CORM 2011

Annual Conference and Business Meeting

NIST Workshop & Tour, Solid State Lighting, Practical Lab Light Measurement, Production vs. Laboratory SSL Metrology

May 4-6, 2011

National Institute of Standards and Technology
Gaithersburg, MD

CORM

Council for Optical Radiation Measurements

OVERVIEW

CORM 2011
Annual Conference and Business Meeting

May 4 - 6, 2011

The CORM 2011 conference will be held in Gaithersburg, MD. All technical sessions including the NIST workshop and tour will take place at NIST. The Grum Banquet & Lecture will be held at the Holiday Inn, Gaithersburg also serving as the conference host hotel.

The NIST workshop themes will include: **Uncertainty analysis fundamentals and case studies for optical measurements**

The conference themes include **Solid State Lighting: Novel Ideas/Applications & Standardization Updates, Practical Ideas and Tips for Laboratory Measurement of / with Light, Optical Properties of Materials, Laboratory versus Production SSL Metrology.**

The 2011 Annual CORM Technical Conference is structured to provide interaction between the optical radiation industry and National Metrology Institutes (NMI's) such as the National Institute of Standards and Technology (NIST), National Research Council (NRC) of Canada, and National Center for Metrology (CENAM) of Mexico.

Schedule and Locations

Wednesday, May 4th	8:30 AM	NIST Workshop	NIST
Wednesday, May 4th	1:30 PM	NIST Tour	NIST
Wednesday, May 4th	4:00 PM	CORM BoD Meeting	NIST
Thursday, May 5th	8:30 AM	Session 1: SSL Novel Ideas	NIST
Thursday, May 5th	1:15 PM	Session 2: Practical Ideas and Tips	NIST
Thursday, May 5th	6:00 – 9:00 PM	Grum Reception & Banquet	Holiday Inn
Friday, May 6th	8:30 AM	Session 3: Optical Properties of Materials	NIST
Friday, May 6th	11:00 AM	Session 4: Lab vs. Production SSL Metrology	NIST

Conference Coordinators

Alan Tirpak Gooch & Housego / Optronic Laboratories 4632 36th Street Orlando FL32811 Tel: 407-422-3171, x – 207 atirpak@goochandhousego.com	Bob Angelo Gigahertz-Optik Inc 5 Perry Way Newburyport MA 01950 Tel: 978-462-1818 b.angelo@gigahertz-optik.com

CORM Conference 2011

CORM 2011 Annual Conference and Business Meeting

PROGRAM

May 4-6, 2011 Gaithersburg, MD

Wednesday May 4th

6:30 – 7:30 AM	***Registration Open Full Breakfast at Holiday Inn*** ***Bus Departs from HI to NIST at 7:30 AM***
	Tutorial Workshop Sponsored by NIST
8:30 AM	**Fundamentals of uncertainty analysis for optical measurements**: Where do I start? (Cameron Miller)
9:15 AM	**Case Study: Uncertainty analysis for luminance ratio measurements** (Cameron Miller)
9:45 AM	Coffee Break
10:00 AM	**Case study: Uncertainty analysis for NIST spectral irradiance measurements** (Howard Yoon)
10:30 AM	**Case study: Uncertainty analysis for NIST reflectance colorimetry measurements** (Maria Nadal)
11:00 AM	**Uncertainty budgets for integrated photometric measurements** (Rolf Bergman)
11:25 AM	**Case study: Uncertainty analysis for integrating goniometric measurements** (Cameron Miller)
11:50 AM	Discussion
12:00 PM	**LUNCH – Available in NIST cafeteria for a fee (cash only – no credit cards)**
1:30 PM	NIST Tours
4:00 PM	***Bus Departs from NIST to HI***
4:00 PM	CORM BoD Meeting -

Notice: There will be no technical committee meetings

CORM Conference 2011

Thursday May 5th

6:30 – 7:30 AM	***Registration Open Full Breakfast at Holiday Inn*** ***Bus Departs from HI to NIST at 7:30 AM***
Session 1	***SSL Novel Ideas/Applications, Standardization Updates*** *- Chair: James Leland*
8:30 AM	**A Practical Photometer for CIE Performance Based Mesopic Photometry System** (Tatsukiyo Uchida)
9:00 AM	**Proficiency Test Group 12 results** (Rolf Bergman)
9:30 AM	**Calculation of CCT and Duv and Practical Conversion Formulae** (Yoshi Ohno)
10:00 AM	Coffee Break
10:30 AM	**Development of a 365 nm LED Source as a UV Transfer Standard** (Dr. Shen Zhu**)**
11:00 AM	**Fluorescence errors in integrating sphere measurements of remote phosphor type LED light sources** (Arno Keppens – Presented by Yuqin Zong)
11:30 AM	**LUNCH – Available in NIST cafeteria for a fee (cash only – no credit cards)**
Session 2	***Practical Ideas and Tips for Laboratory Measurement of / with Light*** *– Chair: Tim Moggridge*
1:00 PM	**TM-21 Update: Method for Projecting Lumen Maintenance of LEDs** (Eric Richman)
1:30 PM	**Real-time Passive Fluorescence Spectra of Induced Stress in Vegetation** (Arnold Theisen)
2:00 PM	**Review of Commercial Light Meter Calibration** (K Frank Lin)
2:30 PM	**Practical Lumen Maintenance Testing Using LM - 80 - A discussion of Best Practices and Recent Standards Activity** (Jeff Hulett)
3:00 PM	**A closer look at photobiological safety measurements** (Egbert Lenderink)
3:30 PM	**Simple silicon photodiode based femto-watt measurement system and its implication** – (Yuqin Zong)
4:45	***Bus Departs from NIST to HI***
6:00–9:00 PM	**Frank Grum Memorial, Reception, Banquet and Lecture - :** ***"A view from the other side of technology: SSL, market forces, politics, and communication" – Dale Work***

CORM Conference 2011

Friday May 6th

6:30 – 7:30 AM ***Registration Open Full Breakfast at Holiday Inn***
Bus Departs from HI to NIST at 7:30 AM

Session 3 ***Optical Properties of Materials*** *- Chair: Leonard Hanssen*

8:30 AM **Characterisation of Fluorescent Materials** (Sven Leyre)

9:00 AM **Results of a Nationwide Intercomparison of Infrared Spectral Reflectance Capabilities** – (Boris Wilthan/Leonard Hanssen)

9:30 AM **A high-power, tunable, supercontinuum-based VIS-SWIR light source for the STARR II gonioreflectometer** (Heather Patrick/and Clarence J. Zarobila)

