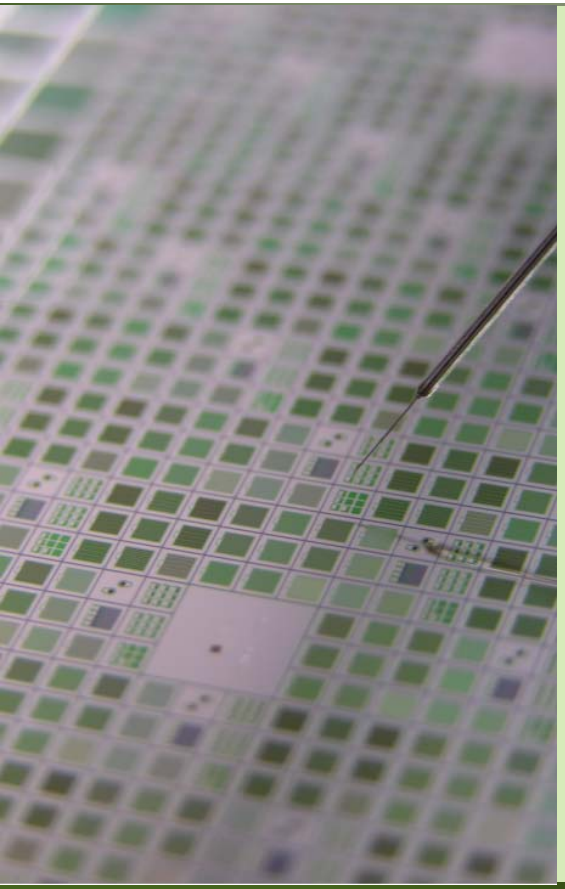
EXCELITAS TECHNOLOGIES



Characterization study of a new UV-SiPM with low dark count rate

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

ID : S1-2-157

ENGAGE. ENABLE. EXCEL.

50 years ago …

Robert John McIntyre
1928 - 1998

PerkinElmer
For the Better

EG&G

EXCELITAS TECHNOLOGIES

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.

SPCM (Single Photon Counting Module)

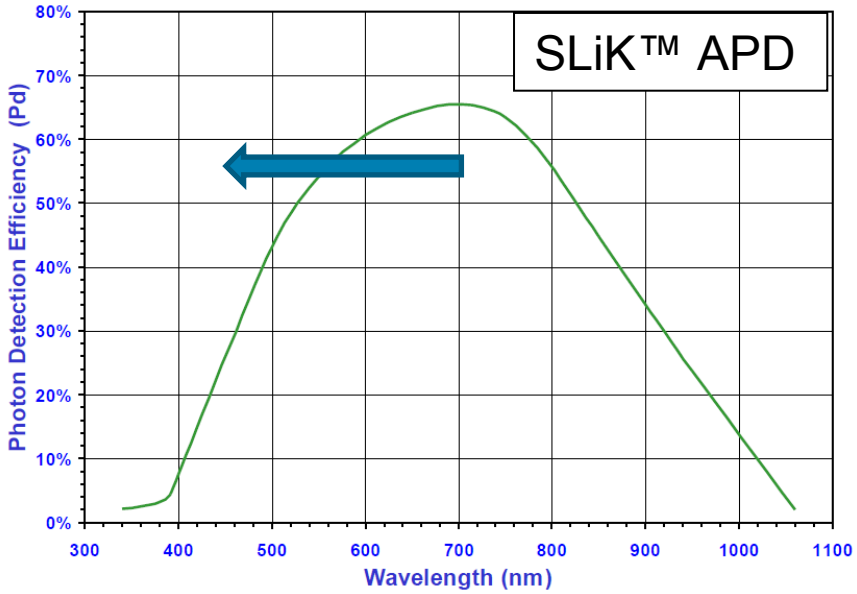
Self contained, SLiK™ APD based module which detects single photons ranging from 400 –1100nm. Also available *UV-SLiK™ and IR-SLiK™*

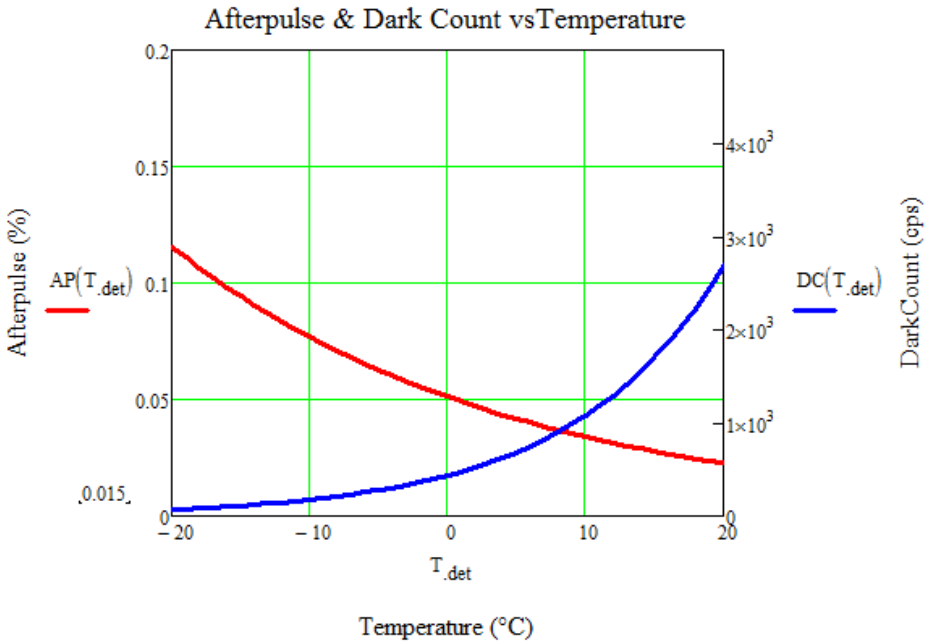
- Plug and play module with electronics integrated
- Includes thermoelectric cooler
- Includes quenching circuit
- Digital output

- **Active diameter :180 µm**
- **Photon detection efficiency (PD) @ 700nm : 65 %**
- **Dark Count Average : 200 cps @ -10°C and 20 OV**
- Maximum count rate : 30 Mcps
- Dead time : 32 ns
- After pulse probability : 0.5 %
- Timing resolution Typ. : < 500 ps

EXCELITAS TECHNOLOGIES

From SPCM to SiPM





Develop an UV-enhanced SiPM

Improve photon detection efficiency around 400 nm while maintaining low dark count and tile-up smaller pixel

Address needs of molecular imaging, particle physics and astroparticle physics community.

EXCELITAS TECHNOLOGIES

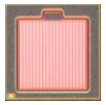
From SPCM to SiPM

1st SiPM engineering wafer lot

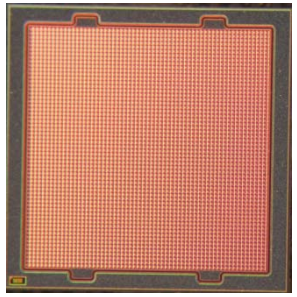
SiPM dimension : - 1 mm x 1 mm
- 3 mm x 3 mm
- 5 mm x 5 mm

