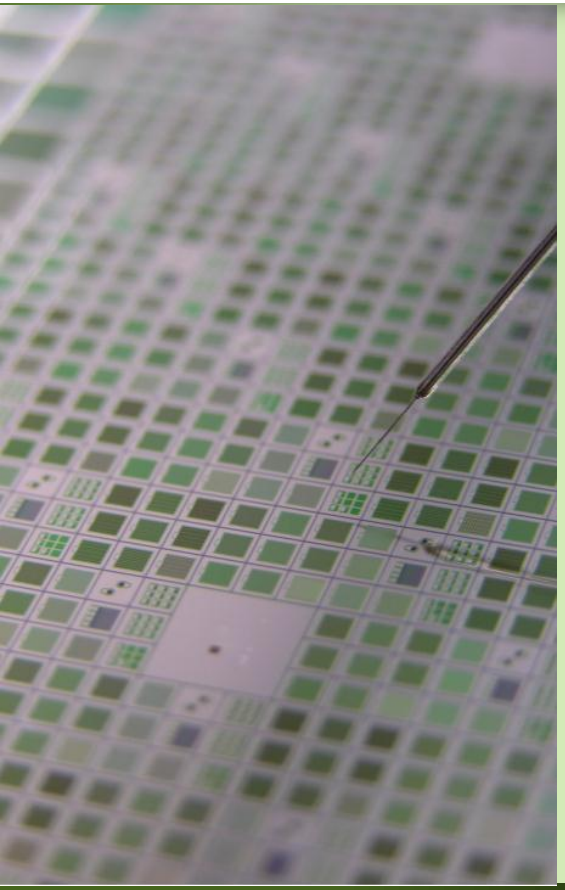
EXCELITAS TECHNOLOGIES



Low Dark Count UV-SiPM: Development and Performance Measurements

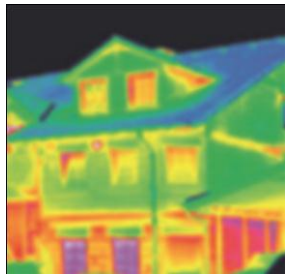
P. Bérard, M. Couture, P. Deschamps, F. Laforce
H. Dautet and A. Barlow

LIGHT 11
Workshop on the Latest Developments of Photon Detectors
Oct 31- Nov 4 2011, Ringberg Castle, Germany

ENGAGE. ENABLE. EXCEL.

Excelitas - Who we are

- Focused on delivering **innovative, customized optoelectronics** to OEMs seeking **high-performance,** market-driven technology solutions.
- 2010 revenues of over $300 million
- **3,000 employees** worldwide
- **13 global manufacturing locations** in North America, Europe, and Asia
- Operates under three business groups: Lighting, Detection, Advanced Electronic Systems (AES)
- Privately held (Veritas Capital), since Nov 2010
- Formerly part of PerkinElmer



50 years ago …

Robert John McIntyre
1928 - 1998

Robert J. McIntyre (RCA Electro Optics, Canada) presented his Theory of Microplasma Instability in Silicon in 1961, laying the basis for the development of the Geiger mode Silicon Avalanche Photodiode (G-SAPD).

R.J. McIntyre. “Theory of Microplasma Instability in Silicon”, *Journal of Applied Physics*, vol. 32, no. 6, pp. 983 – 995, 1961.

R.J. McIntyre. “On the avalanche initiation probability of avalanche diodes above the breakdown voltage”, *Electron Devices, IEEE Transactions on*, vol. 20 no. 7, pp. 637 – 641, 1973.

P. P. Webb, R. J. McIntyre, and J. Conradi, “Properties of avalanche photodiodes” *RCA Review ,* no. 35, pp. 234-278, 1974.

Today ……SPCM (Single Photon Counting Module)

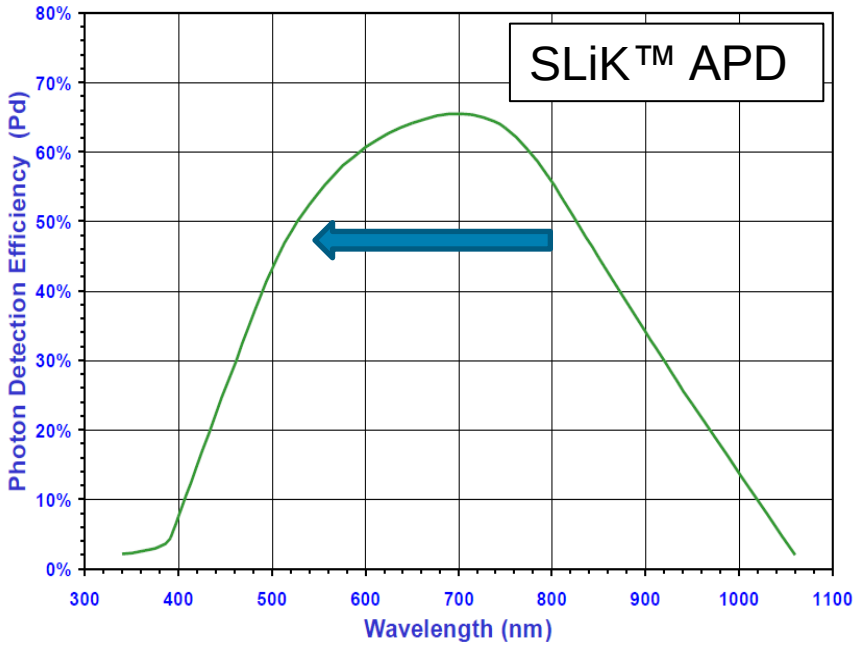
Self contained, SLiK™ APD based module which detects single photons ranging from 400 –1100nm.

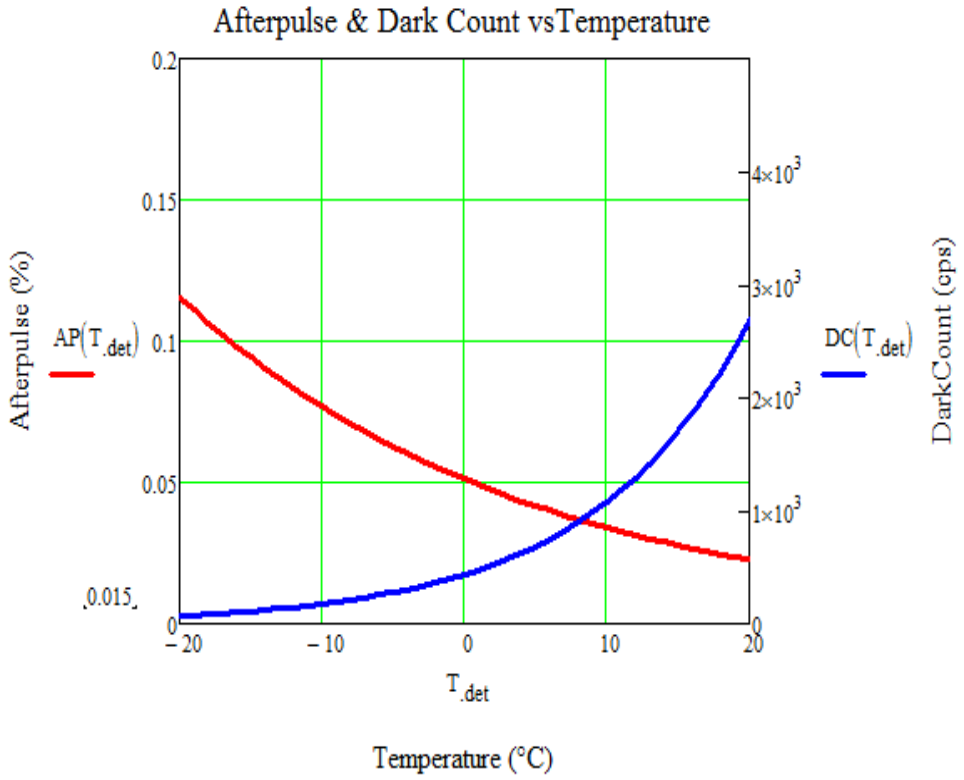
- Plug and play module with electronics integrated
- Includes thermoelectric cooler
- Includes quenching circuit
- Digital output

- **Large Active diameter :180 µm**
- **Photon detection efficiency (PD) @ 700nm : 65 %**
- **Dark Count Average : 200 cps @ -10°C and 20V OV**
- **Timing resolution Typ. : < 200-350 ps**
- Maximum count rate : 30 Mcps
- Dead time : 20 ns
- After pulse probability : 0.5 %

