FIB device surgery for noise reduction in InGaAs SPAD arrays

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Abstract

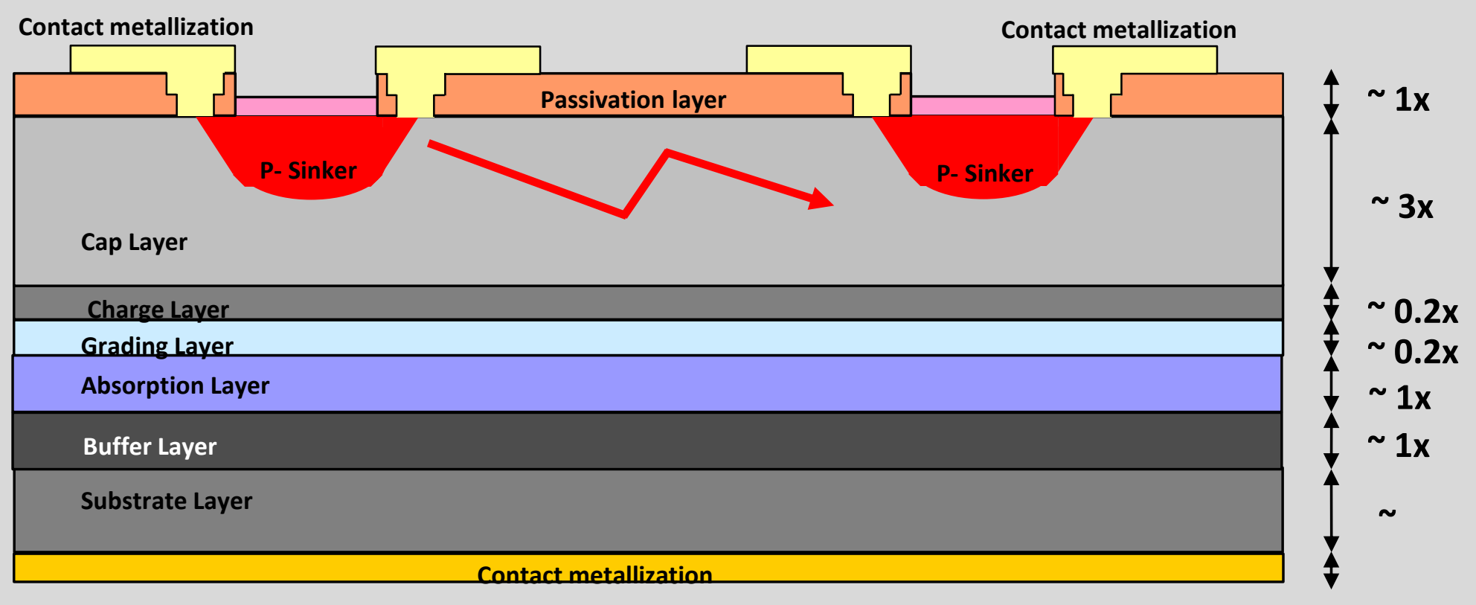
InGaAs/InP Single Photon Avalanche Diodes - SPAD - are used to detect faint optical waveforms, down to single-photon level, in the near-infrared range (up to 1700 nm)[1]. InGaAs/InP SPAD arrays are affected by a strong increase of the noise level due to optical crosstalk between neighboring pixel based on the photons emitted during an avalanche[2]. A new FIB-based approach to reduce crosstalk in SPAD arrays has been developed and implemented on a test structure for characterizing the performance of the detectors before and after the FIB process.

Introduction

When a single photon is detected by a SPAD, an avalanche is triggered and many charge carriers flow through the p-n junction. Such carriers are “hot” because of the high electric field in the multiplication region and they can relax by emitting near-infrared photons that can be detected by neighboring pixels and trigger cross-talk avalanches [3]. The main emission wavelength at 300 K is ~ 950 nm (near band-edge of the InP material) with broadband component that fits roughly a 3000 K blackbody spectrum. This limits the distance between the pixels in an array because the detection of secondary photons by neighbouring pixels introduces false counts thus increasing noise (optical cross-talk).

