New Crosstalk Insight and Characterization Methods in CMOS based SPADs

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1 Introduction & Objective

In common literature crosstalk is mainly assigned to **photon travel directly through the silicon and by reflection at the backside of the substrate [Rech2008], even though silicon is known to absorb VIS photons**. Typical methods to suppress crosstalk therefore include metal-filled deep trenches, which optically separate neighboring SPADs effectively but are not available in common CMOS technologies.

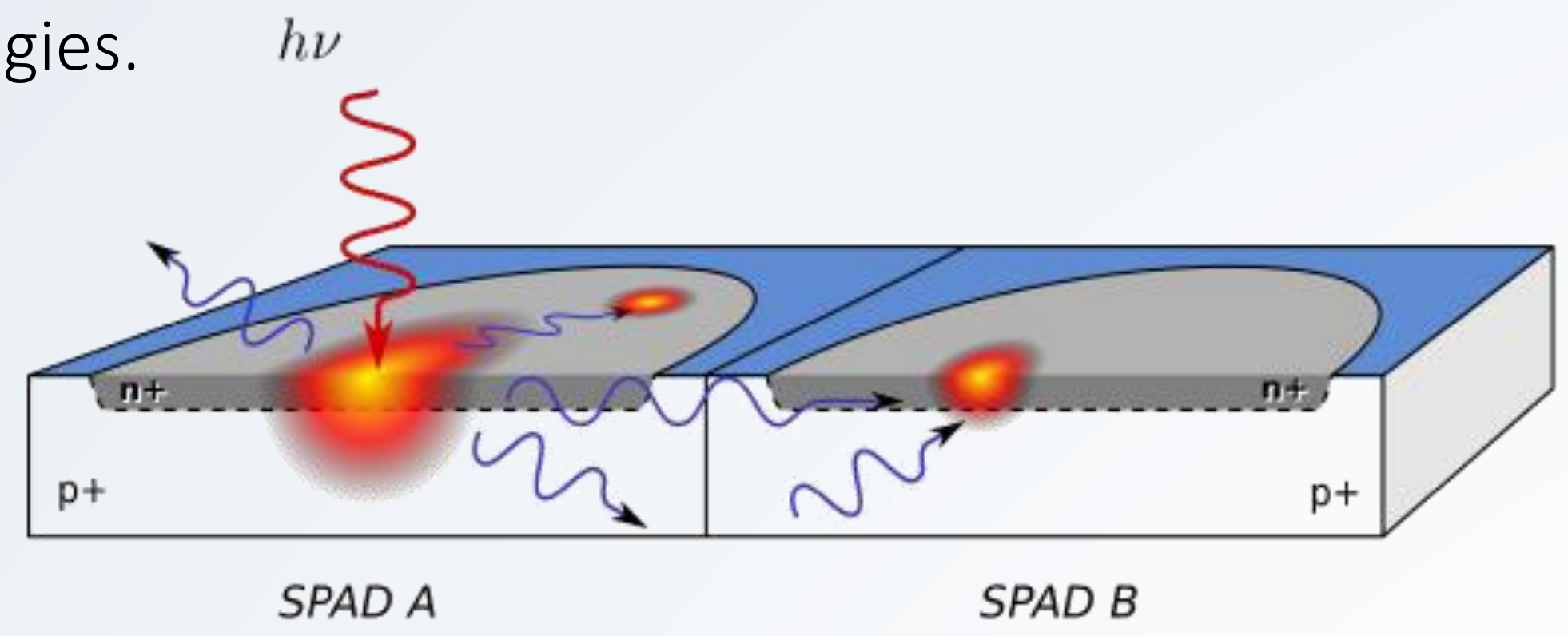

Fig. 1: Conventional crosstalk between neighboring SPADs through the silicon [Rech2008]

In this work, **we propose a new understanding of the crosstalk mechanism considering the photon transfer via the transparent oxide stack in the backend-of-line (BEOL)**, which is commonly neglected. Based on this understanding **new methods to suppress crosstalk are presented and experimentally evaluated.**

2 Material

SPADs are fabricated in BCD technology with a resistor for passive quenching and are arranged in a 6 x 4 Silicon Photomultiplier array.

Three approaches to optically isolate the SPADs are applied:

1) **Formation of a stack of metal and via stripes** (Metal Stack)
2) **Formation of a surface trench using the pad opening passivation etch** (Surface Trench (1))
3) **A combination of the two above** (Surface Trench (2) & Metal Stack)

No modifications of the underlying SPAD structure in the silicon have been performed. All measures are mask neutral, i.e. **no additional dedicated masks and processing steps are needed**. FIB cuts of a reference SPAD and the resulting structures are shown below.

