Development of silicon photodetectors for absolute optical power measurement

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Abstract. Traditional methods used to realize the primary standard for the absolute optical power standard rely on expensive equipment and require well-trained personnel for maintenance and measurement activities. Silicon photonics technologies have enabled the development of predictable photodiodes with uncertainty comparable to (or perhaps better than) traditional methods. This work will report these research activities.

1 Introduction

Radiometric measurements of radiant power at discrete laser wavelengths are possible with cryogenic radiometers with an uncertainty down to 0.005 %. Cryogenic radiometers are accurate for most applications, but are bulky, expensive and require a high skill level to operate. Dissemination outside discrete wavelengths is carried out with silicon trap detectors and interpolation functions. The trap detectors' properties and insufficient stability is limiting the comparison agreement at the National Metrology Institute (NMI) level to a spectrally dependent dispersion around 0.1 %. Existing measurement techniques are not suitable for miniaturisation and providing traceability to integrated measurement systems, which is the direction technology development are moving.
The objective of ScaleUp and chipS-CALe research projects funded by the European Community are the development of improved photodiodes, new instrumentation, and measurement techniques as a self-calibrating photodiode. This is achieved developing photodiode modeling and using knowledge to manufacture improved photodiodes.
Furthermore, the project objectives were to develop the packaging technology and instrumentation to calibrate photodiodes directly related to electrical power measurement (electrical substitution) and demonstrate the measurement capability in their exploitation.
The following paragraphs will introduce the predictable photodiodes and the two-photodiodes light trapping structure with a description of the expected reflectance.

2 Predictable photodiodes

Commercial photodiodes are based on doped p-n junction and the doping is realized by implantation or diffusion of impurities inside the silicon crystal causing crystal defects and hence internal losses due to charge trapping. The knowledge of the doping profile of the p-n junction is extremely important to predict with a physical model the responsivity of a commercial photodiode.
The predictable photodiodes instead are special induced-junction photodiode manufactured with high purity silicon wafer, with very low doping, to drastically reduce internal losses, giving the possibility to predict with very low uncertainty their responsivity. The induced junction is realized by the surface charge trapped in the passivation layer of the silicon [1].

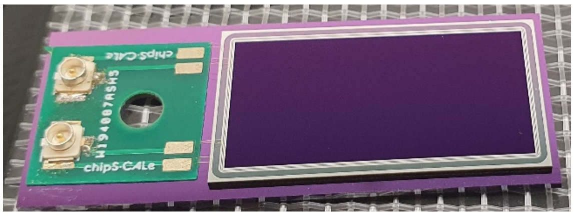

Fig. 1. Predictable photodiode a module with a induced junction developed in ChipS-CALe project used in a light trapping structure.

Figure 1 shows the module with a predictable photodiode with induced junction.
The optical reflectance losses should be properly minimized choosing the optimal thickness for the passivation layer and mounting the photodiodes in a light trapping structure.

3 Trap detector

A simple arrangement for a trap configuration with multiple regular reflections of a collimated beam based on two photodiodes is shown in figure 2. Selecting properly the angle between the diodes the beam is back-reflected along the ingoing path [2].

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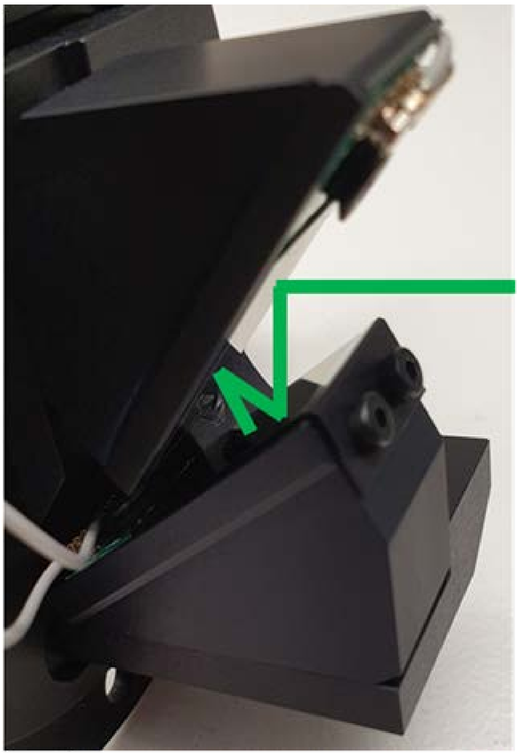

Fig. 2. Structure of a two photodiode light trapping detector.

The reflectance losses for this two-photodiode light trapping detector arranged in a 7-relection configuration (15° between the two photodiodes) can be accurately estimated by software simulation, starting from ellipsometric measurements of the deposition to extract the SiN_x index of refraction. The total reflection losses of the light trapping structure for the optimal deposition layer that minimizes reflection in this trap detector over a the spectral range from 400 nm to 850 nm is shown in figure 3. The results shows that from 450 nm to 850 nm the losses are well below 1 ppm.

4 Conclusion

Developments exploiting predictable photodiodes along a decade of joint research projects have demonstrated improved uncertainty to 10 ppm and the proof-of-concept suitable for miniaturisation [3-6]. The presentation will review the recent results that has created this step-change in radiometry and the foreseen exploitation of this new detectors as built-in standards in various applications.

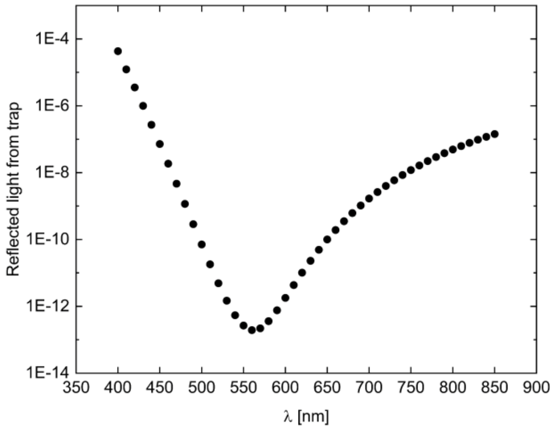

Fig. 3. Simulation of p-polarized light reflected from a 7-reflection trap. The photodiodesvwith induced junction consit of 6 nm of SiO_2 and an optimal SiN_x. thickness of 65 nm.

5 Acknowledgments

The projects 18SIB10 'chipS·CALe' and 22IEM06 'SCALe Up' leading to this publication have received funding from the EMPIR program and from the European Partnership on Metrology, respectively, co-financed by the participating states and the European Union's Horizon 2020 and Horizon Europe research and innovation programmes.

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