From SPCM to SiPM

Develop an UV-enhanced SiPM





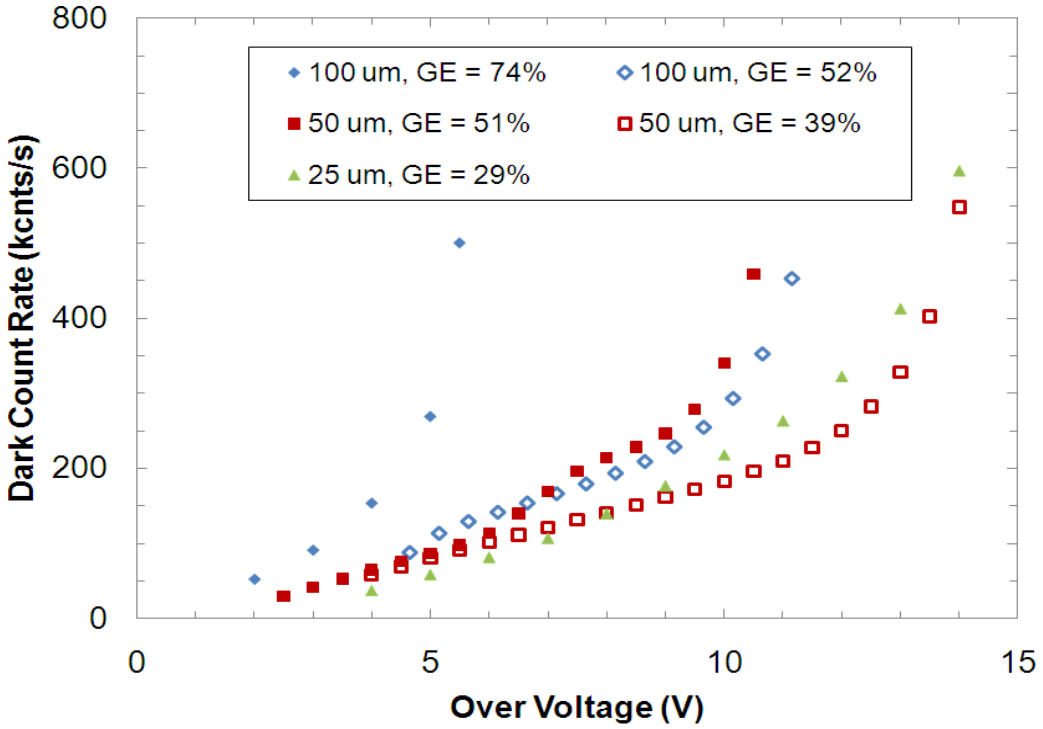
Improve photon detection efficiency around 400 nm while maintaining low dark count and tile-up an array of smaller pixels

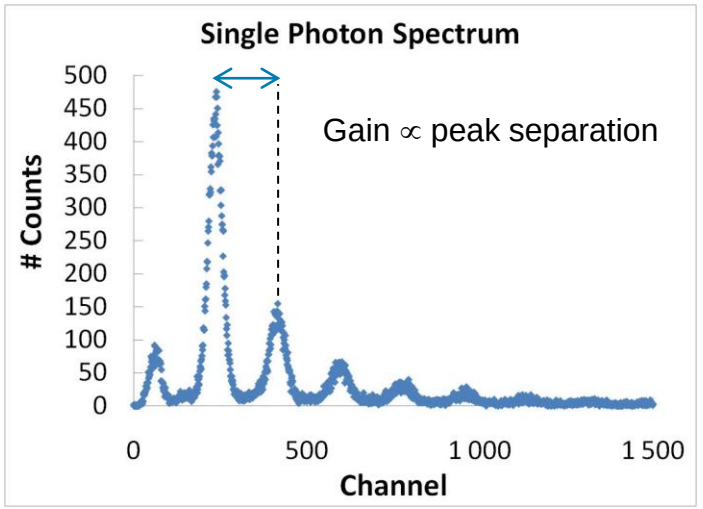
Addressing the needs of molecular imaging and high energy physics communities

EXCELITAS TECHNOLOGIES

Use our long experience to build the best SiPM possible

1st Generation SiPM, 2011 – highlights (1)





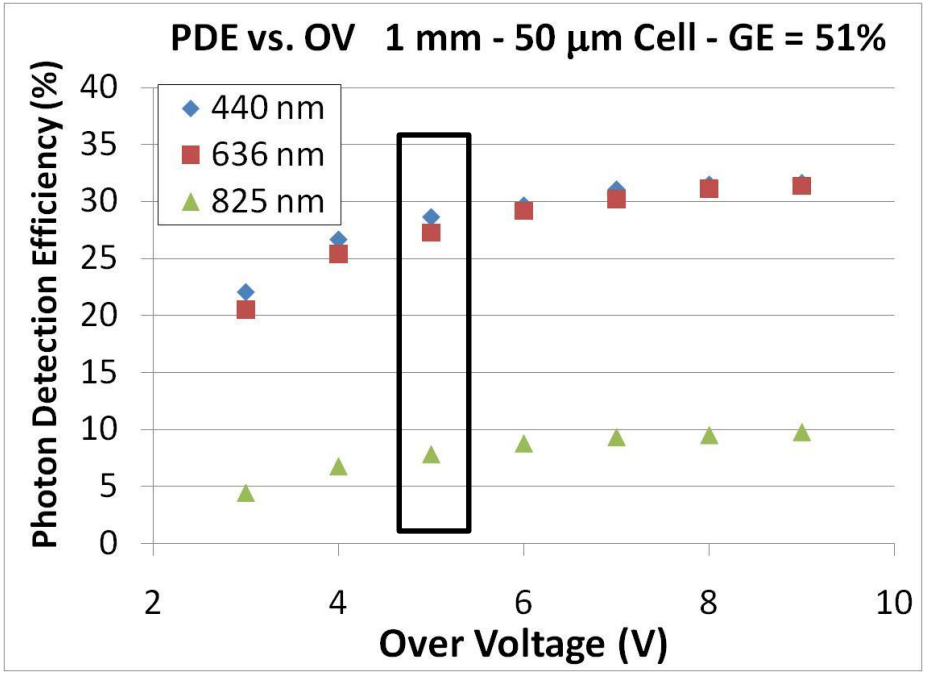
Low Dark Count (25 C)

P. Bérard et al. "Characterization study of a new UV-SiPM with low dark count rate", *2011 NDIP Conference Record, NIMA*

A Barlow, J Schilz, *"SiPM developments", SiPM Matching Event, CERN, 16-17 Feb 2011*

EXCELITAS TECHNOLOGIES

1st Generation SiPM, 2011 – highlights (2)
SiPM PDE in Photon Counting Mode



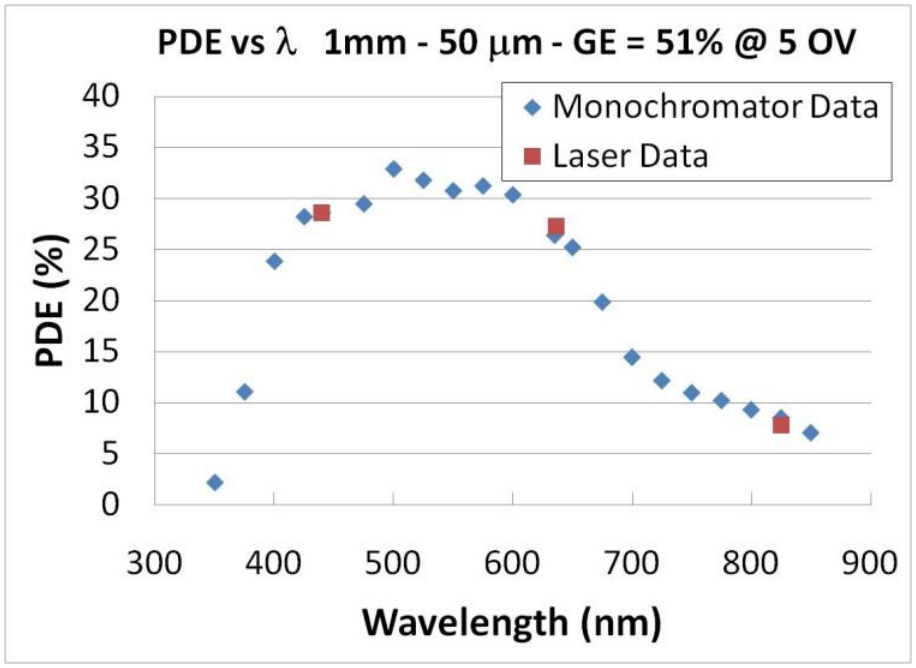
Responsivity obtained with monochromator rescaled to photon counting data points