10:00 AM Coffee Break

10:30 AM **Integrating sphere superposition technique for quantifying the linearity of InGaAs detectors** (Angelo Arecchi)

Session 4 ***Laboratory Versus Production SSL Metrology –*** *Chair: Kathleen Muray*

11:00 AM **Laboratory versus Production SSL Metrology: Lessons and Questions from CALiPER** (Mia Paget – Presented by Eric Richman)

11:30 AM **Thermal issues in relation to metrics reported on LED data sheets** (Andras Poppe)

12:00 PM **Optical Sensors for Semiconductor Process Control** (John Corless)

12:30 PM **CALiPER Deep Dive Long-Term Testing—Correlation from SSL Device Performance to End Product** (Mia Paget – Presented by Eric Richman)

1:00 PM Conference Close
1:15 ***Bus Departs from NIST to HI***

Franc Grum Memorial Lecture: *"A view from the other side of technology: SSL, market forces, politics, and communication"*

The presentation will be guided by these discussion questions:

1) Will SSL "take over" as the global lighting source?
2) Should the government be involved in determining the commercially available lighting choices?
3) How do existing lighting metrics stifle the adoption of new lighting developments?
4) When is the technologist's job over?

Dale Work

Dr. Dale Work *holds degrees in math, chemistry and business. His PhD in chemistry is from Michigan State. His career has been in the lighting industry, primarily with Philips Lighting. He served as VP R&D North America for ten years, then managed the Central Lamps Laboratory in the Netherlands for three years. From 2002-2007 he was a technical lobbyist for Philips in Washington, DC. Before retiring in 2010, he was the General Manager of the Philips Lighting Innovation Campus in Shanghai, China.*

NIST WORKSHOP - Fundamentals of Uncertainty Analysis for Optical Measurements: Where do I start? (Cameron Miller)

The initial talk in the NIST workshop on uncertainty analysis for optical measurements will introduce a set of terms that are commonly mistaken for uncertainty and discuss the eight steps outlined in the Guide to the Expression of Uncertainty in Measurement. The remaining talks will focus on specific examples and elaborate on a specific topic within those examples.

Cameron Miller

Cameron Miller *is a research chemist with the National Institute of Standards and Technology in the United States. He obtained his PhD in Physical Chemistry from Cornell University (1994) studying unimolecular energy transfer using high resolution infrared optothermal spectroscopy. He joined NIST in 1996, to work in the fields of Photometry and Retroreflection and in 2003 was appointed the Photometry Project Leader. His research areas include all aspects of Photometry, Retroreflection, Measurement Uncertainty and Vision*

NIST WORKSHOP - Uncertainty budgets for integrated photometric measurements

Dr. Rolf Bergman *has been an independent consultant for the last ten years. In that capacity he assesses laboratories for NVLAP as well as being the round 12 proficiency test coordinator.*
Before starting his own business he had over twenty-eight years of experience with GE Lighting at Nela Park, Cleveland, OH. While at GE Lighting he was involved new product and process development, measurement capability and industry standards. His title for the last nine years at GE was Chief Scientist, Lamp Technology.
Dr. Bergman served as President of the CIE/USA National Committee from 2003 to 2008. He also serves as chair of CIE TC 6-47, the group that is producing a global standard for photobiological risk evaluation of lamps. He is as a member of the IESNA Testing Procedures and Photobiology Committees. Finally he had the honor of being the Frank Grum lecturer at the 2009 CORM meeting.

Dr. Bergman graduated with a Ph.D. in Electrical Engineering from the University of Minnesota in 1972. He received his undergraduate and Master of Arts degrees in Electrical Engineering from the U of Minnesota, respectively in 1966 and 1968, as well.
While at GE he was the author or co-author of 19 US Patents and published about 20 Journal articles with an additional 20 to 30 internal GE reports

NIST WORKHOP: Case study: Uncertainty analysis for NIST spectral irradiance measurements

Howard Yoon

Howard Yoon – NIST physicist involved in advancing spectroradiometry for improvements in fundamental and disseminated standards of spectral radiance, spectral irradiance, and radiance temperature. Activities include US Representative to the Consultative Committee on Thermometry and Member of IEC TC65/SC65B/WG5.

NIST WORKSHOP: Case study: Uncertainty analysis for NIST reflectance colorimetry measurements

Maria Nadal

Maria Nadal – NIST research chemist involved in spectrophotometric measurements in the Optical Technology Division at NIST. Her primary areas of research are color and appearance. She is involved in developing new calibration service and standard reference materials for surface color, specular gloss, and diffuse transmittance, as well as research in the goniochromatic attributes of special effect coatings.

NIST WORKSHOP: Case study: Uncertainty analysis for integrating goniometric measurements

Cameron Miller

***Cameron Miller** is a research chemist with the National Institute of Standards and Technology in the United States. He obtained his PhD in Physical Chemistry from Cornell University (1994) studying unimolecular energy transfer using high resolution infrared optothermal spectroscopy. He joined NIST in 1996, to work in the fields of Photometry and Retroreflection and in 2003 was appointed the Photometry Project Leader. His research areas include all aspects of Photometry, Retroreflection, Measurement Uncertainty and Vision*

A Practical method for realization of the CIE performance based mesopic photometry system

Tatsukiyo Uchida[1, 2], Yuqin Zong[2], Cameron Miller[2], and Yoshi Ohno[2]
[1]Panasonic Electric Works, Co., Ltd., Japan, and guest researcher of NIST
[2]National Institute of Standards and Technology, Gaithersburg, Maryland

Mesopic photometry is gaining high attention as it is the key for evaluation of the performance of LED street lighting luminaires or installations. CIE has just published a new technical report (CIE 191), which recommends a system of mesopic photometry. The mesopic photometry system uses a simple model composed of $V(\lambda)$ and $V'(\lambda)$ to define the mesopic spectral luminous efficiency function for easy implementation, and it is based on visual task performance such as detection, discrimination and reaction time. The new mesopic photometry system is expected to allow design of lighting systems optimized for both energy efficiency and sufficient task performance on road and street lighting.

To adopt the new CIE mesopic photometry system for lighting applications, it is critical to develop simple methods so that mesopic measurements can be done without much difficulty and high cost. Thus, a practical method for realization of the CIE mesopic photometry system is being developed at NIST. The method includes measurement of photopic and scotopic luminance on adaptation field to determine mesopic/photopic ratio (M/P ratio). The design of a prototype photometer will be discussed. The photometer is capable to measure mesopic quantities in real road and street scenes.

