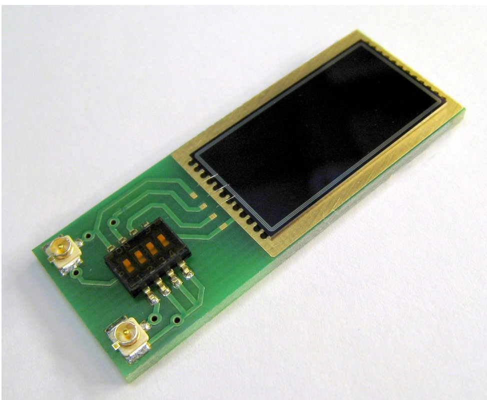
Department of Signal Processing and Acoustics
Metrology Research Institute

BIENNIAL REPORT 2011–2012



Aalto University

SCIENCE + TECHNOLOGY

ANNUAL REPORT

Metrology Research Institute BIENNIAL REPORT 2011–2012 Aalto University

Aalto University publication series
SCIENCE + TECHNOLOGY 13/2013

BIENNIAL REPORT 2011–2012

Editors: Ulla Sikander, Tuomas Poikonen

Aalto University
School of Electrical Engineering
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Graphic design: An induced junction photodiode developed for the predictable quantum efficient detector (PQED).

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CONTENTS

1 INTRODUCTION

The close collaboration between the Metrology Research Institute of Aalto University and the Centre for Metrology and Accreditation (MIKES) has developed during 2011–2012 to an even closer co-operation. Doctoral students with fixed term contracts now routinely move between the two legal organizations and there are also a number of joint senior researcher posts. This new level of co-operation became necessary because of the large fraction of own funding in European Metrology Research Program (EMRP) projects required from Aalto University as Designated Institute in photometry and radiometry. As a consequence, significant EMRP project volume with associated personnel was moved from Aalto to MIKES in 2012, and all new EMRP projects in photometry and radiometry are now started with MIKES as the partner.

Although there appeared surprising problems in carrying out EMRP projects at the Aalto University, the Metrology Research Institute has also significant advantages due to operation in the University environment. One of those advantages is contact to excellent students who typically start working in the research projects as summer trainees and sometimes continue until the doctor's degree. Another advantage is that the Energy Efficiency Research Programs at the Aalto University match very well with the expertise and research base of the Institute offering welcome resources and collaboration within the University.

The Metrology Research Institute provides teaching within the Aalto University and it operates under the Finnish name MIKES-Aalto Mittaustekniikka as the Finnish national standards laboratory for optical quantities. Two doctoral degrees and four M.Sc. degrees were achieved in 2011–2012. The number of degrees is significantly less than that for the period 2009–2010, partly caused by the time-consuming processes of re-organizing the operational environment of the Institute. The number of calibration certificates issued in 2011–2012 is 107, which is about the same number as for the period 2009–2010.

The Metrology Research Institute has active international collaboration with world leading research units in the field of optical radiation measurements. Altogether ten EMRP projects, where the Institute participates, are listed on the following page and some additional research contributions are described in more detail in Sec. 5 of this biennial report. In 2011–2012, the first EMRP project became completed, where the Institute developed the Predictable Quantum Efficient Detector (PQED). The PQED is a compact silicon detector standard of optical power, which offers at room temperature similar measurement uncertainties as could earlier be obtained only with voluminous cryogenic radiometers operated close to 10 K temperatures.

Erkki Ikonen

European Metrology Research Program projects where the Metrology Research Institute participates

Candela: Towards Quantum-Based Photon Standards (2008–2011)

Metrology for Solid State Lighting (2010–2013)

Metrology for Earth Observation and Climate (2011–2014)

Traceability for Surface Spectral Solar Ultraviolet Radiation (2011–2014)

Metrology for Industrial Quantum Communication Technologies (2011–2014)

Metrology for the Manufacturing of Thin Films (2011–2014)

Metrology of Electro-Thermal Coupling for New Functional Materials Technology (2012–2015)

Multidimensional Reflectometry for Industry (2013–2016)

Single-Photon Sources for Quantum Technologies (2013–2016)

New Primary Standards and Traceability for Radiometry (2013–2016)

2 PERSONNEL

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Jokela, Kari	STUK, Radiation and Nuclear Safety Authority
Kalliomäki, Kalevi	Centre for Metrology and Accreditation
Kauppinen, Jyrki	University of Turku
Ludvigsen, Hanne	Aalto University
Häkkinen, Esa	Helsinki Institute of Technology

3 TEACHING

3.1 Degrees

3.1.1 Doctor of Science (Technology), D.Sc. (Tech.)

Tuomas Hieta (2011), *Applied Diode Laser Spectroscopy and Characterization of Optical Fiber Nonlinearity*, Opponents: Prof. Frans J.M. Harren, Radboud University Nijmegen, The Netherlands and Dr. Jan C. Petersen, Danish Fundamental Metrology, Denmark.

Tuomas Poikonen (2012), *Characterization of Light Emitting Diodes and Photometer Quality Factors*, Opponent: Dr. Armin Sperling, Physikalisch-Technische Bundesanstalt, Germany.

3.1.2 Master of Science (Technology), M.Sc. (Tech.)

Jukka Kallio (2011), *Optisella takaisinkytkennällä stabiloidun laserin käyttö pilvenkorkeusmittauksissa (in Finnish)*, guided by Atte Salmi.

Timo Dönsberg (2012), *Improved Reference Infrared Spectrometer*, guided by Farshid Manoocheri.

Tomi Pulli (2012), *Improved Diffusers for Solar UV Spectroradiometers*, guided by Petri Kärhä.

Ossi Likander (2012), *Piirikorttien tehonkulutuksen mittausmenetelmät (in Finnish)*, guided by Petri Kärhä and Olli Kivimäki.

3.2 Bachelor of Science (B.Sc.) Theses

In the earlier biennial report 2009–2010, only the B.Sc. degrees were recorded. Beginning from this biennial report, all B.Sc. theses completed in the laboratory are listed.

Esko Lehtomäki (2009), *Spektroradiometrin epälineaarisuuden mittaaminen*, guided by Pasi Manninen.

Sami Oila (2009), *Ultraviolettiloistediodeihin perustuvan fluoresenssiheräte-lähteen suunnittelu*, guided by Pasi Manninen.

Janne Sorsanen (2009), *Teollisuuden mittaustiedon siirtojärjestelmät*, guided by Petri Kärhä.

Tuomas Tikka (2009), *Lentoyhtiön luotettavuusohjelman hälytysilmoituksen käytännön toteutus*, guided by Pasi Manninen.

Teemu Jaakkola (2011), *Liitäntäelektroniikka kuituoptiselle gyroskoopille*, guided by Petri Kärhä.

Jukka Kallio (2011), *Pilvenkorkeusmittarin lähetys- ja vastaanottolinssin suunnittelu*, guided by Erkki Ikonen.

Teemu Kääriäinen (2011), *Säteilylähteet keski-infrapuna-alueelle*, guided by Maksim Shpak.

Jarno Luoma (2011), *Resonanssikammioloistediodi*, guided by Juha-Matti Hirvonen.

Henry Lähteenmäki (2011), *Infrapunatermografia vaiheistetun ultraäänitarkastuksen apuna lasikuitulujitetun muovin NDT-tarkastuksessa*, guided by Juha-Matti Hirvonen.

Toni Parvela (2011), *Sähköiset lämpötila-anturit*, guided by Hans Baumgartner.

Mikko Teittinen (2011), *Integroidut anturit*, guided by Petri Kärhä.

Jalmari Toivanen (2011), *CCD-kennon pikseliherkkyyksien määrittäminen goniofluorometrisessä mittausjärjestelmässä*, guided by Tuomas Poikonen.

Anna Vaskuri (2011), *Energiansäästölamppujen sähköiset karakterisoinnit*, guided by Tuomas Poikonen.

Patrik Fagerholm (2012), *Laitteisto energiansäästölamppujen ikäännyttämiseen*, guided by Timo Dönsberg.

Teemu Koskinen (2012), *Elektronimikroskooppi JSM-840 – Rakenne ja käyttö,* guided by Hans Baumgartner.

Sari Lakkonen (2012), *Etanoli-vesiliuoksen etanolipitoisuuden määrittäminen optisesti*, guided by Toni Laurila.

Mikko Linnamaa (2012), *Integroidut anturiverkot*, guided by Petri Kärhä.

Toni Malinen (2012), *Orgaaniset loistediodit - valmistus, käyttö ja ominaisuudet*, guided by Tuomas Poikonen.

3.3 Courses

The following courses were offered by the Metrology Research Institute in 2011–2012. Those marked by * are given biennially.

S-108.1010	Fundamentals of Measurements A, 4 p (Petri Kärhä, Maija Ojanen)
S-108.1020	Fundamentals of Measurements Y, 3 p (Petri Kärhä, Maija Ojanen)
S-108.2010	Electronic Measurements, 3 p (Petri Kärhä)
S-108.2110	Optics, 5 p (Toni Laurila, Pasi Manninen)
S-108.3011	Sensors and Measurement Methods, 5 p (Maksim Shpak)
S-108.3020	Electromagnetic Compatibility, 2 p (Esa Häkkinen)
S-108.3030	Virtual Instrumentation, 5 p (Farshid Manoocheri, Juha-Matti Hirvonen)
S-108.3110	Optical Communications, 5 p* (Farshid Manoocheri)
S-108.3120	Project work, 2–8 p (Erkki Ikonen, Juha-Matti Hirvonen)

S-108.3130	Project Work in Measurement Science and Technology, 2–10 p (Erkki Ikonen, Juha-Matti Hirvonen)
S-108.3140	Project Work in Optical Technology, 2–10 p (Erkki Ikonen, Juha-Matti Hirvonen)
S-108.4010	Postgraduate Course in Measurement Technology, 10 p* (Petri Kärhä)
S-108.4020	Research Seminar on Measurement Science, 2 p (Erkki Ikonen)
S-108.4110	Biological Effects and Measurements of Electromagnetic Fields and Optical Radiation, 4 p* (Kari Jokela)

4 NATIONAL STANDARDS LABORATORY

Metrology Research Institute is the Finnish national standards laboratory for the measurements of optical quantities, as appointed by the Centre for Metrology and Accreditation (MIKES) in 1996.

The institute gives official calibration certificates on various optical quantities in the fields of Photometry, Radiometry, Spectrophotometry and Fiber Optics. During 2011, 46 calibration certificates were issued. In 2012, the number of calibration certificates was 61. The calibration services are mainly used by the Finnish industry and various research organizations. There are three accredited calibration laboratories in the field of optical quantities.

The Institute offers also other measurement services and consultation in the field of measurement technology. Various memberships in international organizations ensure that the laboratory can also influence e.g. international standardization so that it takes into account the national needs.

The Metrology Research Institute performs its calibration measurements under a quality system approved by MIKES. The quality system is based on ISO/IEC 17025.

Further information on the offered calibration services can be obtained from the web-pages of the laboratory (http://metrology.tkk.fi/). Especially the following sub-pages might be useful:

Maintained quantities: http://metrology.tkk.fi/cgi-bin/index.cgi?calibration

Price list for regular services: http://metrology.tkk.fi/files/pricelist.pdf

Quality system: http://metrology.tkk.fi/quality/

Additional information may also be asked from Farshid Manoocheri (Head of Calibration Services) or Petri Kärhä (Quality Manager):

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Petri.Karha (at) aalto.fi, Tel. +358 50 596 8469

5 RESEARCH PROJECTS

5.1 Electrical Instrumentation

Temperature controller for high-power LEDs

A custom temperature-controlled heatsink was built for controlling the temperature of high-power LEDs (Figure 1). The temperature of the heatsink can be increased using high-power resistors, whereas the cooling of the heatsink is obtained by Glycol-based water cooling system with an electronic valve controller. A commercial thermoelectric cooler controller (TEC) is used for controlling the heating of the resistors and the flow of the water cooling system. The system is able to control the heatsink temperature between -4 °C and 110 °C with stability of ± 0.15 °C. The system was utilized in an EMRP project for characterization of LEDs at different operating temperatures in order to determine a physical model for the spectral power distribution of LEDs with different junction temperatures.

