Consultative Committee for Photometry and Radiometry (CCPR)

25th Meeting (on-line 10-11 May 2022)

CCPR member report on activities in radiometry and photometry since the last CCPR meeting (2019)

Reply from: MIKES-Aalto

Delegate: Erkki Ikonen

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1. Summarize the recent progress in your laboratory with respect to measurement standards, research projects, and metrology services to fulfill the demands of customers in:

   (a) broad-band radiometric quantities:
   (b) spectral radiometric quantities:
   (c) photometric quantities:
   (d) other area(s) relevant to CCPR:

   EMPIR project Chipscale, coordinated by JV (Norway), has produced significant new results related to the development of Predictable Quantum Efficient Detector (PQED).

   Tran et al https://iopscience.iop.org/article/10.1088/1681-7575/ac604b/pdf reported in Metrologia a method to determine the internal quantum deficiency (IQD) of the PQED based on measured photocurrent dependence on bias voltage and a 3D simulation model of charge carrier recombination losses. The simulation model of silicon photodiodes includes wafer doping concentration, fixed charge of the SiO_2 layer, bulk lifetime of charge carriers and surface recombination velocity as the fitted parameters. With only one set of physical photodiode defining parameters, the simulation shows excellent agreement with experimental data at power levels from 0.1 mW to 1 mW with variation in illumination beam size. The dependence of IQD on bias voltage was also predicted at the wavelength of 476 nm using photodiode parameters determined independently at 647 nm wavelength. The fitted values of doping concentration and fixed charge extracted from the simulation model are in close agreement with the expected parameter values determined earlier. At bias voltages larger than 5 V at the wavelength of 476 nm, the internal quantum efficiency of one of the tested PQEDs was measured to be 0.999970 ± 0.000027, where the relative expanded uncertainty of 0.000027 is one of the lowest values ever achieved in spectral responsivity measurement of optical detectors.

   Askola et al https://doi.org/10.1088/1681-7575/ac0e7b reported in Metrologia that a nitrogen flow used to prevent dust and moisture entering the PQED may influence

measurements performed in overfilled conditions. A stable light source was measured with the PQED with a 4 mm entrance aperture, and the nitrogen flow rate was varied. The nitrogen flow was found to have the largest effect of up to 0.8% on the responsivity of the detector at around 1.0 liters/min flow rate. The effect of nitrogen flow can be removed down to 0.02% by an added crossflow which removes the nitrogen out of the optical axis. In another experiment, the effect was removed almost completely by changing the flowing gas from nitrogen to synthetic dry air. In underfilled beam geometry, the responsivity changes due to nitrogen flow are smaller than 0.002%, even without the added crossflow. Based on simulations, the nitrogen flow through the PQED forms a gradient-index type gas lens in front of the detector increasing the effective aperture area and thus the responsivity. In the underfilled measurement geometry there is no light close to the aperture edge which could be refracted inside the detector.

In the Chipscale project, Sintef from Norway has produced new type of induced junction photodiodes for PQEDs which have as low IQD as the induced junction photodiodes produced around 2010 by VTT. Another favorable feature of the Sintef photodiodes is that they are available. MIKES-Aalto is collecting interested partners who would make a joint order of the photodiodes
http://chipscale.aalto.fi/joint_order.html

2. What work in PR has been/will be terminated in your laboratory, if any, in the past /future few years? Please explain the reasons and provide the name of the institution if it has been/will be substituted by a DI or accredited laboratory.

   reply

3. Summarize the Capacity Building and Knowledge Transfer activities undertaken by your institute in photometry and radiometry (courses, training, …):

   reply

4. Summarize the research projects currently performed within a collaboration with one or more NMIs or DIs (name of the project, participants):

   MIKES-Aalto participates in following EMPIR projects in the technological areas relevant to the CCPR. Other project participants can be found from the project websites maintained by EURAMET
   https://www.euramet.org/research-innovation/research-empir/empir-calls-and-projects/

