaN material which is important one of III nitrides has applications in visible and UV light emitting devices and in high power, high temperature electronics. Also, GaN-based ultraviolet-C (UV–C) light emitting diodes (LEDs) are of great interest for water disinfection. They offer significant advantages compared to conventional mercury lamps due to their compact form factor, low power requirements, high efficiency, non-toxicity, and overall robustness. However, GaN grown on foreign substrate still has high dislocation density. In case of using sapphire substrate, the large lattice mismatch between the GaN epitaxial layer and the applied substrate causes high defect density, which can affect device performance. We used patterned sapphire substrate to decrease defect density instead of conventional sapphire substrate to grow GaN by using MOCVD. In addition, we investigated the effect of changing V/III ratio during 3D-2D growth region (transition from 3 dimension to 2 dimension) of GaN on reduction of defect density.

We have obtained the following highly exciting results.
-Dislocation density in GaN grown on PSS is obtained lower dislocation densities compared with that of the GaN grown on conventional sapphire substrates.

AlGaN-based UV LEDs with emission below 230 nm

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In the deep ultraviolet (UV) spectral region below 230nm, applications such as gas and biochemical sensing (NO: λ = 226nm, NH_3: λ = 217nm, $(NO_2)^-$: λ = 209nm) would benefit from the development of light emitting diodes (LEDs) with sufficiently high spectral power. However, the fabrication of such short wavelength LEDs is very demanding as carrier injection and confinement, light extraction, and minimizing electrical losses in the heterostructure layers and at the contacts become challenging for the high aluminum mole fractions required in these LEDs.

In this contribution, we will present the development of AlGaN–based multiple quantum well (MQW) LEDs with emission below 230nm and discuss systematical variations of the heterostructure in order to improve the device efficiency. By varying the design of the MQW active region, we tuned the peak emission wavelength between 235nm and 225nm. However, a strong decrease in output power with decreasing emission wavelength is observed, which is most likely due to a reduction of carrier injection efficiency as well as a drop in light extraction efficiency. In order to maximize the spectral power needed for applications, the trade–off between the cut–off wavelength of the current spreading layer and its conductivity needs to be considered. Besides minimizing the sheet resistivity of the $Al_xGa_{1-x}N$:Si current spreading layers, realizing ohmic contacts to $Al_xGa_{1-x}N$:Si with high aluminum content is extremely challenging and typically results in high operating voltages. By optimizing the four–metal electrode V/Al/Ni/Au configuration, we were able to sensibly reduce the contact resistivity of the n–contacts on $Al_{0.9}Ga_{0.1}N$:Si. Finally, we fabricated UV LEDs emitting at 233nm, 229nm, and 225nm with on-wafer measured integrated output powers of 130µW, 25µW, and 3µW, respectively, at 60mA and 13V in cw operation. Additionally, a maximum output power of 1mW, 240µW, and 30µW at 400mA was reached in pulsed mode operation, respectively.

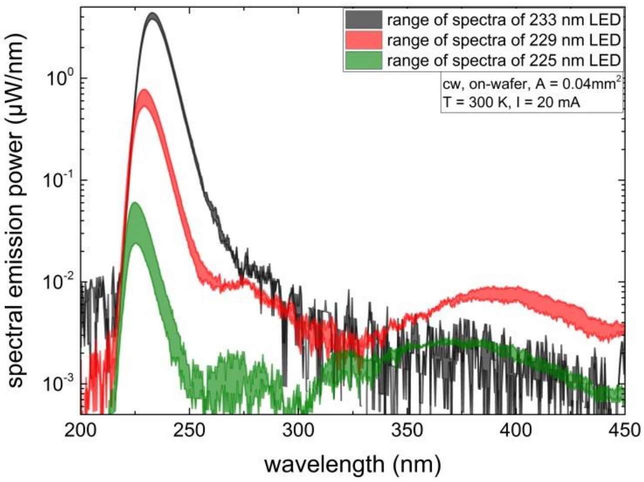

Fig. 1: Spectral power density of 233 nm, 229 nm, and 225 nm LEDs measured on-wafer at 20 mA. The parasitic luminescence at ~400 nm and ~275 nm is attributed to deep level transitions ($V_N^{3+} \rightarrow Mg^0$) within the $Al_{0.2}Ga_{0.8}N$:Mg layers of the p-superlattice and the last barrier, respectively.

Demands on packaging for high performance UV LEDs

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The costs and the long term performance are decisive for the fast market entry of UV LED-based system. Especially for high-power UV LEDs, the optimized thermal management plays an important role because it affects the lifetime of the UV LEDs. These three issues (cost, performance, life time) are significantly determined by the assembly of UV LEDs.

Due to characteristics of UV LEDs this LED type has to mount on heat spreader by flip chip technique either by soldering or by ultrasonically supported thermal compression bonding. Both methods have their advantages and disadvantages with respect to the assembly costs and the dissipation of the heat generated by the UV LED. In terms of cost, performance and durability, both assembly procedures are compared and arguments are supported by simulation results and heat flow analyzes. Furthermore alternative joining methods like sintering or diffusion bonding and aspects of the assembly of the sub-device onto the cooling system will be introduced and results will be discussed.

For selected applications from the fields of UV curing in the production process, medical skin irradiation, plant irradiation with multispectral UV light and an absorption sensor system for DNA analysis, the conditions for the assembly of UV LEDs and the criteria for selecting the components are compared and discussed. The packaging approaches range from UV LED single package (see figure 1) up to array arrangements for higher UV doses (figure 2) to the combination of different wavelengths for a multispectral devices (figure 3).

Fig. 1: UVB LED in an AlN ceramic carrier

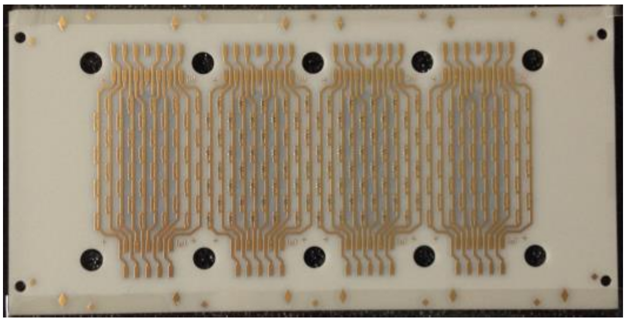

Fig. 2: UVB LED array used for phototherapy

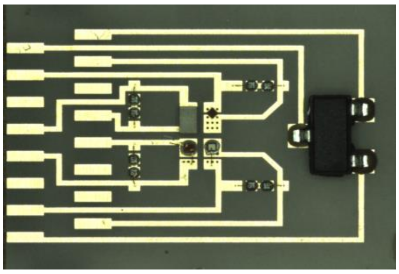

Fig. 3: multi-spectral sub-device

Effect of AlN Capping on Thermal Stability of GaN Nanowires Grown on Sapphire by PAMBE Technique

S.Bhunia[1], R.Sarkar[1], D. Nag[1], S. Mahapatra[1], Apurba Laha[1]
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In recent years, GaN Nanowires (NWs) have emerged as one of the most promising candidates for high efficient optical devices due to their superior structural and optical properties over their planar counterpart [1]. However, at higher temperature (> 850˚C) the GaN NWs start to decompose from the top contour that reduces the length and the diameter of NWs which makes the NW based devices unsuitable for high temperature device processing [2].

In the present work we have investigated the thermal stability of GaN NW under various process conditions. It is observed that the GaN NWs exhibit significantly higher thermal stability at higher temperature when they are capped with ~15 nm AlN layer. For the present study, three types of samples of GaN NWs have been grown on Sapphire substrates by PAMBE under the identical growth condition. After the growth, two of the samples were annealed in-situ at ~ 950˚C for 120 minutes in vacuum (~5x10^{-8} Torr) with and without AlN capping, respectively. The Scanning Electron Microscopy images show that with respect to the unannealed sample, there is hardly any decomposition of the NWs in the AlN capped sample, whereas without AlN capping there was a significant reduction of length and diameter of the NWs. Photoluminescence spectra measured at room temperature show that the FWHM of the band edge emission is reduced in the case of AlN capped sample compare to the unannealed one, which implies an improvement of the structural quality of NWs.

Thus, we argue that the AlN capping on NW could be an effective approach to improving the thermal and structural stability of GaN NW based devices at very high process temperatures.

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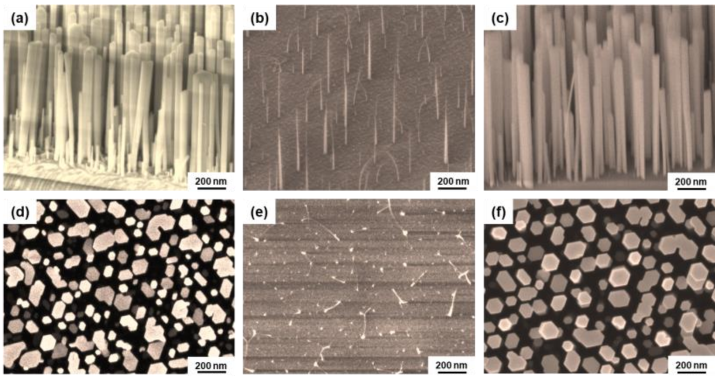

Fig. 1: SEM images show that there is inconsiderable reduction of length and diameter of the capped NWs (c,f) w.r.t uncapped and unannealed one (a,d). However, there is significant reduction of length and diameter of the NWs which were annealed without capping (b,e).

$Al_{0.5}Ga_{0.5}N$ Nanowires Grown Directly on Sapphire Substrate by Plasma Assisted Molecular Beam Epitaxy with Minimal Compositional Inhomogeneity.

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$Al_xGa_{(1-x)}N$ III-Nitride semiconductor with its wide spectrum of emission wavelength in ultraviolet (UV) range is considered to be one of potential materials for UV LED and Laser diode. However, the difficulty in p-doping, presence of large polarization field and a large number of extended defects are the fundamental bottlenecks for the rapid growth of AlGaN based UV technology. AlGaN nanowire (NW) could be the possible solution to overcome these barriers because it minimizes the defects, dislocation, reduces the activation energy for p-doping as well as nullify the polarization effect. However, increasing Al content into GaN leads to (a) formation of GaN/AlN core shell structure and (b) the growth of Al rich AlGaN layer between the NWs are turning out to be fundamental limitations of AlGaN NW growth. As of now the growth of AlGaN nanowire has been reported primarily on Si substrate via priorly grown GaN NW template which prevents the formation of Al connecting layer due to shadowing effect [1, 2].

In the present work, we have resolved these two fundamental problems by growing AlGaN (Al~50%) nanowires directly on the sapphire substrate without using GaN NW template for the first time by plasma assisted molecular beam epitaxy (PAMBE). Our growth strategy consists of thin AlN layer which eventually forms AlN network under N-rich growth condition followed by growth $Al_{0.5}Ga_{0.5}N$ NW at very high substrate temperature(>870 °C). Our investigation infers that new growth mode in PAMBE prevents the sticking of Al between the two AlGaN nuclei as well as minimize the compositional inhomogeneity along the growth axis and thus minimize the radial growth of it. Scanning electron microscopy (SEM) imaging shows the formation of excellent quality AlGaN NWs with diameter 30-50 nm and length ~1 micron. The structural perfection of the NW was further confirmed by high resolution XRD and Raman Spectroscopy.

Reference:

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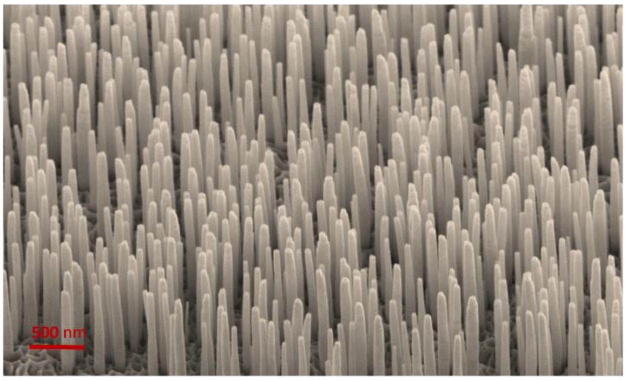

Figure 1. SEM image of AlGaN Nanowire.

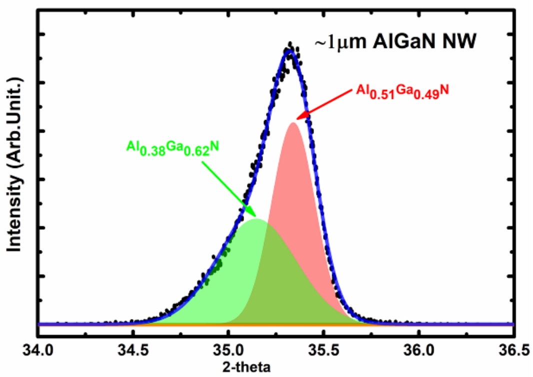

Figure 2. XRD of AlGaN Nanowire.