Tatsukiyo Uchida

Tatsukiyo Uchida *is an engineer at Lighting Research & Development Center in Panasonic Electric Works Co., Osaka, Japan. He has been working in the area of lighting applications for road lighting, interior lighting and agriculture since 1998. He currently works at National Institute of Standards and Technology (NIST) as a guest researcher since Nov. 2010. His research theme is practical measurement for mesopic photometry.*

Summary of NVLAP Round 12 Proficiency Test

NVLAP (National Voluntary Laboratory Accreditation Program) conducted round 12 of proficiency testing for the labs accredited for Energy Efficient Lighting (EEL) during 2008-10. Three different tests were available: 1) five-120V/60W A-line 'halogena,' 2) five-120V/13W Integral CFL and, 3) six 32W T-8 LFL (2 each in three different colors). Twenty-four labs participated in the incandescent test, 22 labs in the CFL test and 10 labs in the linear fluorescent test. To expedite testing time, the incandescent and CFL labs were divided into three groups, labeled A, B and C, with a fourth group, D, prepared for new labs that obtained accreditation after the round started. Only one group was used for LFL. Even so, completing the test took nearly 30 months, or twice as long as expected.

A central lab was assigned to measure all lamps of a given type before and after the test. NIST also participated by measuring all incandescent and LFL lamps after the test.

Summary graphs of the power, lumen output and lumen efficacy for each lamp type will be shown. The alignment between the various groups, A-D, was done using the central lab initial data. Lumen depreciation was taken into account in the CFL testing due to the long pre-burn time required before testing at each lab. The average data from each lab was compared to the initial central lab data as well as NIST. Also, a comparison of each lab to the grand mean of all labs was recorded. The presentation will conclude with a discussion of how well the industry can measure the power and lumen output of various lamp types using integrating sphere technology.

Dr. Rolf S. Bergman – PT coordinator

***Dr. Bergman** has been an independent consultant for the last ten years. In that capacity he assesses laboratories for NVLAP as well as being the round 12 proficiency test coordinator. Before starting his own business he had over twenty-eight years of experience with GE Lighting at Nela Park, Cleveland, OH. While at GE Lighting he was involved new product and process development, measurement capability and industry standards. His title for the last nine years at GE was Chief Scientist, Lamp Technology.*

Dr. Bergman served as President of the CIE/USA National Committee from 2003 to 2008. He also serves as chair of CIE TC 6-47, the group that is producing a global standard for photobiological risk evaluation of lamps. He is as a member of the IESNA Testing Procedures and Photobiology Committees. Finally he had the honor of being the Frank Grum lecturer at the 2009 CORM meeting.

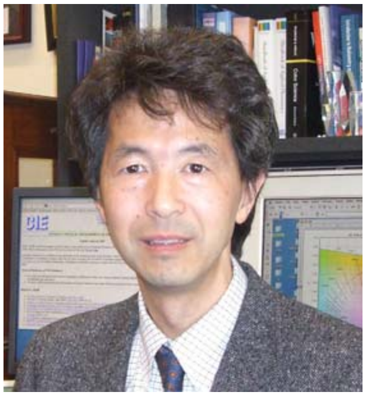
Dr. Bergman graduated with a Ph.D. in Electrical Engineering from the University of Minnesota in 1972. He received his undergraduate and Master of Arts degrees in Electrical Engineering from the U of Minnesota, respectively in 1966 and 1968, as well.

While at GE he was the author or co-author of 19 US Patents and published about 20 Journal articles with an additional 20 to 30 internal GE reports

Calculation of CCT and Duv and Practical Conversion Formulae

The correlated color temperature (CCT) and the signed distance from Planckian locus, Duv, can specify the chromaticity of white light sources in much more intuitive way than using chromaticity coordinates (*x, y*) or (*u'v'*). The concept of Duv existed for a long time, but it was officially defined first time by ANSI C78.377-2008 and used for specifying the range of acceptable chromaticity. CCT and Duv are now calculated for many solid state lighting products, but discrepancies in calculation results are occasionally reported. There have been no good references for calculation of CCT since 1968 (Robertson's paper). In this paper, a most accurate method for calculation of CCT and Duv is presented, which can work as the reference. The uncertainty of the developed program is less than 0.01 K in all range of CCT and Duv where CCT calculation is allowed. Then, the accuracies of other programs are evaluated by comparison with this reference program. Also, new formulae have been developed to calculate CCT and Duv from chromaticity (*x, y*) or (*u', v'*) by using one or two polynomials, with no need for a large table of values or Planck's equation. These may be useful to implement in portable instruments requiring only small memory space. Also, in some cases, the values of (CCT, Duv) need to be converted back to (*x, y*) or (*u',v'*). Such conversion formulae have also been developed. Some of these formulae will be included in the revision of ANSI C78.377.

Yoshi Ohno



***Yoshi Ohno** is the Group Leader for Optical Sensor Group, Optical Technology Division of NIST, and is also recently appointed as a NIST Fellow. His group maintains and disseminates national standards of the lumen, candela, and other photometric units and colorimetric scales. He received his Ph.D. in engineering from Kyoto University, Japan. He started his career at Panasonic Lighting Research Laboratory in Osaka Japan. He joined NIST in 1992. His research work spans from fundamentals to applications in photometry and colorimetry including color rendering and solid state lighting. He serves as the Director of CIE Division 2 and is Vice-President Technical Elect of CIE. He is a Fellow of IESNA, and is now very active in standardization activities for solid state lighting in ANSI, IESNA, and CIE, being the primary author of IES LM-79 and ANSI C78.377.*

Development of a 365 nm LED Source as a UV Transfer Standard

Currently high pressure mercury lamps are used as 365 nm ultraviolet (UV) sources in the US Army laboratories for material characterizations and sample inspections. The mercury lamps are susceptible to electric shock (due to high voltage operation) and mercury contamination. These bulky, hazardous mercury lamps require long stabilization time and have poor repeatability and reproducibility. Thus, a detector-based device must be used as the UV transfer standard. Due to unwanted additional spectral lines (other than the 365 nm line), a 365 nm narrow-band filter must be added in the detector-based transfer standard, which introduces additional errors from the filter transmittance and inter-reflection between the filter and the detector unless they are calibrated as a single device.

