Consultative Committee for Photometry and Radiometry (CCPR)
23rd Meeting (22 - 23 September 2016)

Questionnaire on activities in radiometry and photometry

Reply from: MIKES

Delegate: Erkki Ikonen

1. Summarize the progress in your laboratory in realizing top-level standards of:
   (a) broad-band radiometric quantities
   (b) spectral radiometric quantities
   (c) photometric quantities

2. What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

Answers to questions 1) and 2) are highlighted below and their relation to the indicated EMRP projects is also specified by the project abbreviation. These are results where many project partners have contributed and the references in the bibliography in point 8) give a more complete description of some of the results.

Newstar: This project aims for further development of the Predictable Quantum Efficient Detector (PQED). A new process of producing n type PQED photodiodes instead of the earlier p type photodiodes has been studied. Preliminary results of the n type photodiodes indicate that for the first time independent 3D modelling of the photodiode responsivity is in agreement with the independently measured responsivity. Another significant result is that the earlier p type photodiodes produced in 2010 still have the same responsivity within 100 ppm as six years ago. This is at least ten times slower aging rate than that of trap detectors built from Hamamatsu photodiodes.

Siqute: The MIKES contribution to this project developed a predictable single-photon source based on a silicon vacancy centre in a nano diamond which is optically excited by a pulsed laser. At an excitation rate of 70 million pulses per second, the source delivers a photon flux large enough to be measured by a sensitive analog-mode silicon detector. By changing the repetition rate of the pulsed laser, we are able to reduce in a controlled manner the photon flux of our single-photon source.

XDreflect: The angular profiles of emission and reflectance of fluorescent surfaces have been shown to deviate from Lambertian behaviour, however, in industry and calibration facilities single geometry measurements are often used, which requires assumptions to be made on the angular distributions. In the MIKES contribution to this project, a novel material was developed which demonstrates more Lambertian emission and reflectance profiles than conventional polytetrafluoroethylene based materials and a smaller dependence of angular reflectance on the absorbance of the sample.

PhotoLED: This project aims to develop LED standard lamps to be used in photometric calibrations and comparisons in order to allow lower measurement uncertainty at NMIs and at test laboratories. One of the early achievements is the promising result on testing a fisheye camera for angular non-uniformity correction of integrating spheres in luminous flux measurements. The new method promises lower uncertainty, lower costs, and easier measurement as compared with earlier methods based on goniophotometers.

MIKES and/or Aalto University participate in the following EMRP and EMPIR projects in the technological areas relevant to the CCPR:

- Newstar: New primary standards and traceability for radiometry (2013–2016)
- Siqute: Single-photon sources for quantum technologies (2013–2016)
- XDreflect: Multidimensional reflectometry for industry (2013–2016)
- Traceability for atmospheric total column ozone (2014–2017)
- Metrology for Earth observation and climate II (2014–2017)
- Metrology for III-V materials based high efficiency multi-junction solar cells (2014–2017)
- Traceable characterisation of thin-film materials for energy applications (2014–2017)
- Towards an energy-based parameter for photovoltaic classification (2014–2017)
- Metrology for efficient and safe innovative lighting (2014–2017)
- Optical metrology for quantum-enhanced secure telecommunication (2015-2018)
- Metrology for the photonics industry – optical fibres, waveguides and applications (2015-2018)
- PhotoLED: Future photometry based on solid state lighting products (2016-2019)

3. What work in PR has been/will be terminated in your laboratory, if any, in the past /future few years? Please provide the name of the institution if it has been/will be substituted by a DI or accredited laboratory.
4. What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.
5. What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?
6. Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?
7. Have you got any other information to place before the CCPR in advance of its next meeting?
8. Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (September 2014)?

Refereed journal publications

T. Dönsberg, T. Pulli, T. Poikonen, H. Baumgartner, A. Vaskuri, M. Sildoja, F. Manoocheri, P. Kärhä, and E. Ikonen, ”New source and detector technology for the realization of photometric units,” *Metrologia* **51**, S276–S281 (2014).

P. Jaanson, F. Manoocheri, H. Mäntynen, M. Gergely, J.-L. Widlowski, and E. Ikonen, “Gonioreflectometric properties of metal surfaces,” *Metrologia* **51**, S314–S318 (2014).