Modeling of nitride nanostructures with the nextnano software

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Nitride nanostructures are of enormous relevance for commercial applications such as LEDs and lasers. By modeling the electronic properties of these devices, one gains physical insight into how they operate which is an essential necessity for improving and optimizing device performance. Testing and evaluating an epitaxial design via modeling before the actual growth takes place can save considerable amount of effort, time and money. The commercial nextnano software [1, 2] is a semiconductor nanodevice simulation tool that has been developed for predicting and understanding a wide range of electronic and optical properties of quantum structures such as internal quantum efficiency or the absorption spectrum. The underlying idea is to provide a robust and generic framework for modeling device applications in the field of nanosized semiconductor heterostructures (quantum wells, wires and dots). The simulator deals with realistic geometries and any combination of materials in one, two, and three spatial dimensions. It focuses on an accurate and reliable treatment of quantum mechanical effects and provides a self-consistent solution of the Schrödinger, Poisson, and current equations. The electronic structure is represented within the single-band or multiband **k·p** envelope function approximation, including strain, piezo and pyroelectric fields and arbitrary crystallographic growth directions. The user interface simplifies running repetitive tasks such as parameter sweeps. The material database includes binaries, ternaries and quaternaries of group IV, III-V and II-VI materials in both zinc blende and wurtzite crystal structure.

In this contribution, we give a brief overview of the nextnano software and present typical nitride examples such as LEDs and nanowires.

[1] http://www.nextnano.com
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Added value or operational imperative? Water disinfection in vehicular systems

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The use of deep-UV LEDs for water treatment is predicted to be one of the major applications for this emerging technology. Due to their physical and electrical characteristics deep-UV LEDs introduce the potential for small-scale, decentralised water disinfection systems, with one such market covering the disinfection of otherwise potable water sources within vehicular systems.

Vehicular applications vary considerably from those where UV disinfection has previously been employed (municipal, water coolers, building point-of-entry) in terms of size, scale, mass, power, durability, environment, and usability. By mobilising the UV system, many of the regular operating conditions which restrict Hg-lamp system design are removed. The well-known characteristics of deep-UV LEDs (small footprint, DC powered, high durability, instant responsiveness, scalability) give system designers the potential to match challenging specifications with novel solutions.

Three broad categories of vehicular systems will be examined: extreme applications where environmental systems have life or death consequences (spacecraft, submarines, exploration vehicles), additional security applications where a baseline contamination risk is reduced (luxury yachts, recreational vehicles, caravans), and added value applications where UV enables the inclusion of a new potable source (passenger aircraft, long-haul coaches). The contamination risk, design restrictions, and development opportunities will be used to assess the suitability of deep-UV LEDs for each scenario.

Pulsed Sputter Deposition of III-Nitrides for UV Emitters

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Pulsed Sputtering Deposition offers unique features for the fabrication of III-Nitrides. The composition can be adjusted freely because no metalorganic precursors are needed. Pulsed plasmas offer the possibility of adjusting the energy of impinging species, this can act as a substitute for high process temperatures. The purity of the process is not depending solely on the base vacuum, because of the deposition pressures at around 1 Pa, gas purity is crucial. Furthermore, sputter processes can be transferred to very large areas. The process is conducted with high purity metal targets as group III source. Mixtures of argon and nitrogen are used as reactive sputter gas.

We present AlGaN layers on Si111 with emission wavelengths from 250 nm to 320 nm. The composition is only changed by sputtering powers. The influence of different process parameters as pressure and argon to nitrogen ratios on the growth rate are investigated. All experiments were proceeded on 4 inch wafers.

The luminescence properties of the sputtered layers are investigated by cathodoluminescence. Integral element ratios are measured by EDX. Transmission electron microscope gives an insight to AlGaN/AlN heterostructures.

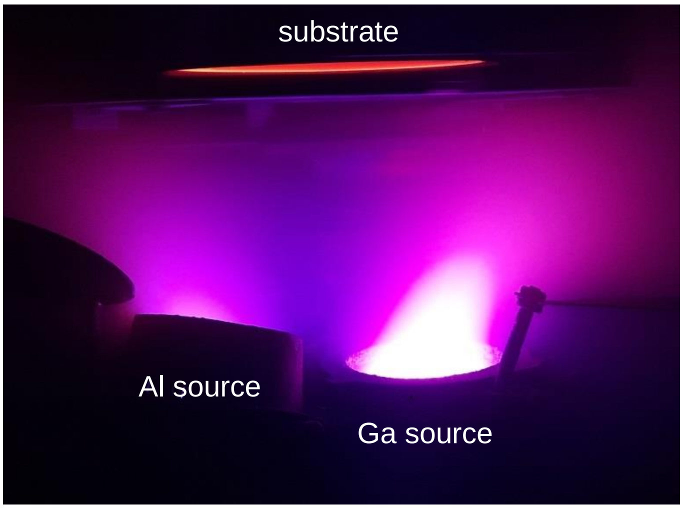

Fig. 1: Image of the sputter deposition with the heated substrate at the top. The co sputtering of Al und Ga is done in sputter up geometry. Due to the liquid Ga the right source is horizontal.

AlGaN-Based UV-C LEDs Emitting Near 270 nm on Low Defect Density AlN/Sapphire Templates

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AlGaN-based ultraviolet (UV) light emitting diodes (LEDs) with emission in the UV-C wavelength range ($\lambda \leq 280$ nm) enable a wide range of applications such as medical diagnostics, gas sensing, biochemical agent detection, and water disinfection. However, the external quantum efficiency of UV-C LEDs compared to visible LEDs is still relatively modest.

In this paper, we report on the fabrication of AlGaN-based UV-C LEDs ($\lambda = 270$ nm) grown by metalorganic vapor phase epitaxy, processed by standard lithography and metallization techniques, and finally flip-chip mounted. Essential for the performance of the devices are the AlN buffer layer on sapphire, the electron confinement capability of the AlGaN electron blocking heterostructure and the transparency and conductivity of the p-side of the LED heterostructure. We will compare UV-C LED heterostructures grown on epitaxially laterally overgrown AlN/sapphire to sputtered and high temperature annealed AlN/sapphire templates. Furthermore, we will discuss efficient carrier injection into UV-C LEDs based on Mg-doped AlGaN electron blocking heterostructures.

On-wafer tests of LEDs in cw operation show an output power of 0.9 mW and an external quantum efficiency larger than 0.91% at 20 mA and at an operation voltage of 7.7 V. The spectra exhibit single peak emission at 269 nm with a full width at half maximum below 11 nm, with parasitic luminescence at longer wavelength of only 1% of the total emitted power.

Off-grid UV-LED Water Disinfection – Surface Water Case Study

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Ingesting microbiologically contaminated water is one of the most common sickness routes for people living off the grid, such as remote communities and those travelling with recreational vehicles.

Ultraviolet (UV) radiation is known as the most effective water disinfection route. However, conventional UV-lamp based water purifiers cannot be utilized for off-grid applications, due to their high electrical power requirements and frequent maintenance. On the other hand, ultraviolet light emitting diodes (UV-LEDs) based water purifiers enable low energy consumption and maintenance-free operation.

Here, we will present the results of a case study on the off-grid disinfection of Grand River and Laurel Creek surface water using Acuva Technologies UV-LED water purification system. The testing site was selected based on the importance of the water resources to the community, as well as implemented restrictions due to microbial contaminations.

Grand River and Laurel Creek supply 30% of the Waterloo and Kitchener, Ontario drinking water. Yet, both are known to be heavily contaminated by Total and Fecal Coliform bacteria, being close to swimmers and tourists in the last few years. The onsite water disinfection tests were conducted using flowing and stagnant water, using Acuva's UV-LED water treatment system and carbon filter without pre-treatment. The bioassay tests were conducted in compliance to United State environmental protection agency (EPA) ultraviolet disinfection guidance manual (UVDGM), in collaboration with a third-party laboratory in Ontario, Canada. The microbial test data indicated that drinking safe water can be obtained using Acuva's UV-LED water treatment system, despite the low UV transmission expected for surface water. We will discuss that complete inactivation of Total Coliform is attributed to National sanitation foundation (NSF) 55 Class A (>40 mJ/cm^2) UV-dose delivery, which ensures water safety for off-grid applications, and can be realized via effective UV-LED reactor design.

p-n junction visualization and quantitative characterization of nanowire based $Al_xGa_{1-x}N$ LEDs

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Actual 2D AlxGa1-xN LEDs exhibit a reduced internal quantum efficiency (IQE) due to a high density of extended defects that affect the optical and electrical properties by trapping carriers or favouring point defect incorporation. The requirement for improved efficiency of actual devices could benefit from the use of nanowire heterostructures presenting the advantage of plastically relaxing the constraints during growth. Improved solubility limit of dopants in this type of nanostructures with respect to their 2D counterparts as well as an eased light extraction coming from their particular morphology makes them a realistic alternative to 2D devices. In order to get past the proof of concept nanowire based devices, it is important to control and quantitatively characterize the n and p-type doping in AlxGa1-xN NW based structures grown by plasma assisted Molecular Beam Epitaxy. Experiments performed on GaN pn junctions show that n and p-type upper limits are higher in NWs than in 2D layers. Interestingly, it has been found that nanowire morphology is affected above a doping threshold limit for both n and p-type (with Si and Mg respectively). Furthermore, electron beam induced current (EBIC) studies were performed on individual and as-grown GaN and AlxGa1-xN NW pn junctions, with different AlN content, assessing the pn junction formation as well as allowing its visualization and abruptness characterization. In particular, electrical characterizations and EBIC measurements provide information on the quality of materials and allow extracting the electrical parameters of the junction, such as minority carriers' diffusion lengths and depletion region, giving access to the n and p-type doping levels [1].

[1] Fang Z. et al Nanotechnology 29 01LT01 (2017)

An innovative Si package for high-performance UV LEDs

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Deep ultraviolet (UV) light emitting diodes (LEDs) have a wide range of applications such as water treatment, medical diagnostics, medical device sterilization and gas sensing. The internal quantum efficiency of UVB and UVC LEDs is extremely low. Added to this is the high refractive index of the sapphire substrate. The electrical input power is converted to more than 95% to heat. Typically, ceramic packages of alumina with metal core or aluminum nitride are used. These promise a minimized thermal resistance. Comparative thermal simulations show that even Si with slightly lower thermal conductivity of 150 W / mK compared to aluminum nitride with 180 to 200 W / mK does not necessarily impair thermal management. From the calculations, basic information was extracted that forms the basis of the Si package layout. The advantage of the Si packing due to the possibility of integrating functional components has been worked out. An optimized Si package is presented that meets in particular the requirements of the assembly and packaging technology of UVB and UVC LEDs. The process technology was designed and implemented. The first samples with integrated protection diode, an optimized reflector and an optically adjusted single and multiple Fresnel lens are presented. The Si packages are designed for the flip-chip technology of UV LEDs with SnAg soldering, thermo-compression or thermosonic bonding and silver sintering. Furthermore, an outlook is given on the possibilities of an encapsulating technology to improve the light extraction.

Hybrid top-down/bottom up fabrication of AlN/AlGaN core-shell nanorods for deep-UV emitting LEDs

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[1]*Dept. Electrical & Electronic Engineering, University of Bath, Bath, BA2 7AY, UK 0FS, UK*
[2]*Department of Physics, SUPA, University of Strathclyde, G4 0NG, UK*

The use of 3D core-shell nanostructures has the potential to circumvent the key problems existing in UV planar 2D technology and highly improve the efficiency of deep-UV LEDs, owing to their low defect density, reduced quantum-confined Stark effect, high-quality nonpolar growth and improved extraction efficiency. However, a key obstacle to their implementation in UV devices is the immaturity of techniques to grow such structures in AlxGax-1N-based materials. Indeed, whereas the selective area growth (SAG) of GaN nanorod arrays and subsequent InGaN/GaN based core-shell LEDs has been demonstrated by metal organic vapor phase epitaxy (MOVPE) on various substrates, the SAG of AlN and Al-rich AlGaN nanorods has not been achieved yet due to the low diffusion length of Al-adatoms. Alternatively, the use of molecular beam epitaxy (MBE) leads to the formation of high density inhomogeneous AlN nanorods which are not suitable for core-shell structures.
This paper reports the use of an original hybrid top-down/bottom-up approach to successfully fabricate highly uniform core-shell AlN/AlGaN nanorod arrays with straight nonpolar AlGaN/AlN single quantum wells (SQW). Our recent progress in nanolithography, top-down etching of an AlN nanorod scaffold (Fig 1.a), and subsequent bottom-up MOVPE regrowth of AlxGa1-xN (Fig 1.b and c) layers will be presented and discussed for various pattern configurations and growth conditions. The reported hybrid top-down/bottom-up approach is promising and opens new perspectives for deep-UV emitting LEDs based on core-shell nanostructures.

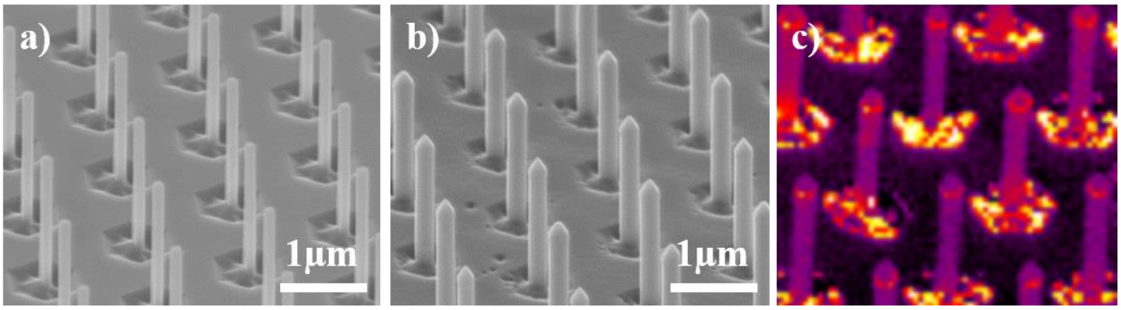

Fig. 1: (a) AlN nanorod array after ICP dry etching and KOH based wet etching. (b) AlN nanorod array after AlN MOVPE regrowth. (c) Intensity map extracted from AlGaN/AlN single quantum well core-shell structures over an emission range of 4.9-5.5eV.