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

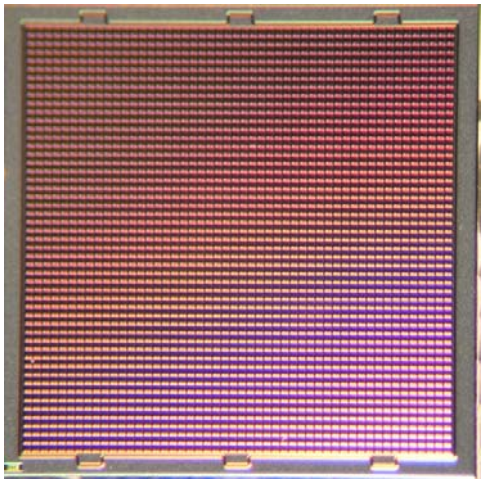
1 mm



3 mm

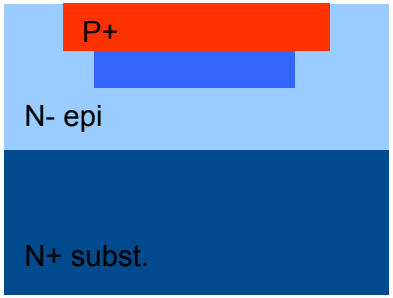


5 mm

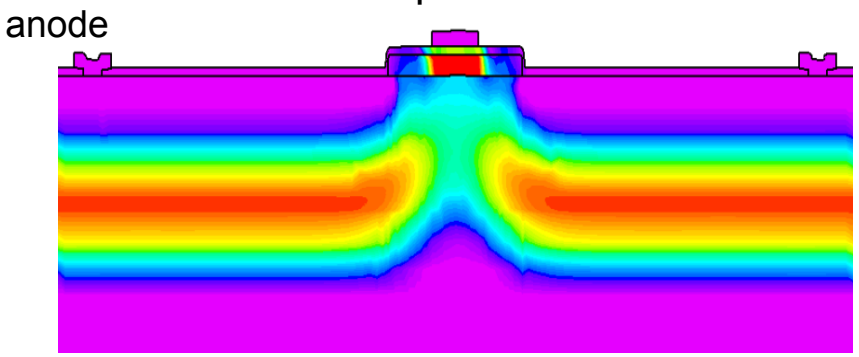


Geometrical efficiencies (GE) ranging from 74% to 29 %

P on N structure

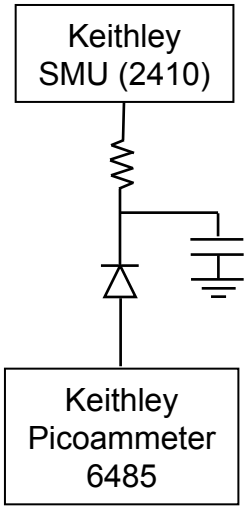


Electrical field profile simulation



EXCELITAS TECHNOLOGIES

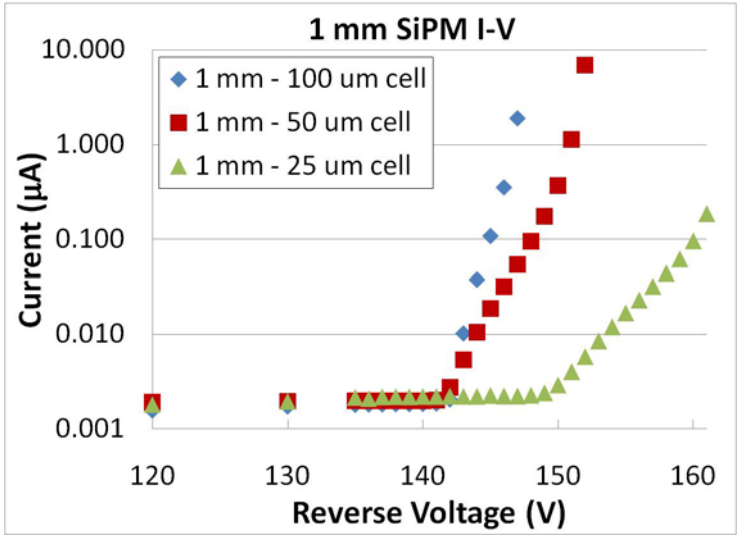
SiPM IV and Quench Resistor



- I-V

Large Over Voltage range
~10 Volts

Vbd ~140 – 150 V



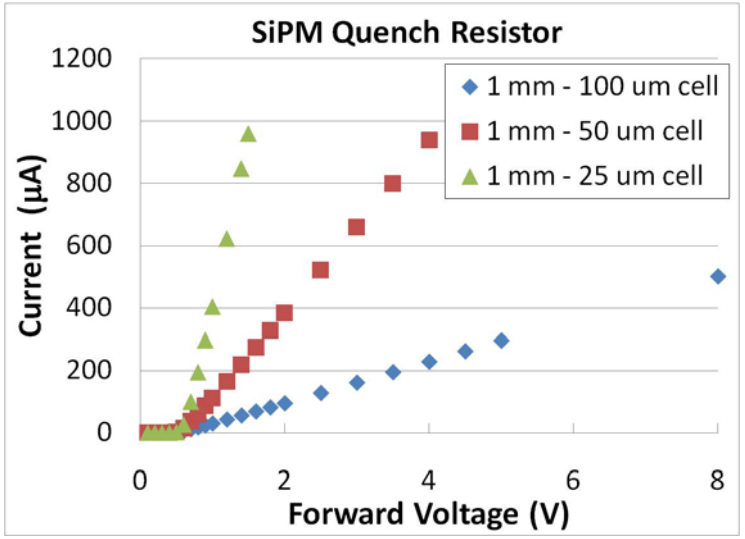
- Quench Resistor

Rq = 1/slope * #cells

Rq ~ 1.45 MΩ

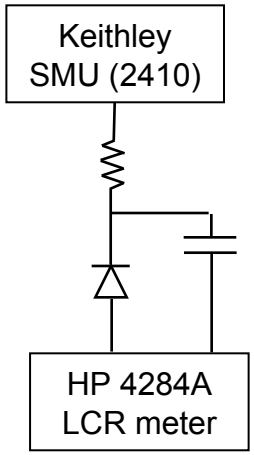
Large Quench resistance limiting re-ignition

Could be tailored to requirements



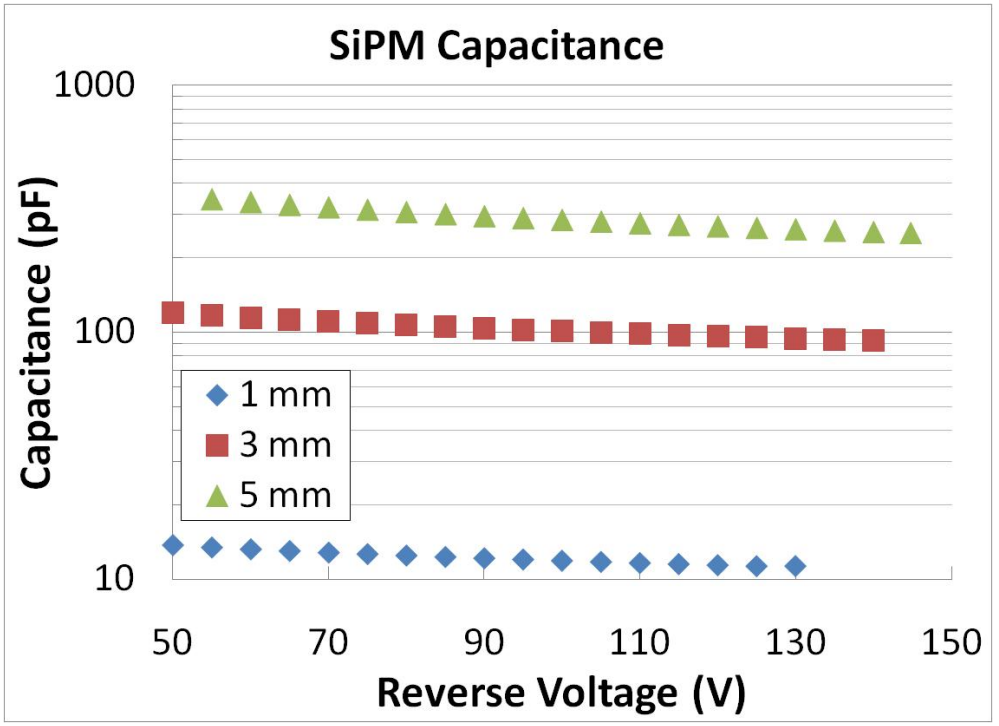
EXCELITAS TECHNOLOGIES

SiPM Capacitance



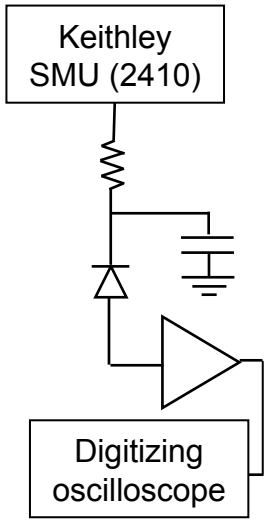
Capacitance
- 1 x 1 mm : 12 pF
- 3 x 3 mm : 93 pF
- 5 x 5 mm : 255 pF

