ICULTA
2021

The 2nd International Conference on

UV LED Technologies & Applications

April 19 – 20, 2021

ADVANCED
UV FOR LIFE

INTERNATIONAL
IUVA
ULTRAVIOLET ASSOCIATION

THANK YOU FOR YOUR SUPPORT!

Sponsors

↗ **www.aquisense.com**

↗ **www.lasercomponents.com**

↗ **www.osram.com**

Conference Chairs

Sven Einfeldt | Ferdinand-Braun-Institut
Oliver Lawal | AquiSense Technologies

Program Chairs

Jutta Eggers | TZW: DVGW – Technologiezentrum Wasser
Markus Weyers | Ferdinand-Braun-Institut

Conference Office

Mickey Fortune | IUVA
Antje Mertsch | Advanced UV for Life

2nd International Conference on UV LED Technologies & Applications

Welcome to ICULTA 2021

April 19 - 20, 2021
Virtual event

The inaugural ICULTA conference in 2018 was an outstanding success. With over 260 participants from 23 countries gathered together to educate, discuss, learn, connect and arrange business, specifically centered around UV LED technology and their multiple applications. At the time, we commented that “The great success of ICULTA demonstrates the rapid advancement of UV LEDs, and wide range of solutions the technology has to offer.” Now in a world reeling from the impact of a global pandemic, the need for robust disinfection technologies has become highlighted in a way not imaginable three years ago.

So as we enter this 2021 conference we can be both proud of the progress we have made in developing this technology into life-saving applications, and also excited about the future developments still to be achieved. Of course the application in UV-LED technology is wide ranging and this conference will really highlight the amazing breath of work being completed.

Sessions have been organized along key topics, including “LED Technology”, “Disinfection & Purification”, “Medical Applications”, “SARS-CoV-2”, “Food & Biotech Applications”, “Analytics”, “Measurement Technology”, “UV Curing”, and “Standardization”. The virtual event will feature oral talks, a panel discussion, poster sessions, and an accompanying exhibition.

ICULTA is organized jointly by the German consortium “Advanced UV for Life” (www.advanced-uv.de) and the “International Ultraviolet Association” (IUVA | www.iuva.org). On behalf of everyone involved, the many that have providing organizational support, thank-you for spending your time here with us.

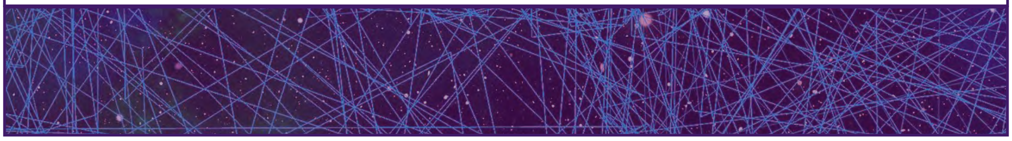
We look forward to the stimulating content and encourage everyone to engage fully in the program and discussion available.

Your conference chairs

Sven Einfeldt
Ferdinand-Braun-Institute, Germany
Representative of the ‘Advanced UV for Life’ consortium

Oliver Lawal
AquiSense Technologies, USA
Past-President of the International Ultraviolet Association

Conference Program



Monday, April 19, 2021

Time in CET – Central European Time (UTC +1)

08:15-08:30

Welcome & Opening Remarks

08:30

Exhibition Open

08:30-09:00

Plenary Session Mo-AB1

UV-LEDs for Water Disinfection: The Forefront of Research and Applications
Kumiko Oguma | *University of Tokyo*

Chair: Tim Wernicke | Technische Universität Berlin

09:00-10:10

Session: Mo-A2
Analytics

Chair: Humberto M. Foronada | OSRAM

09:00-09:20 | Mo-A2.1 (Invited)
Characteristics of UV-LED sources for spectroscopic applications
C. Söller, L. Schäfer, A. Schnabl, O. Deppert, T. Jenek
Heraeus Noblelight GmbH, Germany

09:20-09:40 | Mo-A2.2 (Invited)
Development of LED based diffuse reflectance spectroscopy device for the non-invasive in vivo measurement of UVA-PF and SPF
G. Wiora[2], C. Throm[1], C. Reble[2], S. Schanzer[1], S. Kobylinski[1], J. Schleusener[1], H. Karrer[3], L. Kolbe[4], I. Gersonde[5], N. Lobo-Ploch[6], G. Khazaka[2], M. Meinke[1], J. Lademann[1]
[1]Charité - Universitätsmedizin Berlin, [2]Courage + Khazaka electronic GmbH, [3]Hans Karrer GmbH, [4]Beiersdorf AG, [5]University of Potsdam, [6]Ferdinand-Braun-Institut

09:40-09:55 | Mo-A2.3
Construction and characterization of a high-power UV-LED module as radiation source for goniometric spectral radiance factor measurements
I. Santourian[1], S. Teichert[1], A. Schirmacher[1], T. Quast[1], K.-O. Hauer[1]
[1]Physikalisch-Technische Bundesanstalt (PTB)

09:55-10:10 | Mo-A2.4
DNA analysis with UV LEDs
C. Möller[1], M. Hentschel[2], M. Weizmann[3], Th. Ortlepp[1]
[1]CiS Forschungsinstitut für Mikrosensorik GmbH, [2]Analytik Jena AG, [3] OSA Opto Light GmbH

09:00-10:10

Session: Mo-B2
Food & Biotech Applications

Chair: Tim Wernicke | Technische Universität Berlin

09:00-09:20 | Mo-B2.1 (Invited)
Peach flesh metabolome is modulated by UV-B radiation although UV-B does not penetrate the peach skin
A. Ranieri[1]*, M. Santin[1], A. Castagna[1], M.-T. Hauser[2], M. B. M. Moreno[3], L. Lucini[4]
[1]University of Pisa, [2]University of Natural Resources and Life Sciences,
[3]Università Cattolica del Sacro

09:20-09:40 | Mo-B2.2 (Invited)
UV-C LED usage for bacterial decontamination of technical surfaces in food processing
S. Fleischmann[1], S. Opherden[1], P. Rotsch[2], G. Wiese[3], T. Alter[1]
[1]Freie Universität Berlin, [2]OSA Opto Light GmbH, [3]SKS Sondermaschinen- und Fördertechnikvertriebs-GmbH

09:40-09:55 | Mo-B2.3
LED technology for decontamination of dried food ingredients
L. Hinds[1,2] , C. O'Donnell[2] Brijesh, K. Tiwari[1,2]
[1]Teagasc Food Research Centre, [2]University College Dublin

09:55-10:10 | Mo-B2.4
Extracts from UVB treated plants do not provoke cytotoxicity, genotoxicity or oxidative stress in vitro
M.Wiesner-Reinhold[1], C. Herz[2], S. Neugart[1,3], S. Baldermann[1,4], T. Filler[5], K. Czajkowski[5], M. Schreiner[1], E. Lamy [2]
[1]Leibniz Institute of Vegetable and Ornamental Crops e.V., [2]University of Freiburg, [3]Georg-August-Universität Göttingen, [4]University of Potsdam, [5]Ferdinand-Braun-Institut

---

10:10-11:30

Break

11:30-12:50

Session: Mo-A3
LED Technology

Chair: Humberto M. Foronada | OSRAM

11:30-11:50 | Mo-A3.1 (Invited)

Characterization of AlGaN deep-ultraviolet light-emitting diodes grown on AlN/sapphire templates with dense macro-steps and its application of high-speed solar-blind optical wireless communications

K. Kojima[1], A. Hirano[2], Y. Nagasawa2, Y. Honda[3], H. Amano[3], Y. Yoshida[4], M. Shiraiwa4, Y. Awaji[4], A. Kanno[4], N. Yamamoto[4], and S. F. Chichibu[1,3]

[1]Tohoku University, [2]UV craftory Co., Ltd., [3]Nagoya University, [4]National Institute of Information and Communications Technologies (NICT)

11:50-12:10 | Mo-A3.2 (Invited)

Understanding the degradation mechanisms of UVB and UVC LEDs to improve their reliability

J. Glaab[1,], J. Ruschel[1], J. Rass[1, 2], H.-K. Cho[1], N. Lobo Ploch[1, 2], T. Kolbe[1, 2], A. Knauer1, S. Walde[1], S. Hagedorn[1], C. Stölmacker[1], K. Hilbrich[1], N. Susilo[3], L. Sulmoni[3], M. Guttmann[3], F. Mehnke[3], T. Wernicke[3], M. Weyers[1], M. Kneissl[1, 3] , S.Einfeldt[1]

[1]Ferdinand-Braun-Institut,Leibniz-Institut für Höchstfrequenztechnik, [2]UVphotonics NT GmbH, [3]Technische Universität Berlin

12:10-12:35 | Mo-A3.3

Enhanced Light Extraction for UV-LEDs by SMD-Packaging with Integrated Reflectors

U. Hansen[1], S. Maus[1], O. Gyenge[1], X. Hu[1], M. Queisser[2], S. Marx[2]

[1]MSG Lithoglas GmbH
[2]Technical University of Berlin

12:35-12:50 | Mo-A3.4

Fabrication of Aluminum-Coated Plastic Reflectors with an Innovative Metallic Intermediate Layer for High-power UV LED Modules

M. Weizman[1], A. Ruhe[1], S. Cinque[1], P. Rotsch[1], W. Arnold[1], S. Nieland[2]

[1]OSA Opto Light GmbH,
[2]GMBU e.V.

11:30-12:50

Session: Mo-B3
Medical Applications

Chair: Elliot M. Kreitenberg | Dimer

11:30-11:50 | Mo-B3.1 (Invited)

233 nm UVC LED irradiation for MRSA and MSSA eradication and risk assessment of skin damage ex vivo

M. Meinke[1*,] P. Zwicker[2], J. Schleusener[1], S. B. Lohan[1], L. Busch[1,3], C. Sicher[2], A. A. Kühl[4], C. Keck[3], J. Glaab[5], N. Lobo-Ploch[5], H: Kyong Cho[5], T. Filler[5], S. Hagedorn[5], L. Wittenbecher[5], M. Weyers[5], S. Einfeldt[5], M. Kneissl[6], C. Witzel[1], U. Winterwerber[5], A. Kramer[2]

[1]Charité – Universitätsmedizin Berlin,
[2]Universitätsmedizin Greifswald
[3]Universität Marburg, [4]iPATH.Berlin
[5]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik,
[6]Technische Universität

11:50-12:10 | Mo-B3.2 (Invited)

Applications of Ultraviolet Light in Healthcare

R. Martinello[1,2]

[1]Yale School of Medicine,
[2]Yale New Haven Health

12:10-12:35 | Mo-B3.3

Preventing hospital-acquired infections with UVC LEDs

M. Ruffin

Excelitas Technologies

12:35-12:50 | Mo-B3.4

UV-activated prevention of biofilm spreading in siphons

L. Steinhäußer[1*,] G. Gotzmann[1], F. Fietzke[1], J.-M. Albrecht[2], U. König[1]

[1]Fraunhofer *Institut Organische Elektronik,*
[2]MoveoMed GmbH

12:50-14:30

Break

14:30-15:30

Poster Session

15:30-16:00

Plenary Session Mo-AB4

Thinking outside the treatment plant: UV LEDs for distributed disinfection applications

K. Linden*[1], N. Hull[2] and V. Speight[3]

[1]University of Colorado Boulder

[2]The Ohio State University

[3]University of Sheffield

Chair: David Rubin | Healthe

16:00-17:10

Session: Mo-A5
Disinfection & Purification I

Chair: David Rubin | Healthe

16:00-16:20 | Mo-A5.1 (Invited)

Defining a Figure of Merit for UVC Radiation Efficiency in a Water Disinfection Reactor and the Impact of UVT, Reflectivity and Size

L. Schowalter[1], A. Miller[1]

[1]Crystal IS

16:20-16:40 | Mo-A5.2

Comparing UV-LED and UV lamps for micropollutant degradation with free chlorine advanced oxidation process in different water matrices

A. Kheyrandish, M. Mohseni

University of British Columbia

16:40-16:55 | Mo-A5.3

Selection, Evaluation and Integration of UV-LED Water Disinfection Modules

B. Adeli, M. Keshavarzfathy, A. Babaie

Acuva Technologies

16:55-17:10 | Mo-A5.4

Fundamentals of Design for UV-C LED Surface Disinfection Applications

R.M. Simons, J. Pagan

AquiSense Technologies LLC

16:00-17:10

Session: Mo-B5
SARS-CoV-2

Chair: Elliot M. Kreitenberg | Dimer

16:00-16:20 | Mo-B5.1 (Invited)

Factors affecting UV device validation in air and surface disinfection

C. A. Bernardy, N. M. Elardo, A. M. Trautz, J. P. Malley

University of New Hampshire

16:20-16:40 | Mo-B5.2 (Invited)

Is far-UVC radiation a promising approach to prevent airborne infections in regard to the ongoing SARS-CoV-2 pandemic?

Axel Kramer und Paula Zwicker

16:40-16:55 | Mo-B5.3

Disinfection of coronavirus by UVC LEDs: a line of defense to contain pandemics

Hadas Mamane[1], Yoram Gerchman[2], Nehemya Friedman[3,1], Michal Mandelboim[3,1]

[1]Tel Aviv University, [2]University of Haifa and Oranim College , [3]Central Virology Laboratory, Ministry of Health

16:55-17:10 | Mo-B5.4

UV Inactivation Kinetics of SARS-CoV-2 and HCoV-229E using UV-LEDs

B. Adeli[1*], M. Raeiszadeh[1], M. Keshavarzfathy[1], E. Espid[1]

[1]Acuva Technologies

17:10

End of Conference Day & Exhibition

Tuesday, April 20, 2021

Time in CET – Central European Time (UTC +1)

08:30

Exhibition Open

08:30-09:00

Plenary Session TU-AB1

UV LEDs: Recent advances and future prospects of this versatile technology

N. Lobo Ploch | *UVphotonics NT GmbH*

Chair: Tim Wernicke | Technische Universität Berlin

09:00-10:05

Session: Tu-A2
Disinfection & Purification II

Chair: Marc P. Hoffmann | OSRAM Opto Semiconductors

09:00-09:20 | Tu-A2.1 (Invited)

UV LED system put to the test: a diary of a test center

T. Schwarzenberger, K.-H. Schön, J. Eggers

TZW: DVGW – Technologiezentrum Wasser

09:20-09:35 | Tu-A2.2

Hydroxyl radical formation and removal efficiency of sulfonamide antibiotics from real water matrices using UV-LED irradiated TiO2 and ZnO photocatalysts

M. Náfrádi, T. Alapi

University of Szeged

09:35-09:50 | Tu-A2.3

Enhanced bacterial inactivation through sequential irradiation with UV-LEDs at specific wavelengths

K. Song[1,2], F. Taghipour[1], M. Mohseni[1]

[1]The University of British Columbia, [2]Nanjing Forestry University

09:50-10:05 | Tu-A2.4

UV LED Validation Per USEPA UVDGM and Innovative Approaches

T. Brooks[1], H. Wright[1], M. Heath[1], M. Simpson[2], O. Autin[2], A. Renton[2], T. Schwarzenberger[3], K. Schoen3

[1]Carollo Engineers, [2]Typhon Treatment Systems Ltd., [3]TZW: DVGW - Technologiezentrum Wasser

09:00-10:05

Session: Tu-B2
UV Curing

Chair: Tim Wernicke | Technische Universität Berlin

09:00-09:20 | Tu-B2.1 (Invited)

Characteristics of UV-LEDs for Industrial Curing Solutions

P. Burger

Dr. Hönle AG, Gräfelfing

09:20-09:35 | Tu-B2.2

Continuous nap-core production process including UV-LED curing

M. Köhler[1], C. Dreyer[1,2], T. Förster1, A. Bernaschek[2,3], A. Bauer[3]

[1]Fraunhofer-Institute for Applied Polymer Research IAP, [2]Technische Hochschule Wildau, [3]InnoMat GmbH

09:35-09:50 | Tu-B2.3

UV-LED-curing – A next-generation technology for textile industry

R. Lungwitz

Sächsisches Textilforschungsinstitut e.V.

09:50-10:05 | Tu-B2.4

Innovative UV LED Curable Polymer Coatings for Glass Fibers

J. Rosenkranz[1], M. Köhler[2], Jan. Klein[3], C. Dreyer[2,4]

[1]j-fiber GmbH, [2]Fraunhofer-Institute for Applied Polymer Research IAP,[3]micro resist technology GmbH, [4]Technische Hochschule Wildau

10:05-11:30

Break

11:30-11:55

Plenary Session TU-AB3

Exploring the wavelength & efficiency limits of deep UV LEDs

Michael Kneissl1,2

1Institute of Solid State Physics, Technische Universität Berlin, 10623 Berlin, Germany

2Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany

Chair: Martin Guttmann | Technische Universität Berlin

12:00-13:15

Session: Tu-A4
Measurement Technology

Chair: Martin Guttmann | Technische Universität Berlin

12:00-12:15 | Tu-A4.1

Optical internal quantum efficiency determination of UVC LEDs – towards a standardization of experimental conditions

C. Frankerl[1,2], M. P. Hoffmann[1], F. Nippert[2], H. Wang[1], C. Brandl[1], N. Tillner[1,3], H.-J. Lugauer[1], R. Zeisel[1], A. Hoffmann[2], M. J. Davies[1]

[1]OSRAM Opto Semiconductors GmbH,
[2]Technische Universität Berlin,
[3]TU Braunschweig

12:15-12:30 | Tu-A4.2

Accurate UV-C LED measurement techniques include the removal of fluorescence effects

M. Clark, R. Zuber, M. Ribnitzky

Gigahertz-Optik

12:30-12:45 | Tu-A4.3

Advances in in-situ metrology of UV-LED structures in MOCVD

K. Haberland[1], A. Knauer[2], M. Weyers[2], J.-T. Zettler[1]

[1]LayTec AG, [2]Ferdinand-Braun-Institut

12:45-13:00 | Tu-A4.4

UV-LED activated semiconductor biosensor for lactate monitoring in sweat

N. Taleghani, F. Taghipour

The University of British Columbia

13:00-13:15 | Tu-A4.5

Measurement systems and calibrations for UV radiation

D. Konjhodzic, B. Eder, W. Beloglazov

Instrument Systems GmbH

12:00-13:15

Session: Tu-B4
UV Applications

Chair: Marc P. Hoffmann | OSRAM Opto Semiconductors

12:00-12:15 | Tu-B4.1

UVC-LED based pretreatment for biofouling control in desalination processes with thin-film composite membranes

P. Sperle, C. Wurzbacher, J.E. Drewes, B. Skibinski

Technical University of Munich

12:15-12:30 | Tu-B4.2

Impact of irradiation frequencies and duty intervals on UV-LEDs photoreactor performance used in Advanced Oxidation Processes

M.H. Rasoulifard, M. Ganjkhanloo, M.R. Eskandarian

University of Zanjan

12:30-12:45 | Tu-B4.3

Effect of Wavelength and Intensity on E. coli Inactivation Kinetics

H. Mamane[1], D. Pousty[1,2], Y. Gerchman[1], R. Hofmann[2]

[1]School of Mechanical Engineering,
[2]University of Toronto

12:45-13:00 | Tu-B4.4

UV-C LED – challenges, status quo & outlook A perspective from an LED manufacturer

J.Klee

Nichia Chemical Europe GmbH

13:00-13:15 | Tu-B4.5

UV-C LEDs and their advantages in various system designs

A. Wilm

OSRAM Opto Semiconductors

13:15-15:00

Break

15:00-16:00

Poster Session – Voting for the best poster ends at 15:30.

16:00-16:10

Closing Remarks

16:10-18:15

Joint Plenary on Standardization of UV LED (Systems) Characterization Tu-AB5

Chair: Tim Wernicke | Technische Universität Berlin

16:10 | AB5.1

UV radiometry for LED-based systems
Peter Sperfeld and Thorsten Gerloff | *PTB, Germany*

16:35 | AB5.2

The need for standards in UV-LED water disinfection systems, and challenges for application to a world market
Gordon Knight | *International Ultraviolet Association, USA*

16:55 | AB5.3

New alternative UV test method in NSF/ANSI 55 – Ultraviolet microbiological water treatment systems
Mike Blumenstein | *NSF International, USA*

17:10 | AB5.4

UV LED disinfection for public water supply: Preparation of a test protocol in Germany
D. Warschke[1], K.-H. Schön[2], J. Eggers[2]
[1]*Gelsenwasser AG, Willy-Brandt-Allee 26, 45891 Gelsenkirchen, Germany*
[2]*TZW: DVGW-Technologiezentrum Wasser, Karlsruher Straße 84, 76139 Karlsruhe, Germany*

17:25 | AB5.5

Raising the standard: The case for holistic guidelines for UV-C LED based water treatment systems
Oliver Lawal | *AquiSense Technologies, USA*

17:40-18:15

Panel Discussion

Standardization: What is needed and what is in the pipeline?

Chair: Ian Mayor Smith | University of Brighton

18:15

End of Conference & Exhibition

Poster Session

Mo-P1
Adsorption of selenate on activated carbon by UV light
S. Aguilar C., J. Alejandre, M. Ortíz G., N. Dasgupta-Schubert
Universidad Michoacana de San Nicolás de Hidalgo

Mo-P2
How the UVC LED industry is organizing to reach high power and new applications
P. Boulay
Yole Développement

Mo-P3
Triggering the release of drugs from nanocarriers in hair follicles by the application of UV-LEDs
L. Busch[1,4], Y. Avlasevich[2], G. Thiede[1], K. Landfester[2], A. Kramer[3], G. Müller[3], P. Zwicker[3], M. E. Darvin[1], M. C. Meinke[1], C. M. Keck[4], J. Lademann[1], A. Patzelt[1]
[1]Charité – Universitätsmedizin Berlin, [2]Max Planck Institute for Polymer Research
[3]University Medicine Greifswald, [4]Philipps University Marburg

Mo-P4
Some parameters for technological migration from Hg lamps to LEDs in the UV range for germicidal dose applications
P. Fredes[1,2*], U. Raff[1]
[1]Univ. de Santiago de Chile, [2]Hydraluvx Spa

Mo-P5
Electro-optical properties of deep UV LEDs with an emission wavelength near 230 nm
M. Guttmann[1]*, L. Sulmoni[1], N. Lobo-Ploch[2,3], F. Mehnke[1], P. Gupta[1], J. Glaab[2], J. Ruschel[2], H. Kyong Cho[2], J. Rass[2,3], S. Hagedorn[2], T. Wernicke[1], S. Einfeldt[2], M. Weyers[2], M. Kneissl[1,2]
[1]Technische Universität Berlin, [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik,
[3]UVphotonics NT GmbH

Mo-P6
Rapid Integration of LEDs for UVC surface treatment driven by pandemic requirements
Y. Haj-Hmeidi1
[1]LUMITRONIX® LED-Technik GmbH

Mo-P7
UVC LEDs Promise a Giant Leap in Decontamination Efficiency
A. Hedrick, D. Georgeson, Dr. M. Hardwick, Dr. R. Louis
Crystal IS, Cleanbox Technology, Hoag Memorial Hospital

Mo-P8
Integrated digitally adjustable step down converter to control one individual or a series of UV-LED(s)
C. Heinze[2], M. Frisch[1], Th. Ortlepp[2]*, O. Brodersen[2]
[1]eesy-ic GmbH, [2]CiS Forschungsinstitut für Mikrosensorik GmbH

Mo-P9
Flexible and cost effective UVC LED system design using packageless WICOP LED Technology
M.Hofmann, JR.Kim, JH.Jeong
Seoul Viosys Co. LTD. Ansan

Mo-P10

Factors influencing the emission characteristics of UV LED chips - A modular system for customized design

I. Käpplinger[1]*, D. Mitrenga[1], G. Leibeling[2], F. Gindele[3], Y. Kikuchi[4], O. Brodersen[1], T. Ortlepp[1]

[1]CiS Forschungsinstitut für Mikrosensorik GmbH, [2]JenCAPS Technology GmbH, [3]Schott AG, [4]NGK Insulators, LTD

Mo-P11

Integrated dose simulation tool for UV-LED reactors

M. Keshavarzfathy, B. Adeli, A. Babaie

ACUVA Technologies Inc.

Mo-P12

Emergence of UV-LED as a new technology

S. Kumar, C. Ruckstuhl, H. Maiweg

ACUVA Technologies Inc.

Mo-P13

Stress responds measurements in skin induced by UV-LEDs

S. Lohan[1], D. Ivanov[1], N. Schüler[2], B. Berger[2], J. Lademann[1], M. Meinke[1]

[1]Charité – Universitätsmedizin Berlin, [2]Freiberg Instruments GmbH

Mo-P14

Application of UV LEDs for Tender Coconut Water Processing

M. RaJ Kumar, Y. Sudheer Kuma

CSIR-Central Food Technological Research Institute

Mo-P15

Combination of UV-LED and membrane filtration to treat surface water

A.P. Marques[1,2], J. Bernardo[2], R. Huertas[1,2], J.G. Crespo[1,2], V.J. Pereira[1,2]

[1]iBET, [2]Universidade NOVA de Lisboa

Mo-P16

UV-C LED Systems Verse Low Pressure: A Five-Year Cost Comparison

M. McManus, O. Lawal

Aquisense

Mo-P17

Employment of computational tools for optimization of high flow UV-LED water disinfection systems

M. Mohaghegh Montazeri, F. Taghipour

University of British Columbia

Mo-P18

A multi-wavelength tunable LED source covering UV-B and UV-A from 280nm to 405nm

A.P. Morrison, N. Molnar

University College Cork

Mo-P19

COVID-19 pandemic: The spark for UVC LED to become a multi-billion dollar business in the next 5 years?

P. Mukish, P. Boulay

Yole Développement

Mo-P20

Efficacy of UV-C irradiation emitted by mercury vapor lamp and LED on the bacterial load of eggshells
S. Opherden1, S. Fleischmann1, T. Alter1, C. Robé1, I. Szabo2, S. Hadziabdic2, A. Gensch3, P. Rotsch4, G. Wiese5, U. Roesler1
[1]Freie Universität Berlin, [2]German Federal Institute for Risk Assessment (BfR),
[3]Löwendorfer Geflügelhof GmbH (LGH),
[4]OSA Opto Light GmbH, [5]SKS Sondermaschinen- und Fördertechnikvertriebs- GmbH

Mo-P21

Visible blind SiC-based UV spectrometer - Development and characteristics
N. Papathanasiou[1], S. Langer[1,2], T. Weiss[1], D. Prasai[2]
[1]sglux GmbH, [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik

Mo-P22

A Protocol for Design and Validation of UV-LED Devices for Air and Surface Disinfection
M. Raeiszadeh, B. Adeli, M. Keshavarzfathy, E. Espid
Acuva Technologies

Mo-P23

UV-LED Air Purifier for Degradation of Volatile Organic Compounds in Indoor Air
S. Rouhani, F. Taghipour*
University of British Columbia

Mo-P24

Ceramic-based UV-LED photocatalytic membrane reactor development, evaluation, and optimization
S. Sakhaie, F. Taghipour
University of British Columbia

Mo-P25

UV LEDs: Improving lifetimes by optimal thermal management
P. Sharma, P. Chen, S. Han, P. Chung, C. Han
Violumas Inc

Mo-P26

Ultraviolet light decontamination in chicken breast meat
A. B. Soro[1], P. Whyte[2], D. J. Bolton[1], B. K. Tiwari[1]
[1]Teagasc Ashtown Research Centre, [2]University College Dublin

Mo-P27

Aluminium Nitride substrates for epitaxial AlGaN layers with low dislocation density
T. Straubinger[1], M. Bickermann[1], C. Hartmann[1], L. Matiwe[1], J. Wollweber[1], A. Knauer[2], M. Weyers[2], T. Wernicke[3], M. Kneissl[3]
[1]Leibniz-Institut für Kristallzüchtung,[2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik,
[3]Technische Universität Berlin

Mo-P28

On the road to direct, optical, on-line germ detection
F. Stüpmann[1], M. Sarcander[1], M. Moschall[1], D. Röll[2], O. Talkenberg[2], S. Hartmann[1], R. König[2]
[1]Silicann Systems GmbH, [2]Center for Sepsis Control & Care

Mo-P29

Optic concepts for UV LED lamps at long working distances

T. Vehoff, J. Grade, A. Stahl
Heraeus Noblelight GmbH

Mo-P30

Light extraction efficiency enhancement of UVC and UVB LEDs via encapsulation with UV-transparent silicone resins (Deep UV200)

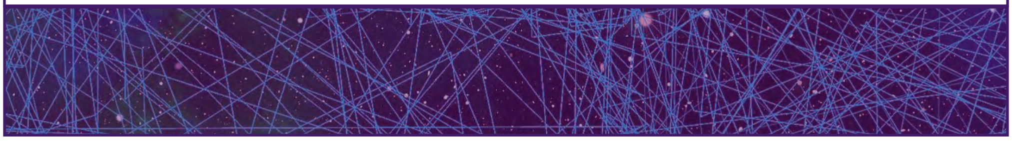
S. Wu[1], M. Guttmann[1], N. Lobo-Ploch[2], N. Susilo[1], F. Gindele[3], A. Knauer[2], T. Kolbe[2],
J. Raß[2], H. K. Cho[2], K. Hilbrich[2], S. Einfeldt[2], T. Wernicke[1], M. Weyers[2], and M. Kneissl[1,2]
[1]Universität Berlin, [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik
[3]Schott AG

Mo-P31

Disruptive GLED devices and Disinfection Solutions

L. Zhou
Bolb Inc

Lecture Abstracts



UV-LEDs for Water Disinfection: The Forefront of Research and Applications

Kumiko Oguma[1*]

[1]University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

UV light-emitting diodes (UV-LEDs) have made substantial improvements in terms of the output power, lifetime and cost. Now is the time to expand this novel technology to various applications for the better future.

UV-LEDs offer attractive features such as mercury-free, tiny size, flexible layout, quick start without warm-up, and undamaged by frequent on-off. All these features enable new applications that were not feasible with conventional mercury UV lamps.

