KETEK GmbH Munich - Germany

Silicon Photomultipliers with enhanced Blue-Light Sensitivity

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KETEK

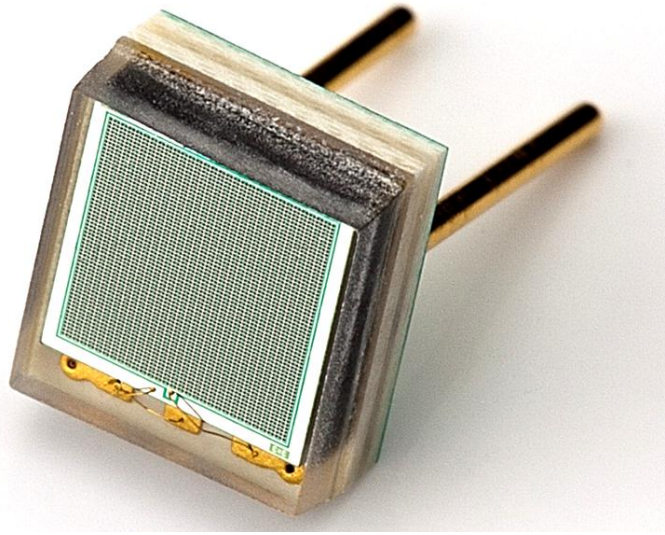
Creative Detector Solutions

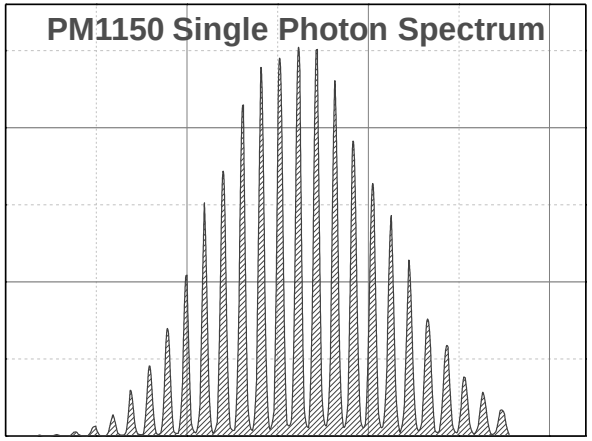
Content

- KETEK SiPM technology
- PDE of different microcell types
- Dark rate
- Optical cross talk
- Temperature coefficient of the gain

PM3350

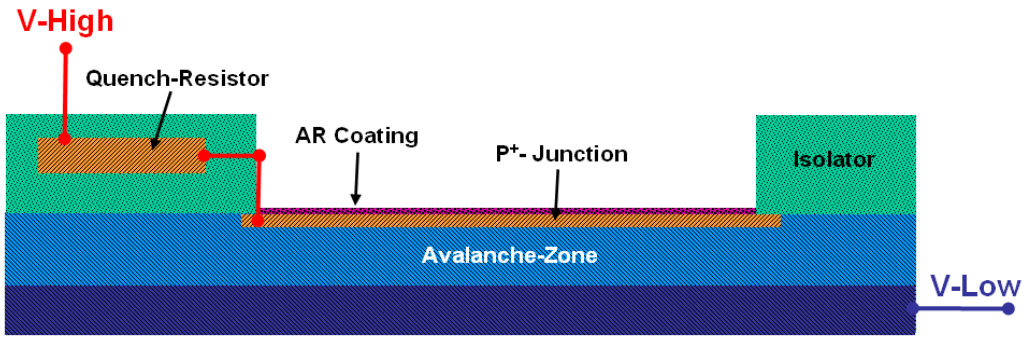
3 x 3mm² active area; 50 µm microcell type; peak wavelength 420 nm; plastic package





Basic Construction of the KETEK Microcell

Section of KETEK Basic Microcell



- Silicon **P on N structure** with high Geiger efficiency
- **Shallow entrance window** with high quantum efficiency
- Optimized **geometrical fill factor**

⇒ **High photon detection efficiency**

- Available in two technologies -

Non-Trench Technology

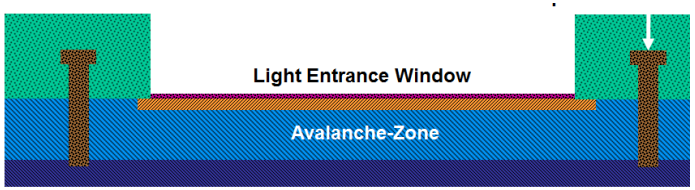
- Technology optimized for **maximum GE**
- Devices with very **high PDE**
- Particularly suitable for small microcells and small active area