New developments in UV LED process control – using Inline Continuous Automated Dynamic Technology (ICAD-Technology)

T. Efsen
Efsen UV & EB Technology, Vedbaek, Denmark

UV LED Systems consist of numerous LED dies, which are bundled into boards that are then placed side by side to make a UV LED Lamp. Running a measure under a UV LED Lamp only gives the value of that exact spot and does not detect variances/defects in the length of the lamp. To get a correct view of the output of the full web width, one would have to measure as many times as there are boards – This is not practical. This paper will give an overview of how ICAD-Technology is a solution to safe operation of UV LED Lamps in any width while knowing at all time the full output situation.

Extracting near- and far-field radiation patterns of AlInGaN-based UV-LEDs

Martin Guttmann[1], Anna Ghazaryan[1], Shaojun Wu[1], Norman Susilo[1], Johannes Enslin[1], Frank Mehnke[1], Christian Kuhn[1], Luca Sulmoni[1], Tim Wernicke[1], Jens Rass[2], Hyun Kyong Cho[2], Neysha Lobo-Ploch[2], Tim Kolbe[2], Arne Knauer[2], Sylvia Hagedorn[2], Andreas Braun[2], Alexander Külberg[2], Marcel Schmidt[2], Olaf Krüger[2],Katrin Hilbrich[2], Steffen Knigge[2], Dennis Mitrenga[3], Indira Käpplinger[3], Thomas Ortlepp[3], Sven Einfeldt[2], Markus Weyers[2], and Michael Kneissl[1,2]

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Deep ultraviolet (UV) light emitting diodes (LEDs) have a wide range of applications such as water purification, medical diagnostics, sterilization of medical equipment and gas sensing. All applications require a specific irradiation pattern. For the design of packages and modules which shall provide a homogenous illumination, minimizing the losses in the module or incorporation of additional optical elements such as lenses or reflectors, the knowledge of the near- and far-field radiation pattern is crucial.

In this paper we investigate the near- and far-field radiation patterns of UV-LEDs by measuring the electroluminescence and comparing it with Monte Carlo ray tracing simulations. The evaluation of different flip-chip mounted and packaged UV-LEDs shows that the light is not only emitted through the bottom surface of the substrate but also through the chip side facets leading to very complex far-field distribution patterns. The total light output depends on the degree of light polarization of the active region, the chip dimensions and the surface properties. Especially the chip dicing method has a strong influence on the roughness and transmittance of the chip sidewalls. We will provide a deeper understanding into the light extraction mechanisms and its influence on the far-field by comparing far-fields measured on different packaged and on-wafer LEDs as well as simulated radiation patterns. Finally, we demonstrate the usability of such simulated ray files for the production of a Fresnel lens as a chip cap for a UVB-LED emitting at 310 nm.

UVC LED disinfection of medical device tube lumen

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UVC kills bacteria by modifying their DNA and has been used for more than a century for disinfection. The emerging UVC LED light sources combined with appropriate front optics show promise for the development of small handheld devices for disinfection of implanted medical devices. Several medical device applications include polymer tubing with narrow lumens for transport of blood, saline solutions and drugs. Catheters, supply lines and endoscopes are common examples. Working in the UVC spectral region adds complexity with various optical requirements which are necessary to overcome in order to launch and guide the UVC light in narrow tubes. The selection of applicable materials with appropriate optical properties for use in the UVC region is sparse in comparison with materials available in the visible spectral region. We demonstrate that UVC LED light can be launched into small polymer tube openings and disinfect the tubes contaminated with a bacteria suspension. UVC device concepts for intra-luminal disinfection of medical tubing are presented. It is demonstrated that disinfection can be achieved in short periods of UVC exposure in extended and narrow polymer tubes. Pathogenic bacteria are used for testing the disinfection efficiency of device prototypes in various settings.

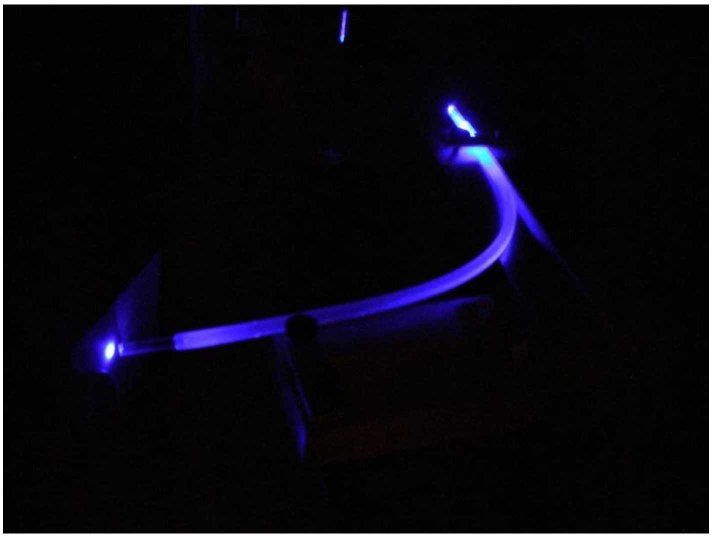

Fig. 1: UV – VIS light propagation in Teflon polymer tubes

Integrated dose simulation tool for UV-LED reactors

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[1]2366 Main Mall, Vancouver, British Columbia, Canada. V6T 1Z4

Using virtual prototyping for the design of UV-LED reactors can help significantly to reduce the cost and development time. Without the proper simulation tools, the reactor design may need to go through multiple design revisions and prototyping stages without delivering the required dose or LRV at the end. Complete simulation of a reactor's performance requires precise modelling of reactor's hydrodynamics, optics and the microbial kinetics, each of which are equally important for an accurate reactor simulation. Hydrodynamic simulation can be quite challenging if not all the parameters are considered or set properly. Meshing quality, flow models including turbulence, particle tracking setting they can all significantly affect the flow simulation and the dose performance respectively. In fact, through examples it will be discussed that traditional measures of simulation convergence as having the residuals below a certain level will not necessarily verify the accuracy of simulation. In addition, optical simulation will equally be important to achieve an accurate prediction of the reactor's performance. Precise simulation of the LED die, package, radiation pattern and wavelength, and modelling of optical surfaces will all influence the accuracy of the simulation tool. Eventually the results of hydrodynamics simulation and optical simulation need to be integrated to measure the overall reactor's performance in terms of dose and LRV. We have used our in-house tool to predict the reactor's performance and the results are compared with bio-assay test results. Results from both tests reveal ±10% variation between the experimental results and the simulation. This level of accuracy can be achieved between experiments and simulation by paying extra attention to the detail of hydrodynamics, optics and kinetics simulation.

Tuesday, April 24

Room Barcelona I	Room Barcelona II
8:00 - 17:00 Registration	
8:30 - 10:00 | Tu-A1 **Semiconductors & Devices III** *Chair: M. Jo* L. Schowalter (invited) S. Einfeldt (invited) M. Weizman U. Hansen	**8:30 - 10:00 | Tu-B1** **Plant Growth & Food II** *Chair: M. Jansen* M. Wiesner-Reinhold (invited) A. Ranieri (invited) C. Möller
10:00 - 10:30 | Coffee Break & Exhibition	
10:30 - 12:00 | Tu-A2 **Water & Disinfection III** *Chair: S. Kaemmerer* G. Knight (invited) M. Mohseni (invited) J. Pasquantino B. Adeli	**10:30 - 12:00 | Tu-B2** **Medical Applications II** *Chair: R. Sommer* U. Heinrich (invited) M. Meinke (invited) S. Albrecht A. Patzelt
12:00 - 13:00 | Lunch Break (Buffet) & Exhibition	
13:00 - 14:30 | Tu-A3 **Water & Disinfection IV** *Chair: S. Beck* R. Sommer (invited) M. Ruffin (invited) M. Rasoulifard Y. Zhang	**13:00 - 14:30 | Tu-B3** **Spectroscopy II** *Chair: F. Stüpmann* M. Degner (invited) G. Wiegleb (invited) F. Taghipour K. Haberland

<table>
<tr><td colspan="2">14:30 - 15:00 | Coffee Break & Exhibition</td></tr>
<tr><td>15:00 - 16:30 | Tu-A4
Semiconductors & Devices IV
<u>Chair:</u> N. Lobo Ploch
F. Gindele (invited)
B. Sumpf (invited)
X. He
M. Tollabi Mazraehno</td><td>15:00 - 16:30 | Tu-B4
Measurement I
<u>Chair:</u> S. Einfeldt
P. Sperfeld (invited)
K.-H. Schoen
T. Schwarzenberger
K. Sholtes
M. Clark</td></tr>
<tr><td colspan="2">16:30 - 17:00 | Closing Remarks (Barcelona I)</td></tr>
<tr><td colspan="2">17:00 - 18:30 | Roundtable on UVC LED System Standards (Barcelona II)
J. Eggers, N. Morgenbrod</td></tr>
<tr><td colspan="2">19:00 – 20:00 | optional: Guided Sightseeing</td></tr>
</table>

Development of short wavelength UVC LEDs at 265nm and below for water disinfection and water quality monitoring

L.J. Schowalter
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Asahi Kasei Corp, 2-1 Samejima, Fuji-shi, Shizuoka, 416-8501, Japan

Crystal IS, Inc. has developed aluminum nitride (AlN) crystal growth and then uses the resulting single crystal AlN wafers in the commercial manufacturing of UVC LEDs which emit at wavelengths shorter than 280nm. The commercial development of UVC LEDs (Optan™ and Klaran™) with superior power, lifetime and irradiance has been enabled by the development of pseudomorphic epitaxial layers of AlGaN on the high quality AlN substrates. Further improvement in the wall plug efficiency of Crystal IS devices will be enabled by improved photon extraction efficiency.

Even though radiation at wavelengths shorter than 285nm can disinfect, the effectiveness rapidly decreases for most organisms of interest as wavelength is increased beyond 275nm while in the wavelength range from 260nm to 275nm, the disinfection efficacy is not only higher but also nearly flat for most organisms. This is an important consideration in the design of disinfection reactors since LED manufactures bin their diodes into a wavelength range. Small fluctuations in the wavelength around 265nm will not affect the efficacy of the disinfection reactor in which the LEDs are used while fluctuations around longer wavelengths will have much more of an impact on the efficacy.

There are also a number of interesting optical probe applications that require emission wavelengths shorter than 250 nm. These applications include the monitoring of nitrate concentrations in water where LEDs emitting at 230nm are desired. The AlGaN/AlN technology is extremely advantageous for this work due to the very low defect density of pseudomorphic AlGaN layers grown on AlN substrates when the Al content is high. Unfortunately, light extraction is hindered at these short wavelengths as the emission mode switches to being mostly parallel to the emission surface for standard orientation of substrates (the so-called TM mode). In spite of the photon extraction issue, UVC LEDs at 240 nm have been demonstrated with 2.4 mW of power at 200 mA. At 230nm and at 227nm, and at a current of 100mA, 0.25mW and 50µW have been demonstrated, respectively.

Improving the reliability of UV-B and UV-C LEDs

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[1]*Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany*
[2]*UVphotonics NT GmbH, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany*
[3]*Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany*

Most of the applications of UV LEDs require devices which do not only emit a high optical power with the highest possible efficiency but also exhibit a high reliability. Whereas visible and near-UV LEDs show extended lifetimes in the range of tens or hundreds of thousands hours, state-of-the-art UV-B and UV-C LEDs usually degrade much faster. In this paper we provide an overview on our studies to understand the physical mechanisms of degradation processes in UV-B and UV-C LEDs. The findings are used to improve the design of the LEDs with respect to a maximum reliability. In long term stress experiments at typical operation currents of 100 mA or 350 mA the evolution of the optical power, voltage and capacitance as well as the emission- and photocurrent spectra are monitored. Moreover, the distribution of the optical power over the emitting active area of the devices is measured during operation. Finally, material analyses are made by secondary ion mass spectrometry to find out about changes in the distribution of doping atoms or non-intended impurities in the semiconductor heterostructure. For example, degradation effects are shown to depend on the design of the heterostructure such as the electron blocking layer as well as the type of the metal contacts and the insulator materials used in the chip. The results point to an operation-induced activation of hydrogen-containing defect complexes, such as Mg-H, and an electromigration of hydrogen close to the active region during the first hours of operation (compare Fig. 1). Finally, our degradation studies have resulted in an improved reliability of UV-B LEDs with L50 lifetimes of more than 8,000 hours.