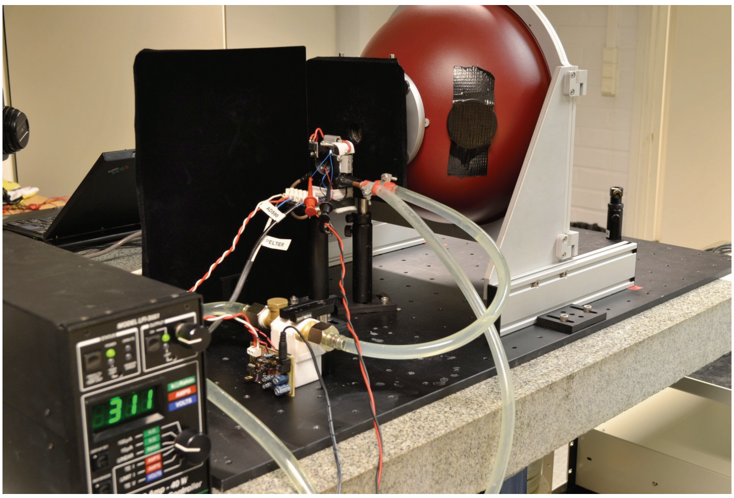

Figure 1. Temperature stabilized heatsink for measurements of high-power LEDs.

Electrical power characterization of energy-saving lamps

Measurement of the electrical power consumption has a large contribution to the uncertainty of luminous efficacy (lm/W) measurement of energy-saving lamps, such as LED lamps. These lamps use small built-in electronics for the AC/DC-conversion. The stability and the amount of total harmonic distortion (THD) of the lamp are heavily dependent on the topology and the quality of the parts used in the power converter. For determining the uncertainty of electrical power measurements, the waveforms of the voltage and the current need to be measured. For this purpose, a measurement amplifier (Figure 2) was designed and constructed.

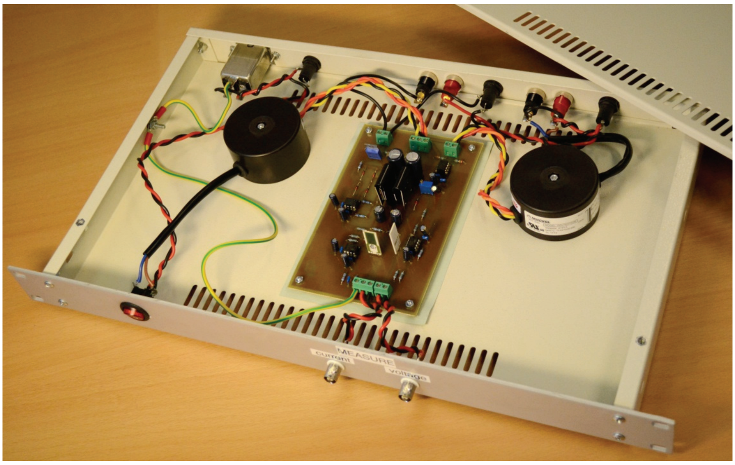

Figure 2. Constructed measurement amplifier for electrical power measurements.

The current measurement is based on an instrumentation amplifier and a low-side shunt-resistor. The voltage is measured using a transformer and an instrumentation amplifier. The parts of the current measurement circuitry were optimized for frequencies up to 1 MHz. All circuits were over-voltage protected. The amplifier outputs the current and voltage waveforms using standard 50 Ω BNC-connectors. A high-speed digital storage oscilloscope is used for recording the waveforms for analysis. Test measurements conducted for a group of 25 LED lamps showed large differences in the quality of built-in lamp electronics. The THDs were between 30 % and 280 %, while the power factors were in the range of 0.35–0.95. Lamps with THD above 200 % and power factor below 0.4 were found to be problematic in the measurements, causing temporal variations of 0.5–1.0 % in the measured electrical power.

High speed transconductance amplifier for LED-pulsing

A high speed transconductance amplifier was designed and built for pulsing of LEDs at high frequencies. The amplifier features selectable transconductance between 100 µS to 10 S allowing accurate operation from microamperes to peak and RMS currents up to 20 A and 1.5 A, respectively. As part of the design, various amplifier topologies were modeled and tested to achieve the desired high speed operation. The chosen circuitry consists of fast high power MOSFET connected as a common drain amplifier that is driven by high speed current-feedback amplifier. Low inductance shunt-resistors are used in the current loop providing feedback for the video amplifier. The wide range of gains with high accuracy is achieved using high frequency relays to change the shunt resistors. The performance of the device was confirmed for frequencies up to 30 MHz and pulses down to 100 ns (Figure 3). Despite optimized for high frequency operation, the device is also suitable for low frequency and DC-operation.

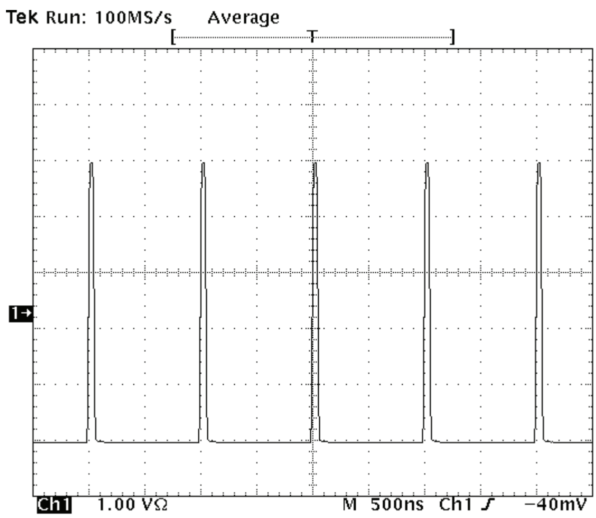

Figure 3. Current pulses (500 mA and 100 ns) generated using the developed amplifier.

Switched aging setup for solid state lamps

A device was designed and constructed for long term electrical power cycling of solid state lamps to study their lifetime under varying power switching conditions. The device has four independent output channels, each capable of switching a load of 230 W to the electrical network (Figure 4). Due to the limited life expectancy of standard relays, the design utilizes optocoupled Solid State Relays (SSRs). Instead of a typical thyristor-based SSR, SSRs based on Insulated Gate Bipolar Transistors (IGBT) were used, since their switching characteristics are closer to a normal mechanical switch. The on and off time within each power cycle can be set from a few milliseconds up to 50 days. The switching pattern is typically regular, but also arbitrary switching patterns can be programmed. The microcontroller-based timing circuitry of the device is operated via USB, but the device is also capable of standalone operation. The device can measure the phase of the line voltage and enables switching at a specific phase angle. Therefore, the possible advantages and disadvantages of switching at the peak or zero cross point of the mains voltage can be studied. In order to mimic the typical power cycling of lamps, random phase switching is also possible.

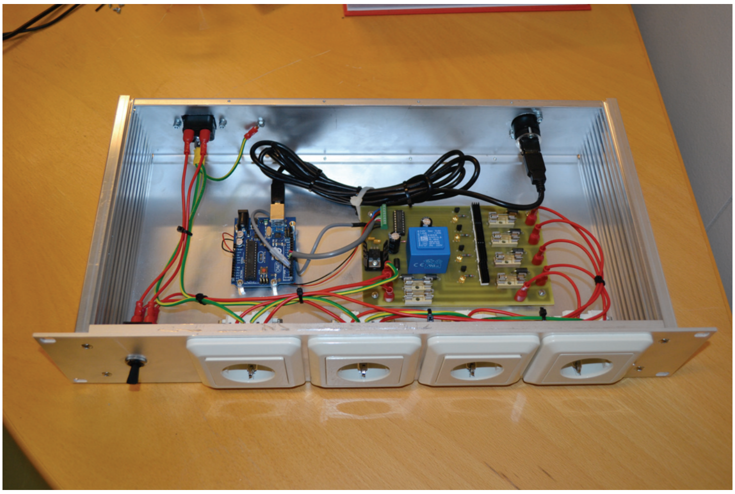

Figure 4. Constructed power cycling unit for solid state lamps.

5.2 Optical Radiation Measurements

Goniospectrometer for angular and spectral characterization of LED lamps

A goniospectrometer was built for characterization of the relative angular and spectral distributions of LED lamps. The measurement data are used for calculating the spatial correction factors for integrating sphere measurements, and for characterizing the spectra of the lamps as a function of the angle of observation (Figure 5). The setup consists of two motorized rotary stages for turning the lamp, Konica Minolta CS-2000A spectroradiometer, and a cabinet containing a limiting aperture, a diffuser and baffles for straylight rejection. The spectral radiance on the backside of the diffuser is measured using the spectroradiometer. The distance between the diffuser and the axis of rotation of the goniometer was chosen to be the same as the radius of the integrating sphere, i.e. d = 825 mm.

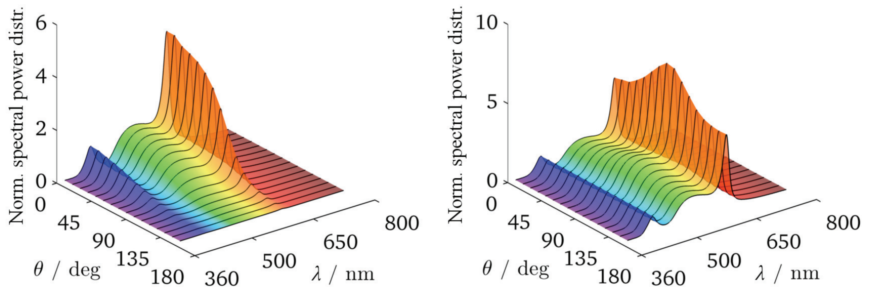

Figure 5. Relative spectral irradiance of an LED lamp. The data on the left is normalized to the value at the blue peak at an angle of 0°, top of the lamp facing the detector. The data on the right is normalized to the blue peak at each measurement angle.

The relative spectral irradiance responsivity of the system was calibrated using a spectral irradiance standard lamp. The movement of the rotary stages was minimized in the measurement sequence to avoid unnecessary cooling of the lamp. The temperature of the LED lamp is monitored using two NTC-thermistors attached on the opposite sides of the heatsink. A typical 2-axis measurement of an LED lamp with a 5° step requires 4 hours of time. The goniospectrometer forms a part of the luminous efficacy measurement system developed for characterization of solid state lamps.

Characterization of UV-LEDs for industrial monitoring applications

Ten UV-LEDs were characterized for a CLEEN-project. The angular intensity distributions of the LEDs were measured using a turntable and a Silicon detector. For measurements of the spectral radiant flux, a setup consisting of a 30-cm integrating sphere and a scanning double monochromator spectroradiometer was used. The detector in use was an electronically cooled photomultiplier tube (PMT). In addition to the measurement with the sphere, the spectrum of each LED was measured on an optical bench due to the possible spectral differences between the two geometries (Figure 6). In the measurements with the optical bench, the tip of the LED was aligned towards the diffuser of the spectroradiometer with a viewing angle corresponding to that of the final application of the LED.