Thinking of the small footprint and less maintenance frequency, UV-LEDs can be a practical, reliable and sustainable option for household water treatment of point-of-use (POU) and point-of-entry (POE) applications [1]. Moreover, UV-LEDs are a good-fit option for private and semi-private community water supplies (CWS) where limited number of households are connected and sourcing locally available groundwater with simple treatment. It is notable that social demands for decentralized water supply systems, i.e. POU, POE and CWS, are now growing not only in the developed world but also in developing countries, particularly those under rapid urbanization and economic growth.

Beyond decentralized systems, UV-LEDs can be a feasible option even at facilities of municipal level. In fact, a UV-LED disinfection system has been working since February 2019 at a municipal water supply in Japan [2]. This facility is relatively small for public system, having treatment capacity of 250 m^3 per day and service population of about 1100 in a town. Still, this should be the big first step forward for UV-LED industries and applications.

The UV-LEDs require relatively low power and voltage to drive, allowing simple connection and operation using a solar panel with a rechargeable battery. Solar power is abundant in low latitude regions where many developing countries are located, and many of them have low access to safe drinking water. Based on these facts, we have got started an implementation project of solar-powered UV-LED water treatment system in an off-the-grid remote island in the Philippines [3]. Although still at the early stage of project, we have obtained some lessons to modify the prototype for the future challenge.

As such, UV-LED applications are now expanding to the real world. Some field test projects will be presented at the talk to show how UV-LEDs can be the good-fit option for decentralized disinfection of drinking water.

References

[1] Fariborz Taghipour and Kumiko Oguma, IUVA Journal UV Solutions 2019 Quarter 1, 22-26 (2019). https://uvsolutionsmag.com/articles/2019/uv-led-system-design-operation-and-application-for-water-treatment/

[2] Kumiko Oguma, IUVA Journal UV Solutions 2020 Quarter 3, 28-19 (2020). https://uvsolutionsmag.com/articles/2020/deep-uv-led-equipment-in-operation-for-municipal-drinking-water-supply/

[3] Bernice Yu Jeco, Aris Larroder and Kumiko Oguma. Technosocial feasibility analysis of solar-powered UV-LED water treatment system in a remote island of Guimaras, Philippines. J. Photon. Energy 9(4), 043105 (2019). doi: 10.1117/1.JPE.9.043105.

Characteristics of UV-LED sources for spectroscopic applications

C. Söller*, L. Schäfer, A. Schnabl, O. Deppert, T. Jenek
Heraeus Noblelight GmbH, Heraeusstr. 12-14, 63450 Hanau, Germany

Technological advances over the past decade have made UV LEDs commercially available over a wide range of wavelengths, spanning from the UV-A into the UV-C region. As a result, UV LEDs have emerged as potential or even already established light sources in a variety of spectroscopic applications. At the same time, classical, discharge-based light sources continue to offer features that are difficult to address with LEDs. This still restricts the use of LEDs to certain measurement tasks, depending on the analytical requirements.

As a starting point, we review important parameters for spectroscopy light sources in general and compare different types of state-of-the-art sources, outlining the differences and potential advantages of each technology. Among the considered characteristics are spectral range, flux, stability, power consumption and lifetime. We then present recent results on the characterization of a newly developed broadband UV-LED light source. It is based on the combination of a single LED with a broadband-emitting phosphor. The resulting spectrum ranges from 250 to 490 nm (see Fig. 1). In addition to the above-stated parameters, noise measurements and electrical characteristics under various operating conditions are analyzed. The results are presented in context with state-of-the-art sources for spectroscopy, allowing an assessment of the suitability for specific applications.

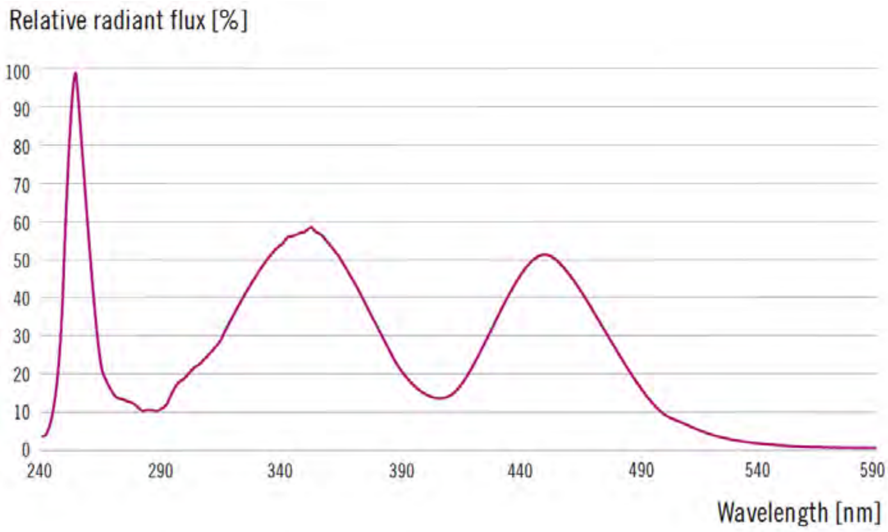


Fig. 1. Spectrum of a broadband UV-LED light source

Development of LED based diffuse reflectance spectroscopy device for the non-invasive in vivo measurement of UVA-PF and SPF

Wiora, Georg[2]; Throm, Carolin[1], Reble, Carina[2]; Schanzer, Sabine[1]; Kobylinski, Susanna1; Schleusener, Johannes[1]; Karrer, Hans[3]; Kolbe, Ludger[4], Gersonde, Ingo[5]; Lobo-Ploch, Neysha[6]; Khazaka, Georg[2]; Meinke, Martina C.[1] ;Lademann, Jürgen[1]

[1] Charité - Universitätsmedizin Berlin, Berlin, Germany; [2] Courage + Khazaka electronic GmbH, Cologne, Germany; [3] Hans Karrer GmbH, Augsburg, Germany; [4] Beiersdorf AG, Hamburg, Germany, [5] University of Potsdam, Potsdam, Germany; [6] Ferdinand-Braun-Institut, Berlin, Germany

For every new sunscreen or cosmetic product claiming protection from UV radiation, the sun protection factor (SPF) must be determined [1]. The current method is invasive by inducing a sun burn (erythema) for each product. Due to the invasiveness of this method, FDA and the corresponding EU commission advised the development of non-invasive measurements years ago.

Spectroscopic in vivo measurements were previously developed in the UVA [2,3]. By fitting an in vitro transmission spectrum in the whole UV range to the in vivo transmission spectrum in the UVA, SPF values could be obtained with a very good correlation to the erythema test (Hybrid Diffuse Reflection Spectroscopy – HDRS).

In this contribution, we present our developments in the field of DRS, which use LED-based light sources in order to overcome limitations of traditional solar simulators. We applied the spatially resolved reflectance principle to the UV in order to determine the extinction by the sunscreen, which is traversed two times - in and out - the skin. By measuring the reflectance before and after the application of sunscreen, the attenuation spectrum of the sunscreen on the skin can be determined.

We present the results of an in vivo study on human skin using a functional sensor design, which consists of one UVB-LED and a photodiode as well as a customized fiber bundle [4]. A good correlation with the standard erythema test could be obtained [5].

In addition, we present the development of a new spectroscopic DRS device for SPF measurements. The new DRS device consists of a multi lambda LED light source including 8 UV LEDs, a 7 channel probe, and a 84 channel spectrometer to calculate the in vivo SPF and UVA-PF. Our current in vivo study suggests that the system is suitable for UVA-PF measurements and SPF determination based on the HDRS principle [6]. In addition, pure in-vivo spectra may be useful for research applications. Additional determination of photo stability by an external device is required yet. Our method uses non-invasive UV-doses and is much faster as compared to the erythema test.

References

[1] ISO 24444: Cosmetics - Sun protection test methods - In vivo determination of the sun protection factor (SPF), 2010
[2] E. Ruvolo et al., Photodermatol Photoimmunol Photomed, vol. 30, no. 4, pp. 202-211, 2014.
[3] M. Rohr et al., Skin Pharmacol Physiol., vol. 31, no. 4, pp. 220-228, 2018
[4] C. Reble et al., Optic & Photonic, vol. 13, no. 1, pp. 32-35, 2018.
[5] S. Kobylinski et al., J. Biophotonics. 2021;e202000453
[6] C. M. Throm et al., J. Biophotonics 2021;14:e202000348.

Construction and characterization of a high-power UV-LED module as radiation source for goniometric spectral radiance factor measurements

I. Santourian[1*], S. Teichert[1], A. Schirmacher[1], T. Quast[1], K.-O. Hauer[1]

[1]*Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany*

Due to their long lifetime, efficiency and the available high radiation power the application areas for LEDs continue to grow. Also, the use and production of new semiconductor compounds lead to an increase of accessible spectral ranges and make them attractive for many applications. Therefore, the suitability of LEDs as an additional short-wavelength radiation source for the existing robot-based gonioreflectometer at PTB was investigated.

The gonioreflectometer at PTB is the national standard for the determination of the absolute spectral radiance factor $\beta(\lambda)$ of diffuse reflecting materials in a variety of bidirectional measurement geometries. Using a fixed detection direction, the sample under test is placed on a five-axes robot in the center of the apparatus and illuminated with a special integrating sphere radiation source, which can be swiveled around the sample along a large rotation stage. The sphere radiator creates a highly homogeneous and Lambertian beam profile on the sample which is required by the measuring principle. Ideally the entire solar spectrum from 250 nm to 2500 nm shall be covered by the illumination unit. However, even by using a 400 W high-power tungsten halogen lamp as a radiator, in the current set-up the achievable measurement uncertainty for wavelengths below 400 nm is dominated by the available output power level.

Therefore, an LED sphere radiation source (LED-SR) was constructed based on the principle of the currently used integrating sphere radiator to improve the available radiant power in the short VIS to UVA wavelength spectral range. For this purpose, a board with 21 SMD LEDs covering the spectral range from 365 nm to 410 nm was designed consisting of LEDs with three different peak wavelengths.

The temporal stability of the radiation source and the homogeneity of the radiation field on the sample surface were investigated extensively since they are of great importance for goniometric measurements. An active temperature regulation was added to the LED-SR to obtain a better temporal stability. In a next step of evaluation, the LED-SR was implemented in the measuring system to perform comparative measurements. Preliminary tests with a previous LED-SR model implemented in the gonioreflectometer setup showed a smaller variation for the spectral radiance factor even with few measurement cycles. These results indicate that the LED-SR is a valuable supplementary radiation source for the existing robot-based gonioreflectometer.

DNA analysis with UV LEDs

Ch. Möller[1], M. Hentschel[2], M. Weizmann[3], Th. Ortlepp[1]
[1]CiS Forschungsinstitut für Mikrosensorik GmbH, Konrad-Zuse-Straße 14, 99099 Erfurt, Germany
[2]Analytik Jena AG, Konrad-Zuse-Straße 1, 07745 Jena, Germany
[3]OSA Opto Light GmbH, Köpenicker Str. 325b / Haus 201, Berlin, Germany

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 of the DNA has to be removed. The in situ measurement of all reaction chambers of the titer plate is the goal of our work.

We demonstrate a completely automated prototype which determines the DNA-content of a 96-well titer plate within 2 minutes. The basic components such as LED chip, ceramic housing, quartz-glass with coatings and detector unit were characterized and subjected to long-term tests.

Peach flesh metabolome is modulated by UV-B radiation although UV-B does not penetrate the peach skin

Annamaria Ranieri[1,2*], Marco Santin[1], Antonella Castagna[1,2], Marie-Theres Hauser[3], Maria Begoña Miras Moreno[4], Luigi Lucini[4]

[1]Department of Agriculture, Food and Environment, University of Pisa, via del Borghetto 80, 56124 Pisa, Italy

[2]Interdepartmental Research Center Nutrafood "Nutraceuticals and Food for Health", University of Pisa, Via del Borghetto 80, 56124 Pisa, Italy

[3]Department of Applied Genetics and Cell Biology, University of Natural Resources and Life Sciences, Muthgasse 18, 1190 Vienna, Austria

[4]Department for Sustainable Food Process, Università Cattolica del Sacro Cuore, Via Emilia Parmense, 84, 29122 Piacenza, Italy

The greatly appreciated effect of UV-B radiation in promoting phenolics accumulation, depending on the UV-B dose and the phenolic class considered, has been already elucidated in many fruit and vegetables. Previous studies reported that 10 min and 60 min of UV-B irradiation were effective in stimulating a strong phenolic accumulation in peach, especially the strongest antioxidant dihydroflavonols, anthocyanins and flavones within the phenolics. However, almost the entire relevant literature has considered the UV-B-driven phenolics changes only in the fruit skin, since it represents the outermost tissue and therefore directly exposed to the UV-B radiation. It is also important to point out that most people use to peel the fruit due to the possible presence of harmful chemicals, e.g. pesticides and fungicides, thus they would not benefit from the skin phenolics enrichment. In the light of above, this work aimed to figure out whether the UV-B exposure might influence the secondary metabolism within the peach flesh, focusing particularly on phenolic compounds. Based on these considerations, melting flesh yellow peaches (*Prunus persica* L., cv. Fairtime) were exposed to UV-B radiation (2.31 W m^{-2}) for 10 and 60 min, and the flesh was sampled at two different recovering times, 24 and 36 h. Through UHPLC-ESI/QTOF-MS followed by a fold-change analysis we were able to find which metabolites were mostly affected by UV-B radiation in the flesh. Phenolics compounds, showed an initial slight decrease after 24 h from the irradiation, and later an accumulation after 36 h. Since this behavior reflects what has been already observed in the skin, a possible transduction mechanism of the UV-B signal from the skin to the flesh below is likely to occur. This is because UV-B radiation does not penetrate peach skin at all, regardless the skin color (from yellow to dark orange) or UV-B wavelength considered Terpenoids were also highly affected by UV-B, showing a great increase of most subclasses, especially after 36 from the treatments. In detail, carotenoids showed the highest increase among terpenoids after both 24 and 36 h recovery timepoints. Individual UV-B-responsive metabolites will be further discussed. These findings pave the way for a possible application of UV-B irradiation to increase the nutraceutical value of plant products in the view of a sustainable food chain. Furthermore, our research is now shifting towards the study of the metabolomics on UV-B and -A irradiated plant-based food (from fruits to vegetables) by using UV LEDs instead of lamps. Such new technology, in fact, ensures a narrower emission spectrum, avoiding undesirable emission tails, allowing us to better discriminate the metabolomics effect of specific wavelengths. In addition, the greater efficiency, longer lifespan, and lower energy consume make LEDs the perfect candidate for lighting in greenhouses and plant-based food processing industries.

UV-C LED usage for bacterial decontamination of technical surfaces in food processing

S. Fleischmann[1*], S. Opherden[1], P. Rotsch[2], G. Wiese[3], T. Alter[1]
[1]*Institute of Food Safety and Food Hygiene, Freie Universität Berlin, Berlin, Germany*
[2]*OSA Opto Light GmbH, Berlin, Germany*
[3]*SKS Sondermaschinen- und Fördertechnikvertriebs-GmbH, Berlin, Germany*

Contamination and cross contamination of food with zoonotic pathogens in food-producing companies is a main problem of consumer health protection. Every year, the World Health Organization estimates that approximately 420.000 people die worldwide from infections caused by the consumption of contaminated food. Most infections are associated with pathogenic bacteria of the genera *Salmonella*, *Listeria*, *Campylobacter*, *Escherichia* (*E.*) *coli* and *Shigella*. Furthermore, the spoilage flora causes worldwide the spoilage of a large share of food. Overall, the prevention of cross contamination via technical contact surfaces is a key element in food processing.

Therefore, the aim of this study was the improvement of hygiene in food production through the development, optimization and establishment of efficient procedures for decontamination of contact surfaces via UV-C LED.

For laboratory tests, thin plates of different technical surface material were inoculated with a defined bacterial concentration and the bacterial count was estimated before and after UV-C treatment. The bacterial decontamination efficiency was tested with and without an organic load to simulate a production-related pollution.

Finally, a reproducible method for detecting the decontamination efficiency via UV-C on technical surfaces was developed and established. A high bacterial (10^9- 10^7 CFU/ml) and organic load of 3g bovine serum albumin (BSA) resulted in a protective effect of bacteria against UV-C treatment. Gram-positive bacteria like *Staphylococcus, Streptococcus* and *Listeria monocytogenes* are less vulnerable to UV-C. A high contamination dose of 10^9 CFU/ml with *E. coli* showed a reduction of up to 6log CFU/ml after UV-C LED treatment with a wavelength of 265nm and an irradiance of ~ 5mW/cm^2 for 1sec. After a treatment for 5sec, *E. coli* was no longer detectable.

Concluding the described results, UV-C LED usage is a very useful tool to increase the hygiene of technical surfaces by reducing the bacterial contamination in food processing. However, a production-related organic contamination reduce the irradiation efficiency dramatically. A combined application comprising UV-C LED and a mechanical cleaning of the technical surfaces is therefore an optimal method.

LED technology for decontamination of dried food ingredients

Laura M. Hinds*[1,2], Colm P. O'Donnell[2], Brijesh K. Tiwari[1,2]

[1] *Food Chemistry & Technology, Teagasc Food Research Centre, Dublin, Ireland*
[2] *School of Biosystems and Food Engineering, University College Dublin, Dublin, Ireland*

This study investigated the potential of an ultraviolet light emitting diode (UV LED) technology as a decontamination tool in the food industry. Black peppercorns and tapioca starch were subjected to various UV LED treatments employing different wavelengths (280 nm, 300 nm and 365 nm) and treatment durations (5, 10 and 20 min). For microbiological analysis black peppercorns and tapioca starch were inoculated with B. subtilis and subjected to treatment. Furthermore, quality analysis was carried out for both ingredients. Significant reductions ($P < 0.05$) of B. subtilis were achieved for the treatment with 280 nm for 20 min showing a 1 log reduction (90 %) in black peppercorns. Reductions of B. subtilis were also observed in tapioca starch samples, achieving > 3 log (99.99 %) and > 1 log (90 %) reductions for 300 nm and 365 nm, respectively. Piperine and piperyline compounds were determined as the predominant phenolic compounds by LC-DAD-ESI-MS-MS and piperine levels slightly increased after 5 min treatment. Pasting profiles of non-treated and UV LED treated tapioca starch did not show any differences. Furthermore, scanning electron microscopy imaging showed that the surface morphology was not affected by UV LED treatment. This study highlights the potential of this technology in the food industry.

Extracts from UVB treated plants do not provoke cytotoxicity, genotoxicity or oxidative stress in vitro

Melanie Wiesner-Reinhold[1], Corinna Herz[2], Susanne Neugart[1,3], Susanne Baldermann[1,4], Thomas Filler[5], Kamil Czajkowski[5], Monika Schreiner[1], Evelyn Lamy [2]

[1]Leibniz Institute of Vegetable and Ornamental Crops e.V., Theodor-Echtermeyer-Weg 1, 14979 Grossbeeren, Germany
[2]Medical Center – University of Freiburg, Molecular Preventive Medicine, Engesserstraße 4, 79108 Freiburg, Germany
[3]Division Quality and Sensory of Plant Products, Georg-August-Universität Göttingen, Carl-Sprengel-Weg 1, D-37075 Goettingen, Germany
[4]Institute of Nutritional Science, University of Potsdam, Arthur-Scheunert-Allee 114-116, 14558 Nuthetal, Germany
[5]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany

Ultraviolet B (UVB) radiation in low but ecological-relevant doses acts as regulator in the plant's secondary metabolism.

Brassica juncea `Red Giant`, *Brassica campestris* `Mizuna` and *Lactuca sativa* `Navarro` plants were grown under controlled climate conditions. At 4-5 leaf stadiums, plants were treated at a dose of 4.51 kJ m^{-2} of biological effective UVB (UVB_{BE}) radiation at 290 ± 2 nm for 4 consecutive days and harvested on day five. The plant extracts were prepared as described before [1]. Briefly, 250 mg lyophilized plant powder was added to 5 ml PBS (w/o Mg and Ca, pH 7.0) and incubated for 30 min at room temperature. The plant extract was strained through gaze, sterile filtered (0.22 µm), and used for determination of cell viability (WST-1 assay and trypan blue staining), genotoxicity (comet assay) and production of reactive oxygen species (DPPH and FRAP assay as well as ESR) using metabolically competent human derived liver (HepG2) cells.

UVB radiation led to a significant increase of several secondary plant metabolites, especially of glucosinolates and phenolic compounds. For example, UVB treatment of `Red Giant` plants increased significantly the content of the aliphatic glucosinolates, especially of the alkenyl glucosinolates. In UVB treated `Navarro` plants, the kaempferol- und quercetin glycoside concentrations were significantly increased compared to untreated plants; however, hydroxycinnamic acids were unaffected.

Extracts from untreated and UVB treated plants were tested in different short-term *in vitro* assays. No adverse effects in terms of cytotoxicity, genotoxicity or oxidative stress were seen in a concentration range of 3.125 – 100 µg ml^{-1}. Only at very high concentrations for some plant extracts cytostatic effects were seen for extracts from untreated and UVB treated plants.

In conclusion, the application of narrow-band UVB radiation from LEDs increases structure-specifically health-promoting secondary plant metabolites, however changes in metabolite profiles did not provoke relevant adverse effects of plant extracts as determined *in vitro*.

References

[1] Tran, H., et al., Nasturtium (Indian cress, Tropaeolum majus nanum) dually blocks the COX and LOX pathway in primary human immune cells. . Phytomedicine. , 2016. **23**(6): p. 611-620.

Characterization of AlGaN deep-ultraviolet light-emitting diodes grown on AlN/sapphire templates with dense macro-steps and its application of high-speed solar-blind optical wireless communications

K. Kojima[1*], A. Hirano[2], Y. Nagasawa[2], Y. Honda[3], H. Amano[3],
Y. Yoshida[4], M. Shiraiwa[4], Y. Awaji[4], A. Kanno[4], N. Yamamoto[4], and S. F. Chichibu[1,3]
[1]Institute for Multidisciplinary Research for Advanced Materials (IMRAM), Tohoku University, Sendai, Japan
[2]UV craftory Co., Ltd., Nagoya, Japan
[3]Institute of Materials and Systems for Sustainability (IMaSS), Nagoya University, Nagoya, Japan
[4]National Institute of Information and Communications Technologies (NICT), Koganei, Japan

Broadband optical wireless communications (OWC), particularly Gbps-class technologies such as Li-Fi based on light-emitting diodes (LEDs), will be an element of 5G wireless access networks. One of limiting issues of the OWC performance is the background radiation noise due to sunlight, which causes >10-dB loss of signal-to-noise power ratio (SNR), when compared between day and night [1]. Therefore, the OWC in the "solar-blind" spectral regime by using deep ultraviolet (DUV) AlGaN LEDs is an attractive approach for this problem. We recently demonstrated LED-based DUV OWC at 280-nm band over a 1.5-m direct line-of-site channel realizing the effective data rate of >2 Gbps [2,3] under standard room lighting and >1 Gbps under direct sun with outdoor experiments. These experiments were performed by using off-the-shell DUV AlGaN LEDs, which were grown by metalorganic vapor-phase epitaxy using an AlN/sapphire template with dense macrosteps [4,5].

The cross-sectional transmission electron microscope observations and microscopic energy dispersive X-ray spectroscopy revealed that the AlGaN cladding layer under the AlGaN quantum well (QW) layer has a microscopic compositional modulation, which originates from the macrosteps at the AlN template surface. The Ga-rich portion of the cladding layer can behave as a current micropath. Moreover, the micropaths are connected with the carrier localization structure formed in QWs with wider well and lower AlN mole fraction. The edges of macrosteps at the sample surface show brighter cathodoluminescence with a lower peak photon energy, confirming the carrier localization. This localization structure in the QWs combined with the current micropaths in the cladding layer can contribute the increase of radiation efficiency of AlGaN LEDs as well as the realization of the high-speed DUV OWC.

References

[1] M. S. Islim, S. Videv, M. Safari, E. Xie, J. J. D. McKendry, E. Gu, M. D. Dawson, and H. Haas., J. Light. Technol., 36, 2376 (2018).
[2] K. Kojima, Y. Yoshida, M. Shiraiwa, Y. Awaji, A. Kanno, N. Yamamoto, and S. F. Chichibu, European Conference on Optical Communication (ECOC) 2018, Rome, Italy, September (2018).
[3] Y. Yoshida, K. Kojima, M. Shiraiwa, Y. Awaji, A. Kanno, N. Yamamoto, S. F. Chichibu, A. Hirano, and M. Ippommatsu, Conference on Lasers and Electro-Optics (CLEO) 2019, San Jose, USA, May (2019).
[4] M. Kaneda, C. Pernot, Y. Nagasawa, A. Hirano, M. Ipponmatsu, Y. Honda, H. Amano, and I Akasaki, Jpn. J. Appl. Phys. 56, 061002 (2017).
[5] K. Kojima, Y. Nagasawa, A. Hirano, M. Ippommatsu, Y. Honda, H. Amano, I. Akasaki, and S. F. Chichibu, Appl. Phys. Lett. 114, 011102 (2019)

Understanding the degradation mechanisms of UVB and UVC LEDs to improve their reliability

J. Glaab[1,*], J. Ruschel[1], J. Rass[1, 2], H.-K. Cho[1], N. Lobo Ploch[1, 2], T. Kolbe[1, 2], A. Knauer[1], S. Walde[1], S. Hagedorn[1], C. Stölmacker[1], K. Hilbrich[1], N. Susilo[3], L. Sulmoni[3], M. Guttmann[3], F. Mehnke[3], T. Wernicke[3], M. Weyers[1], M. Kneissl[1, 3], S. Einfeldt[1]

[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, Institute of Solid State Physics, Hardenbergstr. 36, EW 6-1, 10623 Berlin, Germany

In order to pave the way for the use of UVB and UVC light emitting diodes (LEDs) in established and novel applications, these devices need to exhibit stable electro-optical parameters over several thousand hours of operation. Accordingly, to increase the reliability of these LEDs empirical optimizations and a detailed analysis of degradation mechanisms is needed. In this work, we present the current status of reliability studies on UV LEDs emitting around 232 nm, 265 nm and 310 nm. For example, the impact of operation parameters (e.g. current density, see Fig. 1a) and b)), specific heterostructure designs and fabrication conditions on the temporal change of the optical power, the operation voltage and the current at low bias have been studied [1]. Moreover, spatially resolved material analysis techniques such as secondary ion mass spectrometry have been applied to draw conclusions on the type of defect responsible for the degradation and the change of the defect concentration during LED operation [2]. Special attention has been paid to similarities in the degradation behavior of UV LEDs with different emission wavelength (compare, for example, Fig. 1a) and b)) with the aim to derive a universal degradation model. The proposed model includes the activation of point defects within the p-side and the active region of the diode triggered by hot carriers generated from Auger recombination. Finally, strategies for realizing more reliable devices by optimized manufacturing technologies and device designs will be proposed.

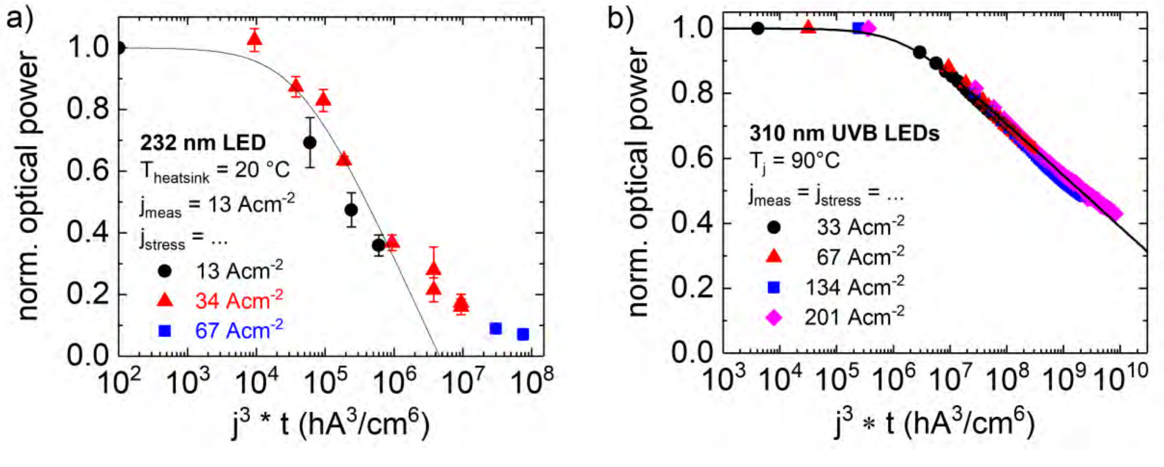


Fig. 1: Normalized optical power of a) 232 nm and b) 310 nm LEDs driven at different cw current densities as a function of the product of operation time and the cube of stress current density.

References

[1] J. Ruschel et al., Photonics Research 7 (7), B36 (2019).
[2] J. Glaab et al., IEEE Photon. Techn. Lett. 31 (7), 529 (2019).

Enhanced Light Extraction for UV-LEDs by SMD-Packaging with Integrated Reflectors

U. Hansen[1*], S. Maus[1], O. Gyenge[1], X. Hu[1], M. Queisser[2], S. Marx[2]

[1] *MSG Lithoglas GmbH, Maria-Reiche-Str. 1, 01109 Dresden, Germany*
[2] *Technical University of Berlin, Gustav-Meyer-Allee 25, 13355 Berlin, Germany*

UV-A LEDs have become a success story. The same is expected for lower wavelength devices (DUV) used for water or air purification. However, for LEDs in the UV-C wavelengths it is known to become increasingly difficult to increase the light output power. Yet, packages used to encapsulate these UV-C LEDs are typically TO-packages or 3D-structured ceramic housings with quartz lid. Due to DUV-LEDs radiating up to 50% of their light to the sides a significant share is lost in the package.

We propose a packaging solution that recovers this side-emitted UV-light by integrating mirror structures into an optical window. This window is designed to be placed on a submount over the already mounted LED to form a small outline SMD-Package. Attachment of this window can be hermetic by soldering or non-hermetic by the use of silicones.

This approach combines several advantages. As the side emitted light is reflected to the output surface of the package, higher optical power can be obtained for the same existing LEDs. Simultaneously, as this recovered light is not turned into heat at the sidewalls as with common packaging approaches, the overall thermal performance of the package is much improved. As a result the LED can be driven at higher currents to increase light output further.

