Aalto University School of Science and Technology
Department of Signal Processing and Acoustics
Metrology Research Institute
Espoo 2010

ANNUAL REPORT 2009

Aalto University
School of Science
and Technology

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Editor Ulla Sikander

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Aalto-yliopiston teknillinen korkeakoulu
Signaalinkäsittelyn ja akustiikan laitos
MIKES-Aalto Mittaustekniikka

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CONTENTS

1 INTRODUCTION

At the end of year 2009 the Helsinki University of Technology (TKK) ceased to be an independent university. TKK was one of the three merging universities in the Helsinki area which now operate under the name Aalto University. The Metrology Research Institute is a joint unit of the Aalto University and Centre for Metrology and Accreditation (MIKES). The Finnish name of the Institute is MIKES-Aalto Mittaustekniikka and it acts as the Finnish national standards laboratory for optical quantities. The Metrology Research Institute is part of the Department of Signal Processing and Acoustics at the Faculty of Electronics, Communications and Automation of the Aalto School of Science and Technology. Welcome simplification of the organisation and names is expected during the coming years.

The research highlights of 2009 include new methods for linking results of key comparisons and for temperature measurement of a microbridge. A systematic procedure with real measurement data was developed for determining the uncertainty of the degree of equivalence of a regional comparison participant wishing to link their results to the key comparison reference value. Optical temperature measurements of the microbridge were developed and compared successfully with contact temperature measurements made with a micro-thermocouple at the temperature range of 600–1000 °C. Additional research contributions are described in more detail in Sec. 5 of this Annual Report.

The number of calibration certificates issued in 2009 was 56. Two doctoral degrees and six M.Sc. degrees were achieved in 2009. These are about the same numbers as in 2008.

Erkki Ikonen

2 PERSONNEL

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Häkkinen Esa	Helsinki Institute of Technology	+358 9 310 8311

3 TEACHING

3.1 Courses

The following courses were offered by the Metrology Research Institute in 2009. Those marked by * are given biennially.

S-108.1010	Fundamentals of Measurements A 4 p (Kärhä Petri)
S-108.1020	Fundamentals of Measurements Y 3 p (Kärhä Petri)
S-108.2010	Electronic Measurements 3 credits (Petri Kärhä)
S-108.2110	Optics 5 credits (Pasi Manninen, Tuomas Hieta, Erkki Ikonen)
S-108.3011	Sensors and Measurement Methods 5 credits (Pasi Manninen)
S-108.3020	Electromagnetic Compatibility 2 credits (Esa Häkkinen)
S-108.3030	Virtual Instrumentation* 5 credits (Petri Kärhä)
S-108.3110	Optical Communications 5 credits (Farshid Manoocheri, Goery Genty)
S-108.3120	Project Work 2-8 credits (Erkki Ikonen, Tuomas Poikonen)
S-108.3130	Project Work in Measurement Science and Technology 2-10 credits (Erkki Ikonen, Tuomas Poikonen)

S-108.3140	Project Work in Optical Technology 2-10 credits (Erkki Ikonen, Tuomas Poikonen)
S-108.4010	Postgraduate Course in Measurement Technology* 10 credits (Petri Kärhä)
S-108.4020	Research Seminar on Measurement Science 2 credits (Erkki Ikonen)
S-108.4110	Biological Effects and Measurements of Electromagnetic Fields and Optical Radiation* 4 credits (Kari Jokela)
S-108.4120	Special Course in Measurement Science and Technology* 2-6 credits (Erkki Ikonen)

3.2 Degrees

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

Mikko Puranen, *Pulsed Radar Measurements and Related Equipment*

Opponent: Prof. Mike Underhill, Underhill Research, United Kingdom

Silja Holopainen, *Absolute Measurement Methods for Reflectance and Fluorescence*

Opponent: Prof. Andy Monkman, Durham University, United Kingdom

3.2.2 Licentiate of Science (Technology), Lic.Sc. (Tech.)

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

Kaija Rantoja, *Goniometric Measurements of Liquid Fluorescent Materials,*

Petteri Ahonen, *Extension of Spectral Responsivity Scale for Infrared Detectors*

Nicklas Forss, *An Ozone Measurement Device Utilizing a UV-LED Light Source*

Marko Kanto, *Statistical Methods in Integrated Circuit Characterisation*

Akseli Miranto, *Microelectromechanical Infrared Spectrometer*

Jussi Mäkynen, *A Lightweight Hyperspectral Imager*

3.2.4 Bachelor of Science (Technology), B.Sc. (Tech.)

Antti Matinlauri, *Puolisiltamoduulin automaattisen testilaitteen mittaustulosten tilastollisen seurannan toteuttaminen* (guided by Petri Kärhä)

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 April 1996.

The institute gives official calibration certificates on various optical quantities in the fields of Photometry, Radiometry, Spectrophotometry and Fiber Optics. During 2009, 56 calibration certificates were issued. 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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5 RESEARCH PROJECTS

5.1 Optical Radiation Measurements

Improvements in LED luminous flux setup

The integrating sphere setup of LED luminous flux has been further improved by a new LED holder and baffle design (see Figure 1). The original baffles and the LED holder of the sphere were replaced with our custom-made parts. The size of the new baffles was optimized to be as small as possible to reduce unnecessary screening, while maintaining the functionality. The design of the LED holder was also revised. The holder was equipped with an aluminum cone head to reduce absorption of the backward emission of LEDs. The new baffle, which is needed in the total luminous flux measurements, is now fixed to the holder and can be detached from the sphere together with the holder. These design changes clearly improve the spatial responsivity of the measurement setup.

Figure 1. New custom parts of the LED luminous flux sphere.

