

Title: Self-calibrating photodiodes for integrated and infrared technologies

Abstract

Photonics has many potential applications in light-based sensing, health, industry and environment. However, as the technological development moves towards miniaturisation, integrated measurement systems are needed to overcome current metrological systems not capable of calibrating systems and components in photonic integrated circuits (PICs). Proposals addressing this topic should address this need by developing improved, simplified and SI traceable self-calibrating photodiodes in the infrared spectral range, and demonstrate the benefit of having a predictable reference in dedicated measurement set-ups.

Keywords

NMI-on-a-chip, self-calibration, photodiodes, infrared, photonic integrated circuits (PICs), simulation, spectral response, predictable quantum efficient detectors (PQED)

Background to the Metrological Challenges

The European photonics industry has grown from €103 billion in 2019 to €125 billion in 2022, at a growth rate of 6.5 % per year, with a share of 15 % of the global market, and it is expected to continue growing to €175 billion by 2027. The EU defined photonics as Key Enabling Technology; it is used in climate monitoring, medical treatment, health diagnostics, photonic industries, and it has impact in energy saving by LED illumination, electricity production, science, quantum and many more applications.

Within all fields of PICs, e.g. passive, active and programmable, there is the need for metrology to overcome the technological challenges and limitations in the current technology and provide confidence in the results measured by the chip. The European technology platforms Photonics21 and Quantum Flagship, individually and in joint strategies, highlight the integration of self-calibrating systems and products as one of the technology, research and innovation challenges ahead.

For integration to deliver its full potential though, technologies should be developed as Process Design Kits (PDKs) with guaranteed timeline, cost and quality for future use in different applications. A PDK is a library of modular processes that can be reused to implement a variety of applications within a specific PIC platform. Having a large library available when developing PIC systems will leverage all previous developments, and this is therefore identified by the photonics industry as the preferred way to accelerate developments. EMPIR 18SIB10 chipS-CALe and Metrology Partnership 22IEM06 S-CALe Up projects have provided the basic metrological solutions for this, by developing an NMI-on-a-chip fully integrated in a PIC for the mature spectral range from 500 nm to 900 nm. Similarly to Field Programmable Gate Arrays (FPGAs) in the electrical field, programmable PICs are in rapid development to generate flexible, generic and reconfigurable photonic sensing or measurement systems. However, this rapidly evolving technology at 1550 nm needs SI-traceable measurements and calibration of the programmable devices, as the output is sensitive to the programmed configuration and calibration will quantify the degree of success of the configured PICs. Developing metrology to quantify propagated losses is also needed to configure the devices properly and avoid certain areas of the PICs suffering from non-uniform manufacturing.

EMPIR 18SIB10 chipS-CALe and Metrology Partnership 22IEM06 S-CALe Up projects have demonstrated that self-calibrating predictable quantum efficient detectors (PQEDs) can be exploited as miniaturised primary standard detectors from 300 nm to 1000 nm. The projects demonstrated clear European lead in this research

area and achieved the lowest measurement uncertainty and best detector stability ever reported. Ongoing work is developing similar technology and metrological techniques covering 200 nm to 400 nm. Combining the recently reported induced junction photodiodes on black Germanium with the success recipe of previous projects in the UV and visible spectral range, will enable the development of a predictable spectral response scale in the infrared from 900 nm to 1600 nm. The development of simulation models will support characterisation measurements and is key to improve traceability, which will trigger new measurement techniques in remote and integrated measurement systems in a similar way as in the UV-VIS range.

Infrared technologies are widely used in earth observation, meteorology, communication, thermography and night vision. One of those applications is measuring and modelling the earth energy imbalance (EEI). Essential Climate Variables are defined by World Meteorological Organisation and the ratio between incoming and outgoing radiation of the earth defines if there is a change in global temperature. The atmospheric gas compositions are quantities important for modelling the EEI. To demonstrate the benefit of having predictable self-calibrating photodiodes it is important to implement an improved traceability of spectral solar irradiance measurements from 300 nm to 1600 nm, to reduce the uncertainty of retrieved atmospheric trace gases and aerosol optical depth by shortening the traceability chain.

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 proposal shall focus on the traceable measurement and characterisation of self-calibrating photodiodes for integrated and infrared technologies.

The specific objectives are

1. To develop highly accurate and fast simulation models of loss components for different types of infrared photodiodes, and predict the responsivity based on independent characterisation techniques from 900 nm to at least 1600 nm, with an uncertainty below 0.1 %.
2. To develop an improved, simplified, self-calibrating and predictable spectral response scale in the infrared, from 900 nm to at least 1600 nm, based on available infrared photodiodes (e.g. InGaAs, induced junction Ge), and able to operate at room temperature(s), with an uncertainty of 0.1 %.
3. To provide optical power traceability in PICs by i) developing a Process Design Kit (PDK) with a PQED fully integrated in PICs for the spectral range from 500 nm to 900 nm and ii) carrying out the hybrid integration of the photodiodes from Objective 2 in programmable photonics at 1550 nm, with an uncertainty of 1 %.
4. To increase the TRL-level of PQEDs in the 300 - 1000 nm spectral region from 3 to at least 4, and to demonstrate the benefit of using the predictable self-calibrating photodiodes from Objective 2 and previous projects in end-user applications, such as providing traceability to spectral solar irradiance measurements from 300 nm to 1600 nm, to reduce the uncertainty of retrieved atmospheric trace gases and aerosol optical depth by shortening the traceability chain.
5. To demonstrate the establishment of an integrated European metrology infrastructure and to facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (accredited laboratories, instrument manufacturers), standards developing organisations (CIE), technical committees (e.g. EURAMET TC-PR, CCPR, IEC), 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 both within and outside Europe, plus engagement with existing European research infrastructures and European Partnerships 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 and end users. Where relevant, proposals are encouraged to build on, or seek collaboration with, existing projects and develop synergies with other relevant European, national or regional initiatives and funding programmes. In particular, links are encouraged with (i) the projects funded under earlier relevant topics of the Horizon Europe programme; or (ii) other relevant European Partnerships.

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 EMPIR 18SIB10 chipS·CALe and Metrology Partnership 22IEM06 S-CALe Up projects and how their proposal will build on those.

Proposers should note that the programme funds the activity of researchers to develop the capability, not the required infrastructure and capital equipment, which must be provided from other sources.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.1 M€ and has defined an upper limit of 2.6 M€ for this proposal.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 25 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated partners.

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 proposal's 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,
- Facilitate improved industrial capability, or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- 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 the Metrology Partnership 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.

Timescale

The project should be of up to 3 years duration.