The integrating sphere setup was calibrated using a spectral irradiance standard source, and a 50-mm precision entrance aperture of the sphere. The reference flux was calculated using the known aperture area and the spectral irradiance measured at the aperture plane. In the measurements, each LED was mounted at the entrance aperture of the sphere. The flux measurement data were corrected for the spectral throughput of the sphere and the self-absorptions of the LEDs. The self-absorptions of the LEDs were measured using auxiliary LEDs of the same type as the test LED. In all measurements, the LEDs were driven by DC-current. Each LED was let to stabilize for 10–15 minutes before the measurements began. The stability of the LED was monitored by measuring its forward voltage with a multimeter.

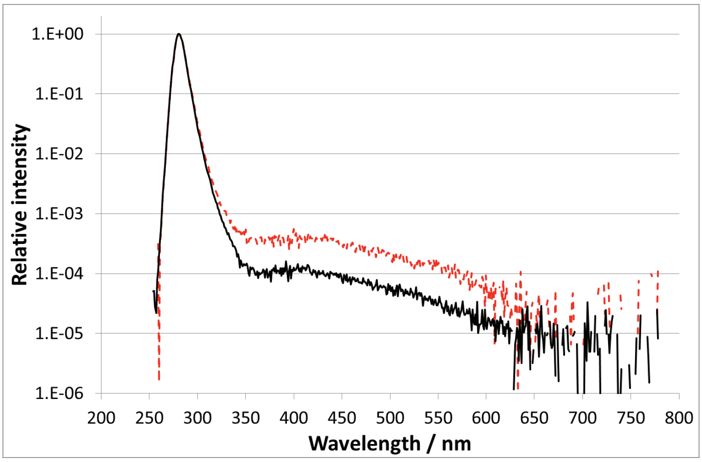

Figure 6. Relative spectral radiant flux in 2π solid angle (red) and relative spectral intensity measured on an optical bench (black) for one of the UV-LEDs studied.

Spectral radiance source based on LEDs

Absolute calibrations of colorimeters and luminance meters are usually carried out using a light source with a standardized broadband spectrum, such as CIE standard illuminant A. These meters are equipped with filters to obtain the spectral sensitivity of the standard colorimetric or photometric observer. However, in order to use the meters reliably for light sources with varying spectra, their spectral radiance responsivities need to be known. The responsivities can be measured by using monochromatic or quasi-monochromatic light at different wavelengths.

Important requirements for the light source in absolute calibration of radiance meters are spatial uniformity and Lambertian angular distribution. We have constructed a radiance source based on LEDs and an integrating sphere, to create a spatially uniform quasi-monochromatic light source (Figure 7). Thirty temperature- and current-stabilized LEDs are mounted on a carousel that is used for coupling the LEDs, one at a time, to the input of a 30-cm integrating sphere. The resulting output spectra were characterized with a spectroradiometer. The reference meter and the device under calibration are focused on the aperture plane of the sphere.

The LEDs used are either single-color narrow bandwidth LEDs or white LEDs with band-pass filters. They cover the visible range of 380–780 nm. With a 75-mm output aperture, the spatial non-uniformity, as difference between the minimum and maximum luminance levels, is less than 1 % with LEDs at wavelengths of 444, 533, 597 and 639 nm.

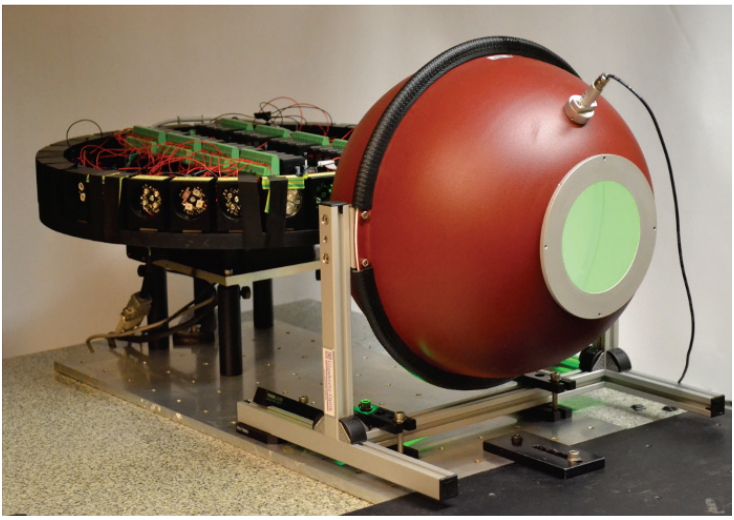

Figure 7. Constructed spectral radiance calibration source.

Refractive index of silicon at high temperatures

This work focused on determination of the extinction coefficient *k* (imaginary part of the refractive index) of silicon with different doping concentrations and in the temperature range from 700 °C to 1200 °C. The measurement method includes heating a multi-layer Silicon-on-Insulator structure to a known temperature in the furnace and measuring sample's emitted radiance spectrum with a focusing spectroradiometer. Radiance was measured in the spectral range of 500–2300 nm. The multi-layer structure of the sample causes interference patterns in the spectrum, which are used for determining the extinction coefficient with optical modeling.

Silicon samples with 3 different doping concentrations were measured, and no differences in the extinction coefficient were observed between different samples at the same temperature. Figure 8 shows extinction coefficients for different temperatures. The dashed portions of the curves at the two lowest temperatures are interpolations and represent the likely upper limits of *k*. A comparison curve is plotted with the data measured by Timans *et al.* (*J. Appl. Phys.* 74, 6353–6364, 1993) at 800 °C and extrapolated to lower wavelengths by Lee *et al.* (*J. Thermophys. Heat. Transf.* 19, 558–565, 2005).

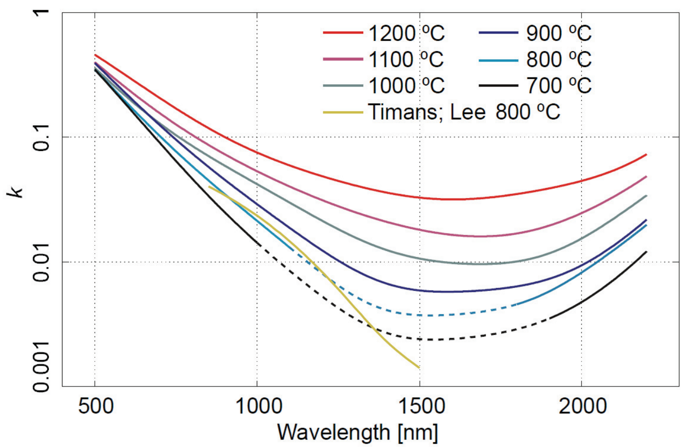

Figure 8. Extinction coefficient of silicon for temperatures 700–1200 °C.

The results are in general agreement with the data from literature. The increasing trend of the extinction coefficient as a function of temperature is evident and is likely attributed to increasing absorption by thermally generated carriers at higher temperatures. No systematic differences with respect to doping concentrations were observed at high temperatures. This suggests that absorption processes at high temperatures are dominated by thermally generated carriers, and doping concentration has relatively small effect on refractive index and therefore emissivity.

Improved Reference Infrared Spectrometer

The reference infrared spectrometer facility was upgraded for measuring the spectral responsivity of detectors, spectral transmittance of optical materials and the spectral power distribution of light sources in the wavelength range of 750 nm to 16 µm. The measurement setup was improved for full automation using LabVIEW. In addition, the previous calibration and automation procedures were refined. The upgraded measurement setup is versatile and easy to operate.

Phase sensitive detection is utilized in the measurement setup by using a lock-in amplifier. It enables detection of very small signals in the presence of overwhelming noise. Optical chopping is used for modulating the measurement signal at a known reference frequency. Typically, the linearity of the measurement system is determined optically. In this work, a fully electronic method for linearity measurements of lock-in amplifiers was developed and tested. The method improves the accuracy of measurements utilizing the lock-in sensing. In addition, a preamplifier for photoconductive detectors was constructed and characterized. The amplifier was designed so that it can be used with wide variety of detectors. The improved measurement setup is fully detailed in the Master's thesis of Timo Dönsberg (*Improved Reference Infrared Spectrometer*).

Tungsten filament lamps as absolute radiometric reference sources

A physical model was developed for the spectral behaviour of the radiation of tungsten filament lamps. The model is based on Planck's radiation law, published values for the emissivity of tungsten, measurement geometry, and measured values for a residual correction function. The spectrum of an incandescent lamp is affected by the emissivity of tungsten, bulb transmittance, absorption of the filling gas, and impurities, material variation, and structure of the filament. In our method, the net effect of the unknown factors of the lamp was determined and used as a residual correction factor. The measurements were made by changing the current of an FEL lamp, thus altering its temperature, and finding a common solution that models all measured spectra.

The model can interpolate and extrapolate spectral irradiances of 1-kW FEL and DXW type lamps, with additional uncertainties better than 1 % within the wavelength range 340–850 nm. The model makes it possible to estimate spectra of incandescent lamps with uncertainties of the order of 2.5 % based on illuminance and colour temperature, or even illuminance and resistance measurements only. These techniques cannot supersede high-accuracy calibrations in national standards laboratories, but may give end users valuable information on their lamps. Figure 9 shows the residual correction factor for the emissivity of tungsten lamps, after taking into account the Planck's law, emissivity of tungsten, and the measurement geometry. Symbols denote correction values obtained for different lamp currents and temperatures. Solid line is an 8th degree polynomial fitted to the average of the results.

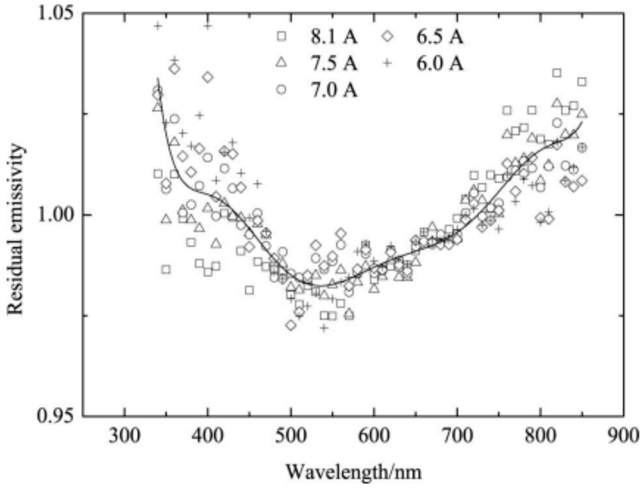

Figure 9. Modelling of tungsten lamps, see text for symbols.

Measurement of UV action spectra of materials

Two spectrographs have been developed earlier at the Metrology Research Institute for measuring UV action spectra of materials. They consist of a 1-kW Xe lamp and a concave holographic grating. Radiation in the sample plane contains wavelengths within 250–500 nm. Various materials have been aged with the spectrographs including paper, stretched and unstretched rubber, polymers, and painted surfaces. In order to accurately reveal the action spectrum from the measurement results, varying irradiance levels at different wavelengths and spectral convolutions need to be accounted for.

The samples were mainly measured for surface colour (*Yxy*), hardness, and FTIR depending on the damage type expected. Also video images, 3D microscope images, and X-ray diffraction spectra were tested to quantify cracking of the surfaces. Figure 10 shows an example of the samples tested – two plates of fibre reinforced polymers that have been aged in the spectrograph for approximately 300 h. The damage caused by the radiation can be seen as yellowing of the samples in the wavelength region 250–350 nm. The wavelengths have been calibrated with a spectroradiometer. Work is underway to derive methodology to convert results to action spectra. Also new materials such as polystyrene and polypropylene are being studied.