The SRDF (Spatial Resonsivity Distribution Function) of the sphere was scanned in partial flux geometry using a green collimated LED and a rotation stage in the center of the 50-mm entrance aperture of the sphere. The scanning was conducted before and after the modifications, in both vertical and horizontal directions covering a measurement angle of ±60°. With the new baffles, variation of less than ±1.5 % in the SRDF was obtained in the area, where the light does not illuminate the baffles directly. This is a vast improvement compared to the old design, which resulted in variation of more than ±5 % in the SRDF. Spatial correction factors were simulated for LEDs having varying angular distributions. The results of the study show that the correction is needed only for LEDs having angular spread larger than ±40° or significant minor beams. Expanded uncertainty (k = 2) of the improved measurement setup varies between 1.2 % and 4.6 % depending on the measurement geometry, color, and the angular spread of the test LED light beam. A paper of the measurement setup has been accepted for publication in Review of Scientific Instruments.

Uncertainty analysis of photometer quality factor f_1'

Quality factor f_1' quantifies the spectral matching of photometers with the $V(\lambda)$ function. We have studied the applicability of random and biased error models for determining the uncertainty of f_1' using Monte Carlo simulations and real spectral responsivity data of two photometers. In the case of filtered detectors, the wavelength uncertainty of the spectral responsivity measurement with a monochromator may cause a large biased error contribution to the relative spectral responsivity $s_{rel}(\lambda)$ of the photometer, in addition to true random uncertainty components. The results show that the random error model alone underestimates the uncertainty of f_1'. The real effect of the biased uncertainty components, such as that due to the wavelength scale, on the uncertainty of f_1' can be evaluated only with the biased error model.

It was also found that the uncertainty of f_1' can be highly sensitive to fine details of the spectral responsivity data when the biased error model is used. Lower uncertainties of f_1' are obtained with spectral responsivity data, which cross the $V(\lambda)$ curve at several wavelengths. The results of Monte Carlo simulations with the biased error model for this type of spectral responsivity data approach the simulation results obtained with the random error model. Due to the absolute value integrand in the definition of f_1', Monte Carlo simulations may produce mean values of the probability distribution of f_1' that are higher than the nominal value of f_1' calculated using the nominal spectral responsivity of the photometer. A practical interpretation of this result is that the estimate of f_1' is given by the nominal value which is accompanied by a skewed probability distribution of f_1'

where the mean does not necessarily coincide with the nominal value of f_1'. Also, in practice the shift from the nominal value is small as compared with the uncertainty of f_1' when the biased uncertainty components dominate. Spectral responsivity data and Monte Carlo simulation results for two photometers are shown in Figure 2. A paper of the study has been published in Metrologia.

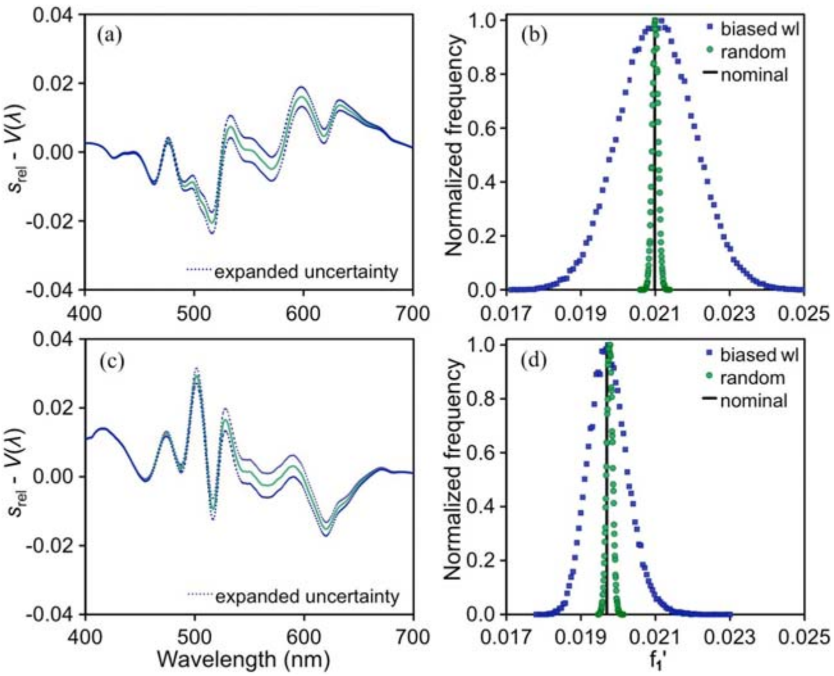

Figure 2. Deviation $s_{rel}(\lambda)-V(\lambda)$ and absolute expanded uncertainty (k = 2) of the relative spectral responsivity (a) for photometer 1 and (c) for photometer 2. Probability distributions of f_1' for (b) photometer 1 and (d) photometer 2.

Measurement of LED luminance

Applicability of the method of effective luminous intensity to the determination of the LED luminance has been studied. Illuminances from a few directional LEDs in variable distances were measured by an illuminance meter (Figure 3). From this measurement data, the effective luminous intensity, size, and location of the virtual source of the LEDs could be analyzed. The effective LED luminance was then obtained as a ratio of the effective luminous intensity to the area of the emitting surface of the virtual source. To verify the applicability of the method, the luminance distributions of the LEDs were measured by a luminance meter with narrow measurement angle. The average luminances were calculated from the luminance distributions measured. The agreement between the methods was typically within 5 %. The method of effective luminous intensity works best for the directional LEDs having flat-top-type luminance distributions. Such LEDs are also important from the point of view of eye safety.

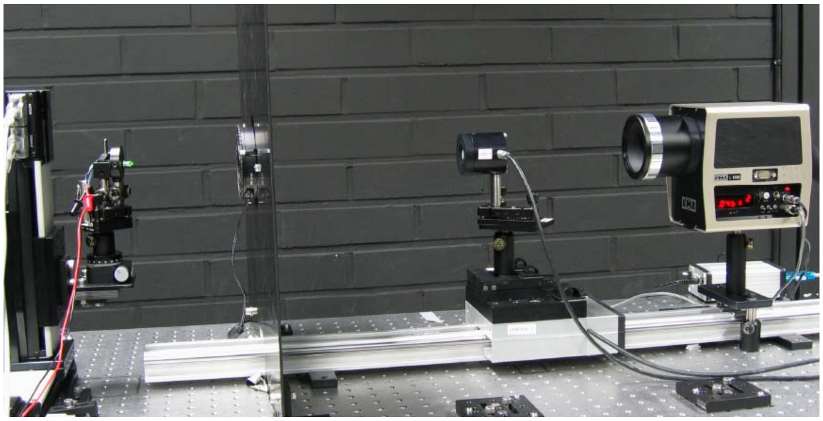

Figure 3. The measurement setup for determination of LED luminance.

