International Journal of Scientific Reports
Dhoska K et al. Int J Sci Rep. 2015 Nov;1(7):271-274
http://www.sci-rep.com

pISSN 2454-2156 | eISSN 2454-2164

DOI: http://dx.doi.org/10.18203/issn.2454-2156.IntJSciRep20151253

Research Article

Alignment position method for SPAD detector calibration and homogeneity

Klodian Dhoska[1]*, Helmuth Hofer[2], Marco López[2], Toomas Kübarsepp[1,3], Stefan Kück[2]

[1]Department of Mechatronics, Tallinn University of Technology, Tallinn, Estonia
[2]Department of Photometry and Applied Radiometry, Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany
[3]Research and Development Division, AS Metrosert, Tallinn, Estonia

Received: 13 November 2015
Accepted: 25 November 2015

***Correspondence:**
Klodian Dhoska,
E-mail: klodian.dhoska@ttu.ee

ABSTRACT

Background: Over the last decade have seen a drastically increase of interest in the Single photon avalanche diode (SPAD) detectors applications at many variety of quantum experiments where the detection efficiency at single-photon level is required. The calibration of such detectors involves predominantly the determination of the detection efficiency.

Methods: The present study was carried out at Department of Photometry and Applied Radiometry, Physikalisch-Technische Bundesanstalt (PTB), National Metrology Institute of Germany. This work is focused in a reproducible and close-to-ideal alignment position method of the SPAD detectors to the incident beam for achieving low measurement uncertainty.

Results: A dominantly Gaussian profile is obtained when the diameter of the detector is smaller than the beam diameter, whereas in case then the detector is larger than the beam, a dominantly rectangular scan is obtained. The optimal position (X/Y/Z) for setting the SPAD detector correspond to X_{center} = 235.11 mm, Y_{center} = 6.28 mm and $Z_{position}$ = 14.6 mm. Homogeneity of the detection efficiency depends on the beam size and evaluated regions.

Conclusions: The experimental set-up and experimental results needed for optimization of the SPAD detector position were described. This analysis gives important information in how to carry out the optimization of the detector position for the calibration of the SPAD and analysis of quantum detection homogeneity.

Keywords: SPAD detector, Detection efficiency, Alignment position, Homogeneity

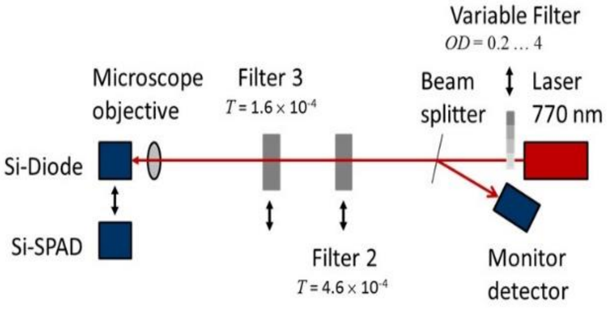
INTRODUCTION

Silicon single-photon avalanche diodes (Si-SPADs) are the most common choice for single-photon detection in the visible to near-infrared spectral range up to 1000 nm.[1,2] In particular, Si-SPADs have been successfully exploited in a variety of scientific research fields such as experimental quantum optics, quantum cryptography and quantum computing but also in applications like medicine, biology, 3D imaging, telecommunication and astrophysics.[3-5] In all these fields, the detection efficiency is a key parameter. Nevertheless, most of the costumers have to rely on the detection efficiency values given by the manufacturers or they have to measure the values themselves. Thus, in order to achieve reliable measurements, PTB Germany established recently a compact setup for Si-SPAD calibration that uses traceable transfer standards.[6,7]

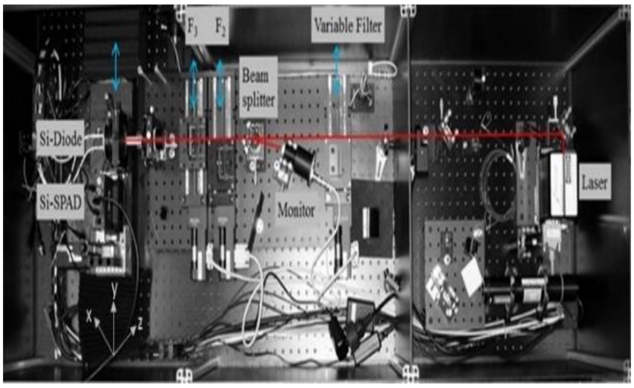
The alignment position of the Si-SPAD to the incident beam has to be carried out with high accuracy to achieve low uncertainty measurements. Here, it has to be assured that the laser spot beam used for the calibration is completely within the active area of the Si-SPAD and hits reproducibly the same location on the detectors active area. This requires some efforts and is very time consuming if the alignment is carried out manually. An accurate and automatic alignment of the SPAD will reduce the measurement time and increase the accuracy of the measurement results. In this paper we describe briefly the PTB´s experimental set-up and present first experimental results for the optimization of the detector alignment position needed for the calibration of the detection efficiency of Si-SPADs and homogeneity.