   - Self-calibrating photodiodes for the radiometric linkage to fundamental constants, 2019–2022
   - New quantities for the measurement of appearance, 2019–2022
   - Metrology for testing the implementation security of quantum key distribution hardware, 2020–2023

- Revision and extension of standards for test methods for LED lamps, luminaires and modules, 2020–2023
- Metrology for emerging photovoltaic applications, 2020–2023
- Metrology for Earth observation and climate IV, 2020–2023
- Metrology for aerosol optical properties, 2020–2023
- Single and entangled photon sources for quantum metrology, 2021–2024
- Metrology for temporal light modulation, 2021–2024
- Quantum sensors for metrology based on single-atom-like device technology, 2021–2024
- Traceable metrology of soft x-ray to IR optical constants and nanofilms for advanced manufacturing, 2021–2024
- Smart specialization and stakeholder linkage in photometry and radiometry, 2021–2022
- Metrological framework for passive radiative cooling technologies, 2022–2025
- Support for the standardisation of luminance distribution measurements for assessing glare and obtrusive light using high-dynamic-range imaging systems, 2022–2025

5. Are there any other 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?

   reply

6. Have you got any other information to place before the CCPR in advance of its next meeting?

   reply

7. Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (September 2019):

   Refereed journal publications

   T. Dönsberg, T. Poikonen, and E. Ikonen, “Transconductance amplifier for optical metrology applications of light-emitting diodes,” *IEEE Trans. Instrum. Meas.* **69**, 3704-3710 (2020).

   E. Martikainen, A. Vaskuri, T. Dönsberg, and E. Ikonen, “Cryostat setup for measuring spectral and electrical properties of light-emitting diodes at junction temperatures from 81 K to 297 K,” *Rev. Sci. Instrum.* **91**, 015106, 7 p (2020).

   P. Kärhä, H. Baumgartner, J. Askola, K. Kylmänen, B. Oksanen, K. Maham, V. Huynh, and E. Ikonen, “Measurement setup for differential spectral responsivity of solar cells,” *Optical Review* **27**, 195-204 (2020).

   S. Porrasmaa, T. Dönsberg, F. Manoocheri, and E. Ikonen, “Predictable quantum efficient detector for low optical flux,” *Optical Review* **27**, 190-194 (2020).

K. Maham, A. Vaskuri, F. Manoocheri, and E. Ikonen, “Calibration of near infrared detectors using a wavelength tunable light source”, *Optical Review* **27**, 183-189 (2020).

D. Lanevski, F. Manoocheri, A. Vaskuri, J. Hameury, R. Kersting, C. Monte, A. Adibekyan, E. Kononogova, and E. Ikonen, “Determining the shape of reflectance reference samples for curved surface reflectors,” *Meas. Sci. Technol.* **31**, 054010, 8 p (2020).

A. Hovi, M. Mottus, J. Juola, F. Manoocheri, E. Ikonen, and M. Rautiainen, “Evaluating the performance of a double integrating sphere in measurement of reflectance, transmittance, and albedo of coniferous needles,” *Silva Fennica* **31**, 054010, 22 p (2020).

M. Ojanen, M. Shpak, P. Kärhä, R. Leecharoen, and E. Ikonen, “Corrigendum: Uncertainty evaluation for linking a bilateral key comparison with the corresponding CIPM key comparison (2009 *Metrologia* **46**, 397–403),” *Metrologia* **57**, 049501 (2020).

J. Askola, K. Maham, P. Kärhä, E. Ikonen, “Increased detector response in optical overfilled measurements due to gas lens formation by nitrogen flow through the entrance aperture,” *Metrologia* **58**, 055008, 5 p. (2021).

M. Tanabe, H. Shitomi, T. Dönsberg, and E. Ikonen, “Characterization of predictable quantum efficient detector in terms of optical non-linearity in the visible to near-infrared range,” *Metrologia* **58**, 055012, 6 p (2021).