Spectral irradiance model for 1 kW tungsten halogen lamps

We have developed a physical model for the spectral irradiance of 1-kW tungsten halogen incandescent lamps for the wavelength range 340 – 850 nm. The model consists of the Planck's radiation law, published values for the emissivity of tungsten, and a residual spectral correction function taking into account unknown factors of the lamp (Figure 4). The correction function was determined by measuring the spectra of an FEL type incandescent lamp at different temperatures. The model was tested with 1-kW tungsten halogen lamps of types FEL and DXW. Comparisons with measurements of two national standards laboratories (MIKES/Aalto and NPL) indicate that the model can account for the spectral irradiance values of lamps with an agreement better than 1 % throughout the spectral region studied. The spectral irradiance of a lamp can be predicted with an expanded uncertainty of 2.6 % if the color temperature and illuminance values for the lamp are known with expanded uncertainties of 20 K and 2 %, respectively. Using resistance measurements at room temperature and at burning temperature, the temperature of the filament may be obtained by using the known temperature dependence of the resistance of tungsten. A paper of the results has been accepted for publication in Applied Optics.

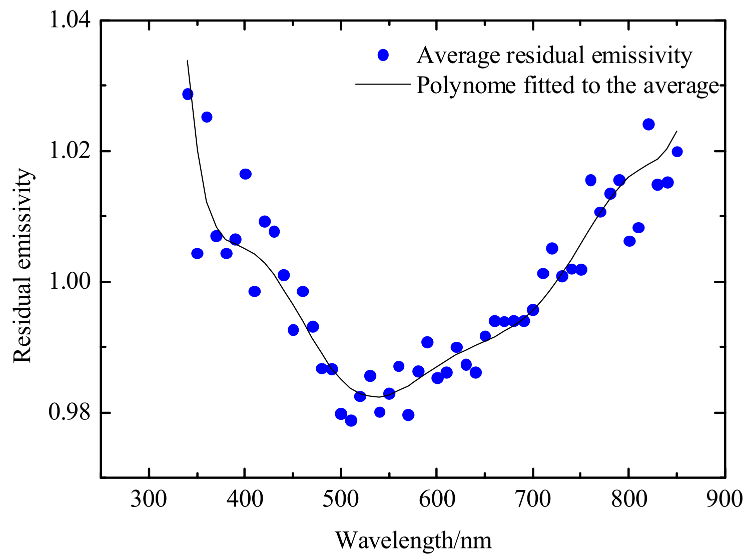

Figure 4. Averaged measured residual emissivity and an 8th degree polynomial fitted to the average.

Radiation temperature measurements

Preparations for the development of the lower temperature measurement facility (500 – 850 °C) were continued. Linear pyrometer of type LP3 was calibrated, and it was used to characterize a new copper fixed point cell and a sodium heat-pipe, which were purchased in spring 2009. The single-diode Si filter radiometers with nominal wavelengths of 800 and 900 nm and a new electrometer will be used to measure the temperature of the sodium heatpipe in spring 2010.

Temperature measurements of silicon microbridge emitters

Microbridges are miniature suspended structures fabricated in silicon. Microbridges can be used as wideband light sources when heated by passing a current through them. We investigated the behavior of the microbridge by measuring its emitted spectrum and determining the temperature from Planck's radiation law. The emissivity was modeled with thin-film Fresnel equations. Temperatures of 500–1100 °C were obtained from the measured spectra at different levels of applied power. The range is limited by the sensitivity of the detectors at lower power levels, and by the stability of the bridge at higher levels. Results of the optical measurements were compared with contact temperature measurements in collaboration with the Department of Micro and Nanosciences. Contact measurements were made with a microthermocouple in the same temperature range, and the results of the two methods agree within 100 K. A paper on the results of the study has been accepted for publication in Applied Optics.

Goniofluorometer for characterization of fluorescent materials

A goniofluorometer can characterize the angular behaviour of fluorescence emission from various materials. The device can also measure the luminescent radiance factors in the wavelength range of 250 – 800 nm. Such measurements are needed so that the colour of a fluorescent specimen can be determined for a desired source and observer. Part of the research work has been devoted to investigations on possible non-Lambertian behaviour of the opaque fluorescent standard materials. Also extensive measurements of the fluorescence spectra of several well known fluorophores such as fluorescein, rhodamine 101, and quinine sulphate as liquid samples have been performed and reported. The work in developing methods for determination of fluorescent quantum yield is ongoing. There are also difficulties in traceable calibration of commercially available fluorometers used in various industries. To address this issue we have initiated the development of a calibration method using well known fluorophore liquid solutions with spectral and quantum efficiency traceability to our measurements using the goniofluoromer facility. For this purpose a luminescence spectrometer type LS 55 manufactured by Perkin Elmer is used.

Detector responsivity at infrared

The development of the infrared spectrometer facility is nearly complete for accommodating accurate measurement of spectral power responsivity in the wavelength range from 0.7 μm to 15 μm. The measurements performed with the facility are traceable via a reference pyroelectric detector to the scale of optical power maintained by the laboratory. The uncertainty of the measurements depends on the spectral range and the device under test among other factors. At present, the best measurement uncertainty is about 4% with components arising from measurement repeatability, linearity and spatial uniformity of reference detector, wavelength scale, and ambient condition of the measurement compartment.