S. Pourjamal, H. Mäntynen, P. Jaanson, D. Rosu, A. Hertwig, F. Manoocheri, and E. Ikonen, “Characterization of thin film thickness,” *Metrologia* **51**, S302–S308 (2014).

M. L. Rastello, I. P. Degiovanni, A. G. Sinclair, S. Kück, C. J. Chunnilall, G. Porrovecchio, M. Smid, F. Manoocheri, E. Ikonen, T. Kubarsepp, D. Stucki, K. S. Hong, S. K. Kim, A. Tosi, G. Brida, A. Meda, F. Piacentini, P. Traina, A. Al Natsheh, J. Y. Cheung, I. Müller, R. Klein and A. Vaigu, “Metrology for industrial quantum communications: the MIQC project,” *Metrologia* **51**, S267–S275 (2014).

J. I. Peltoniemi, T. Hakala, J. Suomalainen, E. Honkavaara, L. Markelin, M. Gritsevich, J. Eskelinen, P. Jaanson, and E. Ikonen, “Technical notes: A detailed study for the provision of measurement uncertainty and traceability for goniospectrometers,” *J. Quant. Spectrosc. Radiat. Transf.* **146**, 376–390 (2014).

T. Dönsberg, M. Sildoja, F. Manoocheri, M. Merimaa, L. Petroff, and E. Ikonen, “Primary standard of optical power operating at room temperature,” *EPJ webconf.* **77**, 00012 (2014).

A. Vaigu, T. Kübarsepp, F. Manoocheri, M. Merimaa, and E. Ikonen, Compact Two-Element Transmission Trap Detector for 1550 nm Wavelength, *Meas. Sci. Technol.* **26**, 055901, 6 pages (2015).

T. Pulli, T. Dönsberg, T. Poikonen, F. Manoocheri, P. Kärhä, and E. Ikonen, Advantages of White LED Lamps and New Detector Technology in Photometry, *Light: Science and Applications* **4**, e332, 7 pages (2015).

A. Vaskuri, P. Kärhä, A. Heikkilä, and E. Ikonen, High-Resolution Setup for Measuring Wavelength Sensitivity of Photoyellowing of Translucent Materials, *Rev. Sci. Instrum.* **86**, 103103, 8 pages (2015).

M. Shpak, P. Kärhä, and E. Ikonen, Mathematical Limitations of the CIE Mesopic Photometry System, *Lighting Res. Technol.* DOI 10.1177/1477153515599436, 11 pages (2015).

H. Baumgartner, D. Renoux, P. Kärhä, T. Poikonen, T. Pulli, and E. Ikonen, Natural and Accelerated Ageing of LED Lamps, *Lighting Res. Technol*. DOI 10.1177/1477153515599436 (2015).

A. Vaskuri, H. Baumgartner, P. Kärhä, G. Andor, and E. Ikonen, Modeling the Spectral Shape of InGaAlP-based Red Light-Emitting Diodes, *Journal of Applied Physics* **118**, 203103, 7 pages (2015).

P. Jaanson, F. Manoocheri, and E. Ikonen, Goniometrical Measurements of Fluorescence Quantum Efficiency, *Meas. Sci. Technol.* **27**, 025204, 8 pages (2016).

T. Dönsberg, H. Mäntynen, and E. Ikonen, Optical Aperture Area Determination for Accurate Illuminance and Luminous Efficacy Measurements of LED Lamps, *Optical Review*, DOI 10.1007/s10043-016-0181-2, 12 pages (2016).

Conference papers

T. Pulli, J. Schreder, A. Partosoebroto, G. Hülsen, J. Askola, J. Mes, P. Kärhä, and J. Gröbner,"Realization of Improved Solar UV Diffusers," UVNet 8th Workshop on Ultraviolet Radiation Measurements, Davos, July 15–16, 2014.

P. Kärhä, S. Nevas, P. Blattner, O. El Gawhary, T. Pulli, L. Egli, and J. Gröbner, "Characterisation of nonlinearities of array spectroradiometers," UVNet 8th Workshop on Ultraviolet Radiation Measurements, Davos, July 15–16, 2014.