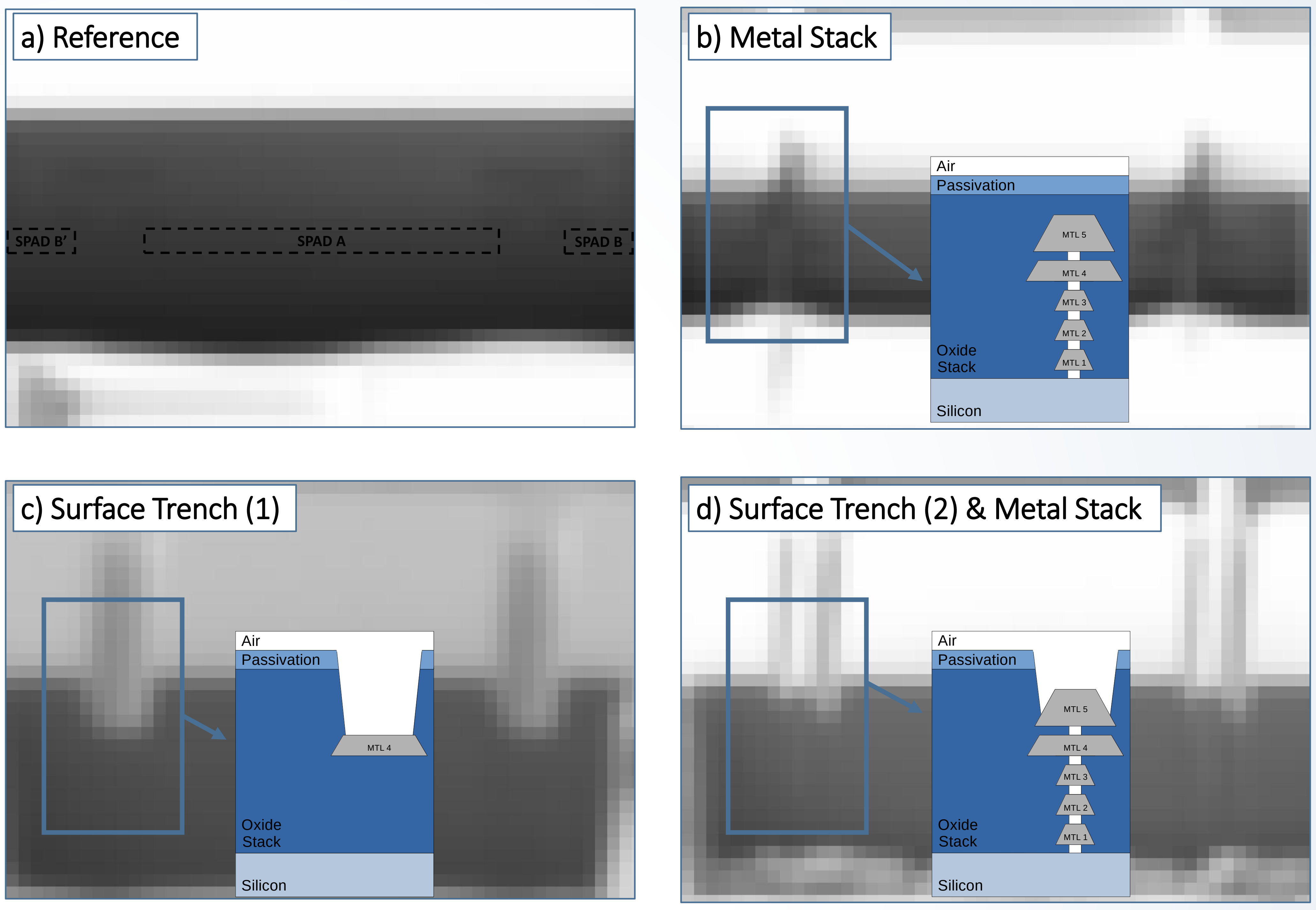

Fig. 2: FIB cuts of the proposed structures with a) no modifications for reference, b) metal stacks between SPADs, c) etched surface trenches between SPADs and d) a combination of metal stacks and trenches. A schematic cross-section for each proposed structure is shown as an inset.