Predictable Quantum Efficient Detector

A new type of primary standard – Predictable Quantum Efficiency Detector (PQED) – is developed under the EMRP (European Metrology Research Programme) joint project Quantum Candela. The challenging goal is to design and construct a primary detector with 1 ppm uncertainty for optical power measurements. In this project Aalto University is a collaborator supported financially by the Academy of Finland and MIKES is responsible of building the detector consisting of two large area silicon photodiodes having a natural inversion layer instead of a conventional pn-junction. The photodiodes (produced by VTT) are operated at liquid nitrogen temperatures under reverse bias and must be kept in very clean environment. Working at such low temperatures and fulfilling the condition of cleanliness requires that the diodes are placed into a cryostat and surrounded with high vacuum. In 2009 the test PQED was built (Figure 5) and measurements against reference standard trap detector were carried out at the level of 500 ppm of uncertainty. The results showed that external quantum efficiency close to 1 is achievable.

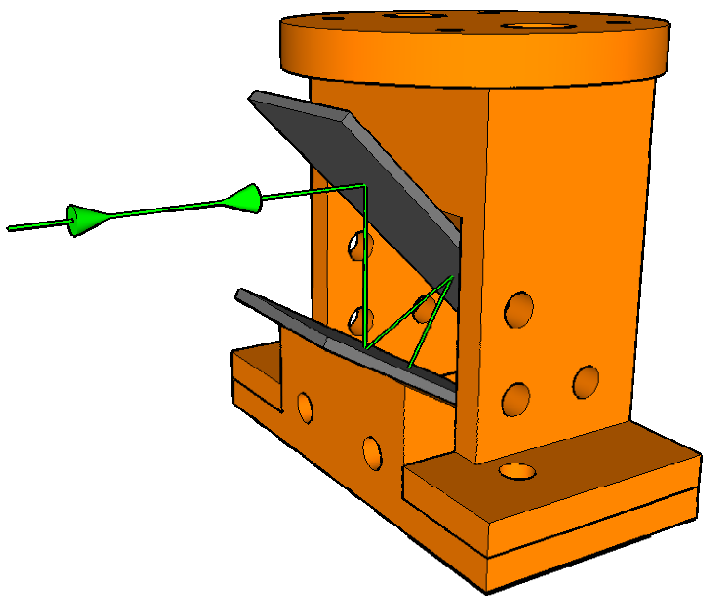

Figure 5. Laser beam travelling between two PQED diodes placed into custom designed copper holder. Metal holder is required for good thermal conductivity. The diodes are misplaced for clear vision. In reality they are entirely inside the holder.

Effects of UV radiation on MAterials 2 (UVEMA-2)

This two-year project funded by TEKES is a continuation of an earlier project. The work is carried out in collaboration with the Finnish Meteorological Institute, Tampere University of Technology and several industrial partners. The role of the Metrology Research Institute is to build an improved version of the device that can be used for studying the effect of wavelength on the UV ageing of materials.

The improved device (Figure 6), as its predecessor, is based on a concave flat-field holographic grating and a 1-kW Xe-lamp. The major improvements are:

1. The sample can be heated up to 80 °C to accelerate the ageing.

2. The output spectrum is limited to wavelengths 280 – 420 nm to avoid the problems associated with higher order diffraction.

3. There is an additional sample port for the zero order diffraction.

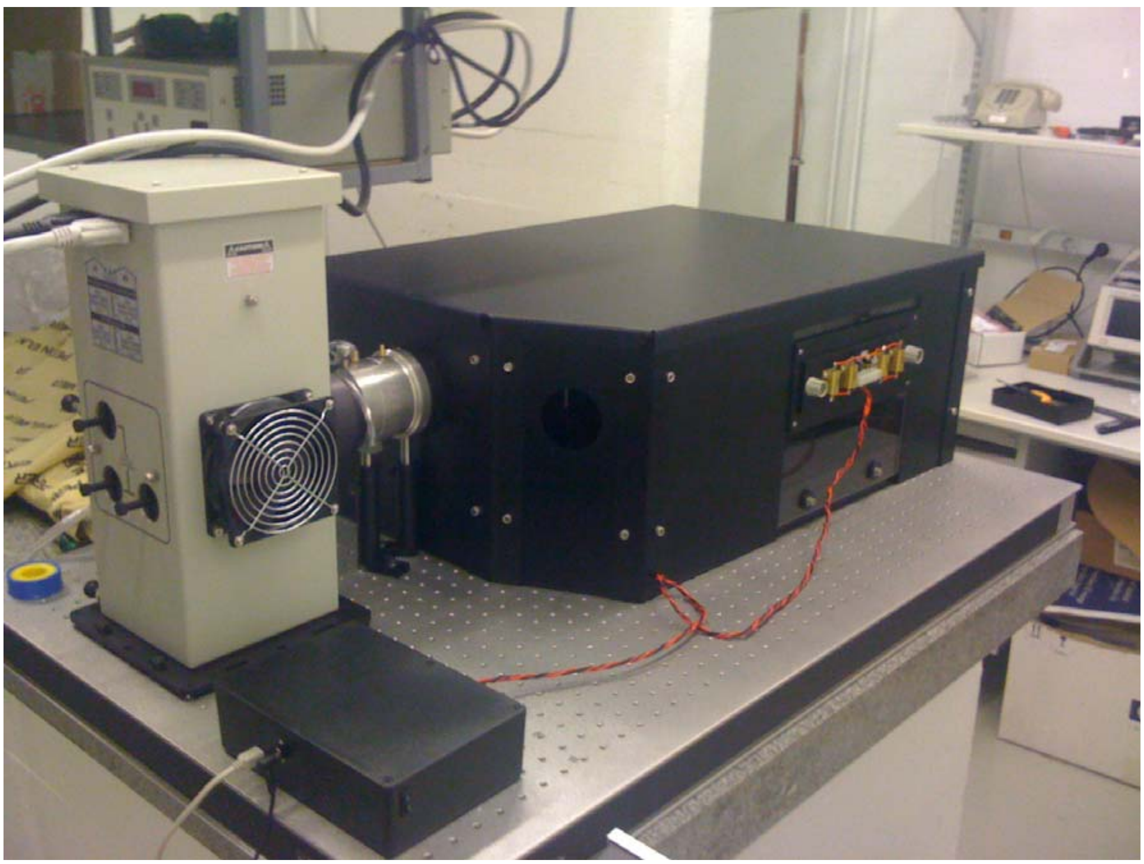

Figure 6. The new ageing facility. Light of the 1-kW Xe-lamp (left) is coupled into the spectrograph inside the black box. The components on the front surface of the box include a heater attached on the sample to heat it up to 80 °C. The zero-order diffraction comes out of the spectrograph through the round opening.