L. Egli, S. Nevas, P. Blattner, O. ElGawhary, P. Kärhä, and J. Gröbner, "Characterization of array spectroradiometers for solar UV measurements," Proc. CIE Expert Symposium on Measurement Uncertainties in Photometry and Radiometry for Industry, Vienna, September 11–12, 2014, pp. 22–27.

T. Poikonen, T. Pulli, T. Dönsberg, H. Baumgartner, A. Vaskuri, M. Sildoja, F. Manoocheri, P. Kärhä, and E. Ikonen, "Realization of photometric units without V(λ) filters and their dissemination to led lighting applications," Proc. CIE Expert Symposium on Measurement Uncertainties in Photometry and Radiometry for Industry, Vienna, September 11–12, 2014, pp. 72–74.

T. Poikonen, "Uncertainties in electrical power measurement of energy-saving lighting products," Proc. CIE Expert Symposium on Measurement Uncertainties in Photometry and Radiometry for Industry, Vienna, September 11–12, 2014, pp. 1–6.

A. Vaigu, T. Kübarsepp, C. J. Chunnilall, G. Porrovecchio F. Manoocheri, M. Merimaa and E. Ikonen, "Traceability at the single photon level for quantum communication," QCrypt 2014, 4th International Conference on Quantum Cryptography, Paris, September 1–5, 2014.

E. Ikonen, "Foreword, The 12th International Conference on New Developments and Applications in Optical Radiometry (NEWRAD 2014)," *Metrologia* **51**, 565–567 (2014).

T. Poikonen, T. Pulli, T. Dönsberg, H. Baumgartner, P. Kärhä, and E. Ikonen, Towards LED-Based Photometric Standards, Abstracts of the 28th CIE Session (Manchester, UK, 2015) p. 174.

E. Ikonen, T. Pulli, T. Dönsberg, T. Poikonen, F. Manoocheri, and P. Kärhä, Accurate Measurement of Illuminance and Luminous Efficacy of White LED lamps, Abstracts of the 28th CIE Session (Manchester, UK, 2015) pp. 138-139.

H. Baumgartner, J. Oksanen, T. Pulli, E. Tetri, P. Kärhä, and E. Ikonen, Effects of Intelligent Control on the Lifetime of LED Street Lights, Proceedings of the 28th CIE Session (Manchester, UK, 2015) pp. 1662-1668.

H. Mäntynen and E. Ikonen, Optical Aperture Area Determination for Accurate Illuminance and Luminous Efficacy Measurements of LED Lamps, The Eleventh Finland-Japan Joint Symposium on Optics in Engineering (Joensuu, Finland, 2015) pp. 108-109.

T. Poikonen, T. Pulli, T. Dönsberg, H. Baumgartner, P. Kärhä, and E. Ikonen, Review of Challenges and Disadvantages of LED-Based Photometric Standards, Abstracts of the CIE Lighting Quality & Energy Efficiency Conference (Melbourne, Australia, 2016) pp. 59-60.

T. Pulli, A. Vaskuri, H. Mäntynen, P. Kärhä, and E. Ikonen, Uncertainty Evaluation of Spectral Integrals for LED Lamps, Proceedings of the CIE Lighting Quality \& Energy Efficiency Conference (Melbourne, Australia, 2016).

P. Jaanson, T. Pulli, F. Manoocheri, and E. Ikonen, A Reference Material with Close to Lambertian Refelectance an Fluorescence Emission Profiles, 4th CIE Expert Symposium on Colour and Visual Appearance - Abstract Booklet (Prague 2016) p. 20.

E. Ikonen, P. Jaanson, T. Pulli, and F. Manoocheri, Uncertainty Evaluation of Fluorescence Quantities Obtained from Goniometric Measurements, 4th CIE Expert Symposium on Colour and Visual Appearance - Abstract Booklet (Prague 2016) p. 23.

P. Kärhä, A. Vaskuri, J. Gröbner, L. Egli, and E. Ikonen, Monte Carlo Analysis of Uncertainty of Total Atmospheric Ozone Derived from Measured Spectra, Proceedings of the International Radiation Symposium (New Zealand 2016).

A. Vaskuri, P. Kärhä, A.Heikkilä, and E. Ikonen, Facility for Determining Action Spectra of UV Photodegradation, Proceedings of the International Radiation Symposium (New Zealand 2016).