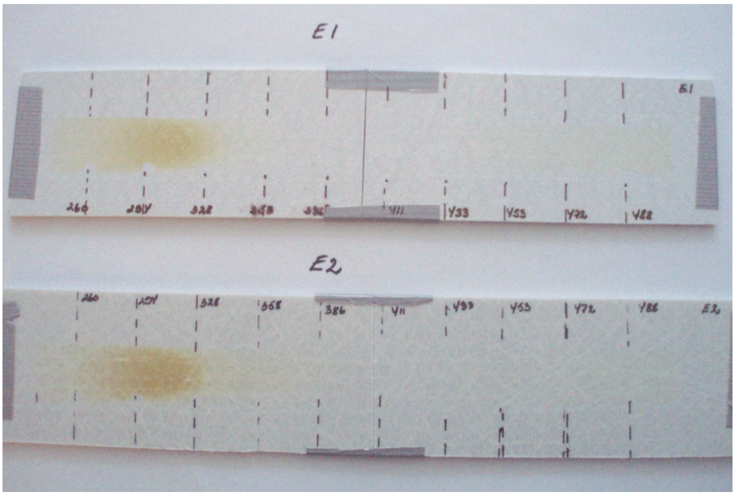

Figure 10. Two fibre reinforced polymer samples aged in the spectrograph.

Uncertainty analysis of photometer directional quality index f_2

The uncertainty analysis of the photometer directional response index f_2 was investigated using Monte Carlo simulation. Five error models were derived for the directional response measurements, taking into account the measurement noise, drift of the light source, alignment of the photometer and the errors caused by the rotary stage. Both random and biased types of errors were combined in the analysis, depending on the nature of the uncertainty.

The directional responses of three real photometers were first measured, after which their f_2 distributions were obtained by calculating f_2 values for a large group of responses perturbed within the uncertainties. The results (Figure 11) show that the f_2 values measured at different azimuth angles of a photometer are sensitive to the asymmetry of the directional response. This is caused by the possible manufacturing tolerances or the constructions of the photometers. Adjusting the symmetry of the directional response does not significantly change the mean value or the standard deviation of f_2 calculated as an average of all simulated values. Further test runs with the error models showed that with typical measurement distances, the quality index f_2 can be sensitive to the position of the axis of rotation with respect to the receiving plane of the photometer. The simulated f_2 values of the three photometers with expanded uncertainties (k = 2) were (4.325 ± 0.035) %, (1.698 ± 0.027) % and (4.315 ± 0.030) %.

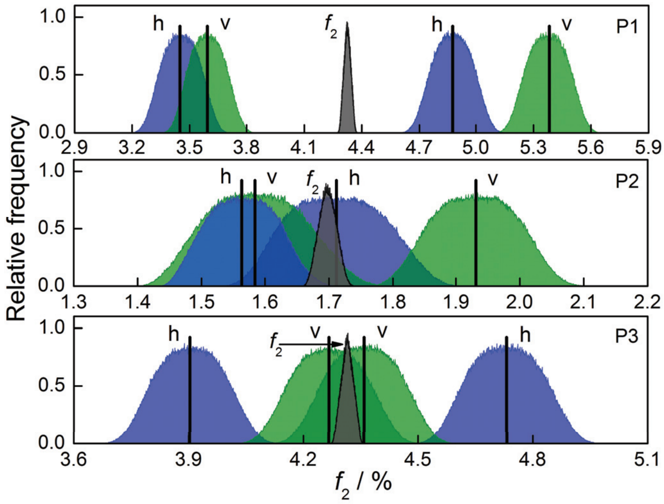

Figure 11. Simulated f_2 distributions of photometers P1, P2 and P3. Measurements were conducted in horizontal (blue) and vertical (green) planes. The f_2 distributions calculated as an average of all simulated values are marked with dark gray color.

Goniofluorometer for characterization of fluorescent materials

Relative and absolute measurements of angular fluorescence spectra and quantum yield are essential in biochemical and medical industry. The measurement uncertainty depends on the characterization of the reference standards. Therefore high-accuracy instruments with absolute calibrations are needed. Our goniofluorometer was used for measuring the bidirectional luminescent radiance factors and absolute quantum yields of a number of commercial fluorescence standards (Figure 12) in the wavelength range of 375–700 nm with expanded uncertainty (k = 2) of 2 %, confirming the non-Lambertian emission of fluorescence. The circular standards look suspiciously flat.

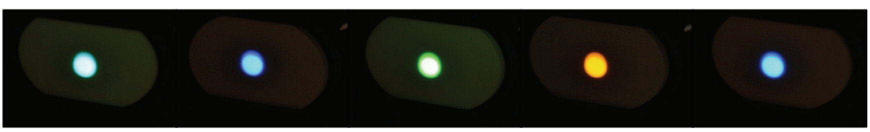

Figure 12. Fluorescence standards excited with UV-light at 350 nm.

EMRP: Predictable Quantum Efficient Detector (PQED)

In the EMRP project Towards Quantum-Based Photon Standards, a novel photodetector based on custom-made high efficiency induced junction silicon photodiodes was developed. Compared to conventional silicon photodiodes, these induced junction diodes have thick ($d > 100$ nm) SiO_2-layer on top of low doped p-type silicon crystal. Low doping helps to reduce the charge carrier losses, whereas inherent positive surface charge in the thick SiO_2-layer introduces an inversion layer in silicon substrate for the generation of pn-junction. Charge carrier collection from the photodiodes can be further improved when the photodiodes are cooled down to 77 K using a liquid nitrogen cryostat (Figure 13).

Figure 13. During the low temperature operation, the photodiodes of the PQED are cooled down to 77 K using a liquid nitrogen cryostat.

Test measurements at room temperature carried out at wavelengths between 476 nm and 760 nm agree well with the predicted values showing that close to 100 % internal quantum efficiency can be achieved within standard uncertainty of ~100 ppm. This is 20 times better in loss terms than earlier reported for silicon- based photodiodes in the wavelength range of 470–760 nm. At low temperature (77 K) the internal quantum efficiency is predictable within 1 ppm in the visible range up to the wavelength of 600 nm, above which the penetration depth of photons becomes larger than charge carrier collection depth. The measured and predicted values at low temperature agree within the measurement uncertainties. The given uncertainty of ~100 ppm is comparable with current primary standard of optical power, the cryogenic radiometer (CR). Compared to sophisticated CR, which is operated at the temperature of 10 K, our developed detector is considerably more compact, easier to operate and works also at room temperature.

EMRP: Simulation of diffusers for solar UV measurements

Solar UV radiation scatters heavily in the atmosphere. Therefore, diffuser heads whose angular response is proportional to the cosine of the zenith angle are needed for the global irradiance measurements. In the EMRP project Traceability for Surface Spectral Solar Ultraviolet Radiation, a combination of measurements and simulations was used to optimize such a diffuser. At the first stage, test samples of various materials were measured for their diffuse transmittance properties in a goniometric setup to find out the most promising material candidate for use in an improved solar UV diffuser head. Quartz materials with gas bubbles that acted as scattering centers were found to be attractive alternatives to the traditional PTFE (polytetrafluoroethylene, Teflon) materials for this purpose. At the next stage, a Monte Carlo ray tracing software (Figure 14) was developed to simulate light transport inside the diffusers. The software was validated by comparing measured and simulated results of the test samples.

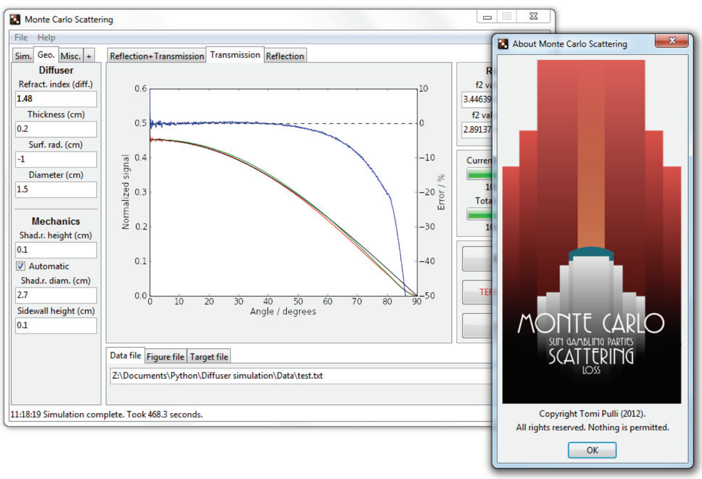

Figure 14. Graphical user interface of the diffuser simulation software.

The effects of various simulation parameters on the overall angular response were studied extensively. The angular response was found to be highly sensitive to variations in some of the parameter values, highlighting the importance of low manufacturing tolerances during production. It was shown that an ideal cosine response cannot be attained without shaping the diffuser in one way or another, due to the refractive index difference between the diffuser material and its surroundings. An integrated cosine error of 1.6 % was reached with an optimized raised flat diffuser. An optimized diffuser with spherical front surface yielded the integrated cosine error of 0.66 %. The measurement setup, the algorithm, and the simulation results are detailed in the Master's thesis by Tomi Pulli (*Improved Diffusers for Solar UV Spectroradiometers*).

EMRP: Reflectance characterization of a reference target to improve the reliability of radiation transfer calculations in Earth observation

Satellite-based Earth observation in visible and NIR wavelengths can provide crucial information on climate changes. In order to interpret the measured data, a variety of radiative transfer (RT) codes have been developed, which simulate the propagation of radiation in the earth's atmosphere by transmission, absorption and scattering. The performance of such codes can be tested by comparing the measured reflectance of a characterized reference target to modelled values.

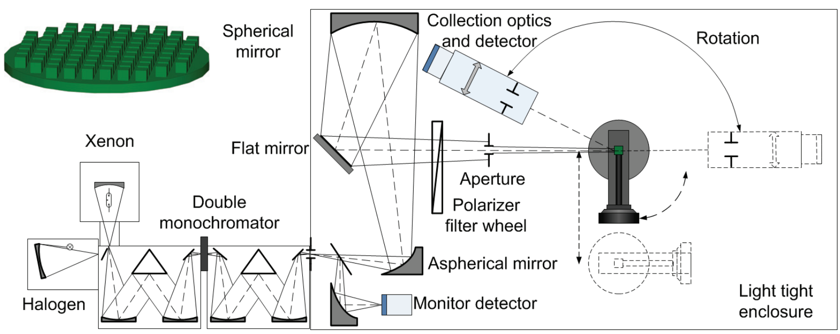

Figure 15. The forest canopy target to be characterized and constructed, and the modified gonioreflectometer setup.

In the EMRP project Metrology for Earth Observation and Climate, a reference target will be constructed and characterized to provide an SI-traceable data set to enable rigorous testing of the performance of the world's RT-codes through the RAMI online model checker. The target designed to resemble the reflective properties of forest canopy comprises a set of anodized aluminium cubes. The multidimensional reflectance of each individual cube is measured using the reference gonioreflectometer (Figure 15). A new sample holder was installed on the gonioreflectometer and angular radiance distribution models were developed for the surfaces to increase the efficiency of the measurements.

EMRP: Metrology for the manufacturing of thin films

The project studies techniques for advanced large-area thin film characterization, novel advanced microstructure characterization tools and reference standards, as well as validated and traceable measurement systems that go beyond the state-of-the-art. The technical work is divided in three work packages. The first one is devoted to validation and traceability of new measurement methods with increasing resolution. The second work package is centered on the development of X-ray and Raman spectroscopy-based methods for the characterization of thin film microstructure. The third work package focuses on large area and multi-scale measurement methods to characterize relevant industrial thin film samples. Metrology Research Institute contributes in one task of WP1 and in two tasks of WP3. The former task involves the qualification of ellipsometry measurements by intercomparison with independent analytical methods such as angular-resolved spectral reflectance measurements. In WP3, we investigate the effects of film inhomogeneity on optical measurements using multiangular reflectance measurements.