Solid-state high-power UV light-emitting diodes (LEDs) have been developed in recent years which may be used in many applications where mercury lamps are used traditionally. We have developed a compact 365 nm UV LED transfer standard source under a Calibration Coordination Group (CCG) Project. The prototype LED source is temperature-controlled which is stabilized within one minute and has a 24 h stability of less than 0.1 %. The prototype UV LED source were characterized for relative spectral power distribution, spatial uniformity of LED beam, irradiance level, and stability. Details will be presented and discussed.

Shen Zhu, US Army Primary Standard Laboratory, Redstone Arsenal, Alabama
Yuqin Zong, National Institute of Standards and Technology, Gaithersburg, Maryland

Fluorescence errors in integrating sphere measurements of remote phosphor type LED light sources

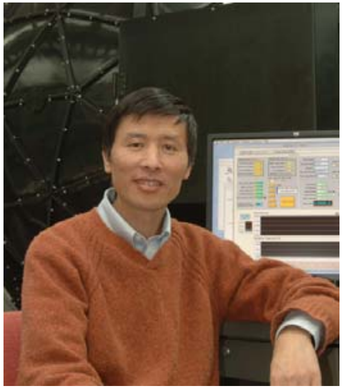
Integrating spheres (Ulbricht spheres) are the preferred instruments for determining light sources' (spectral) radiant or luminous flux, both at industrial and academic measurement facilities. Main reason is the instantaneous spatial integration compared to time consuming goniophotometer measurements. However, several sources reported significant luminous flux errors in integrating sphere measurements caused by fluorescence of phosphor type LED lamps. This error is typically observed in self-absorption measurements for relatively small integrating spheres, and is due to fluorescence of the phosphor excited by the emission from the calibration or auxiliary lamp. The self-absorption is not determined correctly as a result. A similar error occurs in the flux measurement of the phosphor type LED lamp due to excitation of the phosphor by the reflected radiant flux in the sphere. In both cases, the measured spectrum shows a lower blue component and a higher yellow component than the true flux spectrum. This relative spectral radiant flux error depends on the spectral power distribution of the light source and thus on the source type under test, e.g. calibration source, auxiliary source, or LED source. Therefore, straightforward calibration methods do not annihilate this effect and supplementary corrections have to be considered.

This work investigates the relative spectral radiant flux error caused by phosphor fluorescence during integrating sphere measurements both theoretically and experimentally. Integrating sphere and goniophotometer measurements are compared and used for model validation, while simulations provide additional clarification. Only remote phosphor type LED light sources are studied because of their large phosphor surfaces and high application potential in general lighting.

Arno Keppens - Author

Arno Keppens *graduated as a Master in Physics from Gent University (Belgium) in 2006. He has finished a PhD research project at the Light & Lighting Laboratory (Gent, Belgium) in 2010 on the modeling and evaluation of high-power light-emitting diodes for general lighting. This work has been performed while working as a postdoctoral Guest Researcher at the National Institute of Standards and Technology (NIST, Gaithersburg, MD, USA). Arno is currently a member of the Belgian Physical Society, the International Society for Optical Engineering (SPIE), and Technical Committee 2-63 (Measurement of LEDs) of the International Commission on Illumination (CIE).*

Yuqin Zong - Co-Author



Yuqin Zong *is an electronics engineer at the Optical Technology Division, Physics Laboratory, National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, USA. His job responsibility includes realization and maintenance of the NIST photometry and colorimetry scales and providing calibration services to the industry. Recently, his research has focused on the fields of stray-light correction for array spectrometers and imaging instruments, and the measurement of high-power LEDs and solid-state lighting (SSL) products. Yuqin Zong is the chairman of technical committee TC2-63 of the International Commission on Illumination (CIE) for the Optical Measurement of High-Power LEDs. He is also an active member of the Council for the Optical Radiation Measurements (CORM), the Illuminating Engineering Society of North America (IESNA), the Optical Society of America (OSA), and the Society of Photo-Optical Instrumentation Engineers (SPIE).*

TM-21 Update: Method for Projecting Lumen Maintenance of LEDs

The TM-21 Working Group has been working towards development of an LED lumen depreciation prediction method to be used by industry for providing some measure of consistency to life claims of LED products. The working group has completed a final draft that is now ready for IES approval and publication. This update provides a preview of what will likely be included in the final document and how that may affect future requests for application of the method.

***Eric Richman** is a senior research engineer at Pacific Northwest National Laboratories and has been working at the laboratory since 1986 working primarily in building energy efficiency and lighting technology application analysis. He is involved in several major lighting programs focusing on new technology energy efficiency, codes and standards, and control savings assessment. He is currently part of the DOE Solid State Lighting program working on the development of LED test methods and standards, performance program specifications, and field assessments of lighting applications including LED technologies and control effects. He is also the chairman of the ASHRAE/IESNA 90.1 Energy Standard Lighting Subcommittee and has been involved in the Standards development since 1995. He is He has authored over fifty reports and technical papers on lighting and building energy efficiency, received his B.S. in Mechanical Engineering from Washington State University, has held the LC lighting professional credential since 1997 and is LEED accredited.*

Real-time Passive Fluorescence Spectra of Induced Stress in Vegetation

Vegetation fluorescence has been studied for many years for the purposes of determining plant health, crop maturity, and damage from a wide range of sources. An example of the usefulness of this technique was presented when this author successfully demonstrated that the effects of ozone uptake in white pine could be observed previsually with fluorescence obtained with a laboratory instrument.

A new and unique fluorescence remote sensing instrument has been developed by PhytoPhotonics® for observing passive fluorescence spectra of materials in real time using the Sun as the illuminating source. For a preliminary, proof-of-concept study, the PolyChromatic© was used to obtain spectra of grass measured untreated, immediately after the application of an atomized oil, and then ninety minutes later. The oil in this form was used to represent a class of oils that might be deposited on vegetation deliberately (a solvent for herbicides), inadvertently (as overspray), or unsuspectingly (as leakage from an engine of some kind).

Blue and green emissions increased immediately after the oil application and the red emission peak increased and broadened. The 90 minute post application spectra show that the blue and green emissions are much greater, but the red emissions have decreased and narrowed drastically. These are indications of severe stress and photosynthetic shut down consistent with observations from previous studies.

While other investigators have used instruments that observe fluorescence changes in plants in the same spectral regions, the data are collected at discrete wavelengths, not as full spectra. The PolyChromatic analyzes many more wavelengths to generate the spectra than are used by the discrete wavelength instruments. Thus, more information related to known photosynthesis processes can be observed.