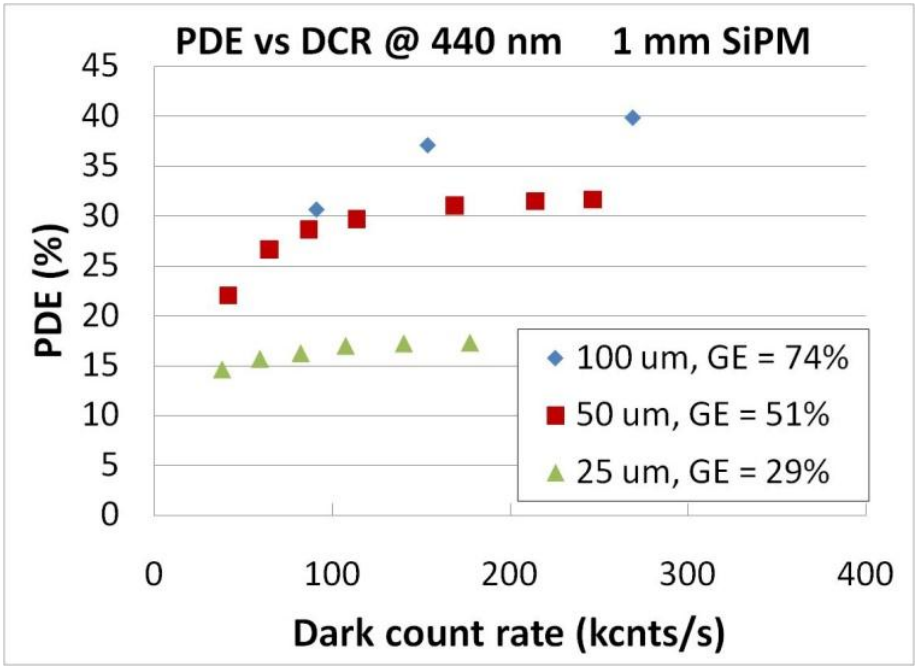
Wide spectral response

P. Eckert *et al.* Characterisation studies of silicon photomultipliers, Nucl. Instr. and Meth. A 620 (2010), pp. 217-226.

EXCELITAS TECHNOLOGIES

1st Generation SiPM, 2011 – highlights (3)





Broad responsivity spectrum

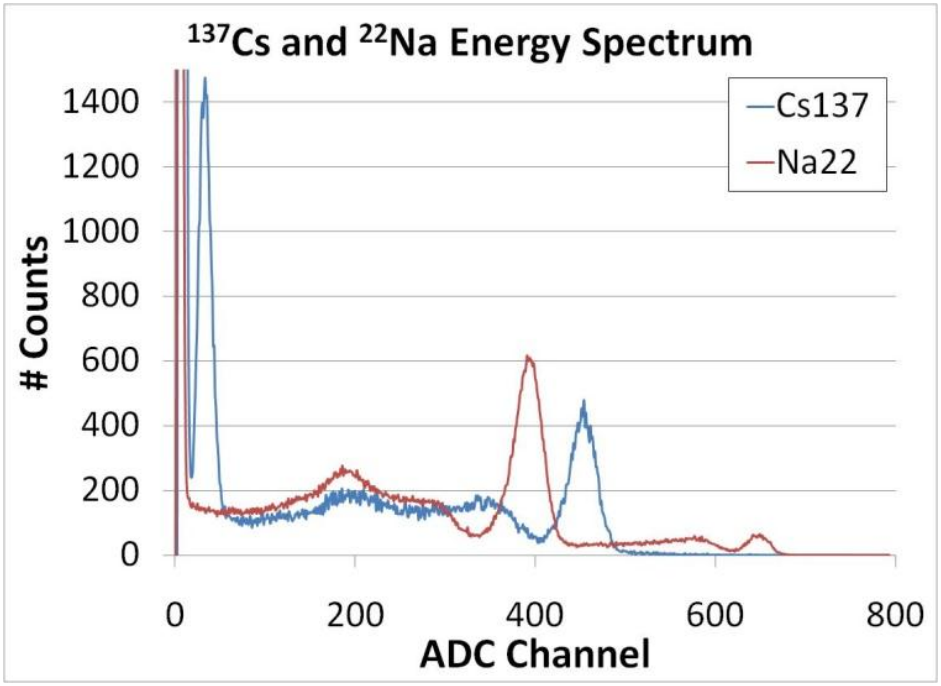
Low dark count even when PDE saturates

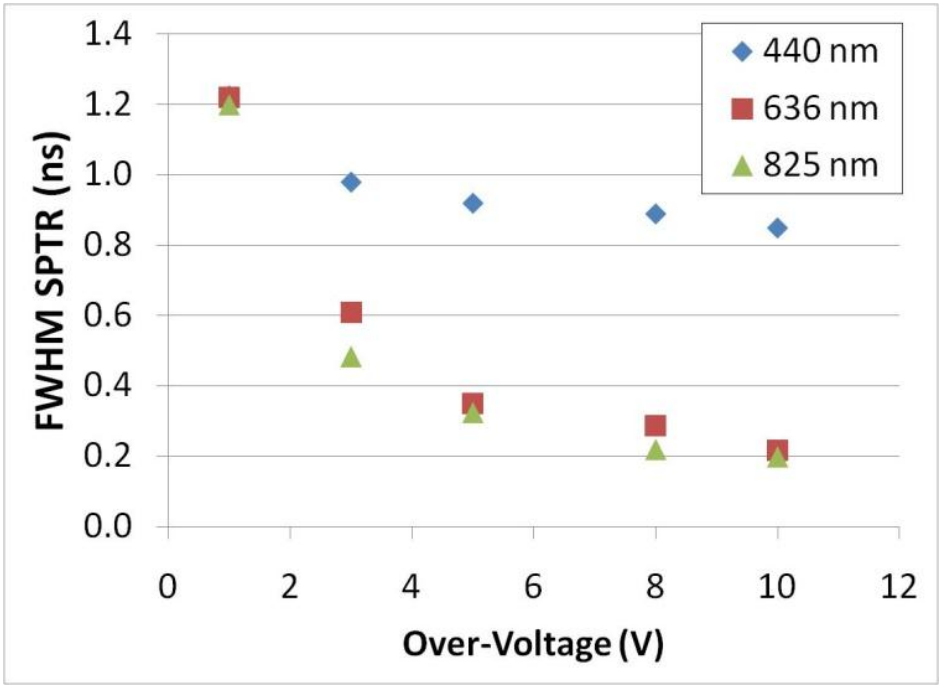
P. Bérard et al. "Characterization study of a new UV-SiPM with low dark count rate", ***2011 NDIP Conference Record, NIMA***

A Barlow, J Schilz, ***"SiPM developments", SiPM Matching Event, CERN, 16-17 Feb 2011***

EXCELITAS TECHNOLOGIES

1st Generation SiPM, 2011 – highlights (4)





13.5 % at 511 keV

Non-optimized SPTR at 440 nm

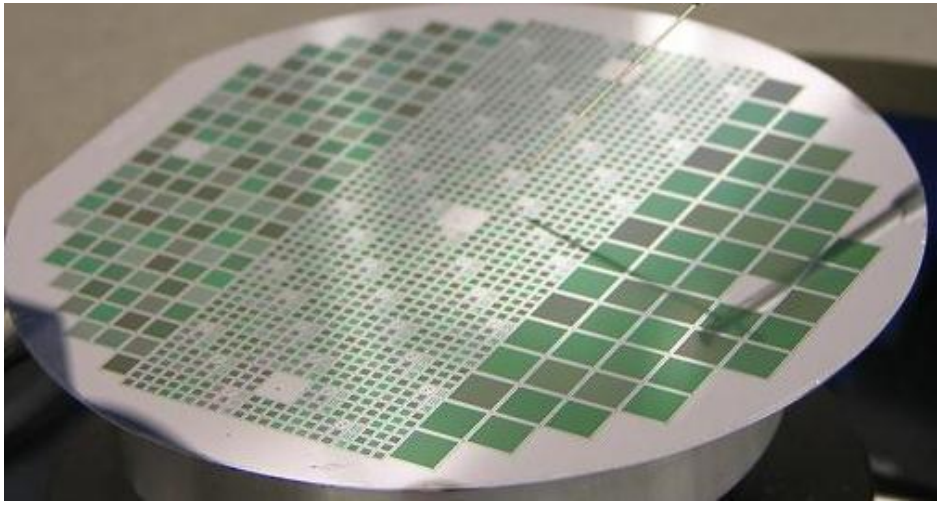
P. Bérard et al. "Characterization study of a new UV-SiPM with low dark count rate", *2011 NDIP Conference Record, NIMA.*

