A Backside-Illuminated SiPM Array with High NIR PDE for Automotive LIDAR Applications

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Introduction:

In this work, a state-of-the art stacked (Cu to Cu hybrid bond),backside illuminated SiPM in 65nm is presented and fully characterized. Thanks to the 7um silicon epitaxial layer, full metal trenches and NIR scattering structure with microlenses, the proposed SiPM achieves excellent performance in terms of PDE (>30% at 905nm) and temperature stability which make the device suitable for automotive LIDAR applications.

Microcell Structure & Simulations:

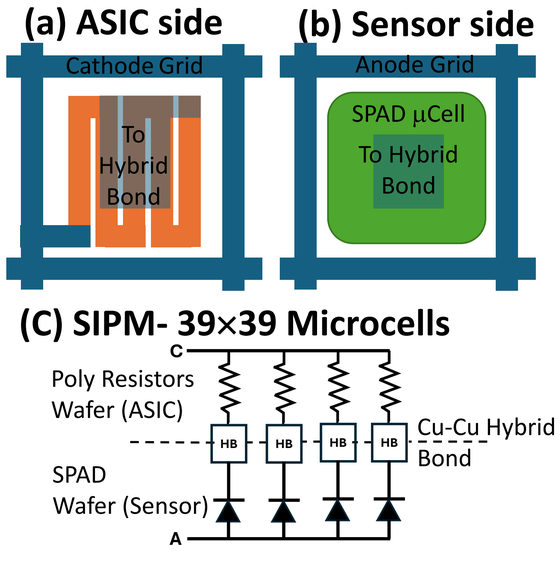

Figure 1- 3D stacked SiPM schematics

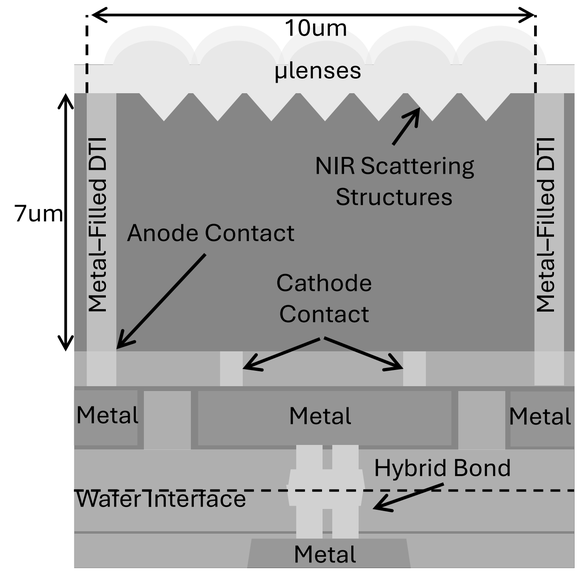

Figure 2- A cross section drawing of the SPAD microcell

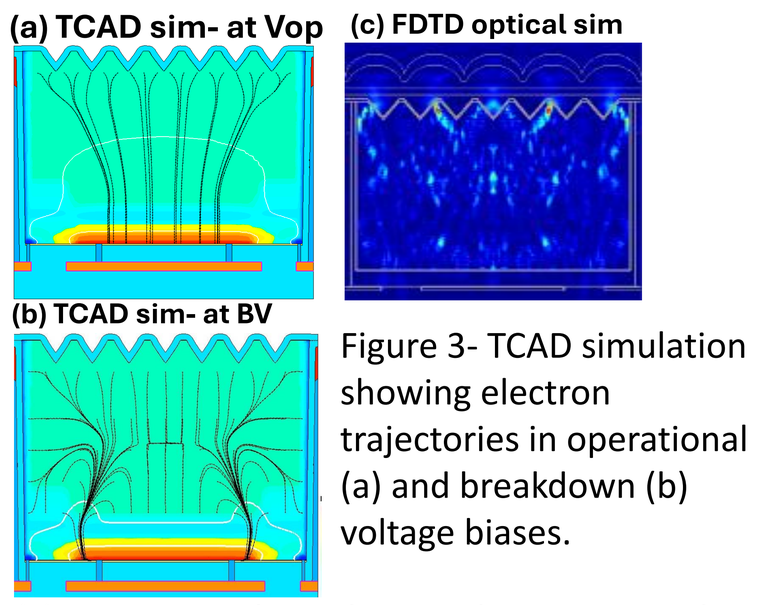

Figure 3- TCAD simulation showing electron trajectories in operational (a) and breakdown (b) voltage biases.

