Title: Self-calibrating photodiodes for the radiometric linkage to fundamental constants

Abstract

This topic concerns the novel combination of two independent primary standard detectors: a solid-state predictable quantum efficient detector (PQED) and a cryogenic electrical substitution radiometer (ESR) to create a robust link to the revised SI by measuring the fundamental constant ratio e/h. The novel packaging of the two standards could also facilitate improved dissemination of optical quantities particularly where a primary standard needs to be used in challenging non-NMI environments, generating for the first time an "NMI-on-a-chip" for optical power measurements. Material research and improved 3D charge-transfer simulation models would also be required to ensure optimum performance in quantum mode at cryogenic temperatures, as well as to predict the response from 400 nm to 850 nm over a wide dynamic range.

Keywords

Predictable Quantum Efficient Detector (PQED), 3D charge transfer models, improved passivation, SI, electrical substitution radiometer (ESR), packaging technology, NMI-on-a-chip.

Background to the Metrological Challenges

The development and exploitation of optical techniques is rapidly emerging as a key enabling technology in applications to support industry, innovation and science. There is a pressing need for simplified traceability for optical quantities over a wide spectral and dynamic range.

Previous projects, iMERA-Plus qu-Candela and EMRP SIB57 NEWSTAR, developed a predictable quantum efficient detector (PQED). The PQED was approved in the *mise-en-pratique* for the definition of the candela as an alternative primary standard to the well-established cryogenic ESR. The SI system is expected to be revised in 2019 based on the definition of seven fundamental constants. Recently, a new method has been demonstrated that enables the measurement of fundamental constants to be done on one artefact by running the photodiodes in two different modes; both as a PQED and cryogenic ESR. A comparison of these two primary standards, which enables the derivation of the e/h ratio, can contribute to strengthen the coherence of the revised SI system.

The SI link requires that a sensitive temperature sensor is properly attached to the PQED photodiodes so that the device can be easily handled while used in either mode of operation and with a geometry and choice of materials ensuring equivalence in optical and electrical heating. Improvements in this packaging technology that ensures equivalence between optical and electrical heating has recently been demonstrated. The same packaging technology would enable the development of a "self-calibration" procedure of commercially available single photodiodes and establish a measurement standard detector that also operates for higher power levels than 1 mW (the current limit of linearity). This would require that both modes are sufficiently accurate and linear in parts of the same power levels. In the Photometry/Radiometry Roadmaps for climate and basic science "self-calibrating instruments making climate quality measurements in the field" and "low-cost, high accuracy transfer standards" are requested as a need in order to provide the necessary accuracy for remote unattended and non-transportable instrumentation. The device would be a self-calibrating detector, working as an "NMI-on-a-chip" in potentially remote operation. Aided by validated 3D models the device could predict the responsivity over the full spectral range with the measurement at one wavelength only. An improved and simplified traceability over a wide dynamic range could be achieved, also at the user level, combining the technology and metrology developments with 3D models.

Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the protocol.

The JRP shall focus on new experimental techniques for optical power measurements over a wide spectral and dynamic range by the production of an “NMI-on-a-chip” developed as a self-calibrating silicon photodiode.

The specific objectives are

1. To develop improved 3D charge-transfer models and to validate the models by measurements. The target prediction uncertainty is 10 % of the internal quantum deficiency value.
2. To use the improved 3D models for evaluation of passivation layer materials, passivation strategy and charge increasing techniques. To manufacture a batch of optimised PQED photodiodes for cryogenic operation and to acquire bare-chip photodiodes for room temperature operation.
3. To develop instrumentation and packaging for self-calibrating photodiodes. The photodiodes should be operated in both photocurrent and electrical substitution mode with sufficient sensitivity and equivalence between optical and electrical heating over a temperature range from 20 K to 300 K.
4. To provide traceability of the self-calibrating photodiodes to the revised SI by measuring the fundamental constant ratio *e/h* to 1 ppm uncertainty at cryogenic temperatures and to 0.05 % uncertainty at room temperature for wavelengths 400 nm – 850 nm over a dynamic range from 10 nW to 10 mW.
5. To facilitate the take up of the technology and measurement infrastructure developed by the project by engaging standardisation bodies and international organisations (CCPR, CIE, EURAMET and other RMO TC-PR), the measurement supply chain (accredited laboratories, instrument manufacturers) and end users (photonics industry).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research work, the involvement of the larger community of metrology R&D resources outside Europe is recommended. A strong industry involvement is expected in order to align the project with their needs and guarantee an efficient knowledge transfer into industry.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

In particular, proposers should outline the achievements of the iMERA-Plus project qu-Candela and the EMRP project SIB57 NEWSTAR and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.8 M€, and has defined an upper limit of 2.1 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 20 % of the total EU Contribution across all selected projects in this TP.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the photonics sector.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include the best available contributions from across the metrology community. Specifically, the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.