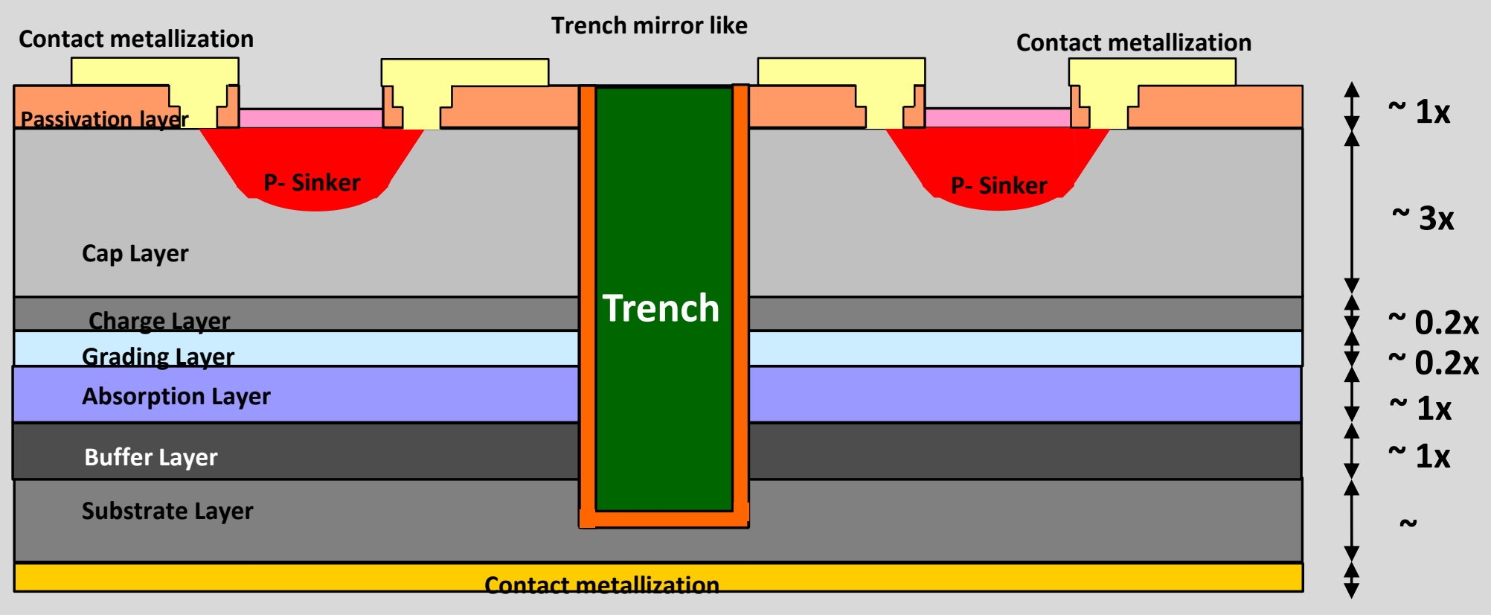
WEAK POINTS

The sensitivity (BIAS related) and / or the spatial density of the SPADs in an array of detectors is limited by the “cross-talking noise”



SOLUTION

Prepare a structure of trenches to avoid the avalanche photons to reach the other neighbor SPAD.