METHODS

Figure 1a shows the schematic setup used for the calibration of the Si-SPADs. The calibration is carried out by comparing the detector count rate of the Si-SPAD with those determined from a calibrated silicon diode.[6,7] The laser beam used for the calibration is focused by a 20X microscope objective lens (numerical aperture = 0.42, working distance = 20 mm) on the detectors. The alignment of the Si-SPAD to the focused beam is carried out using motorized X/Y/Z translation stages as can be seen in (Figure 1b). The circular active area of the Si-SPADs used for experiment is approximately A_D=24.1 μm^2 (diameter ϕ_D=200 μm).[8]



(a)



(b)

Figure 1: (a) Schematic setup of the calibration setup for Si-SPADs. (b) Picture of the Si-SPAD (Perkin Elmer SPCM-AQR) (top view).[6,7]

To find a criteria for the optimization of the position of the Si-SPAD detector with respect to the incoming laser beam, several scans in the (X,Y) - plane (perpendicular to the laser beam) at varying distances Z from the microscope objective were performed, see Table 1. The (X, Y) scanning range was 0.63 mm x 0.63 mm with a resolution of 0.01 mm. The scanning procedure was realized in such a way that the Z - position of the detector was moved by 0.1 mm steps towards the microscope objective. For each Z-axis position a full (X, Y) - scan was performed. This scanning procedure allows us to find the optimum (X, Y, Z) - position of the detector with respect to the incoming beam.

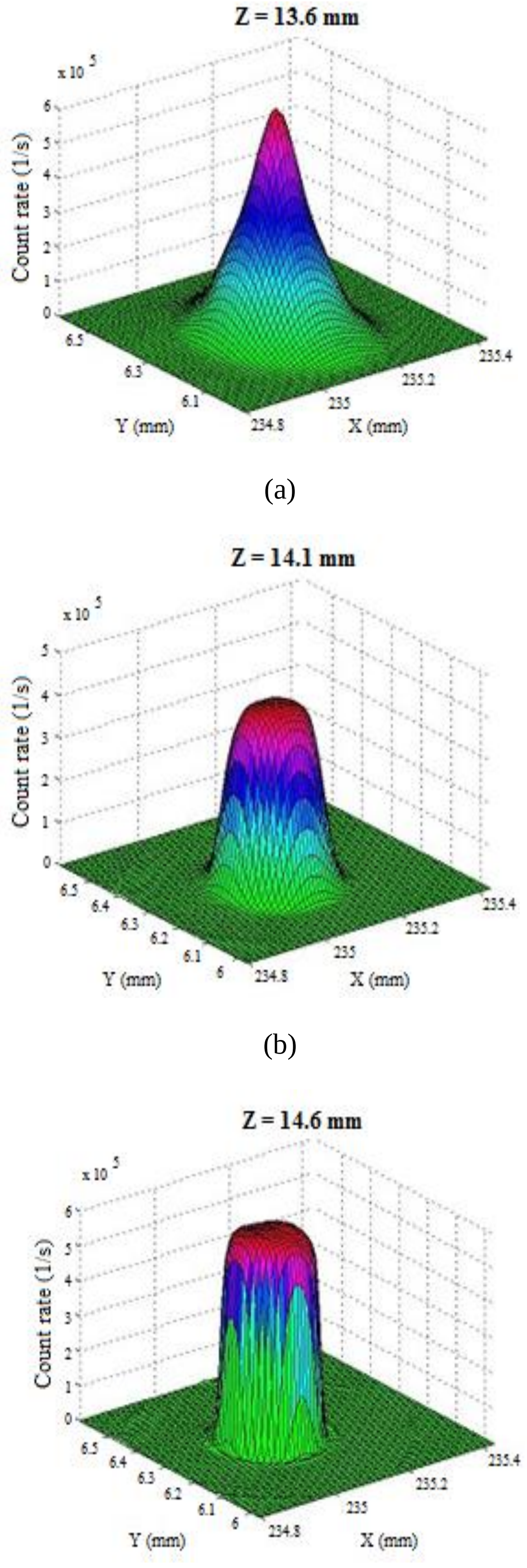
The homogeneity of the Si-SPAD detector was studied as a relative standard deviation. The homogeneity of the detection efficiency depends on the beam size and evaluated region.