During 2009, the device was assembled and thoroughly tested. The performance is comparable to the first prototype. The output power is slightly reduced due to the increased dispersion needed to meet the reduced wavelength region. Test measurements show that the heating works and does really accelerate the ageing (Figure 7). However, it was noted that in some cases the heating also changes the action spectrum. The channel containing the zero-order diffraction was a slight disappointment. This channel contains very little UV and thus samples attached to it age slower than anticipated.

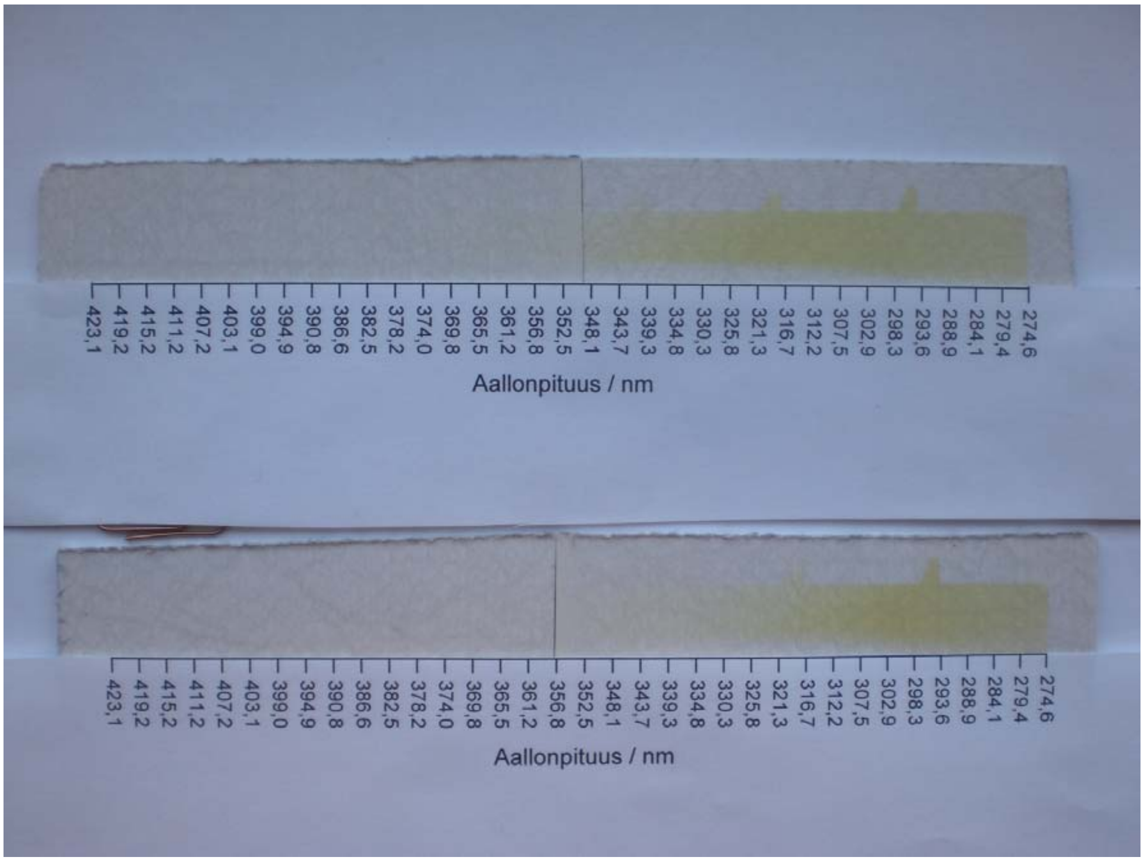

Figure 7. Aged polymer samples. The time for ageing has been the same for both samples, but the upper sample has been heated up to 70 °C. It is clearly seen that the ageing has been significantly accelerated.

5.2 Applied Quantum Optics

Coherence of radiation as studied by multiple coincidences of photons and particles

Analogies between the coherence properties of photon and particle radiation are studied with the aim of applying the results obtained in quantum optics to heavy ion collisions. In particular, multiple coherent source components for particle correlation experiments are considered with partially coherent pion radiation produced by heavy-ion collisions. If the partial coherence in pion radiation will ever be conclusively demonstrated, the source properties producing this radiation become under study. The work contributes to the understanding of properties of such particle radiation. The conventional analysis, which assumes one coherent source current, is extended to cover the case of multiple coherent source currents. Theoretical calculations on the relation between two- and three-pion correlators give some evidence, when compared with experimental data, for the existence of multiple coherent components in heavy-ion collisions. In 2009, these results were presented in particle collision conferences with financial support from the Academy of Finland as an appropriation to Senior Scientist.

6 INTERNATIONAL CO-OPERATION

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

6.1 International Comparison Measurements

Key comparison CCPR-K2.a, spectral responsivity 900-1600nm, pilot NIST

Final report has been published. MIKES results are well in agreement with the reference value.

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

The measurements are complete and the pre-Draft A process is finished. Draft A is expected in May 2010.

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

Draft A-2 in the form of Draft B is being prepared. Informal bilateral comparison results are also being analyzed.

Key comparison EURAMET.PR-K6, spectral regular transmittance, pilot LNE

MIKES acts as one of the seven EURAMET link laboratories in this regional key comparison to be linked to CCPR-K6. The measurement results from the year 2000 of CCPR-K6 were used for the linkage. The final report has been published.