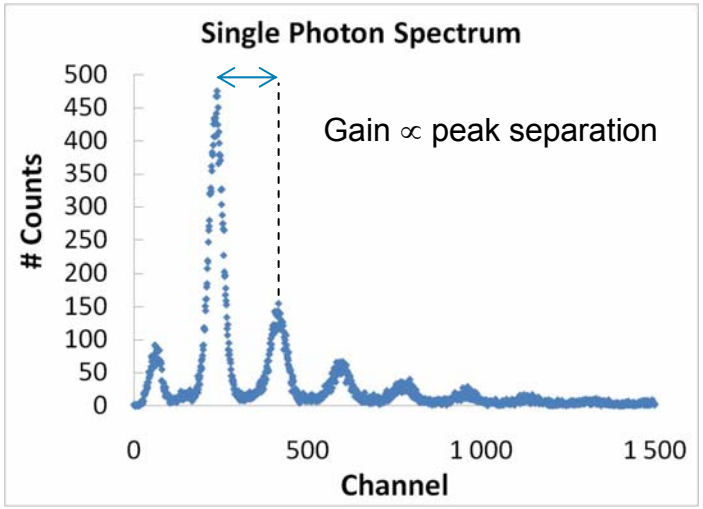
~10 pF/mm²
Lower capacitance than other SiPM devices

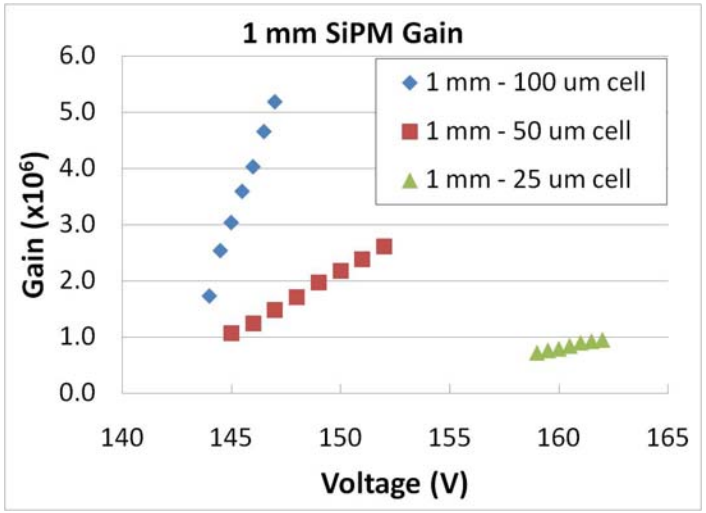


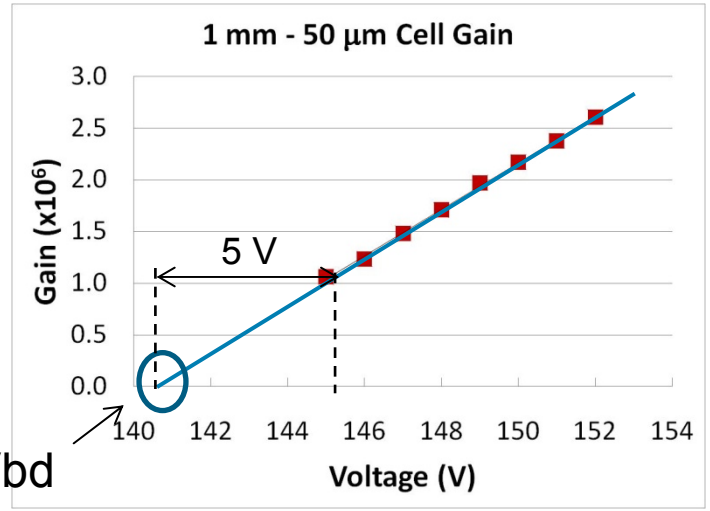
EXCELITAS TECHNOLOGIES

SiPM Gain - Voltage dependence









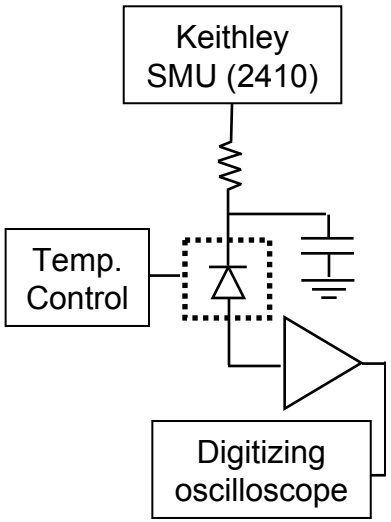
50 µm: 12 pF/400 pixels →
Gain = C·ΔV/q
Gain at 5 OV = 1.0 x 10^6

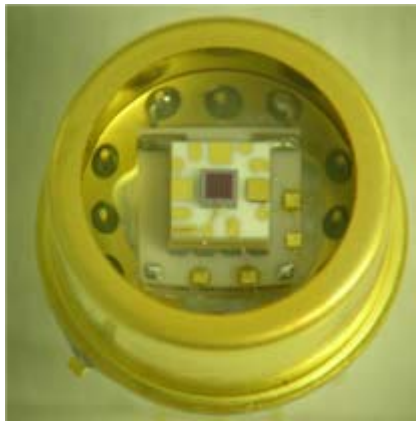
δM/ δV
- 100 µm : ~ 8 x 10^5/V
- 50 µm : ~ 2 x 10^5/V
- 25 µm : ~ 0.5 x 10^5/V