EXCELITAS TECHNOLOGIES

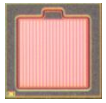
2nd Gen SiPM- towards optimization of overall SiPM performance

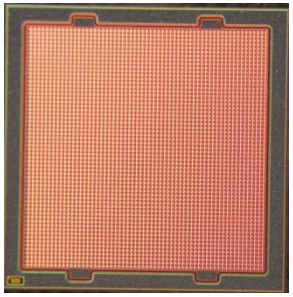
SiPM dimension : - 1 mm x 1 mm
- 3 mm x 3 mm
- 5 mm x 5 mm

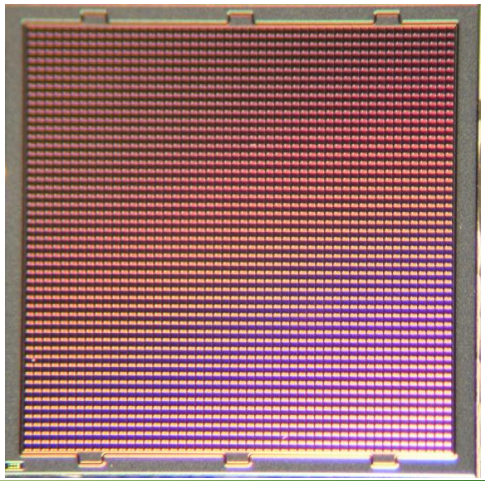
Cell dimension : - 25 µm x 25 µm
- 50 µm x 50 µm
- 100 µm x 100 µm



Geometrical efficiencies (GE) ranging from 74% to 29 % depending on pixel size

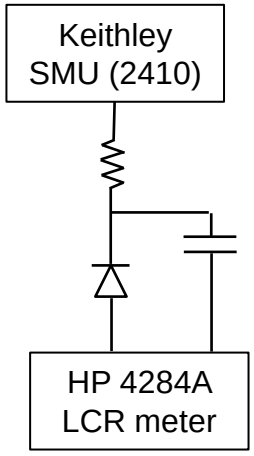


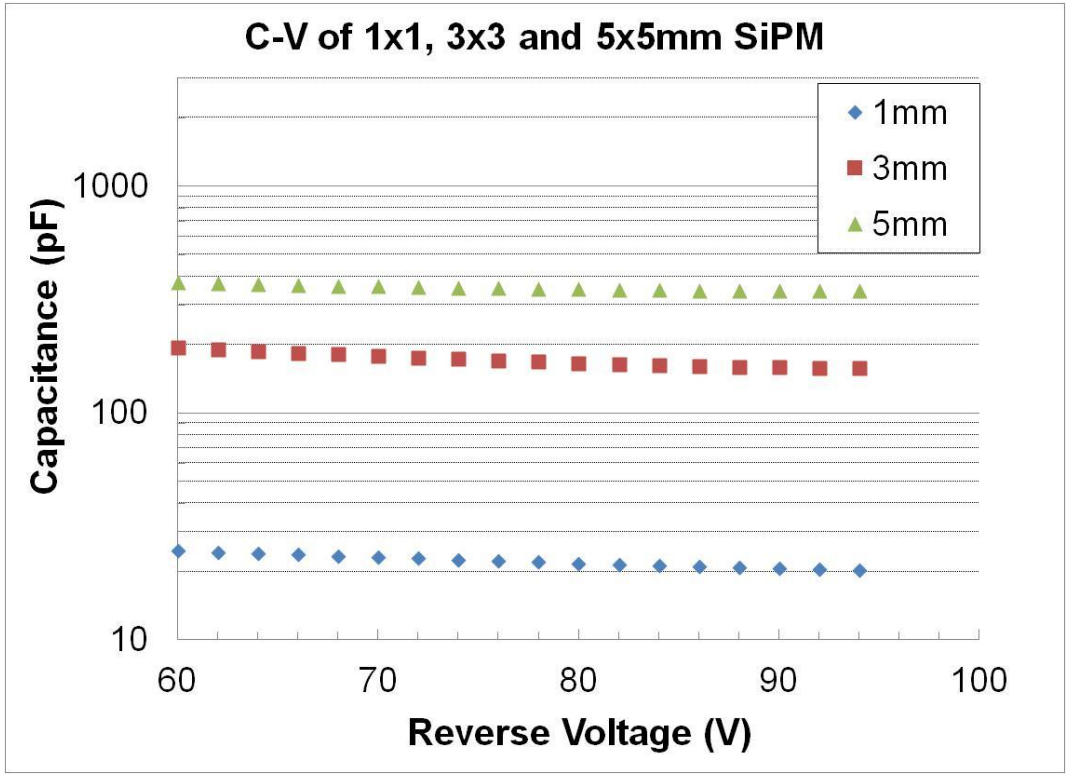




EXCELITAS TECHNOLOGIES

SiPM Capacitance- we trade-off some parameters





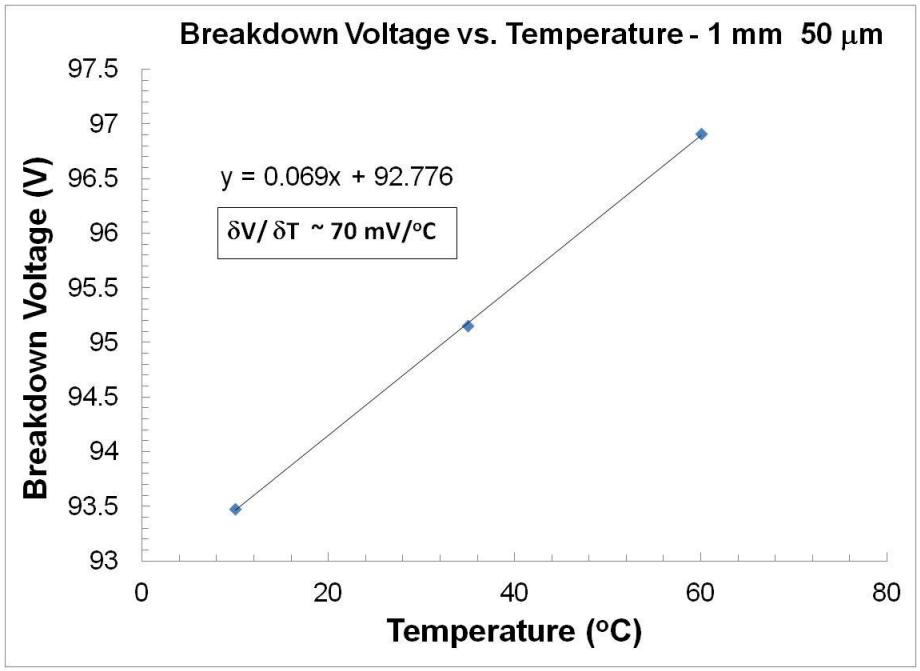
1st Generation Capacitance
- 1 x 1 mm : 12 pF
- 3 x 3 mm : 93 pF
- 5 x 5 mm : 255 pF

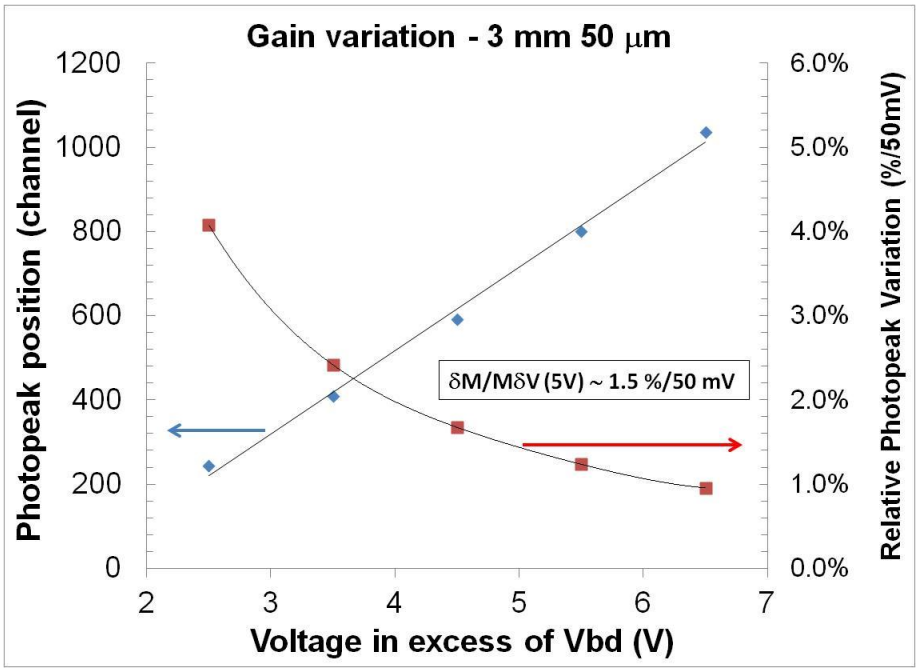
2nd Generation Capacitance
- 1 x 1 mm : 21 pF
- 3 x 3 mm : 158 pF
- 5 x 5 mm : 345 pF