Additionally it can be shown, that by design of the reflector the radiation pattern of the package can be significantly influenced. Newest results show how reflectors with heights in the mm-range can mimic the focusing effect of lenses, while maintaining a flat package surface – much demanded for the integration into applications requiring small output angles like disinfection or curing applications.

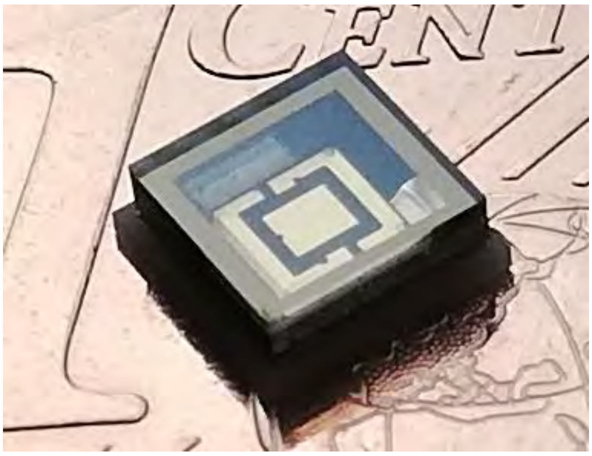


Fig. 1. SMD-type package with integrated reflectors

Fabrication of Aluminum-Coated Plastic Reflectors with an Innovative Metallic Intermediate Layer for High-power UV LED Modules

M. Weizman[1*], A. Ruhe[1], S. Cinque[1], P. Rotsch[1], W. Arnold[1], S. Nieland[2]
[1]OSA Opto Light GmbH, Köpenickerstr. 325, 12555 Berlin, Germany
[2]GMBU e.V. Felsbachstr. 7, 07745 Jena, Germany

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. The usage of transmissive optical elements for beam shaping especially at the UVB/UVC range where quartz glass is the most common material used can be cost intensive. In this paper we demonstrate a method to produce an array of parabolic aluminum (Al) coated reflectors for narrowing the light emission that can be both cost-effective and applicable for high-power UV light.

The biggest challenge we encountered trying to apply Al-coated plastic reflectors at high power densities of about 1 W/cm^2 at UVA and 0.1 W/cm^2 at UVB/UVC was overheating of the reflectors that caused surface damage, cracks, and delamination of the Al coating. The figure below shows that the temperature at the parabolic surface of the reflectors mounted on a test LED module reached for the standard Al-coated plastic reflector temperature as high as 117°C. In order to reduce the reflector temperature we came up with the idea to introduce a metallic intermediate layer underneath the Al layer to improve the overall heat conductivity of the reflector. The results we present in this study demonstrate that by adding a layer of copper (Cu), nickel (Ni), chromium (Cr) or a combination of them with a thickness greater than 30 µm underneath the Al layer, it is possible to dramatically reduce the maximum temperature of the reflector by about 60°C. The reduced reflector temperature resulted in stable operation conditions without any observable degradation over 4000 hours of high-power UV irradiation. These results are a promising achievement on the path to cost-effective high-power UV LED light sources.

Standard Al-coated plastic reflector

Al-coated reflector with a metallic intermediate layer

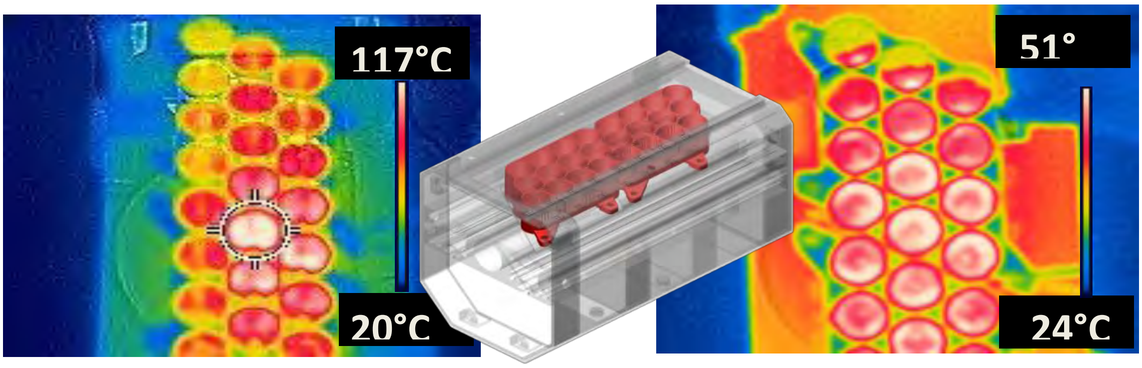


Figure: UV LED Module designed by OSA Opto Light utilizing Al-coated plastic reflectors with an innovative metallic intermediate layer to reduce operation temperature

233 nm UVC LED irradiation for MRSA and MSSA eradication and risk assessment of skin damage ex vivo

Martina C. Meinke[1*], Paula Zwicker[2], Johannes Schleusener[1], Silke B. Lohan[1], Loris Busch[1,3], Claudia Sicher[2], Anja A. Kühl[4], Cornelia Keck[3], Johannes Glaab[5], Neysha Lobo Ploch[5], Hyun Kyong Cho[5], Thomas Filler[5], Sylvia Hagedorn[5], Lucas Wittenbecher[5], Markus Weyers[5], Sven Einfeldt[5], Michael Kneissl[6], Christian Witzel[7], Ulrike Winterwerber[5], and Axel Kramer[2]

[1]Department of Dermatology, Venerology and Allergology, Charité – Universitätsmedizin Berlin, Charitéplatz 1, 10117, Berlin, Germany
[2]Universitätsmedizin Greifswald, Institut für Hygiene und Umwelt-medizin, Ferdinand-Sauerbruch-Str. 1, 17475 Greifswald, Germany
[3]Department of Pharmaceutics and Biopharmaceutics, Philipps-Universität Marburg, Ketzerbach 63, 35032 Marburg, Germany
[4]iPATH.Berlin-Immunopathology for Experimental Models, Core Facility of the Charité – Universitätsmedizin Berlin, Charitéplatz 1, 10117, Berlin, Germany
[5]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin
[6]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany
[7]Division of Plastic and Reconstructive Surgery, Department of Surgery, Charité – Universitätsmedizin Berlin, Charitéplatz 1, 10117, Berlin, *Germany*

Surgical site infections (SSIs) represent an important clinical problem resulting in increased levels of surgical morbidity and mortality. UVC irradiation during surgery has been considered to be a possible strategy to prevent the development of SSIs. Germicidal UV lamps, with a broad wavelength spectrum from 200 to 400 nm, are an effective bactericidal option against drug-resistant and drug-sensitive bacteria [1,2).So far, however, they are assessed as a health hazard to patients and staff. We investigated a newly developed far-UVC LED source with a peak emission wavelength of 233 nm for its suitability of killing microorganisms, especially Methicillin-sensitive and Methicillin-resistant Staphylococcus aureus (MRSA/MSSA), on germ carrier plates. In parallel, we investigated the effect of germicidal radiation doses on skin for human application. Skin cell viability, DNA damage potential and radical production were assessed in comparison to conventional near-UVC irradiation (254 nm) and UVA/B (280–400 nm) irradiation. Far-UVC radiation at 222 nm served as a negative control. At a dose of 40 mJ/cm^2 the far-UVC LED light source could reduce the MSSA and MRSA by 5 log10 levels if no organic substances were included in the medium. Organic substances reduced the germicidal effect to 2 log10 levels independent of the doses. At 40 mJ/cm^2, the investigated skin models showed no reduction in immediate viability: The resulting superficial DNA damage was below 0.1 minimal erythema UVB dose which can be regarded as safe. The low damage vanished after 24h, while irradiation with this dose on four consecutive days showed no DNA damage, at all. The radical formation was far below 0.25 minimal erythema UVA dose. This low radical load can be scavenged by the antioxidant defense system [3].

Acknowledgements: The work is funded by the German Federal Ministry of Education and Research BMBF (FKZ 03ZZ0146B) within the program “Zwanzig20 – Partnerschaft für Innovation” and carried out within the consortium Advanced UV for Life.

References

[1] A. Kramer, M. Meinke, A. Patzelt, M.B. Stolpe, J. Lademann, K. Jacobs, Perspektiven physikalischer Verfahren der Antiseptik und Desinfektion, Hygiene und Medizin, 45;3/2020 D39

[2] M. C. Meinke, A Kramer, S Einfeldt, M. Kneissl, Krankenhauskeime mit UVC-Leuchtdioden bekämpfen, Management und Krankenhaus 39; 9/2020, S.20

[3] Lohan SB, Ivanov D, Schüler N, Berger B, Zastrow L, Lademann J, Meinke MC. Switching from healthy to unhealthy oxidative stress - does the radical type can be used as an indicator? Free Radic Biol Med. 2020 Nov 1:S0891-5849(20)31593-8. Online ahead of print.

Applications of Ultraviolet Light in Healthcare

Richard A. Martinello[1,2]

[1]*Yale School of Medicine, 333 Cedar Street, New Haven, Connecticut, 06510 USA*
[2]*Yale New Haven Health, 20 York Street, Hunter 527, New Haven, Connecticut, 06520 USA*

The use of ultraviolet light (UV) has a long history of providing support for the provision of safer and more effective healthcare and there has been renewed interest in its use. During this past decade, there has been a significant expansion of the use of UV, particularly UV-C, for the disinfection of healthcare environments. While UVC has been used for decades for the disinfection of air, much of the expansion of the use of UVC-based disinfection in healthcare has focused on surface disinfection. More recent applications have included the use of UV to disinfect medical equipment and to treat patients with superficial soft tissue infections. This presentation will provide a discussion of the data supporting these established and emerging uses of UV in healthcare.

Preventing hospital-acquired infections with UVC LEDs

M. Ruffin

Excelitas Technologies, 2260 Argentia Rd., Mississauga, ON Canada

Before the advent of modern medicine, ultraviolet germicidal irradiation (UVGI) was used to treat a variety of diseases. Regardless of the treatment process, the science behind killing the microorganism is the same; UV energy damages the DNA of the microorganism, rendering it unable to reproduce. The use of UVGI continued until it was ultimately replaced by modern drug treatments.

Modern medicine continues to be effective for many diseases. However, the medical industry began to notice that certain treatment dosages kept increasing. What doctors discovered were pathogens developed a resistance to the medicine. These mutations continue today, and we are faced with an increasing number of multiple drug-resistant (MDR) pathogens. Treating infections from MDR pathogens only increases healthcare costs, leading the industry to look for new ways to limit their spread. This search has lead to the rebirth of UVGI.

UVGI treatment started again in the early 2000s; however, it was the environment that received the treatment instead of the patient. These UV exposures lower the environmental bio-load and reduce the possibility of contracting a hospital-acquired infection (HAI), many of which are MDR pathogens. We now move to today and the increasing desire to use “no-touch” disinfection with UVC LEDs.

This presentation will review the prototype design and microbial test results from 2 UVC LED disinfection devices. Subject areas covered include mechanical design, optical simulation and measurements, and microbial disinfection testing.

UV-activated prevention of biofilm spreading in siphons

L. Steinhäußer[1*], G. Gotzmann[1], F. Fietzke[1], J.-M. Albrecht[2], U. König[1]

[1]*Fraunhofer Institut Organische Elektronik, Elektronenstrahl- und Plasmatechnik, Winterbergstraße 28, 01277 Dresden, Germany*

[2]*MoveoMed GmbH, Gartenstraße 34a, 01445 Radebeul*

Antibiotic-resistant germs and nosocomial infections are one of the biggest problems in hospitals. Biofilms form the core of the problem of nosocomial infections. Their formation in siphons, which are located at the sinks in patient rooms, is particularly critical [1]. When water enters the siphon, splash water and the subsequent formed aerosol cloud can release the pathogens into the room and transmit them to patients and nursing staff. Even if the siphon is cleaned regularly and intensively, it is impossible to prevent the formation of biofilms [2]. It is the aim of our research to prevent nosocomial infections transmitted through siphon-associated biofilms. One possible approach to prevent biofilms are titanium dioxide-based surface functionalizations. By installing such a surface in the siphon as a germ barrier, biofilm formation will be confined or prevented completely.

Applications of titanium dioxide are based on two UV-induced mechanisms: photocatalytic decomposition (photocatalysis) and photoinduced superhydrophilicity [3]. Superhydrophilic surfaces prevent the adhesion of pathogens. Using contact angle measurements, we investigated the wetting behavior after activation with a UV-LED (365 nm). Superhydrophilicity was proved, the effect was stable up to 4 days.

In the application-oriented microbiological evaluation it was found that by 30 min UV-activation up to 99 % germ reduction is achieved, using the model organism *E. coli*.

The combination of this surface functionalization with a UV-LED should enable a permanent germ reduction in the siphon, hence preventing infection transmission (Fig. 1).

Fig. 1. Functionalized siphon with integrated UV-activation

The project was conducted in cooperation with MoveoMed GmbH, funded by the Federal Ministry for Economic Affairs and Energy (Grant-Nr. ZF4597702BA8).

References

[1] J. Li, R. Nickel, J. Wu, F. Lin, J. van Lierop, S. Liu, Nanoscale. Volume 11,6905–6915 (2019)

[2] B. Sissoko, R. Sütterlin, M. Blaschke, J. Flicker, A. Schluttig, Hygiene & Medizin, Volume 29, 451–455 (2004)

[3] S. Permpoon, M. Fallet, G. Berthome, B. Baroux, J. C. Joud, M. Langlet, M. Journal of Sol-Gel Science and Technology, Volume 35, 127–136 (2005)

Thinking outside the treatment plant: UV LEDs for distributed disinfection applications

K. Linden*[1], N. Hull[2] and V. Speight[3]

1 University of Colorado Boulder, Environmental Engineering, Boulder, CO 80309, USA
2 The Ohio State University, Department of Civil, Environmental, and Geodedic Engineering, Columbus, OH 43210
3 University of Sheffield, Department of Civil and Structural Engineering, University of Sheffield, Sheffield, S1 3JD UK

This work evaluates the current paradigm of water distribution system management and juxtaposes that with the potential benefits of employing UV irradiation, which we hope will catalyze a re-evaluation of the current practices in water distribution system management and spur critical research and a new way of thinking about secondary disinfection across the extent of distribution systems [1].

We envision a new model for secondary disinfection in water distribution systems utilizing emerging germicidal UV LED-based disinfection. UV irradiation in water treatment can achieve high levels of disinfection of all pathogens and minimize or eliminate the formation of regulated disinfection by-products. The possible locations of UV irradiation in distribution systems are envisioned, potentially including UV booster stations along the distribution network, UV in storage tanks or their inlet/outlets, LEDs distributed along pipe walls, small point of use/entry treatment systems for buildings/homes/taps, or submersible swimming or rolling UV LED drones to reach problem pipes. The benefits of UV applications in water also include high effectiveness against chlorine resistant protozoa, no added disinfection byproducts, and compatibility of adding of UV to existing secondary disinfection strategies for enhanced protection.

Potential challenges and research needs exist, such as use of UV-compatible pipe materials, implementation of sensors to monitor distributed LEDs, management of waste heat from the rear surface of the LED, and understanding the potential for regrowth of opportunistic microorganisms. Rapid advances in UV LED research has propelled the growth of this field, but needs still remain including understanding behavior of biofilms in pipes under UV irradiation, any beneficial effects that may be lost, the potential for fouling of LED emission surfaces and monitoring points, and provision of a distributed power network to run the LEDs.

Currently we are researching means to bring the promise of UV LEDs in the applications envisioned above into reality. The use of LEDs for control of biofilm formation and to disinfect tanks and pipes is being researched using model organisms and field systems. Our initial findings in our current research efforts on control of biofilm formation in pipes and storage tanks with UV LEDs will be presented.

References

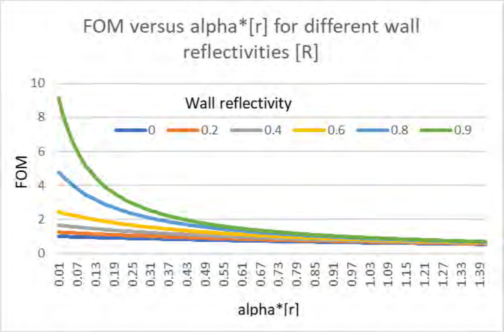
[1] Linden, K.G., Hull, N., Speight, V. (2019) Thinking Outside the Treatment Plant: UV for Water Distribution System Disinfection. Accounts of Chemical Research. Vol. 52, No. 5, 1226-1233. DI 10.1021/acs.accounts.9b0006

Defining a Figure of Merit for UVC Radiation Efficiency in a Water Disinfection Reactor and the Impact of UVT, Reflectivity and Size

Leo J. Schowalter[1*] and Amy C.W. Miller[1]
[1]*Crystal IS, 70 Cohoes Avenue, NY 12183 Green Island, USA*

UVC LEDs are being developed to replace mercury lamps in water disinfection reactors. As pointed out previously, UVC LEDs have advantages over mercury lamps in some applications because of their small footprint, rugged construction, instant on-off, wavelength tailored to the most effective disinfection wavelength, and low operating temperature. However, the wall plug efficiency of UVC LEDs, while continuing to increase, is still substantially below low-pressure mercury lamps. Fortunately, the emitted radiation of LEDs can be used much more effectively than is possible for mercury lamps because the LEDs are nearly point sources of radiation with a very high irradiance near the source, whereas mercury lamps are extended and have much lower irradiance near the source.

The maximum reduction equivalent dose (RED) that is possible for a given UVC radiation power P_c introduced into a water disinfection reactor is $\frac{P_c}{\alpha f}$ where α is the absorption coefficient of the water and f is the flow rate of water through the reactor. This result assumes that all the incoming radiation is absorbed by the water and that all the water which flows through the reactor gets the same dose. In actual reactors, the RED is typically much smaller because radiation is absorbed by walls or other elements of the reactor and it is difficult to achieve flow and radiation conditions where all elements of water flow get the same dose. For large α, most of the radiation is absorbed close to the source, while small α results in path lengths being defined by the walls of the reactor. If the reactor dimension can be approximated by a single typical propagation length [r], then the maximum RED of the reactor is $< \frac{(1-e^{-\alpha[r]})P_c}{\alpha f(1-[R]e^{-\alpha[r]})}$, where [R] is the average reflectivity of the walls of the reactor ([R]=1 is a perfectly reflecting wall). It is useful to define a dimensionless figure of merit (FOM) $\equiv \frac{(1-e^{-\alpha[r]})}{\alpha[r](1-[R]e^{-\alpha[r]})}$, so that the maximum RED < (FOM)(P_c[r]/f). Compared to mercury lamps, LEDs can achieve a high RED, near the maximum derived by this FOM, even when using a long propagation length [r] because the radiation field can be better shaped to match the water flow. In addition, the small footprint of the LED results in higher effective reflectivity. Thus, in most real situations, it appears that UVC LEDs can be configured to be at least 3x better than what is possible with typical, extended-source, low-pressure mercury lamps.



Comparing UV-LED and UV lamps for micropollutant degradation with free chlorine advanced oxidation process in different water matrices

Ataollah Kheyrandish, Madjid Mohseni ,

Department of Chemical and Biological Engineering, University of British Columbia, 2360 East Mall, Vancouver, BC, Canada VT6 1Z3

Advanced oxidation processes (AOPs) are promising technologies for the removal of micropollutants. Ultraviolet (UV) photolysis of aqueous chlorine (UV/Chlorine) is one such AOPs that under lower pH environments can be very efficient and potentially competitive. At pH values below 7.5 (the pKa of HOCl), the higher concentration of HOCl (hypochlorous acid) and greater molar absorption coefficient of HOCl at 254 nm radiation, leads to greater hydroxyl radicals (•OH) production and consequently removing the target contaminants. At pH above 7.5, OCl- is dominant and requires UV radiations with higher wavelengths to generate radical species and hence, efficient performance.

The evolution of UV light-emitting diode (UV-LED) has opened new possibilities and strategies for the application of these sources to water treatment, including UV-chlorine AOPs. The ability to tune the UV-LED peak output to higher wavelengths allows performing UV/chlorine AOP at higher efficiency. For instance, at wavelengths around 290 nm, OCl- has a significantly higher (4×) molar absorption coefficient compared to HOCl. However, there is no clear understanding of the mechanism by which UV-LEDs can influence the process, particularly the impact of water matrix by a standard method to measure the implemented UV fluence.

In this study, we implemented, for the first time, a unique and scientifically sound UV fluence determination protocol for UV-LED systems, to study the feasibility of using UV-LED combined with free chlorine at higher pH. Carbamazepine (CBZ) was used as a model micropollutant, and its degradation was investigated under controlled laboratory conditions by UV-LED/Chlorine and UV/Chlorine (for comparison). UV-LED/Chlorine provided more than three times greater degradation rate at higher pH compared to UV/Chlorine process. In addition to investigating the impact of pH, the effects of common water matrix constituents (i.e., alkalinity and natural organic matter) were investigated, and similar trends were obtained. It was concluded that UV-LED/Chlorine could be a viable alternative to conventional UV/Chlorine AOP, offering enhanced degradation of micropollutants specially for water reuse applications where the water is more alkaline.

Selection, Evaluation and Integration of UV-LED Water Disinfection Modules

B. Adeli[1*], M. Keshavarzfathy [1], A. Babaie[1]

[1]*Acuva Technologies, #1-3771 North Fraser Way, Burnaby, BC, Canada V5J 5G5*

Ultraviolet (UV) radiation is known as the most effective water disinfection route. However, utilization of conventional UV-lamp can be limited for point-of-use (PoU) disinfection applications, due to their high energy consumption, frequent maintenance, warm-up time. Water disinfection systems based on germicidal ultraviolet light emitting diodes (UV-C LEDs) is emerged as an alternative UV source, offering enormous potentials for design and manufacturing of highly efficient PoU disinfection devices.

Development of UV-LEDs enables new demand from industries which were not able to utilize UV disinfection technologies through conventional UV lamps. For instant, design of compact and ultra-low maintenance water disinfection modules for integration into original equipment manufacturer (OEM) appliances can be achieved through UV-LED technology. Yet, the scope of UV-LED based water disinfection modules, from disinfection performance and reliability standpoint is not well established and evaluation criteria are not well documented. Therefore, defining a methodical approach to select a suitable UV-LED module for specific applications appeared to be ambiguous.

In this presentation, the benefits of adopting UV-LED modules, compared to conventional UV lamp devices from performance and economy standpoint will be discussed. In specific, we will present a methodology to select, evaluate, and integrate a suitable UV-LED water disinfection for number of applications. We will show how a certain UV-LED module can be suitable for one certain application, yet causes performance, reliability, or integration challenges for another application. Finally, a comprehensive checklist is introduced to identify the core performance/reliability needs of an application and propose a suitable UV-LED concept accordingly.

Fundamentals of Design for UV-C LED Surface Disinfection Applications

R.M. Simons*, J. Pagan

AquiSense Technologies LLC, 4400 Olympic Boulevard, Erlanger, KY 41018, USA

UV-C LEDs have seen limited uptake in surface disinfection applications, primarily because of the square-scaling effect of target areas: double the target diameter, quadruple the target area. Presently, a relatively high unit cost means that the power problem cannot not be solved by simply using more LEDs and intelligent design effort is required to build effective solutions.

Fortunately, several tools exist to facilitate this intelligent design and enable the wider participation necessary to grow the market; ray optics simulators are readily available in either open-source or commercial packages and may be easily combined with CAD geometries. Development of these methods is being driven by the gaming and cinematography industries and is expected to see continued advancement for the foreseeable future. This synthesis of digital design and expanding means for digital evaluation allows for rapid, low-cost prototyping and product development.

The advent of tools for rapid design evaluation is clearly of benefit to the application of UV-C LED disinfection; however, as a health-related industry at the junction between microbiology, semiconductor physics, medicine, photochemistry, optics, material science, and product design, there is a high risk that newcomers to the field will fall foul of development and realisation pitfalls.

This presentation will provide an overview of *in silico* design and validation methods and key considerations in defining performance specifications; further, case studies shall be provided to illustrate the application of these design and validation principles. It is intended that this work will provide a resource for future UV-C LED surface disinfection system designers to maximise the potential of their work and lead in quality solution development.

Dr. Rich Simons holds a PhD in the development of simulation methods for the optimisation of UV-C LED disinfection systems, with published work in both academic and industrial contexts; Dr. Jennifer Pagan has driven the application science of UV-C LEDs for more than a decade and is CTO of AquiSense Technologies.

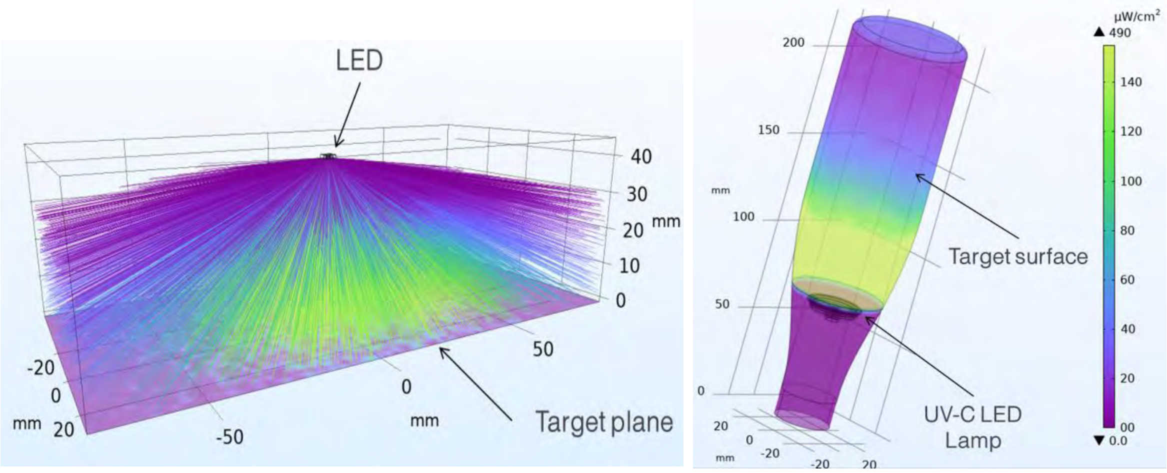


Figure 1. (left) Illustration of the path tracing method: numerous rays are fired from an LED source to a perpendicular plane, resulting in an irradiance distribution across it. (right) example application to the disinfection of the internal surface of a water bottle.

Factors affecting UV device validation in air and surface disinfection

[1]Castine A. Bernardy, [2]Nicola M. Elardo, [3]Alexa M. Trautz, [4]James P. Malley

[1]PhD Student Environmental Engineering, [2]MS Student Environmental Engineering,
[3]BS EnvE/UNH Research Environmental Engineer, [4]Jr., Ph.D.– Professor Civil & Environmental Engineering (corresponding author) University of New Hampshire, Durham, NH USA

UV Technology has been effective for over 100 years when designed, operated, maintained, and monitored properly. A validation and certification protocol for UV devices including the wide array of UV-LED devices available for the treatment of air and surfaces (objects) is essential to ensure quality. A validation endpoint based on Quantitative Microbial Risk Assessment (QMRA) would assist the UV profession ensure public health protection and develop reliable, cost effective, UV devices. UV Devices need to be validated the way they will be used since the system optics, dose distribution, contact time and user safety are all critical considerations. This project uses nebulized E. coli and MS-2 bacteriophage virus applied to a variety of surfaces from PPE masks to cell phones and eyeglasses to determine the log inactivation or percent removals achieved by UV devices. Result presented show that 11 of the 16 commercial and consumer UV devices tested did not achieve their performance claims (which range from 99.9% to 99.9999% 'kill of germs' due to poor optics, low irradiance or poor UV dose distribution delivered to the air or surfaces. Safety considerations based upon ACGIH recommended 8-hour TLV, UV dose exposures especially with UV-LED handheld wand type devices emitting in the 265 to 285nm range raise concerns. Calculations indicate the recommended exposure limits can be exceeded in seconds posing risks to eye or skin health especially when considering probability of repeated exposures from daily use.

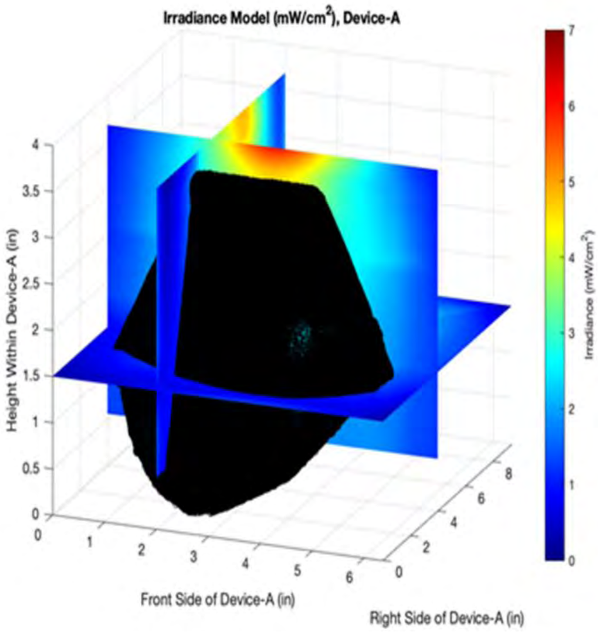


Fig.1. Irradiance Heat Map UV Device A.

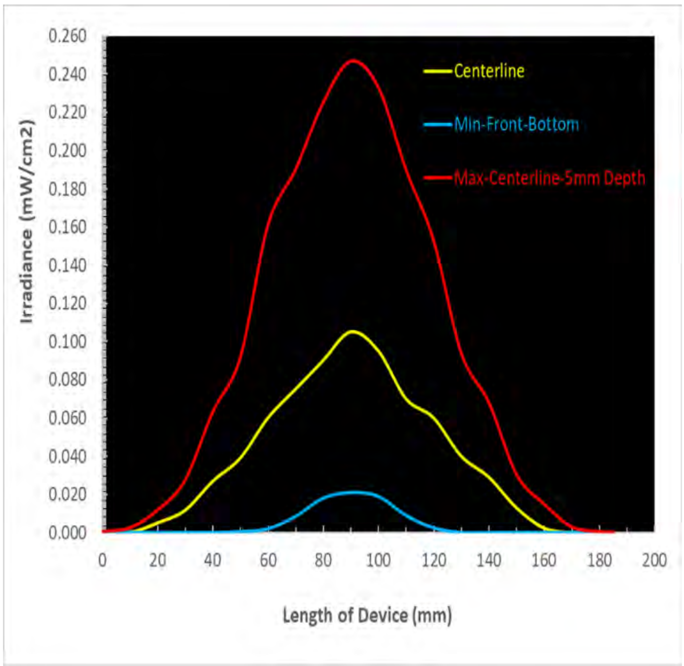


Fig.2. Irradiance Distribution UV-LED Device J.

