sensL
sense light

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The Leaders in Silicon Photomultipliers Since 2004

SensL Silicon Photomultipliers

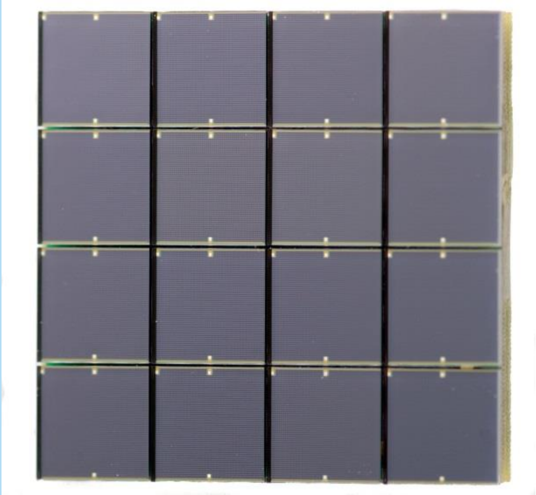
Technology Update
& Introduction to J-Series TSV Sensors

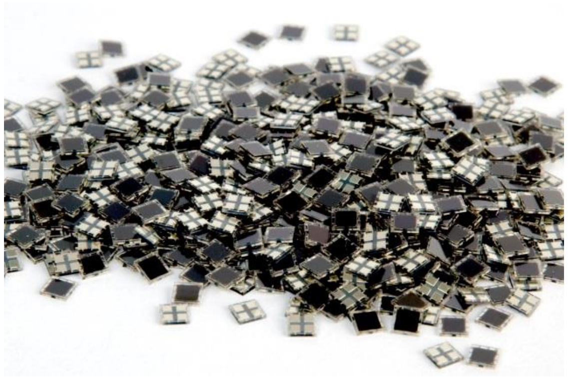
CTA SiPM Workshop,
Palermo, May 2015

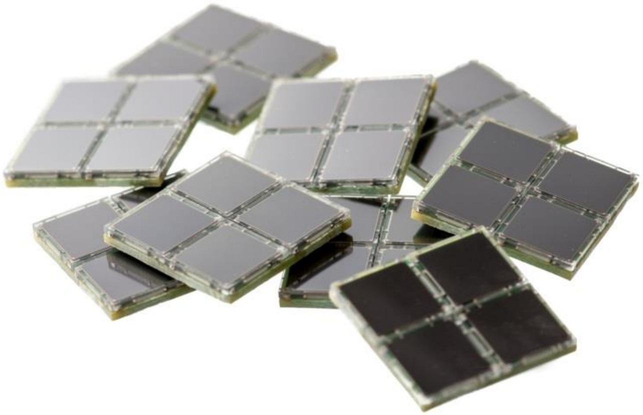
John Murphy, PhD
Sales Director

SensL Quick Facts

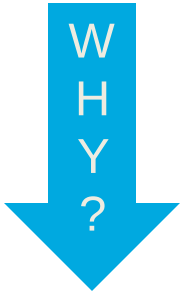
Business	Low Light Sensors High Volume/Industrial Grade
Markets	Medical Imaging Radiation Detection 3D Ranging and Sensing High Energy Physics
Model	Fabless Semiconductor

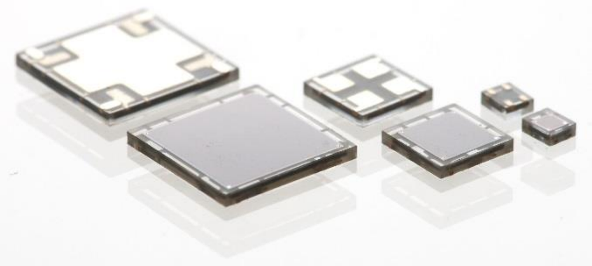






Since 2013 >1Million C-Series SiPMs Produced and Shipped



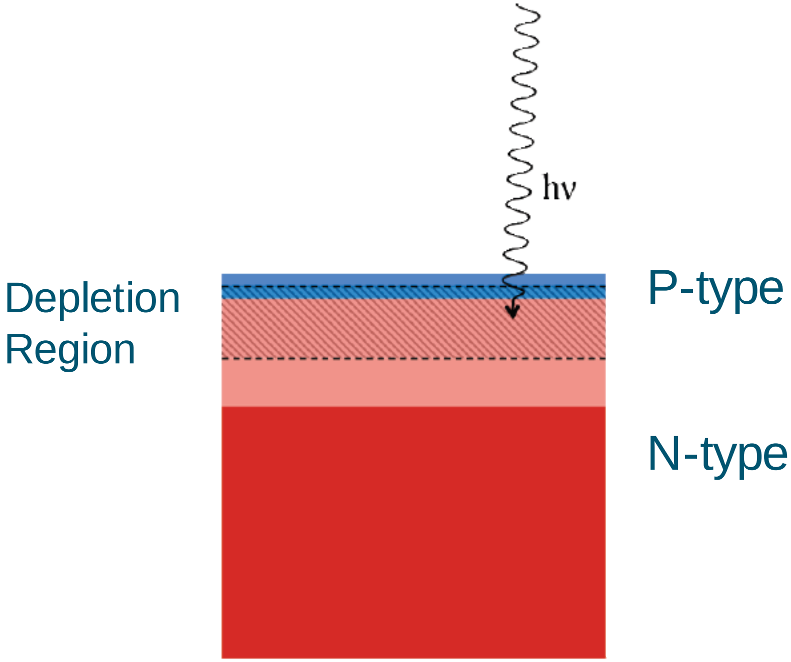


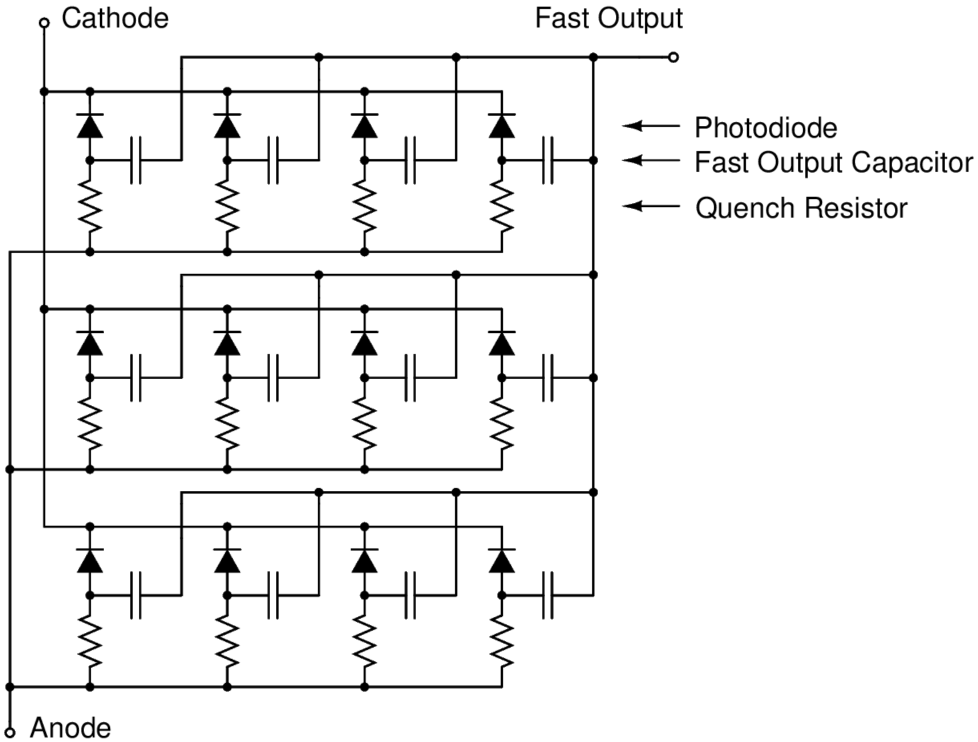
Ultra Low Noise

Exceptional Uniformity

Cost Effective

SensL SiPM Technology



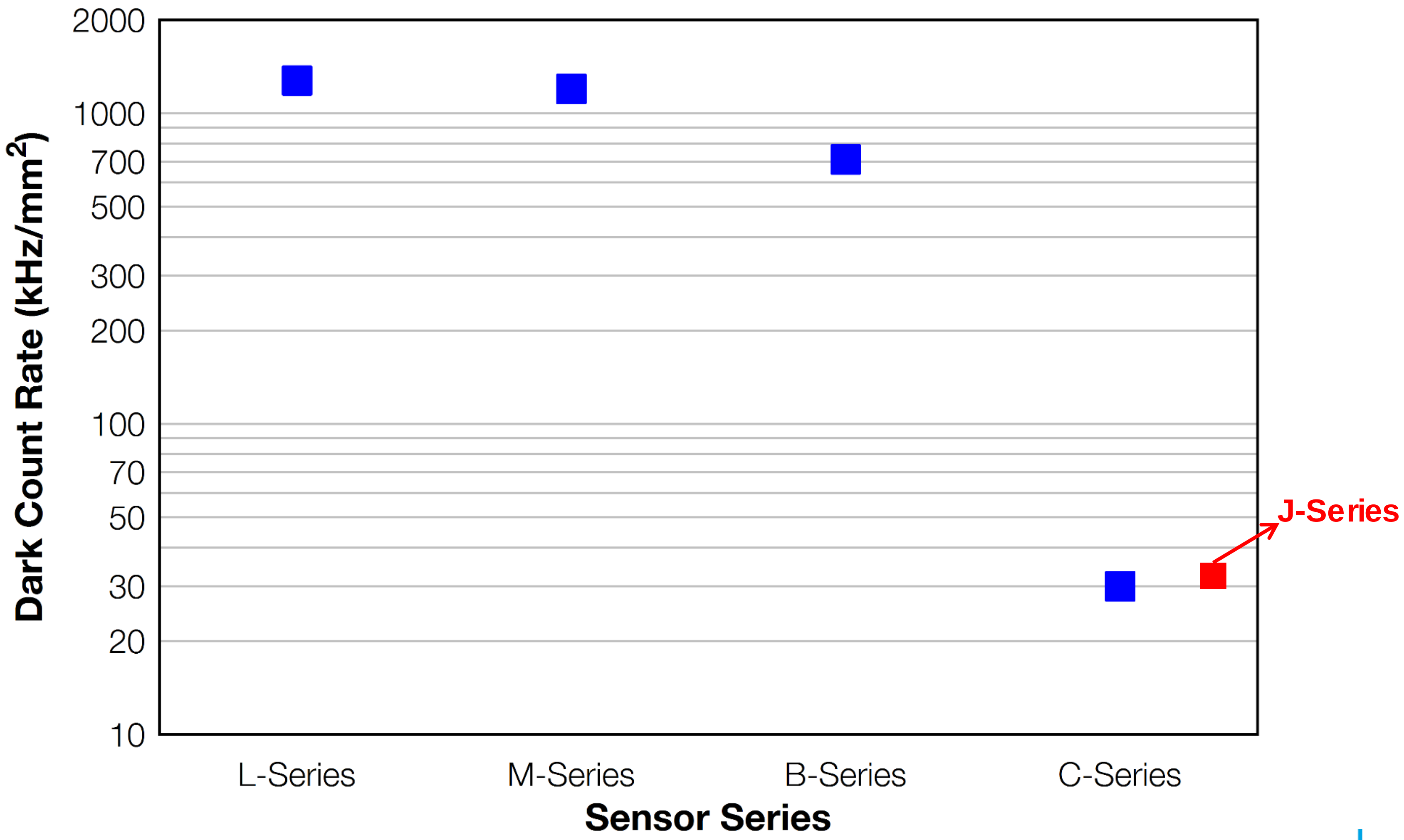


P on N technology provides the highest levels of Blue and UV photon sensitivity

Compatible with
Fast Output (3-terminal) &
Standard Output (2-terminal)

Ultra Low Noise

Lowest Dark Rate in the Industry



C-Series Characteristics

Production Silicon Revision

C-Series Performance Overview

		10000 series	30000 series		60000 series
		10035 [d]	30035 [d]	30050 [d]	60035 [d]
Typical breakdown voltage (VBr) [b]		24.65V ± 250mV			
Bias range (above VBr)		1V - 5V			
Spectral range		300nm - 800nm			
Peak wavelength (λ_p)		420nm			
PDE at λ_p	@ VBr +2.5V [a]	31%	31%	35%	31%
	@ VBr +5V	41%	41%	47%	41%
Gain [a] [e]		3x10^6	3x10^6	6x10^6	3x10^6
Dark count rate - Typ. @ VBr +2.5V		30kHz	300kHz	300kHz	1200kHz
Rise Time (Fast Output) [a] [f]		300ps	600ps		1ns
Signal pulse width - Fast Output (FWHM) [a]		600ps	1.5ns		3.2ns
Temperature dependence of VBr		21.5mV per °C			

[a] Measured at VBr+2.5V and 21°C

[b] The breakdown voltage (VBr) is defined as the value of the voltage intercept of a parabolic line fit to the current vs. voltage characteristic curve

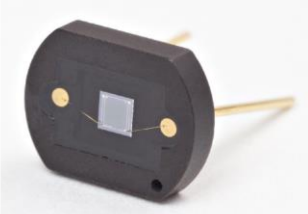
[c] Quoted PDE does NOT include the effects of cross-talk and afterpulsing

[d] SensL naming convention: 30000 represents a 3mm sensor, 035 a 35μm microcell. Therefore, the 30035 is a 3mm sensor with 35μm microcells.

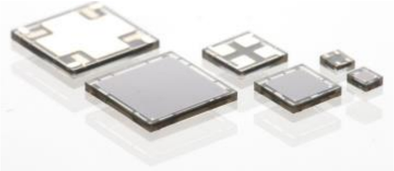
[e] When read out from the anode line. See User Manual for details. Gain from the fast output is significantly lower, ~10^4.

[f] Time taken for the signal to rise from 10% to 90% of the peak amplitude

X18 package option



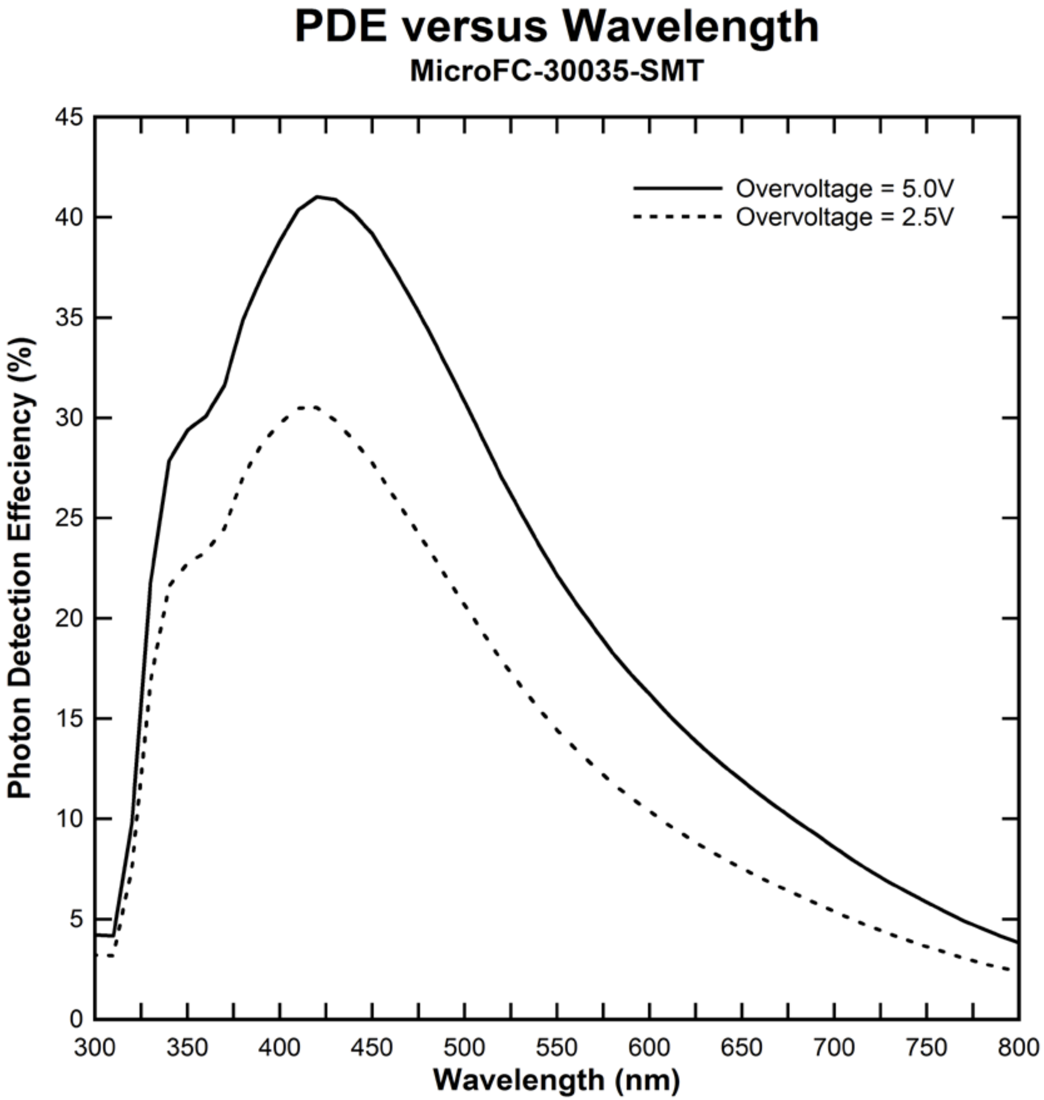
X13 package option



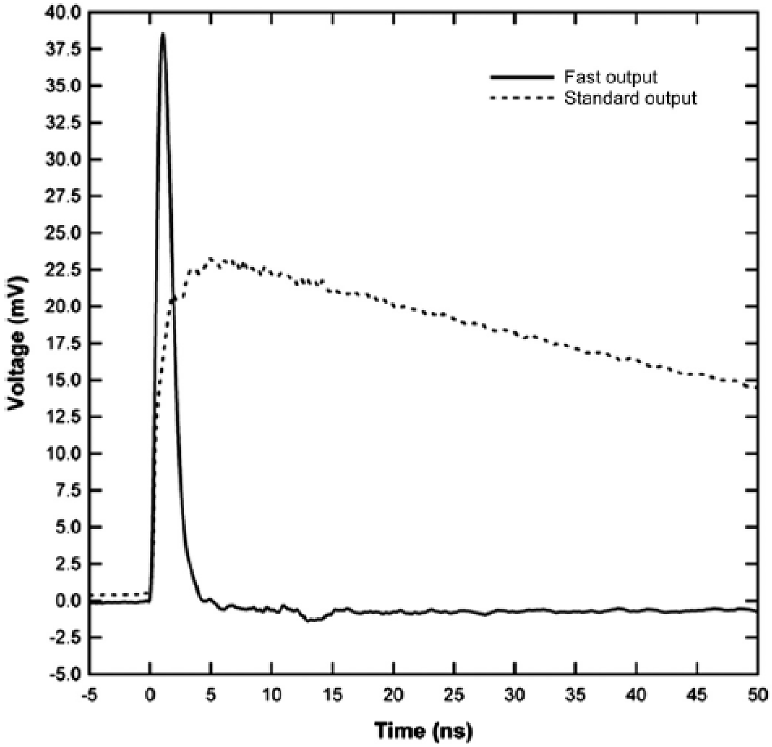
SMT package option

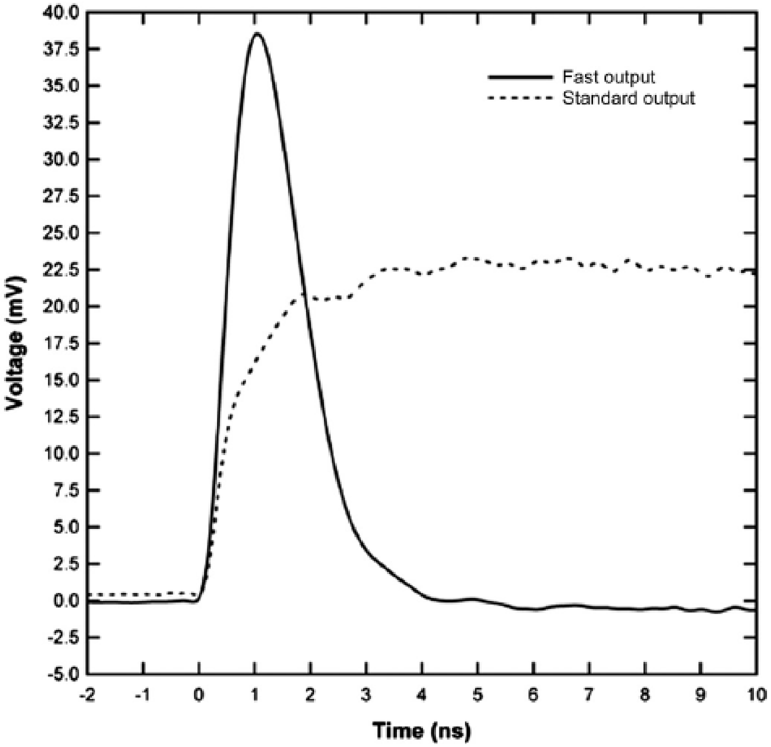
Cell sizes:
10um, 20um, 35um, 50um.

