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Quantum Efficiency of Single Photon Avalanche Diode (SPAD)

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Abstract. Observation of faint sources is affected by the chronic problem of photon lack. This problem becomes crucial when very short integration times are required (from micro to milliseconds), as for example in observations of transient phenomena and adaptive optics to correct in real time the atmospheric turbulence. To detect weak and fast transients, CCDs are inadequate because of the readout noise and the readout technique, while SPADs detectors benefiting from the photon counting operating mode, can perform much better. SPAD detectors are very innovative and will offer further opportunities in astrophysical observations. The electro-optical characteristics of these devices are important to prove the applicability of the above cited scientific programs. At COLD laboratory of INAF Osservatorio Astrofisico of Catania several SPAD characterization campaigns have been carried-out. To measure the SPAD QE two different methodologies have been used, one classic and one by using a different approach. We will discuss both methodologies, the related equipment and the obtained results.

Key words. Singol Photon Avalanche Diode, Photon counting, Device's characterization.

1. Introduction

At COLD laboratory of INAF Osservatorio Astrofisico of Catania we have analyzed two methods to measure the QE of SPAD devices:

1. using an integrating sphere that illuminates uniformly the reference detector and the SPAD device;
2. using a reflection objective that focuses a beam of about 10 μm diameter on the SPAD.

The first method, that we will refer to as the "classic method", relies on the accurate knowledge of the sensitive areas of both the reference detector and the SPAD device. The second method, using a spot smaller than the typical dimension of a SPAD pixel should be largely insensitive to this problem.

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2. Classic method

For QE measurements we realized an appropriate mechanical structure where the detectors are housed, in such way we are able to position the reference photodiode and the SPAD detector at the same distance from the center of the sphere. To calculate the QE, we have used a calibrated (NIST traced) photodiode as reference detector (to measure the flux of the in-

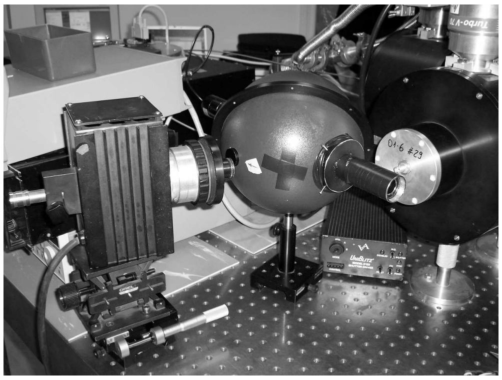

Fig. 1. Image of the measurament apparatus

cident radiation on the SPAD), an integrating sphere to obtain a uniform illumination on the detectors surfaces, an halogen lamp, and a set of interference filters to select the wavelength. We have measured the QE in the 350 - 1050 nm range. Furthermore we investigated the QE dependency on the Over Voltages by measuring the SPADs QE at two different values of Over Volatge that are 4V and 5V. Knowing the photodiode QE at different wavelength, the photodiode area (1 cm^2) and the SPAD area (3 x 10^{-4} mm^2), the spad QE comes directly from the ratio between the diode photocurrent and the counts measured by the SPAD. Applying the propagation error method we have also evaluated the QE standard deviation. In figure 2 the QE plot with the relative error bar of one of the SPAD devices at two different breakdown voltages is shown. The shape of the QE curve, that

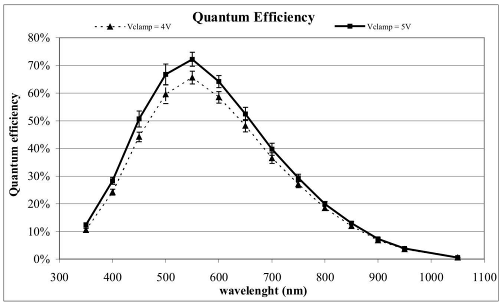

Fig. 2. QE of a SPAD in the 350 - 1050 nm range at two different Over Voltages. Note the increase of the QE with the V_{clamp}.

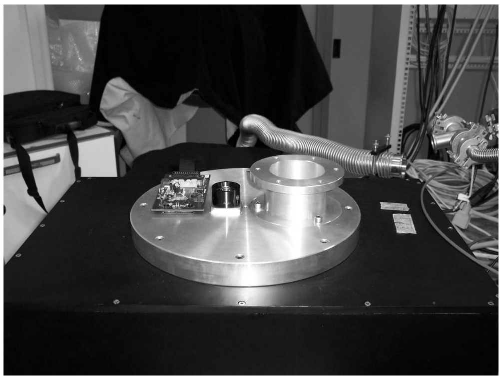

Fig. 3. Box containing the motorized reflection objective, fed by an fiber optic and with the mechanical flange that can support the detectors for characterization and the SPAD.

peaks at 550 nm, is typical for Silicon devices. It is also evident the QE increase respect to the Over Voltage (V_{clamp}).

