SiPM Optical Crosstalk Amplification due to Scintillator Crystal: Effects on Timing

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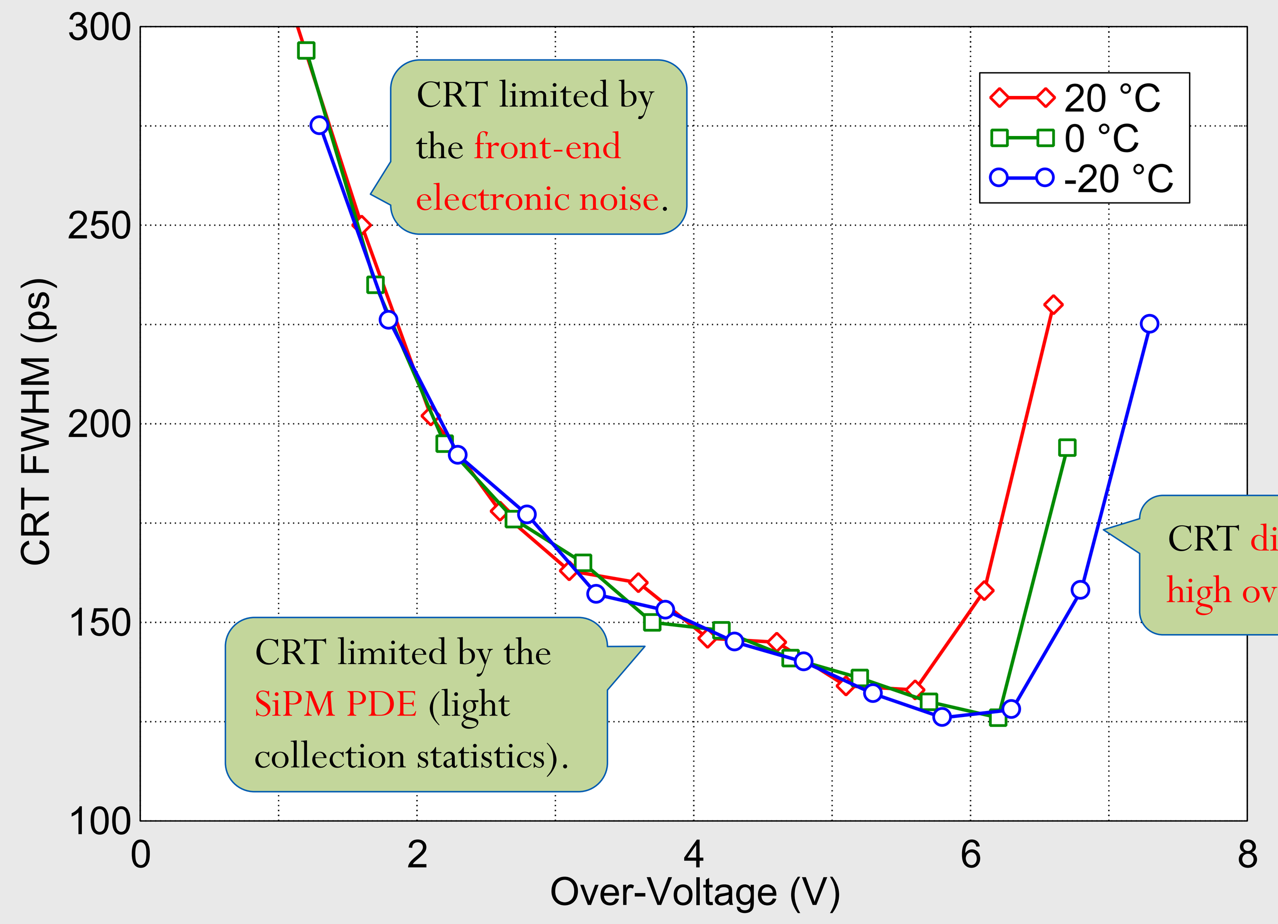
INTRODUCTION

The Dark Count Rate of the SiPM plays an important role in limiting the timing performance of the device when used for the readout of the light coming from a scintillator. We have already shown that it is possible to substantially reduce its effect on the Coincidence Resolving Time with a suitable noise compensation method. In this work we describe a different mechanism that limits the timing performance of the SiPM and can be observed clearly when the contribution of the DCR is cancelled by the noise compensation. The mechanism worsens the CRT at higher over-voltages, actually limiting the maximum bias that can be applied to the device, and seems to be related to the amplification of the optical cross-talk of the device due to the presence of the scintillator crystal. As a consequence, SiPM detectors, with different active areas, Fill Factors and PDE, provide a similar minimum CRT value, for a given crystal size. In this work we describe the experimental evidence of this phenomenon, its relation to the CRT performance of the devices as well as possible solutions.