3 Measurement Method & Results

Crosstalk is evaluated in dark conditions by extracting the amplitude of the SiPM pulse. As shown in Fig. 3 the amplitude levels for single photon events (1 p.e.) and double photon events (2 p.e.) associated with crosstalk can be clearly distinguished. The SiPM signal is measured for different over-voltages using a 2.5 GHz LeCroy WavePro 254HD oscilloscope. The resulting amplitude histogram is converted into a staircase curve as shown in Fig. 4 a). The shift of the first plateau in x- and y-direction with increasing overvoltage is due to the increase in pulse amplitude and crosstalk respectively. The staircase curve is analyzed by forming the 2nd derivative of the curve as shown in Fig. 4 b). **The zero crossing of the derivative marks the position of the 1st grade avalanche and is used to calculate the crosstalk in an objective and semi-automatic manner.**

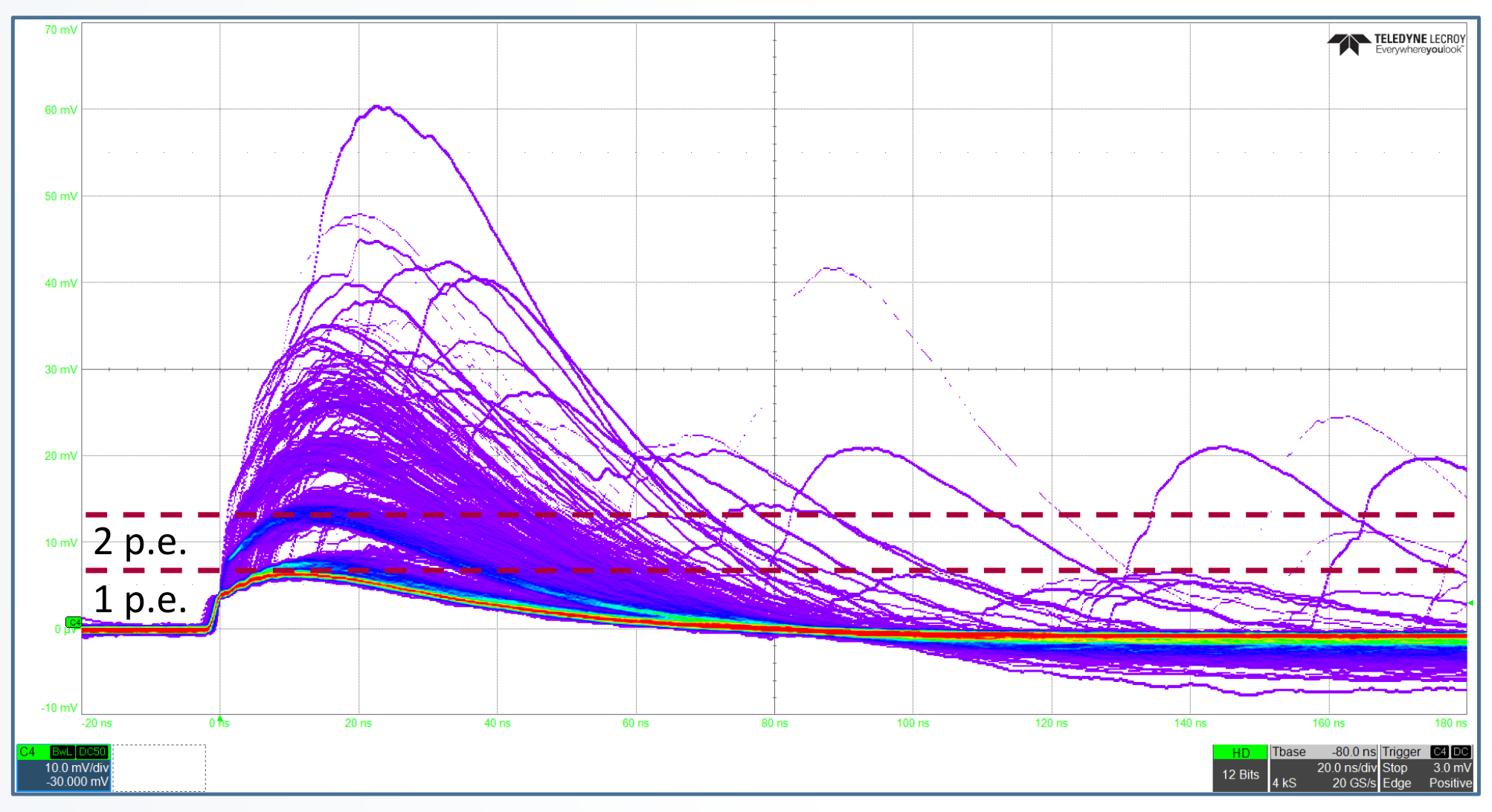

Fig. 3: SiPM pulses in persistence mode

Crosstalk measurements have been performed and evaluated for the proposed structures shown in section 2. The reference SiPM (blue curve in Fig. 4 c)) shows a rather high crosstalk of more than 30 % at 3 V overvoltage. This is due to a high PDE value of the native SPAD cell of about 5 % at 890 nm. As can be seen in Fig. 4 c) the crosstalk value can be decreased by about 10 % by introducing a metal stack between the SPADs. The introduction of only the surface trench (1) results in a similar decrease of the crosstalk. **Since the underlying SPAD structure has not been modified, the decrease in crosstalk is solely due to the disruption of the optical path in the BEOL stack.