Is far-UVC radiation a promising approach to prevent airborne infections in regard to the ongoing SARS-CoV-2 pandemic?

Respiratory viruses as influenza and RS viruses but also SARS-CoV-2 are airborne transmitted pathogens. Since the beginning of the COVID-19 pandemic, concepts for interrupting airborne transmission received increased attention. However, new technologic solutions are required; SARS-CoV-2, an atomic bomb that is visible only by electron-microscopically, will accompany us for many years.

The main transmission route for SARS-CoV-2 is by droplets > 5 µm, but also aerogenic by nuclei < 5 µm with spread about 3 m. In the ambient air, SARS-CoV2 virus particles stay infectious for up to 16 h; sedimented onto different surfaces they are infectious even longer up to 9 days; resulting in a high risk of indoor transmission via droplets released when speaking, coughing, and sneezing. For personal protection, surgical mouth-nose masks (MNM) are an effective barrier against further spread. The bacterial filter performance is > 95 %. Wearing masks is useful to protect people in the vicinity from droplet infection. The wearing of MNM reduced the transmission of SARS by 68 %. Otherwise surgical masks do not fit tightly enough on the face to protect against aerogenic nuclei. Additional measures are social distancing > 1.50 m and window ventilation of rooms every hour for 10 min. But these measures proved not to be sufficient to interrupt the pandemic. A turnaround can only be expected when the majority of the population has been vaccinated. But in light of selection of mutants, technological solutions are needed to reduce indoor viral loads.

The use of UV radiation for virus inactivation in indoor air is known for a long time. Its mode of action relys on the damage of DNA and RNA thus preventing the multiplication of bacteria and virus particles. Typically, radiation with a wavelength of 254 nm is used for inactivation, that, however also harms e.g. human cells. In the last years, the efficacy of shorter wavelengths is getting rising interest because of its supposed higher biocompatibility. For viruses in suspension and on surfaces the use of UVC radiation for inactivation was published manifold. Actually, the inactivation of virus particles in aerosols was already shown for influenza and corona viruses by UV radiation at 222 nm with low doses, which are biocompatible. These data give rise to the assumption, that the SARS-CoV-2 load in the ambient air can be reduced by UV radiation decreasing the risk of infection in enclosed areas and thus may be a possibility for prevention of airborne infections.

Disinfection of coronavirus by UVC LEDs: A line of defense to contain pandemics

Hadas Mamane[a], Yoram Gerchman[b], Nehemya Friedman[c,d], Michal Mandelboim[c,d]

[a]*School of Mechanical Engineering, Faculty of Engineering, Tel Aviv University, Tel Aviv 69978, Israel*
[b]*Department of Biology and Environment, Faculty of Natural Science, University of Haifa and Oranim College, Tivon 3600600, Israel*
[c]*Central Virology Laboratory, Ministry of Health, Chaim Sheba Medical Center, Tel-Hashomer, Ramat-Gan, Israel*
[d]*Department of Epidemiology and Preventive Medicine, School of Public Health, Tel-Aviv University, Israel*

As the global prevalence of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) outbreaks increases there is a dire need for novel disinfection technologies. The use of ultraviolet (UV) can enable another line of defense to allow close-to-normal life conditions even at times of high pandemic risk, by providing reliable means to reduce the risk of infection in confined spaces. The common mercury based ultra-violet (UV) technologies are widely used in water, surface and air treatment, however they contain mercury, emit specific spectrum, and are sometimes difficult to integrate as they are enclosed in a quartz tube, similar to fluorescent lamps. UV-light emitting diodes (LEDs) are a novel technology that allow, due to their small size, flexible design and tuning wavelength according to need. The pandemic has created momentum for the UVC LED industry, with market projection of $2.5 billion in 2025. However, UVC LEDs have low output power making higher wavelengths more attractive. Our results suggest that the sensitivity of human Coronavirus (HCoV-OC43 used as SARS-CoV-2 surrogate) was wavelength dependent with 267 nm ~ 279 nm > 286 nm > 297 nm. Other viruses showed similar results, suggesting UV LED with peak emission at ~286 nm could serve as an effective tool in the fight against human Coronaviruses. The knowledge and insights gained in the current studies will enable us smart design of UV-LEDs in disinfection of hospital rooms, air conditioning systems, surfaces and water, utilizing the benefits of UV-LEDs and contributing to the fight against the COVID-19 pandemic as well as future pandemics.

UV Inactivation Kinetics of SARS-CoV-2 and HCoV-229E using UV-LEDs

B. Adeli[1*], M. Raeiszadeh[1], M. Keshavarzfathy[1], E. Espid[1]
[1] *Acuva Technologies, #1-3771 North Fraser Way, Burnaby, BC, Canada V5J 5G5*

The global health-threatening crisis from the COVID-19 pandemic, caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), highlighted the scientific and engineering potentials of applying ultraviolet (UV) disinfection technologies for biocontaminated air and surfaces as the major media for disease transmission. Nowadays, various environmental public settings worldwide, from hospitals and health care facilities to shopping malls and airports, are considering implementation of UV disinfection devices for disinfection of frequently touched surfaces and circulating air streams. Moreover, the general public utilizes UV sterilization devices for various surfaces, from doorknobs and keypads to personal protective equipment, or air purification devices with an integrated UV disinfection technology. However, limited understanding of the UV inactivation kinetics of SARS-CoV-2 virus resulted in unreliable claims and inaccurate estimates regarding the efficacy of UV disinfection devices. In addition, the UV inactivation kinetics of other strains of Coronavirus and/or organisms as the surrogate for SARS-CoV-2 has been widely employed, in which introduces another source of inaccuracy due to variations in experimental conditions and methodologies.

In collaboration with Centers for Disease Control and Prevention certified BioSafety Level 3 laboratory, our team has conducted series of controlled experiments to develop the UV inactivation kinetics of SARS-CoV-2. These data were also established and analyzed for Human Coronavirus (HCoV-229E), which has been widely used as the surrogate for SARS-CoV-2 virus. Our data suggest the effectiveness of UVC-LEDs in inactivation of SARS-CoV-2 and HCoV-229E on surface, with a quasi-linear kinetics, achieving over 3-log reduction at 14–16 mJ/cm^2 UV dose at 275nm. To the best of our knowledge, the data presented in this study is the first controlled UV inactivation kinetics study using UVC-LEDs as the source of irradiation.

Keywords: SARS-CoV-2, Inactivation kinetics, Surface disinfection, UVC LEDs

UV LEDs: Recent advances and future prospects of this versatile technology

Neysha Lobo Ploch

UVphotonics NT GmbH, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany

III-nitride-based ultraviolet (UV) light emitting diodes (LEDs) have the potential to become a versatile platform technology due to their customizable wavelengths, low operation voltages, ability to be rapidly switched or dimmed and their compact size. These unique advantages of UV LEDs offer new solutions for emerging environmental issues related to drinking water treatment, disease confinement by disinfection of air and surfaces, plant growth lighting and environmental monitoring of pesticides, gases and water. In addition, these versatile sources can be used for industrial curing and in the medical field for phototherapy and medical diagnostics.

Since 2008, the UV LED market has been steadily growing from around \$ 20 million to \$ 144 million in 2019. This has also been reflected in the growth of the number of players in the UV LED market from 10 LED manufacturers in 2008 to around 70 players today. Till now, the market was mainly driven by the UVA (320 nm – 400 nm) LED market sector with UV curing generating more than half the total market revenue. Due to the current COVID-19 pandemic, the increased demand for UVC LEDs (<280 nm) that disinfect surfaces is expected to have doubled the UV LED market volume in 2020. However, the power conversion efficiency of commercial UVC LEDs is still below 10 %. Hence, continued research and development is required to improve the performance of deep UV LEDs to enable large scale adoption.

In this presentation, the technological requirements of the Al(In)GaN deep UV LEDs for each of their diverse applications will be presented and the factors influencing the performance and reliability of the devices will be discussed. The need to develop low cost LED packages with low thermal resistance and UV stable encapsulation materials will be examined. Furthermore, the importance of customizing the LED performance and package based on the application will be explored. Finally, the performance of currently available UV LEDs will be presented and based on historical trends of performance, predictions on the development of UV LED efficiencies and price will be discussed.

UV LED system put to the test: A diary of a test center

T. Schwarzenberger[1*],, K.-H. Schön[1], J. Eggers[1]

[1]*TZW: DVGW – Technologiezentrum Wasser, Karlsruher Strasse 84, 76139 Karlsruhe, Germany*

In general, a validation of conventional UV systems (municipal applications) according the common worksheets and guidelines (W 294-2, ÖNORM M 5873-1/2, DIN 19294-1 and UVDGM) should provide a save future operation of the UV system by taking into account the following requirements and aspects:

- Determination of the disinfection performance by means of biodosimetrical methods
- Characterization of all relevant components
- Solid monitoring concept to comply with minimal disinfection requirements

For LED based UV systems there is currently no standard/guideline that could covers all technical and biodosimetric aspects comparable to conventional validations. As preparation for the new LED DIN starting in May 2021 a small scale validation picking the advantages from existing standards was conducted.

Besides a technical and optical characterization, a comprehensive biodosimetry based on the combined variable approach [1] was conducted using four different surrogate microorganisms showing the impact of wavelength dependency.

The presentation will show the results from these technical and biological investigations and will give some outlook on upcoming challenges for the new LED DIN.

References

[1] Wright, H.; Brooks, T.; Heath, M.: Draft Version: Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems. (September 2019)

Hydroxyl radical formation and removal efficiency of sulfonamide antibiotics from real water matrices using UV-LED irradiated TiO_2 and ZnO photocatalysts

M. Náfrádi*, T. Alapi**

University of Szeged, Department of Inorganic and Analytical Chemistry, Dóm tér 7, H-6720 Szeged, Hungary

Advanced Oxidation Processes (AOPs) may offer a way to remove several non-biodegradable pollutants released to wastewaters, like antibiotics and other pharmaceuticals [1, 2]. Heterogeneous photocatalysis is a widely researched AOP thanks to its efficient degradation and mineralization of most organic pollutants, but its widespread application is not yet solved. UV-LED light sources can prove to be a highly efficient solution for the excitation of wide bandgap semiconductors like TiO_2 and ZnO [3]. This work aims to compare different UV-LEDs emitting in the UV-A region to fluorescent mercury vapor lamps (MVL) for the excitation of commercial TiO_2 and ZnO photocatalysts. Cheap, commercial LEDs emitting at 398 nm ($P_{electric}$=76 mW), high power UV-LEDs emitting at 365 nm ($P_{electric}$=2.0 W), and a MVL emitting in the 300-400 nm range ($P_{electric}$=15.0 W) has been used.

The photon flux of the light sources and electric efficiency were compared based on iron-oxalate actinometry performed at different electric power input. Coumarin was employed to compare the formation rate of hydroxyl radicals ($^\bullet$OH), and the removal rate and mineralization efficiency of two sulfonamide antibiotics was also investigated. The comparison was based on the removal and mineralization rates, photonic efficiencies, and electric power consumption. For practical application, experiments were also performed in two real water matrices (drinking water, biologically treated wastewater).

In the case of TiO_2, a significantly higher $^\bullet$OH formation and mineralization rate were determined compared to ZnO. On the other hand, ZnO was slightly more effective at transforming both coumarin and sulfonamide antibiotics. The LEDs emitting at 398 nm were the least efficient during photocatalysis, but the UV-LEDs emitting at 365 nm were more effective and consumed less electric power than the MVL, especially in the case of ZnO. During photocatalytic experiments with the LED light sources, the photonic efficiencies were reduced with increasing the light intensity. In real water matrices, ZnO proved to be significantly more effective than TiO_2, as some components of the matrices even increased the production of $^\bullet$OH.

References

[1] M.De Liguoro, B.Fioretto, C.Polronieri, G.Gallina, Chemosphere, 75, 1519-1524 (2019)
[2] M.Biosic, M.Mitrevski, S.Babic, Environ Sci Pollut Res Int, 24, 9802-9812 (2017)
[3] O.Tokode, R.Prabhu, L.A.Lawton, P.K.J.Robertson, Handb Environ Chem, 35, 159–179 (2015)

This work was supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences and the new national excellence program of the Ministry for Innovation and Technology (ÚNKP-20-5-SZTE 639). This work was sponsored by the National Research, Development and Innovation Office-NKFIH OTKA, project number FK132742.

Enhanced bacterial inactivation through sequential irradiation with UV-LEDs at specific wavelengths

Kai Song[1,2]*, Fariborz Taghipour[1], Madjid Mohseni[1]

[1]Department of Chemical and Biological Engineering, The University of British Columbia, 2360 East Mall, Vancouver, BC V6T 1Z3, Canada

[2]College of Biology and the Environment, Nanjing Forestry University, Nanjing 210037, China

The emergence of ultraviolet light-emitting diodes (UV-LEDs) with their unique feature of wavelength diversity brings flexibility for various UV wavelength combinations. In our work, we investigated the inactivation of representative microorganisms using UV-LEDs at various wavelengths (UVA, UVB, UVC) with different combinations (simultaneous, sequential). Two types of indicator microorganisms were examined, namely *Escherichia coli* (*E. coli*) as a representative bacteria and bacteriophage MS2 as a representative virus. Different inactivation effects were observed: combinations of UVC/UVB always provided additive effect on microorganisms inactivation due to the same photochemical reactions induced by UVC/UVB on DNA. Combining UVA with UVC/UVB simultaneously or applying UVA after UVC/UVB reduced the inactivation of bacterium *E. coli* due to DNA repair and photoreactivation effect of UVA. However, applying extended UVA exposure before UVC significantly enhanced *E. coli* inactivation. For virus MS2 inactivation, only additive effect was observed under various wavelength combinations.

With the observed enhancement of the *E. coli* inactivation with extended UVA followed by UVC irradiations, this configuration was further investigated. While a substantial shoulder in the *E. coli* UVC inactivation curve was observed, this was reduced by UVA pretreatment (365 nm) at 17 J/cm^2. Further, 52 J/cm^2 UVA eliminated the shoulder in the fluence-response curves, resulting in significantly enhanced UVC (265 nm) inactivation of *E. coli* by over two orders of magnitude. Moreover, UVA pretreatment eliminated photoreactivation of *E. coli* but did not affect dark repair. Detailed investigation of inactivation mechanisms revealed that hydroxyl radicals (•OH) played a significant role during UVA pretreatment. This work demonstrated that •OH was generated inside *E. coli* cells during UVA pretreatment. This in turn resulted in impaired cell functions such as DNA self-repair, and enhanced inactivation following irradiation with the UVC LED at 265 nm.

UV LED Validation Per USEPA UVDGM and Innovative Approaches

Traci Brooks[1], Harold Wright[1], Mark Heath[1], Matt Simpson[2], Olivier Autin[2], Alister Renton[2], Tim Schwarzenberger[3], Karl-Heinz Schoen[3]

[1]Carollo Engineers, 12592 West Explorer, Suite 200, Boise ID 83713
[2]Typhon Treatment Systems Ltd., Unit 10, Newtongate Industrial Estate, Penrith CA11 0BF, United Kingdom
[3]TZW: DVGW - Technologiezentrum Wasser, Karlsruher Strasse 84, 76139 Karlsruhe

Ultraviolet (UV) disinfection is a common technology for inactivation of a range of microorganisms such as *Cryptosporidium*, Giardia, adenovirus, and E. coli in drinking water and wastewater treatment. UV disinfection has traditionally used either low-pressure high-output (LPHO) or medium pressure (MP) mercury lamps which emit light in the germicidal wavelength range. Some limitations of traditional mercury lamps are the potential for mercury contamination resulting from lamp breakage, a warmup time for LPHO lamps, and the high energy costs associated with operation. One alternative to mercury UV lamps is UV Light emitting diodes (LEDs). UV LEDs have mostly been used for small point of use systems to treat water at low flows, and their suitability for larger municipal applications has been limited. However, recent advancements in UV LED technology have made the use of UV LEDs for disinfection at higher flows possible.

This presentation will discuss the recent validation of a UV LED disinfection reactor manufactured by Typhon Treatment Systems (Penrith, UK) conducted in conjunction with the German Water Centre

(TZW) in St. Augustin, Germany and Carollo Engineers, Inc. The Typhon Bio310 uses multiple rings of LEDs that encompass the circumference of a quartz reactor wall. LED output was monitored using UV sensors located radially around the cross-section of the reactor wall. Validation was conducted at UVTs ranging from 70 to 98 percent and flows from 28.4 to 501 m^3/hr (125 to 2206 gpm). Analysis was done in accordance with the UV Disinfection Guidance Manual (UVDGM) and the Innovative Approaches for Validation of Ultraviolet Disinfection Reactors for Drinking Water Systems. The validation dataset was analyzed using an UV dose monitoring algorithm using a combined variable that incorporated an Action Spectra Correction Factor to account for wavelengths differences between the validation test microbes and the target pathogens. The results of this validation show that up to 4 log inactivation of *Cryptosporidium*, Giardia, adenovirus, was achieved at flow rates that make the Typhon B310 a commercially viable option for municipal drinking water treatment.

Characteristics of UV-LEDs for Industrial Curing Solutions

Petra Burger
Dr. Hönle AG, Gräfelfing

During recent years, UV-LED technology has been gaining more and more success for numerous industrial processes. But still, there are applications for which conventional UV technology is rightly the best choice. New developments for UV-LED dies need to respond to this situation and overcome shortcomings of UV-LEDs compared to conventional mercury-based UV systems.

This paper will show the characteristics of UV-LEDs and their positive effects on industrial applications, but it will also explain the flaws of this technology and give examples for successful replacements of conventional UV systems by UV-LEDs.

Continuous nap-core production process including UV-LED curing

Mathias Köhler[1], Christian Dreyer[1,2], Theresa Förster[1], Andreas Bernaschek[2,3], Annette Bauer[3]

[1] *Fraunhofer-Institute for Applied Polymer Research IAP, Research Division Polymeric Materials and Composites PYCO, Schmiedestraße 5, 15745 Wildau*
[2] *Technische Hochschule Wildau, Hochschulring 1, 15745 Wildau*
[3] *InnoMat GmbH, Freiheitstraße 124-126, 15745 Wildau*

Since several years, lightweight construction materials gained special interest in the aircraft, automotive and construction industry. The application range of fiber-reinforced materials is expanding, but new challenges for production processes arise. Hence, the full potential of new engineering technologies have to be exploided by utilization of UV-LEDs.

Especially, thermal curing of prepregs or nap-cores (alternative core material for sandwich structures) is very time and energy consuming [1]. Currently, manufacturing processes of nap-cores are based on thermal curing at temperatures of 130 °C to 180 °C [2]. Thus, the development of an UV-LED curing process for the continuous production of nap-cores offers the opportunity to increase the production speed and minimize energy costs [3].

We present a novel preparation process where the two-dimensional impregnated textile is shaped into a three-dimensional nap-structure cured by UV-LED light (λ = 385 nm). The continuous process consists of three steps: i) the UV curable resin is applied on a special release liner, ii) the textile is placed on the resin film and laminated by a roller and iii) the impregnated textile is shaped between a tool belt and a rotating grid drum and subsequently cured by UV-LED. It was possible to triple the production speed compared to thermal curing processes. A nap-core height of at least 6 mm was achieved. Additionally, the prepared sandwich structures with UV-LED cured nap-cores made of glass fabric had a specific compressive strength of at least 3,000 Pa/(kg/m³).

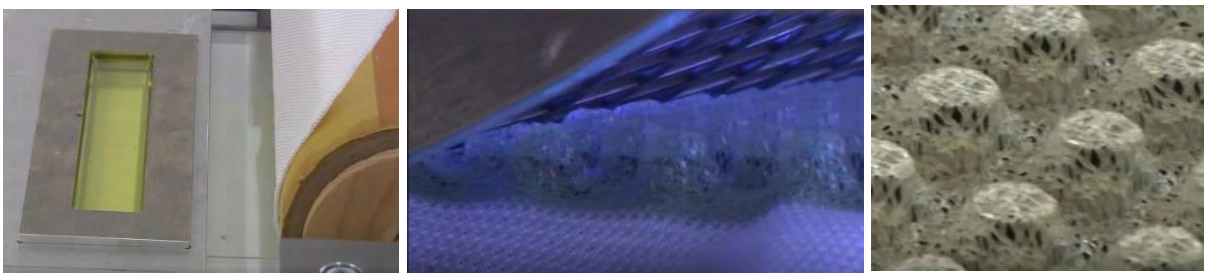


Figure. Nap core preparation with UV-LED; left: impregnation of textile, middle: UV-LED curing of the formed nap-core; right: UV-LED cured nap-core.

[1] A. Bernaschek, Composite Solutions 2012, 6, 10-14: A three-dimensional core material for lightweight sandwich constructions

[2] N. Gerber, M. Bauer, C. Dreyer, Konstruktion - Zeitschrift für Produktentwicklung und Ingenieur-Werkstoffe 2015, 3, IW 14-16: Kontinuierlich herstellbares Kernmaterial zur Funktionsintegration in Sandwichbauteilen.

[3] R. Schwalm, UV Coatings: Basics, Recent Development and New Applications, Amsterdam, Elsevier, 2007.

UV-LED-curing
A next-generation technology for textile industry

Ralf Lungwitz
Sächsisches Textilforschungsinstitut e.V. (STFI) An-Institut der Technischen Universität Chemnitz,
Annaberger Straße 240, 09125 Chemnitz, Germany

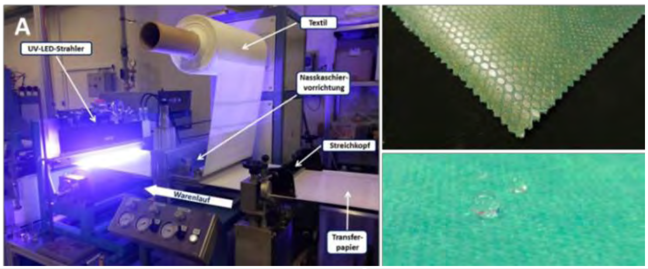
In times of increasing energy costs and a growing environmental awareness the textile finishing tends to modern, ecological, energy and cost efficient methods. UV-curing is a well-known and established technology in many industrial applications such as graphic, wood, paper or varnish sectors.

Actually, more and more modern UV-LED emitters are used instead of classical mercury medium pressure lamps, because of its outstanding advantages like long operating life, no emission of toxic ozone and up heating IR-radiation. The application of UV-LED-curable coatings is an ecofriendly (solvent free 100 % systems) and energy efficient (up to 80 % energy saving in comparison with thermal curing) alternative to traditional thermal drying and curing technologies.

UV-LED-curing is applied at room temperature so thermal sensitive textiles can be coated.

The presentation covers the potential of UV-LED-curing in textile industry. Examples of new developments and applications will be presented:

- UV-LED-curable systems for textile coating → flexible and stretchable direct and transfer coatings based on silikones and urethanes (A)
- UV-LED-curable formulation for fibre reinforced composites → glass and glass/carbon fibre based composites (B)
- UV-LED-curable formulations for 3D printing via dispenser → individual and partial functionalisation (C)



Innovative UV LED Curable Polymer Coatings for Glass Fibers

Jürgen Rosenkranz[1], Mathias Köhler[2], Jan Jasper Klein[3], Christian Dreyer[2,4]
[1] *j-fiber GmbH, Im Semmicht 1, 07751 Jena*
[2] *Fraunhofer-Institute for Applied Polymer Research IAP, Research Division Polymeric Materials and Composites PYCO, Schmiedestraße 5, 15745 Wildau*
[3] *micro resist technology GmbH, Koepenicker Str. 325, 12555 Berlin*
[4] *Technische Hochschule Wildau, Hochschulring 1, 15745 Wildau*

Fast UV LED curable polymers are highly interesting materials since they enable a high processing speed and short production times.[1,2] Especially fast curing coatings with tailored thermal and mechanical properties are needed for optical fibers in sensor and laser applications. Glass fiber coatings consisting of fluorinated (meth)acrylate based polymers with low refractive index (< 1.39 at 1550 nm) are widely used in appications when a high numerical aperture is required. However, there is also a strong demand for temperature stable, high index coatings (> 1.50 at 1550 nm), which can be achieved by inorganic-organic hybrid polymers. In order to save energy and costs by the use of UV LED curing techniques in the fiber drawing process (Figure 1) as well as to replace toxic mercury lamps as UV exposure source, innovative UV LED curable polymer coatings were investigated. The main focus in development was the adaption of viscosity, refractive index as well as enhanced thermal and mechanical properties of the polymer materials.[3] In this work, we present initial results of those investigations especially the influence of the UV source on the degree of polymerization (UV LED curing vs. UV Hg-lamp curing), optical and mechanical properties of the coatings as well as the industrial application. The investigated polymers provide an excellent curing behavior upon both UV LED (especially at 390 nm) and Hg-lamp exposure. Furthermore, the materials show a high mechanical and thermal stability at least up to 150 °C (Figure 2). Due to their robustness against autoclaving and a low internal optical loss, these new polymer coatings can be used in medical as well as material processing applications, taking advantage of a more sustainable and cost-effective UV-curing in fiber manufacturing.

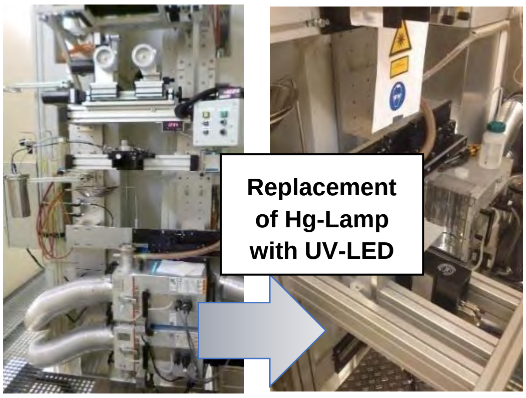


Figure 1. glass fiber drawing tower with Hg-Lamps (left) and UV-LED (right)

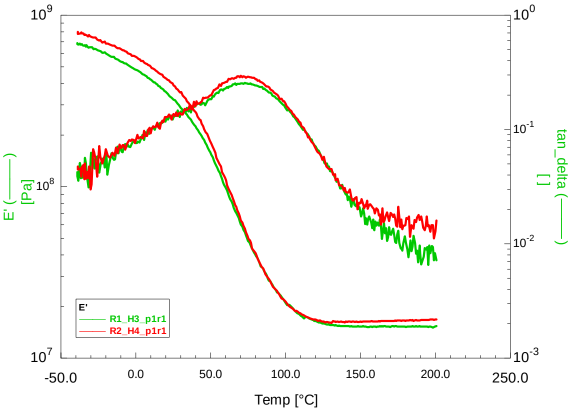


Figure 2. Dynamic mechanical analysis of two acrylate based coating materials

[1] R. Schwalm, *UV Coatings: Basics, Recent Development and New Applications*, Amsterdam, Elsevier, **2007**.

[2] F. Mitschke: *Glasfasern – Physik und Technologie*. Elsevier – Spektrum Akademischer Verlag, **2005**, pp. 75–80.

[3] T. Bishop, K. Gan, **2010**. *LED curing of radiation curable optical fiber coating compositions.* Algonquin, US, Patent No. WO 2011/075549

Exploring the wavelength & efficiency limits of deep UV LEDs

Michael Kneissl[1,2*]
[1]Institute of Solid State Physics, Technische Universität Berlin, 10623 Berlin, Germany
[2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany

Galvanized by high volume applications like water purification and air filtering systems the development of light emitting diodes in the deep ultraviolet spectral range (DUV-LEDs) has significantly intensified with a focus on LEDs emitting near the germicidal effectiveness peak around 270 nm [1]. This presentation will provide an overview of the state-of-the art in DUV-LED technologies and discuss recent advances in the development of low defect density AlGaN materials on sapphire substrates [2]. We will demonstrate high power AlGaN quantum well LEDs emitting near 270 nm and explore the wavelength limits of deep UV-LEDs with emission as short as 217 nm [3]. These deep UV-LEDs are ideally suited for sensing applications like the monitoring of toxic gases, nitrates in water, and may also be utilized for the in-vivo inactivation of multi-drug-resistant germs and airborne viruses without damaging the human skin. However, a strong decline in the external quantum efficiency (EQE) is observed for UV-LEDs below 250 nm. We will investigate the root causes for the drop in EQE at deep UV wavelengths, including changes in the optical polarization of light emission and their effects on light extraction as well as changes in radiative recombination rates and the role of point defects in AlGaN materials with high aluminum mole fractions. Based on these investigations, milliwatt power LEDs emitting near 233 have been realized [4] and a first spectrally pure deep UV LED irradiation module for the in-vivo inactivation of multi-drug-resistant bacteria is demonstrated [5,6].

References

[1] M. Kneissl, J. Rass (Eds.), III-Nitride Ultraviolet Emitters - Technology & Applications (Springer, Cham, Heidelberg, New York, 2016)
[2] M. Kneissl, T.-Y. Seong, J. Han, H. Amano, Nature Photonics 13, 233 (2019)
[3] N. Susilo, E. Ziffer, S. Hagedorn, L. Cancellara, S. Metzner, B. Belde, F. Bertram, S. Walde, L. Sulmoni, M. Guttmann, T. Wernicke, J. Christen, M. Albrecht, M. Weyers, M. Kneissl, Photonics Research 8, 589 (2020)
[4] N. Lobo-Ploch, F. Mehnke, L. Sulmoni, H.K. Cho, M. Guttmann, J. Glaab, K. Hilbrich, T. Wernicke, S. Einfeldt, M. Kneissl, Appl. Phys. Lett. 117, 111102 (2020)
[5] M.C. Meinke, A. Kramer, M. Kneissl, S. Einfeldt, Management & Krankenhaus 9, 20 (2020)
[6] S. Einfeldt, M. Kneissl, M.C. Meinke, J. Schleusener, A. Kramer, P. Zwicker, U. Winterwerber, Wiley Analytical Science (2021), https://analyticalscience.wiley.com/do/10.1002/was.00050176

Optical internal quantum efficiency determination of UVC LEDs – towards a standardization of experimental conditions

C. Frankerl[1,2*], M. P. Hoffmann[1], F. Nippert[2], H. Wang[1], C. Brandl[1], N. Tillner[1,3] H.-J. Lugauer[1], R. Zeisel[1], A. Hoffmann[2], and M. J. Davies[1]

[1]*OSRAM Opto Semiconductors GmbH, Leibnizstr. 4, 93055 Regensburg, Germany*
[2]*Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany*
[3]*Institut für Halbleitertechnik, TU Braunschweig, Hans-Sommer-Straße 66, 38106 Braunschweig, Germany*

UV-C LEDs based on the AlGaN material system suffer generally from low external and internal quantum efficiencies (IQE), especially compared to their commercialized visible and infrared counterparts. One of the first crucial steps of any development effort in the DUV must therefore be the optimization of the LED's active region - the multi quantum well (MQW) structure. For this matter, many groups rely on commonly employed excitation- and/or temperature-dependent PL measurements and treat the obtained IQE values as reliable indicators of the QW growth quality.

