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Ultra-fast silicon detectors (UFSD)

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Introduction

- Ultra-Fast Silicon Detectors (UFSD) are based on Low-Gain Avalanche Detectors (LGAD).
- They are n-on-p sensors with internal charge multiplication due to the presence of a thin, low-resistivity diffusion layer below the junction, obtained with a highly doped implant.
- space-time particle tracking
- ATLAS: HGTD (high granularity timing detector)
- CMS-TOTEM: Precision Proton Spectrometer (CT-PPS)
- Simulation: WeightField2 (WF2)

Question from Kai Liu:
"Since present experience with LGAD is limited to sensors with 300 μm thickness [4], a reliable tool is needed to extrapolate their performance to the planned thickness of 50 μm"
why the thickness is so important?
Answer: Thickness affects the running time of the electron and hole, thus effect the charge collected time and shape of LGAD pulse. There are concerned to the time resolution.

LGAD pulse shapes

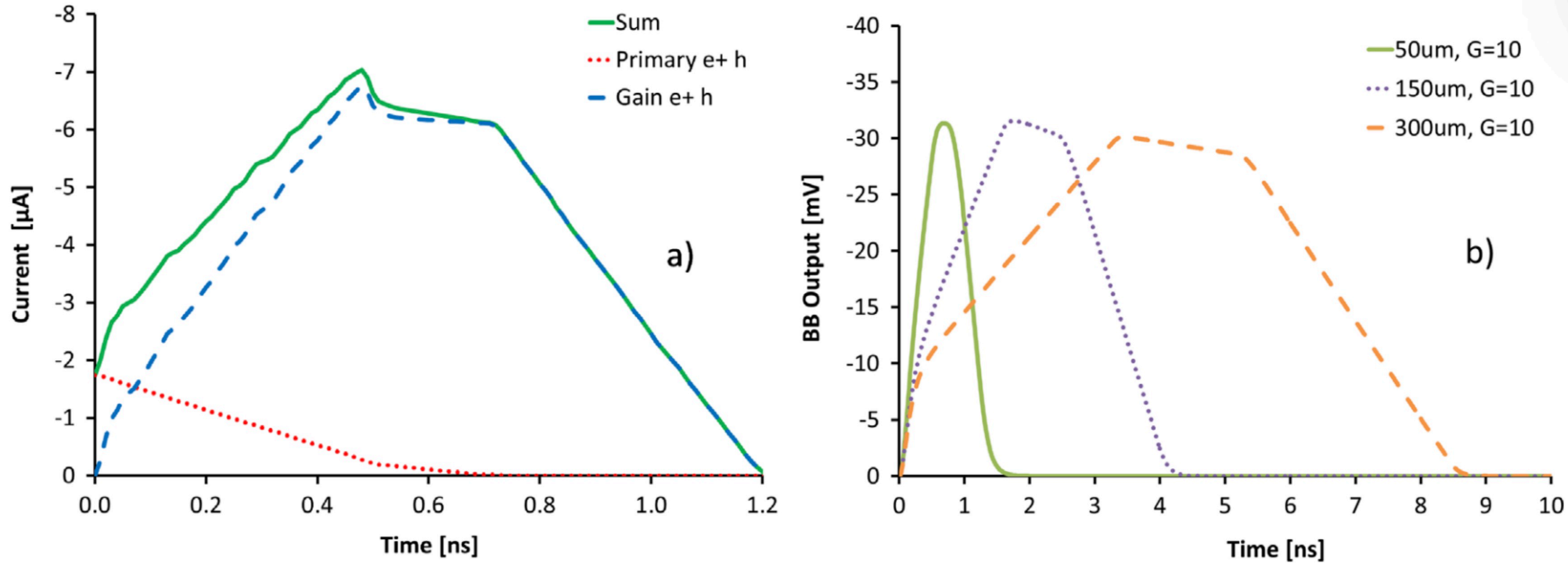


Fig. 1. Pulse shapes of LGAD simulated with WF2 version 3.5: a) detector current for a MIP traversing a 50 μm thick LGAD; b) voltage output from a x100 broad-band amplifier (BB) with 50 Ω input for LGADs with gain of 10 and thickness 50, 150, 300 μ [5].

Ryuta Kiuchi:
Broad-Band amplifier (BB) is emphasized many times throughout this paper, but what is the BB ? (actually, it remind me the other amplifier, CSA, though I'm not quite sure for both)
Answer: Broad band amplifiers are amplifiers which will reproduce a wide range of signals without significant loss throughout the pass band. (I am also not so clear about BB)
CSA is charge sensitive amplifier, the output is proportionate to the input charge.