EMRP: Calibrated attenuation system for photon-counting applications

In order to achieve traceable calibration method for the responsivity of photon counters at telecommunication wavelengths, a calibrated attenuation system is needed. In the EMRP project Metrology for Industrial Quantum Communication Technologies, such an attenuator was designed and constructed. It is based on a transmission trap (Figure 16) and an actively controlled fibre coupling system. In the transmission trap, two identical large area Hamamatsu InGaAs-photodiodes are used. The photodiodes are mounted into the attenuator in such a configuration that the reflections from the photodiode surfaces occur in an angle of 45º. The reflection planes of the mounted photodiodes are perpendicular to each other ensuring polarization insensitivity of the total reflection (and responsivity). The reflected and unabsorbed fraction of the incoming beam exits through the output aperture of the attenuator.

The transmissivity of the trap detector was predicted to be in a range of 0.1 % and the direct measurements confirmed it. The responsivity of the transmission trap detector is 1.09 A/W and it is used as a monitor detector for the input signal of the attenuator. The advantages of this type of detector are that its responsivity is not sensitive to the polarization of the incident light and that it eliminates the effects of the back reflected light in the measurement system.

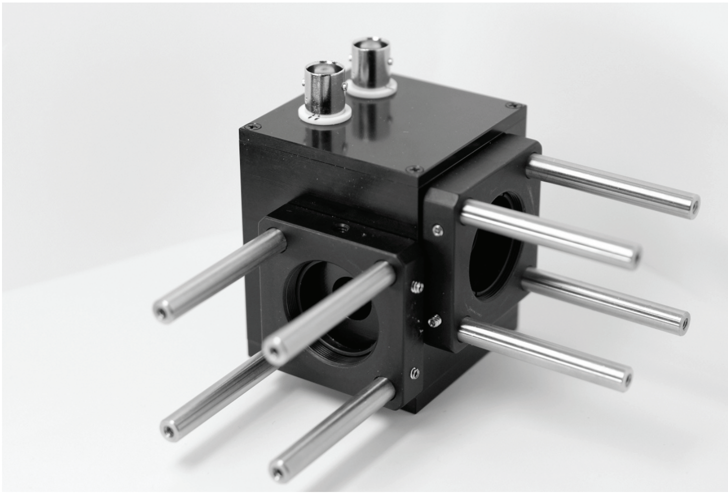

Figure 16. The constructed 45^{o} attenuator.

EMRP ENG05 Metrology for solid state lighting (EMRP SSL)

Metrology for Solid State Lighting is a three-year project funded by the EMRP. The project runs for a time frame of May 2010 – April 2013. In the project, Metrology Research Institute has two wider tasks: 1) To develop a method for predicting the life time of an LED lamp based on its measured spectrum, and 2) Building a mesopic photometer. The work carried out for these tasks is presented in the following subsections.

EMRP SSL: Radiometric determination of the junction temperature of an LED

Junction temperature is an important parameter affecting the lifetime of an LED. In an assembled LED lamp, LEDs are not electrically accessible, thus obtaining the junction temperature is challenging. Various LEDs used in LED lamps were extracted and characterized in different operating temperatures in order to develop a method for determining the junction temperature from the LED spectrum. The junction temperature-voltage characteristics of the LEDs were first determined over a wide temperature range of 30–150 °C using an oil bath and short current pulses. Then, the spectra of the LEDs were measured in different operating temperatures (Figure 17).

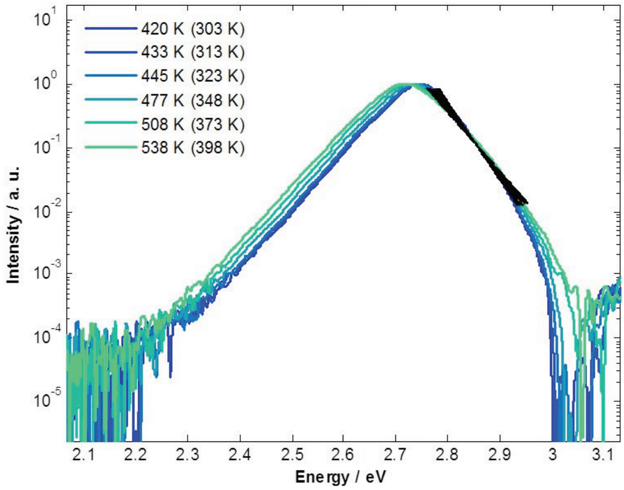

Figure 17. Spectra of a blue LED extracted from a Philips Masterled lamp at 303–398 K temperatures (colored lines), fitted Maxwell-Boltzmann distributions (black lines), and obtained inverse derivative temperatures (legend). The LED drive current was 205 mA.

The analysis showed that the Maxwell-Boltzmann distribution works satisfactorily with red LEDs and, with calibration, also with some white and blue LEDs. However, LEDs at different wavelengths need to be calibrated separately because the relationship between the inverse derivative temperature and the junction temperature depends heavily on the wavelength. It also varies from a manufacturer to another and, as was noted with blue Philips LED, the behavior may even vary considerably between specimens of similar LEDs. Nevertheless, determination of the junction temperature from the LED spectrum seems to give access to LED lifetime estimation via a new method.

EMRP SSL: Lifetime expectancy of SSLs

Illuminating Engineering Society of North America (IES) has defined the lifetime of LED lamps by lumen maintenance. According to the definition, the lamp is at the end of its lifetime when the luminous flux has decreased to 70 % or 50 % of the initial value. Typically, the luminous flux of LED lamps decreases slowly, so it is not practical to measure lamps for a period of 10 years. A lifetime prediction method utilizing measurement data from a shorter period of time is needed (Figure 18).

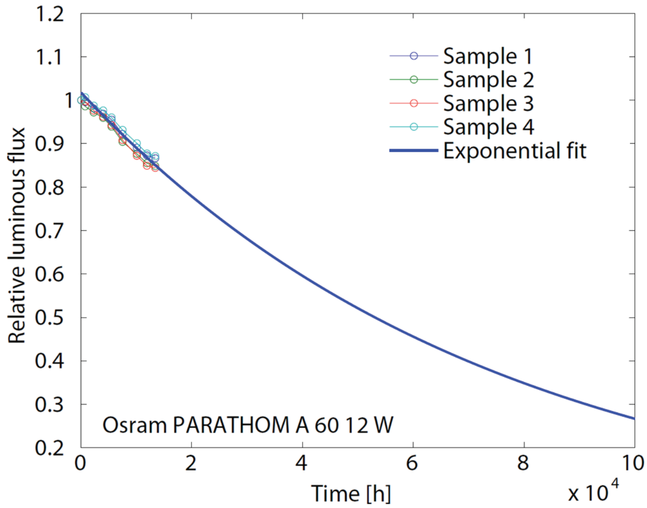

Figure 18. Lifetime-projection of 12-W Osram Parathom A60 LED-lamp obtained by exponential curve fit for the measurement data. The lamp is at the end of its lifetime when the luminous flux has decreased to 70 % of the initial flux value.

The lifetime of LEDs depends on the temperature of the LED chip. In higher temperatures, the lifetime of an LED decreases. We studied the prediction of the lifetime of LED-lamps by ageing lamps both at room temperature and at two elevated temperatures of 45 °C and 60 °C. Five different types of LED lamps from two different manufacturers were studied. The measurement data at the room temperature covered a time period of almost two years.

The method developed by IES uses an exponential curve-fit method to project the lifetime. The projected lifetime at room temperature (23 °C) for the different types of LED lamps varied in the measurements from very long to 30 000 hours. Variations were due to the different working principles of the LEDs used for producing white light. A correlation between the ambient temperature and the LED lifetime was found. At 60 °C temperature, the lifetime of an LED is four times shorter than at the room temperature. Other LED failure mechanisms were found as well.

EMRP SSL: A two-channel luminance meter for mesopic measurement range

The CIE published a new recommended system for mesopic photometry in 2010 (CIE 191:2010. Recommended System for Mesopic Photometry Based on Visual Performance), which should be applied in the luminance range of 0.005–5 cd/m^2. The mesopic luminance is calculated by combining photopic and scotopic luminous efficiency functions in a ratio governed by the visual adaptation conditions. We have constructed a dual-channel spot luminance meter that is able to do fast simultaneous measurements of photopic and scotopic luminance values (Figure 19). The instrument measures collected light in two separate channels with silicon detectors and a custom made computer-controlled dual-channel switched-integration amplifier. The amplifiers were built by Czech Metrology Institute (CMI).

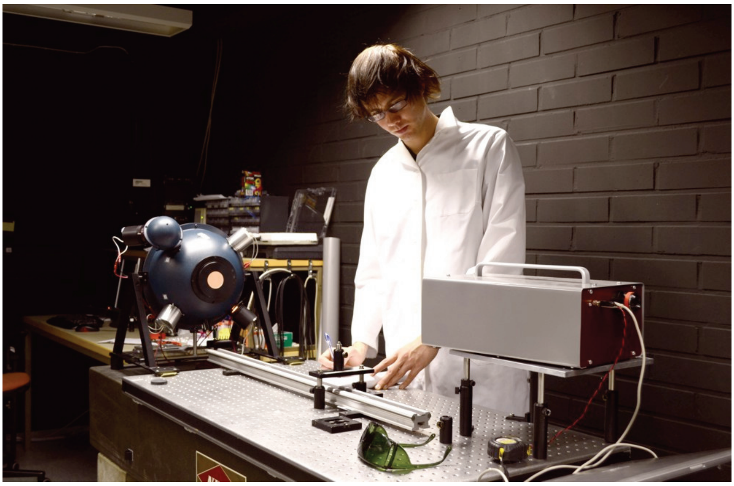

Figure 19. Preparations for measurements with a photopic-scotopic luminance meter.

The spectral responsivity was characterized in the range of 380–780 nm. The spectral quality factors f_1' obtained for the photopic and scotopic channels were 3.6 % and 6.0 %, respectively. The dark currents detected by the amplifiers correspond to a luminance level of 0.0007 cd/m^2, and the noise level with 0.8 s integration time is 6 % of the dark reading. This corresponds to less than 1 % standard deviation of the mean at the lowest level of the mesopic range, i.e. 0.005 cd/m^2. The non-linearity measured in the range of 0.005–0.5 cd/m^2 was less than 0.3 %. The expanded uncertainty of the calibration of the luminance responsivity is estimated to be 3 %, and due to the good noise performance, the system can be further improved with a more accurate calibration.

5.3 Applied Spectroscopy

Development of real-time optical analysis of liquids

Novel optical instrumentation has been developed for real-time analysis of liquid phase samples in close collaboration between the Metrology Research Institute and MIKES. First, novel analyzers employing LED light sources have been designed and studied. LED-based instrumentation has good potential in low-cost solutions for raw and waste water monitoring, as well as for industrial process control. Figure 20 shows a realized laboratory setup that allows for absorption measurements in the wavelength range of 250–600 nm.