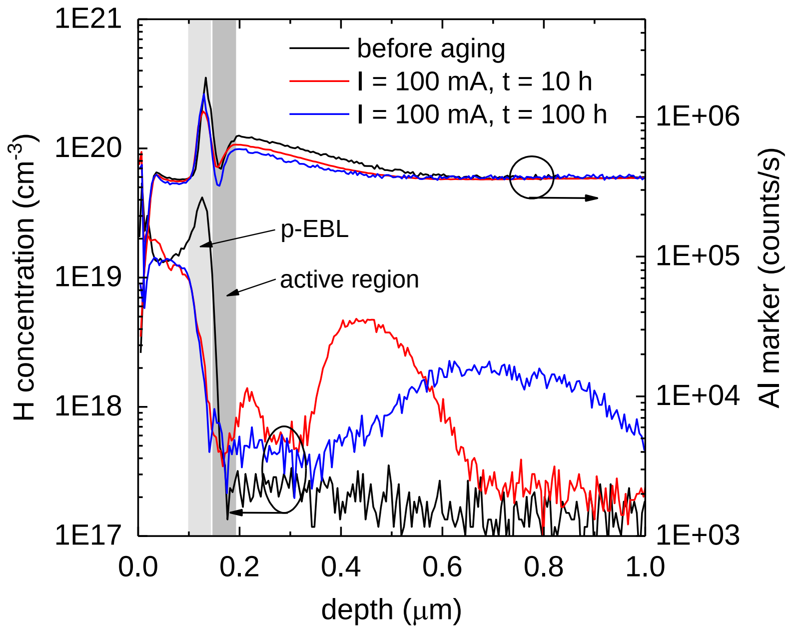

Fig. 1: Depth profiles of the hydrogen concentration and the relative aluminum concentration in the heterostructure of a UV-B LED chip before operation and after operation at 20 °C and 100 mA for 10 h and 100 h, respectively.

Fabrication and long-term Stability of Aluminum Reflector-Arrays for UV-LED Modules

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UV-LED modules have nowadays with the rapid decrease in UV-LED prices a great potential for a wide range of application such as material curing, phototherapy, and disinfections. For applications where the working distance between the LED module and the target is larger than a few centimeters, an optical system to form a narrow-angle light emission is often required. Using optical elements out of cheap glass for shaping the light distribution might be a good strategy for UVA irradiation but as soon as we go into the deep UVB and UVC range this approach requires the usage of expensive quartz glass. In this paper we present an optical solution based on an array of parabolic aluminum reflectors that can be both cost-effective and applicable for the entire UV range.

Three techniques to produce an aluminum reflector-arrays with a full-angle emission of about 20° were investigated: i) CNC milling of a thick aluminum plate ii) Bending thin Al-sheets in a reflector array form iii) Aluminum coating of polycarbonate (PC) injected mold. Special emphasis was put on the reflectivity properties of the Al surface before and after applying an electro-chemical polishing process step. Moreover, for the Al-coated PC reflector array a long term stability test over 5000 hours under high power UVA irradiation was performed. The results that will be presented show critical considerations in the design and production of such reflector arrays that pave the way towards next-generation cost-effective UV LED Modules.

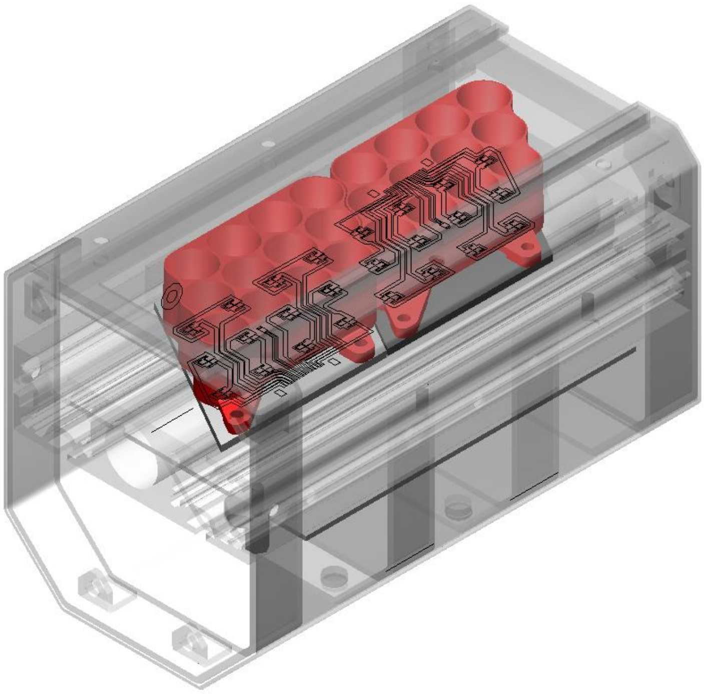

Figure: UV LED Module with reflector arrays designed by OSA Opto Light

Miniaturized Hermetic Reflector Cavity Packaging for UV LEDs

U. Hansen[1], S. Maus[1], O. Gyenge[1], R. Abdallah[1], M. Neitz[2], S. Marx[2]

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[2]Technical University of Berlin, Gustav-Meyer-Allee 25, 13355 Berlin, Germany

UV-A LEDs have experienced a broad acceptance in the market in the past years. The same success is expected for lower wavelength devices in the UV-B and especially UV-C range, driven by applications such as water or air purification and others.

Manufacturing technologies for UV-C LEDs have significantly matured lately. However, there is a challenge opposing the UV-A devices; the choice of packaging materials is limited since most organic materials like glues or plastics are not able to withstand UV-C radiation without significant degradation over time.

As a result, the packages currently used are either the 'classic' bulky and cumbersome to handle TO-packages, or more sophisticated SMD-compatible 3D-structured ceramic housings with hermetically attached quartz glass lids. Due to UV-C LEDs radiating a significant share of up to 50% in total to the sides of the die the main disadvantage of both packaging approaches is that this light is lost. Considering that the achievable overall output power of UV-C devices is still comparably low, this is a major drawback.

This presentation proposes a novel solution. A hermetic SMD-compatible packaging approach that integrates reflectors into the package to maximize the light extraction. Side emitted and thus wasted light can be recovered by a large percentage. Furthermore it shows, how to avoid costly 3D-structured ceramics by incorporating the reflector into a fused silica window, which is then placed over an already mounted LED chip (flip chip or wire bonded) on a standard flat ceramic. To yield a fully hermetic package this attachment can be done by metal bonding. Design choices of the reflector structures allows us to tailor the radiation patterns of the LEDs. The manufacturing approach allows for miniaturization of the packages as well as further enabling miniature packaging of LED arrays.

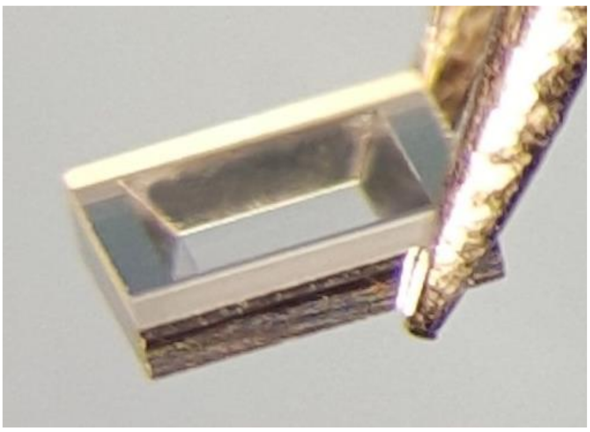

Fig. 1: Macroscopic picture of reflector cap for SMD-packaging

Fluid Disinfection Using Light Guiding and UV Light Emitting Diodes

G. Knight 1; E. Mahoney 1;
1: Trojan Technologies, London ON, Canada;

The advent of “instant-on” UV sources such as UV light emitting diodes (LEDs) enables water treatment where the UV source can be used on demand. A novel disinfection system using light guiding technology and employing LEDs emitting in the 270-290 nm region of the spectrum is presented. Optimum design of the light guide was determined by evaluating the transmission of UVC light through a fluid-filled light guiding chamber of varying length, and determining the UV emission exiting the chamber using an integrating sphere. The absorption coefficient for the system was found to range from 0.063 cm-1 for quartz in air to 1.38 cm-1 for Teflon tubing using a Beer’s law model for the attenuation through the light guide. A Teflon coated quartz tube had a somewhat higher absorption coefficient than that of quartz in air, but did not have absorption that was sensitive to contamination on the outer surface of the quartz tube. Extrapolation of the transmitted power as a function of length to zero length allows for estimation of the UV power injected into the light guide, which is important for system design. This allowed for the assessment of collimated and non-collimated light sources.

The disinfection apparatus was then constructed, where a 254 nm dose of 40 mJ/cm2 was achieved for a flow of 150 mL/minute with an estimated injected UVC power of 20 mW. Improvement of the delivered dose could be achieved with larger diameter tubing for the light guide, which increases the injected power in the system. Scale-up of the injected power through use of higher power UVC sources should be possible, and results for these systems will be presented.

UV-LEDs as emerging sources for UV based advanced oxidation: Opportunities and Challenges

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Advanced oxidation processes (AOPs) are promising technologies with applications in water treatment when conventional biological and physical-chemical processes cannot achieve the expected water quality. AOPs rely on the formation of radicals such as hydroxyl radicals, which are very efficient at degrading recalcitrant micropollutants. Typical AOPs, like UV/H_2O_2 and UV/chlorine, use UV radiation in order to promote the production of radicals. The evolution of light-emitting diode (UV-LED) has opened new possibilities and strategies for the application of these sources to water treatment with plenty advantages over the low pressure mercury lamps (UV-LPs), among them being the possibility to tuning the UV-LED peak wavelength, potentially higher lifetime, and flexibility in reactor design due to their relative small footprint. Tuning the wavelength might allow to perform UV/chlorine at higher efficiency rate, due to the dominant presence of OCl^- at neutral and higher pH, which can facilitate the application of the process in drinking water systems. However, using UV-LEDs as radiation sources has some challenges, largely due to the incipient nature of this technology. This presentation provides an overview of the state-of-the-art in UV-LED based AOP research (e.g., UV-LED photocatalysis, UV-LED/Chlorine, UV-LED/H_2O_2) . A particular emphasis will be given to the UV-LED/ Chlorine process using a recently validated bench scale setup to calculate the UV fluence precisely. Moreover, a holistic comparison between UV-LED and UV-LP was performed in terms of the efficiency of UV/Chlorine. A particular emphasis will be given to the UV-LED/ Chlorine process using a recently validated bench scale setup to calculate the UV fluence precisely. Moreover, a holistic comparison between UV-LED and UV-LP is presented in terms of the efficiency of UV/Chlorine.

Irradiance-dependent UV dose response in microorganism and biomolecule inactivation

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A fundamental premise of ultraviolet disinfection and decontamination is that microorganisms and biomolecules (DNA or enzymes) have a predictable UV-dose response. Without the option to significantly increase germicidal UV intensity above 200 mW/cm², intensity has been assumed to have negligible effect upon inactivation. Initial research with recently available high-intensity UV-C LED lamps (irradiance above 3 W/cm²) highlighted an unanticipated relationship between irradiance and inactivation.

These experiments used a high irradiance UVLED lamp (278 nm) with ~1 W/cm² maximum irradiance at the emitting window. The lamp was positioned 10 mm from the target surface. RNaseA (SigmaAldrich) (1µl of 0.02 U/ml) was spotted onto clean RNase-free glass slides. Post-exposure, RNaseA was recovered in 60 µl RNase-free water. UVLED exposure was conducted at 10% 25%, 50%, 75% and 100% intensity. Samples were assayed for RNase activity using RNaseAlert Kit (IDT) and Gemini XS fluorometer (Molecular Devices).

In this study, RNaseA was totally inactivated (compared to a negative control) with a 3 minute exposure at 100% intensity (total dose of 6.94 J/cm²). Inactivation increased with dose for each intensity level (as expected), however the dose (J/cm²) resulting in inactivation was not equivalent for the different intensity levels. When RNaseA activity was plotted against total dose delivered for a timed inactivation series of two irradiances 50% (316.7 mW/cm²) and 100% (635.3 mW/cm²) the higher irradiance effectively inactivated the enzyme at a lower dose, 4.4 J/cm², than lower irradiance which required 25 J/cm².

Based on Oliver and Cosgrove's [1] investigations of microorganism dose response to UVC, it has been assumed that inactivation relates directly to dose, irrespective of irradiance. However, with the advent of high power UV LEDs, irradiance matters. In light of these findings, it is worth re-examining irradiance as a factor in microorganism inactivation.

Reference

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Decomposition of Organic Compounds through UV-LED Advanced Oxidation Processes

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Water quality is threatened by the presence of organic contaminants, caused by human and natural activities. Conventional methods employed to remove organic pollutants in ground water or industrial effluents, such as air stripping or adsorption by activated carbon, are not considered effective routes, since these methods only transfer the pollutant from one phase to the other, leaving the problem only partially solved.

Direct chemical degradation, as well as decomposition via photolysis were explored for elimination of organic contaminants, yet their slow kinetics and low efficiencies have limited their applications. On the other hand, ultraviolet (UV) assisted advanced oxidation process (AOP), through UV activation of hydroxyl radical ($OH^{\cdot}$), is recognized as an effective technique for decontamination of water from organic compounds. However, the high energy consumption, frequent maintenance, and environmental impact associated with conventional UV lamps are considered as the drawback of UV lamp based AOP.

Ultraviolet light emitted diodes (UV-LEDs) have emerged as superior alternatives to conventional UV lamps, owing to their tailorable optical characteristics, ultra-low energy consumption, durability, and rapid climbing efficiencies.

In this presentation, we will discuss the effectiveness of the UV-LED based systems for hydrogen peroxide-mediated AOP. Syntactically composed water samples, containing 2,4-Dichlorophenoxyacetic (2,4-D) acid pesticide, were exposed to UV-C radiation inside an Acuva's water treatment system and analysed for their inorganic contamination content. The spectroscopy analysis concluded the effectiveness of UV irradiation generated by UV-LEDs for $OH^{\cdot}$-AOP process. A complete decomposition of 2,4-D was accomplished at an efficiency substantially higher than those observed for the direct chemical or photolysis routes. In comparison to an analogous process using a conventional UV lamp, UV-LED driven AOP exhibited superior performance at less hydrogen peroxide concentration. The UV-LED based AOP presented in this study can be further studied for simultaneous disinfection of water from microbiological contaminants, as well as decomposition of organic pollutants.