PDE – C-Series


PDE versus Wavelength
MicroFC-30035-SMT
Photon Detection Effeciency (%)
Wavelength (nm)
0
5
10
15
20
25
30
35
40
45
300
350
400
450
500
550
600
650
700
750
800
Overvoltage = 5.0V
Overvoltage = 2.5V

Fast Output Advantages





Plots show pulsed outputs for a 30035 sensor in response to a pulsed source

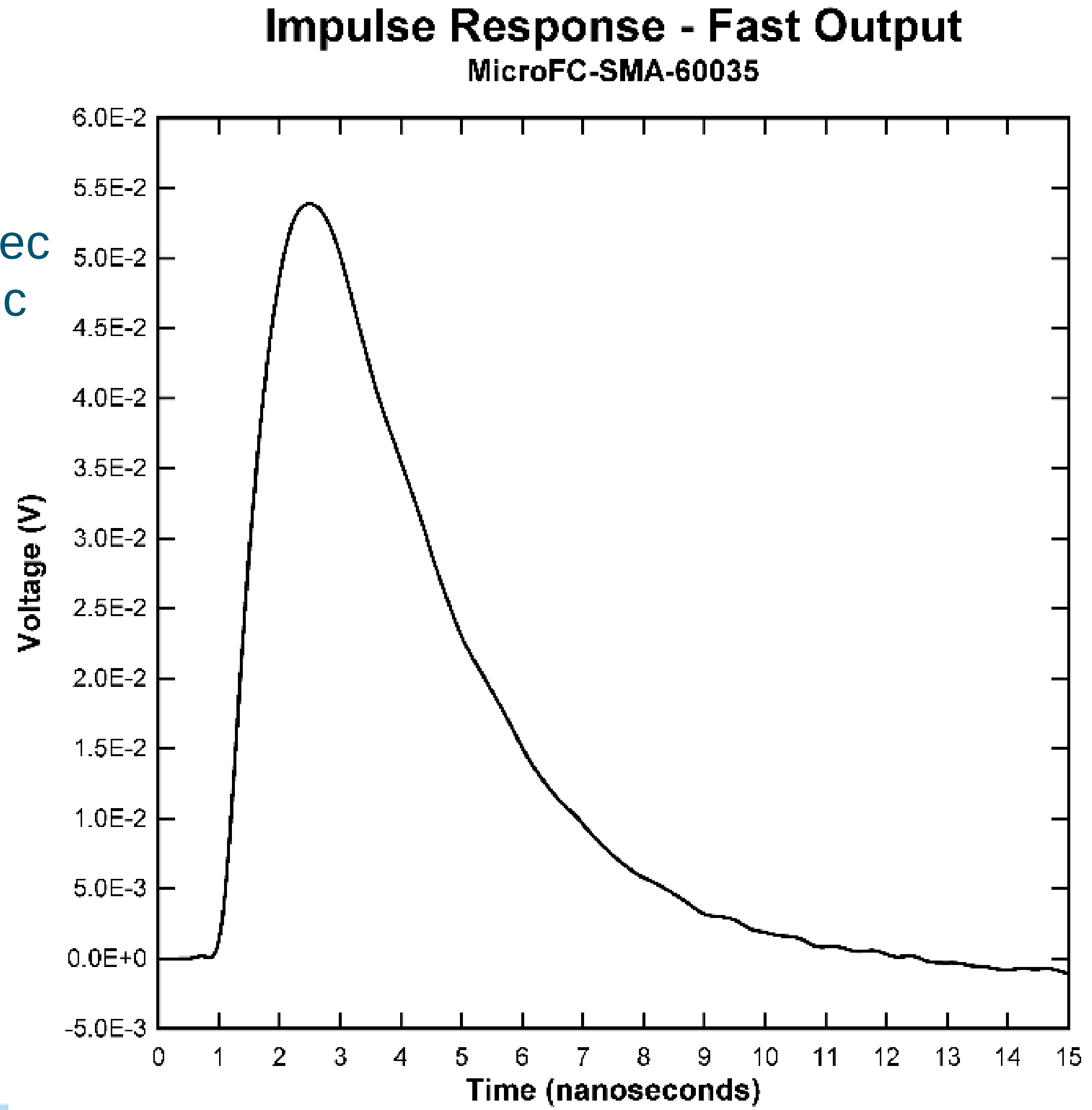
SiPM Type	Fast Output Rise Time	Fast Output Signal Pulse Width (FWHM)
10035	300ps	600ps
30035	600ps	1.5ns
60035	1ns	3.2ns

F-output is proportional – i.e. suited to pulse height analysis as well as timing applications

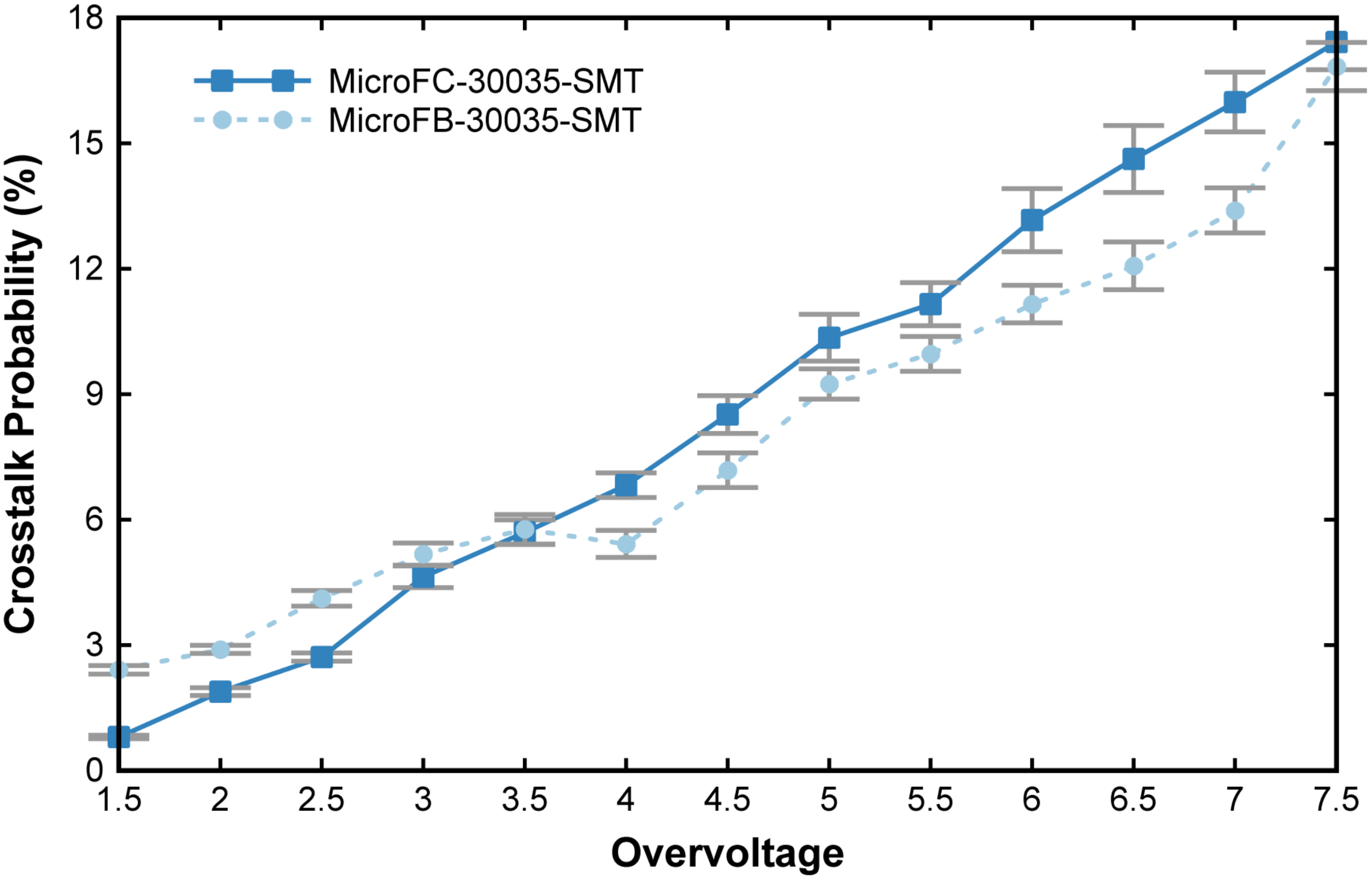
SensL's international patent application no. WO2011117309

C-Series Pulse Response (6mm, 35um cell)

Rise Time = 1nSec
FWHM = 3.2nSec



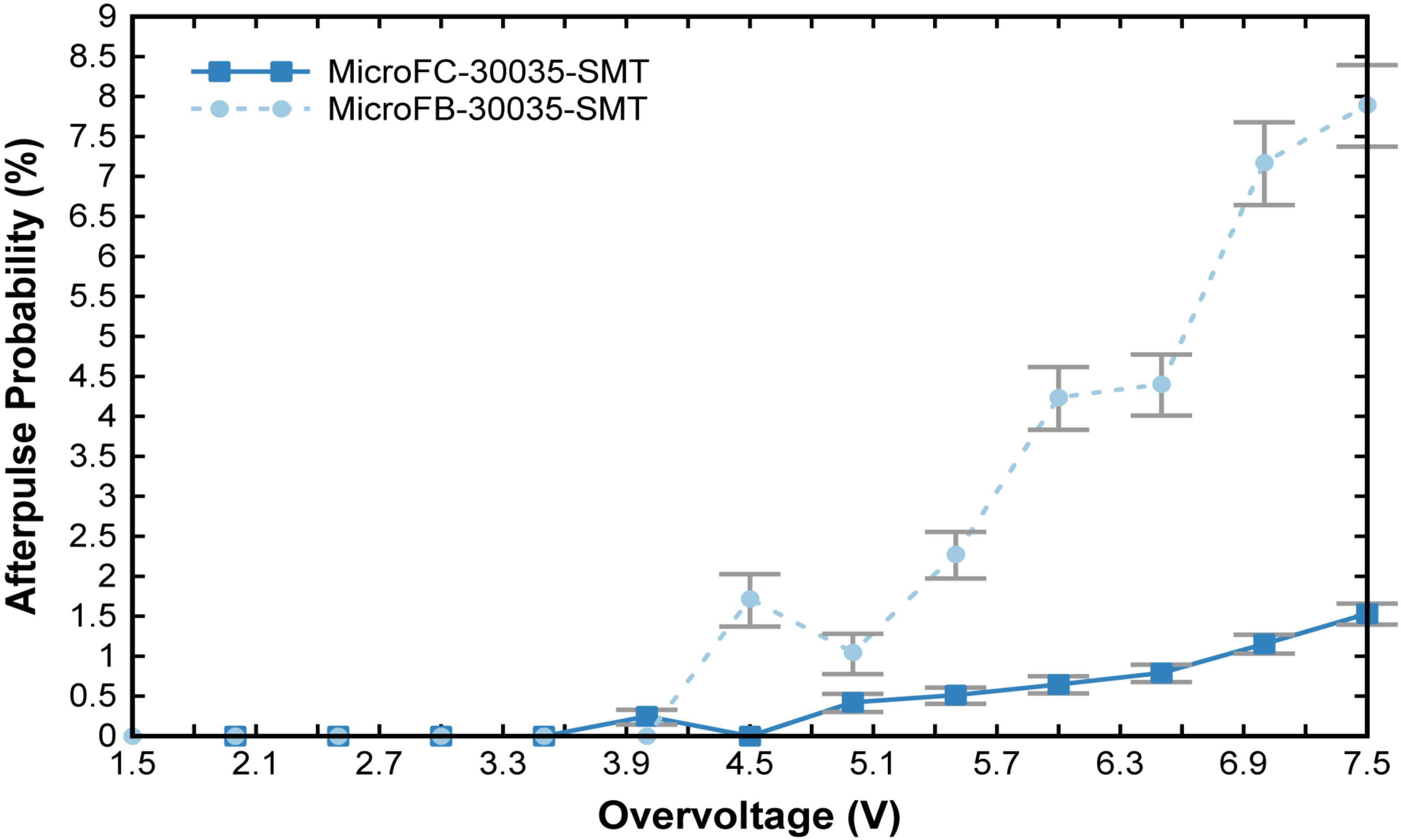
Optical Crosstalk – B-Series V's C-Series



http://authors.elsevier.com/a/1Q-00cPqbGa10

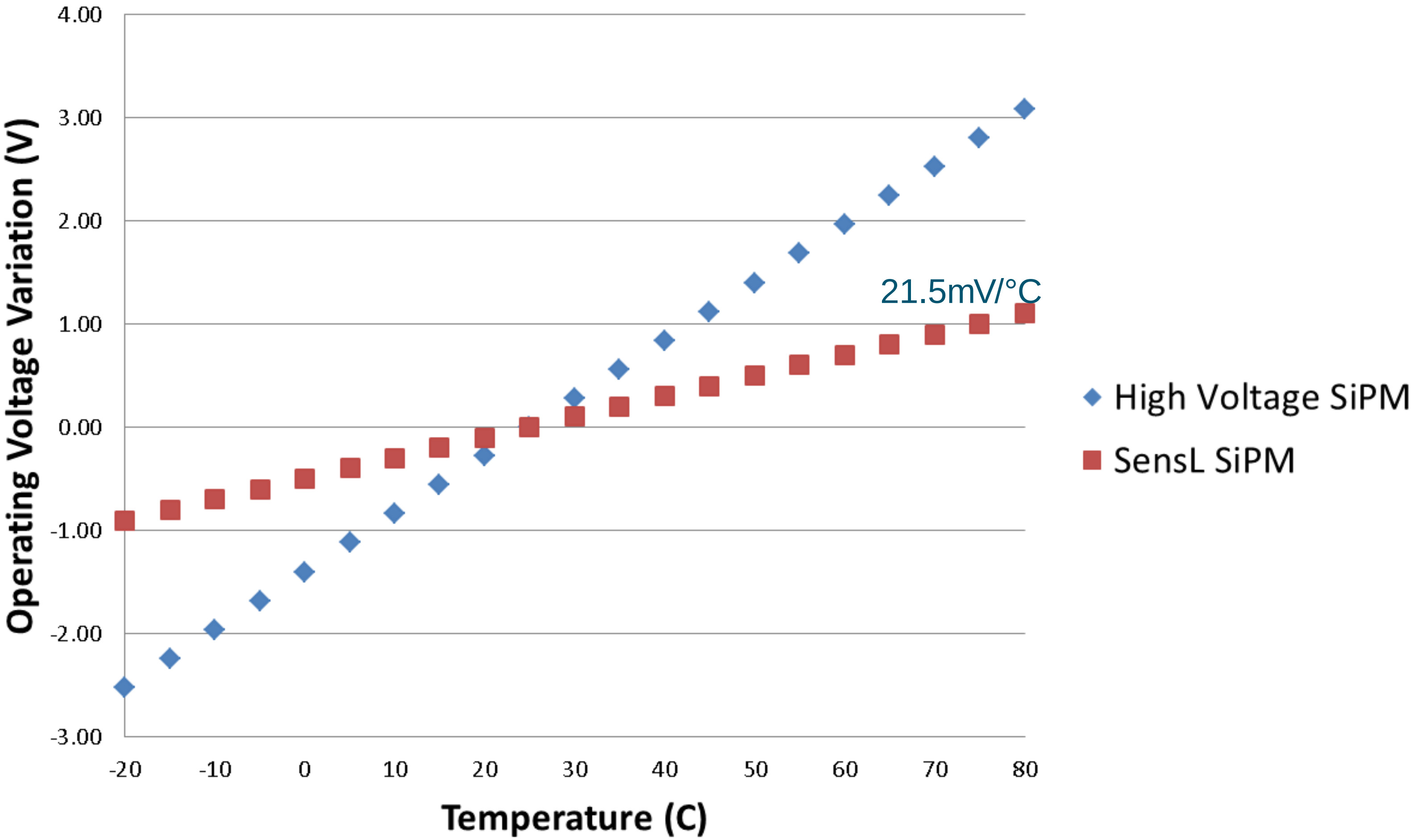
sensL sense light

Afterpulsing – B-Series V's C-Series



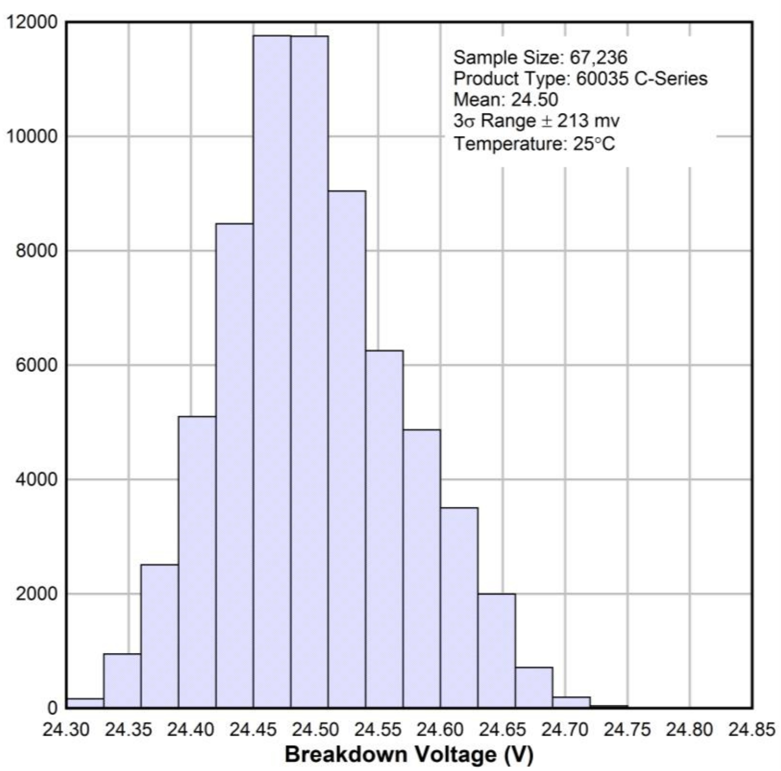
http://authors.elsevier.com/a/1Q-00cPqbGa10