OUTLINE of the PROBLEM

With Pole-Zero [1] noise compensation and smaller detectors we observe almost no dependence of the measured CRT on the DCR of the detector → timing resolution should be limited by PDE of the device only.

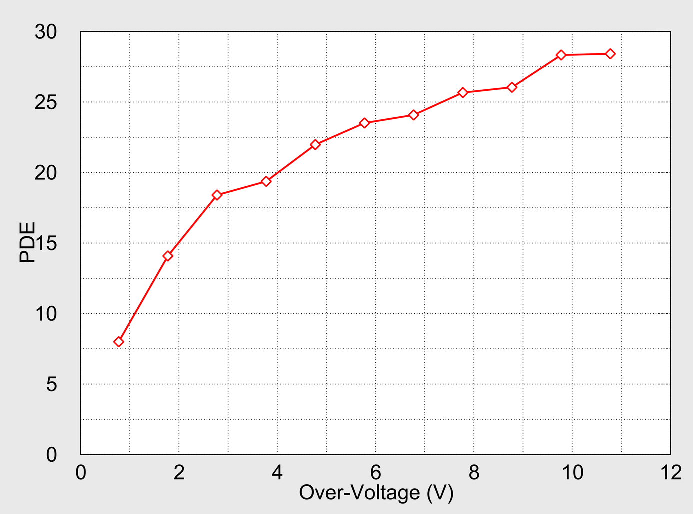


CRT measured coupling a 2x2 mm² FBK SiPM, with cell size of 50 x 50 um², to a 1.8 x 1.8 x 2 mm³ LYSO crystal (Saint Gobain).

The CRT does not change significantly with cooling, whereas the SiPM DCR is reduced sixteen times.

However, the optimum CRT is not obtained at maximum PDE, which is supposed to limit the timing performance when the detector noise is negligible.

The maximum useful operating over-voltage (V_{OVmax}) is similar for the three temperatures considered.

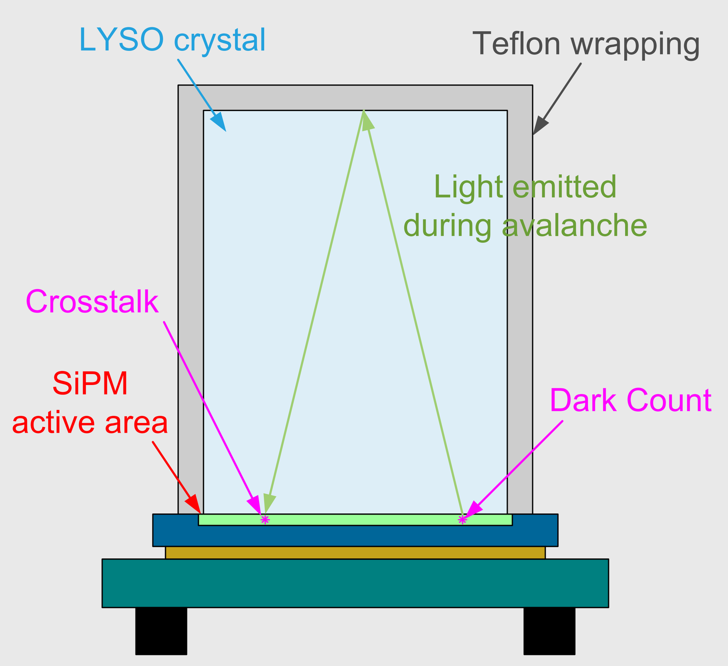


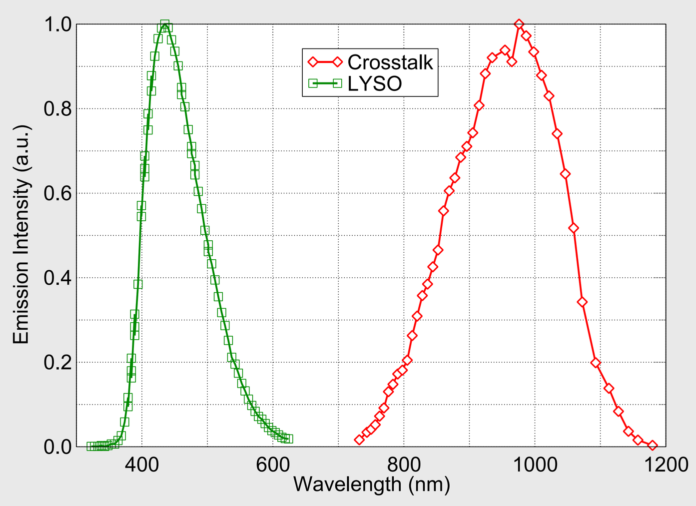
PDE vs. V_{OV} of the 50 um cell SiPM

CROSSTALK AMPLIFICATION due to SCINTILLATOR

As already suggested in [3], the presence of the scintillator can reflect the photons emitted by the hot carriers during the avalanche.