<~20 pF/mm²
Low capacitance

EXCELITAS TECHNOLOGIES

SiPM Breakdown Voltage – Gain – Temperature dependence





1st Generation

V_{bd} ~ 140 – 150 V
δV/ δT ~ 130 mV/°C
$\frac{1}{M}\frac{\delta M}{\delta V}(5V)$ ~ 1%/50 mV
$\frac{1}{M}\frac{\delta M}{\delta T}(5V)$ ~ 2.6%/°C

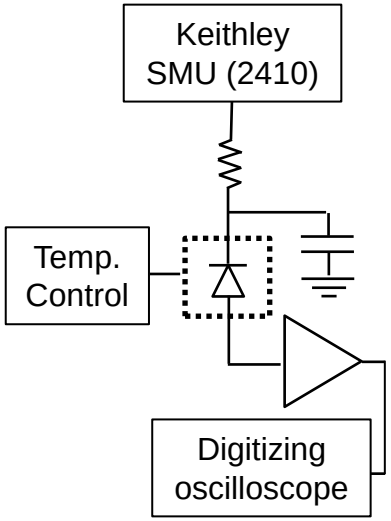
2nd Generation

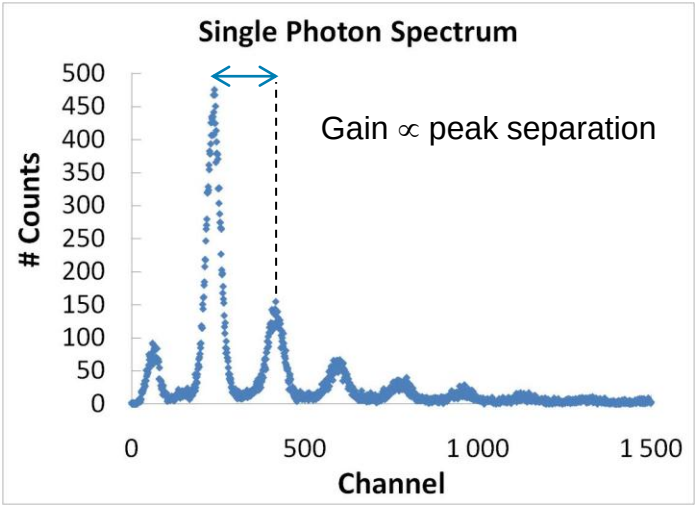
V_{bd} ~ 90 – 100 V
δV/ δT ~ 70 mV/°C
$\frac{1}{M}\frac{\delta M}{\delta V}(5V)$ ~ 1.5%/50 mV
$\frac{1}{M}\frac{\delta M}{\delta T}(5V)$ ~ 2.1%/°C

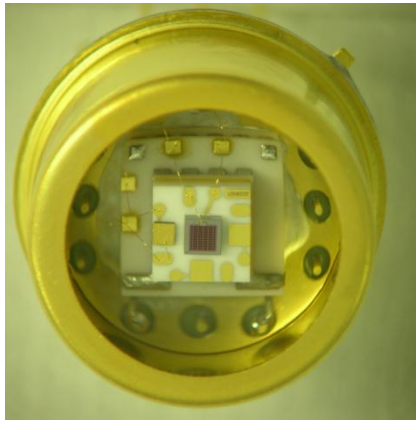
Low sensitivity to voltage and temperature eases SiPM operation