RESULTS

Table 1: Results of the Perkin Elmer SPCM-AQR detector.

No. of Meas.	Z position (mm)	X Center (mm)	Y Center (mm)	ϕD (mm)
1	13.6	235.11	6.26	0.35
2	13.7	235.11	6.26	0.34
3	13.8	235.11	6.26	0.33
4	13.9	235.11	6.26	0.32
5	14.0	235.11	6.26	0.31
6	14.1	235.11	6.26	0.30
7	14.2	235.11	6.27	0.28
8	14.3	235.11	6.27	0.26
9	14.4	235.11	6.27	0.24
10	14.5	235.11	6.27	0.23
11	14.6	235.11	6.28	0.22
12	14.7	235.12	6.28	0.23
13	14.8	235.12	6.29	0.24
14	14.9	235.12	6.29	0.26
15	15.0	235.12	6.29	0.28
16	15.1	235.12	6.29	0.30
17	15.2	235.12	6.29	0.31
18	15.3	235.12	6.29	0.32
19	15.4	235.12	6.29	0.33
20	15.5	235.12	6.30	0.34
21	15.6	235.12	6.30	0.35

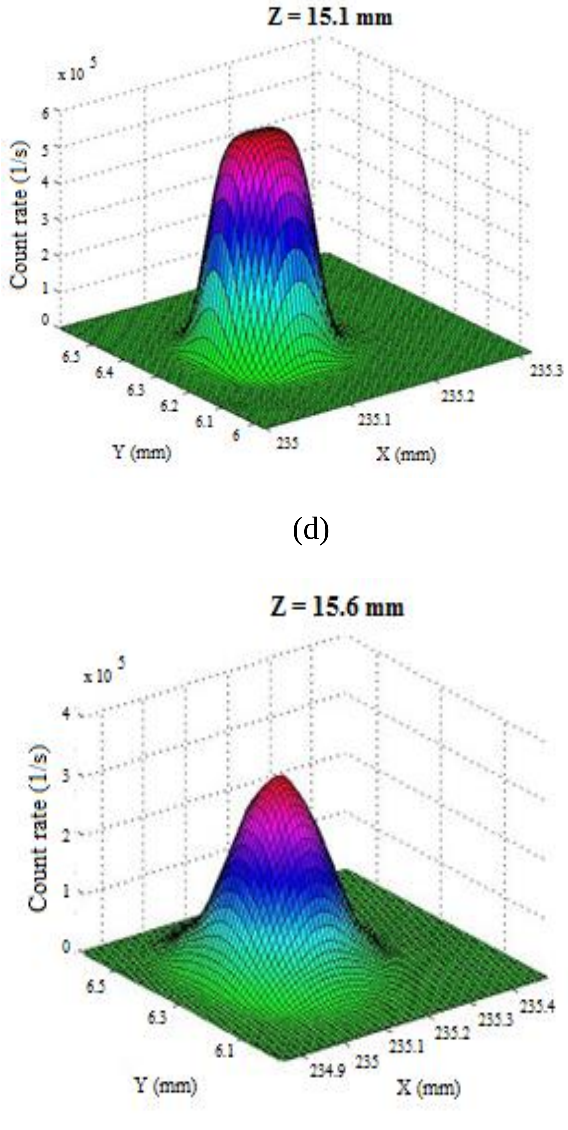
In Figure 2, the scanning results for four different Z-positions are shown and in (Table 1) the results for all performed scans are summarized. For Z-positions from 13.6 mm (Figure 2a) to 14.0 mm, the scan profile correspond dominantly to a Gaussian beam profile, while for Z-positions from 14.1 mm (Figure 2b,c,d) to 15.1 mm it corresponds dominantly to a rectangular profile. The scan profile is again Gaussian dominated for Z-positions from 15.2 mm to 15.6 mm (Figure 2e).



(a)

(b)

(c)



(d)

(e)

Figure 2: Scan profiles for different Z positions. a, e - Gaussian profile and b, c, d- Rectangular profile.

A dominantly Gaussian profile is obtained when the diameter of the detector is smaller than the beam diameter, whereas in case then the detector is larger than the beam, a dominantly rectangular scan is obtained. The optimal position (X/Y/Z) for setting the SPAD detector correspond to Xcenter = 235.11 mm, Ycenter = 6.28 mm and Zposition = 14.6 mm (Figure 2c).

The Figure 3 shows the results for the quantum detection homogeneity of the Perkin Elmer SPCM-AQR Si-SPAD detector. The Figure 3 depicts that the detection efficiency, after optimization of the alignment position, has been normalized to one and is obtained for a beam impinging on the center of the active area of the sensor. For the region one (diameter 120 µm) of the SPCM-AQR detector homogeneity 0.85 % is obtained. The homogeneity can be improved by selecting smaller regions, e.g the region two for diameter 40 µm is obtained homogeneity 0.3 %.