Consequently, there will be an increase in the crosstalk collection efficiency and, possibly, a shift towards shorter wavelengths in the spectrum of the photons actually generating crosstalk, with respect to the case without scintillator (still under investigation).





Simulated spectrum of photons generating crosstalk, without scintillator [2].

REFERENCES

[1] A. Gola, C. Piemonte, A. Tarolli, "Analog circuit for timing measurements with large area SiPMs coupled to LYSO crystals", IEEE NSS/MIC 2011 CR, pp.725-731, 2011.

[2] A. N.Otte, "On the efficiency of photon emission during electrical breakdown in silicon", NIMPR A, Vol. 610 – 1, 2009, pp. 105-109.

[3] P. Barton, et al., "Effect of SSPM surface coating on light collection efficiency and optical crosstalk for scintillation detection", NIMPR A, Vol. 610 – 1, 2009, pp. 393-396.

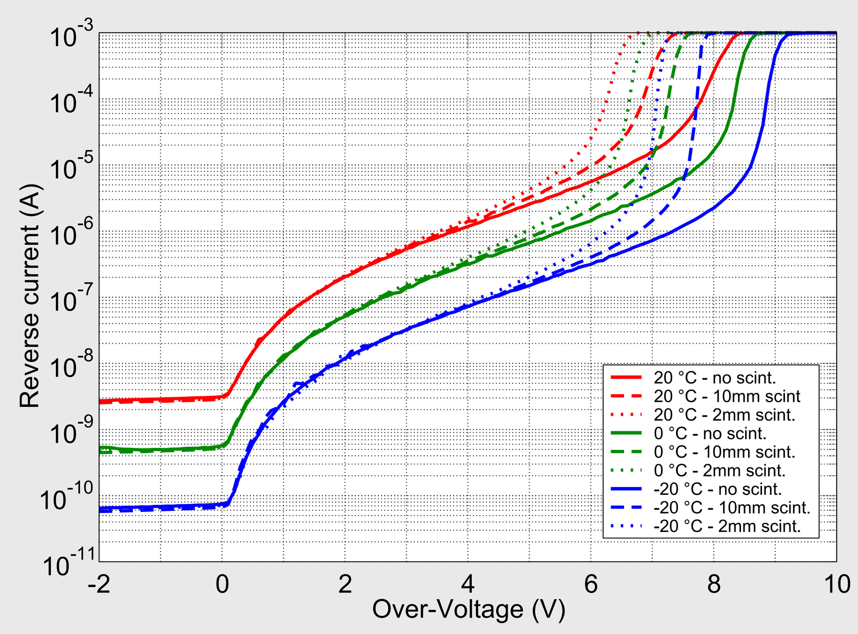
DARK CURRENT AMPLIFICATION

We observed a substantial increase in the reverse current of the SiPM at high over-voltages, due to the presence of the scintillator.

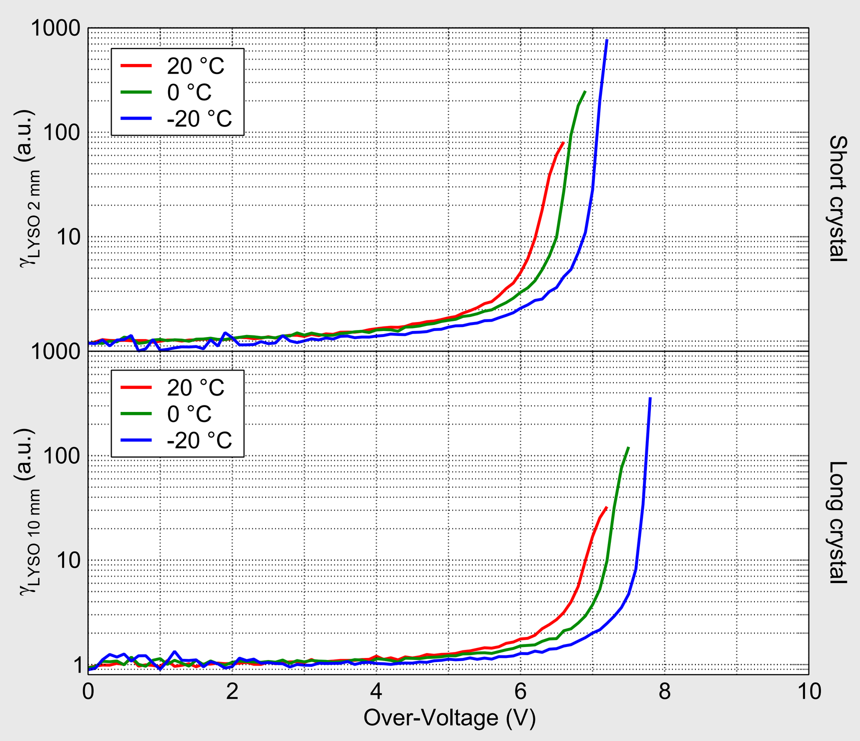
There was no current increase if the top scintillator face was covered with light absorbing paint (not shown here), confirming that the phenomenon is due to the reflection of the crosstalk photons on the scintillator coating.