Low Temperature Dependence of Operating Voltage

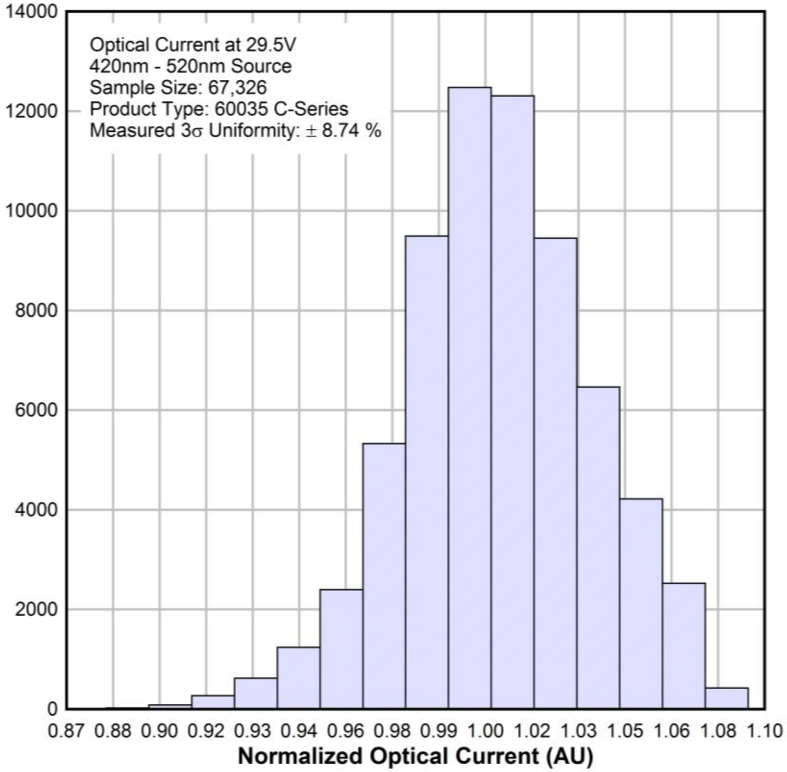


Best Uniformity in the Industry

Raw data from 60k pieces of 6x6mm C series SiPM



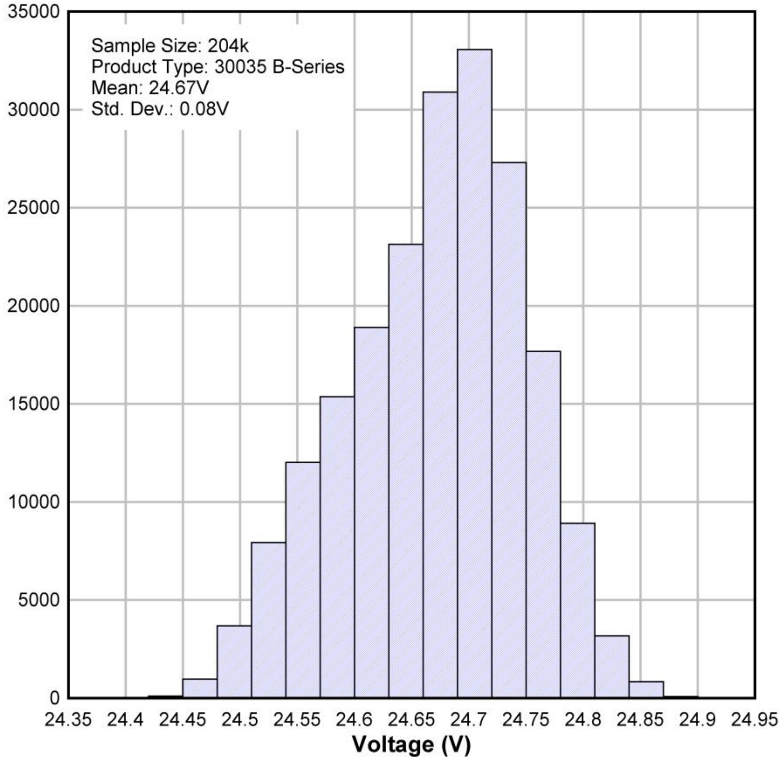
+/-213 mV V_{br} Uniformity



±8.74% Optical Uniformity

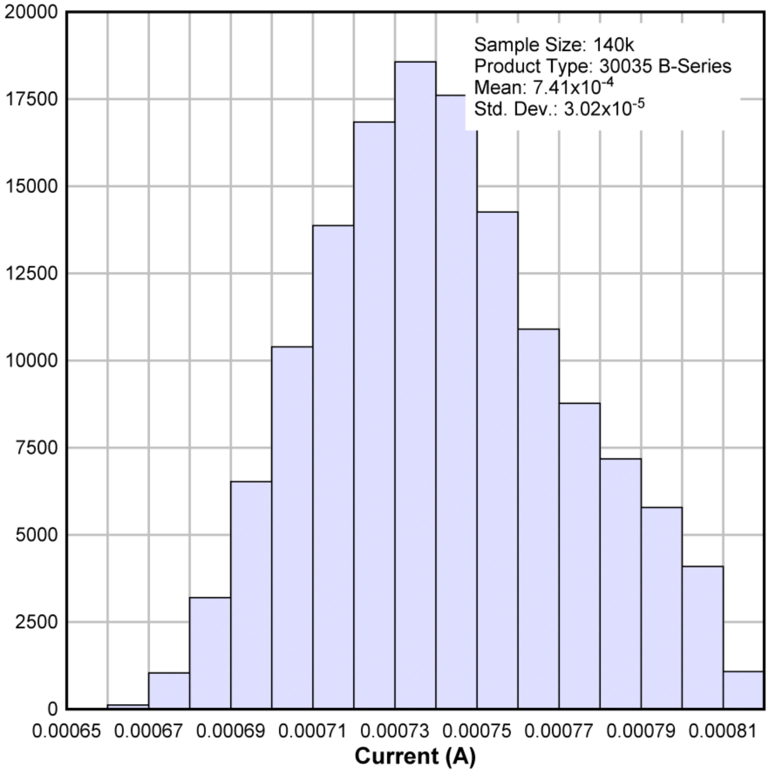
Best Uniformity in the Industry

Raw data from >200k pieces of 3x3mm SiPM



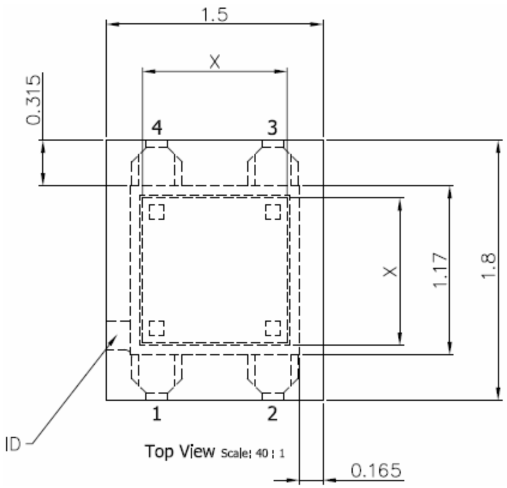
Breakdown Voltage (V)

+/-250 mV Operating Voltage Uniformity

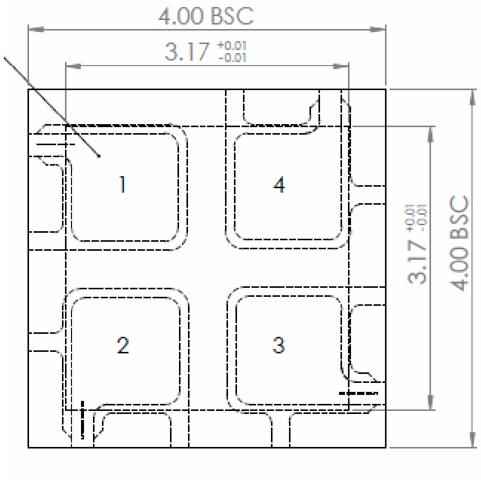


±10% Optical Response Uniformity

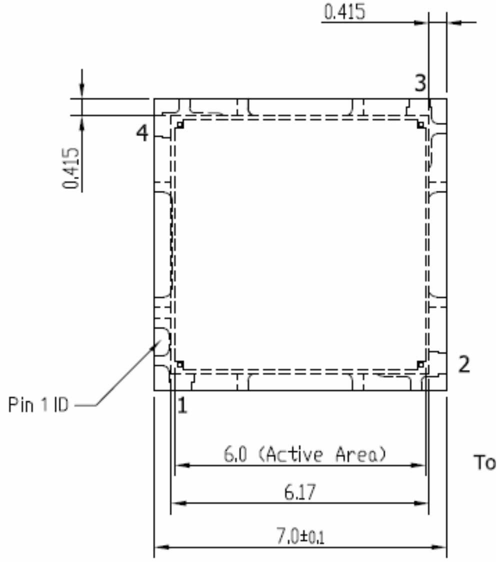
SMT-MLP Devices – Mechanical Specifications



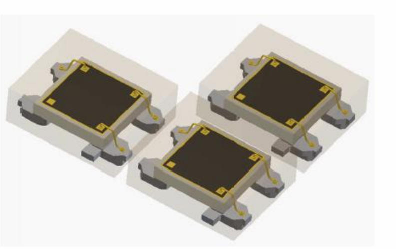
1mm MLP-SMT

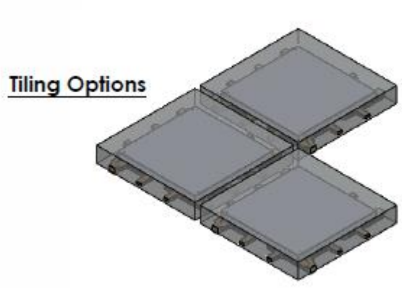


3mm MLP-SMT

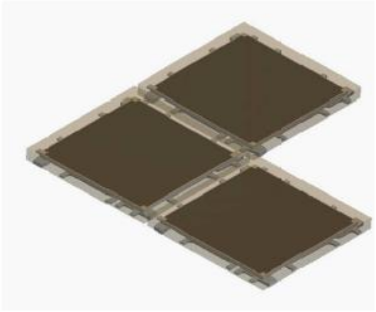


6mm MLP-SMT



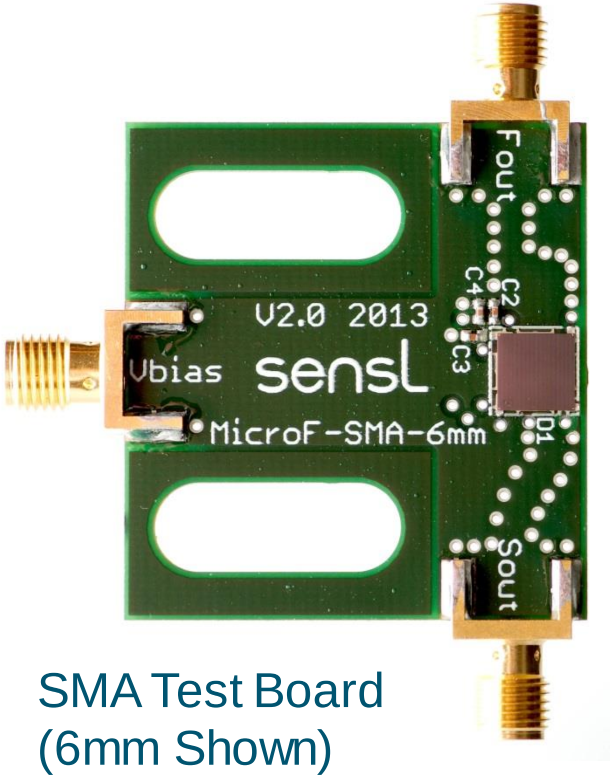


Tiling pitch: 4.2mm

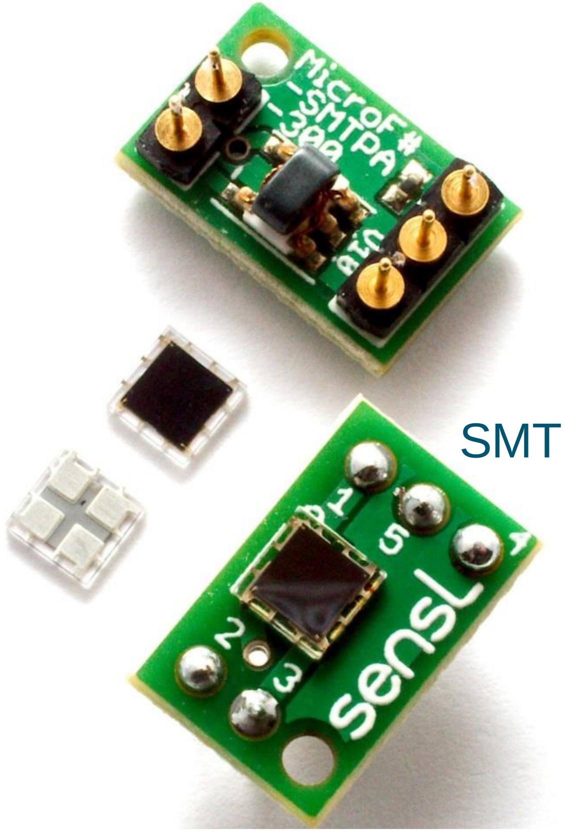


Tiling pitch: 7.2mm

SMA / SMTPA Test Boards

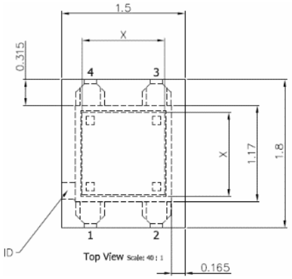


SMA Test Board
(6mm Shown)

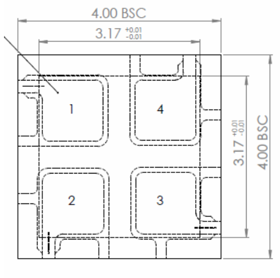


SMTPA Test Board

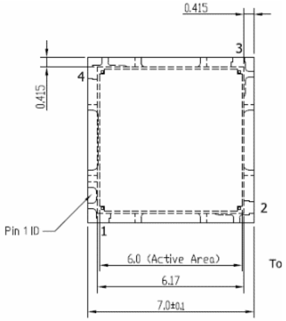
SMT-MLP Shipment – Tape & Reel



1mm
MLP



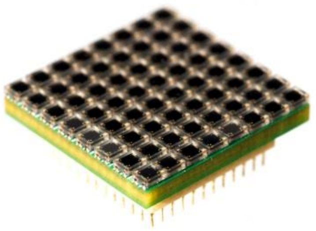
3mm
MLP



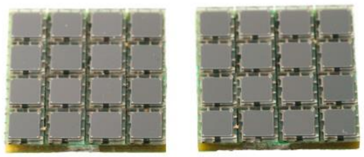
6mm
MLP

- All parts shipped as tape and reel in moisture barrier bag to J-ST 033
- MSL=3 reflow solder compliant
- All parts ship 3000 units per tape
    - 1mm on 7” diameter (8mm width)
    - 3mm on 13” diameter (12mm width)
    - 6mm on 13” diameter (16mm width)
- Full SMT Handling Guide & Array Reference Design available

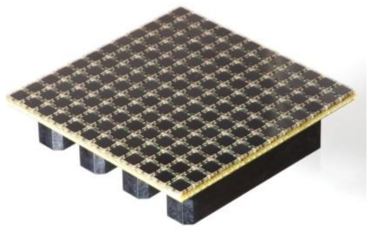
MLP-SMT Array Variants



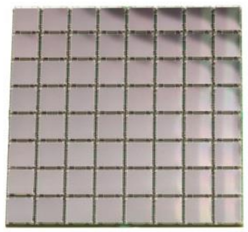
8x8 of 1mm
(2.49 cm²)



4x4 of 3mm
(2.74 cm²)

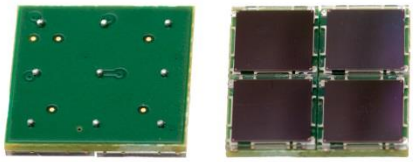


12x12 of 3mm
(25.2 cm²)



8x8 of 6mm
(32.94 cm²)

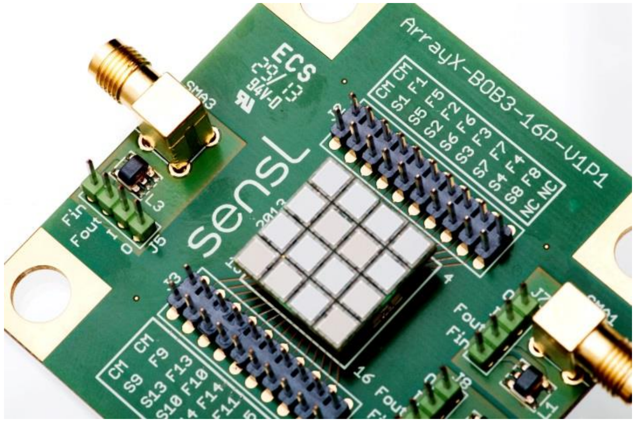
Tileable 2x2 array of 6x6mm MLP:



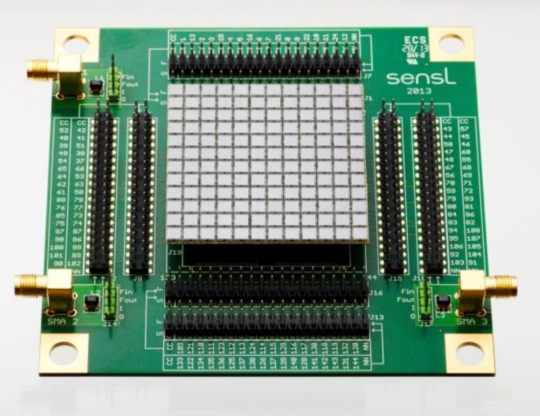
- Available for rapid testing
  - 8x8 of 1mm SMT/MLP
    - 1.7mm pitch
  - 4x4 of 3mm SMT/MLP
    - 4.2mm pitch
  - 12x12 of 3mm SMT/MLP
    - 4.2mm pitch
  - 8x8 of 6mm SMT/MLP
    - 7.2mm pitch
- Passive Breakout Board (BoB)
  - Ability to readout any pixel
  - 3 SMA connection options
- Full Reference Design Available

Passive Array Breakout Boards

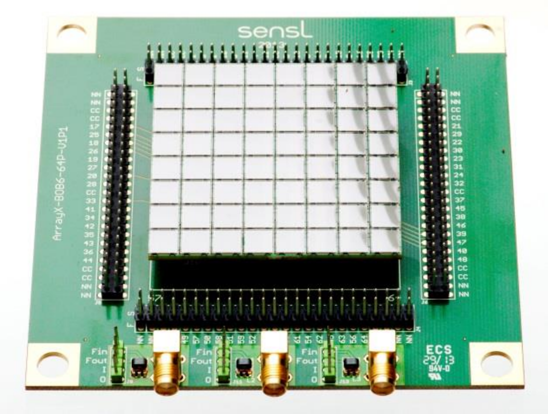
8x8 of 1mm (2.49 cm^2)



4x4 of 3mm (2.74 cm^2)



12x12 of 3mm (25.2 cm^2)



8x8 of 6mm (32.94 cm^2)

Recommended Documentation

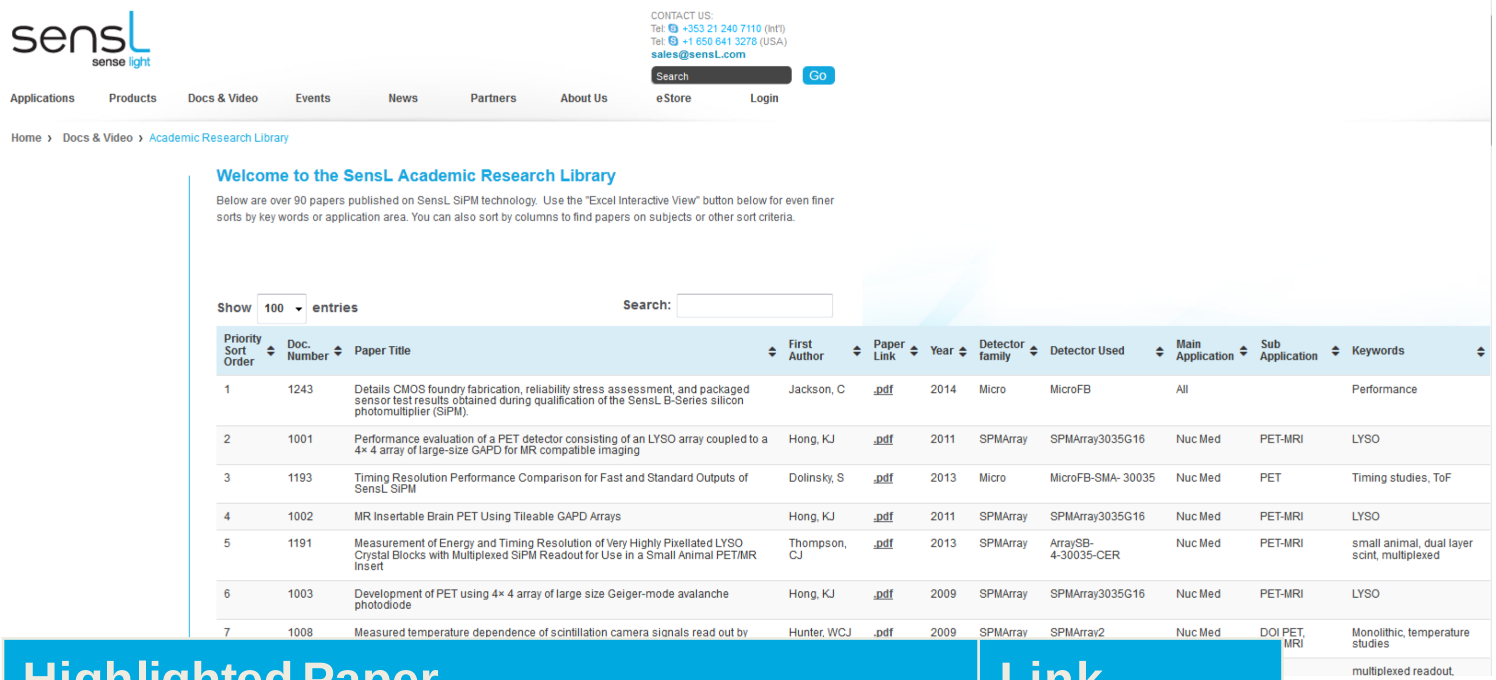
Document Type	Document Description	Current Revision	Web Hyperlink
Product Brief (PB)	SensL SiPM Product Selection Guide	Rev 2.4	.pdf
Tech Note (TN)	Introduction to SiPM Technology Whitepaper	Rev 3.1	.pdf
Data Sheet (DS)	C Series (Low Noise) SiPM Datasheet	Rev 1.6	.pdf
User Manual (UM)	C Series (Low Noise) SiPM User Manual	Rev 1.4	.pdf
Tech Note (TN)	MLP-SMT Device Handling and Soldering Guide	Rev 2.6	.pdf
Tech Note (TN)	Design guide for SMT Arrays	Rev 2.0	.pdf
Product Brief (PB)	Array-SMT Product Brief	Rev 2.2	.pdf
User Manual (UM)	Array-SMT User Manual	Rev 2.3	.pdf
Tech Note (TN)	MicroFB/FC-SMA-30035 Experiment Guide	Rev 1.0	.pdf
Tech Note (TN)	Readout Methods for Arrays of Silicon Photomultipliers	Rev 2.0	.pdf
App Note (AN)	Signal Driven Multiplexing Method For Channel Reduction -- Detailed App Note	Rev 1.0	.pdf