These data were spread out in time, but the PolyChromatic is fast enough that the full transition from one state to the next could have been acquired at intervals of 5 to 10 seconds. An added bonus of the PolyChromatic is that reflectance spectra for the same targets is also available for later analysis. Or, the display of these end products could be programmed into the instrument to suit an investigator's choice of reflectance algorithms with which they are most familiar. Both parameter s are derived from the same raw data.

Dr. Theisen *is no stranger to fluorescence. Over 15 years with the U.S.G.S., rising from electronics tech to Project Chief, he learned fluorescence measurements and applications from the inside out. Following that, Dr. Theisen completed a doctorate at the University of New Hampshire, studying plant physiology using fluorescence.*
Dr. Theisen studied plant stress as Principal Investigator, DOE at WDW/Epcot, beta tested an Aerodyne Research fluorescence instrument, and was an NRC appointee at NASA, Stennis. Dr. Theisen formed PhytoPhotonics to provide laboratory and field measurements and other services for companies including MITRE Corporation, SAIC, and Avian Technologies.

Review of Commercial Light Meter Calibration

This paper will discuss and review the current practice of commercial light meter calibrations. The pitfalls and inadequacies of the calibration processes will be discussed, and a target tolerance of calibration accuracy will be proposed.

***Dr. Lin** did his graduate work on infrared spectroscopy at University of Tennessee. He has designed and marketed CCD Grating Spectrometers, Fourier Transform Spectrometers, Fabry-Perot Spectrometers, Laser Line Markers, Laser Displacement Monitors, IES paint reflectance meters, Automotive Goniometers, Retro-reflector Measurement Systems, LM 77 Video-screen Lighting measurement systems and a Computer Video System to Measure Shot Angles of Basketballs. He has been the COO of Lighting Sciences Canada Ltd.*
since 1987. Lighting Sciences Canada Ltd. has been a key energy-efficiency testing laboratory for lighting products for Canada.

Dr. Lin is a member Of OSA, IES, CNC/CIE

Practical Lumen Maintenance Testing Using LM-80 - A discussion of Best Practices and Recent Standards Activity

LED lumen maintenance testing is widely performed using the techniques outlined in the IES LM-80 standard. While the standard provides a good overview of the testing to be performed, key best practices that are useful for effective lumen testing are omitted, particularly in the area of thermal management, data collection, and reporting. This paper discusses these practices and presents the current efforts of the IES subcommittee to capture this knowledge in a new revision of the LM-80 standard.

Jeff Hulett

***Jeff Hulett** is CTO of Vektrex. He has been active in the LED reliability field since 2004. Prior to that, he led teams that designed numerous computer-based products, including image processing systems, a space-qualified navigation computer for Japan's H2A rocket, graphics accelerators for India's air traffic control network, and high voltage programmable power sources for gene sequencing.*

He is the current chair of the LM-80 Working Group, part of IESNA. He has authored several publications including Measuring LED Junction Temperature, Photonics Spectra, July 2008. Mr. Hulett holds a BSEE from the Illinois Institute of Technology.

A closer look at photobiological safety measurements

The existing standards to assess the photobiological safety of bright light sources are currently under discussion. Especially with respect to the retinal blue light hazard, there are different views on what measurement conditions should be used to assess the risks involved. While the risks are dependent on viewer's distance, the measurements to classify the risks are done at a fixed distance and viewing angle prescribed by the standard. The presentation will make an analysis of the effects of choosing a certain measurement distance and viewing angle on risk classification. It will also be discussed in which way the risk classification of a bare light source can be transferred to the lighting fixture that contains this source.

Egbert Lenderink, Philips Lighting, Eindhoven, the Netherlands

Egbert Lenderink *received his Ph.D. degree in molecular spectroscopy at the University of Groningen, the Netherlands, in 1995. After that, he joined Philips, where he worked on different subjects in the field of optics. Since 2002, he has been active in concept and product development in LED lighting, expanding his scope from optics to all other aspects of product architecture, including product safety.*

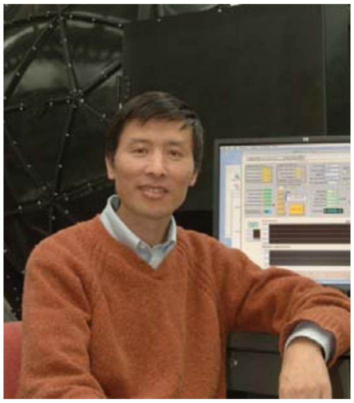
Simple silicon photodiode based femto-watt measurement system and its implication

Silicon photodiodes feature excellent linearity, low dark current, good long-term stability, and a wide spectral response, and are used in a wide range of applications in photometry, colorimetry, and UV radiometry. By using state of the art electronics silicon photodiodes can measure a femto watt level of optical power. However, such detectors are specially designed and built and are not commercially available.

We have developed a simple measurement system by using a silicon photodiode with a built-in thermoelectric cooler and a femto-ammeter, both of which are commercially available. The noise level of this system is one femto-ampere, the dark signal is several femto-amperes, and time constant is three seconds. The measurement system has excellent stability and is currently used for a double monochromator to measure extremely low level of light.

Because of the extremely low noise, femto-ampere detectors such as photometers, colorimeters, and UV radiometers can be calibrated directly for spectral irradiance/radiance responsivity by using a laser-based or even a double monochromator based uniform source (eg, an integrating sphere source); an implication that calibration procedure can be simplified and the calibration uncertainty will be reduced considerably compared to the existing indirect method by which the detector is first calibrated for spectral power responsivity and then is measured for spatial uniformity to obtain the spectral irradiance/radiance responsivity.

Yuqin Zong, National Institute of Standard and Technology, Gaithersburg, Maryland, USA



***Yuqin Zong** is an electronics engineer at the Optical Technology Division, Physics Laboratory, National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland, USA. His job responsibility includes realization and maintenance of the NIST photometry and colorimetry scales and providing calibration services to the industry. Recently, his research has focused on the fields of stray-light correction for array spectrometers and imaging instruments, and the measurement of high-power LEDs and solid-state lighting (SSL) products. Yuqin Zong is the chairman of technical committee TC2-63 of the International Commission on Illumination (CIE) for the Optical Measurement of High-Power LEDs. He is also an active member of the Council for the Optical Radiation Measurements (CORM), the Illuminating Engineering Society of North America (IESNA), the Optical Society of America (OSA), and the Society of Photo-Optical Instrumentation Engineers (SPIE).*

Absolute determination of the quantum efficiency phosphor powders

With the introduction of solid state lighting, blue excitation phosphors are widely used to create qualitative white light. One of the most important properties of a phosphor is the quantum efficiency (QE). It is defined as the ratio of the number of emitted photons to the number of absorbed photons (Eq. 1):

$$QE = \frac{\#\,\text{emitted photons}}{\#\,\text{absorbed photons}} \quad (1)$$

Wrighton et al. [1] described an absolute measurement procedure for phosphor powders based on reflectance spectra. A relative measurement procedure was proposed by Bril et al. [2] comparing reflectance spectra of a sample and a reference phosphor. With this procedure, reliable results can only be expected when sample and reference have identical properties, such as excitation wavelength and absorption cross-section. In this paper, a direct absolute method to obtain QE of phosphor powders is described.