We report on a systematic study of the determination of the IQE in AlGaN-based MQWs using various optical evaluation methodologies and experimental conditions. The examined samples are intended to represent the active region of a DUV LED and vary only in the thickness of an AlN interlayer between the MQWs and the AlGaN buffer layer. The aim of this study is to derive a standard set of measurement conditions for a reliable IQE determination, as well as bring more insight into the measurement techniques itself and finally improve the comparability among research groups.

We identify and discuss potential sources of error, which may distort the IQE obtained by optical measurements. These include, among others, carrier transport effects and morphology issues. A large discrepancy of the determined values is observed if the employed excitation conditions fail to fulfill ideal resonance conditions (compare fig. 1), highlighting the need for an appropriate choice of excitation source. Additionally, the apparent impact of surface morphology – examined in this study by the variation of the AlN interlayer thickness – on the IQE of a DUV LED is investigated and discussed.

Our results emphasize the need for rigorous scrutiny in the interpretation of IQE values obtained by optical experiments either not in fully resonant conditions or performed on sample structures not precisely resembling the intended final active system of a DUV LED.

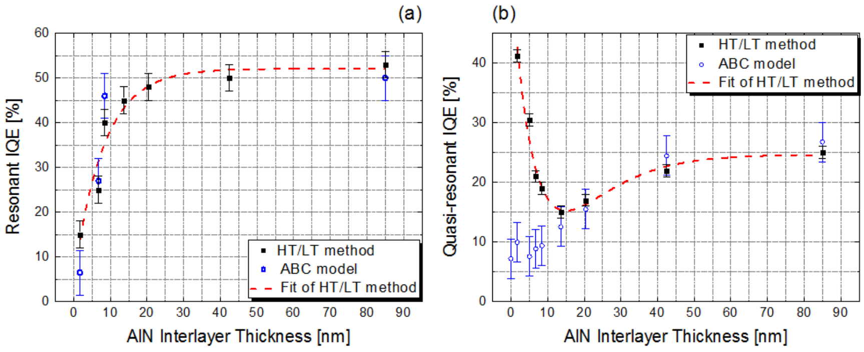


Fig. 1: Resonant (a) and quasi-resonant (b) IQE values measured for a series of AlGaN/AlN MQWs plotted as a function of AlN thickness and extracted via different methodologies.

Accurate UV-C LED measurement techniques include the removal of fluorescence effects.

M. Clark*, R. Zuber, M. Ribnitzky
Gigahertz-Optik, Türkenfeld, Germany

The accurate measurement of UV LEDs encounter more challenges than the equivalent measurements of visible light LEDs. The intrinsically imperfect spectral response of UV radiometers and their associated calibration process must be considered carefully. Spectroradiometers require particular attention to avoid errors resulting from internal stray light. The output power (radiant flux, W) of UV LEDs is most commonly measured with integrating sphere-based spectroradiometer systems. A significant source of error when measuring UV-C LEDs is fluorescence within the integrating sphere. The dominant cause of this fluorescence lies in contaminants such as hydrocarbons and other organic material (micro-organisms) which form on or penetrate the surface of the sphere coating.

For UV measurements the use of integrating spheres with synthetic coatings (e.g. ptfe based) rather than barium sulfate ($BaS0_4$) is generally recommended by manufacturers due to their higher reflectance properties. Fluorescence is known to be reduced by conditioning treatments including the use of heat and irradiation with UV radiation of high irradiance. A study has been undertaken to investigate the short term and long term effectiveness of such treatments on both ptfe and barium sulfate type spheres. The measurement uncertainty arising from fluorescence is determined for an exemplary UV-C LED.

Results show that fluorescence within barium sulfate coated spheres can be reduced significantly more than in ptfe material spheres. When measuring UV-C LEDs the high reflectance advantage of ptfe is countered by increased measurement uncertainty due to fluorescence. The resulting measurement uncertainty contribution of residual fluorescence post-treatment of synthetic coated spheres is approximately ten times that of a barium sulfate sphere when measuring an example UV-C LED. Importantly, fluorescence was found to reoccur, steadily increasing with time, in all cases for integrating spheres used within normal laboratory conditions necessitating the need for ongoing treatment protocols to ensure lowest uncertainty measurements of UV-C LEDs.

Advances in in-situ metrology of UV-LED structures in MOCVD

K. Haberland*[1], A. Knauer[2], M. Weyers[2], J.-T. Zettler[1]

[1]LayTec AG, Seesener Str. 10-13, 10709 Berlin, Germany

[2]Ferdinand-Braun-Institut, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany

The growth of UV-LED structures in metal organic chemical vapor deposition (MOCVD) is a complex and challenging process. It is therefore crucial to precisely control wafer temperature, wafer curvature, layer thickness of different layers, material composition, surface roughness and other properties throughout the whole growth run on multiple wafers.

This task can only be managed by applying state-of-the-art in-situ metrology tools, that are interfaced with the growth system to allow precise and synchronized measurements. In addition to the measurement of relevant data, proper analysis of the data based on the knowledge and understanding of the growth recipe and material properties is essential. Especially for monitoring and control of UV-B and UV-C LEDs, the situation is complicated by using patterned substrates, highly transparent buffer layers, super lattices and high growth temperatures sometimes leading to unwanted surface morphology effects.

In this talk we will present current status and recent improvements that were made regarding the metrology techniques for in-situ reflectance measurement with special focus on the epitaxy of UV-C LEDs on AlN-HTA-templates. It will be shown that using 280nm-LEDs as light sources for in-situ reflectance measurements substantially increases the sensitivity for characterizing thin layers, such as super-lattices and helps to better understand and control the growth process. We will show, that by using 280nm reflectance measurements, unintentional deviations in the growth process can be identified and understood. It can be shown, that 280nm LEDs are a very versatile and valuable addition for in-situ metrology. They can also be used very efficiently for monitoring semiconductor epitaxy for other devices beyond UV-LEDs.

UV-LED activated semiconductor biosensor for lactate monitoring in sweat

Nastaran Taleghani, Fariborz Taghipour*
Department of Chemical and Biological Engineering, The University of British Columbia
2360 East Mall, Vancouver, BC V6T 1Z3, Canada

Recent advances in ultraviolet light emitting diode (UV-LED) create the opportunity for producing UV radiation with monochromatic spectrum, constant intensity, high energy efficiency and controlled temperature. UV-LEDs offers a promising UV radiation source in UV-induced technologies and devices, including sensors. UV irradiation can improve the sensor performance through desorbing surface contaminants and providing available active sites on the photocatalyst. The development of UV-LED based chemical sensors have been discussed in previous works. However, to the best of our knowledge, the utilization of UV-LED in biosensors has not yet been studied in any details. Biosensors are analytical devices using a biological recognition element and transducer to detect the presence and concentration of a specific biomolecule like lactat. The emerging need for more sensitive and stable biosensors has attracted significant attention to the photo-induced biosensing. Besides, photo-induced biosensing gives better insights into understanding the compatibility between semiconductor photocatalysts and biomolecules.

We are in the process of developing a point of care, non-invasive, more sensitive and stable lactate biosensor. To achieve this, we applied semiconducting metal oxide-based nanostructures as the sensing material, because of their high chemical stability and photocatalytic activity. More specifically, we utilized ZnO nanowires due to their excellent features such as wide bandgap along with the biocompatibility and photocatalytic activity. These characteristics have made ZnO a superior choice for direct contact with enzymes by acting as recognition elements in biosensors to enhance the sensitivity and selectivity of detection.

We performed a set of experiments to fully understand factors affecting the mechanism of UV-LED activated ZnO biosensor and more specifically the generation of photocurrent and separation of nano-bio interfaces. The generated photocurrent from the oxidation of lactate produced a signal, which led to the detection of lactate. The photocurrent response of the ZnO nanowires electrode showed a linear relationship with the lactate concentration in a simulated sweat solution and displayed high sensitivity.

We will present how the biosensor developed based on the ZnO nanowires responded under UV-LED radiation to lactate. Further, we describe the effect of UV irradiation specifications on surface reaction kinetics and the biosensor signal to achieve higher sensitivity and optimal performance. Finally, by discussing our ongoing research results, we will show the potential of ZnO nanowire photocatalyst the signal generation and transduction with application as a non-invasive wearable biosensor.

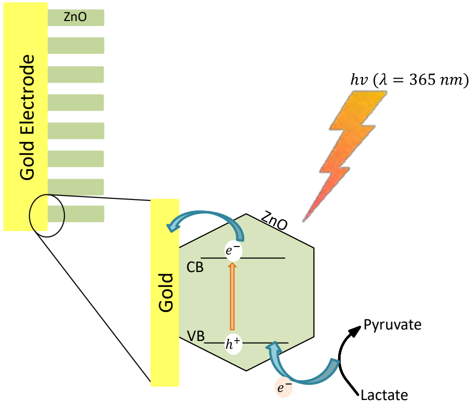


Figure 1. Schematic diagram of the interaction between lactate and photo-induced ZnO nanowire in the UV-LED activated semiconductor biosensor

Measurement systems and calibrations for UV radiation

D. Konjhodzic*, B. Eder, W. Beloglazov
Instrument Systems GmbH, Kastenbauerstr. 2, 81677 Munich, Germany
*Email: konjhodzic@instrumentsystems.com

Nowadays, the pandemic situation caused by the COVID-19 virus inspired many companies, research institutes and lighting designers to adopt UV radiation as a new tool in their projects and research. The promising germicidal effect of the UVC radiation also on the Coronavirus raises the question of the reliable measurement of the UV radiation. However, this complex task needs an expertise and appropriate equipment. The system that meets all requirements for UV measurements consists of a high-precision spectroradiometer with a stray light correction and either irradiance probes or PTFE integrating spheres for total radiant flux measurements.

Nevertheless, a reliable and traceable calibration of the system is a challenging factor. So far, no national metrological institute has offered a reference standard for the total radiant flux in the UVB and UVC spectral region. Therefore, we have realized traceable UV LED calibration standards on our own [1], which complete measurement system for UV radiation presented here.

The UV LED calibration standards have been developed for the typical peak wavelengths of 280 nm (UVC), 305 nm (UVB) and 365 nm (UVA). The traceability of the radiant flux has been achieved by the precise calibration of the spectroradiometer with the irradiance probe and a subsequent integrative measurement using a goniophotometer. Such UV LED calibration standards can be used for monitoring and for absolute calibration of UV measurement equipment consisting of the stray light corrected spectroradiometer and the integrating sphere.

In order to minimize the measurement uncertainty of the spectroradiometer, especially in the UV range, a stray light correction is necessary. This can be achieved by a tunable optical source that emits narrow (<1 nm) spectral lines at different wavelengths. Whereas the light source tunes the output radiation, the UV-enhanced spectroradiometer detects multi-order or internal scattering light beside the actual signal. This so-called stray light is than corrected numerically.

The largest contribution to the measurement uncertainties of the systems containing integrating spheres is the fluorescence of the coating material. Special manufacturing procedure with optically pure Polytetrafluorethylen (PTFE) enabled us to produce new integrating spheres with permanently negligible low fluorescence. Practically fluorescence-free integrating spheres over the entire spectral range beginning at 200 nm can be realized for special applications using completely new manufacturing methods.

Reference

[1] B. Eder, D. Konjhodzic, LEDs Magazine, September 2020, 23- 25 (2020)

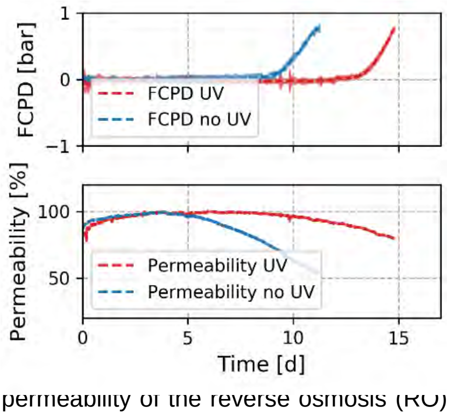
UVC-LED based pretreatment for biofouling control in desalination processes with thin-film composite membranes

P. Sperle[1*], C. Wurzbacher[1], J.E. Drewes[1], B. Skibinski[1]
[1]Chair of Urban Water Systems Engineering, Technical University of Munich
Am Coulombwall 3, 85748 Garching, Germany

Reverse osmosis (RO) membrane filtration is an important process for the treatment and purification of water. A major concern for this technology is the reduction of membrane performance by membrane biofouling. Biofouling is caused by the formation of microbial biofilms on the membrane surfaces, which leads to major operational drawbacks in numerous membrane systems [1]. To mitigate biofouling, a RO system requires an adequate pretreatment. Commonly an appropriate pre-filtration step and the addition of biocides are employed. As the EU regulation 528 2012 aims to limit the use of harmful biocides [2], there is currently a great need for alternative biocide-free pretreatment processes. An alternative treatment approach could be the combination of UV irradiation upstream of the RO treatment as a hybrid process. In particular, UVC-LEDs are offering the possibility to integrate a disinfection step into existing RO systems in flexible new reactor designs.

To examine the potential of the UVC-RO process combination for biofouling control, we set up lab-scale accelerated biofouling experiments using membrane fouling simulators (MFS). These simulators were comprised of a RO flat-sheet system employing the Oltremare LOW1 membrane and a 20 mil spacer. An UVC-LED reactor was attached in immediate vicinity upstream of the MFS. Two fully controlled lines were run in parallel (with and without UV) with a linear channel velocity of 0.12 m/s till a feed channel pressure drop of 0.8 bar.

In all experiments, the UV pretreatment exhibited a significant effect on biofouling [3]. Even at a very low UVC-LED induced irradiation of approximately 2 mJ/cm², the biofilm formation was delayed by more than 15%. Furthermore, the UV treatment induced changes in the biofilm's composition, resulting in a higher permeability. At a feed channel pressure drop of 0.8 bar, the hydraulic resistance was reduced by over 40%. Amongst others this is likely to be caused by a change in the microbial community [3]. Further, first results indicate that this effect is persistent after a hydraulic cleaning. Even though the biofilm is not irradiated directly, the UV pretreatment seems to alter the biofilm's properties sustainably, making UVC-LED disinfection of the feed stream a promising eco-friendly technology for biofouling control, saving energy and chemicals.



permeability of the reverse osmosis (RO) systems with and without UV for one experiment; shaded areas represent the 95 % confidence intervals [3]

References

[1] J.S. Vrouwenvelder, M.C.M. van Loosdrecht, J.C. Kruithof, Water Research, Volume 45, 3890-3898 (2009)
[2] European Parliament and Council, Regulation (EU) No 528/2012 (2012)
[3] P. Sperle, C. Wurzbacher, J.E. Drewes, B. Skibinski, Membranes, Volume 10(12), 415 (2020)

Impact of irradiation frequencies and duty intervals on UV-LEDs photoreactor performance used in Advanced Oxidation Processes

M.H. Rasoulifard[1],*, M. Ganjkhanloo[1], M.R. Eskandarian[1]

[1]*Water and Wastewater Treatment Research Laboratory, Department of Chemistry, University of Zanjan, Zanjan, 313-45195, Iran*

As the main scope of present investigation, degradation of Acid Red 14 (AR14) as an organic target pollutant from aqueous solution has been conducted. It is widely used in textile, dyeing industries and so on. Advanced oxidation processes (AOPs) are one of the most effective ways to remove the recalcitrant contaminants. In this study ultraviolet (UV) light-emitting diodes (LEDs) and potassium persulfate was considered in order to set up a photo-oxidative advanced oxidation process. Results showed that almost no dye degradation was achieved while using UV-LED or persulfate alone. However, a significant and efficient degradation was observed with the simultaneous utilization of UV light and persulfate. The main purpose of present research was to reduce the utilization of electrical energy by the use of a pulsed-illumination system using UV-LEDs. Ultraviolet light converts the persulfate ions to the sulfate radicals and, as a stronger oxidant in comparison with persulfate, participates in the advanced oxidation process. Furthermore, the effects of various parameters such as persulfate concentration, percentage of pulsed irradiation and period on the removal of AR14 have been conducted. The electrical energy consumption was another parameter that was checked in the UV reactor designed by LEDs. Calculation of E_{E0} indicated high performance of LEDs and influence of persulfate on degradation process. The experiments outcomes illustrated that utilizing an advanced oxidation process containing persulfate ions as oxidizing agents, 80% of pulsed radiation and 30 ms time period at the constant concentrations of dye (20 ppm) and 50 mM of persulfate, the optimum removal and lowest energy consumption ratio can be achieved which recognized as the most efficient and cost-effective way in a typical contaminated water treatment process. The optimum conditions approved that the shorter periods of time intervals and also, the higher frequencies of irradiated light provide the more efficiency for contaminants degradation.

References:

[1] M.H. Rasoulifard, M. Fazli, M.R. Eskandarian, Journal of Industrial and Engineering Chemistry, 20 (2014), 3695-3702, http://dx.doi.org/10.1016/j.jiec.2013.12.068

[2] M.R. Eskandarian et al., Chemical Engineering Journal, 300 (2016) 414-422, https://doi.org/10.1016/j.cej.2016.05.049

[3] K. Song, F. Taghipour, M. Mohseni, Chemical Engineering Journal, 300 (2018) 30361-30369, https://doi.org/10.1016/j.cej.2018.03.020

Effect of wavelength and intensity on E. coli inactivation kinetics

Hadas Mamane[1], Dana Pousty[1,2] , Yoram Gerchman[1], and Ron Hofmann[2]
[1]*School of Mechanical Engineering, Environmental Engineering Program, Tel Aviv University, Tel Aviv 69978, Israel*
[2]*Department of Civil Engineering, University of Toronto, 35 St. George Street, Toronto, Ontario, Canada M5S 1A4*

UV disinfection efficiency depends on the UV dose, which is defined as the product of the incident irradiance (fluence rate) and exposure time, corrected by factors such as water absorbance and reflection. It has been reported that the same time-dose reciprocity may not apply to microorganisms when exposed to different light intensities. For example, E.coli showed higher UV inactivation when exposed to a higher UV intensity over a shorter exposure time, for a traditional LP mercury lamp (Sommer et al. 1996). This effect was attributed to repair enzymes in the cell that were impaired more severely by the high average incident irradiance.

UV-LEDs, as a new technology, have some limitations, such as low power and energy efficiencies. Its low irradiances might affect the expected time-dose reciprocity as described above. Furthermore, LEDs enable tuning the wavelengths, with each wavelength possibly exhibiting a different time-dose reciprocity. Each wavelength might also affect the overall metabolic mechanisms of microorganisms differently. For example, Song et al. 2016 showed that different wavelengths can induce different stress mechanisms due to direct or indirect damage to cell components.

This research focused on two aspects; first to examine the time-dose reciprocity on E. coli inactivation using four different wavelengths (LED265, LED275 LED285, and LED295) under different average incident irradiances. It was observed that the microbial inactivation kinetics determined at LED265 is not influenced by fluence rate and exposure time for a given UV fluence, unlike the previously-mentioned effect observed for LP lamps where higher inactivation was observed using a high irradiance and low exposure time combination. In contrast, wavelengths of LED275, LED285, and LED295 led to higher microbial inactivation when using a low fluence rate coupled with a high exposure time. This trend is the opposite trend that has been observed for LP (254 nm).

Since the literature does not provide any explanation for the inactivation kinetic differences between the wavelengths and the intensities, a second aspect was examined; to investigate the UV intracellular damage mechanisms for each LED wavelength by using bioreporters. RecA was used as an indicator for bacterial DNA damage and SoxS was used as an indicator for oxidative stress. For shorter wavelengths (LED265) higher DNA damage was observed. For long wavelengths (LED285 and LED295) higher oxidative stress was observed. These microbial damage mechanisms can shed light on the differences between the E. coli inactivation under different average incident irradiances.

UV-C LED – Challenges, status quo & outlook
A perspective from an LED manufacturer

J.Klee*,
[1]*Nichia Chemical Europe GmbH, Westerbachstr. 28, 61476 Kronberg, Germany*

As founder of the blue and white LED, Nichia has proven many times to be the pioneer and leader in LED technology. The same applies to UV-LED technology where Nichia was able to commercialize the first UV-A LED's for industrial purposes. Back then the efficiency of these LEDs was low and pricing relatively high which was limiting the applications these LED's could be used in. Aligning this with white LED's and have a look to the first application they were used, it is noticeable that also that started with applications which could make use of the advantages of the LED, or enabled developers to create new applications because of the advantages the LED offered. While white LED's are present in all kind of lighting applications today also UV-A LEDs almost reached their peak of technical performance and replaced UV-lamps in many applications already. Transferring this knowledge to today's available UV-C LED's they can be found in the exact same situation.

While UV-C LED's are still far away from replacing applications, which use thousands of watts UV-C lamps for e.g. water disinfection purposes, they are already usable for application where their benefits can be outplayed. These benefits will be explained and application examples will be stated. A lot of industrial players today try to compare the LED to the low-pressure mercury lamp and think about ways how to replace lamps with LED's. In most cases the conclusion is that neither technically nor commercially that makes sense – and they are right. LED's work differently than lamps, bring different characteristics and require a different thinking when trying to make use of them.

Additionally, there is the question of the right wavelengths and how to implement LED's inside a system which is turning out to be a challenge for many companies which have not worked with LED's before. The question of the right wavelengths will be explained based on Nichias 280nm high power LED and the studies made on that topic.

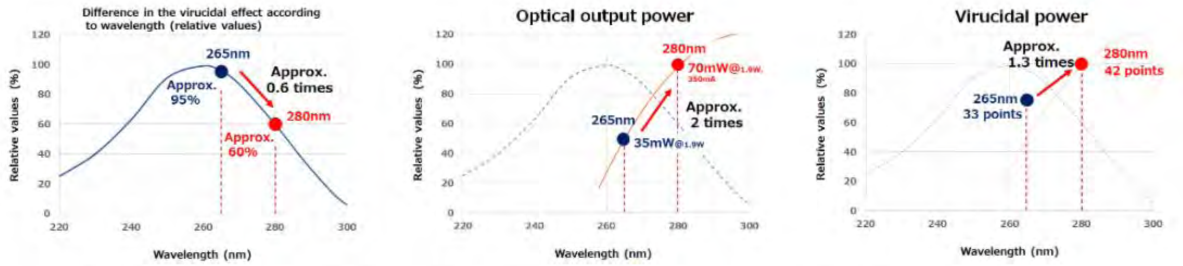


Figure 2. Difference in the virucidal effect according to wavelength

Figure 3. Optical output power

Figure 4. Virucidal power

Fig.1 Nichias study of UV-C LED wavelengths efficiency

While UV-C LED's are still limited by efficiency the market can notice a technology which is moving forward very fast. Nichia could increase the efficiency of their UV-C LED from 2,8% to 3,6% within one year and has specific targets for the next two years. We will provide an outlook to these improvements providing some concrete targets.

UV-C LEDs and their advantages in various system designs

Alexander Wilm

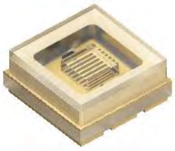
OSRAM Opto Semiconductors, Leibnizstrasse 4, 93055 Regensburg, Germany

The semiconductor light source for UV-C radiation is still the newcomer in the large field of UV Disinfection, but this role is not new for the LED. In the past years it successfully entered other applications like streetlighting, horticulture lighting and general lighting. It always started as the underdog and a direct comparison with conventional sources was difficult and barely in the benefit of the new source. But again, the completely different properties of LED light sources are showing significant benefits in new system designs which have not been possible before.

This presentation will provide insight in the benefits of distinct UV-C LED sources and arrangements in different systems by explaining the features which enable the light source to be competitive and even perfectly suited for various disinfection applications.

- Low and mid power LED arrangements for UV-C applications with high uniformity requirements. Impact of the system design on the average irradiance in a comparison of different arrangements.

- Highly efficient LED solutions for mobile applications and the impact on the uptime of the systems



- High power LED systems and their benefits from an optical point of view. Some etendue limited systems are benefitting significantly from the high luminance of new LED UV-C sources

The information provided will help to design improved and dedicated systems to different requirements by selecting the proper LED solution for each specific task.

UV radiometry for LED-based systems

P. Sperfeld*, T. Gerloff, S. Nevas
Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

The measurement of optical radiation and the assessment of radiation effects requires the implementation of well-founded radiometric units. A comprehensible traceability to reliable physical units, defined by the international system of units (SI), confirms the reliability of measurement results and enables their comparability and confirmation of equivalence with other methods.

At the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig and Berlin, the realization of photometric and radiometric units and dissemination of traceability to these units covers a large area of the activities. Spread over four departments, national primary standards for the representation of photometric and radiometric units are maintained, calibration facilities for radiometric measuring instruments and transfer standards are operated, basic research in the field of radiometric metrology is carried out and close cooperation with research and industry partners takes place.

Photometry and radiometry on LED-based luminaires is anchored in Department 4.1 "Photometry and Spectroradiometry". Here, LED-based transfer standards are calibrated with respect to photometric and colorimetric quantities such as luminous intensity, luminous flux, chromaticity coordinates and dominant wavelength. For UV lamps, radiometric quantities such as spectral irradiance are determined. A special focus of spectroradiometry lies on the measurement of lamps with very high UV irradiances. In cooperation with partners from industry and research, calibration sources for applications in water disinfection, a measurement facility with exchangeable high-power lamps and UV LED-based sources for monitoring solar irradiance measurement devices have been developed.

Mobile measuring devices allow the determination of the spectral irradiance on site directly at the application and allow to characterize emitters in a comprehensive way.

In the future, goniometric measurements will make it possible to calibrate amongst others the total radiant flux of UV LEDs and other gonioradiometrically defined units.

In the presentation, the existing and planned measurement possibilities of photometry and spectroradiometry at PTB as well as the possibilities of transferring radiometric units to calibration laboratories will be presented.

References

[1] Sildoja, M.-M., Nevas, S., Kouremeti, N., Gröbner, J., Pape, S., Pendsa, S.,Sperfeld, P., Kemus, F., LED-based UV source for monitoring spectroradiometer properties, Metrologia, 55(3), 2018, pp. S97

[2] Sperfeld, P., Barton, B., Pape, S., Towara, A. L., Eggers, J., & Hopfenmüller, G. (2014). Spectral irradiance measurement and actinic radiometer calibration for UV water disinfection. Metrologia, 51(6) 2014, pp. S282.

[3] Sperfeld, P., Pape, S., & Nevas, S. (2013, May). The spectral irradiance traceability chain at PTB. In AIP Conference Proceedings, 1531(1), 2013, pp. 801.

[4] Gerloff, T. , Kallenbach, L. , Ledig, J. , Schrader, C. , Sperling, A. , Pulli, T. , Askola, J. , Šmid, M. , Kliment, P. , Pons, A. , Ferrero, A. , Gál, P. , Brida, G., Blattner, P., Stuker, F., Schneider, M., Dönsberg, T., Poikonen, T. , Luminous intensity comparison based on new standard lamps with LED reference spectrum, CIE x046:2019, Proceedings of the 29th CIE SESSION Washington D.C., USA, June 14 – 22, 2019, DOI 10.25039/x46.2019.

The Need for Standards in UV-LED Water Disinfection Systems, and Challenges for Application to a World Market

D.G. Knight[1*],

[1]*International Ultraviolet Association, 6935 Wisconsin Ave, Suite 207*
Chevy Chase, MD 20815

The advent of light emitting diodes that emit in the germicidal ~240-300 nm region of the electromagnetic spectrum has enabled the development of ultraviolet water treatment systems that can be compact, instant-on, operated at low voltage, and have potentially long life for the UV LED light source. These treatment systems can disinfect a wide variety of water-borne pathogens, but the systems must have sufficient disinfection capability in order to be effective. The initial markets for UV-LED water treatment systems can be highly unregulated, so it will be important to assure the user that the systems will function as claimed. It is therefore vital that standards for operation of UV-LED systems be created so that this assurance can be provided.

The effective operation of any UV water treatment system must address the following issues: Effective operation within the claimed range of water flow and UV water transparency, a decrease in UV output of the light source with age, variations in UV output of light sources, and have an accurate measure of the response of organisms to the fluence (“dose”) of UV light. Since germicidal UV LEDs can vary in wavelength, the inactivation response of pathogens will vary with wavelength, so that the needed dose to achieve a specified inactivation will change. To provide a common measure of inactivation, it is proposed that bioassay validation use either a benchmark response of a known stable pathogen surrogate, or the 254 nm dose is used as a common measure by using a low-pressure collimated beam to provide the dose-response curve during the validation of the system. For a global market, use of the 254 nm dose allows the determination of dose over a wide range using different pathogen surrogates. It is also important to choose a surrogate that has low uncertainty in response for determination of the required dose.

Variation in wavelength for UV LEDs also leads to differences in the UV transparency of water with wavelength. This can be an advantage for LED-based systems over low pressure mercury lamp systems, since the transparency of natural waters generally increases with wavelength. However, it is important to consider the transparency of the water at the UV LED system wavelength during validation, rather than 254 nm, so that errors in determination of the transparency of water is avoided. Scenarios for system testing will be discussed. Methods to account for variations in UV output of LEDs due to age or selection of an individual source will also be discussed. These standards of measurement of water treatment systems should provide a common method of comparing system performance.