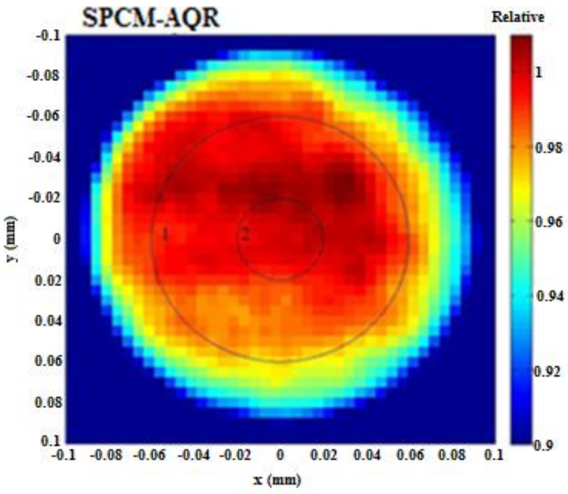


Figure 3: Relative spatial quantum detection efficiency of the Perkin Elmer SPCM-AQR Si-SPAD detector, determined with a beam diameter ΦB ~ 10 µm and circled sensor area with diameter *ΦD1*=200µm.

DISCUSSION

In this paper the experimental set-up and experimental results needed for optimization of the detector position were described. This analysis gives important information in how to carry out the optimization of the detector position for the calibration of the SPAD detector. The optimal position (X/Y/Z) for setting the SPAD detector correspond to X center = 235.11 mm, Y center = 6.28 mm and Z position = 14.6 mm. Based on these results, the future research work will be focused on fitting a mathematical model to the scan results in order to be able to find the best alignment position of the SPAD in a completely automated way and investigation of the homogeneity for different commercial Si-SPAD detectors.

ACKNOWLEDGEMENTS

This research work has been supported by Physikalisch-Technische Bundesanstalt in Braunschweig, Germany and by the project "Single-Photon Sources for Quantum Technology" (SIQUTE) of the European Metrology Research Programme (EMRP). The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

Funding: This research work has been supported by Physikalisch-Technische Bundesanstalt in Braunschweig, Germany and by the project "Single-Photon Sources for Quantum Technology" (SIQUTE) of the European Metrology Research Programme (EMRP). The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.
Conflict of interest: None declared.
Ethical approval: Not required

REFERENCES

1. Gisin N, Ribordy G, Tittel W, Zbinden H. "Quantum Cryptography", Reviews of Modern Physics. 2002:74:145–95.
2. Cova S, Ghioni M, Lotito A, Rech I, Zappa F. "Evolution and prospects for single-photon avalanche diodes and quenching circuits", Journal of Modern Optics. 2004:51:1267–88.
3. Buller GS, Wallace A, "Recent advances in Ranging and Three-Dimensional imaging using time correlated single-photon counting. IEEE J. Sel. Top. Quantum Electron. 2007:13:1006–15.
4. Barbieri C, Naletto G, Occhipinti T, Facchinetti C, Verroi E, Giro E, Di Paola A et al. A single photon counting photometer for astronomy. Jounal of Modern Optics. 2009:56:261–72.
5. Gulinatti A, Rech I, Panzeri F, Cammi C, Maccagnani P, Ghioni M et al. New silicon SPAD technology for enhanced red-sensitivity, high-resolution timing and system integration. Journal of Modern Optics. 2012:59:1489–99.
6. Kück S, Hofer H, Peters S, Lopez M. Detection Efficiency Calibration of Silicon Single-Photon Avalanche Diodes Traceable to a National Standard, In: Proceedings of NEWRAD 2014: NEWRAD 2014 Conference, Espoo, Finland, 24-27, 2014. (Ed.) Park, S. (KRISS), Ikonen, E. (MIKES). 2014: 93-4.
7. López M, Hofer H, Kück S. Detection efficiency calibration of single-photon silicon avalanche photodiodes traceable using double attenuator technique. Journal of Modern Optics. 2015:62:S21-7.
8. Perklin Elmer SPCM-AQR Detector. Single Photon Counting Module, 2008 Available at http://www.pas.rochester.edu/~advlab/APD_SPCM_AQR.pdf Accessed 15 December 2008.

Cite this article as: Dhoska K, Hofer H, López M, Kübarsepp T, Kück S. Alignment position method for SPAD detector calibration and homogeneity. Int J Sci Rep 2015;1(7):271-4.