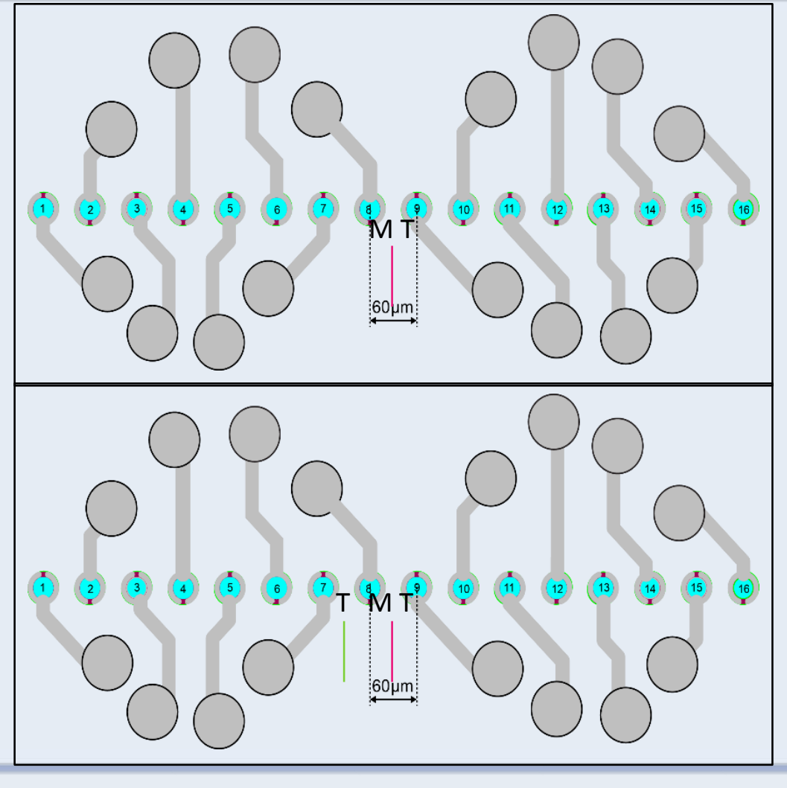
Methodology

BASIC SOLUTION

The FIB modification of a device with 16 SPADs in a row has been to mill a deep trench between two neighboring pixels, namely between SPAD 7 and 8

EVOLUTION.

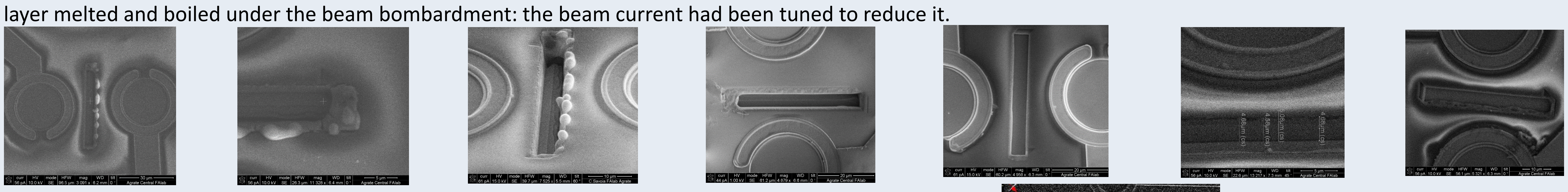
A different approach to the trench has been used adding a metal deposition in the trench, hereafter named “enhanced trench”. The metal filled trench has been prepared between SPAD 8 and 9.
This second trench has been setup on the same array to measure and to compare the two techniques.



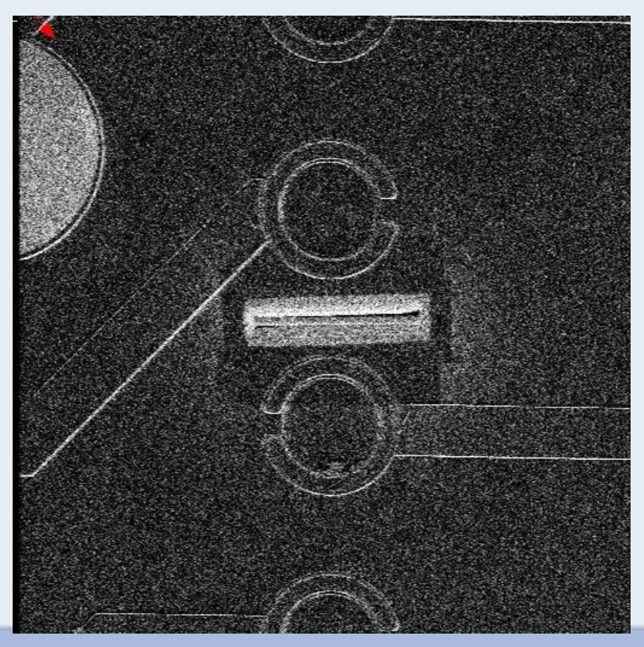
Legenda
T = Basic Trench
MT = Enhanced Trench

FIB APPROACH

The layers to be milled (InP and InGaAs) were completely new for our experience (typically based on Silicon only), so we had to set up non standard milling recipes. The pattern size was 50 µm by 6 µm, the total thickness to mill was about 6 µm. We used a DCG P3X II, the ions beam was at 30 keV, 1 nA, dwell time 100 ns, min. retrace 33 ms both pure physical mill and gas assisted (XeF_2) one have been tested to define the best result.
The InP layer melted and boiled under the beam bombardment: the beam current had been tuned to reduce it.