Complete Library is located at: http://sensl.com/documentation/

*User Manuals and some technical materials require a login (instant access)

Academic Research Library

http://sensl.com/documentation/academic-research-library/



CONTACT US:
Tel: +353 21 240 7110 (Int'l)
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sales@sensL.com

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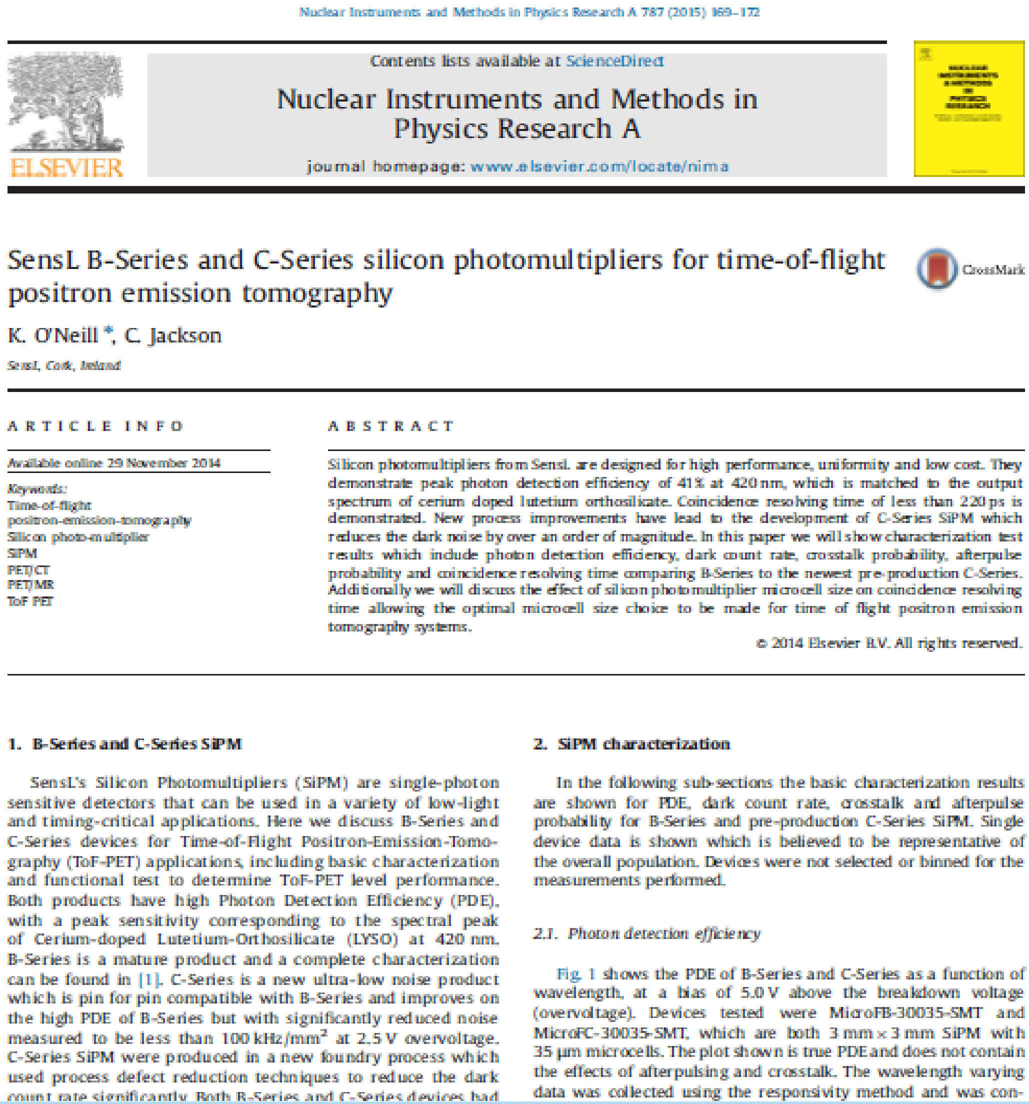
Below are over 90 papers published on SensL SiPM technology. Use the "Excel Interactive View" button below for even finer sorts by key words or application area. You can also sort by columns to find papers on subjects or other sort criteria.

Show 100 entries   Search:

Priority Sort Order	Doc. Number	Paper Title	First Author	Paper Link	Year	Detector family	Detector Used	Main Application	Sub Application	Keywords
1	1243	Details CMOS foundry fabrication, reliability stress assessment, and packaged sensor test results obtained during qualification of the SensL B-Series silicon photomultiplier (SiPM).	Jackson, C	.pdf	2014	Micro	MicroFB	All		Performance
2	1001	Performance evaluation of a PET detector consisting of an LYSO array coupled to a 4× 4 array of large-size GAPD for MR compatible imaging	Hong, KJ	.pdf	2011	SPMArray	SPMArray3035G16	Nuc Med	PET-MRI	LYSO
3	1193	Timing Resolution Performance Comparison for Fast and Standard Outputs of SensL SiPM	Dolinsky, S	.pdf	2013	Micro	MicroFB-SMA- 30035	Nuc Med	PET	Timing studies, ToF
4	1002	MR Insertable Brain PET Using Tileable GAPD Arrays	Hong, KJ	.pdf	2011	SPMArray	SPMArray3035G16	Nuc Med	PET-MRI	LYSO
5	1191	Measurement of Energy and Timing Resolution of Very Highly Pixellated LYSO Crystal Blocks with Multiplexed SiPM Readout for Use in a Small Animal PET/MR Insert	Thompson, CJ	.pdf	2013	SPMArray	ArraySB-4-30035-CER	Nuc Med	PET-MRI	small animal, dual layer scint, multiplexed
6	1003	Development of PET using 4× 4 array of large size Geiger-mode avalanche photodiode	Hong, KJ	.pdf	2009	SPMArray	SPMArray3035G16	Nuc Med	PET-MRI	LYSO
7	1008	Measured temperature dependence of scintillation camera signals read out by	Hunter, WCJ	.pdf	2009	SPMArray	SPMArray2	Nuc Med	DOI PET, MRI	Monolithic, temperature studies
										multiplexed readout,

Highlighted Paper	Link
C Jackson et al., "High-volume silicon photomultiplier production, performance, and reliability" *Optical Engineering*, August 2014, Vol 53	Download
Photonics West 2015 — "Silicon Photomultipliers for High Performance and High Volume Applications"	Whitepaper PPT
Photonics West 2015 — "Through Silicon Via Developments for Silicon Photomultipliers"	Whitepaper PPT

New Publication



Nuclear Instruments and Methods in Physics Research A 787 (2015) 169–172

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

SensL B-Series and C-Series silicon photomultipliers for time-of-flight positron emission tomography

K. O'Neill *, C. Jackson

SensL, Cork, Ireland

ARTICLE INFO

Available online 29 November 2014

Keywords:
Time-of-flight
positron-emission-tomography
Silicon photo-multiplier
SiPM
PET/CT
PET/MR
ToF PET

ABSTRACT

Silicon photomultipliers from SensL are designed for high performance, uniformity and low cost. They demonstrate peak photon detection efficiency of 41% at 420 nm, which is matched to the output spectrum of cerium doped lutetium orthosilicate. Coincidence resolving time of less than 220 ps is demonstrated. New process improvements have lead to the development of C-Series SiPM which reduces the dark noise by over an order of magnitude. In this paper we will show characterization test results which include photon detection efficiency, dark count rate, crosstalk probability, afterpulse probability and coincidence resolving time comparing B-Series to the newest pre-production C-Series. Additionally we will discuss the effect of silicon photomultiplier microcell size on coincidence resolving time allowing the optimal microcell size choice to be made for time of flight positron emission tomography systems.

1. B-Series and C-Series SiPM

SensL's Silicon Photomultipliers (SiPM) are single-photon sensitive detectors that can be used in a variety of low-light and timing-critical applications. Here we discuss B-Series and C-Series devices for Time-of-Flight Positron-Emission-Tomography (ToF-PET) applications, including basic characterization and functional test to determine ToF-PET level performance. Both products have high Photon Detection Efficiency (PDE), with a peak sensitivity corresponding to the spectral peak of Cerium-doped Lutetium-Orthosilicate (LYSO) at 420 nm. B-Series is a mature product and a complete characterization can be found in [1]. C-Series is a new ultra-low noise product which is pin for pin compatible with B-Series and improves on the high PDE of B-Series but with significantly reduced noise measured to be less than 100 kHz/mm^2 at 2.5 V overvoltage. C-Series SiPM were produced in a new foundry process which used process defect reduction techniques to reduce the dark count rate significantly. Both B-Series and C-Series devices had

2. SiPM characterization

In the following sub-sections the basic characterization results are shown for PDE, dark count rate, crosstalk and afterpulse probability for B-Series and pre-production C-Series SiPM. Single device data is shown which is believed to be representative of the overall population. Devices were not selected or binned for the measurements performed.

2.1. Photon detection efficiency

Fig. 1 shows the PDE of B-Series and C-Series as a function of wavelength, at a bias of 5.0 V above the breakdown voltage (overvoltage). Devices tested were MicroFB-30035-SMT and MicroFC-30035-SMT, which are both 3 mm × 3 mm SiPM with 35 µm microcells. The plot shown is true PDE and does not contain the effects of afterpulsing and crosstalk. The wavelength varying data was collected using the responsivity method and was con-

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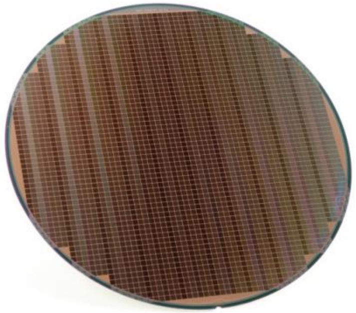
Fabrication

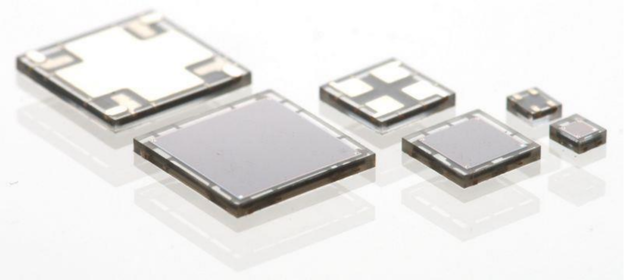
Methodology and wafer level results of SensL's high-volume fabrication process

High Volume SiPM Production



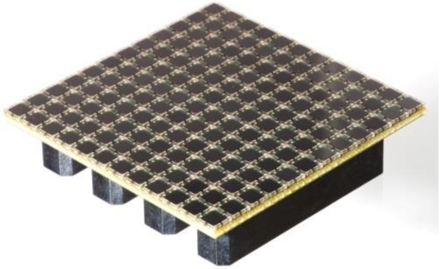
Wafer Processing

- Tier 1 commercial CMOS foundry
- 8 inch process
- PCM Test
- 1,000,000 product tests per batch
  - Electrical (Dark)
  - Electrical (Light)



Package Assembly

- Micro Leadframe Package (MLP)
- High volume mold assembly
- End of line product test
  - Electrical (Dark)
  - Optical inspection
- Ship tape and reel



Array Fabrication

- By SensL or customer
- Product is on tape and reel for integration with standard PCB assembly flow

sensL
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Quality & Reliability:

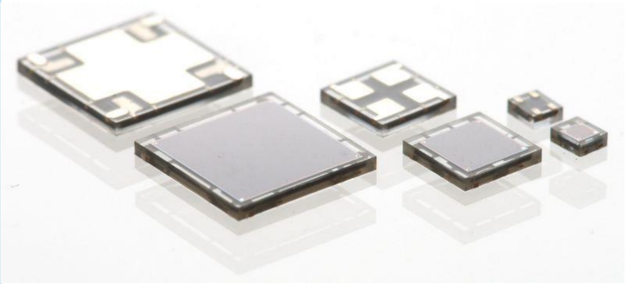
Industrialisation of SiPM Technology

Overview of the MLP-SMT Product Reliability Assessment Program for High Volume Production

Overview of Program

- **The problem**:
  - No standard reliability assessment program exists for SiPM
- **The solution**:
  - SensL follow industry standard test flows designed for integrated circuits

- Recommended assessment program
  - Multiple wafer production batches
  - Multiple package assembly batches
  - Test flows all to integrated circuit industry standards (JEDEC)



- SensL's Clear Micro Leadframe Package (MLP)

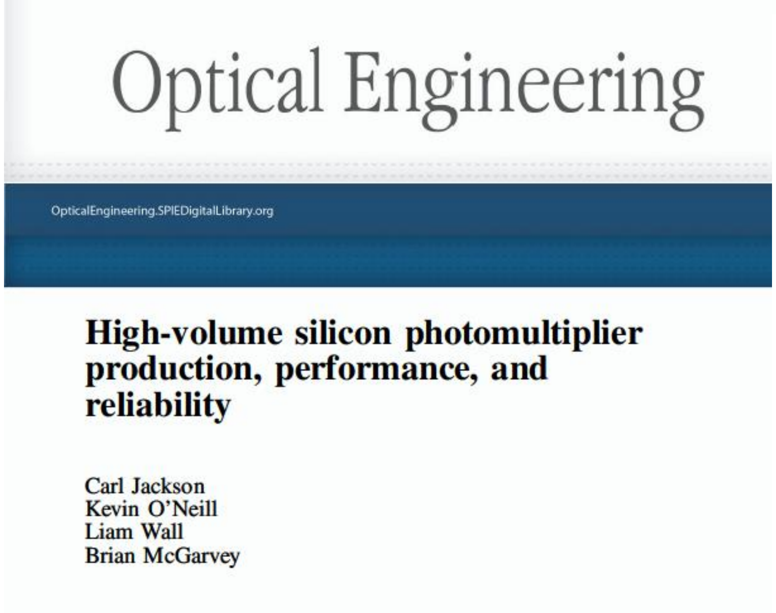
- Typical product MicroFX-10035-SMT, MicroFX-30035-SMT or MicroFX-60035-SMT

sensl sense light

SPIE Publication

Citation:

Carl Jackson ; Kevin O'Neill ; Liam Wall and Brian McGarvey "***High-volume silicon photomultiplier production, performance, and reliability***", Opt. Eng. 53(8), 081909 (Aug 15, 2014). http://dx.doi.org/10.1117/1.OE.53.8.081909



Optical Engineering

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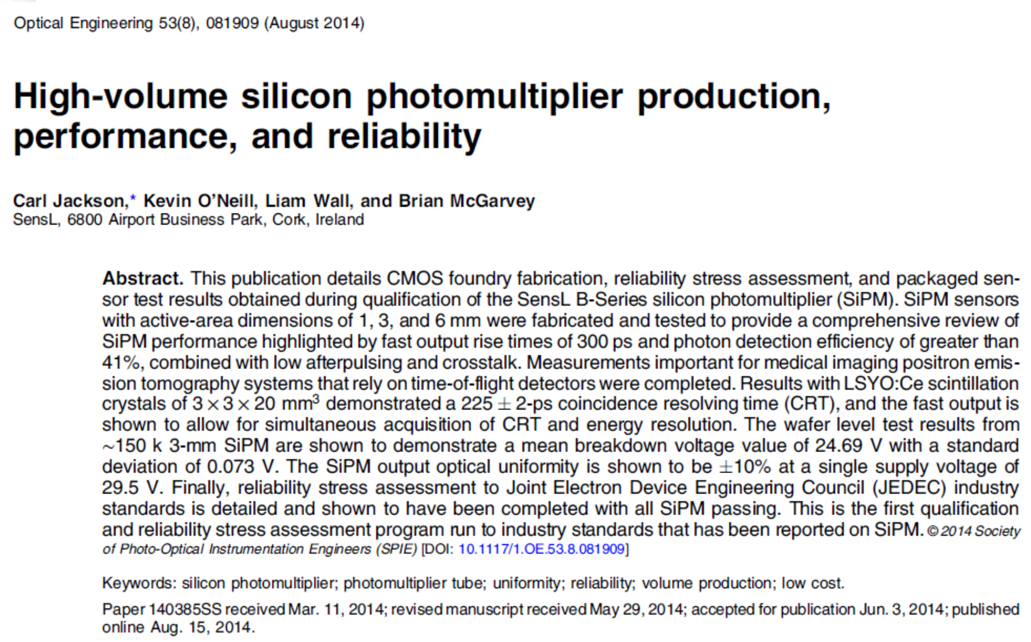
High-volume silicon photomultiplier production, performance, and reliability

Carl Jackson
Kevin O'Neill
Liam Wall
Brian McGarvey



Optical Engineering 53(8), 081909 (August 2014)

High-volume silicon photomultiplier production, performance, and reliability

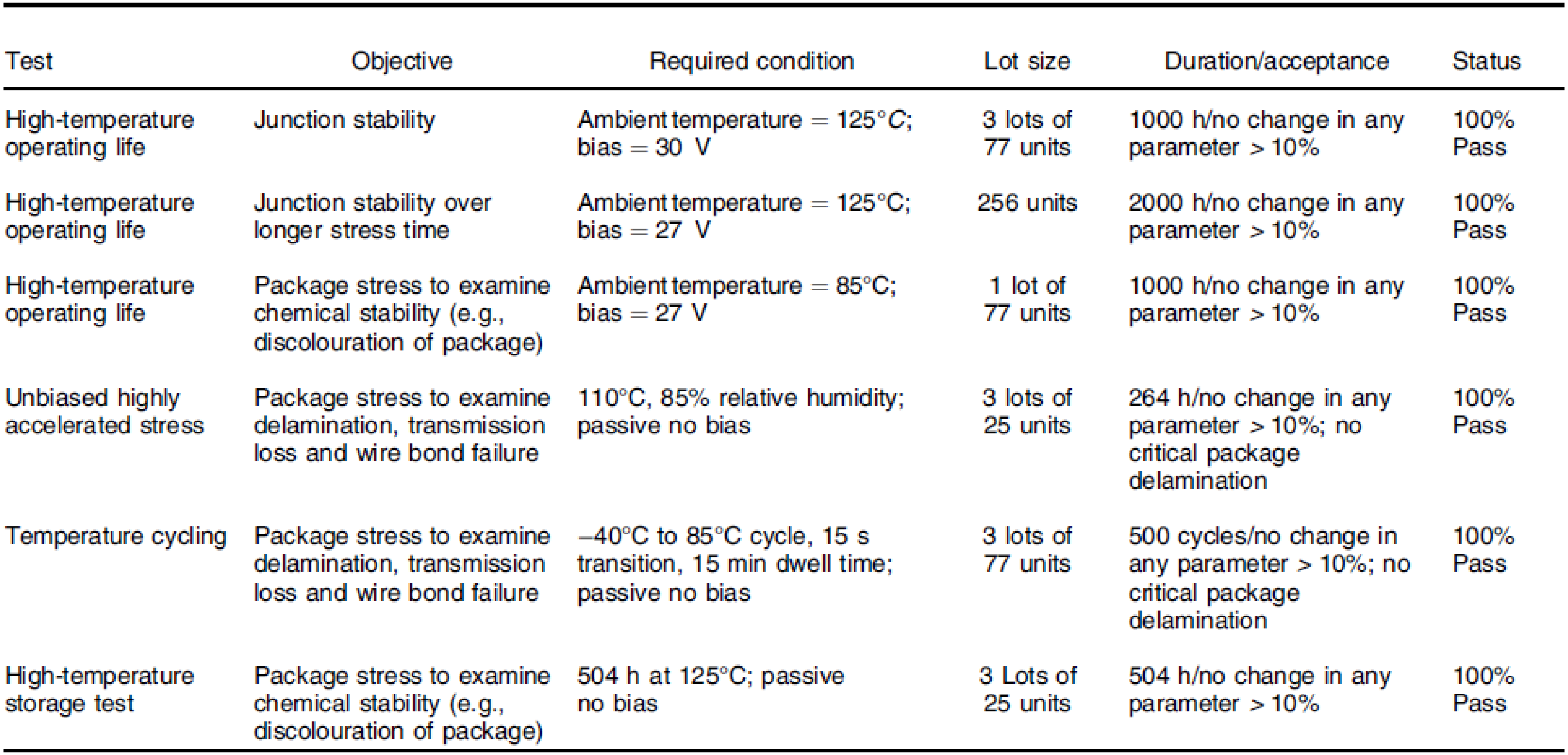
Carl Jackson,* Kevin O'Neill, Liam Wall, and Brian McGarvey
SensL, 6800 Airport Business Park, Cork, Ireland

Abstract. This publication details CMOS foundry fabrication, reliability stress assessment, and packaged sensor test results obtained during qualification of the SensL B-Series silicon photomultiplier (SiPM). SiPM sensors with active-area dimensions of 1, 3, and 6 mm were fabricated and tested to provide a comprehensive review of SiPM performance highlighted by fast output rise times of 300 ps and photon detection efficiency of greater than 41%, combined with low afterpulsing and crosstalk. Measurements important for medical imaging positron emission tomography systems that rely on time-of-flight detectors were completed. Results with LSYO:Ce scintillation crystals of $3 \times 3 \times 20$ mm^3 demonstrated a 225 ± 2-ps coincidence resolving time (CRT), and the fast output is shown to allow for simultaneous acquisition of CRT and energy resolution. The wafer level test results from ~150 k 3-mm SiPM are shown to demonstrate a mean breakdown voltage value of 24.69 V with a standard deviation of 0.073 V. The SiPM output optical uniformity is shown to be ±10% at a single supply voltage of 29.5 V. Finally, reliability stress assessment to Joint Electron Device Engineering Council (JEDEC) industry standards is detailed and shown to have been completed with all SiPM passing. This is the first qualification and reliability stress assessment program run to industry standards that has been reported on SiPM. [DOI: 10.1117/1.OE.53.8.081909]

Keywords: silicon photomultiplier; photomultiplier tube; uniformity; reliability; volume production; low cost.