EXCELITAS TECHNOLOGIES

SiPM Breakdown Voltage – Gain – Temperature dependence



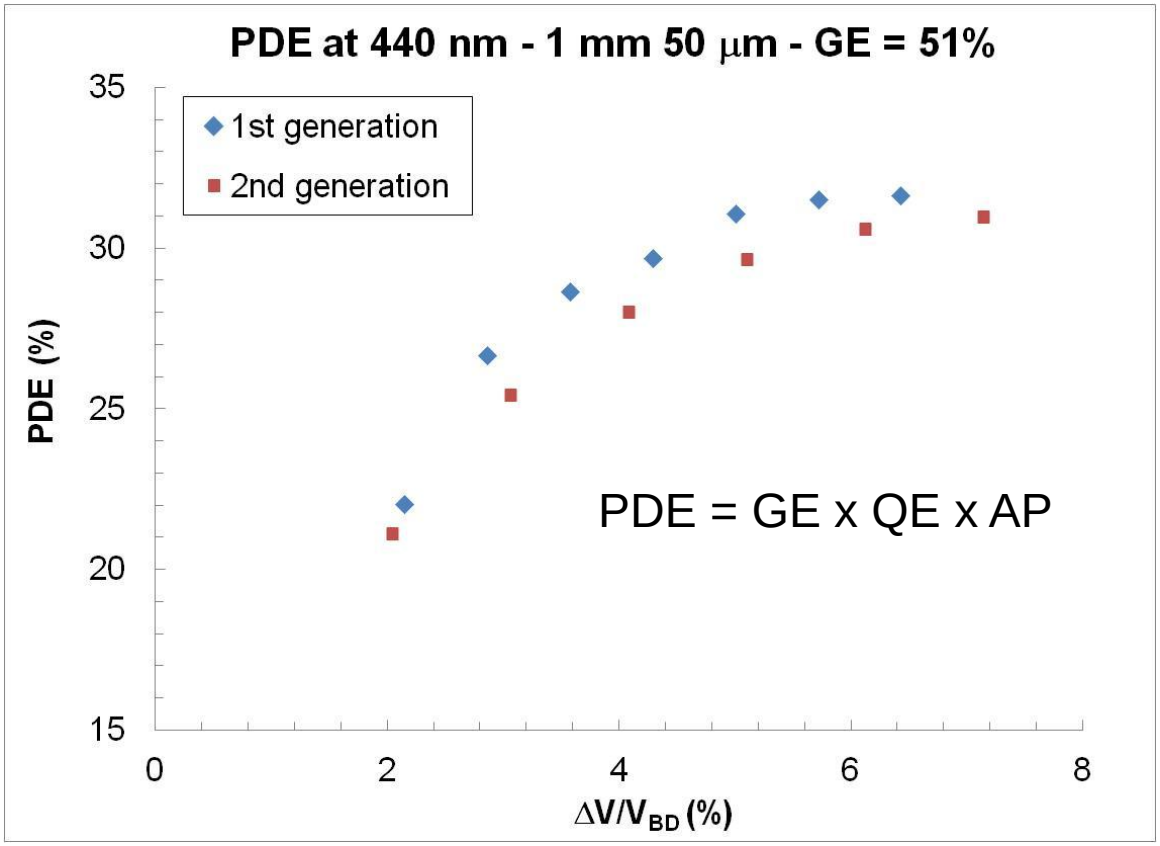




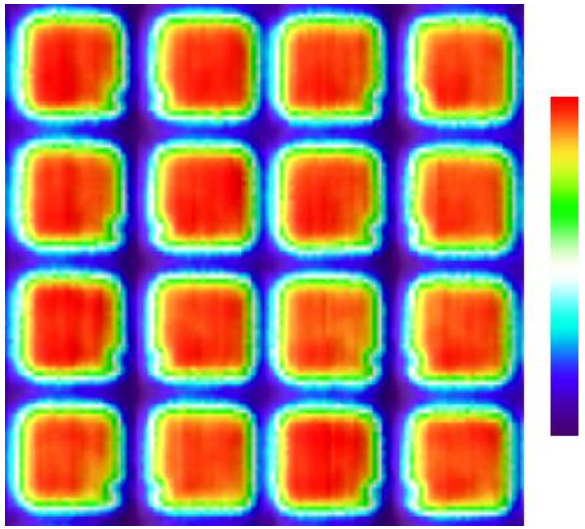
EXCELITAS TECHNOLOGIES

PDE

PDE Measurement obtained in photon counting mode



Zoom of 1 mm 50 μm
SiPM chip with GE = 51%

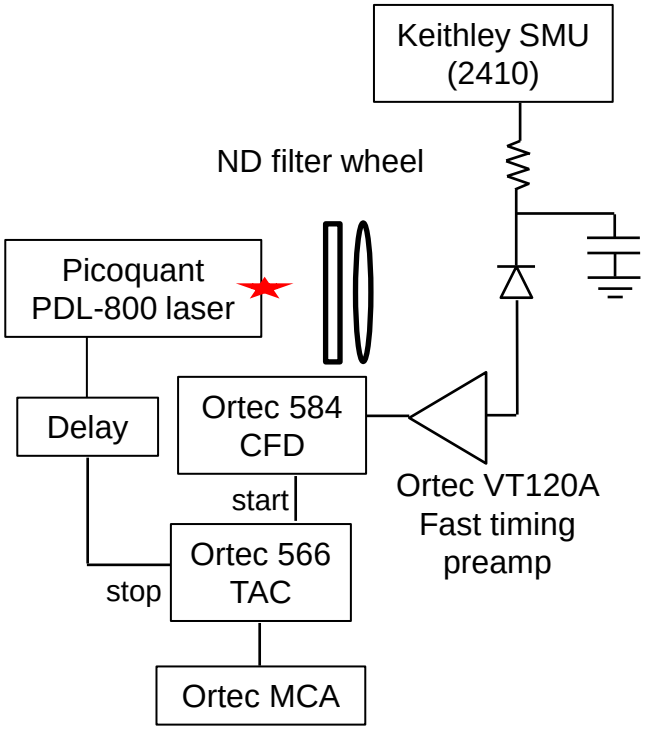


Vop ~ 6 - 8 V

Vop ~ 5 - 6 V

EXCELITAS TECHNOLOGIES

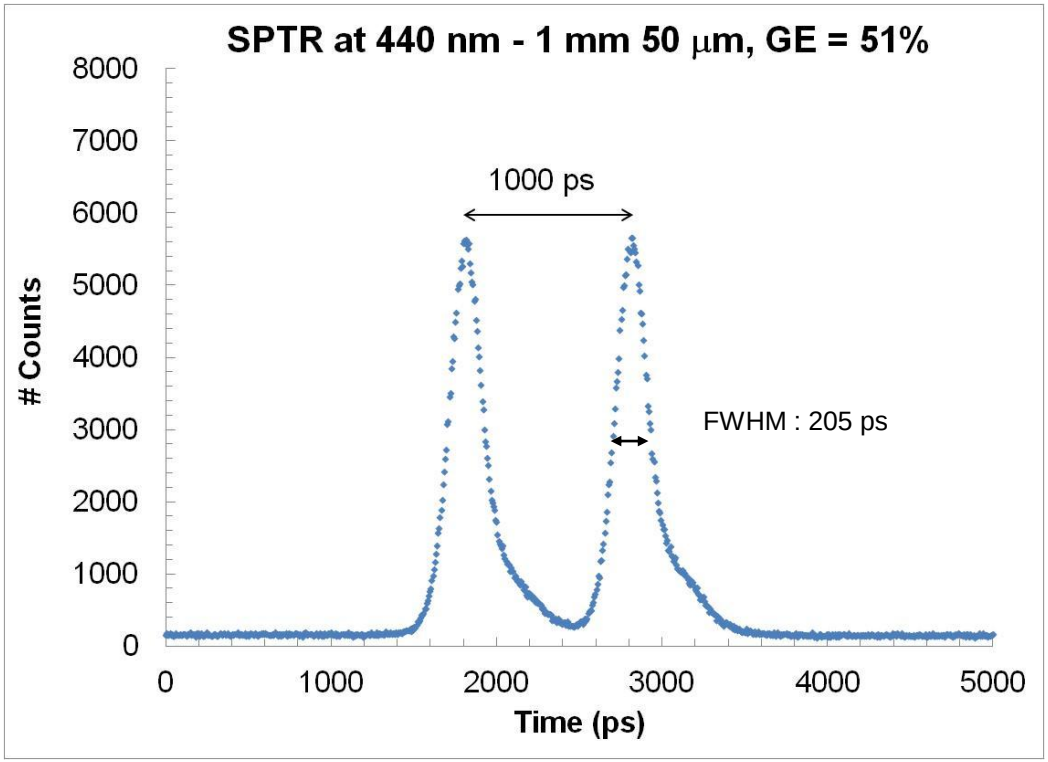
SiPM Single Photon Timing Resolution- major progress



Laser output adjusted to meet single photon counting requirements

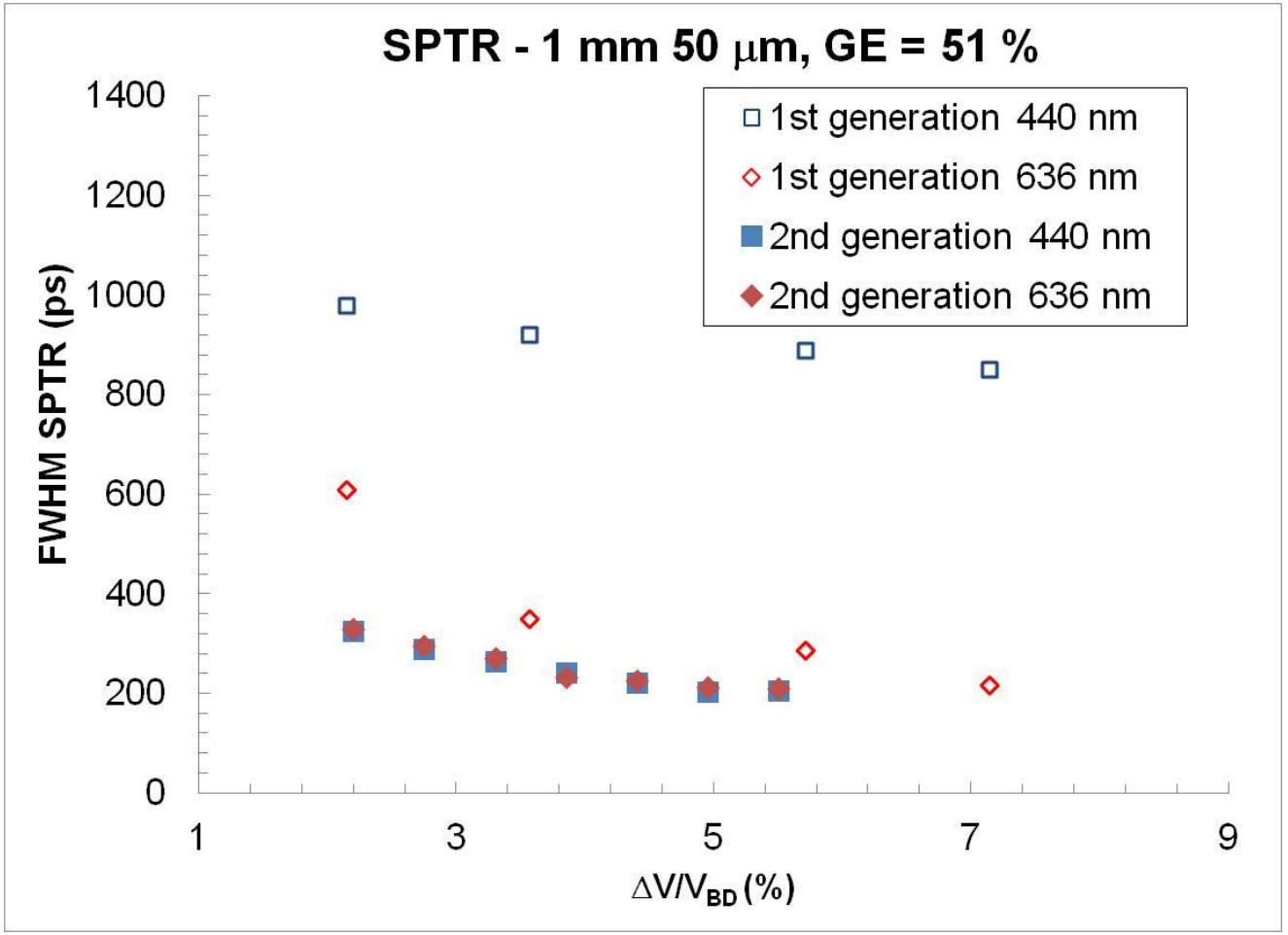
Optics to focus <20 um light spot on one single cell.

Picoquant laser head : 440 and 636 nm, jitter < 70 ps.