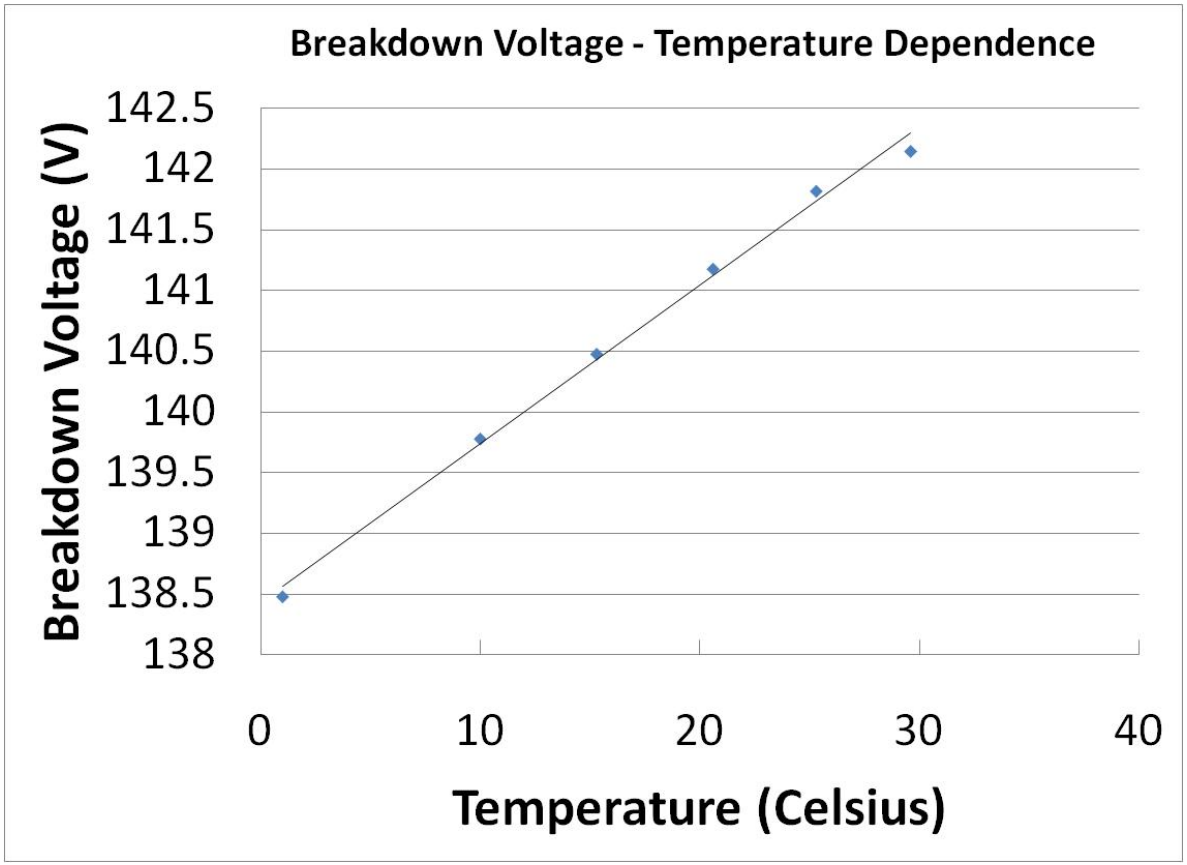
1%/50 mV

EXCELITAS TECHNOLOGIES

SiPM Breakdown Voltage – Temperature dependence





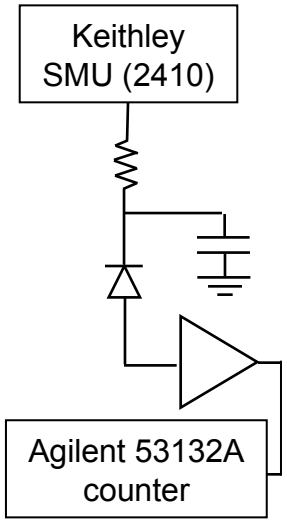


$\delta V / \delta T \sim 130$ mV/°C

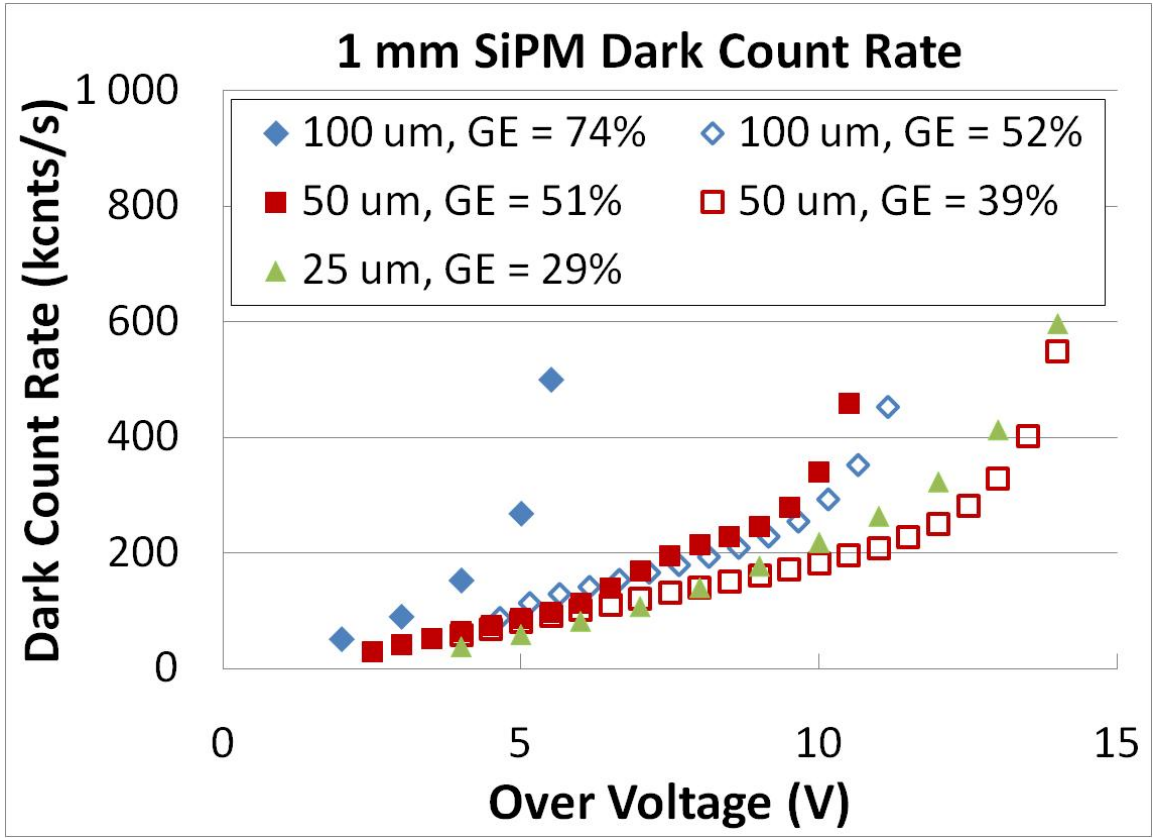
$\delta M / \delta T \sim 2.6$ %/°C

EXCELITAS TECHNOLOGIES

Dark Count Rate



DCR measured at 25°C on 1 mm SiPM

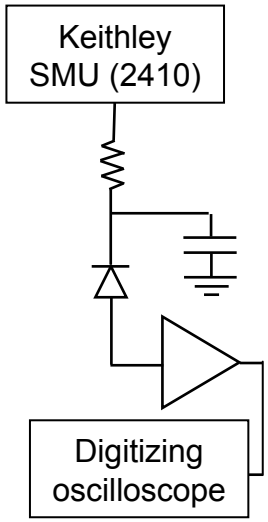


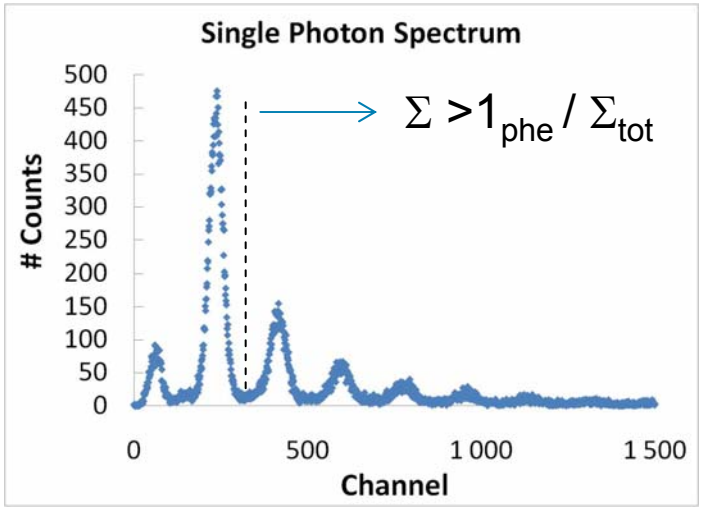
1 mm SiPM
DCR at 5 OV
- 100 µm : < 350 kcnts
- 50 µm : < 150 kcnts
- 25 µm : < 100 kcnts

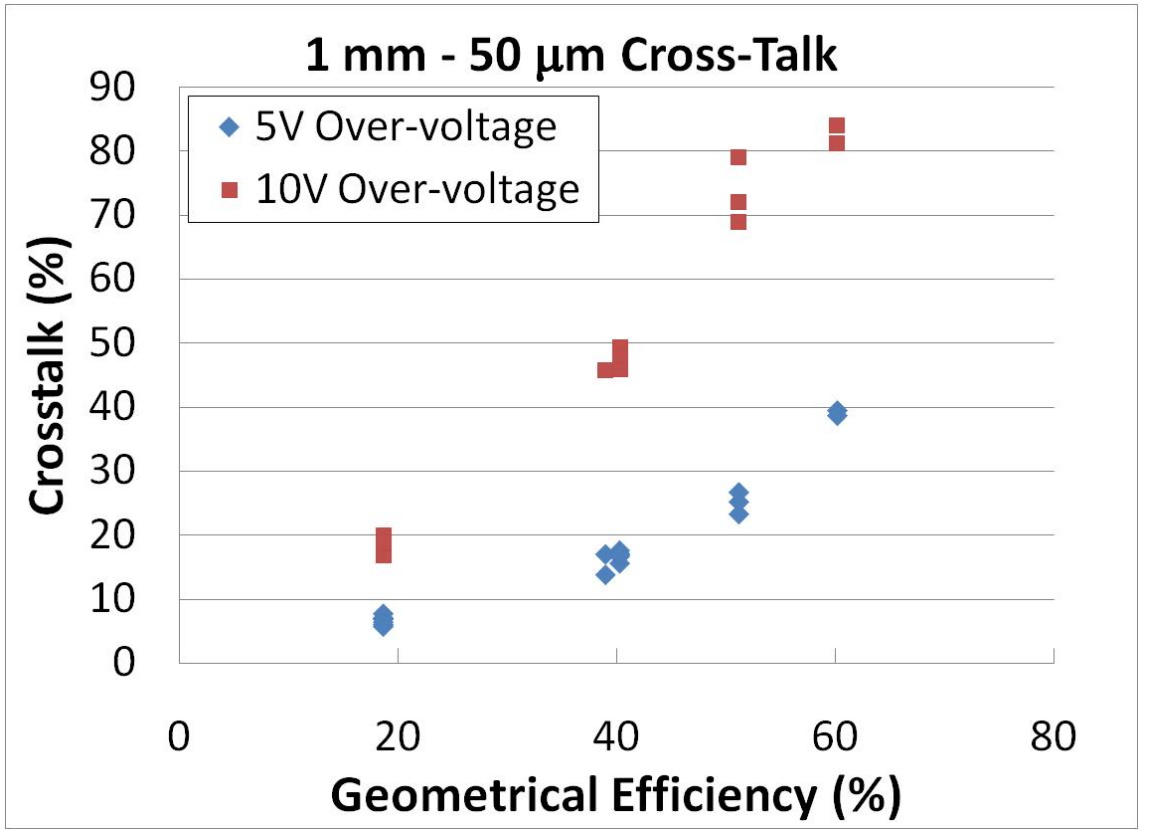
Non-negligible contribution from cross-talk and afterpulse under investigation

