Novel Integrating Sphere Based Attenuation Method for Single Photon Detector Calibrations

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The currently used single photon detectors in quantum technology fields are silicon single-photon avalanche diodes (Si-SPADs). The most crucial parameter in those applications is the detection efficiency of those detectors. We have participated in the pilot study of the CCPR WG-SP TG 11 for determining the detection efficiency of Si-SPADs single-photon detectors at a wavelength of 850 nm in free-space beam using the double attenuation filter protocol. Using various lasers, we have extended our measurements from 500 nm to 900 nm. In this paper, we propose a novel method where an integrating sphere is used as the (second) attenuator. Our first experimental results show that the wavelength dependence of the detection efficiency of our Si-SPADs using the sphere attenuation method follow the same curve as the one determined by the absolute detection substitution technique.

INTRODUCTION

For determining the detection efficiency of Si-SPAD detectors two approaches can be used: the two-photon correlation technique [1] or the detection substitution technique, which uses a strongly attenuated laser and a reference detector [2]. In the pilot study of the CCPR WG-SP TG 11, the latter technique is used. We have also participated in this pilot study (measuring detection efficiency at 850 nm) but also extended our measurements to the wavelength range from 500 to 900 nm using various lasers in order to determine the wavelength dependence of the detection efficiency of our Si-SPADs. Because we wanted to use our tuneable-pulsed laser which is tuneable from 200 nm to 2000 nm, we had to develop an alternative method for measuring the detection efficiency. This owing to the fact that the photon flux per laser pulse (100 µJ in a pulse duration of 4 ns) is very high and the standard filter attenuation method fails owing to saturation effects in the reference detector and the impossibility to create single photon flux at the position of the SPAD.

EXPERIMENTAL SETUP

When one uses the detection substitution technique, typically two strong attenuation filters are required in order to link the sensitive range of the Si-reference detector and the single photon-counting mode of the SPAD. In our sphere attenuation setup, we basically replace the second attenuation filter by an integration sphere and decrease the photon flux to the single photon counting level by separating the SPAD by a large distance from one of the exit ports of the sphere. At the same time, we measure the photon flux in the integrating sphere by a Si-reference detector, allowing us to link the single-photon counting rate at the SPAD to the SI-traceable photon flux reference. Figure 1 shows the experimental setup:

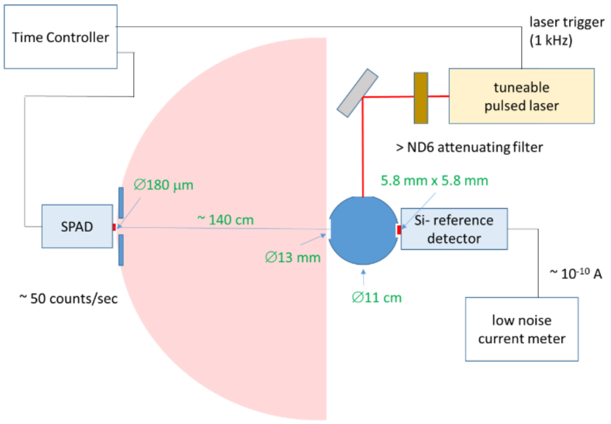

Figure 1. Experimental setup for the integrating sphere attenuation method.

The pulsed laser beam is directed into the entrance port of the integrating sphere. This entry beam is strongly attenuated such that the reference Si-detector can still operate in a linear non-saturating mode. The Si-SPAD is placed at a sufficiently large distance (typically more than 1 m) from a second port of the integrating sphere such that the photon flux is substantially reduced to a single-photon counting level at the position of the Si-SPAD. The Si-reference detector signal is measured by a low-noise current meter with a good signal-to-noise at 10^{-10} A. The single photon count rate of the SPAD is measured by counting the digital pulses from the SPAD in a time controller which is triggered by the pulsed laser. In order to be sure that one is operating in the single-photon counting mode, typically most laser pulse triggers do not create a SPAD signal. In our setup we measured in the average 30 counts per second at a laser repetition rate of 1 kHz.

RESULTS

Using the detection substitution technique [2] we have measured the absolute detection efficiency of our various Si-SPADs using our tuneable Ti:sapphire laser pumped by a diode-pumped solid-state laser at 532 nm. The following figure 2 shows our experimental results:

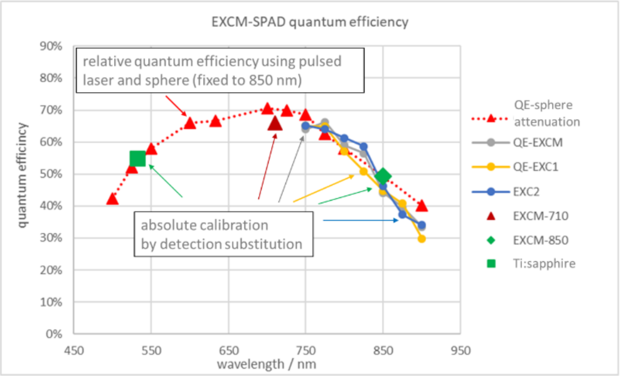

Figure 2. Results comparing our sphere attenuation method (relative measurement) to absolutely calibrated values.

Most of the data points in figure 2 are absolute detection efficiencies for the various Si-SPADs and laser wavelengths using the detection substitution technique. Superimposed are the (relative) detection efficiencies as determined by our pulsed laser and sphere attenuation technique. These results are shown as red triangles, which are connected by a dotted line (for visualization this relative detection efficiencies are fixed to the 850 nm absolute detection efficiency result).

CONCLUSION

Using our sphere attenuation method in combination with a continuously wavelength tuneable pulsed laser, we found a fast way to measure the wavelength dependence of the detection efficiency of a Si-SPAD (relative measurement). We would like to note that this sphere attenuation method could be converted to an absolute method when all the geometrical factors in figure 1 are known within the required uncertainties. One of the critical issues of our method will be the uncertainties produced by the stray light coming from sources other than the exit window of the integrating sphere directed to the Si-SPAD.

REFERENCES

1. S.V. Polyakov et al., Single-Photon Detector Calibration, Proc. SPIE Vol. 6372, 2006
1. K. Dhoska et al., Improvement of the detection efficiency calibration and homogeneity measurement of Si-SPAD detectors, SpringerPlus, Vol 5, 2016