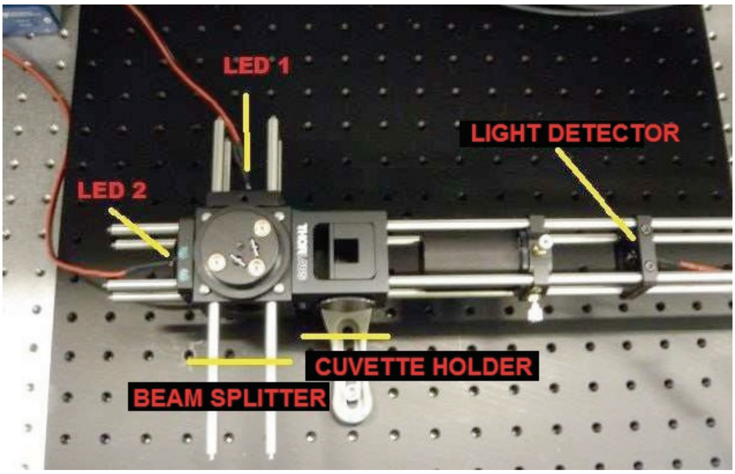

Figure 20. Laboratory setup for measuring UV-absorption of liquids.

Secondly, a compact and real-time elemental analyzer for flowing water samples has been developed. The analyzer employs the microplasma plasma emission spectroscopy (MPES) concept. A small footprint laser-machined ceramic chip has been designed and realized to host the MPES sensor. The operation principle of the device is the following: two platinum electrodes are placed in the laser-machined microfluidic channel and a high voltage pulse is applied to the electrodes. The high voltage pulse vaporises the analyte between the electrodes followed by an electrical breakdown and a microplasma. The peak temperature in the plasma core reaches thousands of Kelvins – high enough to atomise molecules in the liquid sample and excite the atoms. When the excited atoms return to their energetic ground states they emit light at characteristic wavelengths that can be recorded and analyzed using a standard spectrometer.

Samples containing Na, Ag and Mn at mg/L concentrations have been analyzed in the first tests of the MPES analyzer. So called Boltzmann plot method, which accounts for the variations in the plasma temperature from discharge to discharge, was implemented to compensate for the fluctuations in the intensity of the emission lines. This real-time compensation improved the standard deviation of the emission intensities from about 30 % to 7 % or less.

Thirdly, a spectrometer for very sensitive absorption measurements in liquids across broad spectral bandwidths has been developed. The spectrometer combines the unique spectral properties of incoherent supercontinuum (SC) light sources with the advantages of cavity ring-down spectroscopy (CRDS), which is a self-calibrating technique. A custom-built single-photon avalanche photodiode (SPAD) array is used for detection, permitting the simultaneous measurement of ring-down times for up to 64 different spectral components at nanosecond temporal resolution. The minimum detectable absorption coefficient was measured to be 3.2×10^{-6} cm^{-1} $Hz^{-1/2}$ at 527 nm. It was demonstrated that the spectrometer is capable of recording spectral differences at trace levels by analyzing blood samples before and after hemolysis. Spectrally broadband CRDS offers good sensitivity with multi-species measurement capability and is self-referencing. Potential applications for such high-performance spectrophotometers range from biomedical analysis to process industries and basic sciences.

Remote sensing

A hyperspectral remote sensing instrument employing a near-infrared SC light source has been developed for active target identification for distances up to 250 m. A cost efficient SC source having 16 W optical output power and covering 1000 nm to 2300 nm spectral range has been realized. A commercial near-IR spectrometer and a tunable Fabry-Perot filter have been used for detection. Feasibility of the approach was studied both indoors and in the field (Figure 21). Reflection spectra of several test targets have been recorded.

Figure 21. Hyperspectral remote sensing setup in the field tests
at the Technical Research Centre of the Finnish Defence Forces.

6 INTERNATIONAL CO-OPERATION

6.1 Thematic Network for Ultraviolet Radiation Measurements (UVNet)

The Metrology Research Institute is the coordinator of the Thematic Network for Ultraviolet Radiation Measurements, which has continued its activities after the EU-funded period. The activity was limited for a while, but in 2011 the Network was reinitiated as part of the project EMRP ENV03 Traceability for Surface Spectral Solar Ultraviolet Radiation. UVNet has a major role in the dissemination of the project results through its mailing lists and its Newsletter *UVNews*.

6.2 International Comparison Measurements

Since 2005, the Metrology Research Institute has participated in key comparisons under the name MIKES (Centre for Metrology and Accreditation).

Key comparison CCPR-K2.c, spectral responsivity 200–400 nm, pilot PTB

The measurements are complete and the pre-Draft A process is ongoing. Draft A is expected in 2013.

Key comparison CCPR-K5, spectral diffuse reflectance, pilot NIST

Draft B was circulated in 2012. The results indicate excellent agreement within uncertainties, ~0.2 % ± 0.5 %, for MIKES.

Key comparison EURAMET.PR-K3.a, luminous intensity, pilot PTB

Measurements were completed in 2009. Draft A is expected in February 2013.

Key comparison EURAMET.PR-K4, luminous flux, pilot PTB

Measurements were completed in 2009. There was no progress in 2011. Draft A is not yet available. Latest communication from pilot was in May 2012.

Supplementary regional comparisons APMP.PR-S3.a, APMP.PR-S3.b, and APMP.PR-S3.c, LED related quantities, pilot KRISS

The measured quantities in these comparisons include the CIE averaged luminous intensity B, total luminous flux, and chromaticity coordinates x, y of LEDs. Draft B was circulated in 2012.

The results for the average LED intensity indicate excellent agreement within uncertainties, ~0.5 % ± 2 %, for MIKES. The results for total luminous flux are generally in agreement, except for the red LED, where there is a difference of 5 % ± 3 % in the results for MIKES. The temperature sensitivity for this artifact is known to be high. Another possible reason for the deviation is that the integrating sphere was equipped with large stock baffles. The spatial responsivity was significantly improved later by using small custom baffles. No actions are considered necessary. The results for chromaticity coordinates are in good agreement, but the uncertainties are high. Altogether, 1 datum out of 18 is outside its expanded uncertainty limits.

Bilateral comparison of luminous efficacy of LED lamps

In 2010, a comparison of luminous efficacy measurements of LED-lamps was agreed with NIMT. MIKES completed the measurements during fall 2010. The lamps were sent to NIMT for measurements in the beginning of 2011. NIMT results are still missing. There was no progress in 2012.

Comparison of luminous efficacy of SSL products (EMRP ENG05-2.2.1)

Measurements were completed in 2012. Preliminary comparison report draft exists without identifying the participants.

6.3 Conferences and Meetings

The new SI: Units of Measurement Based on Fundamental Constants Conference, January 24–25, 2011, London, United Kingdom; *Erkki Ikonen*

Scientific and Technical Committee Meeting: International Metrology Congress, February 10, 2011, Paris, France; *Erkki Ikonen*

Optical Mini-Conference, March 8, 2011, Oslo, Norway; *Erkki Ikonen*

EURAMET Phora Technical Committee Meeting, March 8–9, 2011, Oslo, Norway; *Erkki Ikonen*

EMRP 'Candela: Towards Quantum-Based Photon Standards' Project Meeting, April 18–20, 2011, Prague, Czech Republic; *Erkki Ikonen, Farshid Manoocheri*

EMRP Subcommittee Meeting, April 27–29, 2011, Braunschweig, Germany; *Erkki Ikonen*

EMRP 'Metrology for Solid State Lighting' Project Meeting, May 9–10, 2011, Braunschweig, Germany; *Petri Kärhä*

EMRP Committee Meeting, May 23–24, 2011, Paris, France; *Erkki Ikonen*

EMRP JRP-n01: 'Novel Mathematical and Statistical Approaches to Uncertainty Evaluation' Partnering Meeting, June 27–28, 2011, Berlin, Germany; *Petri Kärhä*

SPW 2011 Single Photon Workshop¸ June 27–30, 2011, Braunschweig, Germany; *Erkki Ikonen*

EMRP SRT-n13: 'Metrology of Electro-Thermal Coupling for New Functional Materials Technology' Partnering Meeting, June 27–28, 2011, Teddington, United Kingdom; *Maksim Shpak*

EMRP New Technologies Partnering Meeting, June 27–28, 2011, Teddington, United Kingdom; *Farshid Manoocheri*

EMRP TP Health Partnering Meetings, June 29 – July 1, 2011, Berlin, Germany; *Farshid Manoocheri*

EMRP SRT-s09: 'Traceability of Single Photon Sources' Partnering meeting, June 30 – July 1, 2011, Braunschweig, Germany; *Erkki Ikonen*

CIE Session, July 10–15, 2011, Sun City, South Africa; *Erkki Ikonen*

CIE TC Meetings, July 11–13, 2011, Sun City, South Africa; *Erkki Ikonen*

CIE D2 Meeting, July 14–15, 2011, Sun City, South Africa; *Erkki Ikonen*

EMRP 'Metrology for the Manufacturing of Thin Films' Kick-off Meeting, August 10, 2011, Teddington, United Kingdom; *Farshid Manoocheri*

EMRP 'Traceability for Surface Spectral Solar Ultraviolet Radiation' Kick-off Meeting, August 12–13, 2011, Davos, Switzerland; *Petri Kärhä*

EMRP 'Metrology for Industrial Quantum Communication Technologies' Kick-off Meeting, September 1, 2011, Prague, Czech Republic; *Erkki Ikonen, Farshid Manoocheri*

EMRP SRT-s09: 'Traceability of Single Photon Sources' Partnering Meeting, September 2, 2011, Prague, Czech Republic; *Erkki Ikonen, Farshid Manoocheri*

CCPR WG-KC Meeting, September 17, 2011, Hawaii, USA; *Erkki Ikonen, Farshid Manoocheri*

CCPR WG-SP Meeting, September 18, 2011, Hawaii, USA; *Erkki Ikonen*

The 11th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2011) Conference, September 18–23, 2011, Hawaii, USA; *Erkki Ikonen, Farshid Manoocheri, Petri Kärhä, Meelis Sildoja, Tuomas Poikonen*

NEWRAD Scientific Committee Meeting, September 21, 2011, Hawaii, USA; *Erkki Ikonen*

International Metrology Congress, October 4–6, 2011, Paris, France; *Erkki Ikonen*

EMRP 'Metrology for Earth Observation and Climate' Kick-off Meeting, October 26–27, 2011, Teddington, United Kingdom; *Farshid Manoocheri*

EUV Metrology Seminar, October 27–28, 2011, Berlin, Germany; *Erkki Ikonen*

EPS Exact Science Autumn School, October 29–30, 2011, Voore, Estonia; *Meelis Sildoja*

EMRP Review Conference: New Technologies, November 20–21, 2011, Berlin, Germany; *Erkki Ikonen*

EMRP Review Conference: S1 Broader Scope, November 24–25, 2011, Berlin, Germany; *Erkki Ikonen*

EMRP Committee Meeting, November 28–29, 2011, Brussels, Belgium; *Erkki Ikonen*

EU Commission EMRP Event, November 29, 2011, Brussels, Belgium; *Erkki Ikonen*

EMRP 'Metrology for the Manufacturing of Thin Films' Project Meeting, February 1–2, 2012, Delft, The Netherlands; *Farshid Manoocheri*

NOG Annual Meeting of the Nordic Ozone and UV Group, February 8–10, 2012, Helsinki, Finland; *Petri Kärhä*

Temadag "LED-besvär?", February 14, 2012, Göteborg, Sweden; *Petri Kärhä*

CCPR-WG-CMC Meeting, February 21, 2012, Paris, France; *Erkki Ikonen*

CCPR WG-KC Meeting, February 22, 2012, Paris, France; *Erkki Ikonen*

CCPR WG-SP Workshop, February 22, 2012, Paris, France; *Erkki Ikonen*

CCPR Meeting, February 23–24, 2012, Paris, France; *Erkki Ikonen*

EURAMET Phora Technical Committee Meeting, March 7–8, 2012, Espoo, Finland; *Erkki Ikonen, Farshid Manoocheri, Petri Kärhä*

EMRP 'Metrology for Industrial Quantum Communication Technologies' 1st Interim Meeting, March 8–9, 2012, Espoo, Finland; *Aigar Vaigu, Farshid Manoocheri, Erkki Ikonen*