LGAD pulse shapes

➢ For timing application, the pulse amplitude is more important than the pulse area.

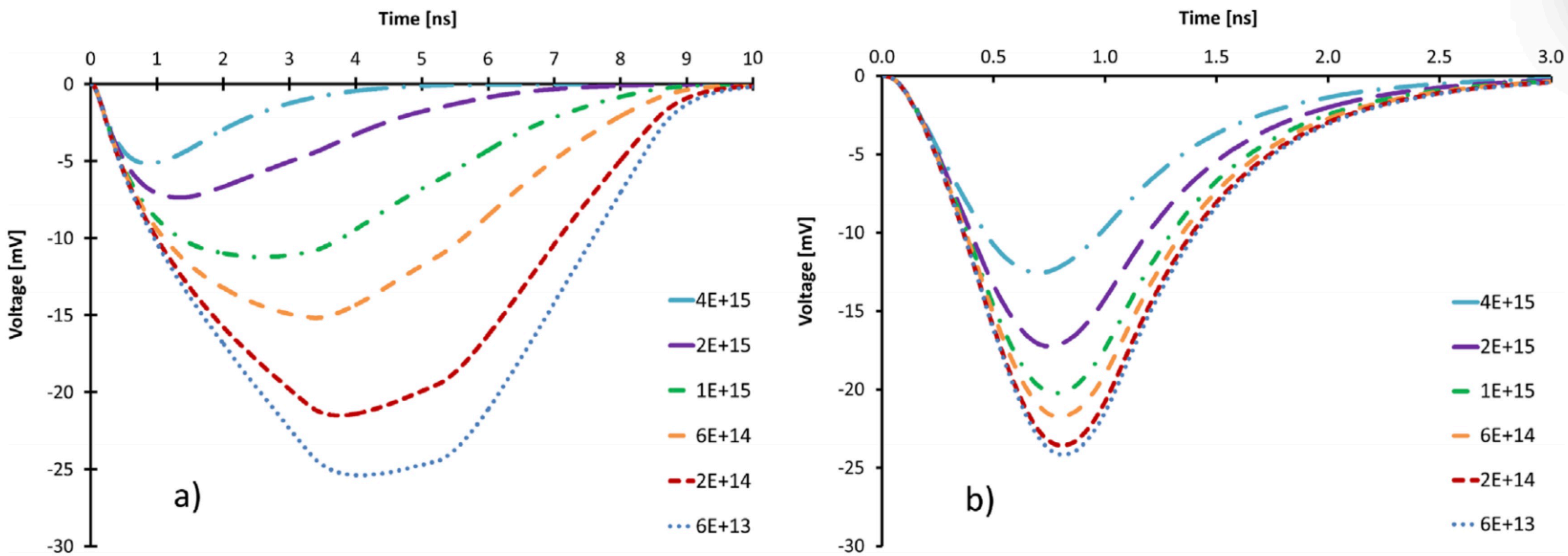


Fig. 2. WF2 simulation of BB pulse shapes of MIP signals due to trapping for different neutron fluences (in units of neq/cm^2) for LGAD of gain 10 with two thickness': a) 300 μm, b) 50 μm. Note the different time scales.

Simulation of the UFSD timing resolution

The time resolution σ_t is given by contributions from time walk, jitter and TDC binning:

$$\sigma^2_t = \left(\left[\frac{V_{th}}{dV/dt}\right]_{RMS}\right)^2 + \left(\frac{N}{dV/dt}\right)^2 + \left(\frac{TDC_{bin}}{\sqrt{12}}\right)^2$$

with V_{th} the signal threshold, dV/dt the signal slope or slew-rate, N the noise, and TDC_{bin} the size of a TDC bin, indicating the central role of the slew-rate of the signal dV/dt [10]. This means that we