$$\gamma(V_{OV}) = \frac{I_{scint}(V_{OV})}{I_0(V_{OV})} = \frac{DCR_{scint}(V_{OV})}{DCR_0(V_{OV})}$$

Since the SiPM gain is fixed, for a given over-voltage, γ can be considered the DCR amplification factor.



SiPM reverse current without scintillator and with 1.8 x 1.8 x 2 mm³ and 1.8 x 1.8 x 10 mm³ crystals.



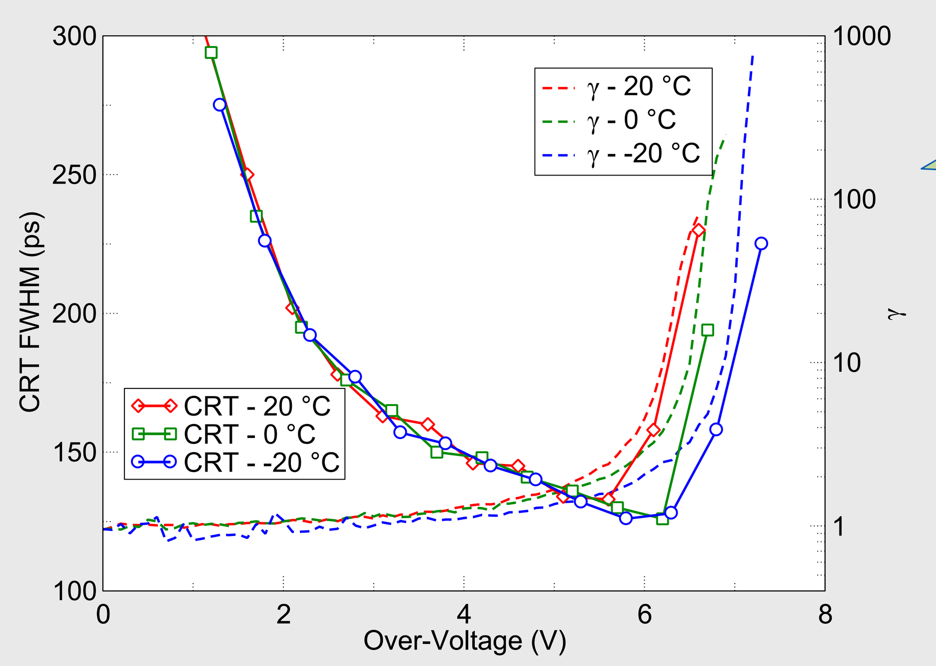
γ(V_{OV}) for different scintillator sizes.

The DCR starts diverging at lower over-voltages for the smaller scintillator, due to a more efficient collection of crosstalk photons.

The γ coefficient shows little temperature dependence.

CORRELATION with TIMING

When the SiPM DCR is diverging, the CRT rapidly gets worse because the PZ algorithm can no longer compensate for the detector noise. Additionally, there is a reduction of the effective PDE due to an increasing number of cells that, at any time, are discharged due to a dark count.



Correlation between γ and CRT.

The divergence of the CRT curve shows an almost perfect correlation with the divergence of γ.

The γ(V_{OV}) curve is very steep at high V_{OV}, whereas PDE(V_{OV}) is sublinear → small difference in timing at different temperatures.

CONCLUSIONS and ACKNOWLEDGEMENTS

We found experimental evidence of the change in the SiPM crosstalk due to the presence of the scintillator. The phenomenon is clearly evident in the reverse IV characteristic of the device and is very well related to the minimum measured CRT. It turns out that the crosstalk amplification due to the scintillator limits the ultimate timing performance of the SiPM, when the effects of detector noise are removed, either by cooling or with a suitable noise compensation algorithm. The most effective solution, which we have implemented through a process upgrade, is to reduce the gain of the cell, by reducing its size, while maintaining the same Fill Factor. It is also possible to use wavelength selective dyes, attenuating the crosstalk but preserving the scintillation light, as suggested in [3], even though the results still need to be confirmed.

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