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

MIKES and pilot measurements of four transfer standard lamps of luminous intensity were completed during 2008. The return measurements by MIKES were made in 2009.

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

MIKES measurements of four transfer standard lamps of luminous flux were completed during 2008. The pilot measurements and return measurements by MIKES were made in 2009.

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. The MIKES measurements were completed during 2008. The draft A is expected in October 2010.

Bilateral comparison of spectral diffuse reflectance

A comparison between the absolute gonioreflectometric scales at the Metrology Research Institute and the Physikalisch-Technische Bundesanstalt (PTB) has been accomplished. Six different reflection standards were measured for their 0:45° spectral radiance factors between 250 nm and 1650 nm in 10 nm intervals. Also, the 0:d reflectance factor between 400 nm and 1600 nm in 100 nm intervals was determined from the goniometric reflectance measurements over polar angles with subsequent integration within the hemisphere above the sample. The differences between the results were within the expanded uncertainty of the comparison ranging from 0.6% to 2.7%. A full report of the results has been published in Applied Optics **48**, 2947–2957 (2009).

Bilateral comparison of spectral regular reflectance at infrared wavelengths

A comparison between the absolute regular reflectance scales of the Metrology Research Institute and of the Physikalisch-Technische Bundesanstalt (PTB) has been performed in the wavelength range 1000 -2500 nm at 50 nm intervals. Two mirrors, aluminium and gold, were used for the measurements at incident angles of about 6°. PTB measured reflectance for the wavelengths 1400 nm, 1700 nm, 2000 nm, 2200 nm and 2500 nm. The differences between the results were within the expanded uncertainty of the comparison ranging from 0.2% to 0.5%. An internal report on the result will be prepared in 2010.

Bilateral comparison MIKES-PTB in radiation temperature

The radiation temperature scales of PTB and MIKES were compared in the range of 1570 - 2770 K using four filter radiometers of MIKES, one filter radiometer of PTB, and linear radiation thermometers of both MIKES and PTB. The agreement was partial: Two filter radiometers and the linear radiation thermometer of MIKES agreed well with the equipment of PTB, while two filter radiometers deviated from the other equipment. The results of the comparison have been published in Measurement **43**, 183-189 (2010).

Trilateral comparison of fiber optic power

In 2009, MIKES took part in a trilateral comparison measurement of fiber optic power with the accredited laboratory of NEMKO as the pilot. Measurements were completed in 2009.

6.2 Conferences and Meetings

iMERA+ Regenmed JRP meeting, Turin, Italy, January 14–17, 2009; *Farshid Manoocheri*

EMRP Committee meeting, Turin, Italy, March 3–5, 2009; *Erkki Ikonen*

Green Lighting Event 2009, Frankfurt, Germany, March 24–26, 2009; *Erkki Ikonen*

iMERA+ Candela JRP meeting, Sofia, Bulgaria, April 22, 2009; *Erkki Ikonen, Farshid Manoocheri*

EURAMET TC Phora meeting, Sofia, Bulgaria, April 22–24, 2009; *Erkki Ikonen, Farshid Manoocheri*

Interreg-meeting, Tallinn, May 13, 2009*; Erkki Ikonen*

CIE Light and Lighting Conference, Hungary, Budapest, May 26–29, 2009; *Erkki Ikonen, Pasi Manninen and Tuomas Poikonen*

CIE TC and Division 2 meetings, Hungary, Budapest, May 31 – June 3, 2009; *Erkki Ikonen, Pasi Manninen*

EURAMET General Assembly, Malta, June 9–10, 2009; *Erkki Ikonen*

EMRP Committee meeting, Malta, June 10–11, 2009; *Erkki Ikonen*

NPL Optical Technologies Workshop, London, UK, June 16–19, 2009; *Tuomas Poikonen*

International Metrology Congress, France, Paris, June 22–25, 2009; *Erkki Ikonen*

EMRP Sub-Committee meeting, Ajaccio, France, July 21–24, 2009; *Erkki Ikonen*

Northern Optics 2009 Conference, Vilnius, Lithuania, August 26–28, 2009; *Erkki Ikonen*

OIE 2009, the Eighth Japan-Finland Joint Symposium on Optics in Engineering, Tokyo, Japan, September 2–5, 2009; *Erkki Ikonen*

Preparation meeting of EMRP SSL project, Delft, The Netherlands, September 8 – 9, 2009; *Petri Kärhä*

iMERA+ Candela JRP meeting, Turin, Italy, September 8–12, 2009; *Farshid Manoocheri, Erkki Ikonen*

EURAMET TC Phora additional meeting, Paris, France, September 14, 2009; *Erkki Ikonen*

CCPR WG-SP TG-4 meeting, Paris, France, September 14, 2009; *Erkki Ikonen*

CCPR WG-KC meeting, Paris, France, September 15, 2009; *Erkki Ikonen*

CCPR WG-CMC meeting and WG-SP meeting, Paris, France, September 16, 2009; *Erkki Ikonen*

CCPR meeting, Paris, France, September 17–18, 2009; *Erkki Ikonen*

CCPR WG-KC TG RMO Linking meeting, Paris, France, September 18, 2009; *Erkki Ikonen*

OFMC 2009 Conference, London, UK, September 16–18, 2009; *Tuomas Hieta*

BIPM Worksop of Physiological Quantities and SI Units, France, Paris, November 15–17, 2009; *Erkki Ikonen*

Hadron Collider Physics Symposium, France, Evian, November 17–20, 2009; *Erkki Ikonen*

EMRP Proposal Review Conference, Berlin, Germany, November 25–26, 2009; *Erkki Ikonen*

EMRP Sub-Committee meeting, Berlin, Germany, November 26, 2009; *Erkki Ikonen*

EMRP Committee meeting, Berlin, Germany, November 27, 2009; *Erkki Ikonen*

iMERA+ Regenmed JRP meeting, London, UK, November 26–27, 2009*, Farshid Manoocheri*

Hadron 2009 Conference, Tallahassee, Florida, USA, November 29 – December 4, 2009; *Erkki Ikonen*