(c) FDTD optical simulations showing optical power distribution in the cell area at 905nm wavelength

Experimental Results:

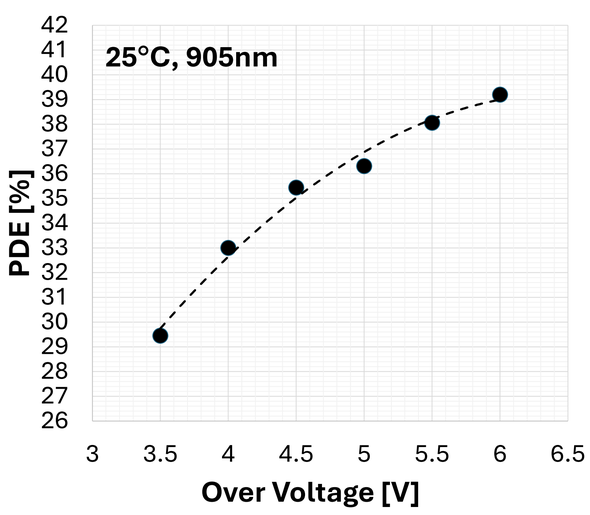

Figure 4- PDE vs. Over Voltage

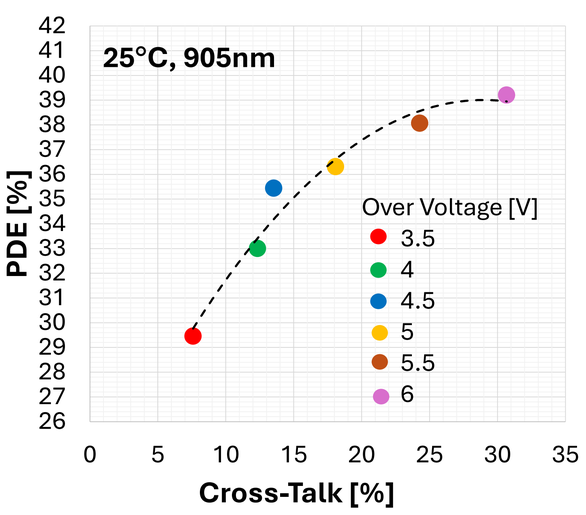

Figure 5- PDE/Cross-Talk Correlation

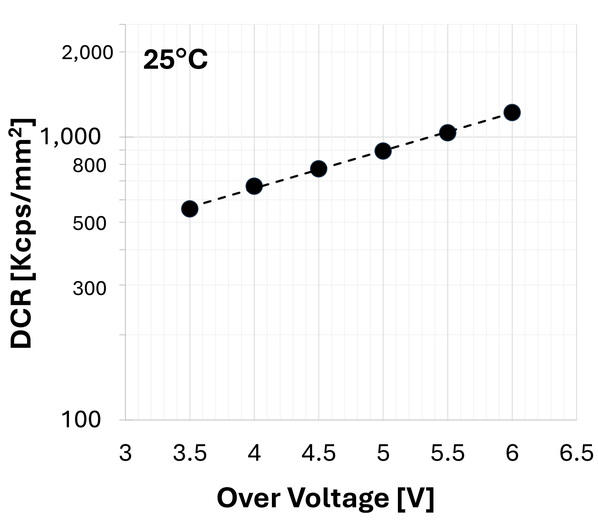

Figure 6- DCR vs. Over Voltage

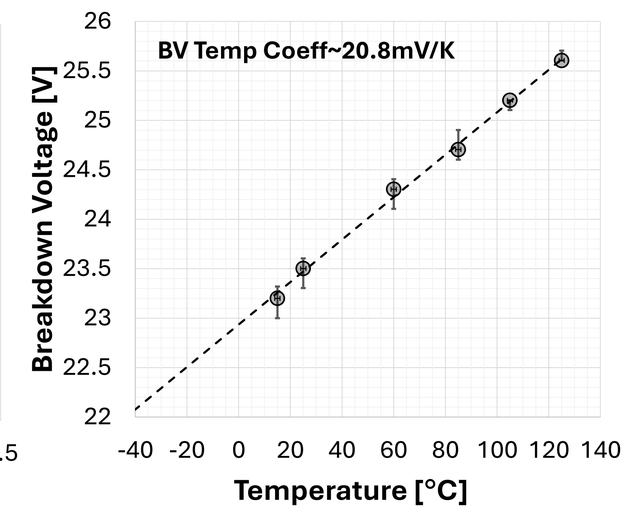

Figure 7- Breakdown Voltage vs. Temperatures

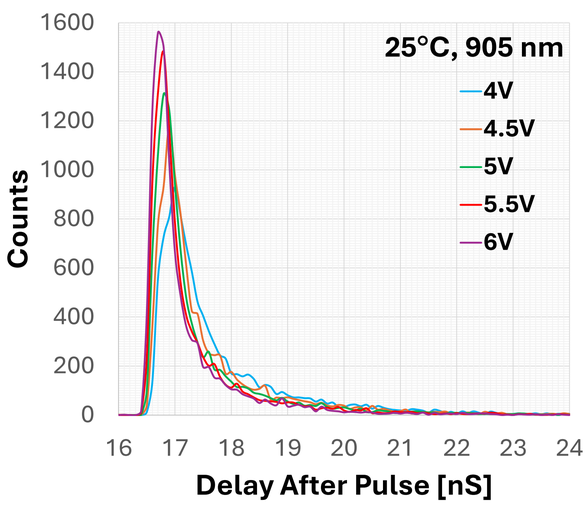

Figure 8- SPTR Histogram (Jitter) vs. Over Voltage

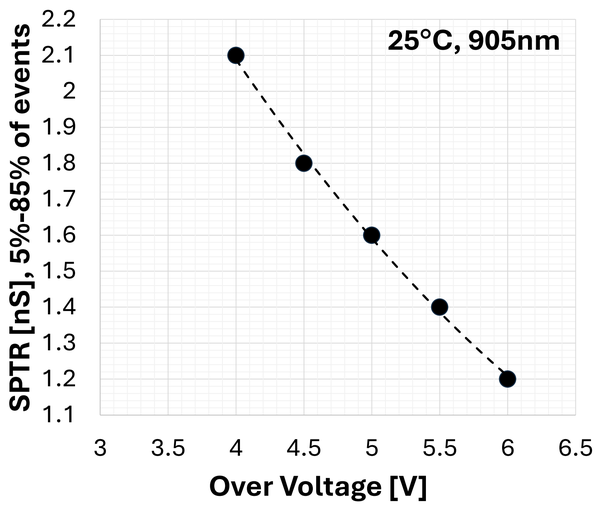

Figure 9- SPTR (5%-85% of events) vs. Over Voltage

Table 1- Key Parameters Summary

Parameter	Unit	This Work
Technology	-	BSI 65nm, 3D Stacked
Application	-	Automotive LIDAR SiPM
Microcell pitch	µm	10
$V_{OV}/\lvert V_{BR}\rvert$	V	4.5/23.5
V_{BR} Temp Coeff	mV/K	20.8
PDE @ 905nm	%	35
Cross-Talk Prob.	%	14
DCR @ 25°C	Kcps/mm²	780
DCR Doubling Temperature	°C	5.6
DCR Activation Energy	eV	1.12
SPTR (5%-85% of events)	nS	1.8

Summary & Conclusions:

A state-of-the-art BSI SiPM sensor have been developed & fabricated, utilizing a 65nm process, featuring full metal filled trenches, NIR scattering structures and Cu-to-Cu 3D hybrid bond wafer