**European Partnership on Metrology**
**Call 2022 – Digital Transformation, Health, Integrated European Metrology, Normative and Research Potential**

Selected Research Topic number: **SRT-s01**
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# Title: Self-calibrating photodiodes for UV and exploitation of induced junction technology

## Abstract

As one of Europe's Key Enabling Technologies (KET), photonics has widespread applications across industry, environment, health, medicine, energy, lighting and science. However, the photonics sector and standardisation organisations require miniaturised, cost-effective, integrated and self-calibrating measurement systems, which cannot be provided by traditional methods and existing metrological systems. Recent developments in Predictable Quantum Efficient Detectors (PQEDs) demonstrated improved uncertainty of 10 ppm and the proof-of-concept of an NMI-on-a-chip suitable for miniaturisation. Proposals addressing this SRT should develop improved methods and photodiodes that can be used as built-in references in different applications and develop improved standard detectors for the UV range.

## Keywords

Predictable Quantum Efficient Detector (PQED), photodiodes, photodiode packaging, fibre optics, photonics, UV detectors, dual mode detectors, 3D simulation

## Background to the Metrological Challenges

The European photonics industry has grown from €76 billion in 2015 to €103 billion in 2019 with a growth rate of 7 % per year and a share of 16 % of the global market. Besides components and materials, the major application segments are photonics for consumers IT, medicine and biology, environment, lighting, energy and industry 4.0 showing that photonics is participating directly in the challenges for the future. Europe is well positioned in the field of photonics systems for production i.e. industrial laser systems, semiconductor manufacturing and machine vision. But this is a rapidly evolving field that moves in the direction of miniaturisation, more integrated measurement systems and distribution of standalone sensor systems in possibly remote locations. Current metrological systems are not capable of calibrating detectors in integrated systems nor remote locations. Therefore, in both the European technology platform Photonics21's strategic roadmap, "Europe's age of light" from 2021 to 2027 and Quantum Flagship's Strategic Research Agenda March 2020, integration of self-calibrating systems and products are highlighted as one of the technology, research and innovation challenges ahead.

The current state-of-the-art for spectrally dependent uncertainty is approximately 0.1 % (400 nm – 900 nm), but this is limited by the properties and stability of current silicon transfer standard detectors. Previous EMRP and EMPIR European projects have developed PQEDs based on induced-junction technology, which have proven to have an extremely low external quantum deficiency (EQD) of around 10 ppm and an undetectable drift over 9-10 years. This means that 99,999 % of the responsivity of the PQEDs is determined by the values of fundamental constants. These properties make PQEDs very attractive calibration standard detectors, which comply well with the low-cost, high-accuracy, transfer standard requested by CIPM's Consultative Committee for Photometry and Radiometry (CCPR). However, predicted values of PQEDs' response and associated uncertainty must be improved so that the uncertainty in the responsivity can go beyond internal quantum deficiency (IQD) losses, and to independently extract the photodiode model parameters. 3D simulation provides improved understanding of the systems and enable new measurement techniques to be developed and applied. Great progress has been made in recent years where simplified IQD models are exploited and accurately predict photodiode responsivity at the 10 ppm level despite necessary simplifications.

The insufficient stability of detectors in the visible spectral range is much more pronounced into the UV range, which is of great importance to health and earth observations. Therefore, the development of improved and predictable standard detectors in the UV range is a natural step forward to support metrology in this challenging spectral region. Recent developments of predictability model in the visible spectral range should be implemented as a built-in standard enabling improved predicted responsivity and uncertainty in the UV. In the future, applications of dual-mode detectors may be exploited at a wider spectral range on photodiodes of different materials for optimum benefit to the optics and photonics community. Therefore, the development of improved and generic packaging technology is required to enable a smooth uptake of technology to extended spectral ranges of various photodiode types in the future.

The International Commission on Illumination (CIE), as the world standardisation organisation for light and lighting, has requested research on new low-cost high accuracy primary standard detectors [1] of optical radiation allowing better standardisation in a wide range of applications and industries. In particular, CIE requires predictable detectors slightly outside the current spectral range from 400 nm to 850 nm [2].

## 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 the traceable measurement and characterisation of photodiodes and extend their predictable spectral responsivity range, to support their applications in the photonics sector.

The specific objectives are

1. To develop 3D simulation models of photodiode charge carrier transportation in Predictable Quantum Efficient Detector (PQED) for better physical representation, higher calculation speed, wider availability and improved uncertainty approaching 1 ppm, and to extend the quantum yield prediction from 400 nm down to 250 nm with an uncertainty better than 0.1 %.
2. To use PQEDs with very low spectral responsivity uncertainty in the 400 nm to 850 nm range as built-in references in different applications (e.g. optical power measurement, fibre optics, pulsed laser radiation, photometry without V(λ) filters) taking into account practical aspects, such as current measurements, stray light, geometry, heat and dark current variations.
3. To develop and fabricate improved photodiodes for the UV range and validate their stability and suitability as a spectral responsivity standard from 400 nm to 250 nm. Additionally, to develop thermal simulations and packaging technology of dual mode detectors with heat equivalence better than 0.03 % suitable for implementation into the UV spectral range.
4. To extend the spectral response range of photodiodes between i) 250 nm and 400 nm, and ii) 850 nm and 1050 nm, with a target uncertainty better than 0.2 %. For this, the improved detectors and packaging developed in objective 3, and improved charge carrier simulation and quantum yield modelling developed in objective 1, may be used.
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) 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.

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 EMRP SIB57 and EMPIR 18SIB10 projects and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.9 M€ and has defined an upper limit of 2.6 M€ for this project.

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 JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Develop an integrated self-sustaining European metrology infrastructure,
- 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 the 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.

## Time-scale

The project should be of up to 3 years duration.

## Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] *007 CIE Div 2 primary standard detectors of optical radiation*

https://www.metpart.eu/go/need07

[2] *014 CIE Div 2 detector-based calibration of spectroradiometers*

https://www.metpart.eu/go/need14