6.3 Visits by the Laboratory Personnel

Erkki Ikonen, Petri Kärhä, Farshid Manoocheri, Silja Holopainen, Maija Ojanen, Tuomas Poikonen, Meelis-Mait Sildoja, Maksim Shpak, Antti Kunnas, Timo Dönsberg, jarkko Koski and Prasad Thakur, Research Group Development Day and visit to Tartu University, Estonia, May 14–15, 2009

Erkki Ikonen, NMIJ, Tsukuba, Japan, September 2, 2009

Erkki Ikonen, SPring-8, Hyogo, Japan, September 7, 2009

Erkki Ikonen, PTB, Braunschweig, Germany, October 23, 2009

Erkki Ikonen, Ohio State University, Columbus, Ohio, USA, December 7, 2009

Maija Ojanen, LNE, Paris, France, December 18, 2009.

6.4 Research Work Abroad

Silja Holopainen, PTB, Braunschweig, Germany, January 1 – April 30, 2009

Farshid Manoocheri, Measurements for the Quantum Candela project, PTB, Berlin, Germany, April 2–9, 2009

6.5 Guest Researchers

M.Sc. Julie Dahl, Justervesenet, Norway, August 3–21, 2009

6.6 Visits to the Laboratory

Dr. Jouni Envall, Tartu Observatory, Estonia, February 3–6, 2009

Ilmar Ansko, Tartu Observatory, Estonia, February 3–6, 2009

Joel Kuusk, Tartu Observatory, Estonia, February 3–6, 2009

Dr. Toomas Kubarsepp, Metrosert, Estonia, February 5, 2009

Prof. Mike Underhill, Underhill Research Ltd, United Kingdom, March 24–25, 2009

Dr. Jouni Envall, Tartu Observatory, Estonia, June 9–10, 2009

Prof. Andy Monkman, Durham University, United Kingdom, June 16–17, 2009

Dr. Giorgio Brida, INRIM, Italy, August 20, 2009

Dr. Jarle Gran, Justervesenet, Norway, August 20, 2009

Dr. Marek Smid, CMI, Czech Republic, August 20, 2009

Dr. Lutz Werner, PTB, Germany, August 20, 2009

Stian Samset Hoem, Justervesenet, Norway, August 20, 2009

Dr. Ingmar Muller, PTB, Germany, August 20, 2009

Dr. Toomas Kübarsepp, Metrosert, Estonia, August 20, 2009

Anne Anderson, SP, Sweden, August 24, 2009

Priit Jaanson, Metrosert, Estonia, August 24, 2009

Lukasz Litwiniuk, GUM, Poland, November 24, 2009

7 PUBLICATIONS

7.1 Articles in International Journals

A. Heikkilä, P. Kärhä, A. Tanskanen, M. Kaunismaa, T. Koskela, J. Kaurola, T. Ture, and S. Syrjälä, “Characterizing a UV chamber with mercury lamps for assessment of comparability to natural UV conditions,” *Polymer Testing* **28**, 57–65 (2009).

V. Ahtee, R. Lettow, R. Pfab, A. Renn, E. Ikonen, S. Götzinger, V. Sandoghdar, “Molecules as sources for indistinguishable single photons,” *Journal of Modern Optics* **56**, 161–166 (2009).

T. Poikonen, P. Kärhä, P Manninen, F. Manoocheri and E. Ikonen, ”Uncertainty analysis of photometer quality factor f_1’,” *Metrologia* **46**, 75–80 (2009).

M. Sildoja, F. Manoocheri and E. Ikonen, “Reflectance calculations for predictable quantum efficient detector,” *Metrologia* **46**, S151–S154 (2009).

M. Ojanen, M. Shpak, P. Kärhä, R. Leecharoen, and E. Ikonen, “Report of the Spectral Irradiance Comparison EURAMET.PR-K1.a.1 between MIKES (Finland) and NIMT (Thailand),” *Metrologia* **44**, Tech. Suppl. 02001, 16 pages (2009).

Y. J. Liu, G. Xu, M. Ojanen, and E. Ikonen, “Spectral irradiance comparison using a multi-wavelength filter radiometer,” *Metrologia* **46**, S181–S185 (2009).

T. Hieta and E. Ikonen, “Measurement of Erbium-doped fiber nonlinearity using continuous-wave self-phase modulation method,” *IEEE/OSA Journal of Lightwave Technology* **27**, 2977–2982 (2009).

T. Widmaier, T. Salmela, P. Kuosmanen, J. Juhanko, P. Kärhä, and J. Uusimäki, “Reducing thickness variation of hot rolled steel strip by non-circular backup roll geometry,” *Ironmaking and Steelmaking* **36**, 133–140 (2009).

S. Holopainen, F. Manoocheri, E. Ikonen, K.-O. Hauer, and A. Höpe, “Comparison measurements of 0:45 radiance factor and goniometrically determined diffuse reflectance,” *Applied Optics* **48**, 2947–2957 (2009).

S. Holopainen, F. Manoocheri and E. Ikonen, "Non-Lambertian behaviour of fluorescence emission from solid amorphous material," *Metrologia* **46**, S197–S201 (2009).

M. Ojanen, M. Shpak, P. Kärhä, R. Leecharoen, and E. Ikonen, "Uncertainty evaluation for linking a bilateral comparison with the corresponding CIPM key comparison," *Metrologia* **46**, 397–403 (2009).

P. Manninen, T. Koskela, L. Ylianttila, P. Kärhä, and E. Ikonen, "Estimation of the optical receiving plane positions of solar spectroradiometers with spherical diffusers on the basis of spatial responsivity data," *Opt. Lett.* **34**, 3241–3243 (2009).

T. Hieta, M. Vainio, C. Moser, and E. Ikonen, External-cavity lasers based on a volume holographic grating at normal incidence for spectroscopy in the visible range, *Optics Communications* **282**, 3119–3123 (2009).