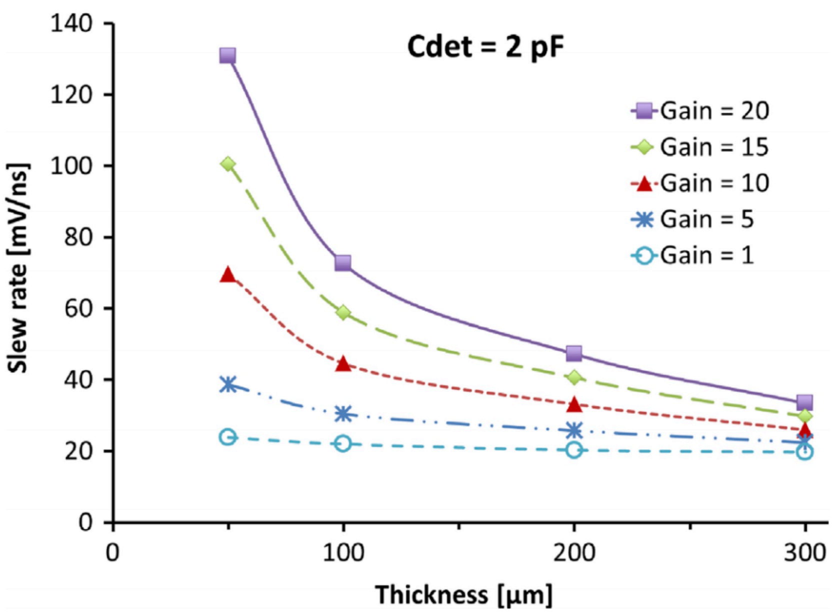


Fig. 4. WF2 simulations of the slew-rate dV/dt as measured by a 50 Ω Broadband amplifier as a function of sensor thickness and various gain values. They indicate the good time resolution achievable with thin LGAD with gain. At 50 µm thickness, a gain of 10 results in a three-fold improvement in the time resolution when compared to a no-gain sensor.

Timing resolution measurement

- We measured the time resolution of 300 mm thick LGAD pads with internal gains between 10 to 20 in the CERN H6 170 GeV pion beam using sensors with different capacitances (4 pF and 12 pF).

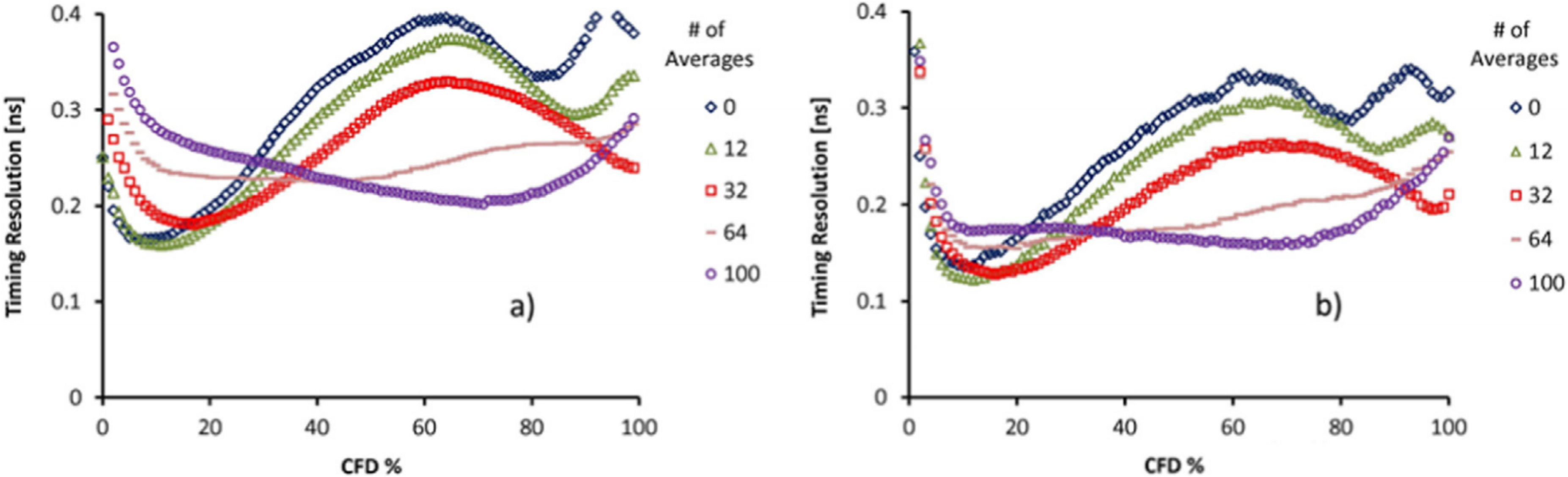


Fig. 6. CFD Time resolution of LGADs with different capacitances: a) 12 pF (left) [11] and b) 4 pF.