Trench Technology

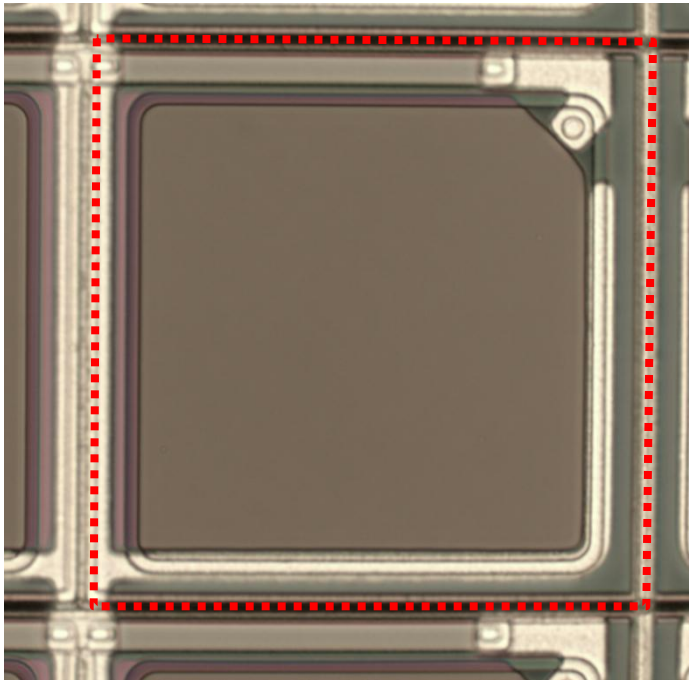
- **Reduced direct cross talk** due to optical isolation trench between single microcells
- **Improved device scalability** due to reduced parasitic RC-values
- Particularly suitable for large microcells and large area devices