Control of water-borne infections by UV irradiation

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Safe water is a pre-requisite for reducing the spread of water-borne infectious diseases. Besides source water protection, disinfection serves as most efficient tool to protect human health from infectious diseases via the water route. The increasing demand for clean water and the limited water resources makes it necessary to reuse waste water for manifold applications including drinking water purposes representing the highest quality.

Infection routes due to impaired water quality are as varied as the uses of water, comprising drinking, food preparation, personal hygiene, recreation and medical applications as well as for technical and industrial purposes. Routes of infection are ingestion, contact, inhalation or intravenous administration.

UV irradiation has proven successful since decades its high value as primary disinfection of drinking water. Due to the progress in quality assurance and international standardisation of the requirements (Austrian Standards International, German Association for Gas and Water, US-EPA) this techniques gained worldwide acceptance [1-3]. In contrast, no generally accepted requirements for the needed degree of inactivation for waste water disinfection systems exist so far. If recreational surface waters serve as receiving water for the effluent of wastewater treatment plants (WWTP) bathers can be exposed to a wide range of bacterial, viral and protozoan pathogens. Moreover many bacteria (e.g. *E. coli, Vibrio cholera*) possess the enzyme photolyase, which enables the repair of UV damages of nucleic acids leading to retrieval of infectivity. This may happen, if the delivered UV fluence to the waste water effluent is not sufficient.

So far, the application of UV irradiation for water in engineered installations like cold and hot water systems inside buildings or cooling towers has its limitations. Although free *Legionella* can be inactivated efficiently even if associated with amoebae, biofilm control is not possible since UV irradiation does not hit the target [4]. The same holds for pool water disinfection, in which the main infection route is human to human.

Prerequisite for successful infection control in all applications are the careful control of the operation conditions of the UV system (flow, UV irradiance) and of the essential physical and chemical water quality parameters (UV transmittance, turbidity, total organic carbon).

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Air disinfection with an UVC LEDs device

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UVGI is used to disinfect water, surfaces, and air; regardless of the method, the science behind killing the microorganism is the same. UV-C energy damages nucleic acids and destroys the DNA of the microorganism, rendering it unable to reproduce and ineffective.

Until recently UVGI systems exclusively used gas discharge lamps which contain mercury emitting at a peak wavelength of 253.7nm. These lamps are comprised of a fragile quartz tube with two electrodes which vaporizes the mercury inside the lamp. Although these lamps can achieve lifetimes of 10,000 hours in a laboratory environment, in the real world their fragility often leads to shorter life. Coupled with the handling and disposal hazards of mercury, UVGI systems have seen limited use to date.

With recent advancements in UVC LED technology and the increase in antibiotic resistance the use of UVGI has seen renewed interest. LEDs, unlike gas discharge lamps, are a smaller and robust light source capable of withstanding impact and vibration forces that would destroy traditional lamps. The smaller size allows for greater light collection that leads to less stray light, which increases the level of safety. These features, along with a low forward voltage which enables direct solar power operation, offers a level of flexibility not seen within the industry.

This presentation will review the prototype design, and microbial test results, of a UVC LED based air disinfection fixture. Devices like this can be used to reduce the risk of hospital acquired infections and other airborne transmitted diseases. With any luck, UVC LED devices can be used to fight the world's greatest infectious killer, TB, an airborne transmitted disease.

Subject areas covered include LED selection, optical modeling, optical simulation, goniometric measurements (light range) and microbial disinfection testing.

Efficiency of UV-LED/TiO_2/ $K_2S_2O_8$ system for photocatalytic decomposition of pharmaceutical pollutants in contaminated water

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Photocatalytic degradation of pharmaceutical and personal care products (PPCPs) has been regarded as one of the most attractive concerns among environmentalist scientists. Globally presence, increasing usage, wide range of categories and above all, environmentally effects of PPCPs have been the most motivate features in recent years which urge researchers to investigate the degradation of these toxin contaminants from environment. Currently, the role of photochemical techniques for degradation of recalcitrant contaminants has been magnetized as a vigorous route. In spite of its ability, few surveys involving the utilization of photochemical methods to decomposition of refractory pollutants such as pharmaceuticals have been reported. The use of Ultraviolet (UV) light has become progressively more fashionable because comprise no-known disinfection by-products formation. Moreover, UV light has no resulting odor and taste matters and also over-dosing will not jeopardize public health. However, most of mentioned surveys relied on usual photochemical methods such as conventional UV lamps. Herein, set of experiments considering influential parameters, oxidant dosage, UV light intensity, and photocatalyst dosage has been considered owing to investigation of photocatalytic destruction of target PPCPs under illumination of UV light and TiO_2-$K_2S_2O_8$ photooxidatvie system. UV-light emitting diodes (UVLEDs) have been utilized as UV light sources in present research. Recently investigated (UVLEDs) have been achieved a distinguishing position among other light sources for photocatalytic approaches. UV-LEDs not only offer some potential advantages over traditional UV lamps such as an improved efficiency in high quantum yields, lower power necessities, toughness, disposal troubles, but they also provide longer operational life and flexibility in design because of their miniaturized scale which possibly makes them best candidate for photoreactor design approaches.

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Ultraviolet Membrane Bioreactor for Enhancing the Removal of Organic Matter in Micro-Polluted Water

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Thise research investigated the organic matter removal efficiency in micro-polluted surface water using an ultraviolet (UV) treatment membrane bioreactor (UV-MBR). Compared with a conventional MBR process, the UV-MBR process achieved much higher organic matter removal efficiencies in terms of the reduction of the permanganate index (CODMn) and the absorbance at 254 nm (UV254), which were reduced by 58% and 63%, respectively. The organic matter removal rate increased significantly arising from biodegradation mechanisms. Through the UV treatment, a fraction of the refractory aromatic hydrocarbons decomposed and was transformed into biodegradable organics available to the microbial consortium in the MBR, which resulted in a significant reduction of contaminants in the raw water. UV treatment of the raw water leads to the an increase of the Biodegradable Dissolved Organic Carbon (BDOC) content from 0.22 to 0.88 mg L–1 after 5 days inoculation. From the analysis of the relative molecular weight distribution, a characteristic of hydrophobic and hydrophilic compounds and the fluorescence excitation-emission matrix of the organics, it was also found that the organics were transformed into biodegradable substances because the larger moleculares weight fractions were split into simple organics by the UV treatment, and a majority of organics removed by the UV-MBR process were hydrophobic fractions.

Highly reliable package technologies for UVC LED modules

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The predicted progress in increased performance of UVC LED dies and market expectations for UVC LED products requires a highly reliable and innovative package technology in order to push forward. There are major technical challenges to be solved for LED dies, especially to address growing market segments such as water and air purification, surface sterilization and portable disinfection systems. These challenges include the needs for increased efficiency, greater lifetime and reduced cost per output power. The performance of the LED housing is equally important to that of the LED dies and must fulfill various complementary requirements. These include needs for outstanding thermal conductivity, use of non-aging materials that withstand UVC radiation, low optical losses, optics that are highly transparent for UVC radiation and useable for beam shaping, and in general the ability to perform without issue in harsh environmental conditions – preferably with hermetic protection of the LED die.

Glass-to-metal sealing (GTMS) and ceramic-to-metal sealing (CerTMS®) technology, developed by SCHOTT, offers a suitable package solution for UV LED modules, especially for shorter wavelength applications in the UVC spectral range. The presented package technology is based on a highly transparent glass material that can be directly sealed to a metal frame or LED housing and act as an optical lens or window. No other interface materials or processing (such as soldering or gluing) are required to form the hermetic connection between the glass and metal. The UV LED die is assembled on a metal or ceramic substrate with high thermal conductivity. The substrate is joined with the optical window by soldering or welding. In cases where a metal substrate is used, copper is partially applied as a thermal path from the LED die to the surrounding material. However, this challenges the interface technology due to the thermal mismatch of the substrate materials. For dielectric isolation, glass is used as the bonding material between the electrical contacts and the substrate, allowing the LED module to be free of electrical potential. Alternatively, an AlN ceramic substrate enables the possibility to utilize a SMD design of the LED module. In summary, both gas-tight through-hole and SMD module designs are possible.

Several lifetime and reliability tests of GTMS and ceramic LED modules have been conducted. These tests show clear advantages in comparison to polymer-based modules.

In addition to the important reliability qualities of the package, the increase of the outcoupling efficiency of the LED package is addressed by using an encapsulation material with high transmission in the UVC spectral range. First results of the optical and general properties will be presented.

Deep UV light source at 222 nm based on second harmonic generation of GaN high power diode lasers

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Light sources in the deep ultra-violet spectral range, i.e. between 200 nm and 300 nm, are requested for several applications that reach from medical diagnostics over identification of biological agents by DUV Raman spectroscopy to gas sensing and monitoring, etc. Whereas the longer wavelength range in this region can be addressed by LEDs, especially for the range below 230 nm, there is a lack of compact light sources with sufficient output power.

In this contribution the second harmonic generation of GaN high power diode lasers as potential alternative will be presented. This compact and reliable diode laser-based system could help to address applications in environments where a portable and robust light source with low power consumption is necessary.

A compact diode laser based light source based on the single-pass frequency doubling of the emission of high-power GaN diode will be presented.

A commercially available 1.6 W GaN laser diode from OSRAM Opto Semiconductors is used as pump source having a maximal power consumption of 6 W. To meet the phase matching requirements, the laser diode is spectrally stabilized in a micro-integrated external cavity diode laser module having a footprint of 25 x 25 mm^2 by applying a volume Bragg grating for wavelength stabilization and emission narrowing. This light source reaches an optical output power of about 1.4 W at 445 nm. Over the entire power range, the emission width is smaller than 50 pm (FWHM) at 445 nm suitable for the SHG.

Using a BBO crystal of a length of 7.5 mm and critical phase-matching, a maximum power of 160 µW at 222.5 nm could be generated.

The design of this light source, their power characteristics and spectral properties will be presented and concepts for an even more compact and tunable source will be discussed. Such devices are suitable for Raman spectroscopic experiments as well as for absorption spectroscopy.

Deep UV micro-LED arrays for optical communications

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Deep ultraviolet (UV) optical communications have attracted considerable attention recently. As most of the Sun's ultraviolet radiation is absorbed by the ozone layer in Earth's stratosphere, UV optical communications offer not only a high-security communication link between satellites in the upper atmosphere, but also data transmission with low solar background noise for outdoor communication on the ground. Furthermore, deep UV light is strongly scattered in the air caused by abundant molecules and aerosols, which enables non-line-of-sight short-range optical communication. However, in comparison with visible light communications, the data transmission rate based on deep UV light emitting diodes (LEDs) has been little explored and is still quite low. This is mainly due to the low modulation speed of conventional deep UV-LEDs. Therefore, developing high speed deep UV-LEDs is of paramount importance.

In recent years, we have developed the micro-LEDs (µLEDs) as novel high-speed transmitters for visible light communications.[1] These µLEDs, of edge dimension/diameter typically in the 10-100µm range, have extremely high modulation bandwidths due to their high operating current densities. Based on these studies, we report here the first III-nitride deep UV-µLED array emitting at around 262 nm to demonstrate its full potential for deep UV optical communications. This array consists of 15 µLED elements with a flip-chip configuration. With an emission area of 565.5 μm^2, each µLED element is individually addressable. The UV optical power of a single µLED element is 196 µW at 3.4 kA/cm^2 direct-current (DC) operating current density. We are currently measuring the modulation bandwidth of these deep UV-µLEDs. As they can sustain such a high DC operating current density, we expect a high modulation bandwidth and, in turn, a high data transmission rate for fast free-space optical communication. These results will be presented in the conference.

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MOVPE Growth of Deep Ultraviolet LEDs with Emission Wavelength below 240nm on Native AlN and Sapphire Substrates

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Deep ultraviolet LEDs with emission wavelengths below 240nm were investigated. These devices are based on the AlGaN material system grown by metalorganic vapor phase epitaxy on native c-plane AlN substrates with threading dislocation densities (TDD) below <1E4cm-2, as well as on AlN on sapphire templates with TDD around 1×1E9cm-2. AlGaN growth on AlN on sapphire templates is dominated by spirals formed around threading dislocations with a screw component, which lead to increased surface roughening. It is shown that the density and size of the spirals, hence surface roughness, can be reduced by decreasing the metal supersaturation during growth. In contrast, due to very low TDD, growth on native AlN substrates is spiral free and consequently smooth surfaces with monolayer steps are formed. The device performance is interpreted considering these extreme growth modes and in relation to the TDD.

Temperature and excitation dependent PL measurements were carried out in order to identify the dominant loss mechanisms inside the deep UV multi quantum well structures (MQWs). Both resonant and non-resonant photoexcitation were utilized for evaluation of the internal quantum efficiency and the implications investigated. IQE values of about 10% were demonstrated at 232nm. A strong reduction of the IQE at high carrier densities (efficiency droop) is observed for these MQWs. Time resolved PL spectroscopy and spatially resolved CL measurements were used in order to further identify the origins of loss channels and efficiency droop.