EMRP 'Metrology for Earth Observation and Climate' Project Meeting, April 3–4, 2012, Berlin, Germany; *Erkki Ikonen, Farshid Manoocheri*

EMRP Sub-committee Meeting, April 24–27, Braunschweig, Germany; *Erkki Ikonen*

EMRP 'Metrology for Solid State Lighting' Project Meeting, May 2–3, 2012, Torino, Italy; *Petri Kärhä*

Project Proposal Evaluation for the Research Council of Lithuania, May 10–11, 2012, Vilna, Lithuania; *Erkki Ikonen*

EURAMET General Assembly and EMRP Committee Meeting, May 22–25, 2012, Copenhagen, Denmark; *Erkki Ikonen*

International Scientific Metrology Symposium "Metrology for Energy", May 24, 2012, Copenhagen, Denmark; *Maksim Shpak, Erkki Ikonen*

EMRP SRT-s18: 'Traceable Camera-based Photometry and Radiometry' Partnering Meeting, June 28–29, 2012, Espoo, Finland; *Petri Kärhä, Tuomas Poikonen, Juha-Matti Hirvonen*

EMRP SRT-i23: 'Metrology for Surface Waves and Surface State-assisted Devices' Partnering Meeting, June 28–29, 2012, Espoo, Finland; *Farshid Manoocheri, Hans Baumgartner, Priit Jaanson*

EMRP SRT-i21: 'Multidimensional Reflectometry for Industry' Partnering Meeting, June 28–29, 2012, Espoo, Finland; *Farshid Manoocheri, Priit Jaanson, Tomi Pulli*

EMRP SRT-s19: 'New Primary Standards and Traceability for Radiometry' Partnering Meeting, June 28–29, 2012, Espoo, Finland; *Erkki Ikonen, Meelis Sildoja, Timo Dönsberg*

EMRP SRT-x07: 'Single-Photon Sources for Quantum Technologies' Partnering Meeting, June 28–29, 2012, Espoo, Finland; *Erkki Ikonen, Aigar Vaigu, Toni Laurila*

EMRP SRT-i03: 'Metrology for Long Lifetime Flexible Large Area Electronics' Partnering Meeting, July 3–5, 2012, Teddington, United Kingdom; *Tuomas Poikonen*

International Radiation Symposium, August 7–10, 2012, Berlin, Germany, *Tomi Pulli*

International Radiation Symposium, August 9–10, 2012, Berlin, Germany; *Erkki Ikonen, Petri Kärhä*

EMRP 'Traceability for Surface Spectral Solar Ultraviolet Radiation' Project Meeting, August 13–14, 2012, Braunschweig, Germany; *Petri Kärhä*

EMRP 'Metrology for the Manufacturing of Thin Films' Project Meeting, August 22–23, 2012, Espoo, Finland; *Farshid Manoocheri, Henrik Mäntynen, Priit Jaanson, Erkki Ikonen*

EMRP 'Metrology for Earth Observation and Climate' Project Meeting, September 17–18, 2012, Teddington, United Kingdom; *Farshid Manoocheri*

CIE Lighting Quality & Energy Efficiency Conference, September 19–21, 2012, Hangzhou, China; *Erkki Ikonen, Maksim Shpak*

CIE Division 2 Meeting, September 22, 2012, Hangzhou, China; *Erkki Ikonen*

CIE Division 2 and TC Meetings, September 22–26, 2012, Hangzhou, China; *Maksim Shpak*

Joint Meeting of EMRP Contacts at NMIs/DIs and MSU, October 29–30, 2012, Berlin, Germany; *Erkki Ikonen*

EMRP Review Conference, November 18–24, 2012, Monte Carlo, Monaco; *Ikonen Erkki*

Northern Optics 2012 Conference, November 19–21, 2012, Snekkersten, Denmark; *Toni Laurila, Aigar Vaigu, Priit Jaanson, Juha-Matti Hirvonen, Hans Baumgartner*

EMRP Committee Meeting, November 26–27, 2012, Paris, France; *Erkki Ikonen*

EMRP 'Metrology of Electrothermal Coupling for New Functional Materials Technology' Project Meeting, November 26–27, 2012, Trappes, France; *Maksim Shpak*

6.4 Visits by the Laboratory Personnel

Erkki Ikonen, LNE-INM, Paris, France, February 9, 2011

Meelis Sildoja, PTB Berlin, Germany, June 15–17, 2011

Erkki Ikonen, PTB Berlin, Adlershof, Germany, October 27, 2011

Erkki Ikonen, PTB Berlin, Charlottenburg, Germany, October 28, 2011

Petri Kärhä, NPL, Teddington, United Kingdom, November 14–17, 2011

Erkki Ikonen, PTB Berlin, Charlottenburg, Germany, November 21, 2011

Petri Kärhä, SP, Borås, Swerige, February 15, 2012

Petri Kärhä, VSL, Delft, The Netherlands, April 27–28, 2012

Erkki Ikonen, PTB Berlin, Germany, June 5, 2012

6.5 Research Work Abroad

Maija Ojanen, LNE Laboratoire national de métrologie et d'essais, Trappes, France, 1 January – 31 May, 2011

Meelis Sildoja, CMI Czech Metrology Institute, Prague, Czech Republic, 23–27 May, 2011

Meelis Sildoja, CMI Czech Metrology Institute, Prague, Czech Republic, 6–10 June, 2011

6.6 Visits to the Laboratory

Toomas Kübarsepp, Metrosert, Estonia, August 17 and October 25, 2011

Riho Vendt, Metrosert, Estonia, October 25, 2011

Jan Petersen, DFM, Denmark, December 8, 2011

Frans J.M. Harren, Radboud University Nijmegen, The Netherlands, December 8, 2011

Laura Houston, Andor Technology, North Ireland, February 20, 2012

Gerard O'Hanlon, Andor Technology, North Ireland, February 20, 2012

Staffan Eriksson, LOT-Oriel Nordic, Sweden, February 20, 2012

Richard Arbus, Gammadata, Sweden, May 3, 2012

Chu Liu, Beijing Jiaotong University, China, October 1–5, 2012

Niklas Saxén, Edmund Optics, November 29, 2012

Armin Sperling¸ PTB, Germany, December 6–7, 2012

EURAMET TC-PR meeting March 7–8, 2012

Norbert Hörhager-Berl, BEV, Austria, March 8, 2012

Nikolay Alexandrov, BIM, Bulgaria, March 8, 2012

Michael Stock, BIPM, Paris, March 8, 2012

Geiland Porrovecchio, CMI, Czech Republic, March 8, 2012

Marek Smid, CMI, Czech Republic, March 8, 2012

Joaquín Campos Acosta, CSIC, Spain, March 8, 2012

Lukasz Litwiniuk, GUM, Poland, March 8, 2012

Olivier Pellegrino, IPQ, Portugal, March 8, 2012

Jarle Gran, Justervesenet, Norway, March 8, 2012

Jimmy Dubard, LNE, France, March 8, 2012

Peter Blattner, METAS, Switzerland, March 8, 2012

Nigel Fox, NPL, United Kingdom, March 8, 2012

Teresa Goodman, NPL, United Kingdom, March 8, 2012

Armin Sperling, PTB, Germany, March 8, 2012

Klaus Stock, PTB, Germany, March 8, 2012

Stefan Nagy, SMU, Slovakia, March 8, 2012

Stefan Källberg, SP, Sweden, March 8, 2012

Ferhat Sametoglu, UME, Turkey, March 8, 2012

Edgar Vuelban, VSL, The Netherlands, March 8, 2012

Lutz Werner, NPL, United Kingdom, March 9, 2012

EMRP partnering meeting June 27–29, 2012

Geiland Porrovecchio, CMI, Czech Republic, June 28, 2012

Marek Smid, CMI, Czech Republic, June 28, 2012

Kathryn Nield, MSL, New Zealand, June 28, 2012

Dieter Taubert, PTB, Germany, June 29, 2012

EMRP Thinfilms meeting August 22–23, 2012

Andreas Hertwig, BAM, Germany, August 22–23, 2012

Dana Maria Rosu, BAM, Germany, August 22–23, 2012

Miroslav Valtr, CMI, Czech Republic, August 22–23, 2012

Peter Petrik, Fraunhofer IISB, Germany, August 22–23, 2012

Stephan Brunken, HZB, Germany, August 22–23, 2012

Jong Soo Kim, Imperial College London, United Kingdom, August 22–23, 2012

Marie-Christine Lepy, LNHB, CEA Saclay, France, August 22–23, 2012

Andrea Cappella, LNHB, CEA Saclay, France, August 22–23, 2012

Louise Brown, NPL, United Kingdom, August 22–23, 2012

Fernando Castro, NPL, United Kingdom, August 22–23, 2012

Burkhard Beckhoff, PTB, Germany, August 22–23, 2012

Martin Gerlach, PTB, Germany, August 22–23, 2012

Beatrix Pollakowski, PTB, Germany, August 22–23, 2012

Sabine Zakel, PTB, Germany, August 22–23, 2012

Omar El Gawhary, VSL, The Netherlands, August 22–23, 2012

Richard Koops, VSL, The Netherlands, August 22–23, 2012

7 PUBLICATIONS

7.1 Articles in International Journals

P. Kärhä, A. Heikkilä, K. Ruokolainen, and M. Kaunismaa, “A novel facility for ageing materials with narrow-band UV radiation exposure,” *Rev. Sci. Instrum.* **82**, 023107, 6 p (2011).

Y. J. Liu, G. Xu, X. B. Huang, F. Manoocheri, and E. Ikonen, “Performance of a multi-wavelength filter radiometer for spectral irradiance measurement in the near IR,” *Light & Engineering* **19**, 61–69 (2011).

L. Sainiemi, A. Shah, V. Jokinen, M. Shpak, S. Aura and S. Franssila, “Non-reflecting silicon and polymer surfaces by plasma etching and replication,” *Adv. Mater.* **23**, 122–126 (2011).

T. Hieta, M. Merimaa, M. Vainio, J. Seppä, and A. Lassila, “High-precision diode-laser-based temperature measurement for air refractive index compensation,” *Appl. Opt.* **50**, 5990–5998 (2011).

E. Ikonen, “Three-pion correlations for studying partial coherence in nuclear collisions,” *Physics of Particles and Nuclei Letters* **8**, 1004–1006 (2011).

R. Vendt, M. Juurma, P. Jaanson, V. Vabson, T. Kübarsepp, and M. Noorma, “Effects of environmental conditions on the performance of thermal imagers,” *Int. J. Thermophysics* **32**, 248–257 (2011).

T. Poikonen, T. Pulli, A. Vaskuri, H. Baumgartner, P. Kärhä, and E. Ikonen, “Luminous efficacy measurement of solid-state lamps,” *Metrologia* **49**, S135–S140 (2012).

M. Ojanen, P. Kärhä, S. Nevas, A. Sperling, H. Mäntynen, and E. Ikonen, “Double-coiled tungsten filament lamps as absolute spectral irradiance reference sources,” *Metrologia* **49**, S53–S58 (2012).

J. Gran, T. Kübarsepp, M. Sildoja, F. Manoocheri, E. Ikonen, and I. Müller, “Simulations of predictable quantum efficient detector with PC1D,” *Metrologia* **49**, S130–S134 (2012).

C. Liu, E. J. Rees, T. Laurila, S. Jian, and C. F. Kaminski, “Periodic interactions between solitons and dispersive waves during the generation of non-coherent supercontinuum radiation”, *Opt. Express* **20**, 6316–6324 (2012).