KETEK Trench Technology

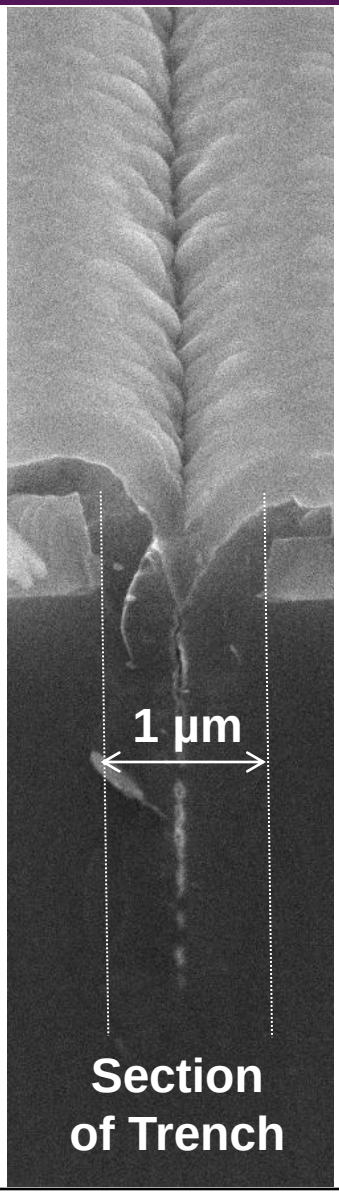
Section



Top View

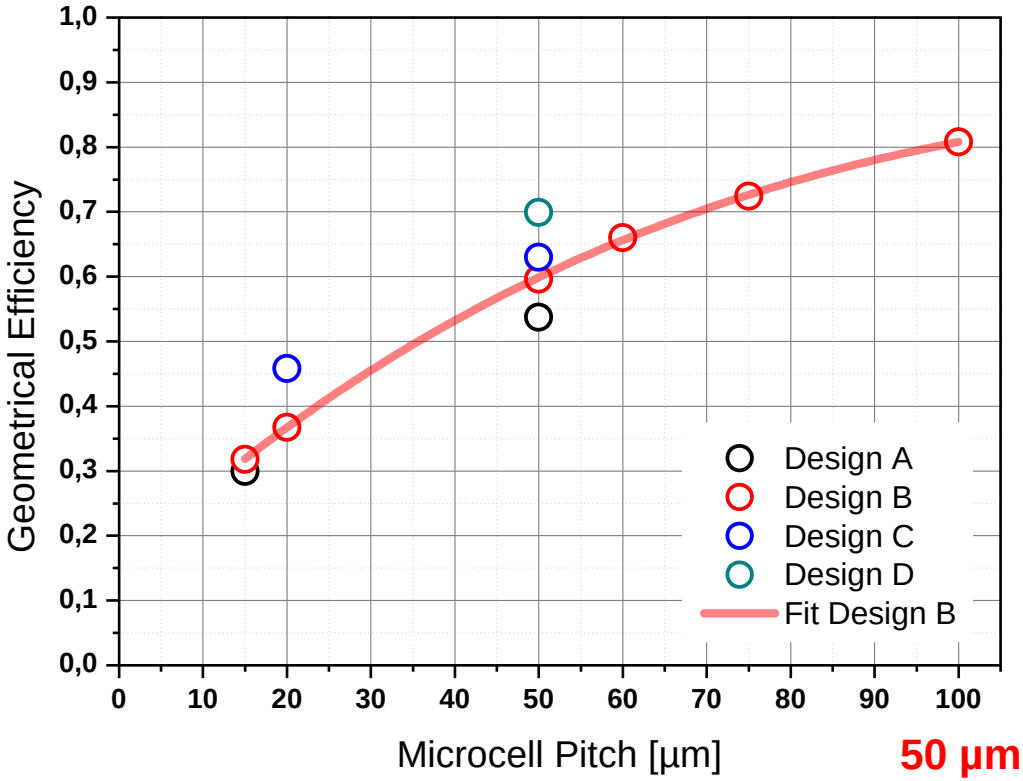


- Each microcell is completely surrounded by an optical trench isolation
- The trench is quite narrow with a width of 1.0 µm
- Together with the trench technology an effective impurity gettering has been implemented

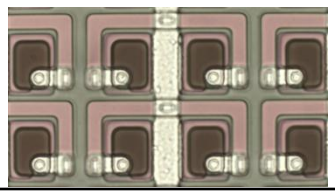


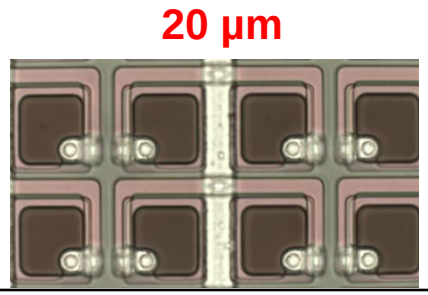
KETEK SiPM Microcell Types

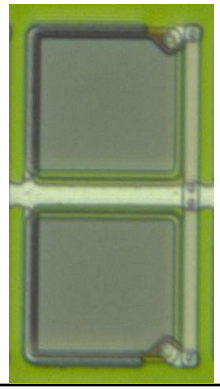
Geometrical Efficiency

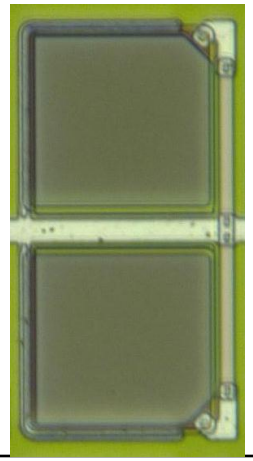


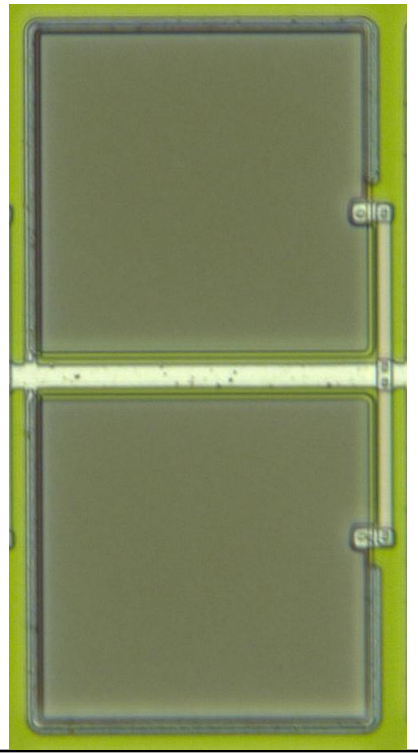
- Microcell sizes from 15µm up to 100µm realized
- Geometrical efficiency up to 70% for 50 µm microcell type