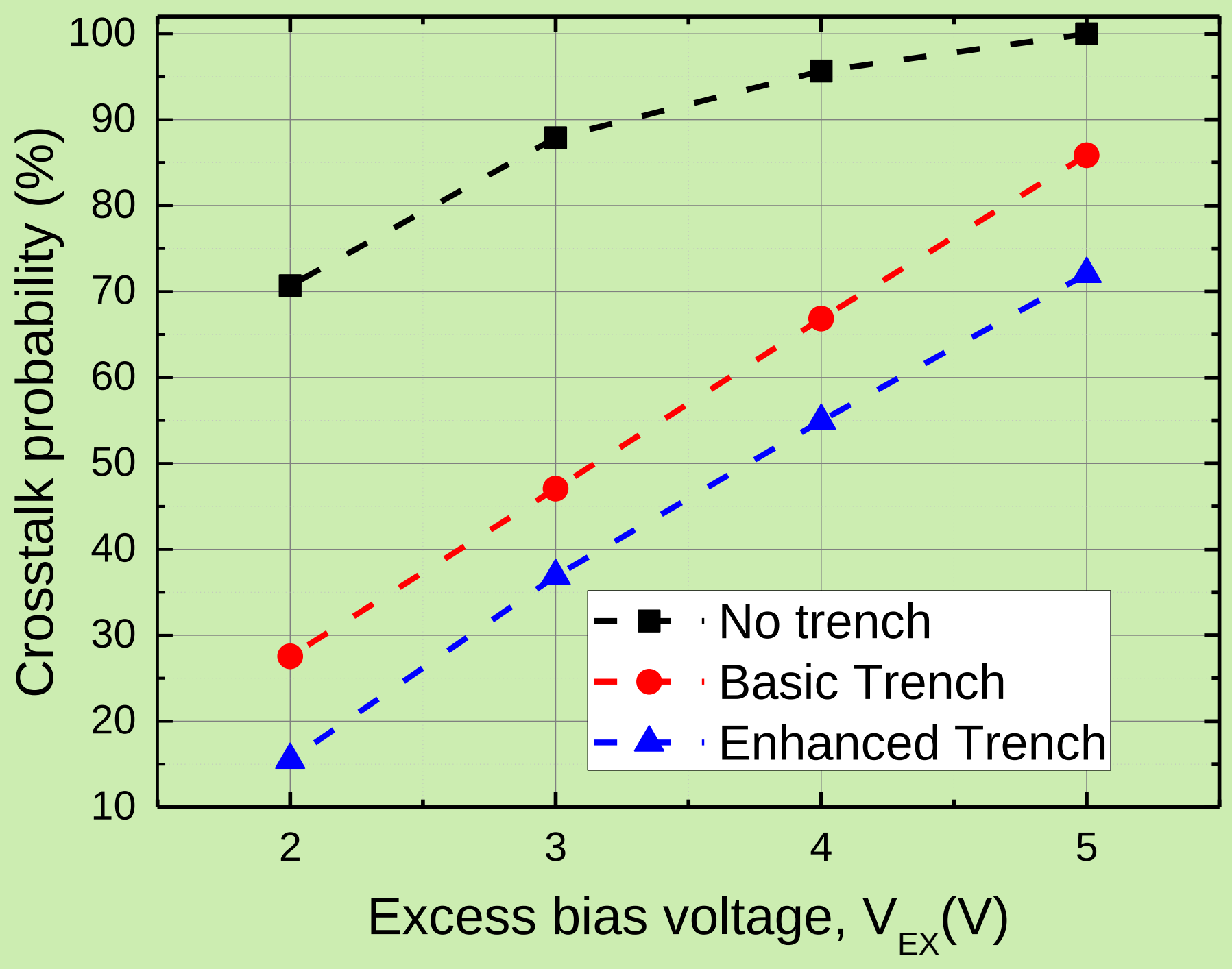
We chose a metallization process to obtain a thin metal layer (Platinum) as a liner instead of completely fill the trench: while the Pt deposition valves were open we refreshed several time the image. The result is to have a thin and uniform metal layer acting as a mirror. The drawback of this method is the risk to short all the metal structures exposed to the ion beam.
It’s necessary to add a beam cleaning of the surface near the conductive geometries to have no electrical path that can generate shorts.