3. Motorized reflection objective method

The motorized reflection objective is essentially made by the objective itself, by a fiber optic, and three motorized tables. The objective is able to focus a beam with a FWHM of about 10-15 μm, depending on the pinhole and on the focus condition. The fiber optic is connected to the COLD detector characterization system (Bonanno et al. 1996,for a detailed description) and feeds the objective. The three

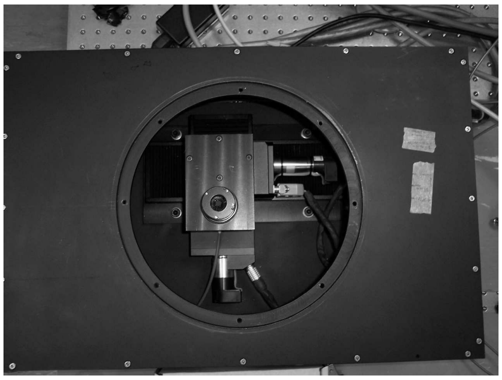

Fig. 4. Image of the measurament apparatus

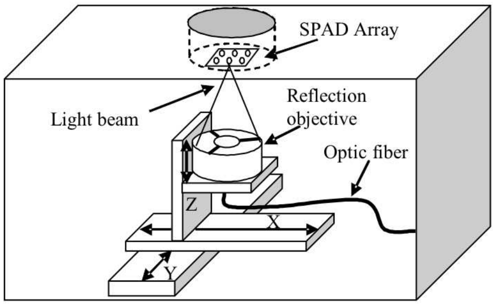

Fig. 5. Motorized reflection objective draft. The optic fiber is connected to one of the two cameras of the characterization system.

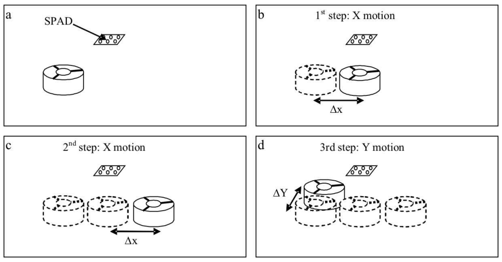

Fig. 6. Procedure to find the beam focus on the SPAD.

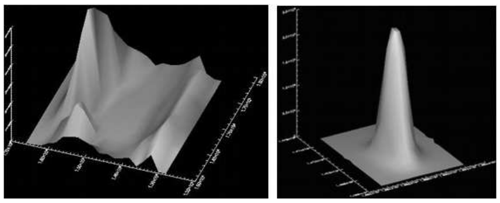

Fig. 7. 3D plots obteined by the IDL procedure. On the left plot the beam is unfocused, the signal is distributed in hundreds microns and it shows the topical shape of an objective unfocused. On the right plot the beam is focused and the signal is concentrated in few microns.

motorized tables have an accuracy and repeatability of 1 μm. The motion of the device is completely automated and controlled by a PC. The wavelength is selected by the characterization system. Figure 3 shows the mechanical flange that allows to mount three different detectors: two identical supports for the reference detectors and another for the detector to be characterized. At the same time, we can mount a calibrated photodiode to measure the flux intensity, and a CMOS-APS for beam profile analysis. Subsequently, knowing the light spot parameters, we can characterize the sample detector. The procedure to find the focus of the beam on the SPAD is showed in figure 6. The objective from the starting position (a), moves of a given ΔX (b). Once the position is reached, the program acquires the count rate, then the objective is moved again along X (c) and another count rate is acquired. When all the acquisition procedure has been completed, the program moves the objective to the X starting position, then the entire procedure is repeated along the Y axis. The number of steps in X, Y and Z can be programmed and also any ΔX, ΔY, and ΔZ can be selected. Simultaneously the data file can be elaborated by an IDL procedure to obtain images like those shown in figure 7. Because of the weak flux intensity we had some problem to use the photodiode as reference detector and we have not yet obtained any reasonable QE measure.

4. Conclusion

As we have discussed, the classic method, used to measure the QE, suffers from the inaccurate knowledge of the sensitive areas, the illumination uniformity and the involved optical path. A monochromatic spot with a size smaller than 10 μm FWHM may be the solution to these problems. Infact using a calibrated detector and measuring the flux we can measure the SPAD QE avoiding to take into account for geometry variations of the luminous spot and of the SPAD area. We cannot use a photodiode as reference detector but either a CCD or a photomultiplier.

References

Bonanno, G. et al. 1996, Proceedings SPIE, Vol. 2808, p. 243-249