Developing photodiodes with record-low internal quantum deficiency and self-calibrating methods in the chipS·CALe project

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In the European project chipS·CALe (Self-calibrating photodiodes for the radiometric linkage to fundamental constants, 2019-2022) lead by Justervesenet, we have an ambitious goal to improve and simplify the traceability chain by taking advantage of the intrinsic quantum properties of a Predictable Quantum Efficient Detector (PQED). The PQED consists of two self-induced silicon photodiodes (a photodiode with fixed charge in passivation layer, which induces a pn-junction eliminating the need for doping in the active area), for which the responsivity is determined to 99,999 % by the values of fundamental constants. Developing new and improved technology, accompanied by novel metrological methods, chipS·CALe generates for the first time an "NMI-on-a-chip" for optical power measurements.
We will show how we developed photodiodes with internal quantum deficiency (IQD), slightly spectrally dependent, in the 1 - 10 ppm range as a collaboration between SINTEF, Justervesenet, IFE and other consortium partners [1]. The record-low IQD is confirmed by measurements against the world's most accurate cryogenic radiometer at PTB.
It will be demonstrated how 3D device modelling of the charge carrier recombination can be exploited to extract the internal loss parameters of the self-induced photodiode. These parameters define the properties of the photodiode and can be extracted by characterisations done at one wavelength [2]. Once the defining parameters of the photodiode are known, the full spectral response of the photodiode (400 nm – 850 nm) can be predicted from the characterisations done at one wavelength only with an uncertainty in the 10 ppm range.
The dual-mode detector combines photodiodes and electrical substitution in one single detector that directly measures the IQD. This requires special packaging developed and manufactured by USN based on thermal simulations. The simulations predicted a beam position sensitivity of the heat equivalence between optical and electrical heating at room temperature of 280 ppm per mm, that was experimentally confirmed at Justervesenet with a low noise set-up [3].
The excellent photodiodes and new metrological methods developed in chipS·CALe paves the way for high accuracy optical power measurement that can pick up detector drift in potentially remote locations [4].

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