thin LGAD

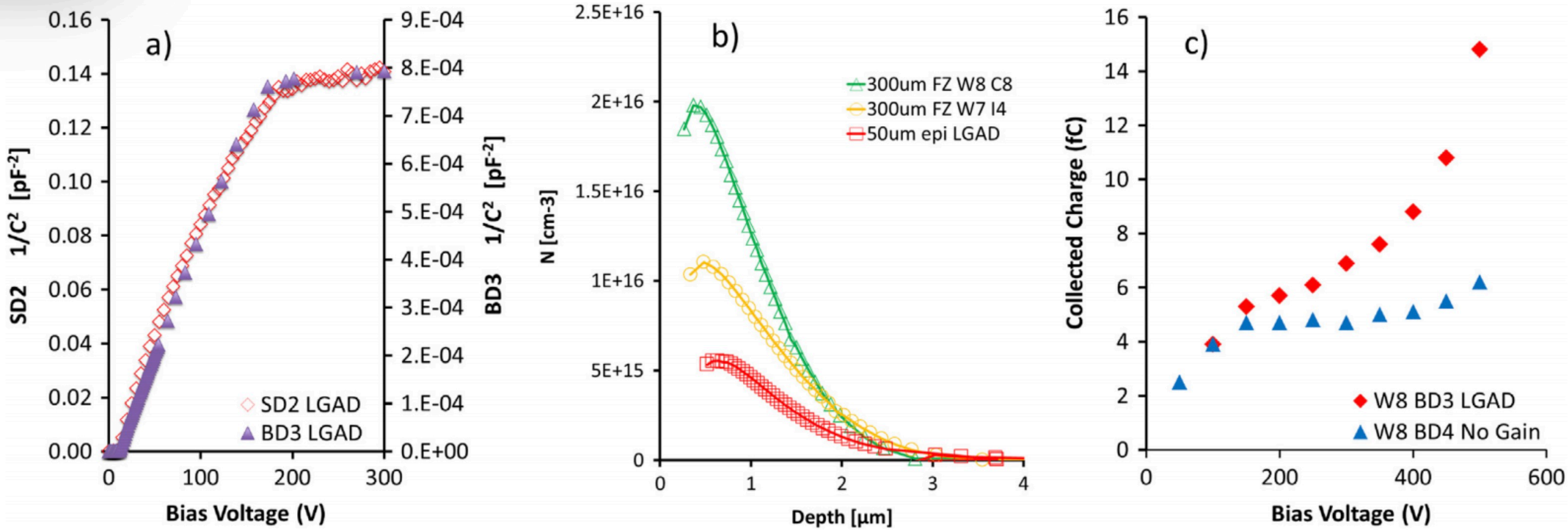


Fig. 8. Measurement results on 50 μm thick epitaxial LGAD: a) *C–V* measurement showing a relatively small "voltage lag" at low bias; b) doping profile extracted from C-V for FZ and epi LGAD indicating lower doping concentration in the multiplication layer for the epi LGAD; c) comparison of charge collection in IR laser injection on epi LGAD and no-gain diode yielding a gain of 3.5 for the LGAD.