Paper 140385SS received Mar. 11, 2014; revised manuscript received May 29, 2014; accepted for publication Jun. 3, 2014; published online Aug. 15, 2014.

Reliability Test of Silicon

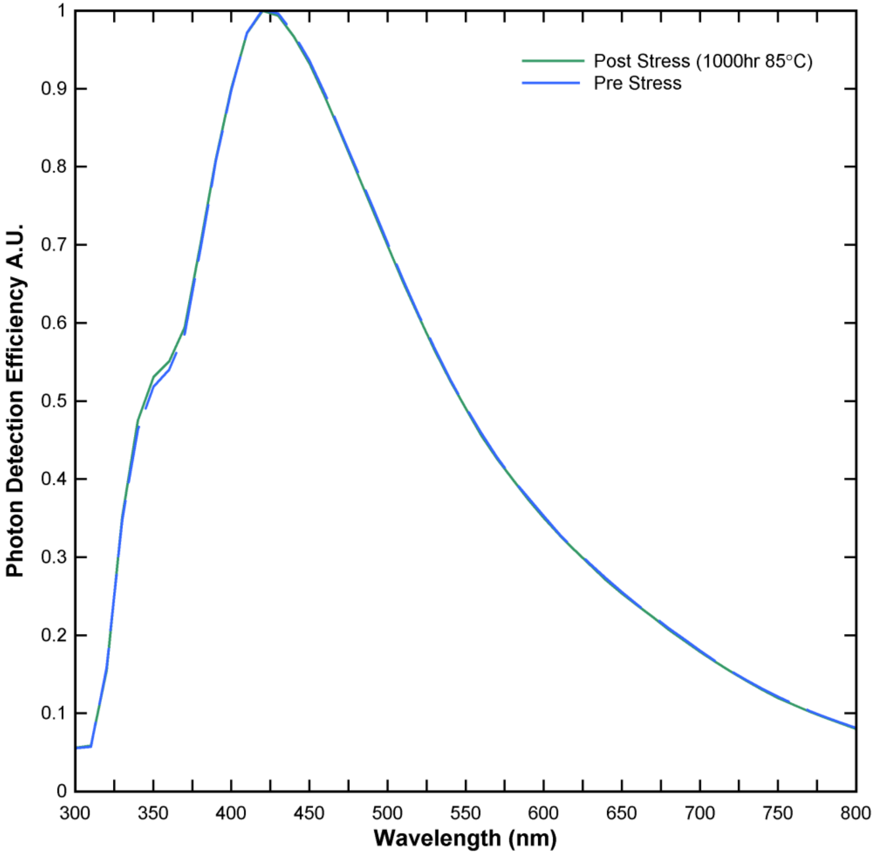


Test	Objective	Required condition	Lot size	Duration/acceptance	Status
High-temperature operating life	Junction stability	Ambient temperature = 125°C; bias = 30 V	3 lots of 77 units	1000 h/no change in any parameter > 10%	100% Pass
High-temperature operating life	Junction stability over longer stress time	Ambient temperature = 125°C; bias = 27 V	256 units	2000 h/no change in any parameter > 10%	100% Pass
High-temperature operating life	Package stress to examine chemical stability (e.g., discolouration of package)	Ambient temperature = 85°C; bias = 27 V	1 lot of 77 units	1000 h/no change in any parameter > 10%	100% Pass
Unbiased highly accelerated stress	Package stress to examine delamination, transmission loss and wire bond failure	110°C, 85% relative humidity; passive no bias	3 lots of 25 units	264 h/no change in any parameter > 10%; no critical package delamination	100% Pass
Temperature cycling	Package stress to examine delamination, transmission loss and wire bond failure	−40°C to 85°C cycle, 15 s transition, 15 min dwell time; passive no bias	3 lots of 77 units	500 cycles/no change in any parameter > 10%; no critical package delamination	100% Pass
High-temperature storage test	Package stress to examine chemical stability (e.g., discolouration of package)	504 h at 125°C; passive no bias	3 Lots of 25 units	504 h/no change in any parameter > 10%	100% Pass

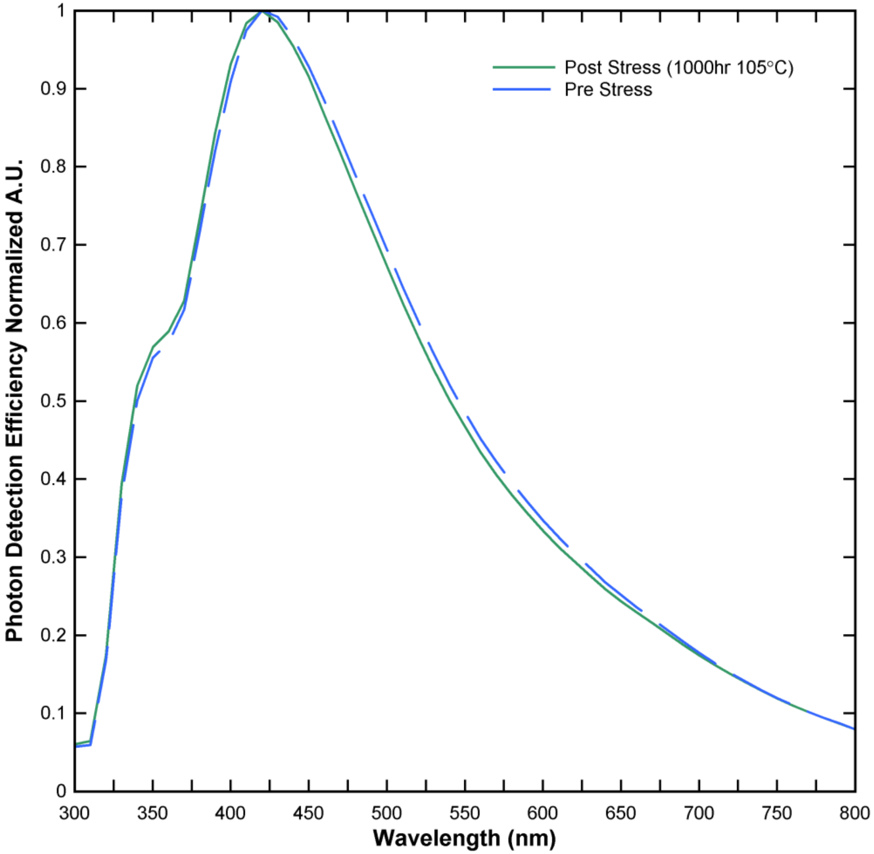
All stress and test steps were carried out as per Joint Electron Device Engineering Council (JEDEC) standard conditions – JESD22-A108D "*Temperature, bias and operating life*"

Additional SMT Temperature Stress Details

1000hr @ 85˚C



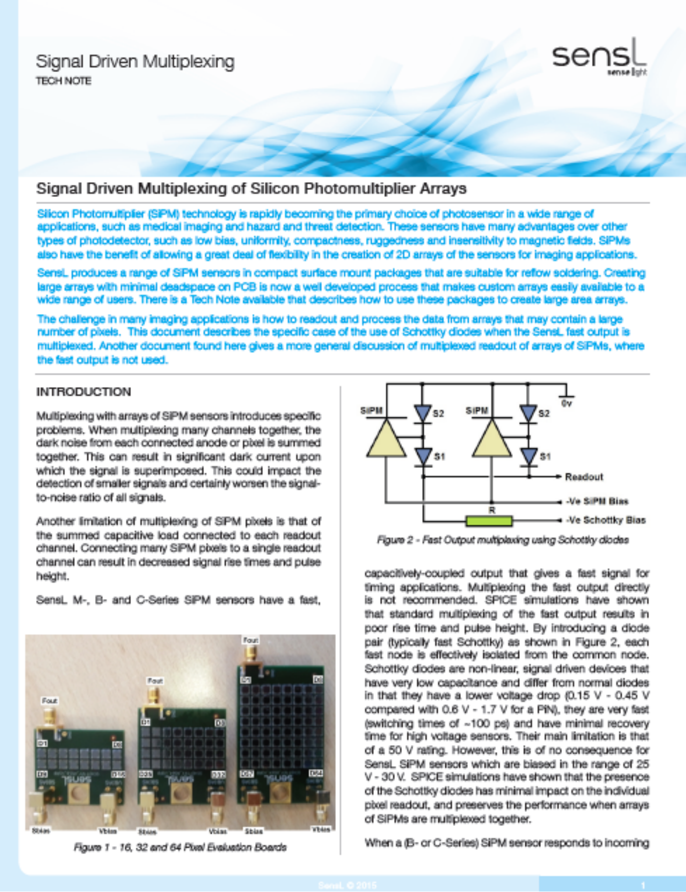
1000hr @ 105˚C



No change in optical performance for +85˚C and +105 ˚ C 1000hr temperature stress. All data within PDE measurement system error. (No epoxy yellowing)

Large Arrays & Signal-Driven Multiplexing

- Many applications require large NxM arrays of SiPM
- Spectroscopic resolution & timing frequently required to be optimized



Signal Driven Multiplexing
TECH NOTE

Signal Driven Multiplexing of Silicon Photomultiplier Arrays

Silicon Photomultiplier (SiPM) technology is rapidly becoming the primary choice of photosensor in a wide range of applications, such as medical imaging and hazard and threat detection. These sensors have many advantages over other types of photodetector, such as low bias, uniformity, compactness, ruggedness and insensitivity to magnetic fields. SiPMs also have the benefit of allowing a great deal of flexibility in the creation of 2D arrays of the sensors for imaging applications.

SensL produces a range of SiPM sensors in compact surface mount packages that are suitable for reflow soldering. Creating large arrays with minimal deadspace on PCB is now a well developed process that makes custom arrays easily available to a wide range of users. There is a Tech Note available that describes how to use these packages to create large area arrays.

The challenge in many imaging applications is how to readout and process the data from arrays that may contain a large number of pixels. This document describes the specific case of the use of Schottky diodes when the SensL fast output is multiplexed. Another document found here gives a more general discussion of multiplexed readout of arrays of SiPMs, where the fast output is not used.

INTRODUCTION

Multiplexing with arrays of SiPM sensors introduces specific problems. When multiplexing many channels together, the dark noise from each connected anode or pixel is summed together. This can result in significant dark current upon which the signal is superimposed. This could impact the detection of smaller signals and certainly worsen the signal-to-noise ratio of all signals.

Another limitation of multiplexing of SiPM pixels is that of the summed capacitive load connected to each readout channel. Connecting many SiPM pixels to a single readout channel can result in decreased signal rise times and pulse height.

SensL M-, B- and C-Series SiPM sensors have a fast, capacitively-coupled output that gives a fast signal for timing applications. Multiplexing the fast output directly is not recommended. SPICE simulations have shown that standard multiplexing of the fast output results in poor rise time and pulse height. By introducing a diode pair (typically fast Schottky) as shown in Figure 2, each fast node is effectively isolated from the common node. Schottky diodes are non-linear, signal driven devices that have very low capacitance and differ from normal diodes in that they have a lower voltage drop (0.15 V - 0.45 V compared with 0.6 V - 1.7 V for a PIN), they are very fast (switching times of ~100 ps) and have minimal recovery time for high voltage sensors. Their main limitation is that of a 50 V rating. However, this is of no consequence for SensL SiPM sensors which are biased in the range of 25 V - 30 V. SPICE simulations have shown that the presence of the Schottky diodes has minimal impact on the individual pixel readout, and preserves the performance when arrays of SiPMs are multiplexed together.

When a (B- or C-Series) SiPM sensor responds to incoming

Figure 2 - Fast Output multiplexing using Schottky diodes

Figure 1 - 16, 32 and 64 Pixel Evaluation Boards

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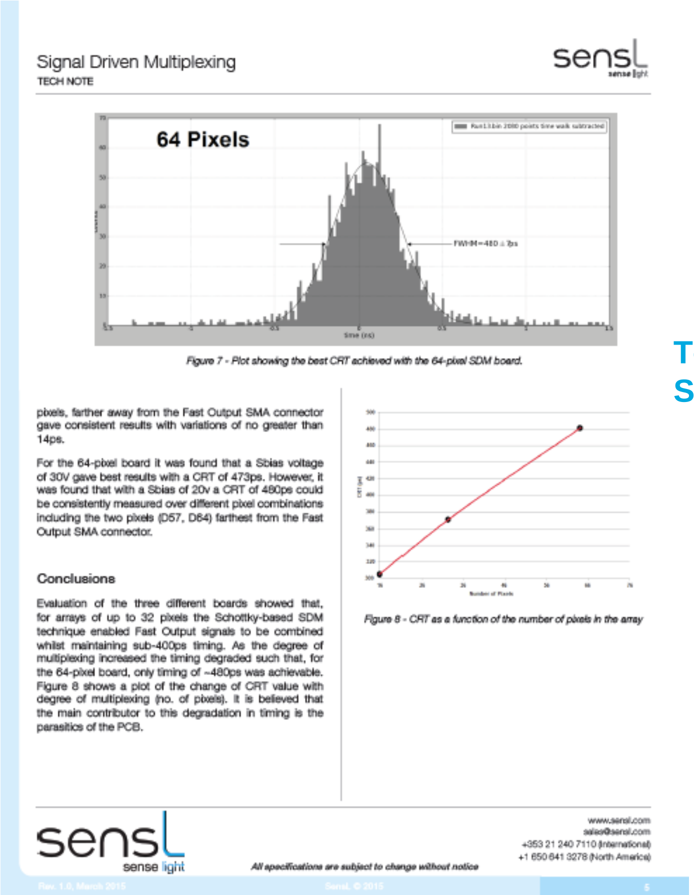

Signal Driven Multiplexing
TECH NOTE

Figure 7 - Plot showing the best CRT achieved with the 64-pixel SDM board.

pixels, farther away from the Fast Output SMA connector gave consistent results with variations of no greater than 14ps.

For the 64-pixel board it was found that a Sbias voltage of 30V gave best results with a CRT of 473ps. However, it was found that with a Sbias of 20v a CRT of 480ps could be consistently measured over different pixel combinations including the two pixels (D57, D64) farthest from the Fast Output SMA connector.

Conclusions

Evaluation of the three different boards showed that, for arrays of up to 32 pixels the Schottky-based SDM technique enabled Fast Output signals to be combined whilst maintaining sub-400ps timing. As the degree of multiplexing increased the timing degraded such that, for the 64-pixel board, only timing of ~480ps was achievable. Figure 8 shows a plot of the change of CRT value with degree of multiplexing (no. of pixels). It is believed that the main contributor to this degradation in timing is the parasitics of the PCB.

Figure 8 - CRT as a function of the number of pixels in the array

www.sensl.com
sales@sensl.com
+353 21 240 7110 (International)
+1 650 641 3278 (North America)

All specifications are subject to change without notice

Rev. 1.0, March 2015 SensL © 2015 5

Technical note available at Sensl.com/documentation

Recent 3rd party publications

- ArDM – Dark Matter research
- DUNE – Neutrino physics
- NEXT – Neutrinoless Double Beta Decay

ArDM Publication

Status of ArDM-1t: First observations from operation with a full ton-scale liquid argon target

J. Calvo[1], C. Cantini[1], M. Daniel[2], U. Degunda[1], S. Di Luise[1], L. Epprecht[1],
A. Gendotti[1], S. Horikawa[1], L. Knecht[1], B. Montes[2], W. Mu[1], M. Munoz[1], S. Murphy[1],
G. Natterer[1], K. Nguyen[1], K. Nikolics[1], L. Periale[1], C. Regenfus[1], L. Romero[2],
A. Rubbia*[1], R. Santorelli[2], F. Sergiampietri[1], D. Sgalaberna[1], T. Viant[1] and S. Wu[1]

[1]ETH Zurich, Institute for Particle Physics, CH-8093 Zürich, Switzerland
[2]CIEMAT, Div. de Física de Partículas, Avda. Complutense, 22, E-28040, Madrid, Spain

The ArDM Collaboration

May 10, 2015

arXiv:1505.02443v1 [physics.ins-det] 10 May 2015

Abstract

ArDM is the first operating ton-scale liquid argon detector for direct search of Dark Matter particles. Developed at CERN as Recognized Experiment RE18, the experiment has been approved in 2010 to be installed in the Spanish underground site LSC (Laboratorio Subterraneo de Canfranc). Under the label of LSC EXP-08-2010 the ArDM detector underwent an intensive period of technical completion and safety approval until the recent filling of the target vessel with almost 2 t of liquid argon. This report describes the experimental achievements during commissioning of ArDM and the transition into a stage of first physics data taking in single phase operational mode (ArDM Run I). We present preliminary observations from this run. A first indication for the background discrimination power of LAr detectors at the ton-scale is shown. We present an outlook for completing the detector with the electric drift field and upgrade of the scintillation light readout system with novel detector modules based on SiPMs in order to improve the light yield.

1 Introduction

In February 2015 the ArDM experiment [1, 2, 3] achieved a major milestone by completing the filling of the detector vessel with a total of nearly 2 t of liquid argon (LAr). Now the project has entered the first period of physics data taking in the single-phase operation mode (ArDM Run I). This paper is based on a report submitted to the scientific committee of LSC in April 2015 and presents recent experimental accomplishments of ArDM, including the status of the underground operation at LSC, the progress in data taking and analysis, as well as the in-situ measurement of the environmental neutron flux in Hall A. Emphasis is also put on the mid-term future describing for the first time potential upgrades of ArDM.

The commissioning of the detector went smoothly and is described in detail in chapter 2.1. The next step in the experimental program is to complete the external neutron shield with the missing tiles from the top cover which were not yet installed for better access to the main vessel during the filling period. After we plan to continue mass data taking in the single-phase operation mode through June 2015. This will provide a precise assessment of the long-term stability of the system by regular calibration runs with radioactive test sources. Having achieved these major milestones, ArDM proposes to evolve in the near future with detector upgrades and a second period of physics data taking in the double-phase TPC operation mode.