New Alternative UV Test Method in NSF/ANSI 55 – Ultraviolet Microbiological Water Treatment Systems

M. Blumenstein[1*], R. Andrew[1]

[1]*NSF International, 789 Dixboro Road, Ann Arbor, Michigan, USA*

In 2019 NSF International issued a significant update to NSF/ANSI 55 – Ultraviolet Microbiological Water Treatment Systems. Historically, only POU and POE UV reactors using low-pressure mercury lamps could be certified under NSF/ANSI 55, as the performance test method was a biodosimetry test. A new test method has been developed for alternative UV sources, including LED diodes, allowing certification of systems emitting UV light across the entire range of 240 nm to 300 nm.

In 2014 the NSF Joint Committee on Drinking Water Treatment Units charged their UV Task Group with developing a new test method for alternative UV systems. Because LED diodes can be tuned to emit UV radiation at different wavelengths, the task group decided to abandon the biodosimetry approach and create a new test method that is a direct demonstration of inactivation of a test organism.

After considerable discussion, research, and laboratory validation testing, the task group arrived at the Qβ coliphage virus as the challenge organism. This virus was chosen because of its ease of use, fairly linear dose-response curve, and because it is a conservative surrogate for rotavirus, which has been the benchmark for UV inactivation of viruses.

Systems with a UV sensor and alarm must be tested at the alarm set-point UV transmittance, so another important consideration was identification of UV absorbing compounds that cover the entire wavelength range of 240 nm to 300 nm. The task group found that the best option is a combination of vanillin and SuperHume®.

This new test method provides an important means of validating new alterative UV systems as they become more commonplace in the market

UV LED Disinfection for Public Water Supply: Preparation of a Test Protocol in Germany

D. Warschke[1*], K.-H. Schön[2], J. Eggers[2], K.H. Schön[2]
[1]Gelsenwasser AG, Willy-Brandt-Allee 26, 45891 Gelsenkirchen, Germany
[2]TZW: DVGW-Technologiezentrum Wasser, Karlsruher Straße 84, 76139 Karlsruhe, Germany

The need for standards for UV LED disinfection systems is widely recognized. However, the scope of the testing for the various applications of UV LED technology may differ between the approaches currently undertaken by the various regulatory authorities.

The first technical examination standard for the certification of UV disinfection equipment using UV LEDs was published by the Japan Water Research Center (JWRC) in 2018. In 2019 the US American NSF/ANSI-55 standard for Point of Use (PoU) and Point of Entry (PoE) applications has been updated to address the technical differences of LED technology compared to traditional gas discharge lamps. A task force of the International UV Association (IUVA) is also currently working on basic requirements for UV-LED water treatment devices and specifications on how these are to be validated.

In Germany, so far only devices with low-pressure (LP) and medium-pressure (MP) mercury vapor lamps have been approved for disinfection purposes in the public water supply. These devices need to undergo comprehensive validation testing before they are introduced into the market: this includes the determination of the disinfection efficacy under different test conditions and furthermore the characterization of components used in UV disinfection devices like UV lamps and UV sensors. Testing is carried out in accordance with DVGW worksheet W 294, which has recently been revised for LP lamps and published as DIN 19294 in 2020.

For disinfection devices with UV LEDs, no functional and technical requirements have been defined so far in order to meet the legal requirements for use in the public water supply in Germany. The need to develop a standardized and internationally recognized test protocol, as well as operating and monitoring guidelines for LED devices, was therefore identified. For the development of such a test protocol, a working group was set up by the Standards Committee Water Practice of the German Institute for Standardization (DIN) in cooperation with the German Technical and Scientific Association for Gas and Water (DVGW). The working group consists of members from water suppliers, manufacturers, test facilities and research institutes. In addition, workshops on specific topics will be held in order to incorporate the experience of other stakeholders in the standardization process. The presentation will inform about the steps taken since 2018, the current status and the future timetable of the standardization process.

Based on the new test protocol DIN 19294 for LP devices, this presentation will show whether and to what extent the technical 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.

Raising the Standard: The Case for Holistic Guidelines for UV-C LED Based Water Treatment Systems

Oliver Lawal, Dr. Jennifer Pagan, Dr. Rich Simons
AquiSense Technologies, 4400 Olympic Blvd, Erlanger KY 41018

UV-C LED devices get a lot of attention for their specific characteristics: form factor, emission spectrum, power output, efficiency, etc. However, they are merely one component in a complete UV water disinfection product—batteries in an electric car, if you like. Ultimately, it is the UV system that must deliver the required log reduction, and while wavelength and power are important, they are only part of the story.

Tens of thousands of UV-C LED systems have been produced over the past year and the rate of production is growing exponentially. In the absence of suitable regulations or industry guidelines the responsibility for design, production, and operational quality largely sits with manufacturer. Manufacturers are taken on their word that their products meet their marketing claims and a pyramid of trust is built from the LED manufacturer, through each link of the supply chain to the end user, with no rigorous framework for oversight or accountability.

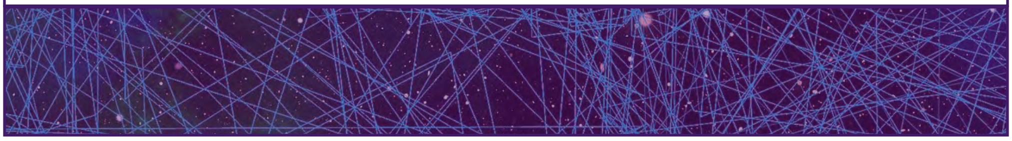
How should standards be applied with this new technology? Why is this even a question? What is wrong with applying existing UV technology regulations to UV-C LED technology? Blindly applying inappropriate regulations is problematic. So, also, is ignoring regulations entirely. By doing so we undermine the credibility of this new technology and limit implementation by serious professionals.

This paper outlines a holistic view of the various elements necessary for safe technology implementation, including;

- Microbiological Verification
- Materials Compatibility
- Safety Compliance
- Functional Operation Verification
- Production Process Verification

It summarizes the efforts already completed and underway by NSF, IUVA, NIST, etc and highlights additional areas that could be helpful in providing a sound basis for UV-C LED technology use in water treatment.

Poster Abstract



Adsorption of selenate on activated carbon by UV light

Sarahit Aguilar C.[1*], Jorge R. Alejandre[1], Mauricio Ortíz G.[1], Nabanita Dasgupta-Schubert[1]

[1]Facultad de Ciencias Físico-Matemáticas, Universidad Michoacana de San Nicolás de Hidalgo
Ciudad Universitaria, 58030, Morelia, Michoacán de Ocampo, México.

Selenium (Se) is a common environmental pollutant. Sodium selenate (Sel) is a common form of Se that is used in nutritional supplements and is found as a metabolite of Se in blood and human urine. Trace element analysis in biomedical samples represent several preparation complications, one of them is the analysis of light elements, using activated carbon (AC) as a substrate to adsorb selenate Ion we will try to improve the detection limit of the trace element analysis. AC is a product that has a large number of applications, more importantly, its excellent surface properties are often used to adsorb and absorb pollutants due to its surface area (adsorption) and pore volume (absorption). Adsorption is a purely surface phenomenon in which unpaired bonds attract molecules in the phase around the substance to pair with them, thus reducing surface energy. UV light can be divided into four wavelengths: Long-wave UV (UVA, 315 ~ 380nm), Medium-wave UV (UVB, 280 ~ 315nm), Short-wave UV (UVC, 200 ~ 280nm) and UV vacuum (UVD, 100 ~ 200 nm). Through the irradiation of UV light, AC particles are excited in order to retain selenate ions more efficiently. The experiment was carried out with 0.1 g of AC with a solution of 50 mg / L of sodium selenate, the AC samples were irradiated for times of 10, 60 and 120 minutes under ambient conditions, then 5 ml of the sodium selenate solution and once equilibrium was reached, samples were taken to measure conductivity, a method used to measure the removal of selenate ions.

Very good results were obtained after having subjected the activated carbon samples to different irradiation times with the UV-C lamp.

The $SeO4^{2-}$ ion removal efficiency was 95-96%. The Langmuir isotherm model indicated that the adsorption is in the form of a monolayer, the Langmuir equilibrium parameter speaks of an irreversible reaction; with this we can ensure that we have a chemical adsorption or chemisorption. A thermodynamical analysis let us know the Gibbs free energy ($\Delta G°$), enthalpy ($\Delta H°$) and entropy ($\Delta S°$) of the system, $\Delta G°$ was negative so we can theorize of a spontaneous adsorption process, $\Delta H°$ and $\Delta S°$ shows that the adsorption process has an endothermic nature.

How the UVC LED industry is organizing to reach high power and new applications

P. Boulay[1*],

[1] *Yole Développement, 75, Cours Emile Zola, 69400, Villeurbanne, France*

The UVA LED industry is already quite mature with many LED manufacturers coming from the visible LED industry. Regarding the UVC LED industry, the number of players is much more limited, mostly due to the difficulty to manufacture reliable and performant LEDs at such wavelengths.

Water disinfection is currently the application where most of UVC LEDs are used but reactors in mass production are mostly limited in flow rates. Several system manufacturers are developing reactors and the majority are targeting Point of Use or Point of Entry applications. Only a few are involved in industrial or municipal application as the main issue is the number of UVC LEDs used and therefore the associated cost.

Regarding performances of UVC LEDs, EQE has improved but is still below 10% for commercial devices and each additional 1% seems harder and harder to achieve. To improve the EQE, LED manufacturers can work on different parameters like the Internal Quantum Efficiency (IQE), the Electron Injection Efficiency (EIE), or the Light Extraction Efficiency (LEE). As of today, the IQE has the highest level but more work is needed to improve the EIE and the LEE. This is why, water reactors using LEDs are much more efficient than those using UV lamps.

The cost of these LEDs was prohibitive a few years ago but it has decreased rapidly to a reach a plateau where commercial applications are possible. Another good sign that this industry is emerging is that some leaders are launching mass manufacturing and some visible LED leaders are releasing their first commercial deep UV LEDs. This competition will stimulate the market and further price decrease is expected in the next years.

A sign that this industry is structuring is that players may become more specialized (pure chip players, pure packagers…) and since a few years, the number of M&A is accelerating. The positioning of LED manufacturers is also different as leaders are expected to target middle/high power applications with best in class LEDs while others should target low power applications with limited performance LEDs.

In this presentation, we are going to highlight the status of the UVC LED industry, the positioning of players and discuss about the current and new applications where UVC LEDs can be used. We are also going to present the challenges that LED manufacturers have to face to improve the performance of their devices.

Triggering the release of drugs from nanocarriers in hair follicles by the application of UV-LEDs

Loris Busch[1,4], Yuri Avlasevich[2], Gisela Thiede[1], Katharina Landfester[2], Axel Kramer[3], Gerald Müller[3], Paula Zwicker[3], Maxim E. Darvin[1], Martina C. Meinke[1], Cornelia M. Keck[4], Jürgen Lademann[1], Alexa Patzelt[1]

[1]Center of Experimental and Applied Cutaneous Physiology, Department of Dermatology, Venereology and Allergology, Charité – Universitätsmedizin Berlin, corporate member of Freie Universität Berlin, Humboldt-Universität zu Berlin, and Berlin Institute of Health, Berlin, Germany
[2]Max Planck Institute for Polymer Research, Mainz, Germany
[3]Institute of Hygiene and Environmental Medicine, University Medicine Greifswald, Greifswald, Germany
4Department of Pharmaceutics and Biopharmaceutics, Philipps University Marburg, Marburg, Germany

The emerging research field of nanotechnology provides a high variety of nanocarriers (NCs) which, for example, can be used for drug delivery approaches in dermatology. In order to initiate a controlled release of the drug in the target anatomical site, different physical trigger-mechanisms (such as diffusion [1], IR [2], UVA) or chemical trigger-mechanisms (such as pH [3], proteolysis [4], [5]) are available today. Since UVA light can reach even deeper skin layers, and thus deeper sections of the hair follicles, it is excellently suited as an external, easily applicable physical trigger for the release of drugs from photodegradable NCs within the follicular compartment. The application of UVA-LED systems in dermatology promises skin tissue protection in connection with a performance being still high enough for photodegradation of NCs. In the framework of our experiments, we have established a novel system, which involves the transportation of a model drug into hair follicles of ex vivo porcine skin by NCs and subsequent UVA-triggered release of the model drug controlled by an LED [6]. UVA-responsive degradation of the NCs ensured liberation of the model drug in the right place and at the right time. The data imply the usage of UVA-LEDs for managing trigger-mechanisms as a promising approach for enhancing the intrafollicular bioavailability of different drugs. This might constitute a future benefit for curing skin diseases using NC-based drug delivery through the hair follicles.

References

[1] N.B.N.N. Tran, F. Knorr, W.C. Mak, K.Y. Cheung, H. Richter, M. Meinke, J. Lademann, A. Patzelt, Gradient-dependent release of the model drug TRITC-dextran from FITC-labeled BSA hydrogel nanocarriers in the hair follicles of porcine ear skin, Eur. J. Pharm. Biopharm. 116 (2017) 12–16. https://doi.org/10.1016/j.ejpb.2016.09.016.

[2] J. Lademann, H. Richter, F. Knorr, A. Patzelt, M.E. Darvin, E. Rühl, K.Y. Cheung, K.K. Lai, R. Renneberg, W.C. Mak, Triggered release of model drug from AuNP-doped BSA nanocarriers in hair follicles using IRA radiation, Acta Biomater. 30 (2016) 388–396. https://doi.org/10.1016/j.actbio.2015.11.052.

[3] P. Dong, F.F. Sahle, S.B. Lohan, S. Saeidpour, S. Albrecht, C. Teutloff, R. Bodmeier, M. Unbehauen, C. Wolff, R. Haag, J. Lademann, A. Patzelt, M. Schäfer-Korting, M.C. Meinke, pH-sensitive Eudragit® L 100 nanoparticles promote cutaneous penetration and drug release on the skin, J. Control. Release 295 (2019) 214–222.

[4] [W.C. Mak, A. Patzelt, H. Richter, R. Renneberg, K.K. Lai, E. Rühl, W. Sterry, J. Lademann, Triggering of drug release of particles in hair follicles, J. Control. Release 160 (2012) 509–514. https://doi.org/10.1016/j.jconrel.2012.04.007.

[5] https://doi.org/10.1016/j.jconrel.2018.12.045.

[6] W.C. Mak, H. Richter, A. Patzelt, W. Sterry, K.K. Lai, R. Renneberg, J. Lademann, Drug delivery into the skin by degradable particles, Eur. J. Pharm. Biopharm. 79 (2011) 23–27. https://doi.org/10.1016/j.ejpb.2011.03.021.

[7] L. Busch, Y. Avlasevich, P. Zwicker, G. Thiede, K. Landfester, C.M. Keck, M.C. Meinke, M.E. Darvin, A. Kramer, G. Müller, M. Kerscher, J. Lademann, A. Patzelt: Release of the model drug SR101 from polyurethane nanocapsules in porcine hair follicles triggered by LED-derived low dose UVA light, Int. J. Pharm. (2021). Article in press. https://doi.org/10.1016/j.ijpharm.2021.120339.

Some parameters for technological migration from Hg lamps to LEDs in the UV range for germicidal dose applications.

P. Fredes[1,2*], U. Raff[1]

[1]Optics and Semiconductors Lab, Physics Department, Univ.de Santiago de Chile, Av. Ecuador 3493, Santiago, Chile.
[2]Hydraluvx Spa, Maipú, Santiago, Chile.

Ultraviolet disinfection technologies are based on artificial emission of germicidal ultraviolet light (UV-C), traditionally by discharge gas lamps. Ultraviolet (UV) light has been used in many applications ranging from water disinfection, UV curing in polymers, medical diagnostics (e.g., blood gas analysis) to phototherapy (discovered by Niels Finsen, Nobel Prize in Medicine in 1903). The disinfection process for water, air or surface, is basically a bio-photochemical reaction. The DNA molecule is damaged when the UV-C light is absorbed by the microorganism, so the maximal value of the absorption coefficient of the DNA is at 260 nm. The absorption value is referred to a specific wavelength and is related with the transmittance through the Lambert-Beer Law. Prior to the appearance of (deep ultraviolet light emitting diodes) UV-C LEDs, all UV disinfection devices were calibrated and characterized for a wavelength of 253,7 nm, which is a property of mercury gas spectrum. However, the use of mercury in the industrial process is now decreasing quickly.

New methodologies have been proposed by different researchers to determine the germicidal UV dose (fluence) with LED technology, considering a series of four key parameters, all strongly depending on the wavelength: ultraviolet Transmittance of the water (UVT), Photodiode responsivity, Kinetic inactivation constant of microorganisms and wall plug efficiency (WPE). Previous research has considered these physical parameters[1], nevertheless not referring to the same wavelength, e.g. for water disinfection devices, the fluence is determined using transmittance measurements referred to 253.7 nm (Hg lamps) but the device is using UV LED at 285 nm, additionally the intensity monitoring is performed applying photodiodes commonly calibrated at 253,7 nm, as opposed to working with 285 nm. On the other hand, all kinetic inactivation constants of microorganisms have been tabulated at 253.7 nm.

The main issue is the question: are we searching for energy consumption efficiency in the process or effective microbiological inactivation?

The UV LEDs have many advantages compared with Hg lamps but, their energy efficiency is 20 to 40 times inferior [2]. The new characteristics of the UV-C LEDs will allow flexible designs, new geometrical configurations and optimal layout in the final devices (products). Energy efficiency is expected to be considerably improved in the future.

References

[1] N. M. Hull, W. H. Herold, and K. G. Linden, “UV LED water disinfection: Validation and small system demonstration study,” AWWA Water Sci., vol. 1, no. 4, pp. 1–11, 2019.
[2] S. Rattanakul and K. Oguma, “Inactivation kinetics and efficiencies of UV-LEDs against Pseudomonas aeruginosa, Legionella pneumophila, and surrogate microorganisms,” Water Res., vol. 130, pp. 31–37, 2018.

Electro-optical properties of deep UV LEDs with an emission wavelength near 230 nm

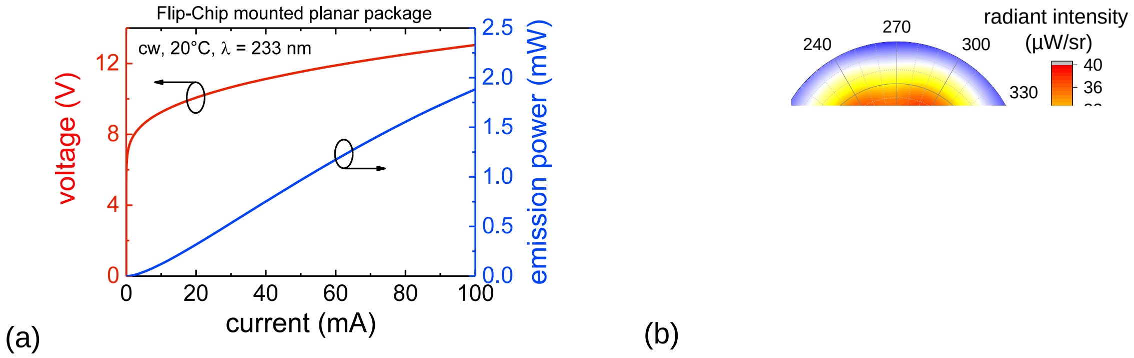
Martin Guttmann[1*], Luca Sulmoni[1], Neysha Lobo-Ploch[2,3], Frank Mehnke[1], Priti Gupta[1], Johannes Glaab[2], Jan Ruschel[2], Hyun Kyong Cho[2], Jens Rass[2,3], Sylvia Hagedorn[2], Tim Wernicke[1], Sven Einfeldt[2], Markus Weyers[2], and Michael Kneissl[1,2]

[1]*Technische Universität Berlin, Institute of Solid State Physics, Hardenbergstr. 36, 10623 Berlin, Germany*

[2]*Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany*

[3]*UVphotonics NT GmbH, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany*

Deep ultraviolet (DUV) light emitting diodes (LEDs) with an emission wavelength below 240 nm can enable a number of applications in the area of gas sensing such as NO or NH_3 or determining nitrate levels in water. Depending on the application a high output power, a narrow far field or a high spectral purity is required. However, the fabrication and characterization of such DUV LEDs are challenging. The output power typically drops significantly when the emission wavelength is reduced. The poor light extraction efficiency, the low radiative recombination efficiency, and the insufficient efficiency of hole and electron injection in the active region result in an external quantum efficiency (EQE) of less than 1 %. In this contribution, we present the electro-optical properties of flip-chip mounted DUV LEDs in a planar AlN SMD package with an emission wavelength around 233 nm. The data includes the current and temperature dependent evaluation of the emission spectrum, emission power and operating voltage as well as lifetime measurements. The output power at 293 K (20 °C) and 100 mA is 1.9 mW, which corresponds to an EQE of 0.36 % (Fig. 1a) [1]. The output power decreases at elevated temperatures, e.g., to one fourth at 373 K (80 °C), but also increases by a factor of three at a cryogenic temperatures of 150 K. This effect can be attributed to the reduction/increase of non-radiative recombinations with decreasing/increasing temperature, respectively. During operation of the LEDs, initially a strong degradation process occurs in the first 50 − 100 h, for example leading to a reduction of the initial emission power down to about 40% after 100 h operation at 100 mA (67 A cm^{-2}) and 20 °C. In addition, the reduction of the optical power is strongly correlated to the operation current density during operation, with stronger effect at high current densities. Furthermore, far-field measurements were performed as well as ray-tracing simulations to provide ray files of the LED for application designing. Far-fields show a maximal radiant intensity of planar packaged LEDs directed 40° off to the package normal axis (Fig. 1b), due to relatively high light extraction from the roughened chip side facets as confirmed by ray-tracing simulations.



(a) (b)

Fig. 1: Voltage and total emission power vs. current (a) and far field at 20 mA (b) at room temperature of flip-chip mounted 233 nm LEDs on planar SMD package.

[1] N. Lobo-Ploch *et al.*, *Appl. Phys. Lett.* **117**, 111102 (2020).

Rapid Integration of LEDs for UVC surface treatment driven by pandemic requirements

Y. Haj-Hmeidi[1]

[1]LUMITRONIX® LED-Technik GmbH, Brunnenstraße 14, 72379 Hechingen, Germany

The LEDs in the UVC range still have a limited optical efficiency. However, advanced engineering of the UVC LEDs modules can overcome this limit. Furthermore, the efficacy of the yielded disinfection rate in many applications can be indeed reached via effective optical design. As such the surface treatment via UVC LEDs is applicable by optical manipulation of the emitted UVC light.

In addition, the transmission of virus covid-19 via aerosols has been proven and reported [1], which has driven the research of disinfection of the air via UV LEDs. Since the virus coved 19 is sensitive for UVC light range and not only for the mercury common lamps which usually emit at ca. 254 nm. We will present new state of the art applications by introducing new complete solutions for air disinfection based on UVC LEDs. Here, we will present the tremendous benefits of the UVC LEDs over other UVC light sources. In particular, the versatility of UVC LEDs is a huge advantage, which emphasizes the utilization of UVC LEDs in eliminating of pandemic effects in our society.

In collaboration with Fraunhofer institute we will discuss systematically recent results on UVC LEDs approaches in the surface treatment as well as the air disinfection. We will show several real life cases such as disinfection of medical instruments, surface treatment of: emergency vehicle, bus stops, EC-card terminal. Moreover, we show that the realization of UVC LEDs solutions require a specific thermal and light management for reaching the needed efficacy for each individual case. A special care must be given to the housing material, since many materials are sensitive for the exposure of UVC light. We emphasize the practical issues of UVC LEDs towards useful realistic approaches. This bridges the gap between the new developed UVC LEDs and the mass production. The latter is very essential for driving the development of the UVC LEDs further beyond the lab conditions.

Furthermore, we explore the requested specifications of the UV LEDs for future applications based on the current overview of the market. We review quickly the new approaches for enhancing the efficiency of UVC LEDs and their influences on the current presented disinfection applications.

References

[1] S. Tang, Y. Mao, R. M. Jones, Q. Tan, J. Ji, N. Li, J. Shen, Y. Lv, L. Pan, P. Ding, X. Wang, C. Macintyre, X. Shi, Environment International, 144, 106039, (2020)

UVC LEDs Promise a Giant Leap in Decontamination Efficiency

Amy Hedrick, David Georgeson,
Dr. Matthew Hardwick, Dr. Robert Louis
Crystal IS, Green Island, New York, USA
Cleanbox Technology, Inc. Carlsbad, California, USA
Hoag Memorial Hospital, Newport Beach, California, USA

Published August 2020 by Cleanbox Technology, Inc.

We design and manufacture products that employ proprietary UVC LED engineering for surface decontamination of tools, electronics, frequently touched or shared devices, and personal protective equipment. Our mission is to build innovative, user-friendly tools that maximize decontamination while reducing the potential waste and environmental concerns created by traditional mercury UV bulbs or other decontamination measures including disinfecting wipes, aerosols and chemicals.

Because UVC light falls off in intensity with distance, there are only two useful ways to use UVC light for surface decontamination: either by using very long cycle times (15 minutes+) so that materials further from the lights can accumulate a necessary dosage, or by positioning an array of lights around the materials to be disinfected, to allow an even distribution of light that requires a shorter cycle time (<2 minutes).

Where UVC LEDs most clearly show increased decontamination efficiency is in their versatility. LEDs have wide arcs of light (>90 degrees) which allows grids of LEDs to be created that have overlapping cones of effect, reducing the potential for shadowing caused by nooks or crevices in the materials being disinfected. Since UVC light efficacy is line-of-sight, this is a tremendous benefit over standard UV bulbs.

UVC LEDs are also smaller than UVC bulbs; generate less heat and use lower power; and can be positioned to create precise dosage of energy onto the materials being disinfected. Additionally, UVC LEDs do not contain mercury or emit ozone, eliminating those toxicity concerns.

UVC LEDs can also be tuned to specific wavelengths, allowing treatment of pathogens at wavelengths other than the traditional mercury bulb wavelength of 254nM. Wavelengths between 260-280nM have been shown to be more effective at destroying a range of pathogens, so UVC LEDs, when used properly, have potential to provide more efficient and effective decontamination by making adjustments to the emitted wavelength as needed.

Although the cost of UVC LED grids is higher than that of traditional mercury bulb devices, and the designs are more complex, the positive benefits of UVC LEDs far outweigh those marginal drawbacks in any case where efficacy of the product is of primary concern.

Integrated digitally adjustable step down converter to control one individual or a series of UV-LED(s)

C. Heinze[2], M. Frisch[1], Th. Ortlepp[2*], O. Brodersen[2]
[*]eesy-ic GmbH, Frauenweiherstraße 15, 91058 Erlangen, Germany
[**]CiS Forschungsinstitut für Mikrosensorik GmbH, Konrad-Zuse Str. 14, 99099 Erfurt, Germany

The usage of UV-LEDs is growing for a variety of applications such as the disinfection of water, the sterilization of medical equipment and the industrial UV curing. It is important that the wavelength and the intensity of radiation needed for the specific application is reliably provided and covers the whole target area evenly distributed.

The individual high precision power supply and control of UV-LEDs is the main application of the **eyIC4UV-01** chip. The **eyIC4UV-01** is an integrated circuit that can measure the light intensity, temperature, current and forward voltage of a connected UV-LED. By digitizing these measurements with a 12 bit accurate SAR ADC and comparing them to their analog or digitally provided reference values, the circuitry will regulate the UV-LED load into an optimum operating point. With the use of an integrated PWM control block, consisting of a PWM modulator controlling a level shifter, a high-side supply and a high-side power switch, the chip steps down voltages of up to 15V with an efficiency of up to 90% with less than 5% current ripple to meet the specified forward voltage of the UV-LED.

The main application of this chip is the control of a single UV-LED by using the integrated circuitry of the **eyIC4UV-01**. In addition, a string of UV-LEDs can be controlled by using the PWM signal from the **eyIC4UV-01** and switching an external power switch. This can be used to control an array of UV-LEDs to emit the intended light intensity.

Flexible and cost effective UVC LED system design using package-less WICOP LED Technology

M.Hofmann*, JR.Kim, JH.Jeong

Seoul Viosys Co. LTD. Ansan, Republic of Korea

In recent years, as in the early days of visible LED technology, there has been a competitive chase to achieve the highest single chip output powers. Having seen the massive market adoption of mid power visible LED technology over high power for many applications, Seoul Viosys and Sensor Electronic Technology have focused on manufacturability, versatility, and long life for UVC LEDs. UVC wafer integrated chip on package (WICOP) technology has the potential change the landscape of UVC LED based systems by increasing design flexibility and enabling dramatically reduced system cost. This advancement in chip technology has been approached with robustness and scalability in mind. The small footprint enables high chip densities making WICOP on board (WOB) arrays as powerful as a COBs. However, the WICOP technology is compatible with standard PCB design rules making customized WOBs as easy to design and manufacture as standard LED modules. We will review benefits of package-less designs such as high power density (>1.000mW/cm2) for flowing water, skin treatment, and surface curing applications as well as optimal uniformity in surface disinfection and horticulture applications. Considerations for thermal management, real world performance data, and system life-time evaluation methodologies will be presented in detail.

Factors influencing the emission characteristics of UV LED chips – A modular system for customized design

Indira Käpplinger[1*], Dennis Mitrenga[1], Guido Leibeling[2], Frank Gindele[3], *Yoshio Kikuchi*[4] Olaf Brodersen[1] and Thomas Ortlepp[1]

[1]*CiS Forschungsinstitut für Mikrosensorik GmbH, Konrad-Zuse-Str. 14, 99099 Erfurt, Germany*
[2]*JenCAPS Technology GmbH, Otto-Schott-Str. 15, 07745 Jena, Germany*
[3]*Schott AG, Business Unit Electronic Packaging, Christoph-Dorner-Str. 29, 84028 Landshut*
[4]*NGK Insulators, LTD., 2-56, Suda-cho, Mizuho-ku, Nagoya, Japan*

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. Depending on the desired application, the light extraction of the UV light must be optimized, because the internal quantum efficiency of UVB and UVC LEDs is still in the range of a few percent or even below. In addition the high refractive index of the common sapphire substrate causes strong internal total reflectance and decreases the efficiency further. Finally the electrical input power is converted to more than 95% into heat. In addition to the work of improvements of the external quantum efficiency, the radiation characteristics of the UV LED chip can be influenced and supported by the performance of the package and the mounting technology. The mounting technology and the choice of the socket material have high impact on the thermal resistance of the package, which is an important factor because the increase of the junction temperature leads to losses of the optical power.