The measurement system presented here is similar to the one described by de Mello et al. for the determination of the efficiency of fluorescent films [3]. The setup consists of an excitation source, an integrating sphere with sample holder, a spectrometer with CCD which is connected to the sphere with an optical fibre, and a PC (Fig. 1). A Xe light source in combination with an interference filter is used as excitation source. The relative spectral response of the detection unit is determined by removing the interference filter and measuring the response of the calibrated Xe source.

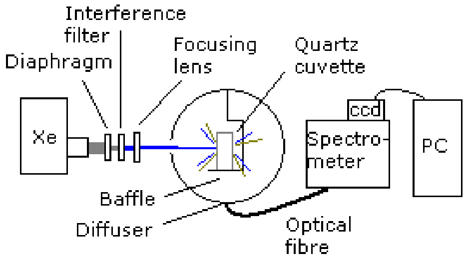


Fig. 1: Schematic representation of the measurement setup with an integrating sphere

The phosphor powder is put in a quartz cuvette which is positioned in the centre of the sphere. The quartz cuvette has diffuse windows to scatter the incident beam. In this way, the optical path of the excitation beam and of the fluorescent emission is similar (diffuse scattering and emission from the centre of the sphere), which is a condition for performing accurate integrating sphere measurements.

First, an empty quartz cuvette is positioned in the centre of the sphere. A second measurement is done after the phosphor has been put in the quartz cuvette. An arbitrary but small quantity of phosphor powder is used, resulting in a negligible substitution error. From both measurements, the QE of the phosphor can be calculated.

The influence of the amount of phosphor seemed to be not critical as long as the absorption didn't drop below 20%, which allows for an easy sample preparation.

The setup was verified for three commercial phosphors. For BaMgAl10O17:Eu2+ and BaAl12O19:Mn2+ the experimental (0.95 and 0.85 respectively) and specified values (0.96 and 0.83 respectively) of the QE were in good agreement. For Y3Al5O12:Ce3+ a large discrepancy between experimental (0.75) and specified value (0.93) was found. This may be caused by the small stokes shift of this phosphor, resulting in self-absorption within the powder. This needs further investigation.

[1] M. Wrighton, D. Ginley, D. Morse, J. Phys. Chem. 78 (1974) 2229.
[2] A. Bril, A.W. de Jager-Veenis, J. Electrochem. Soc., 123 (1976) 396.
[3] J.C. de Mello, H.F. Wittmann, R.H. Friend, Adv. Mater., 9 (1997) 230.

S. Leyre, A. Keppens and P. Hanselaer

Sven Leyre *was born in Veurne, Belgium, in 1984. In 2005, he received a Bachelor degree in Management and in 2009 a Master degree in Electronic Engineering. Afterwards, he joined the Light & Lighting Laboratory from the Catholic University College Ghent and investigated the quantum efficiency of fluorescent materials and their implementation in remote phosphor leds. This year, he started his PhD research entitled "Characterization and modeling of fluorescent materials for opto-electrical devices" (promoter: Peter Hanselaer).*

Results of a Nationwide Intercomparison of Infrared Spectral Reflectance Capabilities

A nationwide intercomparison of infrared spectral reflectance has been completed. 20 participants in the United States and one in Canada, representing government agencies and contractors, equipment manufacturers, measurement service laboratories, and standards laboratories, each completed measurements of individual sets of 5 different transfer standard samples: both specular and diffuse types, high and low reflectance, as well as with spectral structure. Near-normal spectral reflectance, over the infrared spectral range of approximately 2.5 µm to 14 µm, is the measured quantity. NIST prepared, measured and delivered a set of transfer standard samples to each participant. After measurements by the participants, the sets were returned to NIST for repeated measurement, as a check against any change due to contamination, shipping damage, or other sample degradation. Results from each participant, which included measured values and uncertainties, were analyzed and compared to the NIST measurements. As might be expected, the level of agreement, relative to the combined uncertainties varied among the participants. In some cases, the results indicated a significant underestimation of the participant uncertainties, whereas in one case, the opposite was also discovered. An overview of the results and a discussion of their implications will be presented.

Boris Wiltham

A high-power, tunable, supercontinuum-based VIS-SWIR light source for the STARR II gonioreflectometer

Authors: Heather J. Patrick (presenter) and Clarence J. Zarobila, NIST

Abstract:

The Optical Technology Division of NIST provides reference measurements of specular and diffuse reflectance of materials, including measurements that provide traceability for diffuser plaques that are used as onboard calibration standards in remote sensing. The STARR II project aims to expand our measurement capabilities to include increased spectral coverage into the short-wave infrared (SWIR) spectral region, out-of-plane gonioreflectance to replicate customer measurement geometries over a wide range of polar and azimuthal incident and scatter angles, and improved accuracy and speed of measurement. As part of this project, we have acquired a high-power, broadband supercontinuum fiber laser light source operating from 450 nm to 2500 nm, and have coupled it to a tunable monochromator to provide illumination for VIS-SWIR gonioreflectance measurements. This source provides a significant improvement in optical power density at the specimen over that of lamp-based sources, and is expected to result in much-improved signal levels and angular capabilities for STARR II. In this talk, I will give an overview of the planned STARR II gonioreflectometer, and present modeled and measured results for the new light source and its predicted impact on gonioreflectance measurement capabilities.

Dr. Heather Patrick is a physicist in the Optical Technology Division of NIST. Her research interests focus on applications of non-imaging optical measurements, including scattering, reflectance/transmittance, and ellipsometry, to the characterization and metrology of materials. Current projects include the expansion of NIST's facilities for UV-SWIR spectrally-resolved bidirectional reflectance distribution function (BRDF) measurements of specular and diffuse materials , and the application of grating-based scatterometry to optical metrology of patterned nanoscale materials.