thin LGAD

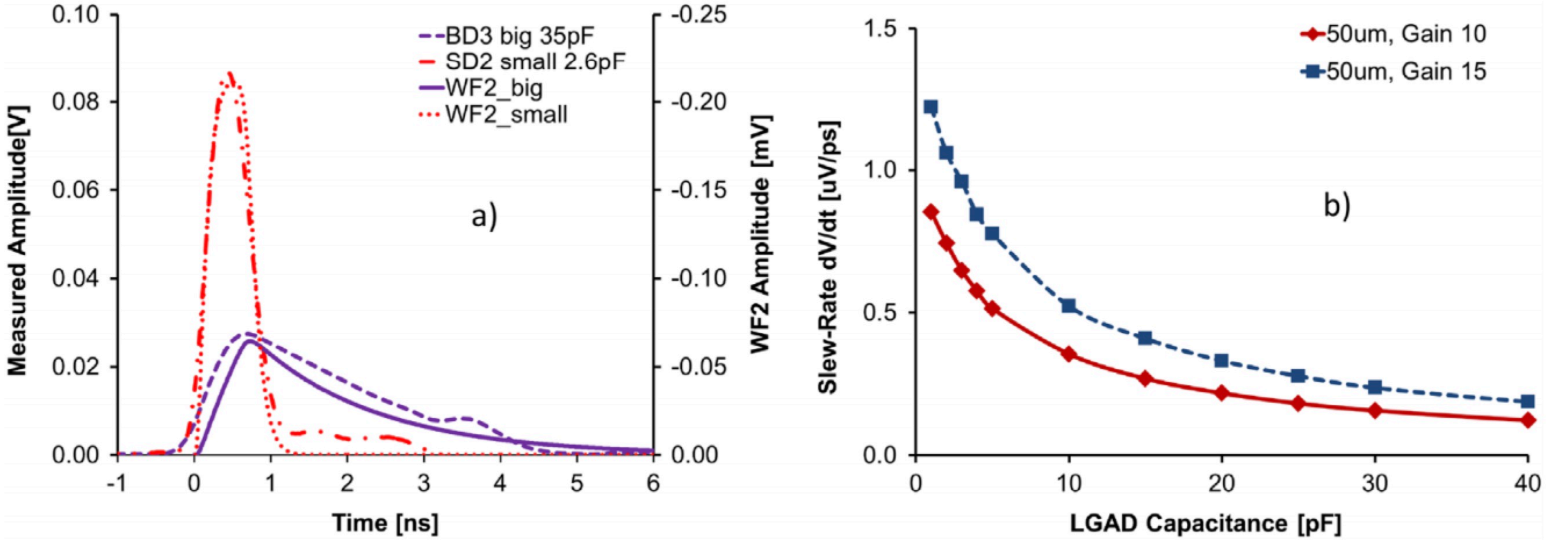


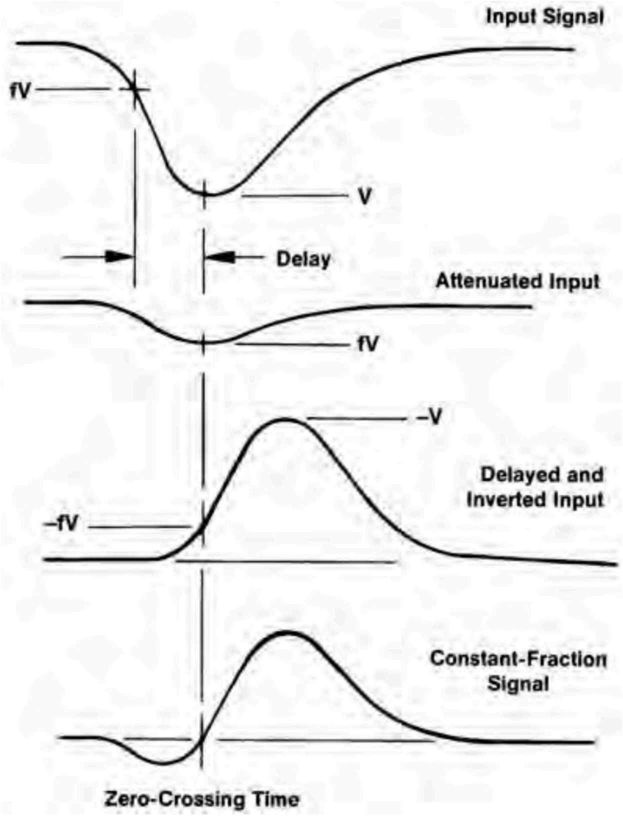
Fig. 9. Response to front α particle injection of 50 μm thick epitaxial LGADs: a) pulse shapes including WF2 simulations for different capacitances and gain of 3.5; b) slew-rate as a function of capacitance for LGAD with gain 10 and 15.

Amit Pathak: I just want to know a better explanation for figure 9A.
I have searched about the Weightfield2, which is a software for 2D simulation for silicon detector. But I want to know about BD3 big 35pF, SD2 small 2.6pF, WF2_big and WF2_small and how they show the gain of 3.5 with the alpha particle injection?
Answer:1....
2. For my understanding, adjust the bias voltage to change the gain.

Question

Yuhang Tan:

There are several analysis algorithms to optimize the time resolution. what's extrapolation of the slope to the base line and constant fraction discriminator(CFD), in fig.6 the meaning of CFD%.



Question

Xin Shi:

For the "decrease in the gain in addition to the signal decrease caused by trapping at fluences beyond 1014 neq/cm2 [8]. This has been identified with an initial acceptor removal, …"

What is "acceptor removal"? And why it's responsible for the gain decrease?

Answer: In actual, don't know. Sorry.

Question

Suyu Xiao:
How can we get the characteristic trapping time if we know a trapping length?

Answer: For my understanding, trapping length is relative to the thickness. Trapping time is the collection time, it is the test result. Or using the charge particle dynamics in electric field.