EXCELITAS TECHNOLOGIES

Cross-talk





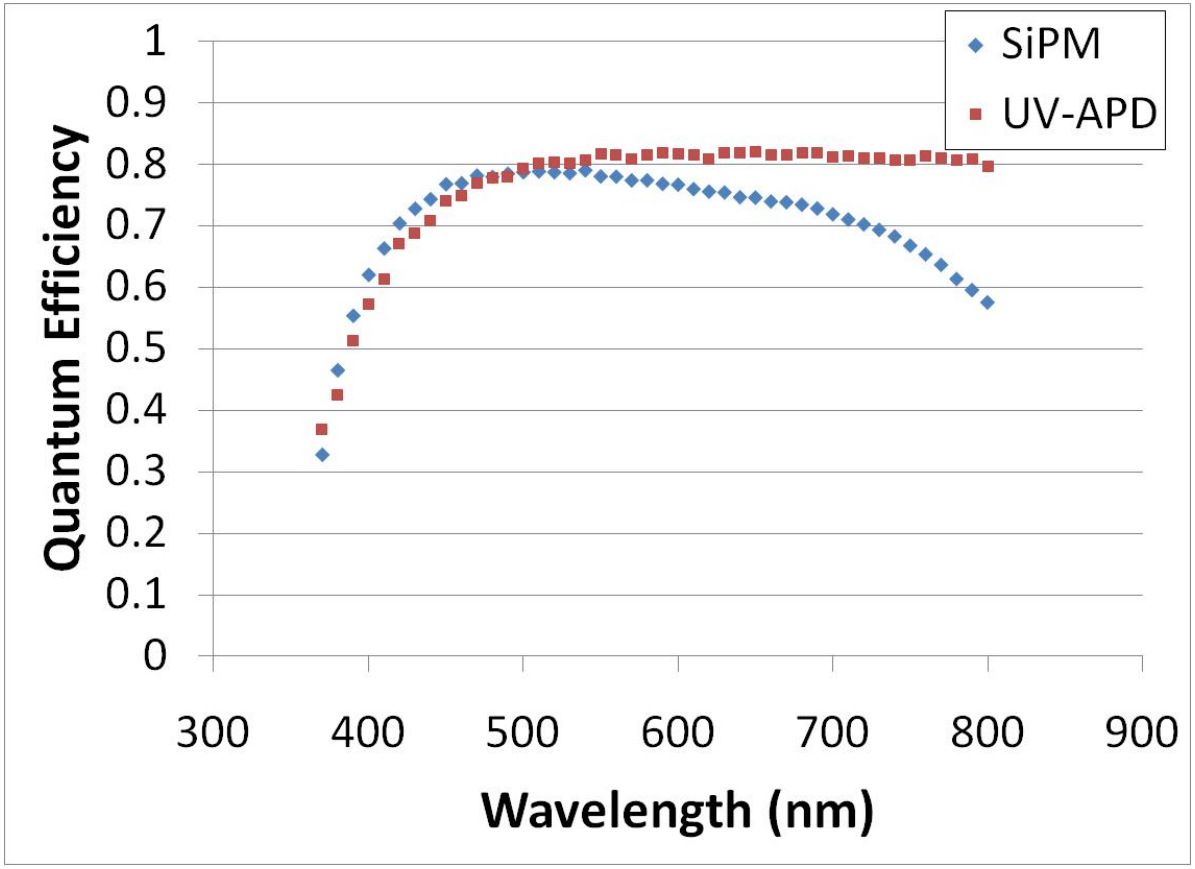


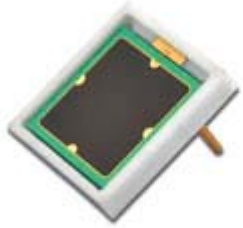
Important to reduce cross-talk

EXCELITAS TECHNOLOGIES

QE measurement

Monochromator light flux calibrated with NIST traceable PIN diode





Excelitas
5 x 5 mm large area
UV-APD

Id = 3 nA, In = 0.3 pA/Hz$^{1/2}$
at Gain = 200

QE similar to state-of-the-art large area UV-APD

Wide spectral response

QE can still be improved at lower wavelength

EXCELITAS TECHNOLOGIES

PDE measurement in photon counting mode

Laser output adjusted to meet single photon counting requirements

Photon flux calibrated with NIST traceable PIN and SPCM with known PD

Light split in 10/90 fibre to continuously monitor laser intensity with SPCM

Picoquant laser head : 440, 636 and 825 nm. Jitter < 70 ps.