Another important issue is the embedding technology. Here we will present first results for improving the optical performance of UV LED chips by optical index matched, UV-transparent materials, which are supplemented by some basic aging studies.

The emission characteristic can be influenced by further optical elements of the package. Thus, an Aluminum reflector can promote the forward performance. Fresnel lenses or aspherical lenses (NGK lenses) can focus the UV light into the desired direction. We want to show the influence of the different optical and thermal elements individually and in combination to show the possibilities of designing the optimal radiator module with the desired properties.

Integrated dose simulation tool for UV-LED reactors

Majid Keshavarzfathy*, Babak Adeli, Ashkan Babaie
ACUVA Technologies Inc. Unit #1-3771 North Fraser Way, Marine Way Business Center, Burnaby, BC, Canada | *V5J 5J2*

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 at the end. Complete simulation of a reactor 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 performance. Precise simulation of the LED die, package, radiation pattern and wavelength, and modelling of optical surfaces will all influence the accuracy of the reactor simulation tool.

Eventually the results of hydrodynamics simulation, optical simulation needs to be integrated to measure the overall reactor's performance in terms of dose. For a benchmark reactor, we have used our in-house tool to predict the reactor 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.

Keywords: UV-LED; Virtual prototyping; CFD; optical simulation

Emergence of UV-LED as a new technology

Sanjay Kumar*, Caine Ruckstuhl, Harald Maiweg
ACUVA Technologies Inc. Unit #1-3771 North Fraser Way, Marine Way Business Center, Burnaby, BC, Canada | *V5J 5J2*

The UV-C band around 260–285 nm, near the peak of RNA/DNA absorption is considered today to be the optimized spectral range for Ultraviolet germicidal irradiation. Within the last few years, UV-LEDs exhibited outstanding efficacies in water disinfection, and recently achieved extremely fast and effective performance in inactivating the SARS-CoV-2 virus. These placed UVC-LEDs among the most promising and viable disinfection technologies for the years to come.

Advancements in UV-C LEDs enabled applications for developing safe and effective solutions not only for water, surface and, air disinfection, but also for protection of everyday person in a post-COVID-19 world. Now, companies are deploying UV-LED based solutions where the use of traditional mercury based lamps was even not possible. The rapid innovation has reduced the cost of ownership significantly and more and more startups are joining hands in making this world a better place by providing a safe environment in all three dimensions – Water, surface and air.

The response from the market has been phenomenal so far and the disinfection/purification market is growing with a CAGR of more than 200%. The number of companies involved in the R&D and commercialization of UV LED products have grown by at least 20 times in last 5 years. The industry has achieved market's confidence in terms of reliability, affordability and effectiveness. Despite all these positive advancements, UV-LED disinfection industry is still facing challenges in terms of certifications standards and unambiguous definitions. For instance, the guidelines from regulatory bodies and certifying agencies are not crisp, mostly confusing and at times absent, which is limiting the use of UV LED based solutions.

In this presentation, the emergence of UV-LED technology and the new applications enabled by this technology from research and commercialization standpoint will be discussed. In particular, we will present a landscape, the so-called UV-LED technology roadmap, and will show how the paradigm is shifting towards UV LED. Finally, we will review the companies active in the commercialization of technology and discuss the future direction of the industry and what needs to be done to strengthen it as a whole.

Keywords: UV-LED; COVID-19; SARS-Cov-2, Evolution of UV-LED, Paradigm shift, Commercialization

Stress responds measurements in skin induced by UV-LEDs

Lohan SB[1], Ivanov D[1], Schüler N[2], Berger B[2], Lademann J[1], Meinke MC[1]

[1]Department of Dermatology, Venerology and Allergology, Charité – Universitätsmedizin Berlin, Corporate member of Freie Universität Berlin, Humboldt-Universität zu Berlin, and Berlin Institute of Health, Berlin, Germany

[2]Freiberg Instruments GmbH, Freiberg, Germany

Free radicals in the body are essential for the metabolism, signal transport and are part of our immune response. Nevertheless, if they exceed a certain level, they could be turn detrimental. Furthermore, some stress is healthy but chronic stress or a high level could induce pathological effects. The point or region where it turns is of high interest. If stress occurs, first reactive oxygen species (ROS) are formed which can be well controlled by the antioxidant system. Does the stress increased, secondly C-centered (CCR) or alkoxy radicals (lipid oxygen species, LOS) are produced – thus, the partitioning of the different types of radicals could give information about the stress level. To measure the amount and type of radicals, electron paramagnetic resonance (EPR) spectroscopy was used. A new method using PCA for quantification, DMPO for characterization only, and UV-LED for in situ irradiation was applied on porcine ear skin. The study revealed that during UVA radiation the ratio of ROS and LOS turned with increasing dose. The region of turn appears at half of the minimal erythema dose of UVA. Important is a sufficient irradiance of the UVA light, because at low irradiance adaptation processes inhibit the revers effect. This method could detect heat induced stress in the skin of pre-stressed pigs in the summer time due to temperatures above 35°C during husbandry or transport. In these ears, the ratio was already reversed, more LOS were produced right from the start of irradiation. This illustrates that the ratio of ROS and LOS produced by irradiation in skin could be used as a stress marker.

Acknowledgements: The work is funded by the German Federal Ministry of Education and Research BMBF (FKZ 03ZZ0140A) within the program “Zwanzig20 – Partnerschaft für Innovation” and carried out within the consortium Advanced UV for Life

References

[1] Albrecht S. et al. Free Radical Biology and Medicine 131:299-308, 2019

Application of UV LEDs for Tender Coconut Water Processing

Maguluri RaJ Kumar[1], Yannam Sudheer Kumar[1*]

[1]CSIR-Central Food Technological Research Institute, Mysuru-570020, Karnataka, India

The safety of beverages can significantly benefit from UV light technologies to control microbial contaminants through UV treatments. Nevertheless, the disinfection capabilities are well known, yet commercial technology exists for juice or beverage processing using a monochromatic low-pressure mercury (LPM) lamp. Light-emitting diodes (LEDs) are made of semiconductor materials that generate monochromatic light (Shur and Gaska 2010). Since they have certain advantages over traditional lamps, they have been used in the food and agricultural industries (Amritha Prasad, 2020). Although UV LED light is still a new technology, limited research has been conducted on UV-C LEDs' effectiveness for the disinfection of fruit juices.

Tender coconut water (TCW) as a food model is treated with UV to investigate UV LEDs' efficacy (255 nm, PearlBeam, Aquisense Technologies) for inactivating the possible foodborne pathogens in TCW. The disinfection kinetic parameters yielded by the UV-LED collimated beam system were the basis for comparing the efficacy of the UV treatment on the different microorganisms. The microbial load in tender coconut water was reduced by 5 logs for all the bacteria (*E. coli*, *S. enterica* and *L. monocytogenes*). According to the data obtained with NMR, which shows no significant effect on UV treatment, suggests that UV LEDs can be a better approach for determining the inactivation efficacy of the UV system. Being smaller and offering higher ultraviolet power densities than UV lamps makes them concentrate lighter in a particular area giving UV LEDs an excellent opportunity to be easily adapted to develop reactors for processing various food products. Although the key constraints for applying UV LEDs are high capital costs, recent advances are expected to significantly improve their efficiency and reduce costs, making this technology a viable alternative to traditional UV-C Lamps. The results obtained in this study allow the further development of proposed technology for the inactivation of other spoilage microbes, spoilage enzymes and extended shelf-life of low acid fruit-based beverages. Further investigation of the UV LED apparatus's scaling-up with the continuous flow-through model for maintaining the quality and safety standards of beverage with desired sensory properties is under process.

References

[1] Shur MS, Gaska R. 2010. Deep-ultraviolet light-emitting diodes. Electron Devices IEEE Trans 57:12–25.

[2] Prasad, A., Du, L., Zubair, M. *et al.* Applications of Light-Emitting Diodes (LEDs) in Food Processing and Water Treatment. *Food Eng Rev* 12, 268–289 (2020).

Combination of UV-LED and membrane filtration to treat surface water

Marques, A.P.[1,3*], Bernardo, J.[2], Huertas, R.[1,2], Crespo, J.G.[1,2] and Pereira, V.J.[1,3]

[1] iBET, Apartado 12, 2780-901, Oeiras, Portugal
[2] LAQV-REQUIMTE, FCT, Universidade NOVA de Lisboa, 2829-516 Caparica, Portugal
[3] ITQB, Universidade Nova de Lisboa, Av. da República, 2780-157, Oeiras, Portugal

The development of effective disinfection treatment processes will be crucial to help the water industry cope with the inevitable challenges resulting from the increase in human population and climate change. Climate change leads to heavy rainfall, flooding and hot weather events that are associated with waterborne diseases. Developing effective treatment technologies will improve our resilience to cope with these events and our capacity to safeguard public health.

Ultraviolet (UV) photolysis and membrane filtration are effective treatment processes to retain and inactivate bacteria from different water sources.

A new hybrid photocatalytic membrane reactor[1] was used to test the efficiency of filtration using unmodified and modified silicon carbide membranes, direct UV photolysis (UVC-LED 265 nm and UVA-LED 385 nm) and the combination of both processes to ensure the retention and inactivation of bacteria present in river water at occurrence levels.

To assess the efficiency of this new disinfection system, enzyme specific rapid microbial methods were used for the detection and quantification of total coliforms, *E. coli* and enterococci. A sustainable sol–gel procedure was followed to obtain photocatalytic membranes using low temperature and under solvent free conditions[2].

This hybrid system effectively retained microorganisms that were successfully inactivated by photolysis and advanced oxidation processes. The new hybrid reactor could be a promising approach to treat drinking water and wastewater in small scale systems.

References

[1] Fraga et al. 2019. Novel submerged photocatalytic membrane reactor for treatment of olive mill wastewaters, Catalysts. Special Issue Photocatalytic Membrane Reactors. 9(9), 769.
[2] Huertas et al. 2019. Solvent Free Process for the Development of Photocatalytic Membranes, Molecules. 24, 4481.

Acknowledgements

Financial support from FCT through the projects PTDC/EAM-AMB/30989/2017 and PTDC/CTA-AMB/29586/2017 and INTERFACE Programme, through FITEC, are gratefully acknowledged. iNOVA4Health - UID/Multi/04462/2013, a program financially supported by FCT/MEC, through national funds and co-funded by FEDER under the PT2020 Partnership Agreement is acknowledged.

UV-C LED Systems Verse Low Pressure: A Five-Year Cost Comparison

Molly McManus, Oliver Lawal

4400 Olympic Blvd. Erlanger, KY 41018 USA

Low pressure mercury-based systems have been the standard for ultraviolet (UV) disinfection in both home and municipal applications. UV-C LEDs are challenging vapor-discharge lamps by simultaneously becoming more cost effective from a capital, operational, and lifecycle cost perspective.

Capital Expense – A review of the two technologies and their likelihood for future improvement in terms of cost and performance.

Operational Expense – An evaluation will be made of the annual costs of electricity, lamp replacement and lamp disposal for both technologies.

Life Cycle – A discussion of lamp replacement intervals, replacement parts, and system maintenance.

This paper reviews the development of UV-C LEDs in terms of efficiency and cost then effectively re-writes the norms for residential systems by comparing the 5-year cost-of-ownership of a low-pressure mercury vapor system with that of a UV-C LED system, using information from a 1-year UV-C LED demonstration study. The discussion will then turn to the present and future roles of UV-C LED systems in the municipal market.

Employment of computational tools for optimization of high flow UV-LED water disinfection systems

M. Mohaghegh Montazeri, F. Taghipour*

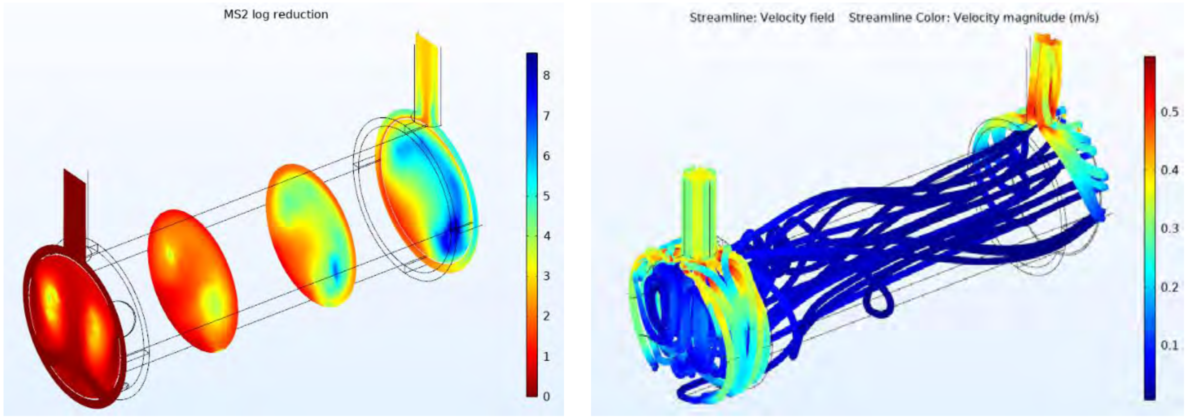
University of British Columbia, 2360 East Mall, Vancouver BC, Canada

Ultraviolet (UV) radiation is a well-known disinfecting technology in water and wastewater treatment. Although many conventional systems employ UV lamps as the source of UV radiation, UV-LEDs are attracting attentions due to some advantages such as wavelength diversity, instant on-off ability and small footprint. Unlike UV lamps, UV-LEDs can be placed outside the reactor and therefore do not affect the hydrodynamics of the reactor. Therefore UV-LEDs have provided a high level of flexibility in the reactor design in terms of both hydrodynamics and radiation management.

While there can be many reactor design ideas, there are limited resources both in terms of time and monetary budget to build and test such ideas. Simulation tools, however, can predict the performance of such reactor designs in a fraction of cost and time. UV LED has so far shown a great potential in the small-scale point-of-use water disinfection systems, but it has a long path to achieve a higher share in the larger market of high flow water disinfection systems.

In this study, we have employed computational modeling tools to test various concepts in terms of hydrodynamics and radiation management to design a UV-LED point-of-entry (POE) water disinfection system. The final design developed from the outcome of our simulations has been fabricated and tested in a benchtop experimental setup. The developed POE system manages radiation using reflectors and its hydrodynamics is controlled by implementing custom mechanical diffusers in the reactor.

We will present the results of our simulation on various design concept for the UV-LED POE reactor. Further, we will demonstrate the evaluation of our modeling predications with the experimental results. Furthermore, we will discuss how a bench-scale reactor that was designed and optimized based on our simulation studies achieved a high degree of MS-2 inactivation at various flowrates of 10 to 40 LPM.



(a) (b)

Figure 1. Employing numerical tools for development of UV-LED POE systems. (a) microbial concentration profile (b) streamlines and their velocity magnitude. Graphics are generated in COMSOL multiphysics.

A multi-wavelength tunable LED source covering UV-B and UV-A from 280nm to 405nm

A.P. Morrison[1,2*], N. Molnar[1,2]

[1]Electrical & Electronic Engineering, School of Engineering & Architecture, University College Cork, College Road, Cork, Ireland.

[2]Environmental Research Institute, University College Cork, Lee Road, Cork, Ireland.

Several studies have previously shown the effects of UV-B irradiation on the growth and development of various plant species[1][2]. The majority of these studies have been limited to using broadband UV light sources, such as mercury lamps, or narrow wavelength UV-B LEDs covering a single peak wavelength. Moreover, the lamps used in previous studies typically do not allow intensity variation, and more importantly don’t allow changing the relative light distribution over the UV-B or UV-A spectrum.

In this paper we describe the development of a multi-wavelength LED source that overcomes these limitations. The lamp comprises nine separate peak wavelengths from thirteen independently controllable LEDs covering the UV-B and UV-A spectrum from 280nm to 405nm. The LED wavelengths used were: [280nm, 310nm x 4, 325nm, 340nm, 365nm, 370nm, 385nm, 395nm, 405nm]. The least efficient of all the LED wavelengths is 310nm necessitating the inclusion of four of these into the lamp to provide sufficient photon flux for experimentation. The LEDs are mounted on a custom designed aluminium-core printed circuit board (PCB) which is then fixed to a finned aluminium heat-sink to maintain the LED operating temperature. There are no observable wavelength shifts in the LED peak wavelengths under normal operating conditions. The lamp fixture takes the form of a ‘tile’ that is 36mm x 30mm in size. This ‘tile’ can be incorporated into larger light fixtures that provide blue and red light for horticultural applications.

Control of the LED source is achieved using a custom designed modular current source that can be set with 12-bit precision up to 300mA per channel. Each channel is set using a Nucleo-F411RE microcontroller via the serial-peripheral interface bus (SPI) protocol. The drive current can be set using a potentiometer input to the microcontroller to establish the current source set-point. At present the output intensity of each of the LEDs is externally measured using a UV-enhanced microspectrophotometer and each LED has its drive current individually set via the microcontroller/potentiometer interface.

Planned development of the lamp includes incorporation of automatic optical feedback to set and maintain the LED output intensity for long-term use. Experimental trials using the lamp are under investigation to establish the effects of UV dose and wavelength on a variety of plant characteristics, including morphology, growth and flavour.

References

[1] T. M. Robson, *et al.* Photochem. Photobiol. Sci., Volume 18, 970 (2019)
[2] A. E. Stapleton. The Plant Cell, Vol. 4, 1353-1358 (1992)

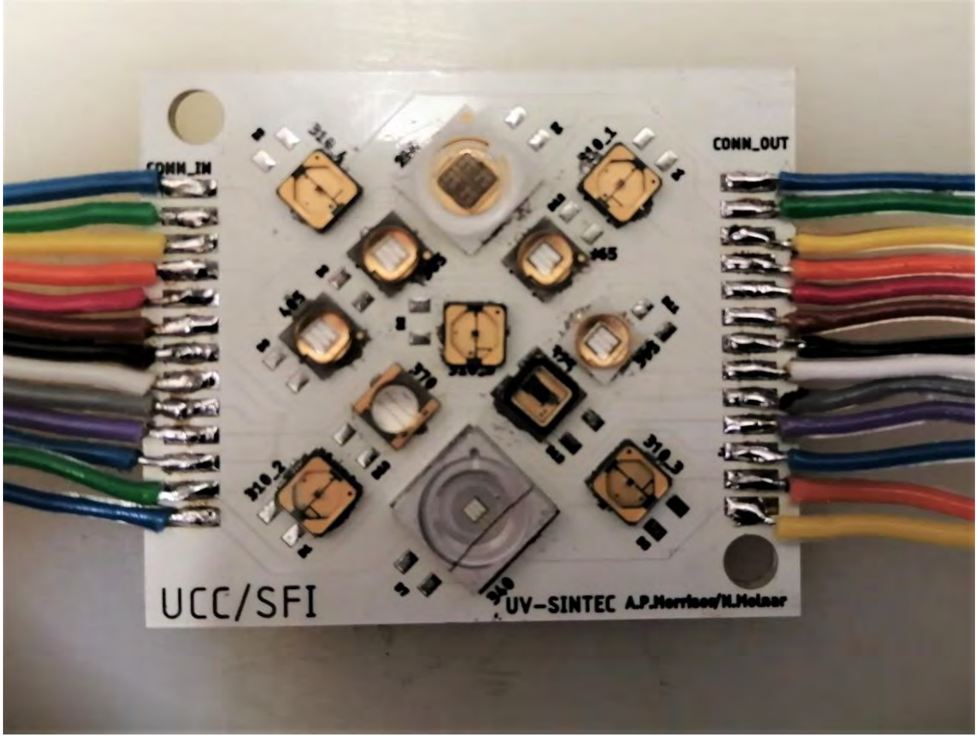
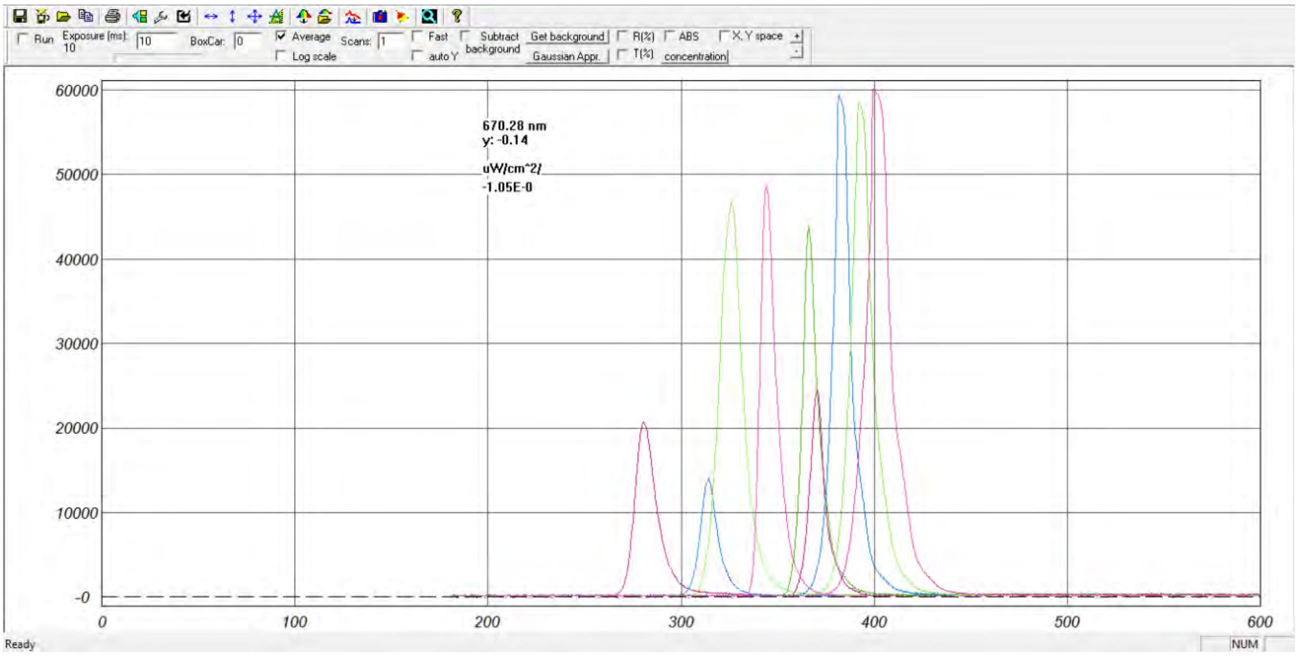


Figure 1: Photograph of the UV-LED Lamp showing 13 independently controllable UV-LEDs



☐ Run Exposure (ms): 10 10 BoxCar: 0 ☑ Average ☐ Log scale Scans: 1 ☐ Fast ☐ auto Y ☐ Subtract background Get background Gaussian Appr. ☐ R(%) ☐ T(%) ☐ ABS concentration ☐ X, Y space

670.28 nm
y: -0.14
uW/cm^2/
-1.05E-0

Figure 2: Spectral output from the nine separate UV-LEDs with current per channel of 200mA. Vertical axis is counts (arbitrary units) and horizontal axis is wavelength in nm.

COVID-19 pandemic: The spark for UVC LED to become a multi-billion dollar business in the next 5 years?

P. Mukish[1*], P. Boulay
[1]*Yole Développement, 75 cours Emile Zola, Villeurbanne (69100), France*

Context:

We have recently made a study on the status of UVC LED industry (ie. application, market, industry, and technology landscape) and the impact of COVID-19 pandemic on it. We would like to share our findings with the UV lighting community and discuss on it.

Abstract:

Finally, we are here. After more than 10 years of waiting, in 2020, the UV LED market could ramp up and reach the billion-dollar mark very rapidly. There is good in everything bad, and the recent COVID-19 pandemic has created some perfect use-cases for the technology to spread across a rapidly changing disinfection/purification market.

From being worth around $20M in 2008, UV LEDs reached a first milestone in 2015 by attaining the $100M market level. Such growth was mostly driven by UVA LEDs that were increasingly used in UV curing applications. But further growth was then restricted by the industry's overcapacity and strong price pressure. In this context, the attention of the industry was then focused on UVC LEDs that could act as a game-changer for disinfection/purification applications. But UVC LED technology is intrinsically different than for UVA LEDs. And whereas UVA LEDs' External Quantum Efficiency (EQE) has rapidly reached more than 50%, UVC LEDs' EQE is still below 10% in most commercial devices. Consequently, the technology was not considered mature by integrators and only early adopters started implementing it.

But that was before COVID-19 pandemic. To reduce spread of the disease, many recommendations have been made by the World Health Organization and governments/authorities. In this field, UV lighting, which can deactivate bacteria and viruses through physical methods, has gained unprecedented attention.

The COVID-19 pandemic has created momentum for the UVC LED industry. From $144M in 2019, the UVC LED market is expected to have more than doubled in 2020 to reach $308M. With market growth now being triggered, we expect it to be worth more than $2.5B in 2025, driven first by surface applications and then water ones.

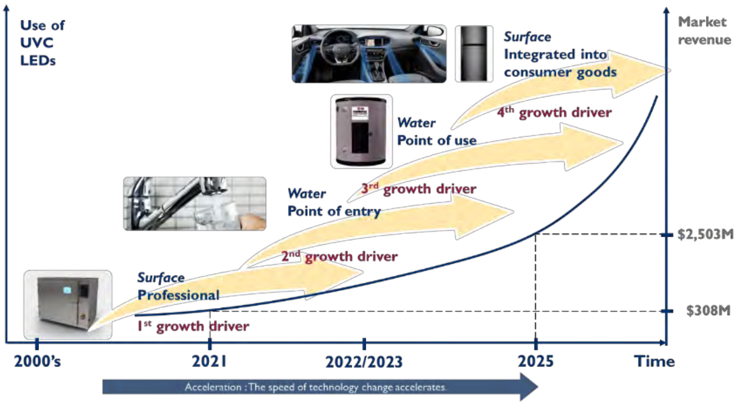


Fig. 1. UV disinfection/purification market growth drivers

References

[1] P. Mukish, P. Boulay, UV LEDs - Market and Technology Trends (2020)

Efficacy of UV-C irradiation emitted by mercury vapor lamp and LED on the bacterial load of eggshells

S. Opherden[1*], S. Fleischmann[1], T. Alter[1], C. Robé[2], I. Szabo[3], S. Hadziabdic[3], A. Gensch[4], P. Rotsch[5], G. Wiese[6], U. Roesler[2]

[1]Institute of Food Safety and Food Hygiene, Freie Universität Berlin, Berlin, Germany
[2]Institute for Animal Hygiene and Environmental Health, Freie Universität Berlin, Berlin, Germany
[3]German Federal Institute for Risk Assessment (BfR), Berlin, Germany
[4]Löwendorfer Geflügelhof GmbH (LGH), Brandenburg, Germany
[5]OSA Opto Light GmbH, Berlin, Germany
[6]SKS Sondermaschinen- und Fördertechnikvertriebs- GmbH, Berlin, Germany

Contamination with zoonotic pathogens is one of the main problems in food production. A specific challenge is the supply of eggs free of pathogenic bacteria. In German packing centers, it is not permitted to wash eggs nor to treat them with chemical substances. Internationally, some companies use ultraviolet-C (UV-C) light-emitting mercury vapor lamps for bacterial decontamination. An alternative approach is the application of UV-C LEDs. They are associated with various ecological and economic advantages.

The objective of this study is the evaluation of UV-C LED irradiation compared to mercury vapor lamps for bacterial decontamination of eggshells.

For laboratory testing, the following gram-positive and gram-negative bacteria were selected, according to the consumer's health risk:

- non-ESBL- and ESBL-producing *Escherichia coli*
- Methicillin-resistant *Staphylococcus aureus*
- *Enterococcus faecium*
- *Campylobacter jejuni*
- *Salmonella* Enteritidis and Typhimurium.

Egg surfaces were inoculated with a defined bacterial number. An organic load was added to simulate practical conditions. Afterward, the surface was sampled with a cotton swab. The bacterial count was estimated with and without UV-C treatment. The LED set-up consisted of a panel of diodes with a maximum spectral density at 280 nm and an irradiance of ~ 2.4 mW/cm^2. In contrast, the experimental arrangement of vapor lamps resulted in an irradiance of ~ 5.0 mW/cm^2. Each treatment was performed for 5 seconds while the egg is rolling on a conveyer.

Recovery rates varied for individual bacterial species. Conventional treatment with mercury lamps resulted in up to 3 $\log_{10}$ reductions. Treatment with LED achieved up to 1.5 $\log_{10}$ reductions. Additional organic load on the eggshell diminished the efficacy of both UV-C sources.

In this study, the swab technique was verified as a convenient sampling method for eggshells. If both UV-C sources achieved same intensity levels, LEDs should be seen as the better choice for egg packaging centers due to their favorable properties.

Visible blind SiC-based UV spectrometer – Development and characteristics

N. Papathanasiou[1*], S. Langer[1,2], T. Weiss[1], D. Prasai[2]

[1]sglux GmbH, Richard-Willstätter-Str. 8,12489 Berlin,Germany
[2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik,
Gustav-Kirchhoff-Straße 4,12489 Berlin

We report about the development of a visible blind UV spectrometer based on a 512 pixel SiC photodiode array. The 512 pixel array was designed and processed at the Ferdinand-Braun-Institute. The assembly of the photodiode-array, read out integrated circuit, and electronics was performed by sglux. The SiC-array was placed in a commercial available spectrometer in replacement of a Si-CCD.

We present the characteristics of the spectrometer such as dark current signal, resolution, homogeneity pixels' response, spectra response and maximum intensity range. Focus will be on visible blindness of the SiC spectrometer and its stray-light performance.

Finally we discuss applications of a visible blind UV spectrometer. Photo biologists need measurements of suns' UV radiation. Manufacturers of gas-discharge IV lamps would like to measure UV emissions lines before an intense visible background. UV LED manufactures could use such as UV spectrometer to provide a fast wavelength binning of their UVC LEDs.