M. Ojanen, K. Anhalt, J. Hartmann, S. Schiller, T. Weckström, P. Kärhä, M. Heinonen and E. Ikonen, "Comparison of the radiation temperature scales between MIKES and PTB", *Measurement* (in press).

7.2 International Conference Presentations

E. Ikonen, T. Poikonen, P. Kärhä, and P. Manninen, "Determination of LED luminance and radiance from effective intensity," *Proceedings of the CIE Light and Lighting Conference*, Budapest, Hungary, May 27–29, 2009, pp. 174–175 (poster).

T. Poikonen, P. Kärhä, P. Manninen, and E. Ikonen, "A multifunctional setup for measurement of LED luminous flux based on integrating sphere method," *Proceedings of the CIE Light and Lighting Conference*, Budapest, Hungary, May 27–29, 2009, pp. 115–116 (poster with short oral introduction).

P. Manninen, "Influence of duty cycle on properties of a phosphor-converted white LED," *Proceedings of the CIE Light and Lighting Conference*, Budapest, Hungary, May 27–29, 2009, pp. 200–201 (poster).

E. Ikonen "Silicon photodiodes as efficient detectors of light," *Proceedings of the Northern Optics 2009 Conference,* Vilnius, Lithuania, August 26–28, 2009, p. 30 (invited talk).

E. Ikonen, A. Haapalinna, M. Sildoja and F. Manoocheri, "Photon-to-electron converter with 1 ppm quantum deficiency," *Proceedings of the Northern Optics 2009 Conference,* Vilnius, Lithuania, August 26–28, 2009, p. 114 (poster).

E. Ikonen, "Coherence of radiation as studies by multiple coincidences of photons and particles," *Technical Digest of the OIE'09 Eighth Japan-Finland Joint Symposium on Optics in Engineering,* Tokyo, Japan, September 3–5, 2009, p. 19 (plenary talk).

P. Manninen, T. Koskela, L. Ylianttila, P. Kärhä, and E. Ikonen, "Imperfections in UV diffusers: practical consequences," 12th Biennial WMO-GAW Brewer Users Group Meeting, Aosta, Italy, 20–26 September 2009 (poster).

A. Heikkilä, S. Kazadzis, O. Tolonen-Kivimäki, O. Meinander, A. Lindfors, K. Lakkala, T. Koskela, J. Kaurola, A. Sormanen, P. Kärhä, A. Naula-Iltanen, S. Syrjälä, M. Kaunismaa, J. Juhola, T. Ture, U. Feister, N. Kouremeti, A. Bais, J.M.Vilaplana, J.J. Rodriguez, C. Guirado, E. Cuevas, and J. Koskinen, "Effects of terrestrial UV radiation on selected outdoor materials: an interdisciplinary approach." *Proc. SPIE* **7462**, 74620G (2009) (poster).

A. Heikkilä, P. Kärhä, K. Ruokolainen, J. Juhola, M. Kaunismaa, and T. Ture, "A new facility for ageing materials with spectrally resolved UV radiation," In: T. Reichert (Ed.) *Natural and Artificial Ageing of Polymers*, 4th European Weathering Symposium 16th - 18th September 2009, Budapest, Hungary. Gesellshaft für Umweltsimulation e.V. GUS, CEEES Publication No 11, 2009. (ISBN 978-3-9810472-8-8) (talk).

T. Hieta and E. Ikonen, "Measurement of Erbium-doped fiber nonlinearity using continuous-wave self-phase modulation method," Optical Fiber Measurement Conference 2009, Teddington, UK, September 16–18, 2009 (talk).

E. Ikonen, "Multiple coherent components in relativistic heavy-ion collisions," Hadron Collider Physics Symposium 2009, Evian, France, November 17–20, 2009 (poster).

E. Ikonen, "Multiple coherent components in relativistic heavy-ion collisions," Hadron 2009 Conference, Tallahassee, Florida, USA, November 29–December 4, 2009 (talk).

7.3 National Conference Presentations

E. Ikonen, "Multiple coherent components in relativistic heavy-ion collisions," *Proceedings of the XLIII annual conference of the Finnish Physical Society,* Espoo, Finland, March 12–14, 2009, p. 133 (poster).

T. Poikonen, P. Kärhä, P. Manninen, F. Manoocheri, and E. Ikonen, "Applicability of random and biased error models in uncertainty evaluation of photometer quality factor f_1'," *Proceedings of the XLIII annual conference of the Finnish Physical Society,* Espoo, Finland, March 12–14, 2009, p. 256 (poster).

M. Shpak, M. Ojanen, P. Kärhä, E. Ikonen, M. Heinonen and T. Weckström, "Optical temperature measurement of miniature silicon emitters," *Proceedings of the XLIII annual conference of the Finnish Physical Society,* Espoo, Finland, March 12–14, 2009, p. 285 (poster).

T. Ture, M. Kaunismaa, A. Sormanen, K. Ruokolainen, P. Kärhä, A. Naula-Iltanen, J. Juhola, J. Hakkarainen, S. Syrjälä, O. Kivimäki-Tolonen, O. Meinander, J. Kaurola, T. Koskela, A. Lindfors, A. Tanskanen, A. Heikkilä, and J. Koskinen, "Effects of UV radiation on materials," *Scientific Day 2009 of Tekes Functional Materials workshop,* April 1, 2009, Espoo, Finland (talk).

A. Heikkilä, S. Syrjälä, P. Kärhä, A. Sormanen, A. Naula-Iltanen, M. Kaunismaa, T. Ture, and J. Koskinen, "UVEMA2 - UV radiation effects on materials," Tekes Annual Seminar "*Driving innovation with nanotechnology and functional materials in Finland",* May 27–28, 2009, Helsinki, Finland (poster).

7.4 Other Publications

A. Pietiläinen, M. Merimaa, T. Niemi, P. Kärhä, and M. Ojanen, *Mittaustekniikan perusteiden laboratoriotyöt*, 16. korjattu painos, Espoo 2009, ISBN 951-22-6737-3, 118 p. (in Finnish).