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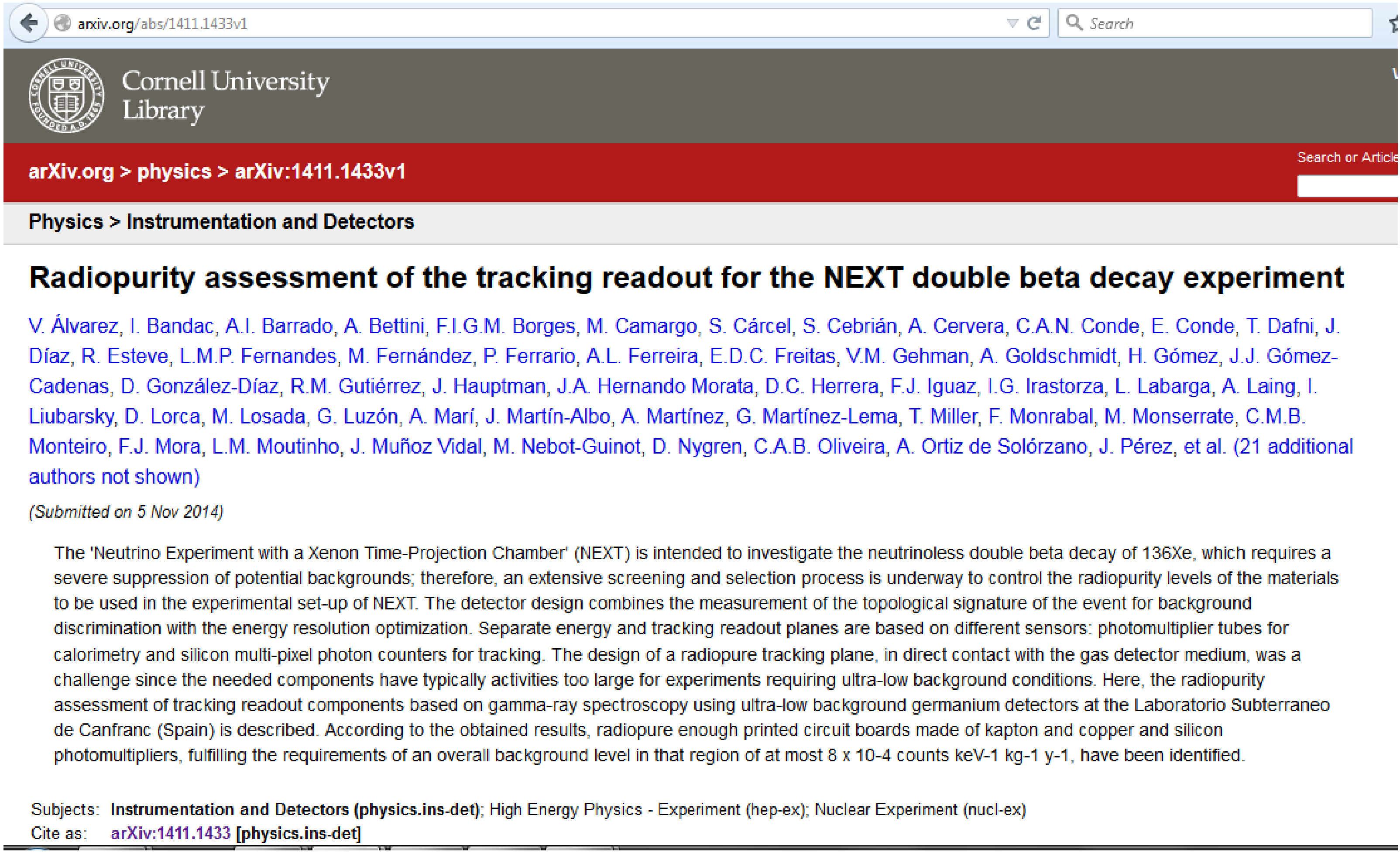
*andre.rubbia@cern.ch

http://arxiv.org/pdf/1505.02443.pdf

NEXT Publication - Radiopurity

- http://arxiv.org/abs/1411.1433



arXiv.org > physics > arXiv:1411.1433v1

Physics > Instrumentation and Detectors

Radiopurity assessment of the tracking readout for the NEXT double beta decay experiment

V. Álvarez, I. Bandac, A.I. Barrado, A. Bettini, F.I.G.M. Borges, M. Camargo, S. Cárcel, S. Cebrián, A. Cervera, C.A.N. Conde, E. Conde, T. Dafni, J. Díaz, R. Esteve, L.M.P. Fernandes, M. Fernández, P. Ferrario, A.L. Ferreira, E.D.C. Freitas, V.M. Gehman, A. Goldschmidt, H. Gómez, J.J. Gómez-Cadenas, D. González-Díaz, R.M. Gutiérrez, J. Hauptman, J.A. Hernando Morata, D.C. Herrera, F.J. Iguaz, I.G. Irastorza, L. Labarga, A. Laing, I. Liubarsky, D. Lorca, M. Losada, G. Luzón, A. Marí, J. Martín-Albo, A. Martínez, G. Martínez-Lema, T. Miller, F. Monrabal, M. Monserrate, C.M.B. Monteiro, F.J. Mora, L.M. Moutinho, J. Muñoz Vidal, M. Nebot-Guinot, D. Nygren, C.A.B. Oliveira, A. Ortiz de Solórzano, J. Pérez, et al. (21 additional authors not shown)

(Submitted on 5 Nov 2014)

The 'Neutrino Experiment with a Xenon Time-Projection Chamber' (NEXT) is intended to investigate the neutrinoless double beta decay of 136Xe, which requires a severe suppression of potential backgrounds; therefore, an extensive screening and selection process is underway to control the radiopurity levels of the materials to be used in the experimental set-up of NEXT. The detector design combines the measurement of the topological signature of the event for background discrimination with the energy resolution optimization. Separate energy and tracking readout planes are based on different sensors: photomultiplier tubes for calorimetry and silicon multi-pixel photon counters for tracking. The design of a radiopure tracking plane, in direct contact with the gas detector medium, was a challenge since the needed components have typically activities too large for experiments requiring ultra-low background conditions. Here, the radiopurity assessment of tracking readout components based on gamma-ray spectroscopy using ultra-low background germanium detectors at the Laboratorio Subterraneo de Canfranc (Spain) is described. According to the obtained results, radiopure enough printed circuit boards made of kapton and copper and silicon photomultipliers, fulfilling the requirements of an overall background level in that region of at most 8 x 10-4 counts keV-1 kg-1 y-1, have been identified.

Subjects: **Instrumentation and Detectors (physics.ins-det)**; High Energy Physics - Experiment (hep-ex); Nuclear Experiment (nucl-ex)
Cite as: **arXiv:1411.1433 [physics.ins-det]**

DUNE Publication – Cryogenic tests

Scintillation Light from Cosmic-Ray Muons in Liquid Argon

D. Whittington[1] and S. Mufson[1]
[1]*Indiana University, Bloomington, Indiana 47405, USA*
(Dated: August 8, 2014)

This paper reports the results of the first experiment to directly measure the properties of the scintillation light generated by minimum ionizing cosmic-ray muons in liquid argon. Scintillation light from these muons is of value to studies of weakly-interacting particles in neutrino experiments and dark matter searches, as well as for particle identification. The experiment was carried out at the TallBo facility at Fermilab using prototype light guides and electronics developed for the Long-Baseline Neutrino Experiment. Analysis of the time-resolved structure of the scintillation light from cosmic-ray muons gives $\langle\tau_T\rangle = 1.43 \pm 0.04$ (stat.) $\pm\, 0.007$ (sys.) μs for the triplet light decay time constant. The ratio of singlet to triplet light measured using surface-coated light guides is $R = 0.39 \pm 0.01$ (stat.) $\pm\, 0.008$ (sys.). There is some evidence that this value is not consistent with R for minimum ionizing electrons. However, the value for R measured here clearly differs significantly from R found for heavily ionizing particles like alphas. Furthermore, there is no apparent difference in R measured using light guides coated with TPB versus bis-MSB, adding additional evidence that bis-MSB is a promising alternative to TPB for detecting scintillation light in liquid argon.

PACS numbers: 13.85.Tp, 14.60.Ef, 29.40.Mc, 78.47.jd

I. INTRODUCTION

Liquid argon (LAr) is proving to be a sensitive and cost-effective detector medium for the study of weakly-interacting particles in neutrino experiments and dark matter searches. Signals generated in LAr by these particles' interactions include ionization electrons from charged daughter particles which can be detected directly by a time projection chamber or by photodetectors sensitive to the scintillation light from excited argon. In this paper we study the properties of the scintillation light generated by cosmic-ray muons in LAr using light collectors, photodetectors, and readout electronics being developed for the Long Baseline Neutrino Experiment (LBNE).

As charged particles pass through LAr, they create excited argon atoms that can pair with neutral argon atoms to form an excited argon dimer, which subsequently decays by emitting a scintillation photon. This process happens through two mechanisms: minimum ionizing cosmic-ray muons and to characterize the relative fraction of early light to late light that they produce.

Detecting the VUV scintillation photons from LAr in large neutrino detectors like LBNE is technically challenging because of the difficulty in detecting the VUV photons efficiently. Since significant photocathode coverage of the detector is prohibitively expensive, the scintillation photons are gathered by light guides that collect them, waveshift them into the optical, and then channel them to optical photodetectors. This detection scheme is inherently inefficient, but can be mitigated by two factors. First, LAr is a copious source of scintillation light, producing tens of thousands of VUV photons per MeV along a track [3]. Second, pure liquid argon is transparent to its own scintillation light, meaning the scintillation signal can be detected at a significant distance from its source. Many designs for the LBNE light guides are currently being evaluated. This investigation uses four prototype light guide designs for the measurements.

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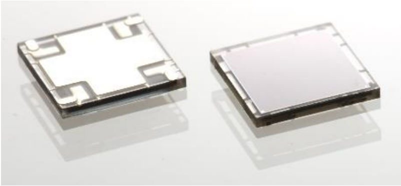
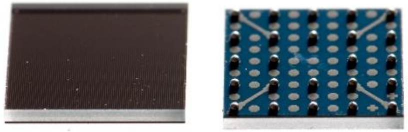
Through Silicon Via Technology Overview

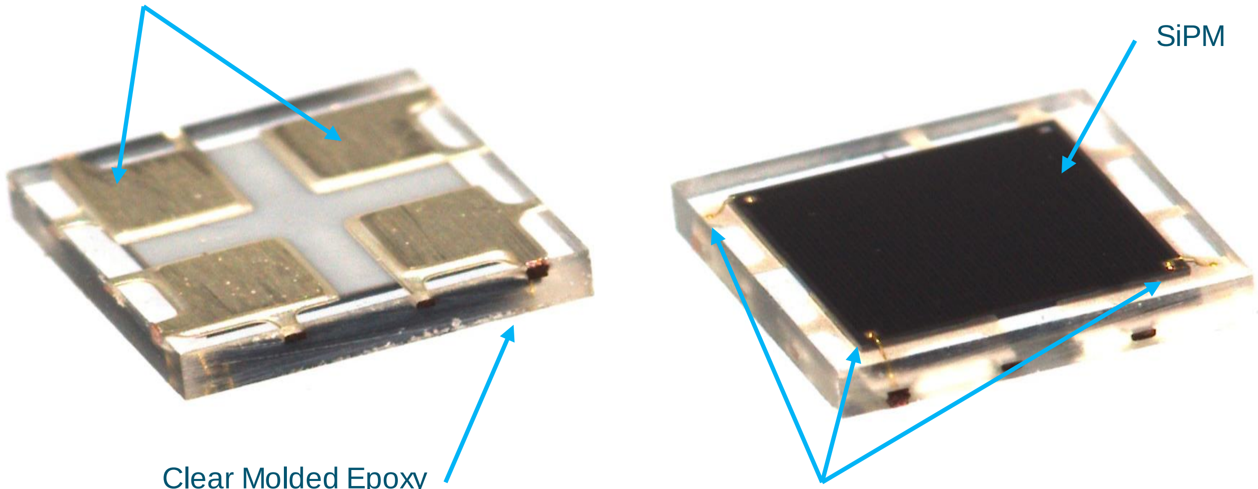
Package Technology Comparison

Parameter	Poured Epoxy	Clear MLP	TSV
Array Fill Factor	Good	Good	Best
Optical Transmission	Poor	Good	Best
Output Impedance	Poor	Good	Best
Operating Conditions	0°C to 40°C	-40°C to 85°C	-40°C to 95°C
Reliability	Manual processing, reduced reliability	Good	Best
Service life	Yellowing of potted epoxy is not well controlled	Good	Best
Uniformity and Reproducibility	Poor	Good	Best
Cost	Not recommended for use in volume. Suitable for research and prototype testing.	Low	Low, but higher than MLP when used in high density arrays using minimal spacing design rules.



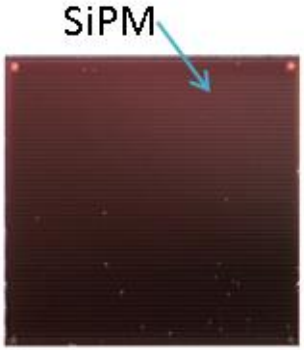


Why TSV?

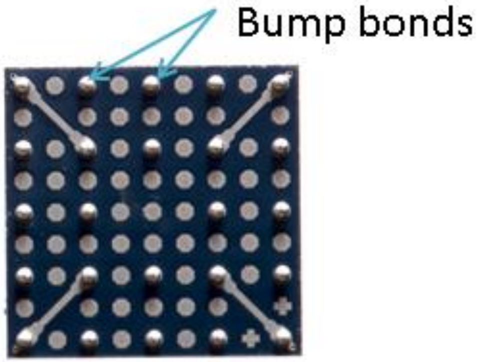


Die Size	Package Size (MLP)	Active Area Fill Factor
1mm x 1mm	1.5mm x 1.8mm	37%
3mm x 3mm	4mm x 4mm	56%
6mm x 6mm	7mm x 7mm	73%

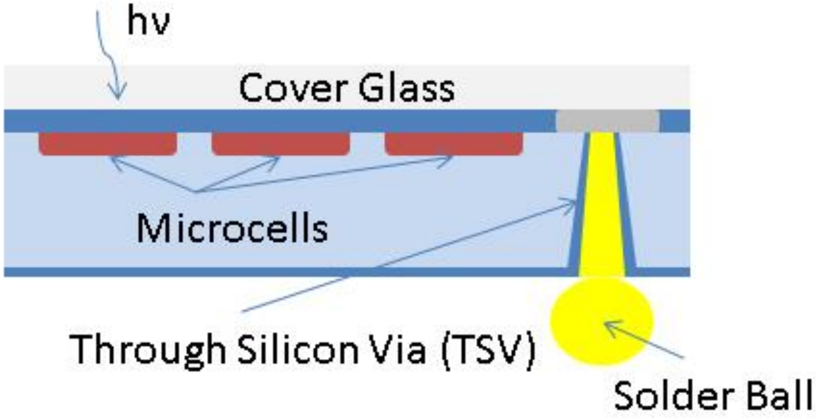
SensL’s Through Silicon Via (TSV)



Sensor
Top view



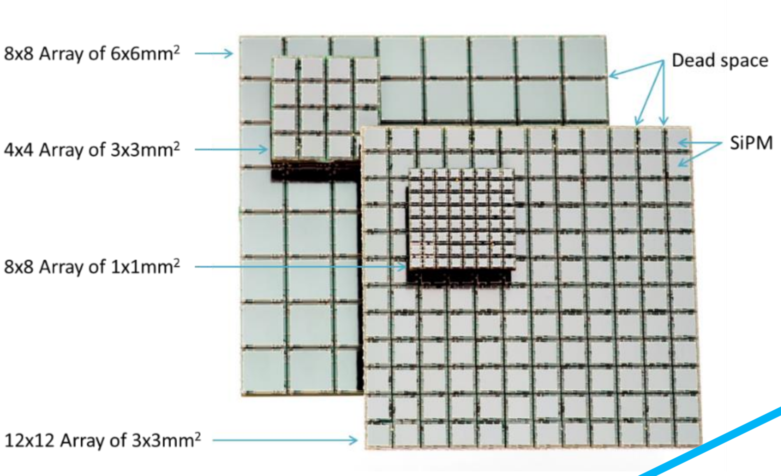
Contact
Bottom view



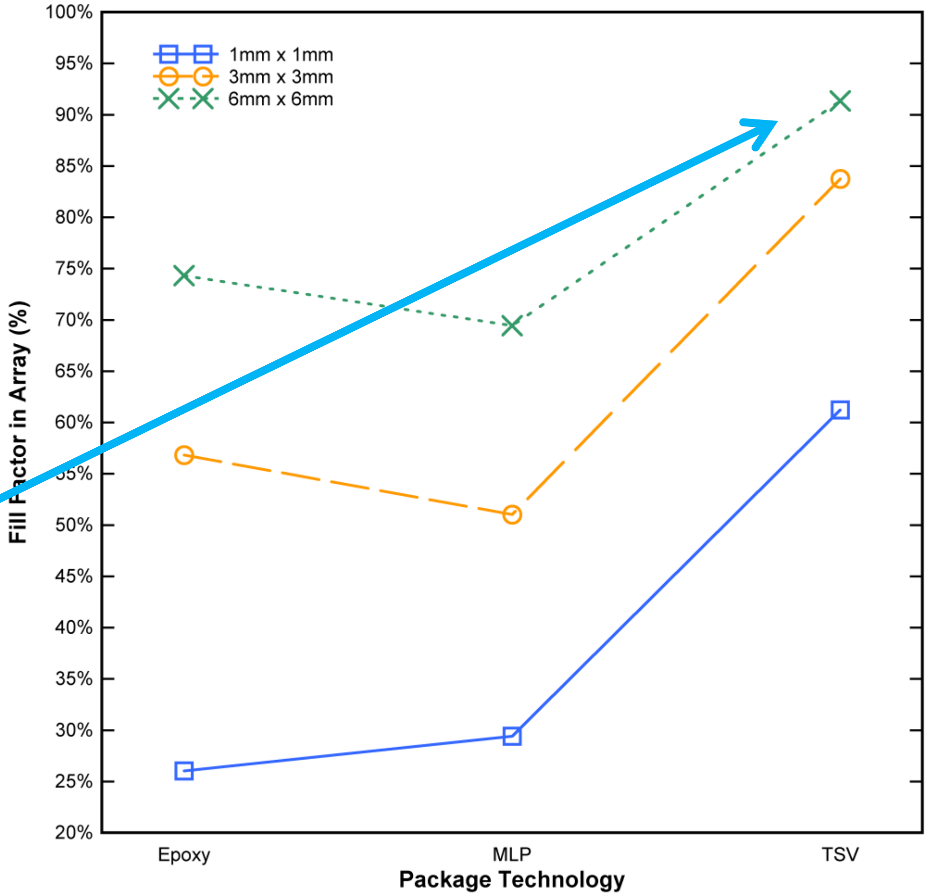
- No ferrous metals (MR compatibility)
- No wire bonds (better reliability & timing)
- SensL’s TSV process is a true *wafer scale package*
  - SiPM can be placed directly on PCB by customers with minimal deadspace

TSV High Array Fill Factor (packing fraction)