EXCELITAS TECHNOLOGIES

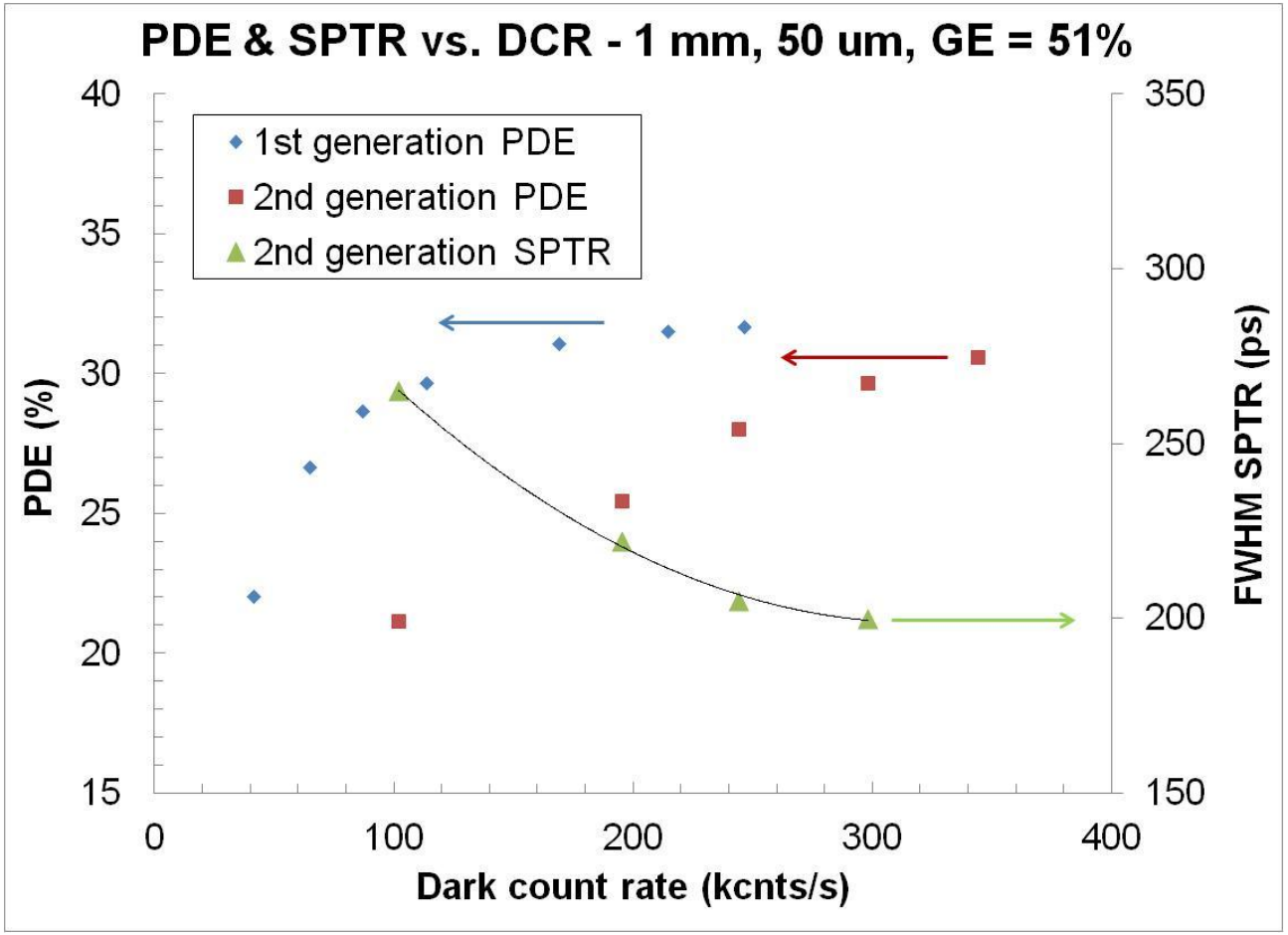
SiPM Single Photon Timing Resolution



Main objective of reaching ~200 ps FWHM SPTR at 440 nm achieved

EXCELITAS TECHNOLOGIES

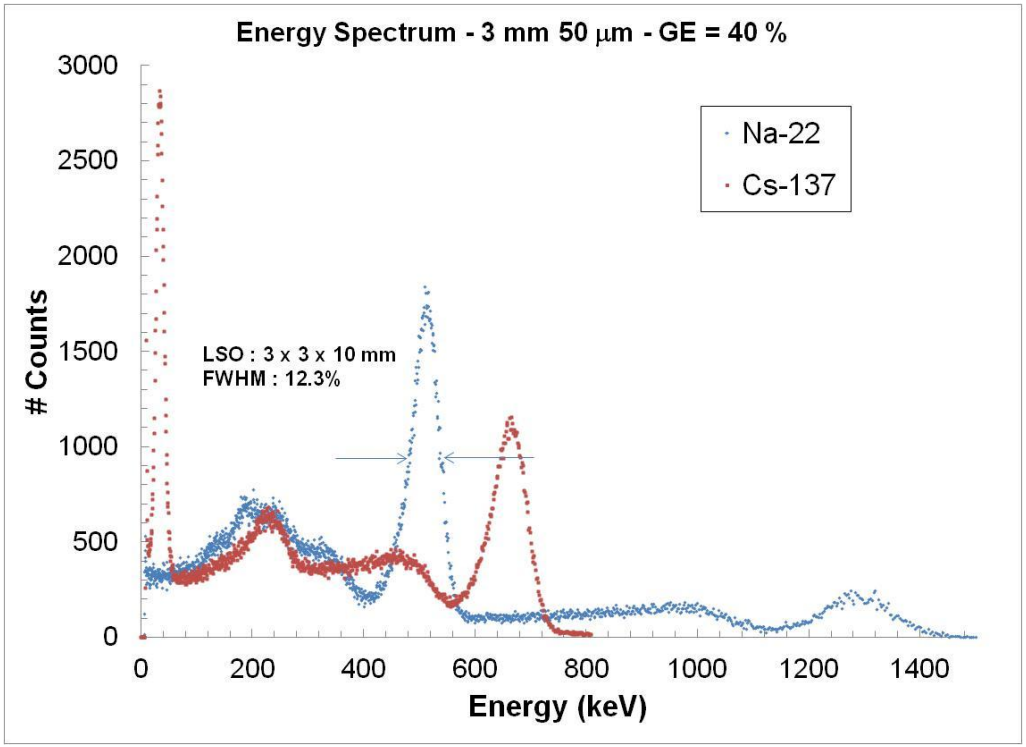
PDE and SPTR vs. Dark count rate



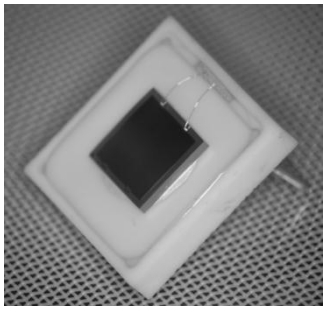
PDE and SPTR optimized at low dark count

EXCELITAS TECHNOLOGIES

SiPM Energy Resolution



3 x 3 mm, 50 um pixels, GE = 40 %



^{22}Na and ^{137}Cs : 32, 511, 662 and 1275 keV
- Correction for non-linearity

3 x 3 x 10 mm LSO
- Wrapped in Teflon
- Optically coupled with Bicron optical grease

2nd Gen SiPM- Performance Summary Table

Parameter (unless indicated otherwise, all measurements taken at Vop and 25°C)	Symbol	C30742-50-1	C30742-50-3	C30742-50-5	Unit
Active area	-	1x1	3x3	5x5	mm
# of pixels	-	400	3600	10000	-
Pixel size	-	50			µm
Geometrical Efficiency	GE	40 - 51			%
Spectral response range	λ	375-800			nm
Peak sensitivity wavelength	λ_p	475			nm
Photon detection efficiency at 440nm [1]	PDE	25 - 30			%
Operating voltage range [2]	V_{op}	90-100			V
Dark count [3]	DCR	200-500			kcps
Terminal Capacitance	C_t	20	175	425	pF
Timing (FWHM) at 440nm with laser	SPTR	200 - 225			ps
Gain	M	$1.5x10^6$			-
Temperature coefficient of Vbr	$T_c = \delta V/\delta T$	70			mV/°C
Gain variation with over-voltage	$\delta M/M\delta V$	1.2			%/50mV
Gain variation with temperature	$\delta M/M\delta T$	1.7			%/°C
Crosstalk [4]	X_t	30 - 40			%
Quench resistor	R_Q	1.0-1.5			MΩ

Notes :

1) Cross-talk and afterpulse are not included in PDE.
2) Vop = Vb + 5V.
3) DCR measured at 0.5 p.e. level.
4) No cross-talk suppression implemented.