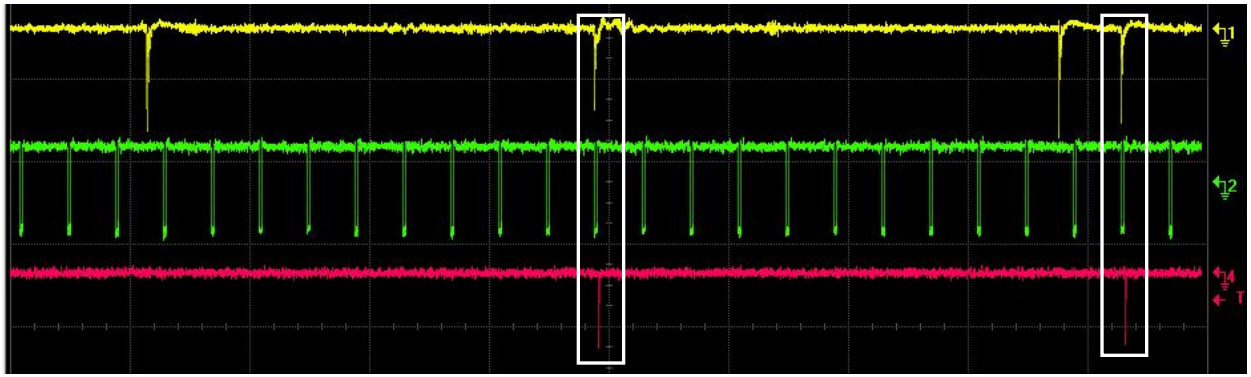
Photon counting mode

suppress afterpulse and cross-talk contribution to PDE

SiPM output

Laser Trigger

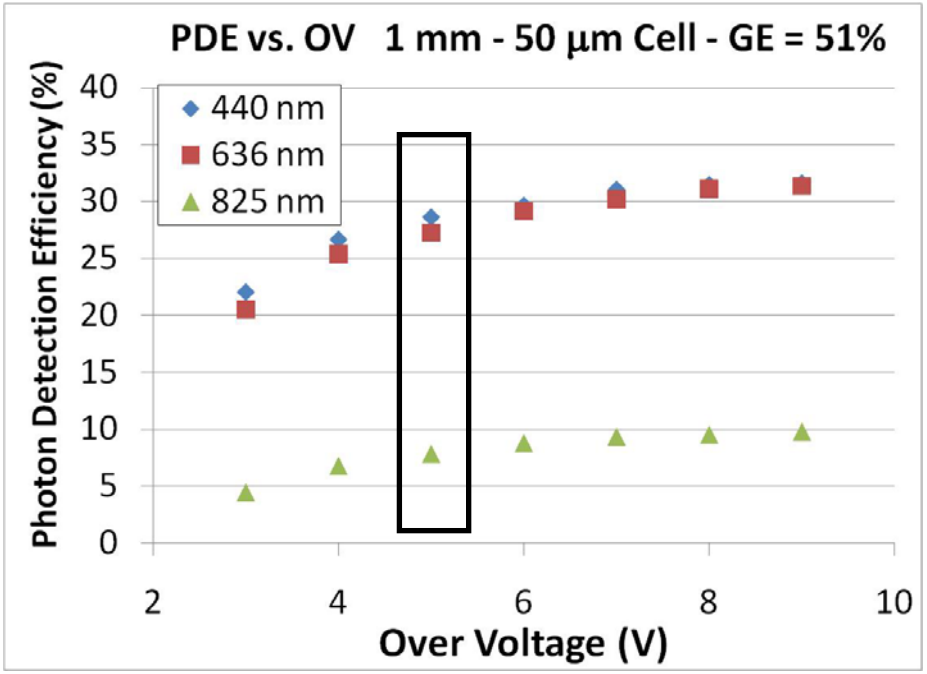
CFD output

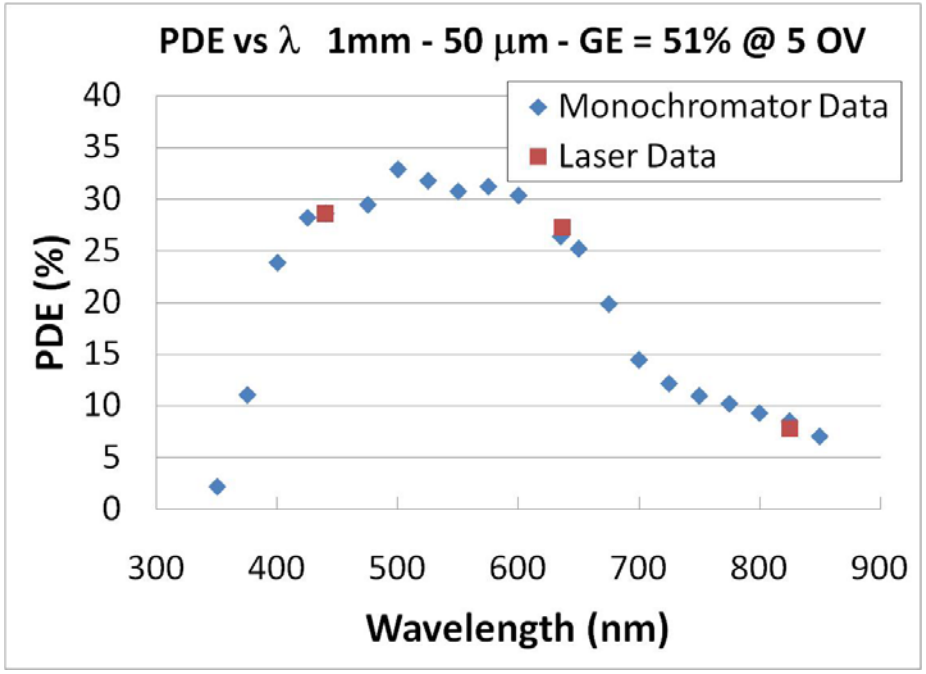


P. Eckert *et al.* Characterisation studies of silicon photomultipliers, Nucl. Instr. and Meth. A 620 (2010), pp. 217-226.

EXCELITAS TECHNOLOGIES

SiPM PDE in Photon Counting Mode



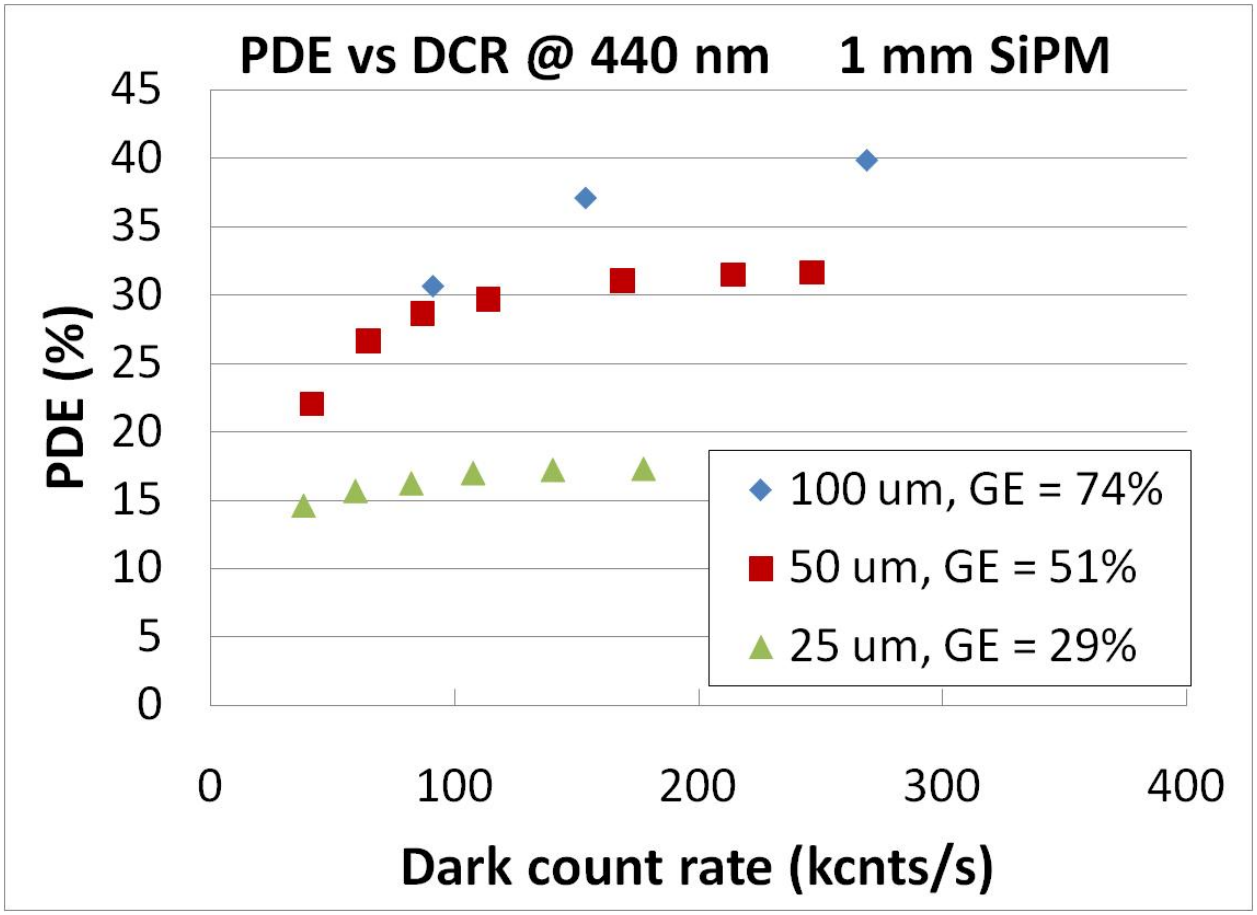


PDE data obtained with monochromator rescaled to 440 nm photon counting data point