** The effect is even stronger when the two measures are combined and the optical path through nearly the whole BEOL stack is blocked. The resulting structure has a crosstalk of about 21 % at 3 V overvoltage. **By combining a surface trench (2) and a metal stack a decrease in crosstalk of > 30 % compared to the reference structure is achieved.** The measurements were verified for a minimum set of 3 samples.

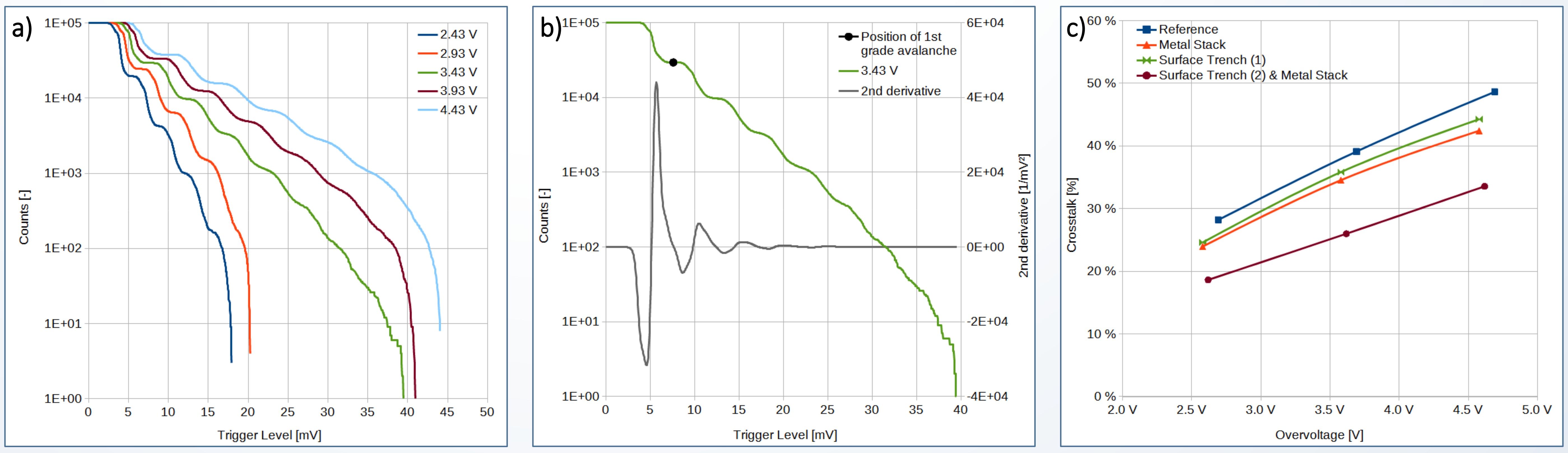

Fig. 4: a) Staircase curves for varying overvoltages used for crosstalk determination, b) objective analysis of a single staircase curve using the 2nd derivative, c) crosstalk values of a reference SiPM and the proposed structures shown in section 2 with a significant decrease in crosstalk

4 Take Away Message

1. The **crosstalk through the BEOL is identified** and has a non-negligible share of the total crosstalk.
2. **Measures to reduce the crosstalk by up to 30 %** are proposed which can be applied universally to any SPAD layout and are **mask neutral, therefore don't involve dedicated masks or processing steps.**
3. **Even partial disruption of the optical path in the BEOL stack leads to a crosstalk reduction of up to 10 %.** This can be applied in SPAD Imager designs where the full metal stack approach is probably not possible.

5 Bibliography & Acknowledgement

Rech et al., "Optical crosstalk in single photon avalanche diode arrays: a new complete model," Opt. Express 16, 8381-8394 (2008)

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