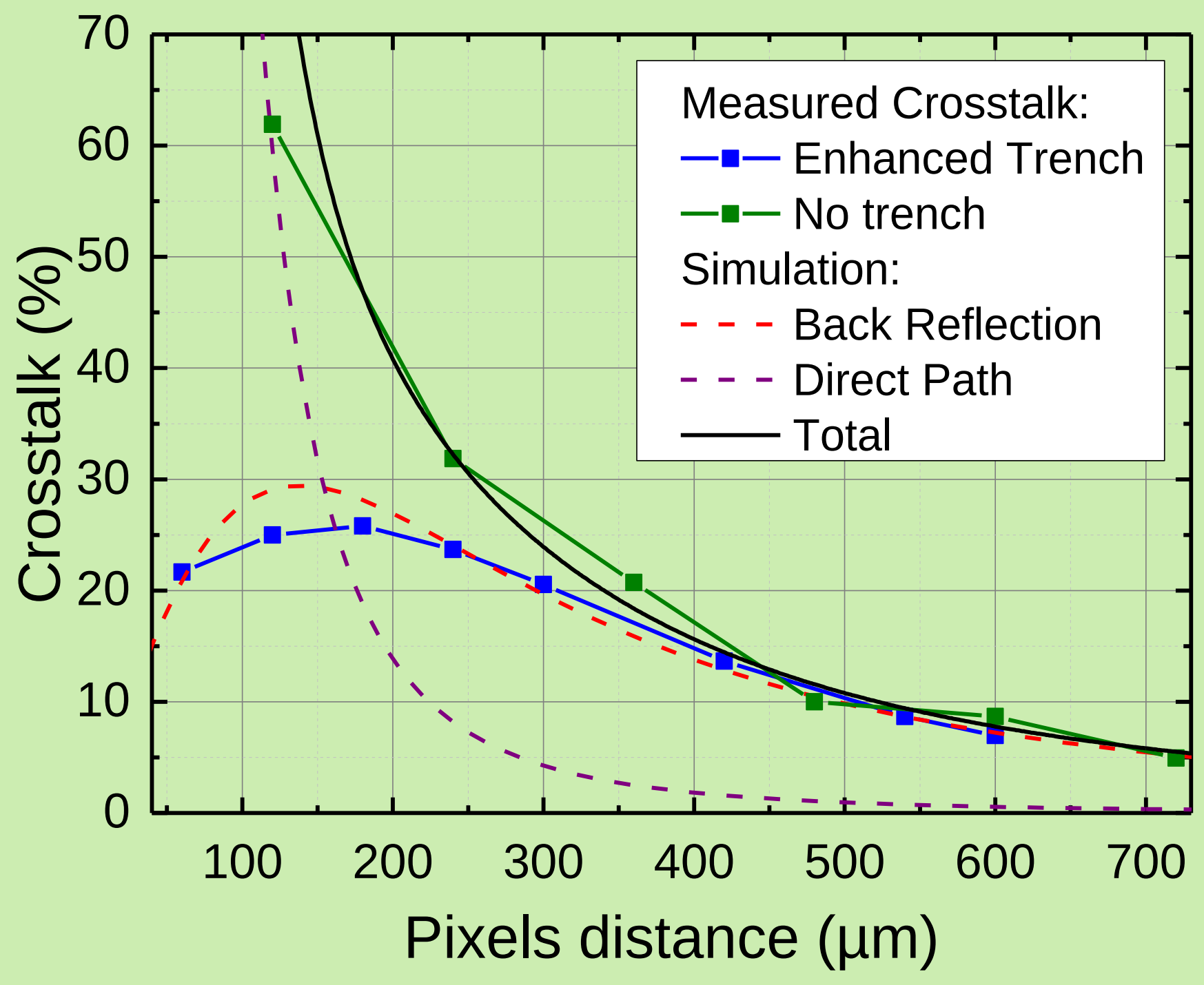


In the picture: the SIM image of the enhanced trench.
The areas were the platinum has been removed are the darker surrounding the trench

Results

A solution to mill the InP and InGaAs layers has been identified.
A deposition recipe has been improved to metallize the trench wall with a thin Platinum layer.
The trench solution shows a good reduction of cross-talk noise.
The enhanced trench (trench plus metallization) reported much better results in cross-talk reduction with respect to the basic empty trench.





Conclusion

We introduced a method for reducing cross-talk noise by means of a metallized deep trench. We obtained very good results by improving the shielding capability of about 50% with respect to the pure trench solution, thus paving the way to SPAD arrays with pixel pitch shorted than 100 µm.

References

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