Wide spectral response

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

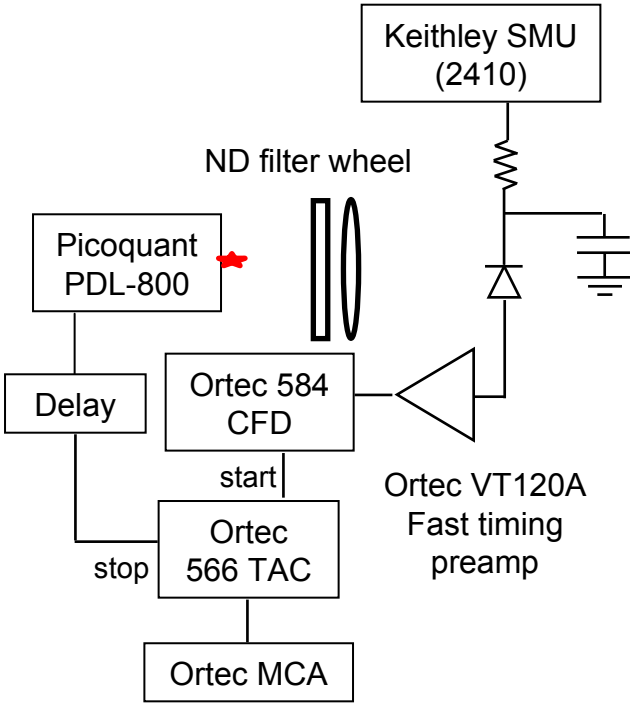
PDE vs. Dark count rate



Low Dark Count Rate vs. PDE

EXCELITAS TECHNOLOGIES

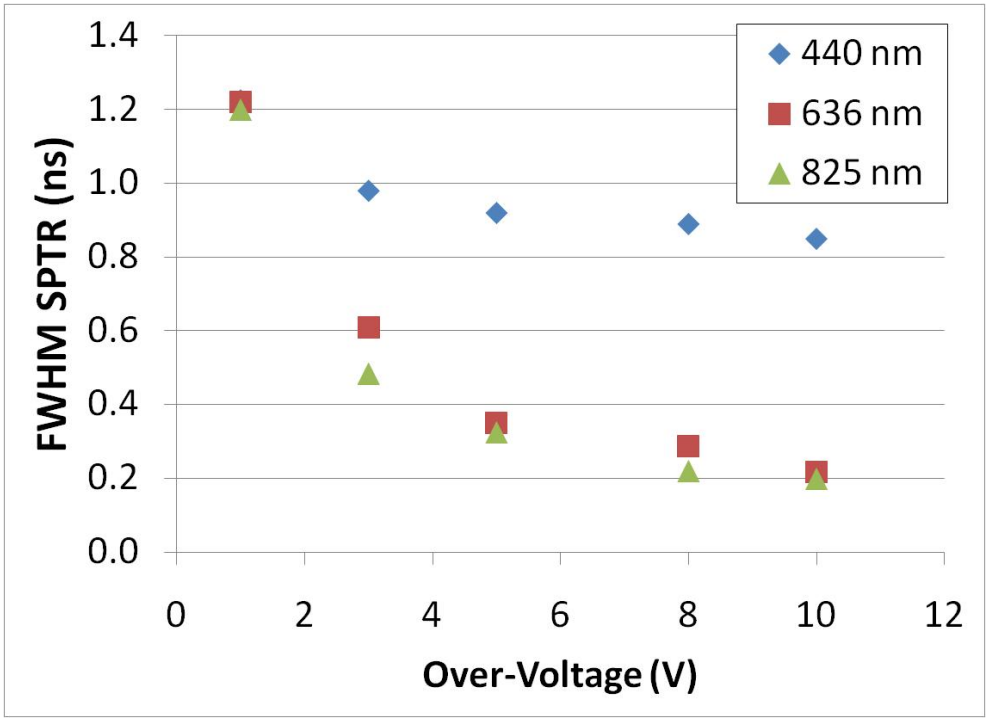
SiPM Single Photon Timing Resolution



Laser output adjusted to meet single photon counting requirements

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

Picoquant laser head : 440, 636 and 825 nm. Jitter < 70 ps.



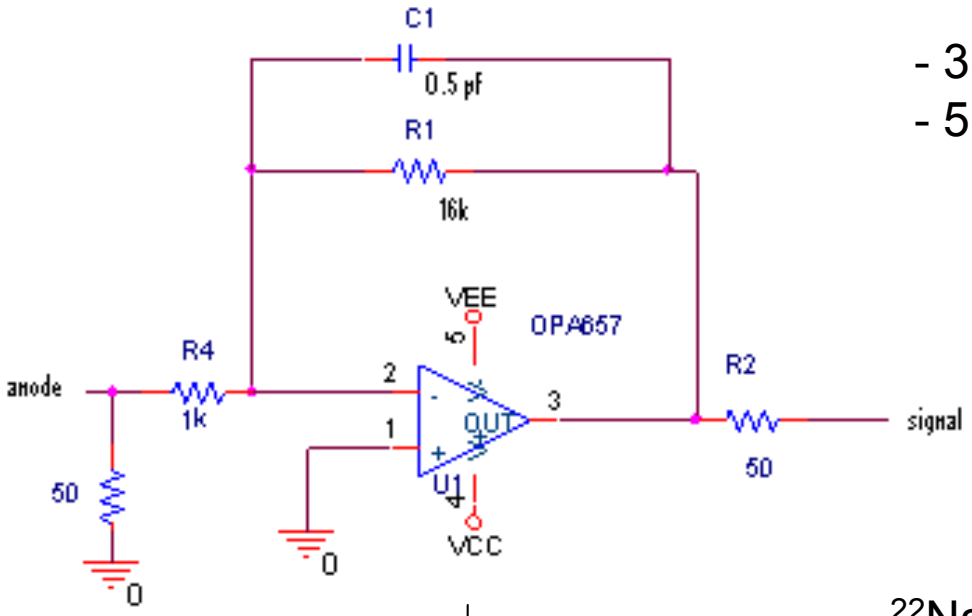
SPTR at 5 OV / 10 OV
< 350 ps / 200 ps at 636 nm
> 800 ps at 440 nm

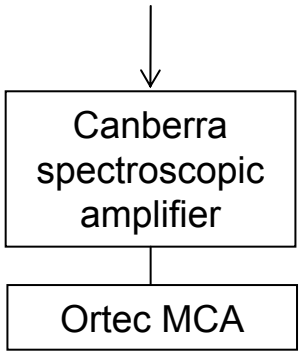
Poor timing at 440 nm → Not optimized wafer thickness ... Will be corrected on next batch

EXCELITAS TECHNOLOGIES

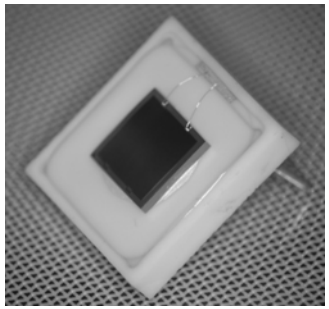
SiPM Energy Resolution

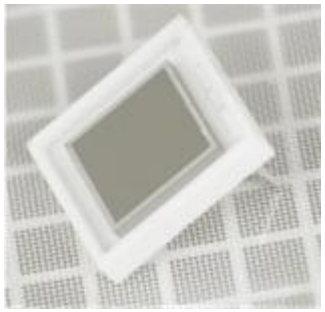
- Voltage sensitive configuration with OPA657





- 3 x 3 mm, 50 um pixels, GE : 40 %
- 5 x 5 mm, 50 um pixels, GE : 60 %





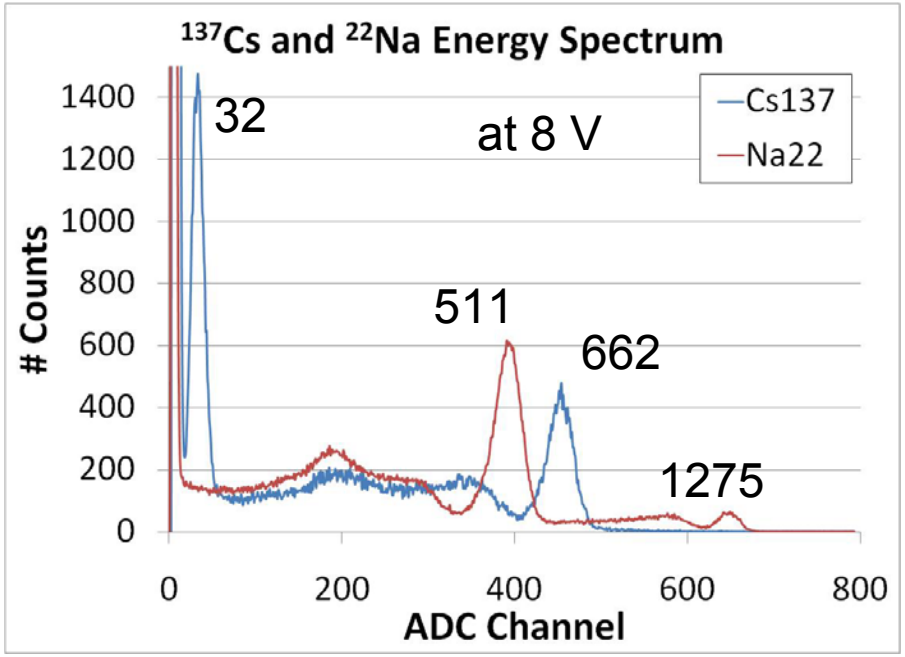
^{22}Na and ^{137}Cs : 32, 511, 662 and 1275 keV
- Correction for non-linearity

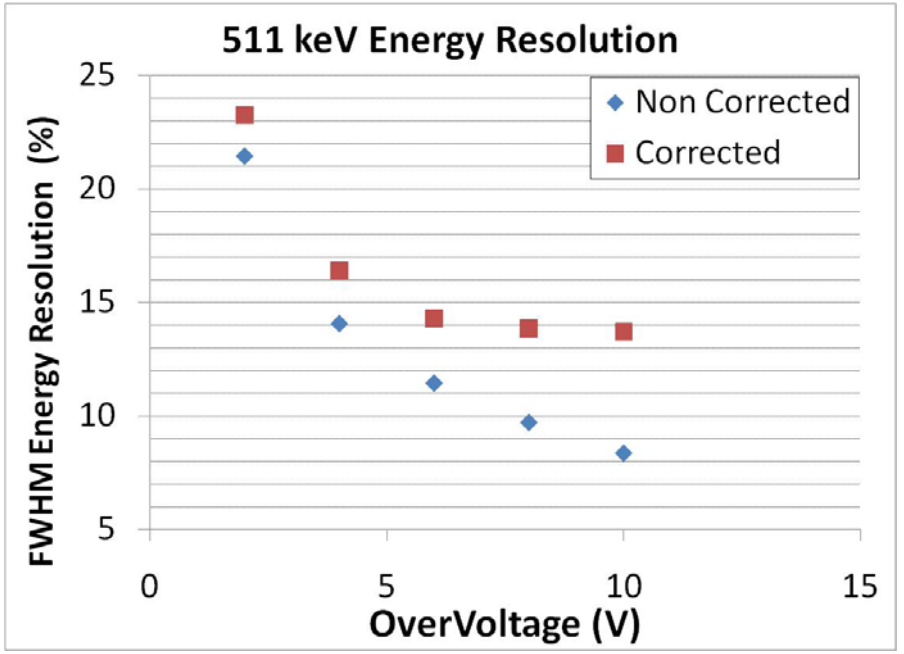
3 x 3 x 10 mm and 4 x 4 x 10 mm LSO
- Wrapped in Teflon
- Optically coupled with Bicron optical grease