Clear MLP SMT Arrays

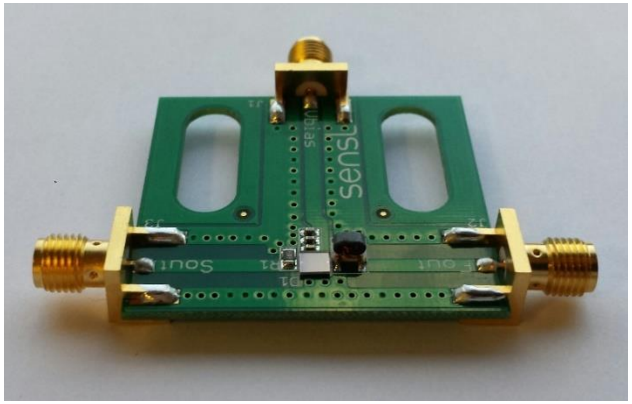


TSV Array Fill Factor Comparison

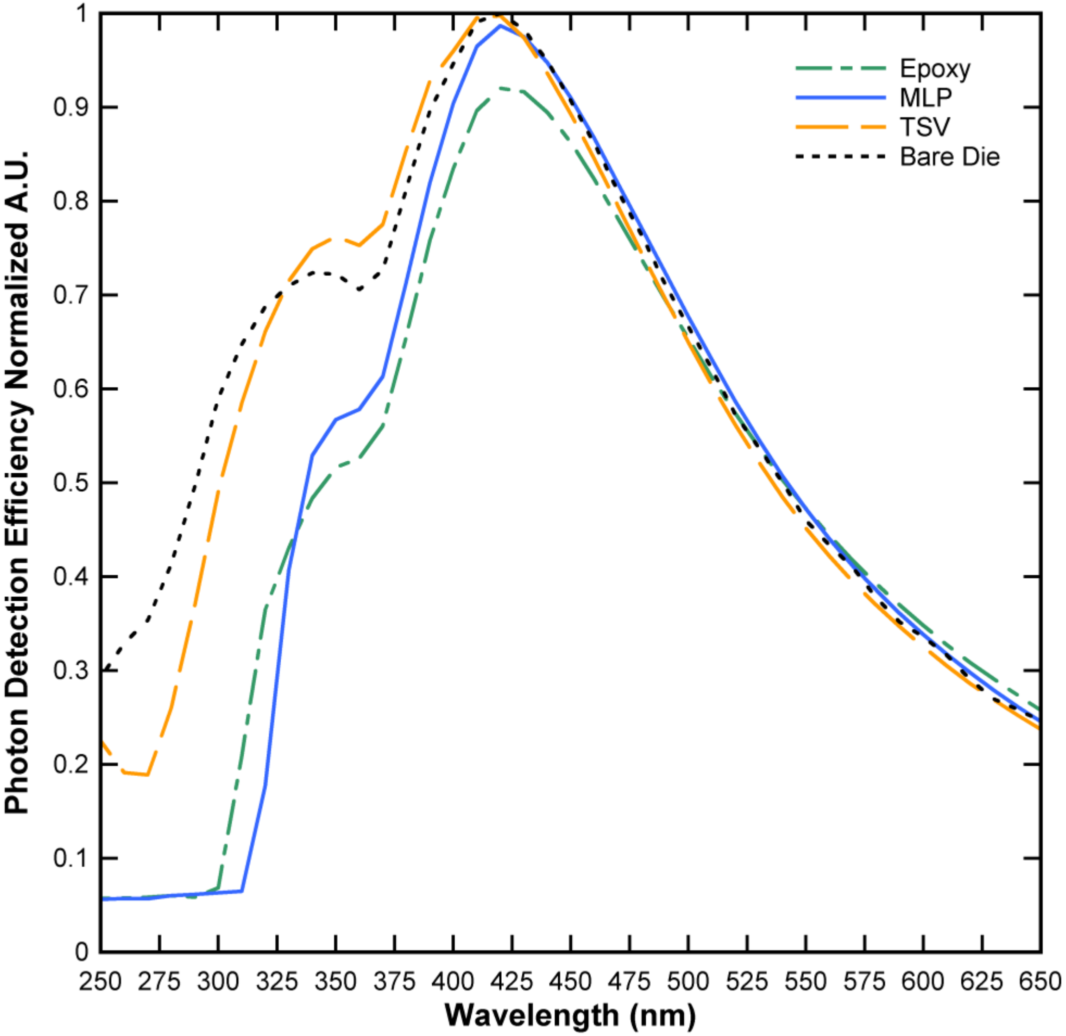


TSV Arrays provide 93% fill factor for 6mm x 6mm SiPM

Photon Detection Efficiency (PDE)



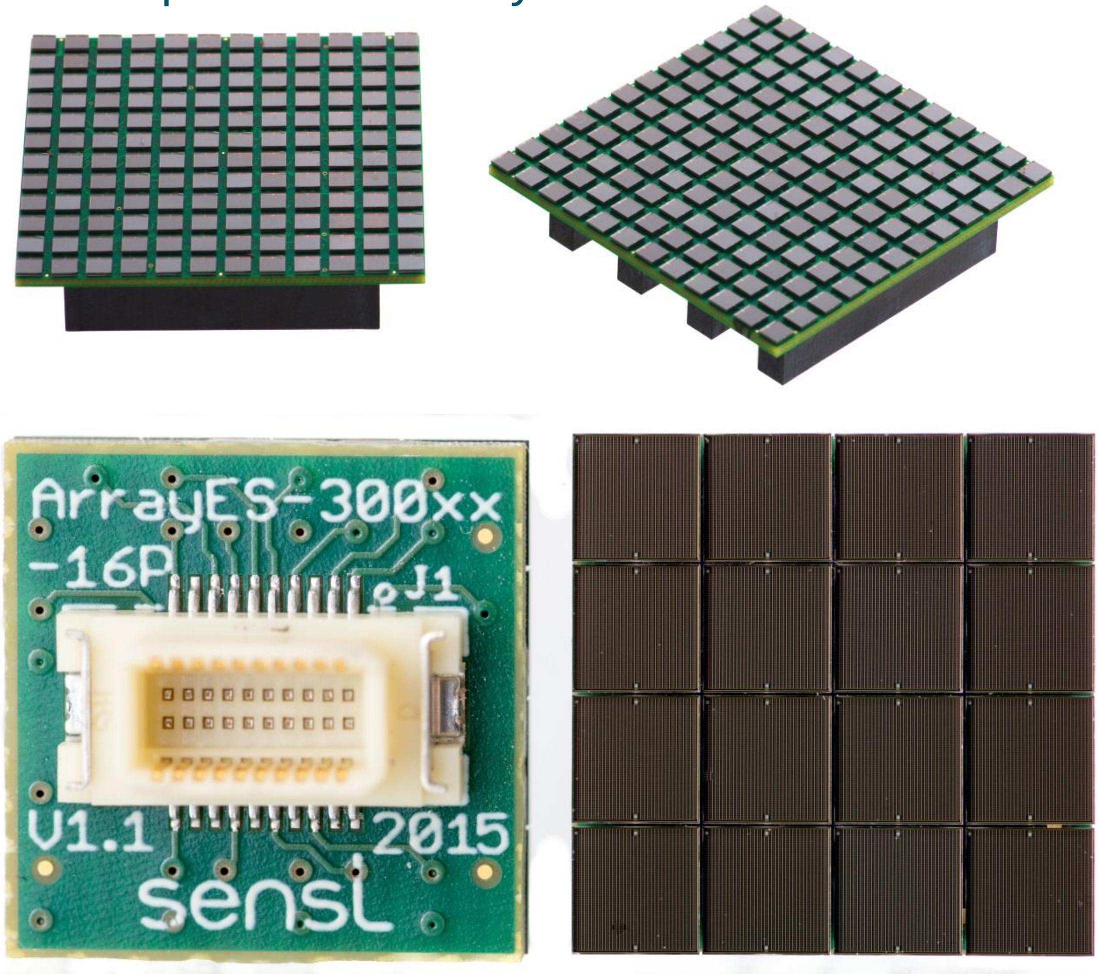
TSV Test Board – SMA Output

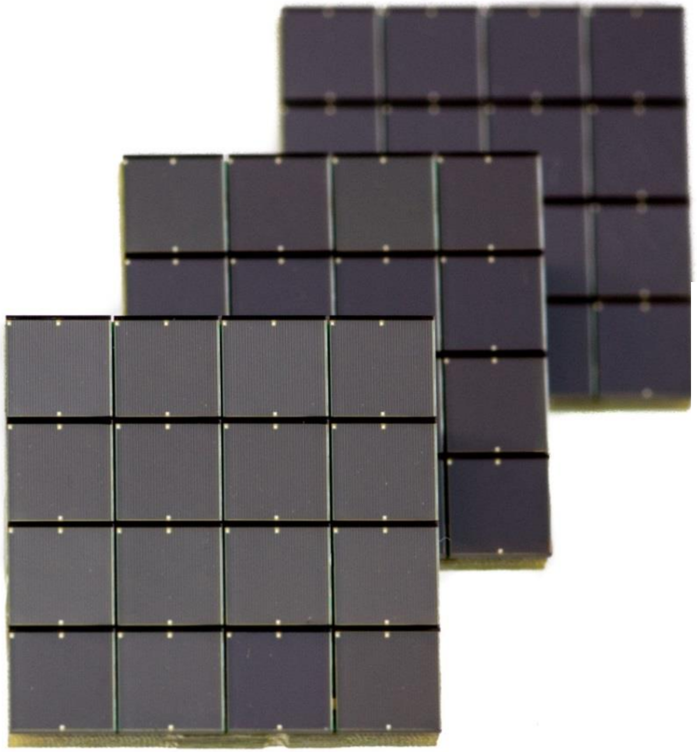


TSV glass has higher transmission compared to clear MLP at short wavelengths. No need for silicone resin.

TSV Arrays

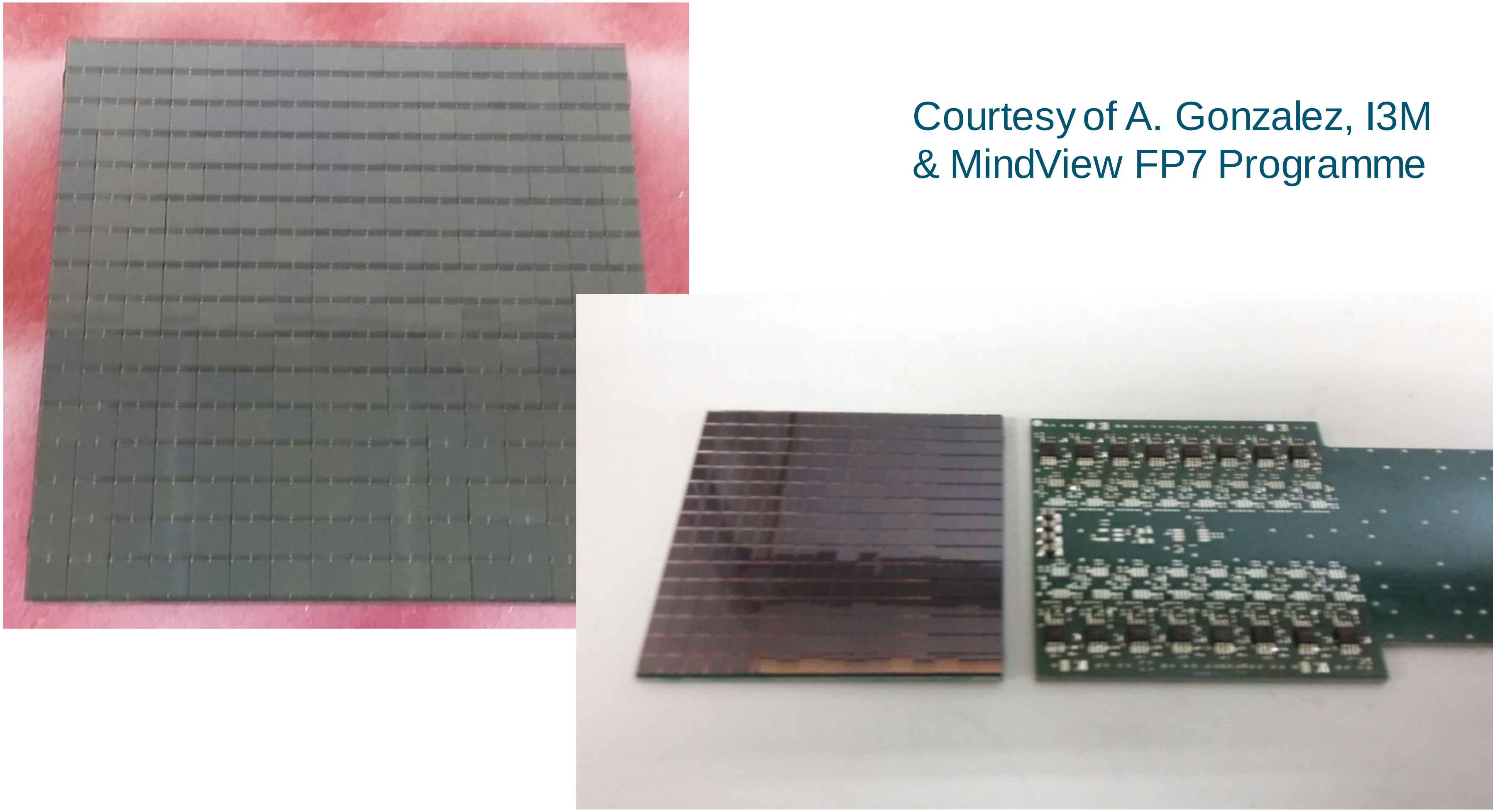
Low pitch 12x12 array of 3x3mm TSV SiPM





4x4 array of 3x3mm TSV SiPM

16x16 TSV Array (3mm x 3mm SiPM)



Courtesy of A. Gonzalez, I3M
& MindView FP7 Programme

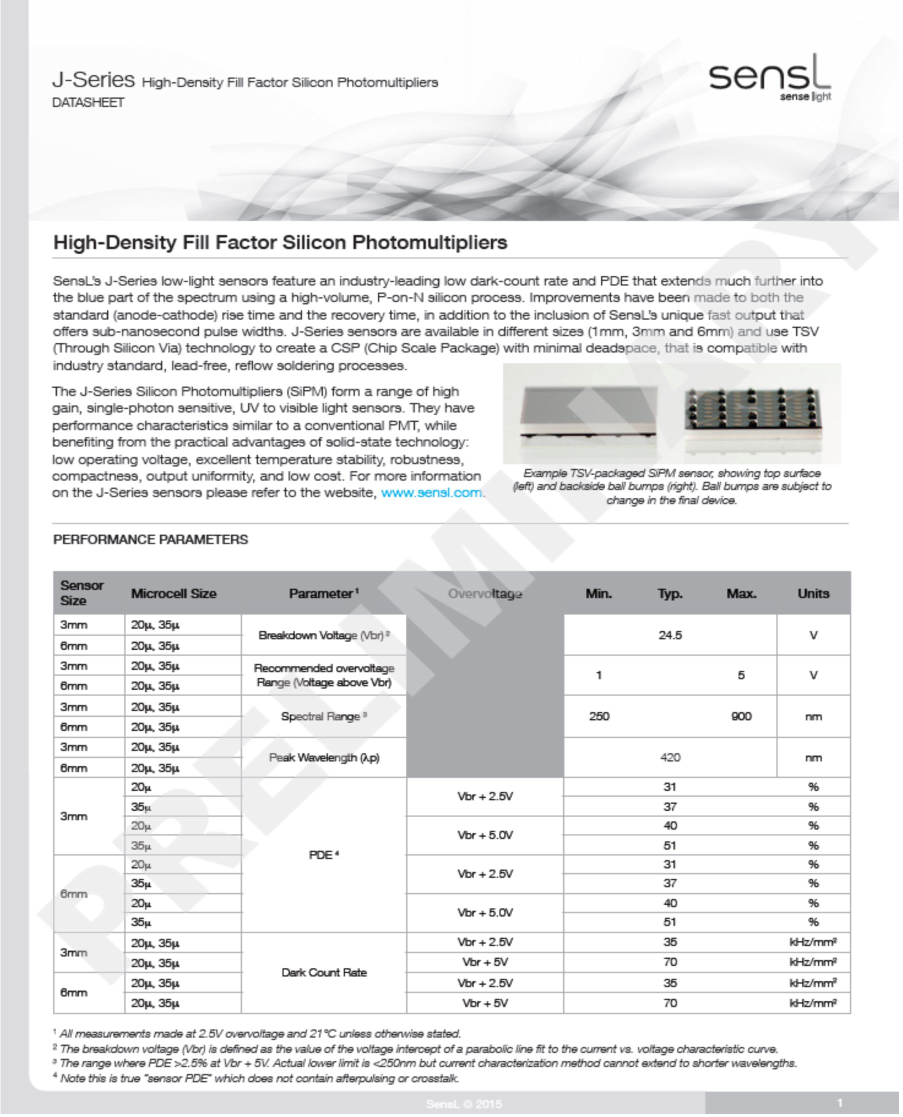
J-Series Overview

J-Series Preview

J-Series Silicon Photomultiplier Targets:

- Improved PDE (>50% target)
  - Improved microcell fill factor
- Improved cell recovery time
- Low time delay
- Faster rise time
- Low SPTR
- Low dark noise (<100kHz per mm^2)
- Low cross talk & afterpulsing
- TSV package
  - Improved array pitch – zero edge dead space
  - **MSL-1** (Moisture Sensitivity Level)
  - **MR-Compatible** (non-ferrous materials)
  - Enhanced UV transmission (for Cherenkov light)
  - Improved rise & recovery times

J-Series Preliminary Datasheet



J-Series High-Density Fill Factor Silicon Photomultipliers
DATASHEET

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High-Density Fill Factor Silicon Photomultipliers

SensL's J-Series low-light sensors feature an industry-leading low dark-count rate and PDE that extends much further into the blue part of the spectrum using a high-volume, P-on-N silicon process. Improvements have been made to both the standard (anode-cathode) rise time and the recovery time, in addition to the inclusion of SensL's unique fast output that offers sub-nanosecond pulse widths. J-Series sensors are available in different sizes (1mm, 3mm and 6mm) and use TSV (Through Silicon Via) technology to create a CSP (Chip Scale Package) with minimal deadspace, that is compatible with industry standard, lead-free, reflow soldering processes.

The J-Series Silicon Photomultipliers (SiPM) form a range of high gain, single-photon sensitive, UV to visible light sensors. They have performance characteristics similar to a conventional PMT, while benefiting from the practical advantages of solid-state technology: low operating voltage, excellent temperature stability, robustness, compactness, output uniformity, and low cost. For more information on the J-Series sensors please refer to the website, www.sensl.com.

Example TSV-packaged SiPM sensor, showing top surface (left) and backside ball bumps (right). Ball bumps are subject to change in the final device.