Integrating sphere superposition technique for quantifying the linearity of InGaAs detectors.

Author: Angelo Arecchi, Labsphere, Inc.

This presentation reports on the linearity characterization of InGaAs detectors.

In an irradiance source for ground calibration of the focal plane array for a satellite camera, four separate InGaAs detectors were employed. Three filtered detectors monitored the source in three SWIR bands and were installed as integral parts of the source. A fourth InGaAs detector was used to transfer the irradiance calibration from an FEL to the three monitor detectors. All four detectors were checked for linearity over the range of their use in the system. A superposition technique was used, employing an integrating sphere with two shuttered light sources. Compensations were made for substitution error associated with the shutters and stray light from outside the integration sphere.

The three monitoring detectors were verified to be linear over their applicable ranges. The calibrating detector was highly nonlinear over its dynamic range, which extended from being illuminated by an FEL at the high end to being illuminated by the irradiance source at the low end. Rather than filter the detector to shift its dynamic range down into a more linear region, the nonlinearity was quantified. The quantified nonlinearity correction was used in the final calibration of the system.

This presentation describes the technique and displays the results.

Angelo Arecchi is the Manager of Special Projects at Labsphere. He was previously the Director of Systems Engineering at SphereOptics and the VP of Engineering at Labsphere. He was on the faculty of the U.S. Coast Guard Academy for several years and is now an adjunct faculty member at Plymouth State University and at The University of New Hampshire at Manchester. Angelo holds an MS degree in Optics from the University of Rochester, an MBA from Plymouth State University, and is a registered Professional Engineer. He is the principal author of the SPIE Field Guide to Illumination. Angelo is a member of the SPIE, OSA, IESNA, and CORM.

Laboratory versus Production SSL Metrology: Lessons and Questions from CALiPER

The DOE CALiPER program acquires market-available SSL products and submits them to qualified, independent lighting testing laboratories for LM-79 testing. Additional types of photometric testing, primarily using spot illuminance measurements are also used in some CALiPER studies. Before publication to a wider public, CALiPER test results are shared with manufacturers, who in many cases appear to be surprised by the CALiPER LM-79 test results. Communications and explanations from SSL manufacturers highlight a number of potential pitfalls and challenges between laboratory and production metrology. This overview will summarize key potential challenges and discrepancies between laboratory and production measurements of SSL products apparent from the past few years of CALiPER testing.

Mia Paget - Author

Mia Paget's *primary areas of expertise are in energy policy and mechanical engineering. She has managed the DOE's Solid State Lighting Commercially Available LED Product Evaluation and Reporting Program (CALiPER) since its inception in 2006, working closely with several stakeholder groups within the lighting industry, from luminaire manufacturers to lighting testing laboratories to standards committees. Ms. Paget also applies her expertise toward the research and development of "smart grid" solutions for the current and future energy grid and in human factors and situational awareness in power grid control systems in the US and internationally.*

Mia Paget's educational background is in Mechanical Engineering and Technology and Policy at the Massachusetts Institute of Technology, where she earned both bachelor's and master's degrees and gained expertise in measurement instrumentation, information technology, energy policy, and electric power systems.

Eric Richman - Presenter

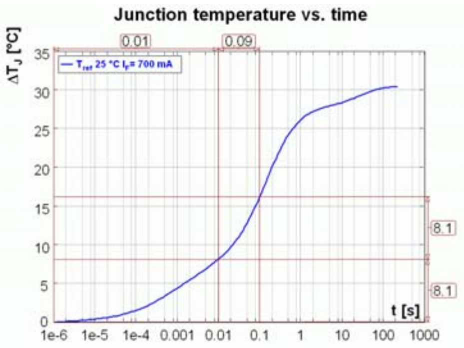
Eric Richman *is a senior research engineer at Pacific Northwest National Laboratories and has been working at the laboratory since 1986 working primarily in building energy efficiency and lighting technology application analysis. He is involved in several major lighting programs focusing on new technology energy efficiency, codes and standards, and control savings assessment. He is currently part of the DOE Solid State Lighting program working on the development of LED test methods and standards, performance program specifications, and field assessments of lighting applications including LED technologies and control effects. He is also the chairman of the ASHRAE/IESNA 90.1 Energy Standard Lighting Subcommittee and has been involved in the Standards development since 1995. He is He has authored over fifty reports and technical papers on lighting and building energy efficiency, received his B.S. in Mechanical Engineering from Washington State University, has held the LC lighting professional credential since 1997 and is LEED accredited.*

Thermal issues in relation to metrics reported on LED data sheets

Andras Poppe

LED performance is strongly influenced by the junction temperature. That is, LEDs' dissipation, the package thermal resistance (or impedance) and thermal environment (including ambient temperature and actual cooling conditions) are key parameters from the point of view of LED operation both at end-users in the field and during laboratory and production testing. Unfortunately LED data sheets usually do not provide sufficient information about the thermal conditions under which luminous/radiant flux, efficacy/efficiency, chromaticity and/or correlated color temperature are measured. In production testing 25oC ambient temperature is assumed and it is believed that during a short nominal forward current pulse of a length of about 10..100 ms the junction temperature does not change significantly. But this assumption is not true.

In recent years thermal transient measurement results (obtained by test equipment realizing the JEDEC JESD51-1 static test method completed with a real-time junction temperature recording between the hot and cold steady-states of the semiconductor PN junction being measured) prove, that in case of state-of-the art power LEDs ~10oC .. 15oC junction temperature change may take place in 10ms/100ms period immediately after switching the current on (see Fig. 1).



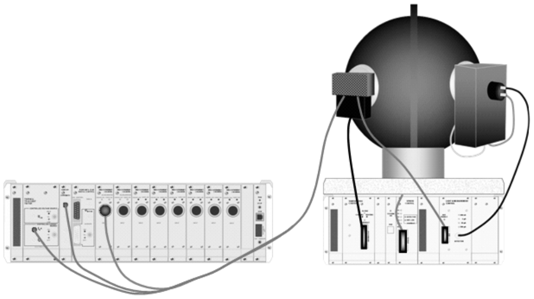


Fig.1: Junction temperature elevation in a white LED when 700mA forward current is applied. In after 10ms/100ms 8.1oC / 16.2oC of junction temperature elevation takes place.	Fig. 2: Combined thermal and radiometric/photometric test setup aimed at the measurement of power LEDs [1], compliant to the JEDEC JESD51-1 and CIE 127-2007 recommendations.