In addition, Si-doped high-Al-content AlGaN layers were grown under high metal supersaturation growth conditions in order to minimize the incorporation of compensating point defects leading to highly conductive and UV-transparent n-AlGaN layers. Transmission and temperature dependent Hall measurements were carried out to assess the transparency and conductivity of the n-AlGaN layers. The resultant LED performance is presented in terms of external quantum efficiency and light output power.

UVB radiation from LEDs impacts the formation of health-promoting secondary plant metabolites

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Ultraviolet B (UVB) radiation in low but ecological-relevant doses acts as regulator in the plant's secondary metabolism. Recent developments allow the use of UVB light emitting diodes (LEDs) as novel light source. This study investigates the effect of UVB radiation from LEDs [peak wavelength of (290 ± 2) nm and (307 ± 2) nm] on health-promoting secondary plant metabolites (carotenoids, phenolics, and glucosinolates) of green and red leafy vegetables species belonging to the botanical family Brassicacea, Chenopodiaceae, Lamiaceae and Lactucaceae.

Plants were grown under controlled climate conditions. At 4-5 leaf stadium, plants were treated with different doses of biological effective UVB (UVBBE) radiation at 4 subsequent days (290 nm: 1.12 kJ m-2, 2.25 kJ m-2, and 4.51 kJ m-2; 310 nm: 0.35 kJ m-2, 0.72 kJ m-2, and 1.43 kJ m-2). After 24 hours of adaption, plants were harvested on day five.

For all analyzed secondary plant metabolites a treatment with both UVB wavelengths influenced the amounts of carotenoids, phenolics, and glucosinolates depending on the chemical structure of the individual compound, applied dose, and plant species. Furthermore, red and green leafy cultivars responded differently to the UVB application. Exemplary, for Brassica rapa ssp. chinensis it was shown that chlorophyll b and lutein increased by 50-70% for the highest UVB doses of both wavelengths. For the glucosinolates, treatments with 4.51 kJ m-2 UVBBE (290 nm LEDs) or 1.43 kJ m-2 UVBBE (307 nm LEDs) increased the content of total indole glucosinolates by 70% and 140%, respectively, compared to control plants. The effects of UVB on phenolics and aliphatic glucosinolates were more complex and strongly structure-specific.

In conclusion, the application of narrow-band UVB radiation from LEDs increases health-promoting secondary plant metabolites in various vegetables. These results are a promising start point to develop a horticultural UVB-LED light system for greenhouses.

Postharvest UV-B application on fruits. A study on nutraceutical quality, shelf life and responses to fungal infection

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At low ecologically-relevant levels, ultraviolet-B (UV-B) radiation (280-315 nm) represents a crucial factor for a wide range of aspects in a plant lifestyle. The discovery of a specific mechanism of UV-B perception, through UVR8 receptor, and the subsequent signal transduction pathway paved the way to investigate the possibility to exploit UV-B radiation to improve the health-protective properties of plant food. In fact, it is well-known that UV-B is able to stimulate the secondary metabolism of plants, thus potentially increasing the health-promoting value of deriving food. Furthermore, few researches investigated the effect of UV-B exposure on the plasticity of cell wall that is responsible for the softening process during shelf-life of fruits. Dismantling of the cell-wall architecture, due to changes in expression/activity of cell-wall localized enzymes acting on specific components (mainly polysaccharides) of this structure, is an important factor of texture changes during ripening of fleshy fruits. Based on all the previous considerations, the results presented will be about the effect of different duration of UV-B exposure on the aspects mentioned above. Melting flesh yellow peaches were exposed for 10 min or 60 min to UV-B radiation (2.31 W m-2). Afterwards, the fruits were kept at room temperature for up to 36 hours. UV-B exposure determined a general decrease of flavonoid compounds after 24 h in all UV-B-treated samples, maybe due to their reaction with UV-B-induced ROS. However, after 36 h, a higher accumulation of most compounds was detected, more evident in the 60 min-treated fruits. Such increase was more evident for anthocyanins, dihydroflavonols and flavones, suggesting an application of UV-B as nutraceuticals increasing tool in fruit. Moreover, molecular analyses revealed a higher expression of several genes involved in the phenylpropanoid pathway (e.g. *CHS*, *F3H*, *F3'H* and *DFR*) as well as some genes involved in the UVR8 pathway (e.g. *COP1*, *HY5*) 6 h after the UV-B irradiation. This could mean that the accumulation of phenolics might be due to an increased expression of flavonoid biosynthetic and regulatory genes in response to UV-B. Besides, an effect of UV-B exposure was shown also on other metabolic classes such as terpenoids, lipids and alkaloids, with different variations according to each class. UV-B was also shown to affect the softening process. in fact, the activity of the enzymes involved in dismantling the cell wall architecture, such as endo-polygalacturonase, β-galactosidase and pectin methylesterase, was negatively affected by UV-B radiation, in a way that the longer was UV-B exposure, the lower was the activity detected. The reduced activity of cell wall degrading enzymes, determining a slower softening, could allow a longer shelf-life of the fruit. UV-B has been shown to be effective in stimulating the defensive mechanisms against pathogen and pest attacks, inducing a fine modulation of protective phenolics. Harvested peaches were UV-B-treated for 1 up to 12 hours, and afterwards infected with *Monilinia fructicola*. The fruit were then stored for 72 hours under PAR light in controlled temperature and humidity conditions. Skin and flesh samples were taken closely outside the necrosis and far from the necrosis. The UV-B exposure of 3 h was effective in stimulating cyanidin-3-glucoside and some flavonols only far from the necrosis, suggesting a potential systemic effect of the fungus in enhancing the phenolic accumulation. In the flesh, trend is different according to each phenolic class. Detailed data about behavior of specific compounds will be further discussed.

Application of UV LEDs for DNA analysis

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Characterising the amount and the purity of nucleic acid is an important step in state of the art polymerase chain reaction (PCR). In most cases, the analysis is done by stand-alone equipment. For the measurement, a small amount out of the PCR-process has to be removed. Furthermore, the evaluation of the measured spectra occurs only at three wavelengths (230 nm, 260 nm, 280 nm). Therefore, it should be possible to monitor the PCR-process in situ.

We demonstrate an illumination unit with three UV-LEDs (245 nm, 265 nm and 280 nm). Every LED is collimated by two lenses. Two longwave-pass filters merge the optical axes of the different wavelength. Lenses and filters are commercial available. The illumination unit is available with and without fiber coupling. Without fiber coupling the illumination unit enables the parallel measurement of titerplates (8 mm pattern).

The optical behavior of the illumination unit will be shown and discussed. Especially the redesign of the lens unit leads to better optical quality. Further, we investigate the observed peak position of the supporting points in dependence of the impurity concentration of an example solution.

Experiences with in-vivo and in-vitro tests of sun protection products

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Sunscreen products aim to help protect the skin against UV-rays and consequently reduce the risk of early skin ageing and skin cancer. The SPF sunscreen labels in EU are divided in four categories, namely low (SPF 6, 10), medium (SPF 15, 20, 25), high (SPF 30, 50) and very high (SPF 50+). The SPF is quantified by a standardized test method according to EN ISO 24444:2010. In short, the minimum erythemal dose (MED) on unprotected and sunscreen protected skin is measured and the just perceptible visible sunburn (redness) is used as biological endpoint. This procedure has several disadvantages, such as ethical problems, seasonal deviations, long irradiation times and high costs.

By developing an alternative in vitro method, we have designed a procedure in which the transmittance of a sun protection product is measured on PMMA plates. Irradiation conditions are similar to the in-vivo method.

However, so far no SPF in-vitro test method has been generally accepted due to the lack of reliable results in international ring studies. Here it is mandatory that the measurements are performed by a trained operator. A further problem is a varying affinity of the sun protection products to the PMMA plates. Here different variations of roughness or structures as well as molded and sand-blasted plates were tested.

In future an alternative method – non invasive, but based on human skin could be a hopeful solution for the SPF determination.

Non-invasive sun protection factor determination using LED light

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Sun protection is important to reduce premature skin aging and skin tumors. The application of sunscreen is one protection strategy and various formulations are available. For every new sunscreen or cosmetic product claiming protection from UV radiation, the sun protection factor (SPF) must be determined. The current method is invasive; determining the time until a sunburn is induced with and without sunscreen application, respectively. So far, all research efforts to establish a method for determining the SPF non-invasively in vitro have failed as the results could not be transferred to skin in vivo. One major problem is the inhomogeneous distribution of the various formulations on the skin.

A new approach for determining the SPF is based on in vivo reflectance spectroscopy applied on skin using a UV-LED with a dose 5 times lower than the minimal erythema dose (minimal dose causing a sunburn) [1]. With this method, the backscattered light is detected at different distances from the incident light. The backscattered light is also dependent on the skin coloring. Porcine skin containing no melanin has 10 times higher reflectance values than human skin. Therefore, in a first in vivo study only skin types I to III were included. This is in accordance with the skin types of volunteers recruited for invasive SPF in vivo determination by test institutes. First results were obtained using one UVB - LED and a photodiode. The method is mainly limited by the low intensity of backscattered light after the application of formulations with high SPF. Nevertheless, the first in vivo data correlated well with the SPF determined by test institutes. Formulations with chemical filters only or in combination with physical filters can be investigated. For the test institutes a more complex device is set up, consisting of multiple UV-LEDs and a spectrometer for detection.

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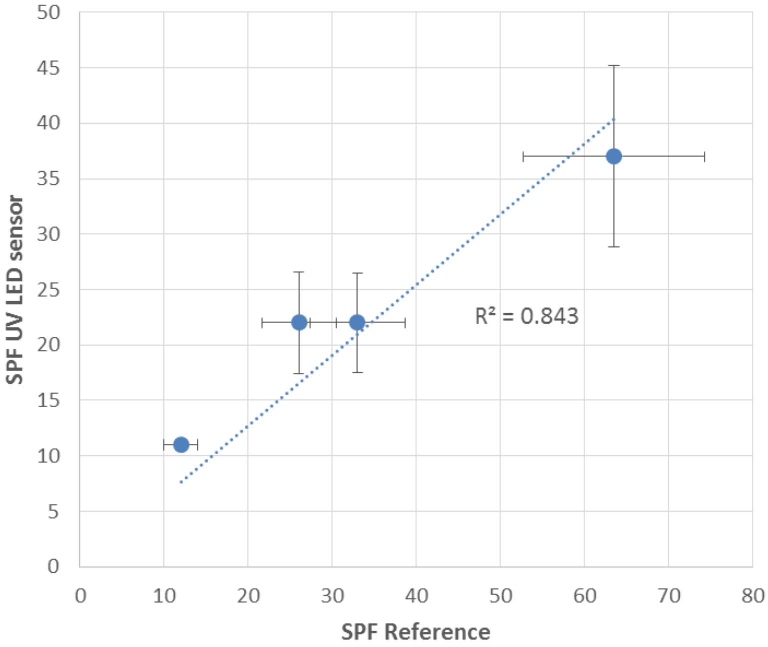

Fig. 1: Comparison of the SPF values of 4 different creams determined by the non-invasive LED reflectance based device and the reference method based on the erythema measurement on the back of volunteers. The error bars correspond to standard error of the mean (SEM, n = 3 to 6). In case of the reference values the maximally allowed SEM according to ISO 2444:2010 is shown, in order to symbolize the uncertainty of the reference values.

Limits and Possibilities to Detect Free Radical Formation in Skin during UV-Irradiation

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A moderate dose of UV irradiation is indispensable for our health; it is needed for the vitamin D synthesis. However an excessive exposure to UV radiation could cause oxidative stress and skin damage, such as an increased free radical formation, erythema, premature skin aging and skin cancer. Too high an amount of free radicals could induce oxidative stress and cell damage. The investigation of the free radical formation provides information about the oxidative stress in skin. Additionally, the relation of reactive oxygen species (ROS) to lipid oxygen species (LOS) is of interest as a marker between positive (ROS > LOS) and negative oxidative stress (LOS > ROS).

To determine the amount and type of free radicals in skin, electron paramagnetic resonance (EPR) spectroscopy can be applied during simulated sun irradiation. In the present study the radical formation was measured in different skin models (reconstructed human skin (RHS), ex vivo human, porcine and murine skin) under comparable conditions.

The highest amount of free radical formation was detected in RHS followed by porcine = murine, and finally human skin, all skin models below one minimal erythema dose (MED, 25mJ/cm² UVB). All skin models formed ROS and LOS within 0-18 MED measured with the spin trap DMPO.

However, the characterization of the free radicals is limited by the irradiation source. As gold standard sun simulators with Xe-lamps are used. However, this irradiation source has a low irradiance and is instable over time. The life time of spin trap radical adducts is limited, therefore a fast irradiation at high irradiance would be needed to avoid decay influences. A solution would be the use of UV LEDs. So higher signal-to-noise ratios and decreased error bars could be achieved

Light-initiated drug release from nanocarriers

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Skin antisepsis is a crucial measure conducted prior to any surgical intervention, as it is essential to prevent surgical site infections (SSI). Unfortunately, due to galenic reasons, traditional skin antiseptics are not able to reach the skin appendages, such as the hair follicles, which are the reservoir of about 25% of the skin pathogens. Originating from this reservoir, the skin pathogens re-colonize the skin surface very easily and rapidly. Especially in surgical procedures lasting longer than an hour, this can increase the risk of SSI drastically. A new approach is to use nanocarriers as transporters for skin antiseptics into the hair follicle in order to also eradicate the hair follicle-associated skin pathogens, which could lead to a significantly delayed re-colonization of the skin. Here, the release of the antiseptics from the nanocarriers has to be time- and site-controlled. This can be realized by UVA-responsive nanocarriers, which transport the antiseptic deeply into the hair follicle. Here, it is released by UVA-irradiation, which is achieved by an UVA-LED-light source fixed on the applicator for the antiseptic. In this way, the UV light and antiseptic are simultaneously applied and can interact directly during application. Previous investigations could already demonstrate that liposomal antiseptics penetrate significantly deeper into the hair follicles due to their particulate structure than traditional antiseptics. However, it is expected that significantly higher concentrations of antiseptics can be transported into the hair follicle when loaded to specifically customized UVA-responsive nanocarriers. The principle of the triggered release concept has already been proven for other trigger sources such as infrared, pH and temperature. For the indication of skin antiseptics, the UVA-responsive release of the antiseptic from the nanocarriers seems to be the most promising approach as it is independent from the patients’ condition and heat generation. The realization of the project will significantly reduce the occurrence of SSI.