EXCELITAS TECHNOLOGIES

SiPM Energy Resolution

3 x 3 x 10 mm LSO coupled to a 3 x 3 mm SiPM - 50 µm cell – GE = 40%





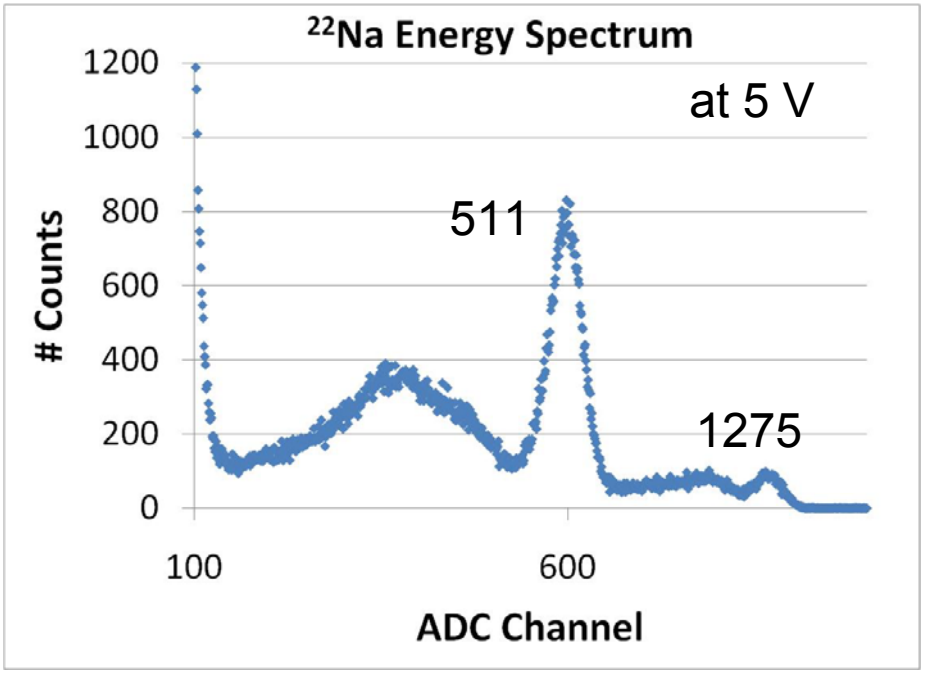
Energy resolution obtained from Gaussian Fit on photopeak

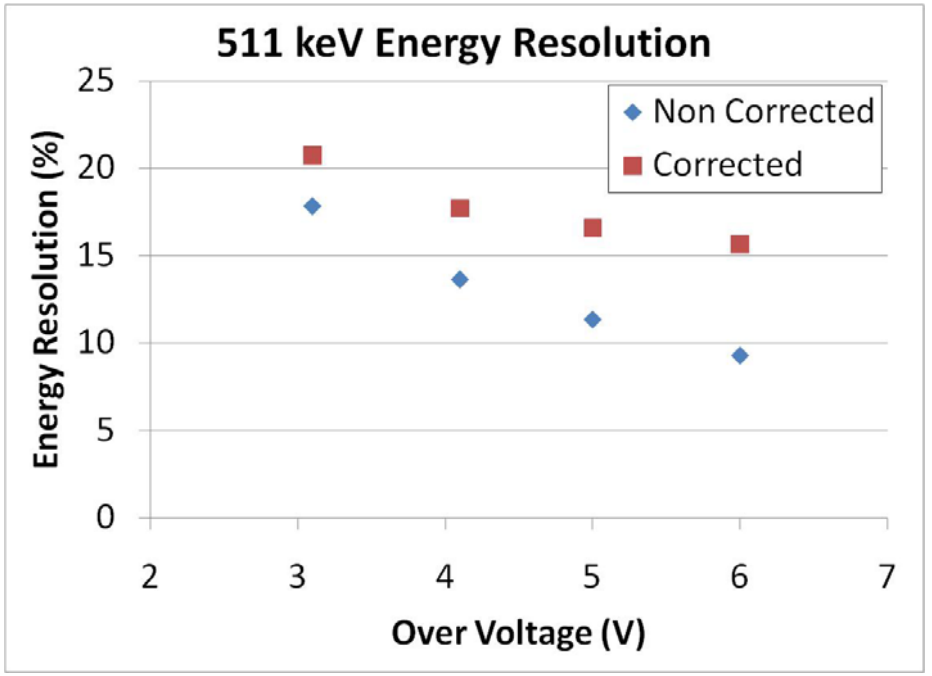
14 % energy resolution at 511 keV w/o Compton suppression from 1275 keV

EXCELITAS TECHNOLOGIES

SiPM Energy Resolution

4 x 4 x 10 mm LSO coupled to a 5 x 5 mm SiPM – 50 um cell – GE = 60%





Energy resolution obtained from Gaussian Fit on photopeak

15.5 % energy resolution at 511 keV w/o Compton suppression from 1275 keV

EXCELITAS TECHNOLOGIES

Performance Summary Table

Parameter (unless indicated otherwise, all measurements taken at Vop and 25°C)	Symbol	Part #			Part #			Unit
		C30742-50-1	C30742-50-3	C30742-50-5	C30742-100-1	C30742-100-3	C30742-100-5	
Active area	-	1x1	3x3	5x5	1x1	3x3	5x5	mm
# of pixels	-	400	3600	10000	100	900	2500	-
Pixel size	-	50			100			µm
Geometrical Efficiency	-	40			70			%
Spectral response range	λ	375-700			375-700			nm
Peak sensitivity wavelength	λ_p	500			500			nm
Photon detection efficiency at 440nm [1]	PDE	30			40			%
Operating voltage range [2]	V_{op}	130-150			130-150			V
Dark count [3]	DCR	50-150	500-1000	1500-3000	150-300			kcps
Terminal Capacitance	C_t	12	100	260	12	100	260	pF
Time resolution (FWHM) at 440nm	SPTR	600-800			600-800			ps
635nm	SPTR	200-300			200-300			ps
Gain	M	$1.0x10^6$			$4.0x10^6$			-
Temperature coefficient of Vbr	$T_c = \delta V/\delta T$	130			130			mV/°C
Gain variation with over-voltage	$\delta M/\delta V$	1			1			%/50mV
Gain variation with temperature	$\delta M/\delta T$	2.6			2.6			%/°C
Crosstalk [4]	-	17						%
Quench resistor	R_Q	1.0-1.5			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.

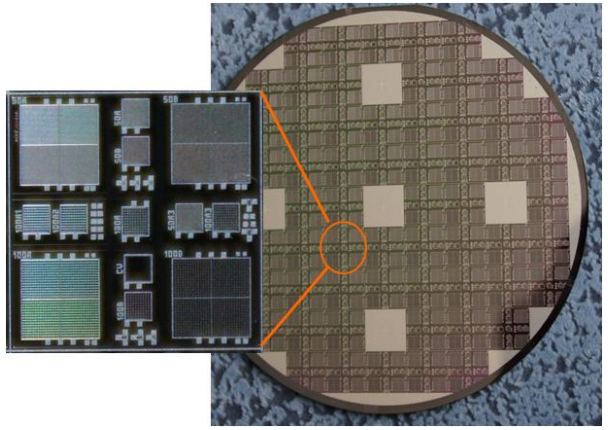
Conclusion

Low dark count rate UV sensitive SiPM has been developed

- ADVANTAGES : Low dark count rate
  Large voltage operation range
  Low capacitance
  Good gain – temperature – voltage characteristics

- IMPROVE : Timing Resolution
  Cross-talk
  PDE in UV

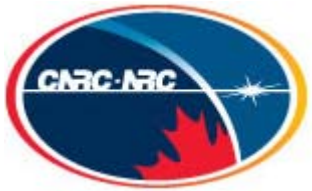
See E. Popova
Next talk



MEPHI / MPI / Excelitas

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 Collaboration

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