If the above mentioned thermal measurements are combined with a CIE 127-2007 compliant test system where the test LEDs are mounted on a temperature controlled holder (Fig. 2), temperature dependence of the light output properties can be identified (see Fig. 3) .

According to our measurements the temperature sensitivity of luminous flux of the particular LED is about 2.22 lm/oC (Fig. 3). This means that the total drop of the luminous flux is by about 68 lm less in the hot thermal steady-state of the LED than in case of the cold junction.

Unfortunately this temperature dependence is not specified by vendors and there is also uncertainty about the temperature reported on product data sheet. In case of the thermal resistance reported by data sheet the radiant flux is usually not considered in calculations, the measured junction temperature rise is simply divided by the supplied electrical power [2], [3], resulting in data often misleading end users.

In case of AC driven LEDs data sheets report a single *thermal resistance* value, though the absolute value of the *thermal impedance* measured at a specified frequency would be the appropriate quantity to report. One has to be aware of the fact that this value drops with increasing frequency, thus, for LED products operated in a 50Hz supply grid this value is higher than in a 60Hz system. Furthermore, there is no widely accepted definition what one would call *AC thermal impedance* of LEDs and there exist no definition either, how exactly this quantity has to be measured [4].

Thermal resistance changes of TIMs applied between the MCPCB of an LED assembly and its heat-sink should also be cared about. On one hand, conventional thermal grease may have temperature dependence. We observed reduction of the thermal resistance with increasing heat-sink temperature [5]. On the other hand, TIMs may show significant degradation which for example need to be considered in LM-80 tests. Our recent thermal transient measurements and subsequent so called structure function analysis during LM-80 tests of LED assemblies prove that measured light output degradation is partially due to ageing of the thermal interface material applied between the MCPCB of the LED assembly and the temperature controlled heat-sink of the test chamber [1], [6]. This aging manifest's in an increase of the total junction-to-ambient thermal resistance of the LED product tested, contributing to the light output drop of the LED being tested (see Fig. 4).

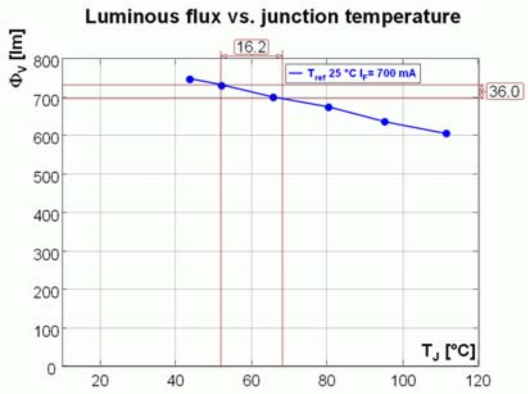


Fig.3: Junction temperature dependence of the luminous flux of the measured white LED.

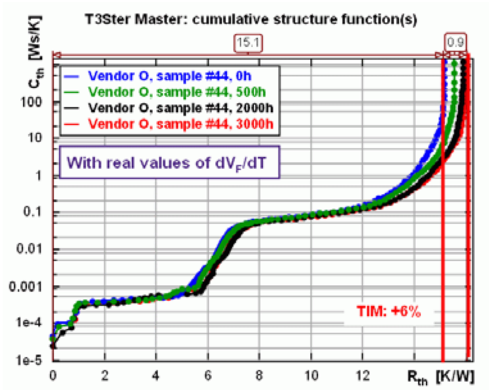


Fig.4: Structure functions (thermal resistance / thermal capacitance maps) of the junction-to-heatsink heat-flow path an MCPCB assembled LED , recorded during LM-80 tests of the product.

The presentation aims to provide details on these issues along with the description of the test equipment / procedures being used during the measurements. Some of these test procedures are being dealt with in the JC15 committee of JEDEC dealing with the development of thermal testing standards of packaged semiconductor devices.

Optical Sensors for Semiconductor Process Control

John D. Corless, Ph.D.
Verity Instruments, Inc.

Optical instrumentation plays an important role in the manufacturing of modern semiconductor devices. When these optical sensors are integrated onto a process chamber they can allow real time data about the process and the wafer, information which ultimately can be used to improve yield. However, instability and drift in the sensor environment present unique technical challenges, while at the same time the evolution towards tighter specifications on the semiconductor devices places tighter performance specifications on the sensors. The UV/Vis spectrograph is a key element for important process control applications such as etch (optical emission spectroscopy), film thickness during planarization or deposition (spectral reflectometry), and fundamental material properties (reflectometry and photoluminescence). I will discuss specific calibration requirements for spectrographs integrated onto current semiconductor process tools and describe some of the specific calibration techniques that we have implemented for these applications.

John D. Corless holds an M.S. ('92) and Ph.D. ('97) in Optics from the University of Rochester's Institute of Optics, where his dissertation was in the area of laser engineering and quantum optics. He has worked in engineering and R&D management at OCLI/JDSU (Santa Rosa, CA) and Forth Dimension Displays (Dalgety Bay, Scotland). He is currently Director of R&D at Verity Instruments, Inc. (Carrollton, TX) where he works on development of new optical sensors for semiconductor process control applications.

CALiPER Deep Dive Long-Term Testing—Correlation from SSL Device Performance to End Product

Using funding from the American Recovery and Reinvestment Act, the U.S. Department of Energy Commercially Available LED Product Evaluation and Reporting (CALiPER) program is obtaining concrete data to examine, illustrate and help stakeholders understand correlations between LED device performance and ultimate performance in an integral luminaire or replacement lamp. Replacement lamp samples using three different types of LED devices and fitted with thermocouples to enable measurement of LED junction temperatures are being operated and tested under three different temperature conditions over the course of 8000 hours. This presentation will provide an update on this on-going testing, highlighting initial results and challenges revealed through the testing configuration. Ultimately, curves characterizing the temperature-dependent and long-term performance of the LED devices will be used to estimate the expected performance in the replacement lamps at different operating temperatures over time. These estimates will be compared to the measured performance of the SSL replacement lamps to provide concrete information for current SSL standards efforts.

Mia Paget - Author

Mia Paget's *primary areas of expertise are in energy policy and mechanical engineering. She has managed the DOE's Solid State Lighting Commercially Available LED Product Evaluation and Reporting Program (CALiPER) since its inception in 2006, working closely with several stakeholder groups within the lighting industry, from luminaire manufacturers to lighting testing laboratories to standards committees. Ms. Paget also applies her expertise toward the research and development of "smart grid" solutions for the current and future energy grid and in human factors and situational awareness in power grid control systems in the US and internationally.*

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