UV-LEDs for spectroscopic sensor application

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Optical spectroscopy in the ultraviolet wavelength range shows some benefits versus the classical absorption spectroscopy in the mid infrared (MIR) and near infrared (NIR). Spectroscopy in the infrared region, the so called finger print region, benefits from the excitation of rotational, vibrational and overtone modes of the molecules. A huge number of gas molecules show characteristic absorption lines here. In the UV-VIS range the light absorption is caused by electron excitation. Line absorptions for gas molecules appear and depending on its complexity a number of lines can overlap to a broad absorption band. Compared to the infrared only a limited number of molecules show a significant absorption in the optical window (ca.>180 nm). In practical application the IR-absorption spectroscopy is often harmed by strong interfering absorbers such as water vapour. Therefor IR-systems often require dry gas and/or very narrow line width measurement techniques (e.g. quantum cascade lasers) to avoid cross-interferences and to reach high resolution.

UV-spectroscopy is well known for a long time, it benefits from the absence of absorption lines from strong absorbers such as water vapour or CO2. While sensitive and robust detectors have been available for long time, no adequate light sources for compact sensor applications have been available since a few years ago. Before the rising of UV-LED development, only gas discharge lamps based on deuterium, xenon or specialised edls (electrodeless discharge lamp) could be utilized. These lamps show issues regarding life time, warm up time, spectral stability, mechanical robustness as well as size and complexity (costs). In this publication we show the use of modern DUV-LEDs for sensor applications with measurement examples of NO, NO2, SO2 and O3. In addition, we demonstrate the partly higher spectral power density of optical fibre coupled UV-LEDs in comparison to a state of the art fibre coupled deuterium lamp.

ULTRA.*sens*®: UV LEDs in industrial gas sensing applications

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The detection of environmental relevant gases like sulfur dioxide SO_2 and nitrogen dioxide NO_2 is very important for many industrial applications. Especially for exhaust gas monitoring in power plants low power and small size gas detector are required for portable applications. NDIR[1] based gas detectors are very sensitive to water vapor content in the exhaust gas. High quality NDIR gas analyzers are mostly sensitive to shock/vibration and the size and power consumption is not suitable for portable purposes.

Based on the NDUV[2] principle we developed a novel low power gas detection system called ULTRA.*sens*® using deep UV LEDs. In 1985 this LED based technology was introduced by G. Wiegleb [1]. At this time LEDs were only available for the detection of NO_2. Today AlGaN-LEDs are commercial available down to 250 nm. Using this type of UV LEDs it is possible to measure SO_2 and NO_2 simultaneously down to a concentration level below 1ppm without any cross interference to other gases in the exhaust like water vapor and carbon dioxide [2]. Furthermore fast response gas analysis is feasible for applications in analytical instruments. Using UV LEDs in different spectral regions, very high dynamic measuring ranges between low ppm level and high Vol.-% level are manageable in one gas detector.

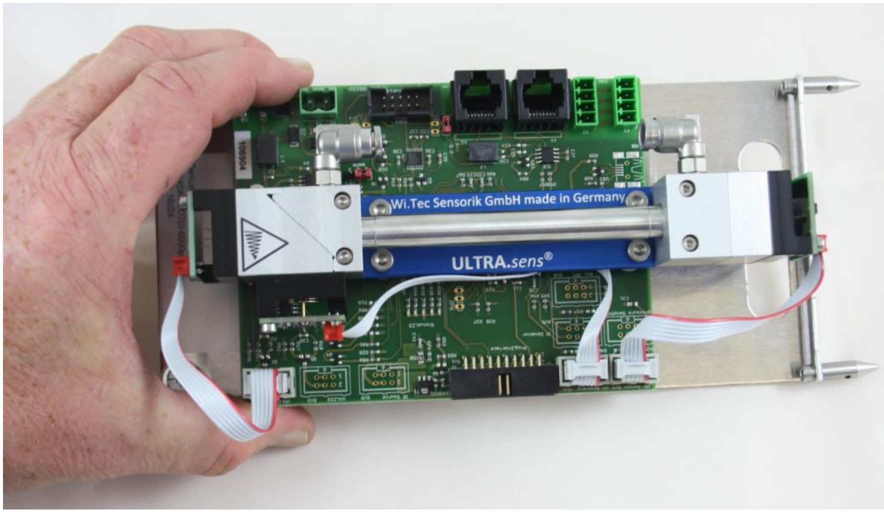

Fig. 1: ULTRA.*sens*® detector for simultaneous analysis of low level SO_2 and NO_2 concentration in flue gas

References:
[1] Wiegleb, G.: Einsatz von LED-Strahlungsquellen in Analysengeräten, Laser und Optoelektronik Nr. 3 (1985) 308-310
[2] G. Wiegleb, Gasmesstechnik in Theorie und Praxis, Springer-Vieweg Verlag 2016

[1] **N**on **D**ispersive **I**nfra **R**ed
[2] **N**on **D**ispersive **U**ltra **V**iolet

Development and Application of UV-LED Gas Sensing Devices

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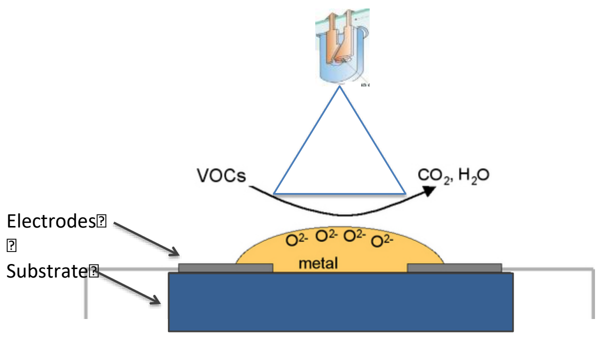
Deep UV-LED is a new technological field that has recently seen rapid improvements and novel possible applications. These include the development of UV-LED based gas sensors.

Detecting and monitoring hazardous gases and gas pollutants in industrial and urban settings is of increasing importance. Chemical gas sensors are one of the most promising devices for gas detection. However, a drawback of conventional chemical-resistive gas sensor is their high operating temperature (200°C to 500°C), which results in high cost and high power consumption, and most importantly limits their technical applicability in the detection of flammable gases. To address these challenges we have developed UV-LED based gas sensing devices for detecting and monitoring toxic gases in industrial settings, and gas pollutants in urban settings.

We will discuss how UV-LED of appropriate wavelengths and intensity was applied to the activation of a UV-sensitive semiconductor layers for detecting toxic gases. We will present our approach for the synthesis of engineered semiconductor thin layers, including mixed metal oxides by advanced fabrication techniques. One example, which will be explained, is the fabrication of coupled n-type semiconductor oxides of ZnO and In_2O_3 to obtain nano-crystalline composite sensing materials. Finally, we will present our results on the development of highly effective UV-activation sensors that operate at ambient temperature. At the end, we will discuss how UV-LED has the potential to significantly impact sensor development and portable gas monitoring systems by enabling novel sensor design concepts and the integration of the LED-based sensors into wearable devices.



The functional principle of UV-LED activated sensors: VOCs (volatile organic compounds) in the environmental air react with oxygen atoms of the semiconductor metal oxide activated by UV photons. The released electrons lead to a change in the resistance of the semiconductor, which then creates a signal.

Application of deep UV-LEDs for metrology and process control in semiconductor industry

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In semiconductor industry, optical metrology is indispensable for monitoring and control of complex manufacturing processes, as optical measurement techniques allow for non-destructive and non-invasive assessment of critical process parameters.

In industrial epitaxy, where thin layers of different materials are deposited to eventually form semiconductor devices such as lasers, light emitting diodes, transistors and solar cells, optical in-situ reflectometry has become a standard method to characterize key layer properties already during the deposition process. Recently, UV-LEDs are complementing the range of visible LEDs, routinely used as light sources in reflectometry, providing an even wider range of wavelengths for in-situ metrology applications. Hence, the development of UV LEDs, emitting in the UV-B and UV-C range, has opened new opportunities to measure very thin layers and graded interfaces in increasingly complex epitaxial growth processes.

In this presentation, it will be shown, how UV-B and UV-C LEDs are used as light sources in optical metrology equipment to control the fabrication of modern semiconductor devices. The short wavelength light allows to characterize ultra-thin layers, with a thickness in the range of just several nanometers. In addition, the shorter wavelength increases the sensitivity to measure surface roughness and other morphology effects. Finally, UV-LED based metrology is also employed to control the deposition process for the fabrication of UV-LEDs itself, providing opportunities for better process control and yield improvement.

Characterization and calibration of compact array spectroradiometers for spectral measurements of UV-LEDs

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Development and application of newly developed UV-LEDs require knowledge of their main radiometric characteristics, such as spectral irradiance, effective wavelength, bandwidth and total (spectral) radiant flux. For measuring such spectroradiometric properties, compact and fast array spectroradiometers are more and more used. However, their applicability for the measurements, especially in the UV spectral region, requires thorough characterizations and calibrations of the instruments.

For traceable measurements of the radiometric quantities, the array spectroradiometers are calibrated using transfer standard lamps, typically of quartz-tungsten-halogen type. However, these calibration standards generally have different spectroradiometric characteristics than the sources to be measured in the radiometric applications. Therefore, the transition from the instrument calibration to the measurement of UV radiators such as UV-LEDs requires knowledge about critical properties of the array spectroradiometers. For example, the increasing fraction of stray-light at shorter wavelengths in the instrument can cause huge measurement errors. Furthermore, the measured spectrum of a UV-LED may be significantly distorted due to irregularly shaped and peak wavelength-dependent bandpass functions of the instrument. Also several other properties of the instruments, such as nonlinearity of the array detector system, pixel-to-wavelength assignment, temperature dependencies, reproducibility, repeatability and geometrical properties of the input optics must be accurately determined and accounted for. Accurate knowledge of the instrumental parameters is required in order to quantify and to reduce the measurement uncertainties.

It has to be noted that since the individual properties of array spectroradiometers vary from instrument to instrument, the respective characterizations should be carried out for every single instrument and its intended application.

The presentation gives an overview of critical array spectroradiometer properties as well as the respective characterization and correction methods. The impact of deficient spectral measurements on determined radiometric parameters of UV-LED will be highlighted as well as possible ways to reach correct and traceable measurement results will be demonstrated.

Why and how to characterize UVC LEDs? Part 1: Test protocols, aging and temperature behavior

K.-H. Schoen[1], T. Schwarzenberger[1], J. Eggers[1]
[1]*TZW: DVGW-Technologiezentrum Wasser, Karlsruher Str. 84, 76139 Karlsruhe, Germany*

Being part of the German Gas and Waterworks Association (DVGW), the TZW (German Water Centre) focuses on close-to-application research and providing scientific advice. The department Test Centre is accredited for over 200 product standards and performs UV-disinfection device validation according the UVDGM and DVGW protocols.
With more LED-disinfection devices pushing on the market, the call for a standardized biodosimetric test procedure gets louder. The next step, important for municipal drinking water or other large-scale applications, is a comprehensive test protocol, which also covers technical requirements. This includes knowledge of crucial parameters for LEDs, how to measure them, what to monitor and general operation guidelines.
We will briefly look at different current LED-disinfection devices and discuss important issues for a validated large-scale usage in the future. To investigate which parameters could influence the disinfection efficacy, TZW started several measurement setups. This presentation focuses on aging and temperature behavior of LEDs modules conducted in an incubator. Operated were eight LED-chips from two manufacturers and five different wavelengths between 260 nm – 280 nm. For a 276 nm module, first measurements show a wavelength shift by about 1 nm and a reduction in the total output of 10 – 15%, when changing the ambient temperature from 2°C to 40°C. For the aging experiments, all LED chips were operated at their recommended forward current starting from an unaged state. Their output was measured regularly with a spectroradiometer. The full spectrum between close to no aging for 278 nm chips up to 40% loss for 260 nm chips was visible after 100 hours. Part 2 is presenting measurement methods and data-sheet comparisons about directivity and absolute UVC output.