stacking for the automotive LIDAR applications. This have yielded an outstanding PDE of 35% at 4.5V overvoltage (905nm) , while keeping crosstalk below 15%, DCR at 25°C below 1000kcps/mm² and time jitter (5% to 85% of events) below 1.8ns. Summary of performance parameters is presented in Table 1.

references:

[1] Acerbi, F., et al. Silicon Photomultipliers: Technology Optimizations for Ultraviolet, Visible and Near-Infrared Range. in Instruments 2019, 3, 15.
[2] M. Perenzoni, D. Perenzoni and D. Stoppa, "A 64 × 64-Pixels Digital Silicon Photomultiplier Direct TOF Sensor With 100-MPhotons/s/pixel Background Rejection and Imaging/Altimeter Mode With 0.14% Precision Up To 6 km for Spacecraft Navigation and Landing," in *IEEE Journal of Solid-State Circuits*, vol. 52, no. 1, pp. 151-160, Jan. 2017
[3] S. Genecchi, C. Jackson, A 1 × 16 SiPM Array for Automotive 3D Imaging LiDAR Systems, in International Image Sensor Workshop 2017.
[4] ANSYS Lumerical FDTD, Release 2022R1.4
[5] K. Ito et al., "A Back Illuminated 10µm SPAD Pixel Array Comprising Full Trench Isolation and Cu-Cu Bonding with Over 14% PDE at 940nm," 2020 IEEE International Electron Devices Meeting (IEDM), San Francisco, CA, USA, 2020, pp. 16.6.1-16.6.4