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J. Rossi, J. Uotila, S. Sharma, T. Laurila, R. Teissier, A. Baranov, E. Ikonen, and M. Vainio, “Photoacoustic characteristics of carbon-based infrared absorbers,” *Photoacoustics* **23**, 100265, 10 p (2021).

J. Karhu, T. Hieta, F. Manoocheri, M. Vainio, and E. Ikonen, “LED-based photoacoustic NO_2 sensor with a sub-ppb detection limit,” *ACS Sensors* **6**, 3303-3307 (2021).

J. Karhu, J. Kuula, A. Virkkula, H. Timonen, M. Vainio, and T. Hieta, “Cantilever-enhanced photoacoustic measurement of light-absorbing aerosols”, *Aerosol Science and Technology* **56**, 92-100 (2022).

S. Sharma, T. Laurila, J. Rossi, J. Uotila, M. Vainio, F. Manoocheri, E. Ikonen, "Electromagnetic radiation detection using cantilever-based photoacoustic effect: A method for realizing power detectors with broad spectral sensitivity and large dynamic range", *Sensors and Actuators A: Physical* **337**, 113191, 8 pages (2022).

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T. Tran, G. Porrovecchio, M. Smid, E. Ikonen, T. Dönsberg, and J. Gran, "Determination of the responsivity of Predictable Quantum Efficient Detector over a wide spectral range based on a 3D model of charge carrier recombination losses," *Metrologia* (accepted for publication).
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Conference papers

J. Askola, H. Baumgartner, T. Pulli, P. Kärhä, and E. Ikonen, “Influence of smart lighting control on the lifetime of high-power LED luminaires,” IOP Conference Series: Earth and Environmental Science 352 (Trondheim, Norway, 2019) 012043, 6 pages. (Talk) DOI 10.1088/1755-1315/352/1/012043

J. Rossi, J. Uotila, T. Laurila, E. Ikonen, and M. Vainio, “Broadband electro-magnetic radiation detector based on photoacoustic effect,” 2020 Conference on Lasers and Electro-Optics, OSA Technical Digest (Optical Society of America), paper AF1K.5, 2 pages (2020).

J. Gran, T. Tran, and T. Dönsberg, “Three-dimensional modelling of photodiode responsivity,” Proceedings of NEWRAD 2021 Conference (online, 2021) pp. 1–2 (Invited talk). DOI 10.5281/zenodo.4882794

K. Maham, P. Kärhä, F. Manoocheri, and E. Ikonen, “Optical power scale realization using the predictable quantum efficient detector,” Proceedings of NEWRAD 2021 Conference (online, 2021), pp. 9–10 (Talk). DOI 10.5281/zenodo.4882794

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P. Kärhä, K. Maham, and E. Ikonen, "Unknown correlations in spectral quantities and a method for taking them into account in uncertainty of spectral mismatch in solar cell calibration," 20th International Metrology Congress CIM2021, Lyon, September 7 – 9, 2021, p. 80 (Talk).

I. Harju, P. Kärhä, E. Ikonen, J. Gröbner, N. Kouremeti, G. Hülsen, and S. Kasadzis, "Angular responsivity measurements of optical radiometers for estimating uncertainties of atmospheric aerosol measurements related to FOV effects," 20th International Metrology Congress CIM2021, Lyon, September 7 – 9, 2021, p. 82 (Talk).

S. Sharma, T. Laurila, J. Rossi, J. Uotila, M. Vainio, F. Manoocheri and E. Ikonen, "Cantilever-based photoacoustic detection of electromagnetic radiation from ultraviolet to near infrared spectral region," 20th International Metrology Congress CIM2021, Lyon, France, September 7 – 9, 2021, pp. 83 (Talk).

K. Maham, P. Kärhä, and E. Ikonen, "Methodologies to measure spatial uniformities of integrating spheres," Abstracts of CIE 2021 Conference (online), September 27 – 29, 2021, pp. 104–105 (Talk).

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