S.-S. Kiwanuka, T. Laurila, J. H. Frank, A. Esposito, K. Blomberg von der Geest, L. Pancheri, D. Stoppa, and C. F. Kaminski, “Development of broadband cavity ring-down spectroscopy for biomedical diagnostics of liquid analytes”, *Anal. Chem.* **84**, 5489–54934 (2012).

T. Poikonen, P. Blattner, P. Kärhä and E. Ikonen, “Uncertainty analysis of photometer directional response index f_2 using monte carlo simulation,” *Metrologia* **49**, 727–736 (2012).

F. Pollinger, T. Hieta, M. Vainio, N. R. Doloca, A. Abou-Zeid, K. Meiners-Hagen, M. Merimaa, “Effective humidity in length measurements: comparison of three approaches, ” *Meas. Sci. Technol.* **23**, 025503/1–11 (2012).

7.2 International Conference Presentations

A. Heikkilä and P. Kärhä, “Evolving facility for studies on wavelength dependence of plant response to UVB radiation,” *Abstracts of the 1st Annual Meeting of COST Action FA0906 UV4 growth*, Szeged, Hungary, February 6–9 2011, pp. 17. (Talk)

A. Heikkilä, A. Sormanen, A.-M. Naula-Iltanen, and P. Kärhä, “Investigating effects of temperature on wavelength dependence of UV radiation induced damages,” *5th European Weathering Symposium Natural and Artificial Ageing of Polymers*, September 21–23, 2011, Lisbon, Portugal, pp. 67–75. (Talk)

P. Kärhä, M. Ojanen, S. Nevas, and E. Ikonen, “Tungsten filament lamps as absolute radiometric reference sources,” *Proc. NEWRAD 2011*, Hawaii, September 18–23, 2011, pp. 94–95. (Talk)

P. Kärhä, A. Heikkilä, and M. Kaunismaa, “Measurement setups and methods for UV action spectra of materials,” *Proc. NEWRAD 2011*, Hawaii, September 18–23, 2011, pp. 136–137. (Poster)

M. Shpak, L. Sainiemi, P. Kärhä, M. Heinonen, S. Franssila, and E. Ikonen, ”Refractive index of silicon with various doping levels at high temperatures,” *Proc. NEWRAD 2011*, Hawaii, September 18–23, 2011, pp. 144–145. (Poster)

T. Poikonen, T. Pulli, A. Vaskuri, T. Hyvönen, P. Kärhä, and E. Ikonen, ”Luminous efficacy measurement setup for solid state lamps,” *Proc. NEWRAD 2011*, Hawaii, September 18–23, 2011, pp. 225–226. (Talk)

M. Sildoja, F. Manoocheri, M. Merimaa, E. Ikonen, I. Müller, L. Werner, J. Gran, T. Kübarsepp, M. Smîd, and M.L. Rastello, “Predictable quantum efficient detector I: Photodiodes and design,” *Proc. NEWRAD 2011*, Hawaii, September 18–23, 2011, pp. 227–228. (Poster)

S.S. Hoem, J. Gran, M. Sildoja, F. Manoocheri, E. Ikonen, and I. Müller, “Physics of self-induced photodiodes,” *Proc. NEWRAD 2011*, Hawaii, September 18–23, 2011, pp. 259–260. (Poster)

J. Gran, T. Kübarsepp, M. Sildoja, F. Manoocheri, E. Ikonen, and I. Müller, “Simulations of predictable quantum efficient detector with PC1D,” *Proc. NEWRAD 2011*, Hawaii, September 18–23, 2011, pp. 263–265. (Poster)

F. Manoocheri, “Predictable quantum efficient detector (PQED),” *Proc. NEWRAD 2011*, Hawaii, September 18–23, 2011, pp. 13–15. (Invited talk)

I. Müller, G. Brida, J. Gran, S.S. Hoem, E. Ikonen, T. Kübarsepp, U. Link1, F. Manoocheri, M. Sildoja, M. Smîd, L. Socaciu-Siebert, and L. Werner, “Predictable quantum efficient detector II: Characterization results,” *Proc. NEWRAD 2011*, Hawaii, September 18–23, 2011, pp. 209–210. (Poster)

T. Laurila, S.-S. Kiwanuka, J. H. Frank, and C. F. Kaminski, “Broadband cavity-enhanced spectroscopy using supercontinuum radiation”, *Proc. Laser Applications to Chemical, Security and Environmental Analysis (LACSEA) conference*, San Diego, USA, January 29 – February 1, 2012, LT5B.4. (Talk)

P. Kärhä, “Life time prediction of LED light sources” (Livstidbestämning av LED-källor), Temadag LED-besvär?, Göteborg, Sweden, February 14, 2012. (Invited talk)

P. Kärhä, A. Heikkilä, and M. Kaunismaa, “Measurement setups and methods for UV action spectra of materials,” *NOG, Annual Meeting of the Nordic Ozone and UV Group*, Helsinki, February 8–10, 2012. (Poster)

P. Kärhä and J. Gröbner, “Improving spectral solar UV traceability to SI (EMRP project),” *NOG, Annual Meeting of the Nordic Ozone and UV Group*, Helsinki, February 8–10, 2012. (Talk)

M. Shpak, “Energy efficiency of outdoor lighting,” *International Scientific Metrology Symposium: Metrology for Energy*, Kgs. Lyngby, Denmark, May 24, 2012. (Invited talk)

T. Laurila, “Advances in the optical analytics of liquids and gases,” *Summer School of the Estonian Physical Society*, June 26–28, 2012. (Invited talk)

K. Lakkala, A. Arola, A. Heikkilä, J. M. Karhu, J. Kaurola, T. Koskela, E. Kyrö, P. Kärhä, A. V. Lindfors, O. Meinander, J. Gröbner, and G. Hülsen, “Two decades of spectral UV measurements at Sodankylä,” *Abstracts of the International Radiation Symposium IRS2012*, August 6–10, 2012, Berlin, Germany, IRS2012-265. (Poster)

P. Kärhä, T. Pulli, P. Jaanson, J. Mes, J. Schreder, and F. Manoocheri, “Improved diffusers for solar UV spectroradiometers,” *Abstracts of the International Radiation Symposium IRS2012*, August 6–10, 2012, Berlin, Germany, IRS2012-359. (Talk)

J. Gröbner, P. Blattner, M. Blumthaler, J. Dubard, L. Egli, O. El Gawhary, G. Hülsen, P. Kärhä, P. Meindl, J. Mes, C. Monte, S. Nevas, K. Nield, S. Nowy, M. Pisani, G. Porrovecchio, M. Rajteri, J. Schreder, M. Schuster, M. Šmíd, P. Sperfeld, A. Sperling, M. Wähmer, L. Werner, “Improving spectral solar UV traceability to SI,” *Abstracts of the International Radiation Symposium IRS2012*, August 6–10, 2012, Berlin, Germany, IRS2012-110. (Talk)

M. Shpak, P. Kärhä, G. Porrovecchio, A. Sjöberg, M. Smid, E. Ikonen, “A two channel photopic-scotopic luminance meter as a basis for mesopic photometry,” *Abstracts of the CIE Lighting Quality & Energy Efficiency Conference*, Hangzhou, China, September 18–21, 2012, pp. 190–191. (Talk)

E. Ikonen, T. Poikonen, H. Baumgartner, P. Kärhä, T. Pulli, A. Vaskuri, "Characterization of LED lamps for energy efficient lighting," *Abstracts of the CIE Lighting Quality & Energy Efficiency Conference*, Hangzhou, China, September 18–21, 2012, pp. 118–119. (Talk)

J.-M. Hirvonen, T. Poikonen, P. Kärhä, Erkki Ikonen, "Spectrally tunable radiance source based on LEDs," *Abstracts of Northern Optics 2012*, Helsingør, Denmark, November 19–21, 2012. (Poster)

H. Baumgartner, A. Vaskuri, P. Kärhä, G. Andor, T. Poikonen, E. Ikonen, "Non-contact methods for high power LED junction temperature measurement," *Abstracts of Northern Optics 2012*, Helsingør, Denmark, November 19–21, 2012. (Talk)

P. Jaanson, F. Manoocheri, E. Ikonen, "Measurements of non-Lambertian fluorescence emission and absolute quantum yield of fluorescence standards," *Abstracts of Northern Optics 2012*, Helsingør, Denmark, November 19–21, 2012. (Talk)

K. Blomberg von der Geest, J. Hyvönen, T. Laurila, "Real-time determination of metal concentrations in liquid flows using micro-plasma emission spectroscopy," *Abstracts of Northern Optics 2012*, Helsingør, Denmark, November 19–21, 2012. (Poster)

T. Laurila, S.-S. Kiwanuka, C. Kaminski "Chemical analysis using supercontinuum radiation," *Abstracts of Northern Optics 2012*, Helsingør, Denmark, November 19–21, 2012. (Poster)

K. Blomberg von der Geest, J. Hyvönen, T. Laurila, "Real-time determination of metal concentrations in liquid flows using micro-plasma emission spectroscopy," *Proc. IEEE Xplore Conference Publications Photonics Global Conference (PCG) 2012*, Singapore, December 13–16, 2012. (Talk)

7.3 National Conference Presentations

M. Shpak, "Ulkovalaistuksen mittaukset," Standardit ja säädökset, luotettavien mittausten edellytykset seminar, MIKES, Finland, May 3, 2012. (Invited talk)

M. Sildoja, F. Manoocheri, M. Merimaa, E. Ikonen, I. Müller, L. Werner, J. Gran, T. Kübarsepp, M. Smîd and M.L. Rastello, "Predictable quantum efficient detector," Aalto Science Day, Espoo, September 20, 2012. (Poster)

T. Kääriäinen, A. Vaigu, T. Laurila, "Optical sensors for real-time analysis of biofuels," Aalto Science Day, Espoo, September 20, 2012. (Poster)

T. Laurila, "Advances in chemical sensing using supercontinuum light," Aalto Science Day, Espoo, September 20, 2012. (Talk)

J.-M. Hirvonen and A. Miranto, "Sählymaali, ball speed measurement setup," Aalto Science Day, Espoo, September 20, 2012. (Demonstration)

P. Jaanson, F. Manoocheri, E. Ikonen, "Measurements of non-Lambertian fluorescence emission and absolute quantum yield of fluorescence standards," Aalto Science Day, Espoo, September 20, 2012. (Poster)

7.4 Other Publications

S. Park and E. Ikonen (Eds.), *Proceedings of NEWRAD 2011*, 299 p (2011).

A. Pietiläinen, M. Merimaa, T. Niemi, P. Kärhä, M. Ojanen, and M. Shpak, *Mittaustekniikan perusteiden laboratoriotyöt*, 18. korjattu painos, Espoo 2011, ISBN 978-952-60-3324-2, 125 p. (in Finnish)

A. Pietiläinen, M. Merimaa, T. Niemi, P. Kärhä, M. Ojanen, and M. Shpak, *Mittaustekniikan perusteiden laboratoriotyöt*, 19. korjattu painos, Espoo 2012, ISBN 978-952-60-3324-2, 125 p. (in Finnish)

E. Hiltunen, L. Linko, S. Hemminki, M. Hägg, E. Järvenpää, P. Saarinen, S. Simonen, and P. Kärhä, *Laadukkaan mittamisen perusteet*, MIKES julkaisu J4/2011, Metrologian neuvottelukunta ja Mittatekniikan keskus MIKES, Espoo 2011, ISBN 978-952-5610-75-8, 134 p. (in Finnish)

E. Ikonen and T. Laurila, *Optiikan perusteet*, 5. korjattu painos, Espoo 2012, ISBN 951-22-4709-7, 123 p. (in Finnish)

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