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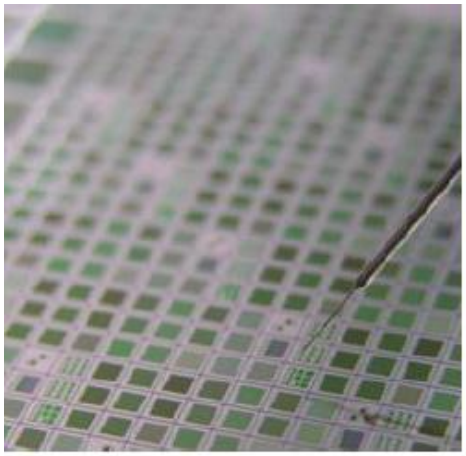
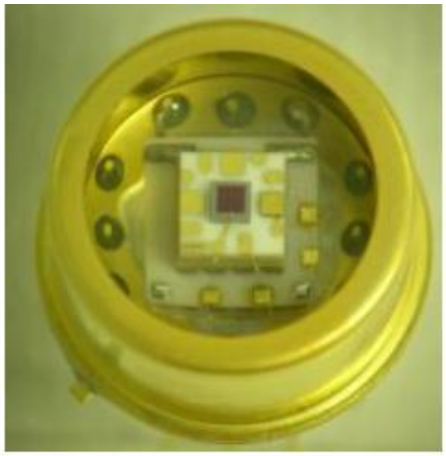
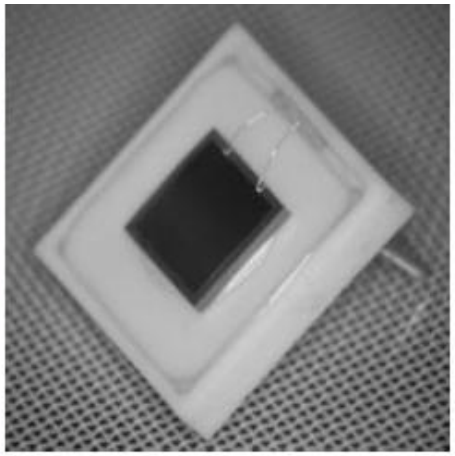
2nd Gen SiPM- Packaging Development

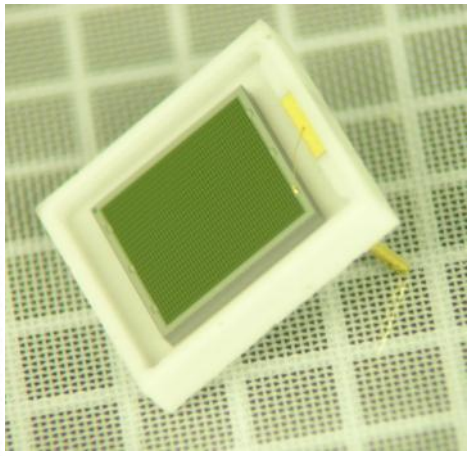


Wafer of chips

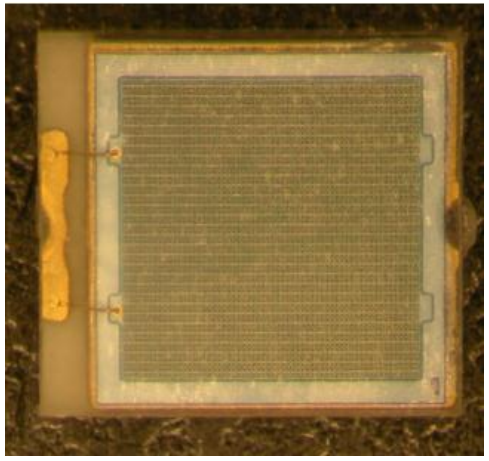


TO-can, cooler





Ceramic Header 3x3, 5x5



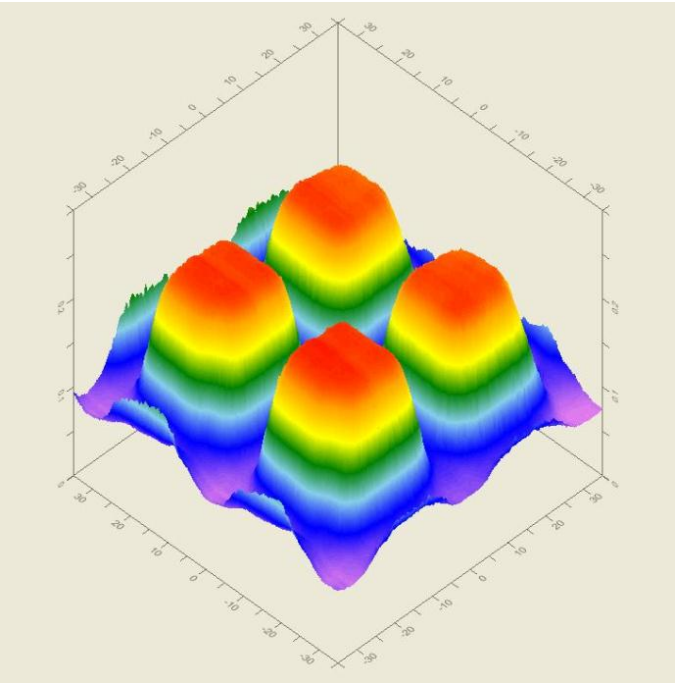
SMT package
(tile-able)

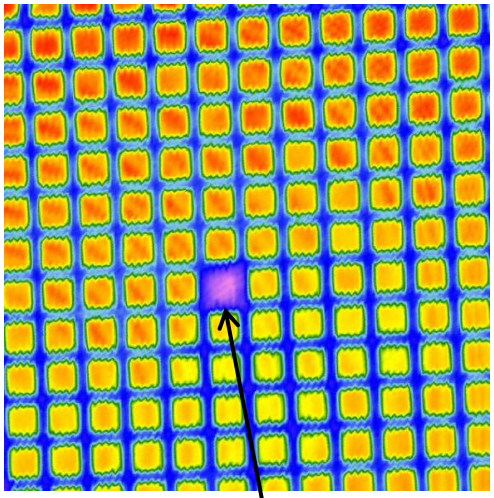
Packaging Development progressing alongside, 1,3 and 5 mm chip sizes

EXCELITAS TECHNOLOGIES

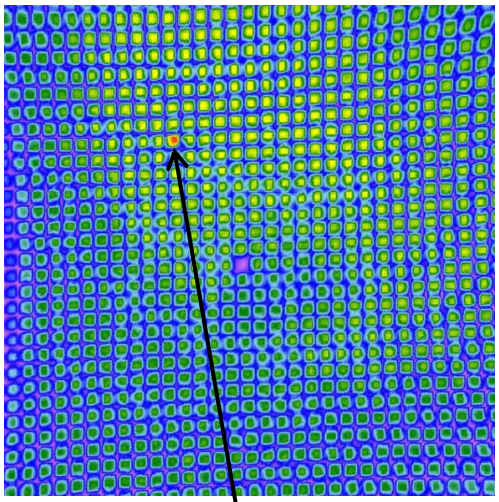
Excelitas SiPM- Towards Volume Production Capability

- 5x5mm SiPM (Optical Beam Induced Current- scanning HeNe laser, 633nm)



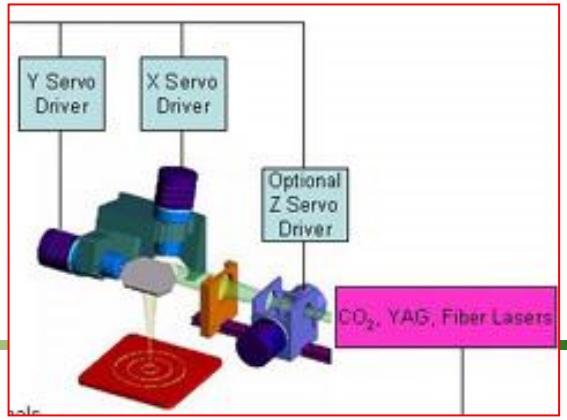


Pixel not connected easily spotted by OBIC system. Array uniformity also visible



Abnormally high gain pixel easily spotted by OBIC system.

- OBIC is a great tool to:
  - Quickly evaluate uniformity,
  - pixel layout, connectivity, etc.



EXCELITAS TECHNOLOGIES

Conclusion

Low-capacitance and low dark-count UV-sensitive SiPM has been developed

- Timing resolution issue at wavelength of interest (440 nm) improved significantly to **200 ps**
- Temperature coefficient and gain variation over temperature improved
- Planned Improvements in next months :

  •Implement cross-talk reduction

  •Improve PDE by improving QE and Geometrical Efficiency

  •Optimize design to combine both the timing resolution of second generation and the ultra-low dark count of first generation~ **100 kcounts/mm^2**

- Sampling to customers now.
- Final product in early 2012.

Addressing the needs of molecular imaging and high energy physics communities

EXCELITAS TECHNOLOGIES

Acknowledgments

NRC Industrial Research Assistance Program

Natural Sciences and Engineering Research Council of Canada

Conseil de recherches en sciences naturelles et en génie du Canada

NSERC Industrial R&D Fellowship

MEPHI/MPI –Excelitas Collaboration

R. Mirzoyan, B. Dolgoshein, E. Popova et al

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