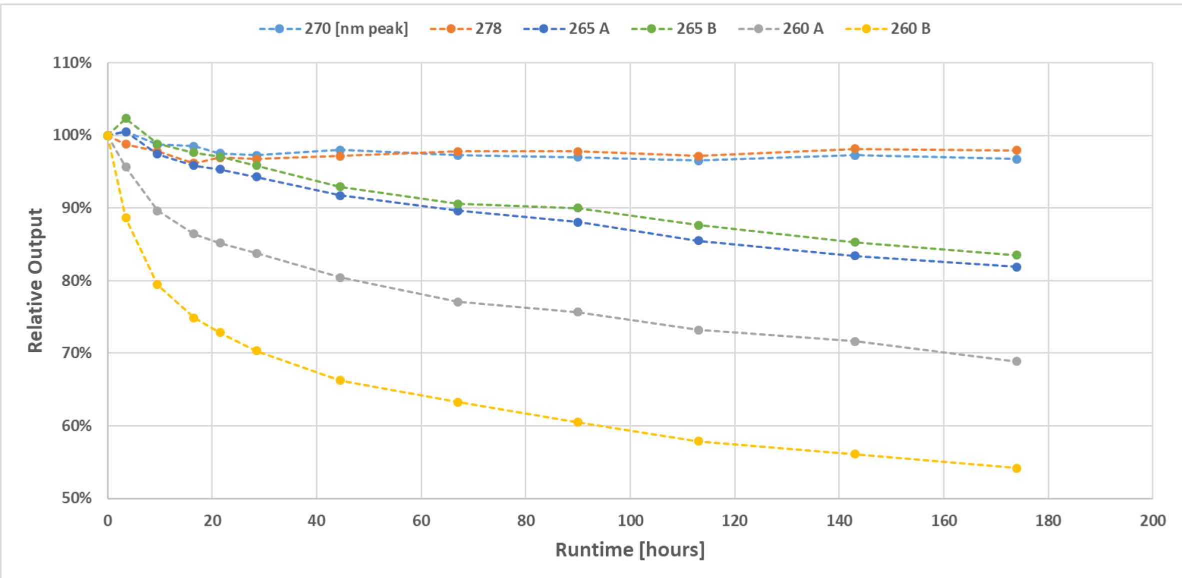

Fig. 1: Loss in UV-output of six different LED-modules due to aging at 22°C.

Why and how to characterize UVC LED? Part 2: Measurement of directivity and UVC output

T. Schwarzenberger[1], K.-H. Schön[1], J. Eggers[1]
[1]*TZW: DVGW – Technologiezentrum Wasser, Karlsruher Strasse 84, 76139 Karlsruhe, Germany*

Following on from "Part 1: Test protocols, aging and temperature behavior", this presentation investigates further specifications of UVC LEDs. The focus lies on the measurement of directivity and presents models to calculate the UVC output in simple lab environments without using expensive integrating spheres or goniometers.

Eight LED chips from two manufacturers with five different peak wavelengths were measured and characterized before and after aging for about 1000 hours. In addition, a possible impact of the ambient temperature from 2-40°C under defined conditions was investigated (see Part 1). Prior to that, each LED chip was mounted on a circuit board with cooling fins and a fan to ensure a stable operation (no increase of the temperature) for a constant forward current in accordance to the data sheet.

For each LED the directivity and UVC output were measured and compared to the related data sheet. To determine the radiation pattern two different methods were used. For method A, a spectroradiometer was fixed and the LED was turned in the rotational axis between -60° and +60° (no change of the measurement distance). For method B the LED was fixed and the plane of irradiation was scanned with a spectroradiometer (change in measurement distance), so that the directivity was calculated by means of trigonometric functions. The measurements, repeated for different distances of source to sensor in the near and far field, were used to compare these simple setups. First results showed a good agreement between the two methods, but discrepancies to the values of the data sheets. Reasons for that and possible sources of errors shall discussed in the presentation as well.

Standardization of Measurement of UV-LED Lamp Output, Feasibility and Tolerance to Error

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The development of a protocol was initiated in 2015 to establish standardized deep Ultraviolet Light Emitting Diode (UV-C LED) output testing conditions, methods, and reporting which will enable greater confidence in UV-C LED applications for system designers, regulators, researchers, and end users. This protocol is an International UV Association (IUVA) initiative, undertaken by a working group of the IUVA Manufacturers Council, and is designed to not only facilitate standardized laboratory methods but also create and validate a formal protocol which laboratories can use to better describe the output of their UV-C LEDs. The protocol was designed to test and compare standardized UV- C LED lamp emission spectra (power output and wavelength) under standardized equipment and different ambient conditions with different operators.

An independent third party at the University of Colorado Boulder developed and validated the proposed testing protocol for the measurement of UV-C LED lamp output. The standardized protocol and calibrated equipment was sent to fourteen USA and international participants (UV LED manufacturers, system designers, and researchers) for round robin testing in 2016. Measurements consisted of experimental conditions, output spectrum, and radiometer readings. Minimal variability resulted from operational differences (i.e., distance from and orientation of the source to the sensor) when comparing the round robin testing equipment. However, significant variability resulted from the in-house testing equipment owned by the various participants. Results from the measurements using shared equipment as well as feasibility and potential costs of proposed strategies for minimizing the variability between each participants' in-house equipment will be presented and discussed. Options for an industry-wide tolerance to error will also be presented.

A stray light corrected array spectroradiometer for complex high dynamic range measurements in the UV spectral range

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[1]*Gigahertz-Optik GmbH, Türkenfeld, Germany*
[2]*Physikalisch- Technische Bundesanstalt, Braunschweig, Germany;*

Internal stray light is often the dominant factor limiting the accuracy of array spectroradiometers when measuring UV radiation. For instance, unwanted scattering, multiple reflections, and higher order diffraction within an instrument contribute to internal stray light resulting in an error signal. Stray light is heavily dependent on the spectral distribution of the source being measured as well the instrument itself. The diminishing responsivity of conventional detectors in the UV region further increases the relative sensitivity to stray light from other wavelengths. Therefore, any stray light becomes increasingly significant at shorter UV wavelengths. Common biological action spectra, such as erythema, require weighting factors covering several orders of magnitude thereby requiring a UV spectroradiometer with wide dynamic range and high stray light suppression. The disparity between the intensity of available calibration sources and the UV sources used for curing and disinfection, for example, also benefits from high dynamic range instruments.

Double monochromators have traditionally been the preferred reference instrument for many UV spectroradiometry applications because of their wide dynamic range and high stray light suppression capabilities. For array spectroradiometers mathematical correction techniques, based on characterization of line spread functions using tunable lasers, may be applied to suppress internal stray light. However, these methods cannot account for stray light resulting from out of measurement range wavelengths. An innovative compact array spectroradiometer is presented in which the stray light is physically reduced with the help of an internal filter wheel incorporating a smart combination of optical filters. The instrument and its elaborate components have been extensively characterized at the PTB.

The precise measurement of solar radiation in the UV spectral range is a particularly demanding application. The intense radiation of the sun in the VIS and IR generates stray light within the spectrometer which can easily dominate over the less intense solar UV radiation. The unit’s performance was demonstrated with measurements of direct solar irradiance during an international inter-comparison of total ozone measurements [1]. With this proven quality, the device’s suitability for UV LED measurements across many fields of application is assured.

[1] Zuber, R., Sperfeld, P., Riechelmann, S., Nevas, S., Sildoja, M., and Seckmeyer, G.: Adaption of an array spectroradiometer for total ozone column retrieval using direct solar irradiance measurements in the UV spectral range, Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2017-240, in review, 2017.

Round Table on UVC LED System Standards

The discussion on UVC LEDs is mainly around components, LED improvements and potential markets. As the technology comes much closer to market, it's time to prepare the basics for system integration. We invite you to take the initiative with us to think towards System testing and validation.

Do we need new design standards?
How should they look like?
Which timeline is required?
We count on your input and thoughts!

Yours,
Jutta Eggers (TZW) and Nico Morgenbrod (OSRAM GmbH)

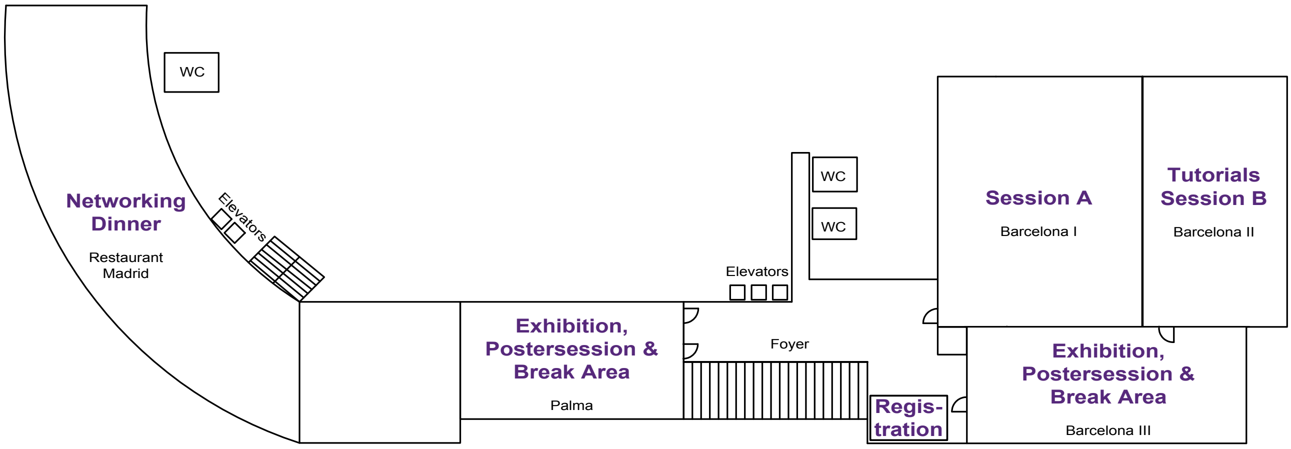
Sightseeing: Berlin – A City in Transition

Meeting point in front of MELIÃ Hotel

Experience Berlins historic and alive side of life and discover in an one-hour tour the German capital as a metropole of constant change, as the symbol of reunion and location of new ideas. You will be guided by a professional consultant starting at the effervescent Friedrichstraße towards famous sights. You will be given a short introduction of what happened to the city's development since the fall of the Berlin Wall, added with an overview of Berlin's political and historical meaning and you will be turning to Berlin's megatrends and it's architectonic giants. Through your tour you will be walking along the river Spree and heading towards the government district with the Parliament, the Pariser Platz, the Brandenburger Tor and finally to the Potsdamer Platz where you in the end experience Berlin as a city in transition!

Participation in the city tour is limited. Please contact the registration counter if you would like to attend.

EVENT AREA MELIÃ HOTEL BERLIN



EXHIBITORS

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ICULTA-2018
PROGRAM AT A GLANCE

Time	Sunday, April 22	Monday, April 23 – Room Barcelona I	Monday, April 23 – Room Barcelona II	Tuesday, April 24 – Room Barcelona I	Tuesday, April 24 – Room Barcelona II	Wednesday, April 25
07:00		7:00 - 17:00 | Registration				
08:00		**8:00 - 8:30 | Opening** (Barcelona I)		8:00 - 17:00 | Registration		
		8:30 - 10:00 | Mo-A1 **Water & Disinfection I**	**8:30 - 10:00 | Mo-B1** **Medical Applications I**	**8:30 - 10:00 | Tu-A1** **Semiconductors & Devices III**	**8:30 - 10:00 | Tu-B1** **Plant Growth & Food II**	
09:00						9:00 - 10:00 Transfer
10:00		**10:00 - 10:30 | Coffee Break & Exhibition**		**10:00 - 10:30 | Coffee Break & Exhibition**		**10:00 - 12:00** **Technical Tours / Visits**
		10:30 - 12:00 | Mo-A2 **Semiconductors & Devices I**	**10:30 - 12:00 | Mo-B2** **Plant Growth & Food I**	**10:30 - 12:00 | Tu-A2** **Water & Disinfection III**	**10:30 - 12:00 | Tu-B2** **Medical Applications II**	
11:00						
12:00		**12:00 - 13:00 | Lunch Break & Exhibition**		**12:00 - 13:00 | Lunch Break & Exhibition**		
13:00	13:00 - 19:00 | Registration	**13:00 - 14:30 | Mo-A3** **Water & Disinfection II**	**13:00 - 14:30 | Mo-B3** **Spectroscopy I**	**13:00 - 14:30 | Tu-A3** **Water & Disinfection IV**	**13:00 - 14:30 | Tu-B3** **Spectroscopy II**	
14:00	**14:00 - 17:30 | Tutorials** (Barcelona II) **14:00 - 14:45 | Su-1** **Selected Topics of Frontend Process Technology of UV LEDs**					
		14:30 - 15:00 | Coffee Break & Exhibition		**14:30 - 15:00 | Coffee Break & Exhibition**		
	14:45 - 15:30 | Su-2 **UV for Disinfection and Water Purification**					
15:00		**15:00 - 16:30 | Mo-A4** **Semiconductors & Devices II**	**15:00 - 16:30 | Mo-B4** **UV Curing I**	**15:00 - 16:30 | Tu-A4** **Semiconductors & Devices IV**	**15:00 - 16:30 | Tu-B4** **Measurement**	
	15:30 - 16:00 | Coffee Break					
16:00	**16:00 - 16:45 | Su-3** **UV LED Lamp Systems in UV Curable Industrial Applications**					
		16:30 - 18:30 | Poster Session & Exhibition		**16:30 - 17:00 | Closing Remarks** (Barcelona I)		
	16:45 - 17:30 | Su-4 **UV LEDs in Medicine - Photobiological Basics and Future Aspects**					
17:00				**17:00 - 18:30** **Roundtable on UVC System Standards** (Barcelona II)		
18:00	**18:00 - 20:00 | Welcome Reception**					
		18:30 - 21:30 | Networking Dinner				
19:00				19:00 - 20:00 | optional: Guided Sightseeing		
20:00						
21:00						