PERFORMANCE PARAMETERS

Sensor Size	Microcell Size	Parameter[1]	Overvoltage	Min.	Typ.	Max.	Units
3mm	20µ, 35µ	Breakdown Voltage (Vbr)[2]			24.5		V
6mm	20µ, 35µ						
3mm	20µ, 35µ	Recommended overvoltage Range (Voltage above Vbr)		1		5	V
6mm	20µ, 35µ						
3mm	20µ, 35µ	Spectral Range[3]		250		900	nm
6mm	20µ, 35µ						
3mm	20µ, 35µ	Peak Wavelength (λp)			420		nm
6mm	20µ, 35µ						
3mm	20µ	PDE[4]	Vbr + 2.5V		31		%
	35µ				37		%
	20µ		Vbr + 5.0V		40		%
	35µ				51		%
6mm	20µ		Vbr + 2.5V		31		%
	35µ				37		%
	20µ		Vbr + 5.0V		40		%
	35µ				51		%
3mm	20µ, 35µ	Dark Count Rate	Vbr + 2.5V		35		kHz/mm²
	20µ, 35µ		Vbr + 5V		70		kHz/mm²
6mm	20µ, 35µ		Vbr + 2.5V		35		kHz/mm²
	20µ, 35µ		Vbr + 5V		70		kHz/mm²

[1] *All measurements made at 2.5V overvoltage and 21°C unless otherwise stated.*
[2] *The breakdown voltage (Vbr) is defined as the value of the voltage intercept of a parabolic line fit to the current vs. voltage characteristic curve.*
[3] *The range where PDE >2.5% at Vbr + 5V. Actual lower limit is <250nm but current characterization method cannot extend to shorter wavelengths.*
[4] *Note this is true "sensor PDE" which does not contain afterpulsing or crosstalk.*

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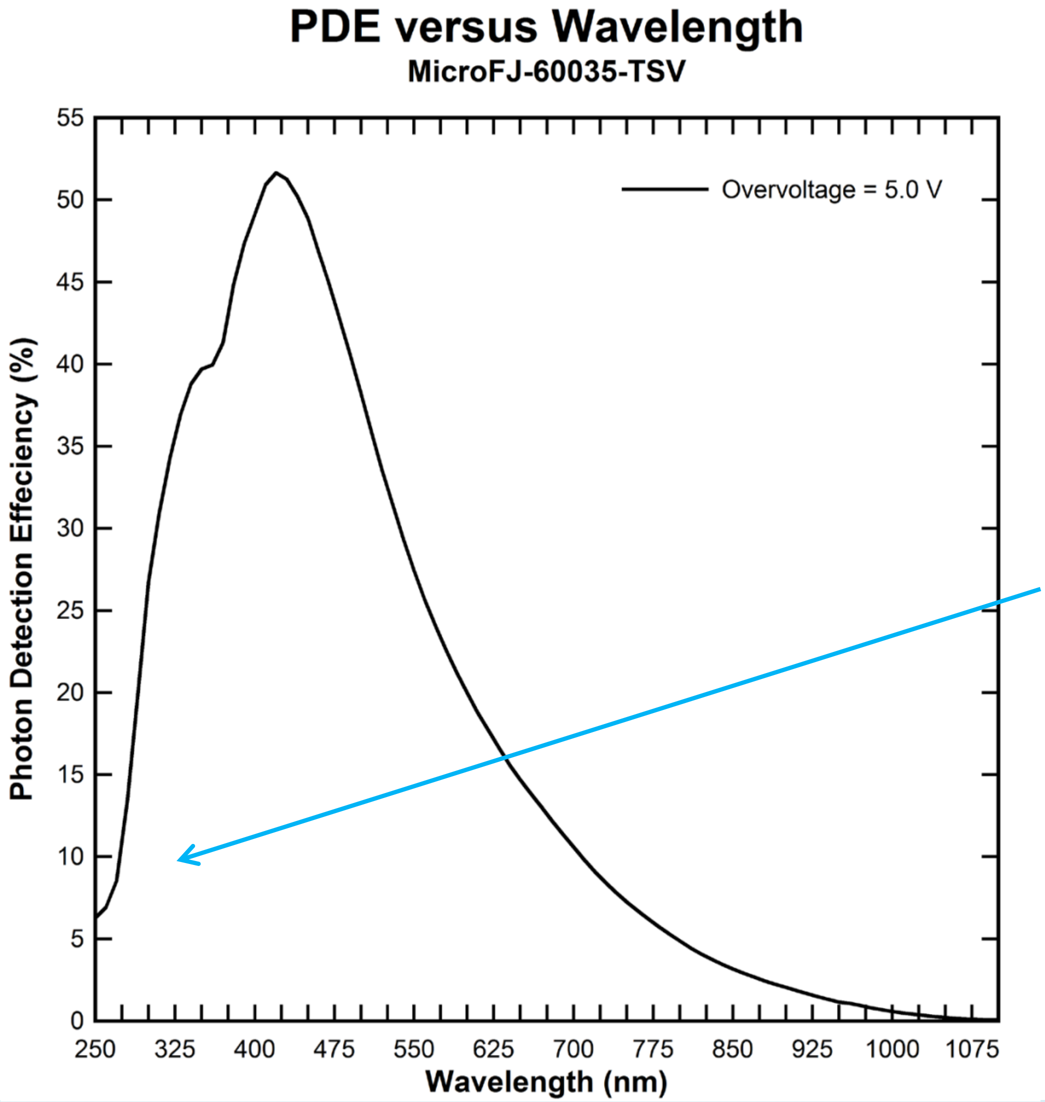
J-Series Preliminary Target Parameters



Short wavelength enhancements are achieved using glass – this enhances the device moisture sensitivity level to **MSL1** and avoids need for silicon resin / epoxy & enhances reliability

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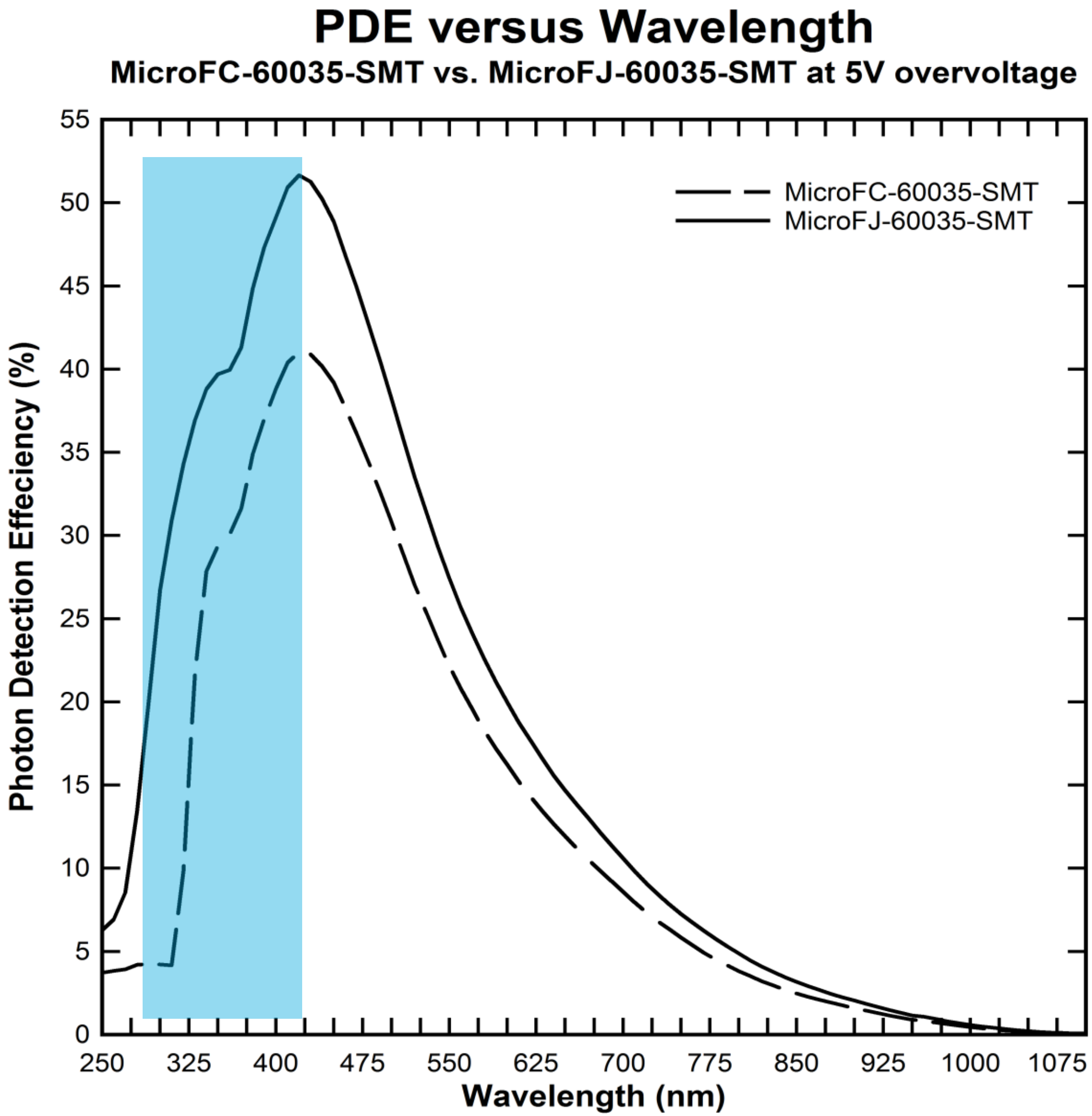
J-Series Preliminary Target parameters

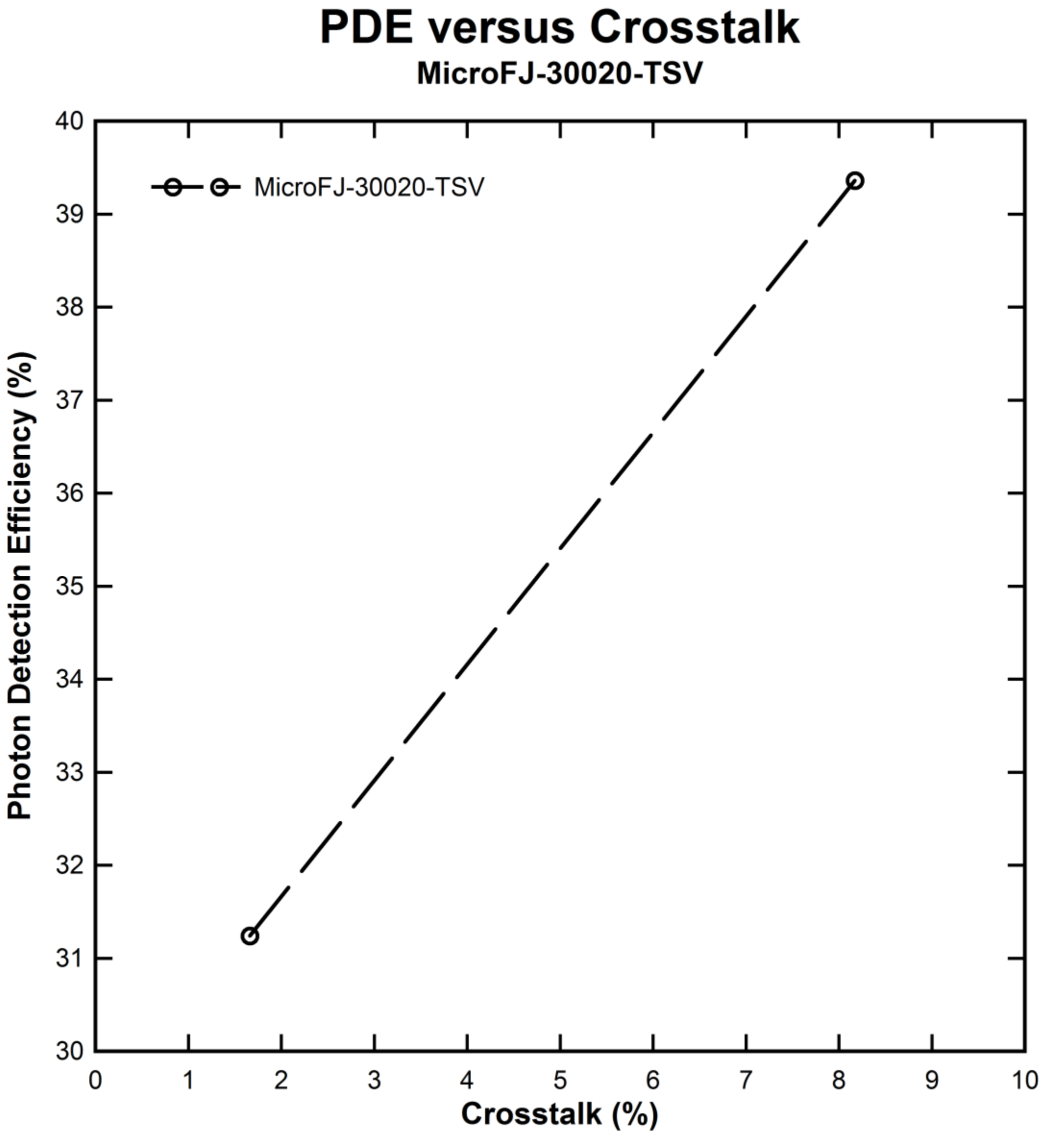


J-Series Preliminary Target parameters

20um cell

9% x-talk @
40% PDE

35ns cell
recovery time

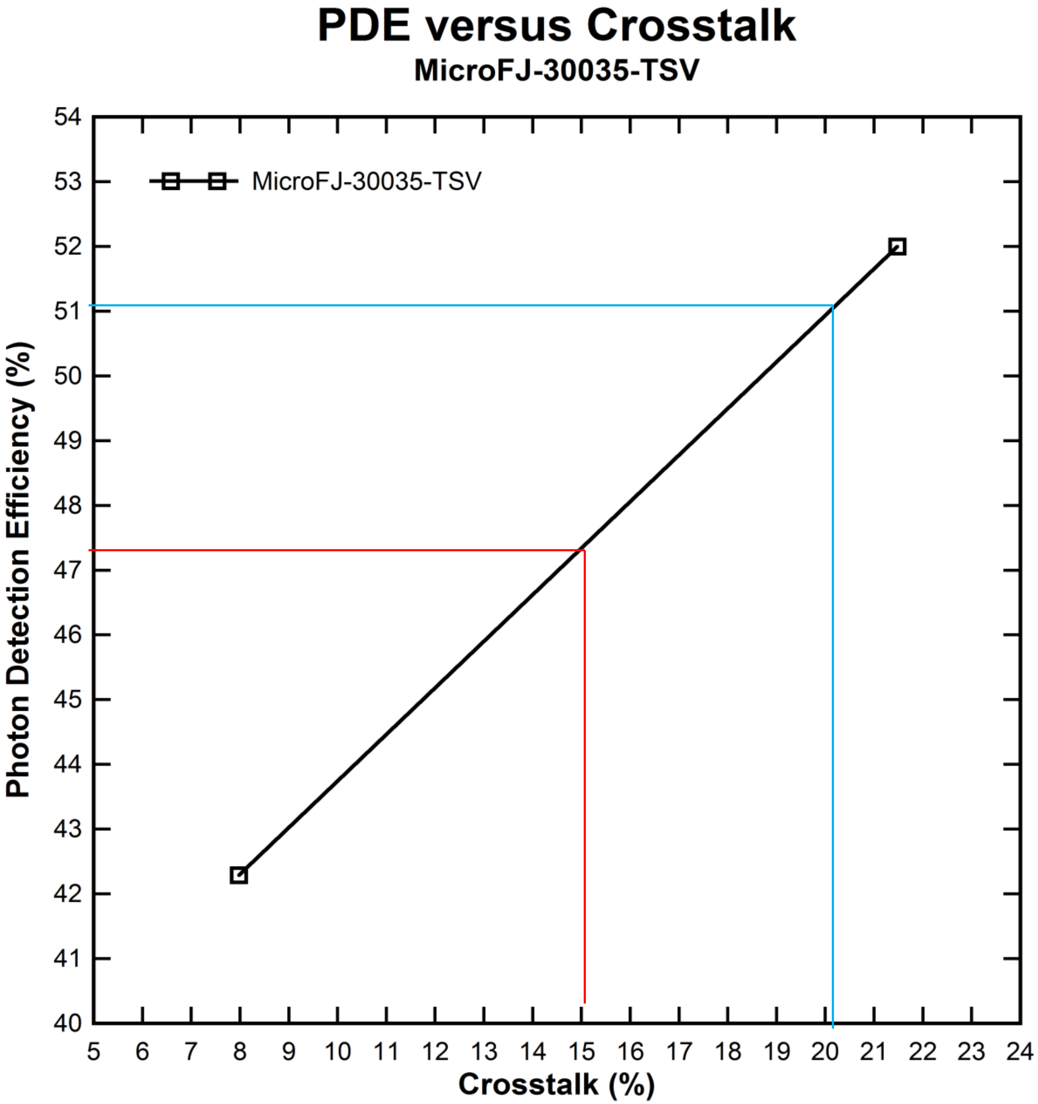


J-Series Preliminary Target parameters

35um cell

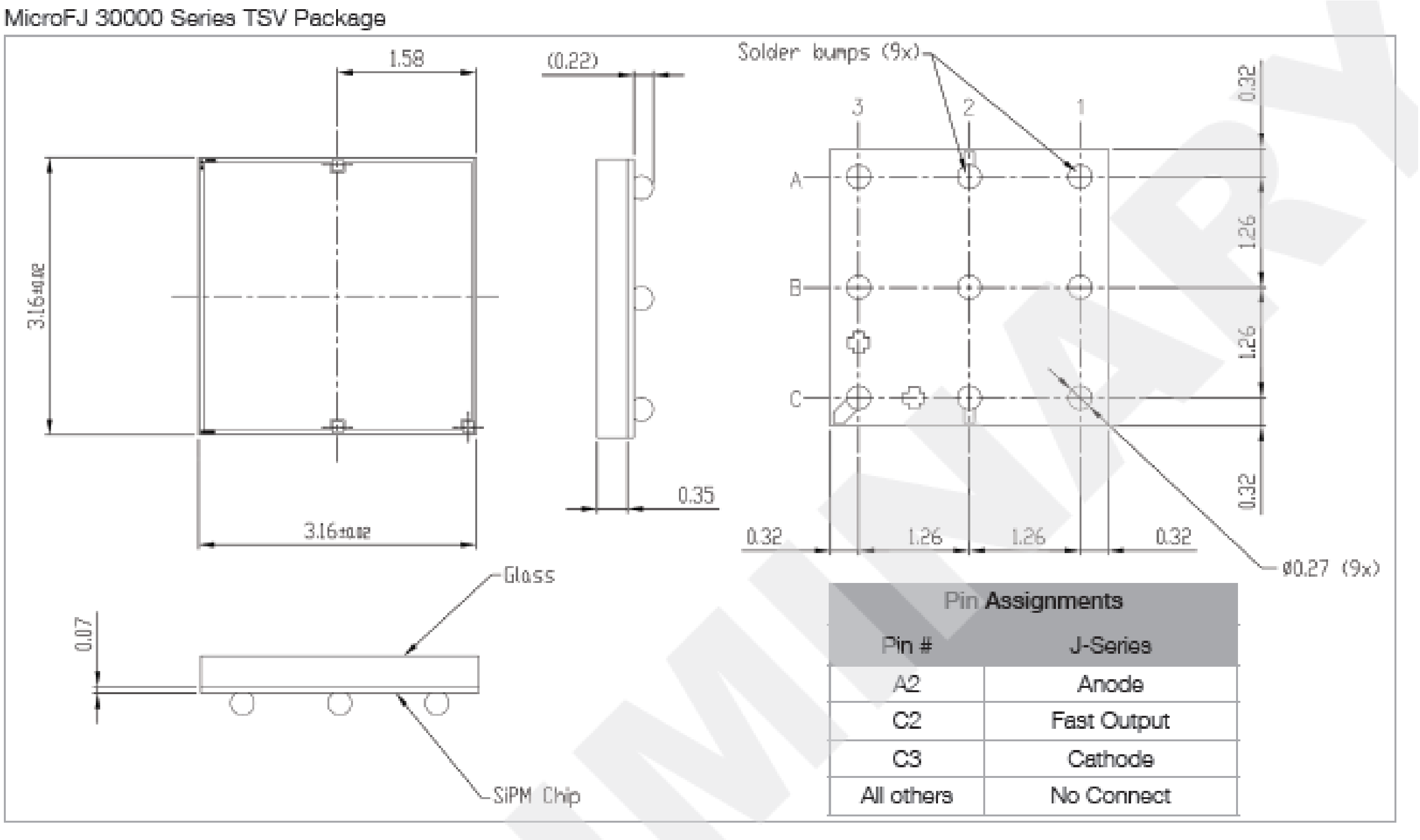
15% x-talk @
47% PDE

100ns cell
recovery time



TSV SiPM Design

MicroFJ 30000 Series TSV Package



Pin Assignments	
Pin #	J-Series
A2	Anode
C2	Fast Output
C3	Cathode
All others	No Connect

Wafer dicing saw accuracy allows for ± 20 µm edge tolerance

C versus J

	MLP-SMT 30020 C	TSV 30020 J
Rise Time (fast output, 10-90%)	600ps	300ps
Microcell Recovery time	90ns	35ns
DCR/mm^2 @ 2.5V over, 20C	30kHz	35kHz
Temp Dependency of Vbr per degree	21mV	21mV
Spectral range	300-800nm	250-900nm
Breakdown voltage	24.5	24.5
Package Size	4x4mm	3.16x3.16mm
Number of Microcells	10,998	14,256

J-Series Availability

- **Availability:**
  - 6x6mm (35um versions)
    - July 2015 – First products available on tray & on SMA boards
    - Engineering samples of 20um variant in July 2015
    - Tape & Reel: September 2015
    - Volume availability from October 2015

  - 3x3mm (20um & 35um versions)
    - Aug/Sept 2015 - 1st products available on tray & on SMA boards
    - Tape & Reel: Oct/Nov 2015
    - Volume availability from December 2015

Questions

- **Detector volumes – 100k approx. pieces (6x6mm)?**
- **Funding status of CTA**
- **Timelines:**
  - **Prototype completion & camera design(s) fixed**
  - **SiPM Target specification released to manufacturers (size, microcells, timing, PDE, x-talk….)**
  - **Vendor selection & procurement timeline**
  - **SiPM delivery timescale & logistics – shipment of *finished arrays or reels of detectors?***
    - ***If arrays – array target spec completion timeline***
- **Trade offs & compromises:**
  - **Best science versus commercial reality**
  - **PDE V's cross talk – PDE in isolation is not full picture – what x-talk can CTA tolerate?**
  - **Standard die size versus custom sizes**
  - **Fully integrated module – cost/volume commercial concerns and "one size does not fit all"**
- **Electronics & Readout Scheme: Discrete or ASIC:**
  - **Capability of electronics to handle range of bias supply voltages, capacitances etc.**
  - **Multi-vendor compatible**

- **Test sites:**
  - **MPI, S. Cruz, Gva/CERN, Catania, Leicester/Heidelberg/Nagoya, GATECH**
  - **"New" groups now testing?**
  - **"who's who"**

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Thank you!

john@sensl.com