A Protocol for Design and Validation of UV-LED Devices for Air and Surface Disinfection

Milad Raeiszadeh[1*], Babak Adeli[1], Majid Keshavarzfathy[1], Ehsan Espid[1]
[1]*Acuva Technologies, #1-3771 North Fraser Way, Burnaby, BC, Canada V5J 5G5*

The health-threatening crisis from the recent COVID-19 pandemic world-wide highlights the scientific potentials of deploying sustainable ultraviolet (UV) disinfection technologies to treat biocontaminated air and surfaces as the major media for disease transmission. To combat against the pandemic, UV air and surface disinfection has attracted tremendous attention and many products became available on the market. General public started utilizing UV sterilization devices for various surfaces, from doorknobs and keypads to personal protective equipment, or air purification devices with an integrated UV disinfection technology. Besides, environmental public settings, from hospitals and health care facilities to shopping malls and airports, are considering implementation of UV disinfection devices for disinfection of frequently touched surfaces and circulating air streams. Among UV devices, UV light emitting diode (UV-LED)-based products have attracted tremendous attention owing to their low voltage requirements, long lifetime, instant on/off capability, structural integrity, and environmentally friendliness (no mercury). However, limited understanding of the critical aspects of UV disinfection, not only among the majority of general public but also with some of the UV device manufacturers, has led to inappropriate use of this promising technology. Dubious and non-scientific performance claims by some of the UV system designers and manufacturers are unfortunately widespread. In the absence of an established protocol and guidelines to design and validate commercial UV disinfection products, numerous UV-based sterilization devices with unknown efficacies against SARS-CoV-2 and lack of safety measured caused a major concern whether such products are yet at a stage to be used by amateur users. In this work, a protocol for design of UV-LED devices for air and surface disinfection applications is elaborated by considering the fundamentals of UV disinfection phenomena and available guidelines by regulatory organizations. Furthermore, the essential parameters and protocols to validate the efficacy of the UV disinfection process are systematically elaborated. Eventually, safety considerations in designing UV devices for air and surface disinfection will be presented and emphasized. Several case from viral products in the market are studied and their compatibility with standard protocol will be discussed. This study, along with the provided illustrations, will play an essential role in the design and fabrication of effective, reliable, and safe UV disinfection systems applicable to preventing viral contagion in the current COVID-19 pandemic, as well as potential future epidemics.

UV-LED Air Purifier for Degradation of Volatile Organic Compounds in Indoor Air

Shahriar Rouhani, Fariborz Taghipour*

Department of Chemical and Biological Engineering, University of British Columbia, Vancouver, BC, Canada

Volatile organic compound (VOC) levels in indoor air are often higher than that of outdoors and can cause irritations, sick building syndrome, and illnesses. We are studying the application of ultraviolet light-emitting diodes (UV-LEDs) for photocatalytic oxidation (PCO) of VOCs in indoor air. UV-LEDs are robust and compact sources of UV and provide a high degree of flexibility for the design of photocatalytic air treatment units with optimized radiation and airflow distribution. We designed and operated a UV-LED air purification system that applies 365 nm UV-LED to generate highly reactive hydroxyl radicals on the TiO_2 photocatalyst immobilized on several substrates (Figure 1). The activated photocatalyst can oxidize various chemical pollutants and transform them into harmless products. In our study, photocatalytic activity measurements were carried out by the degradation of toluene as the model VOC contaminant in a batch reactor.

According to our experiments, the kinetic equation of photocatalytic degradation followed pseudo-first-order reaction kinetics. The reaction rate constant, $\mathrm{K}\,(\mathrm{min}^{-1})$, of the toluene degradation, was measured as an indicator of the overall reactor performance. We studied the effect of mass transfer on PCO over a wide range of flow rates and observed that the mass transfer limitation has a minimal effect on the reaction rate due to the high diffusion rate of toluene in the air. On the other hand, any change in the radiation distribution strongly affected the performance. It was observed that the reaction rate constant, K, was proportional to $\mathrm{I}^{0.56}$, where I is the average irradiance on photocatalyst surface.

We also studied the effect of photocatalyst substrate on the reactor performance. The photocatalyst was immobilized on both solid and porous substrates and the results were compared. We showed that porous photocatalyst could improve the PCO rate by more than 50% due to the higher available reaction sites. Our findings can be applied to the design and optimization of efficient UV-LED reactors that can improve indoor air quality by effectively removing VOCs.

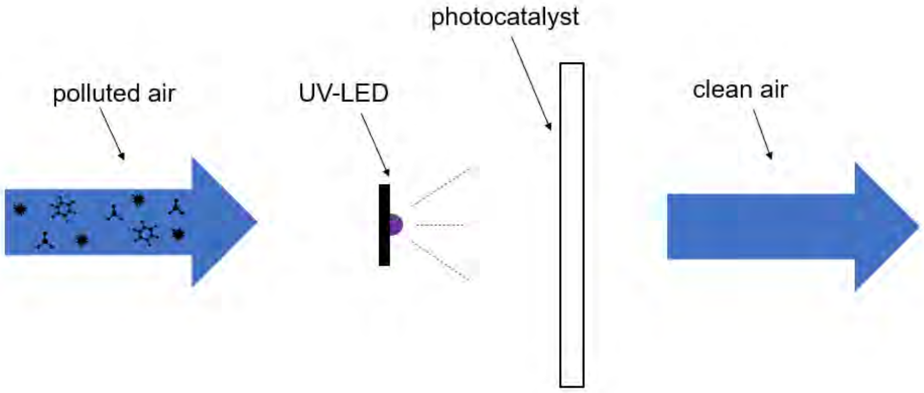


Figure 1: Schematic diagram of UV-LED photocatalytic air purification.

Ceramic-based UV-LED photocatalytic membrane reactor development, evaluation, and optimization

S. Sakhaie, F. Taghipour*

Department of Chemical and Biological Engineering, The University of British Columbia
2360 East Mall, Vancouver, BC V6T 1Z3, Canada

With water shortage shading on the human's future on this planet, the importance of water and wastewater treatment technologies is standing out. Membrane technologies have the potential to provoke a revolution in the water treatment industry. However, there are still some drawbacks including the high cost of frequent membrane replacement, fouling, and high energy demand, which need to be addressed. Immobilizing photocatalyst on the surface of the membrane and initiating a photocatalytic reaction using UV irradiation would be a proper answer to the aforementioned problems. This combination could alleviate the formation of fouling, decrease the operating cost, increase the time of operation, and enhance the life span of the membranes. Conventional UV lamps are not compatible with the membrane-based systems currently used in the industry due to the size and shape restrictions. In contrast, UV LED owing to its small dimensions offers flexibility to be implanted in the existing membrane modules without any further modifications.

We developed a UV-LED coupled photocatalytic membrane reactor (PMR) based on ceramic membranes, which are thermally and chemically stable and currently are widely utilized in microfiltration and nanofiltration [1]. We synthesized a titanium dioxide (TiO_2) composition, which resulted in a highly durable silicon carbide (SiC)-based photocatalytic membrane (PM). To investigate the performance of the PM in conditions similar to those of industry operations, we designed and operated a laboratory-scale PMR for studying the anti-fouling and self-cleaning prosperities of the developed PM (Fig. 1). We achieved enhanced photocatalytic efficiency, several times higher than that of P-25 through optimizing the synthesis technique, the photocatalyst composition, and operating parameters. The proposed method led to highly stable attachments of photocatalyst particles to the membrane, showing nearly the same photocatalytic activity after more than ten consecutive rounds of operation. We will present our latest results on developing the PM and the effect of operational conditions on its performance. More importantly, we will discuss the potential of UV-LEDs to make a breakthrough in the membrane industry by offering novel potential designs for photocatalytic membrane reactors.

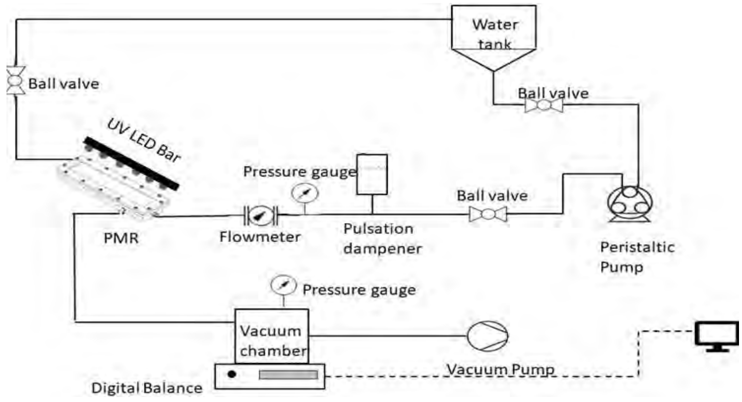


Fig. 1. PMR setup configuration

References

[1] E. O. Ezugbe and S. Rathilal, *Membranes (Basel).*, vol. 10, no. 5 (2020).

UV LEDs: Improving lifetimes by optimal thermal management

Pratibha Sharma, Pao Chen, Saya Han, Peter Chung, Chang Han
Violumas Inc, 48664 Milmont Dr, Fremont, CA 94538, USA

With high costs but low performance levels, recent developments in UV LED technology have been focused on improving radiant UV flux and reliability [1]. While the development of vertical designs and flip-chips [2] in the UV LED space has addressed numerous concerns, thermal management will always be an issue affecting performance.

With up to 95% of UVC LED energy dissipated as heat, proper thermal management is critical to ensure that device lifetimes and LED performance are not compromised. Simple overheating at the chip level can cause premature failures in the overall system, more so in the case of high power applications. To address this, we present the 3-pad technology [3] as an integrated cooling technique at the chip and the package level, allowing for maximizing radiant UV flux with superior thermal dissipation (Figure 1). The pillar coupling occupies the majority of space between the LED chip and the bonding substrate, withholding most of the stress from the bonding and heat. This not only improves device lifetimes but also enables device survival through at least 1000 thermal cycles.

Optimal thermal management allows for maintaining stable junction temperatures which can double LED lifetimes and also minimize the thermal decay that degrades optical output. Different packaging techniques have allowed for the development of a varying range of novel UV LED products. However, it is essential to understand the opto-electrical specifications of various LED packages to discern varying performance levels in different operating conditions. In this paper, we aim to discuss how an improvement at the chip and the package level can allow for the UV LEDs to be used for high-intensity applications at currents greater than 1000 mA per chip of 1.2 mm x1.2 mm area. We will also present new lifetime data obtained with the 3-pad technology and how this improved lifetime at high currents can enable novel applications for UV LEDs. Latest Lifetime measurements with a 280nm UV LED COB show less than 20% decrease in optical output, after 3,400 hours of operation at 700mA, therefore, indicating a L70 lifetime of greater than 8,000 hours.

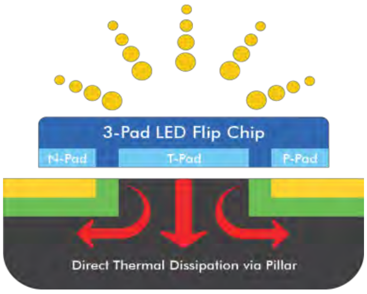


Fig. 1. 3-pad LED flip-chip design [3]

References

[1] Yoshihiko Muramoto et al Semicond. Sci. Technol. 29, 084004, 2014.
[2] M. Shatalov *and* A. Chitnis, Appl. Phys. Lett. **86**, 201109, 2005.
[3] https://www.violumas.com/our-technology/

Ultraviolet light decontamination in chicken breast meat

A. B. Soro[1*], P. Whyte[2], D. J. Bolton[1], B. K. Tiwari[1]
[1]*Teagasc Ashtown Research Centre, Ashtown, Dublin 15, Ireland*
[2]*UCD School of Veterinary Medicine, University College Dublin, Belfield, Dublin 4, Ireland*

Decontamination strategies and technologies are fundamental pillars in the food industry. Many have existed for decades and have been extensively studied to date. Among them, ultraviolet (UV) light has been shown to reduce pathogenic and spoilage bacteria on food and food contact surfaces. Although the effectiveness of this technology has been known for a long time, the application of UV light in foodstuffs needs further evaluation (1). Moreover, the recent development of UV-light emitting diodes (LEDs) may offer new opportunities for implementation within the food industry due to their low cost, longevity and lower heat emissions (2). Globally, the broiler industry has expanded substantially over recent decades. Consumers have a preference for poultry meat due to it's low relative cost, nutritional profile and organoleptic properties. However, fresh chicken has a short shelf-life and readily supports the growth of spoilage organisms (3). The goal of this study was to carry out a decontamination protocol using UV light to reduce the burden of spoilage bacteria in raw chicken meat. Thus, chicken fillets purchased at a local supermarket were cut into square pieces using an aseptic technique and treated with different wavelengths (280, 300 and 365 nm) in a LED unit for 2, 4, 6, 8 and 10 min at a 5 cm distance from the light source. Afterwards, a ten-fold dilution series of each sample was prepared in Maximum Recovery Diluent (MRD) and plated on various growth media. Total viable count (TVC), mesophilic and psychrophilic, were incubated on plate count agar (PCA) at 30 ℃ for 48 h and 6.5 ℃ for 10 days, respectively, total Enterobacteriaceae count (TEC) in Violet Red Bile Glucose agar (VRBGA) for 37 ℃ for 24 h, *Pseudomonas* spp. in *Pseudomonas* selective agar (PSA) at 25 ℃ for 48 h and lactic acid bacteria (LAB) in Man, Rogosa, Sharpe agar (MRS) at 30 ℃ for 72 h. Each treatment was performed in triplicate and experiments were carried out on 3 separate occasions. This study achieved maximum reductions of 1.67 logarithmic colony forming units (cfu)/g in TVC after 6 min with 300 nm, 1.54 log cfu/g in TEC after 4 min with 365 nm, 2.16 log cfu/g in *Pseudomonas* after 8 min with 300 nm and 2.5 and 1.54 log cfu/g in LAB and psychrophiles at 10 min with 280 and 300 nm, respectively. It was concluded that LED treatments, could be applied as a decontamination technology in the poultry industry.

References

[1] Falguera V, Pagán J, Garza S, Garvín A, Ibarz A. Ultraviolet processing of liquid food: A review. Food Research International. 2011;44(6):1580-8.

[2] Hinds LM, O'Donnell CP, Akhter M, Tiwari BK. Principles and mechanisms of ultraviolet light emitting diode technology for food industry applications. Innovative Food Science & Emerging Technologies. 2019;56:102153.

[3] Moutiq R, Misra NN, Mendonca A, Keener K. In-package decontamination of chicken breast using cold plasma technology: Microbial, quality and storage studies. Meat science. 2020;159:107942.

Aluminium Nitride substrates for epitaxial AlGaN layers with low dislocation density

T. Straubinger[1*], M. Bickermann[1], C. Hartmann[1], L. Matiwe[1], J. Wollweber[1], A. Knauer[2], M. Weyers[2], T. Wernicke[3], M. Kneissl[3]

[1]Leibniz-Institut für Kristallzüchtung, Max-Born-Str.2, 12489 Berlin, Germany
[2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str.4, 12489 Berlin, Germany
[3] Technische Universität Berlin, Institute of Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany

Ultra-violet (UV) light emitting diodes (LEDs) are typically processed on sapphire substrates and typically show threading dislocation densities (TDD) in the range of 10^9 cm^2 in the light emitting $Al_xGa_{1-x}N$ multi-quantum well layers strongly reducing the radiative recombination efficiency [1]. One solution to overcome this issue is to use native aluminum nitride (AlN) substrates to grow device layers with TDD multiple orders lower compared to AlN on sapphire, typically < 10^5 cm^2 [2, 3]. We will present and discuss recent progress in physical vapor transport (PVT) crystal growth of AlN and surface preparation and demonstrate AlN buffer layers grown by metal organic vapor phase epitaxy (MOVPE) with TDD below 10^6 cm^2 on our AlN substrates.

Fig. 1: AlN crystal, 8mm diameter

In PVT, AlN powder is evaporated in the source region and by applying a temperature gradient (dT) towards the seed region (at Ts) a supersaturation of the vapor is created leading to crystal growth with shape and size shown in Fig. 1. We found that we can achieve a low TDD by reducing dT and increasing Ts (Fig. 2).

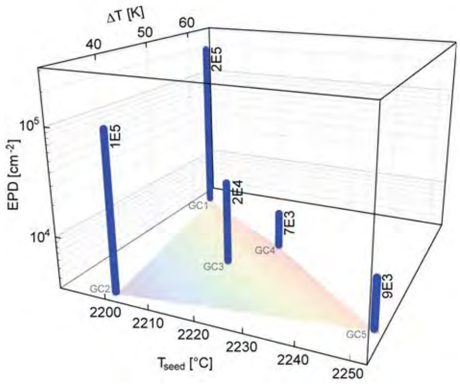


Fig. 2: Dislocation density depending on T-seed and T-difference between source and seed for five growth conditions (GC).

For successful epitaxy the polishing is crucial to avoid generation of defects during the growth start. Subsurface damage can be avoided with an optimized chemo-mechanical polishing process. Epitaxial layers grown by MOVPE on 8 mm diameter AlN wafers exhibit TDD <10^6 cm^{-2} on the entire substrate. Due to a high precision substrate miscut (0.2° off from c-axis in M-direction) as well as the avoidance of subsurface scratches through optimized polishing processes a very smooth surface of the epitaxial layer with a regular step flow pattern could be achieved. Crystalline quality, geometry, substrate orientation and surface quality of the substrates as well as their influence on the properties of the epitaxial layers will be discussed.

References

[1] M. Kneissl et al., Nature Photonics, Volume 13, 233–244 (2019)
[2] R. Dalmau et al., Journal of the Electrochemical Society, 158 (5) H530-H535 (2011)
[3] R. Dalmau et al., Materials Science Forum, Vol. 924, pp 923-926 (2018)

On the road to direct, optical, on-line germ detection

F. Stüpmann[1]*, M. Sarcander[1], M. Moschall[1], D. Röll[2], O. Talkenberg[2], S. Hartmann[1], R. König[2]

[1] Silicann Systems GmbH, Schillerplatz 10, 18055 Rostock, Germany
[2]Center for Sepsis Control & Care, Jena University Hospital, Am Klinikum 1,
07747 Jena, Germany

With increasing rates of automation in foodstuff production, pharmaceutical production and other industries, the demand for fast and ideally continuous bioburden measurements has grown in parallel, not least because of stricter regulative environments. There currently exist a variety of rapid test methods robust enough for productive environments. Utilizing a range of contaminant properties to directly or indirectly detect their presence, it is now possible to now possible to obtain results in up to 15 seconds. Unfortunately most rapid detection methods work sample-based and many necessitate the application of reagents on the samples, which renders these methods unsuitable for continuous and autonomous measurements. Our alternative approach to the problem space belongs to a line of research employing the inherent fluorescent properties of cells to directly measure presence of microbial contaminations (through detection of the ubiquitous amino acid Tryptophan). In this publication we systematize the field of rapid germ detection approaches and lay out the critical role high-luminosity UV LEDs will play in the future of direct, optical germ detection.

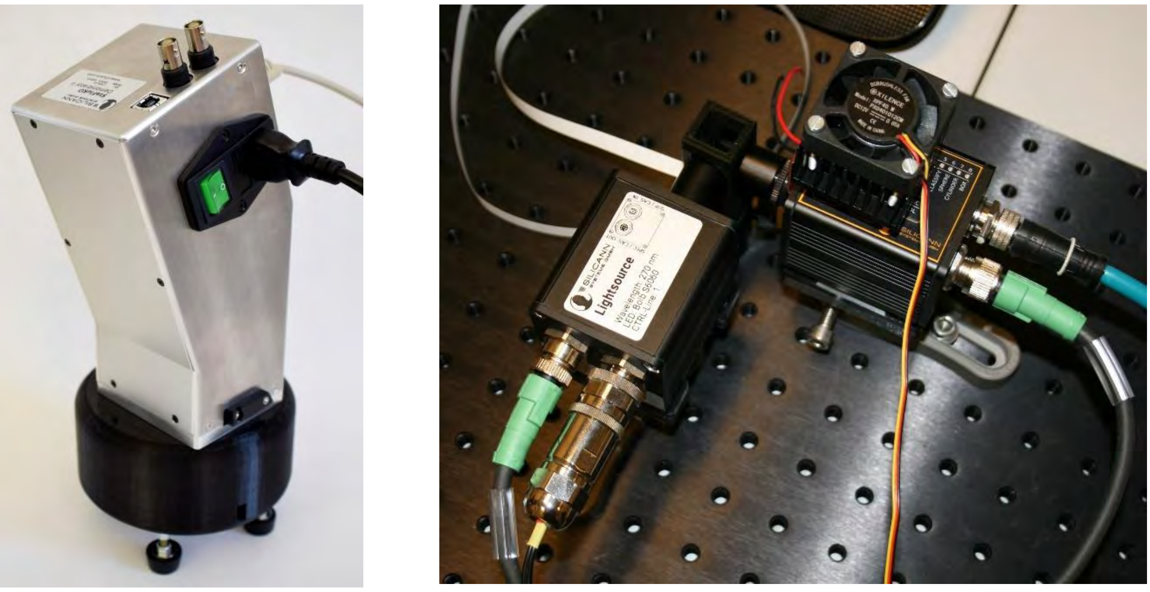


Fig. 1. Functional prototypes of different LED-induced fluorescence spectroscopy sensors

.

Optic concepts for UV LED lamps at long working distances

T. Vehoff*[1], J. Grade[1], A. Stahl[1]

[1]*Heraeus Noblelight GmbH, Heraeusstr. 12-14, 63450 Hanau, Germany*

The small size of LEDs along with its excellent cooling possibilities allow the use of primary optics directly on top or in very close vicinity to the LED chips. These can shape the emitted light from an almost Lambertian (180°) emission to a 30-40° angle. This light can in turn be focused at a large distance by a set of secondary optics aligned and designed to match the corresponding primary optics as well as the LED substrate.

This allows light intensities of 8-10 W/cm² at a distance of 8 cm, which is characteristic in the printing industry and could otherwise only be achieved at distances below 3 cm from the emission window of the lamp.

-

Light extraction efficiency enhancement of UVC and UVB LEDs via encapsulation with UV-transparent silicone resins (Deep UV200)

S. Wu[1*], M. Guttmann[1], N. Lobo-Ploch[2], N. Susilo[1], F. Gindele[3], A. Knauer[2], T. Kolbe[2], J. Raß[2], H. K. Cho[2], K. Hilbrich[2], S. Einfeldt[2], T. Wernicke[1], M. Weyers[2], and M. Kneissl[1,2]
[1]*Institute of Solid State Physics, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany*
[2]*Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany*
[3] *Schott AG, Business Unit Electronic Packaging, Christoph-Dorner-Straße. 29, 84028 Landshut, Germany*

Improving the light extraction efficiency (LEE) is a critical issue for realizing highly efficient AlGaN-based deep ultraviolet light emitting diodes (DUV-LEDs). LEE can be greatly enhanced by a hemispherical encapsulation reducing total internal reflection in the LED chip. In this paper we study the LEE enhancement and total output power improvement of DUV LEDs emitting at 265 nm and 310 nm with encapsulation by a UV-transparent silicone. Simulation of the LEE of encapsulated DUV-LED suggests that a properly placed hemispherical encapsulation with a refractive index in the range from 1.4 to 1.8 yields an LEE enhancement by a factor greater than 1.66. The optical properties of silicone encapsulants were investigated by transmission and reflection measurements and indicated a suitable encapsulation refractive index of 1.4 and a low absorption coefficient of 1.38 cm^{-1} and 0.39 cm^{-1} at 265 nm and 310 nm, respectively. AlGaN-based UVC and UVB LEDs heterostructures were grown by MOVPE and fabricated to LED chips. The LEDs were flip-chip mounted on planar AlN ceramic packages and encapsulated with a silicone by resin casting in a 1.5 mm radius hemispherical PTFE mold and curing at 165 ℃ for 16 h. For the 265 nm UVC LED, the total output power increased from 27 mW to 46 mW at an injection current of 350 mA, whereas the output power of the 310 nm UVB LED increased from 14 mW to 28 mW at 350 mA. Farfield measurements of encapsulated LEDs showed a narrowing of the emission cone with a significant increase of the intensity for small polar angles. Furthermore, the LEE of encapsulated 265 nm and 310 nm LEDs was enhanced by 75% and 73%, which is in good agreement with the optical simulations.

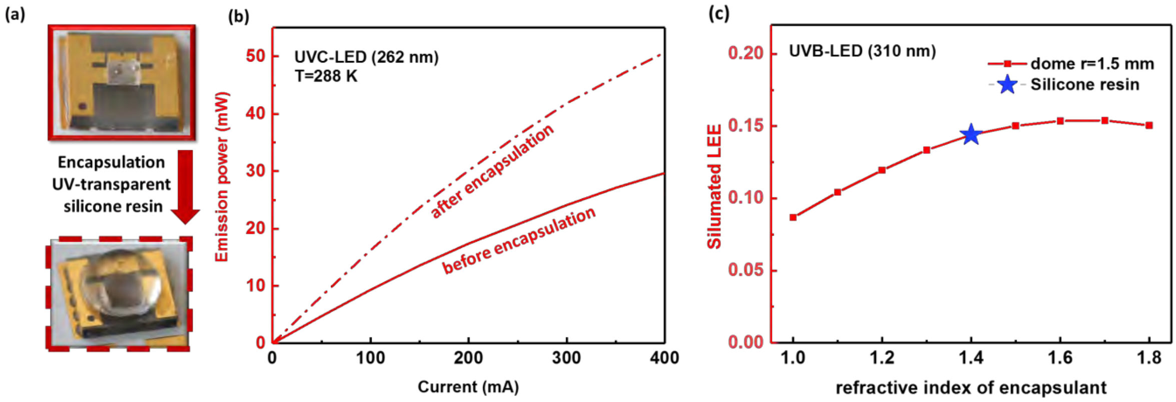


Fig. 1. (a) Photograph of DUV LED package with and without encapsulation with a UV-transparent silicone. (b) Output power of a 265 nm UVC LED as a function of current. Solid and dashed red lines are total emission power before and after encapsulation. (c) Simulated LEE at 310 nm of typical UV-LED as a function of refractive index of encapsulation materials.

Disruptive GLED devices and Disinfection Solutions

Ling Zhou
Bolb Inc, Livermore, CA

Bolb Inc presents an interesting topic which will help to save the world by using UV-LEDs for important applications.

High Wall Plug Efficiency, deep ultra-violet emitting light-emitting diodes based on proprietary device structure breakthroughs, namely a transparent and highly conductive P layer, enable novel germicidal photonic platforms which now exhibit considerably higher Germicidal Performance Application (GPA) proficiencies than legacy low WPE LEDs and 254 nm LP lamps in specific implementations. A high GPA coupled with significant solution footprint reduction, as well as installation, operational, and electrical cost savings, and are important attributes since light in the range of 262-278 nm generated by LEDs disrupts the DNA or RNA of infectious pathogens as well as spoilage organisms more effectively than conventional reliance on light from 254 nm emitters. Such Germicidal LEDs (GLEDs) now positioned to enable wide deployment of non-chemical, non-touch, germicidal applications where footprint, cost, and ease of implementation matter. The implications of such availability has accelerated adoption in Drinking Water Safety, HAI Prevention and Nurse Safety, Horticulture and Food Security, and in room Air Sanitation. Such applications will be discussed including suggested configurations and use approaches and validation methods.

Bolb has obtained the following highly exciting results in 2019.

- A fully transparent 269 nm LED with WPE more than 10% delivered 12 mW @ 20mA
- A fully transparent 271 nm LED delivered 171.5 mW @ 350 mA with VF of 5.65 V
- A semi-transparent 265 nm LED delivered 91 mW @ 350 mW with V_F of 5.76 V

References

[1] Jianping Zhang, Ying Gao, Ling Zhou, UVC LED with p-AlN ohmic contact layer, SPIE opto invited talk, February 4, 2019
[2] Peter E. Gordon, Critical Roles for Germicidal LEDs in Healthcare Delivery Facilities, IUVA UV Solutions Magazine, 2019 Issue 3

Exhibitors

Acuva Technologies Inc | Canada ↗ **www.acuvatech.com**

AquiSense Technologies | USA ↗ **www.aquisense.com**

AURA LIGHTING PTE LTD | Singapore ↗ **www.auralightings.com**

BlueTube Technology | Germany ↗ **www.bluetube-curing.de**

Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik | Germany
↗ **www.fbh-berlin.com**

GIGAHERTZ Optik Vertriebsgesellschaft für technische Optik mbH | Germany
↗ **www.gigahertz-optik.com**

Hergy Lighting Technology Corp. | Taiwan ↗ **www.hergy.com.tw**

International Light Technologies, Inc. | Germany ↗ **www.intl-lighttech.com**

LayTec AG | Germany ↗ **www.laytec.de**

MSG Lithoglas GmbH | Germany ↗ **www.lithoglas.de**

OSRAM Opto Semiconductors GmbH | Germany ↗ **www.osram.com**

Photon Wave Co., Ltd. | Korea ↗ **www.photonwave.co.kr**

Quantum Design GmbH | Germany ↗ **www.qd-europe.com**

ResInnova Laboratories | USA ↗ **www.resinnovalabs.com**

Stanley Electric GmbH | Germany ↗ **www.stanley.co.jp/e**

Taiyo Nippon Sanso | USA/Japan ↗ **www.mocvd.jp**

UVphotonics NT GmbH | Germany ↗ **www.uvphotonics.de**

UV Solutions Magazine | USA ↗ **www.uvsolutionsmag.com**

Violumas | USA ↗ **www.violumas.com**

Watersprint AB | Sweden ↗ **www.watersprint.com**

The virtual event was organized with the support of:

Event agency
Shepard Exposition Services, Inc. ↗ **www.shepardes.com**

Conference platform
Connects.at ↗ **www.connects.at**

Graphic design
info@finkgrafik.de

SEE YOU
IN TWO YEARS AT
ICULTA 2023 !

↗ **www.iculta.com**

Contact

Advanced UV for Life
c/o Ferdinand-Braun-Institut gGmbH
Gustav-Kirchhoff-Str. 4
12489 Berlin | Germany

info@advanced-uv.de
↗ **www.advanced-uv.de**

International Ultraviolet Association
6935 Wisconsin Ave Suite 207
Chevy Chase, MD20815 | USA

info@iuva.org
↗ **www.iuva.org**