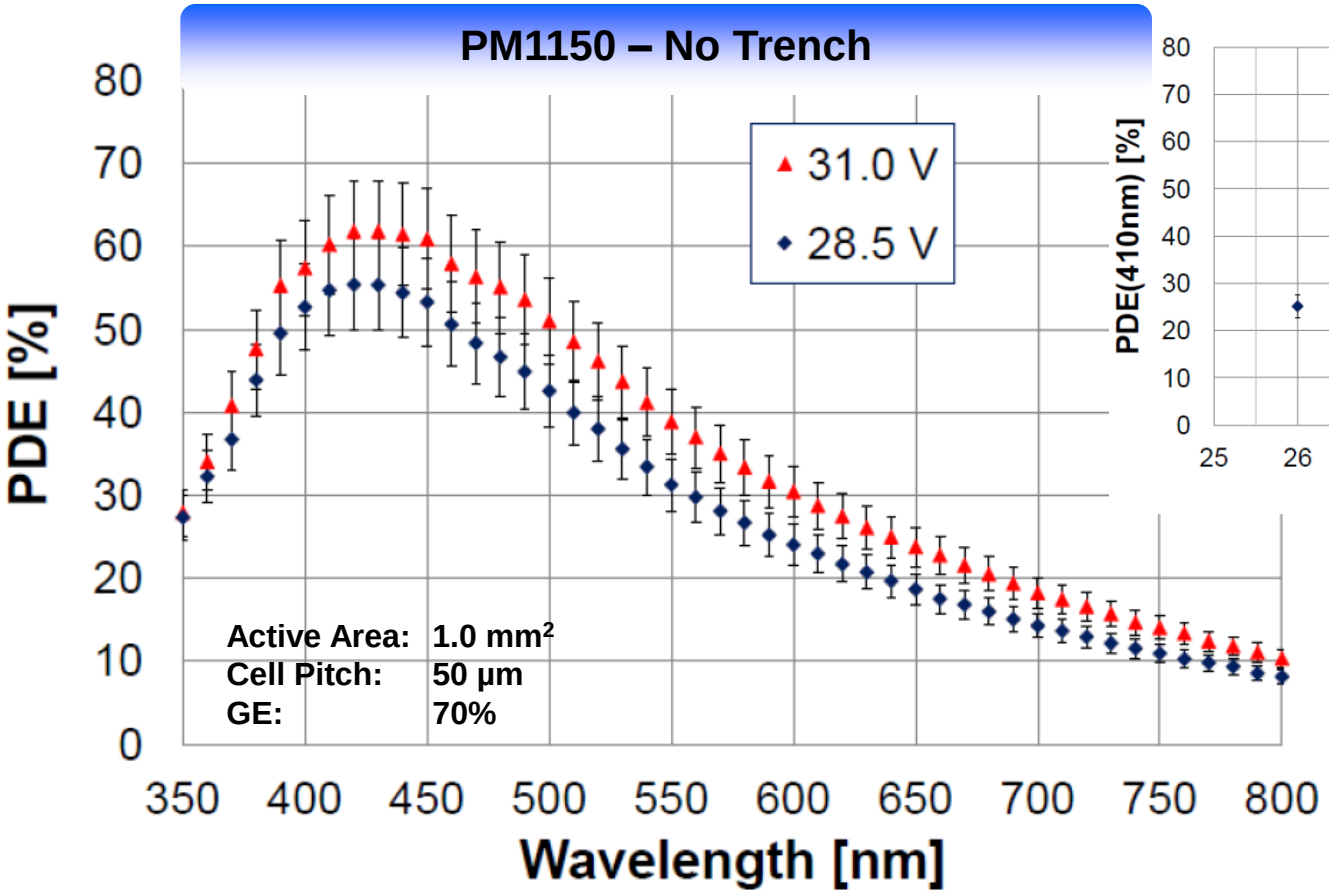


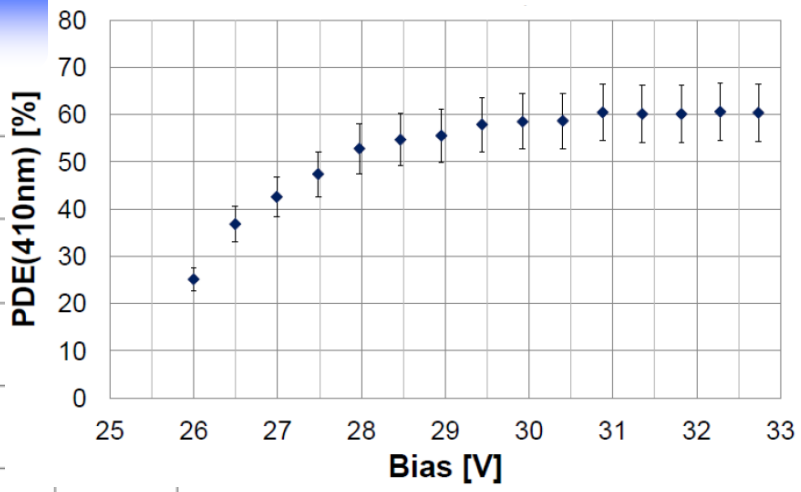






Photon Detection Efficiency

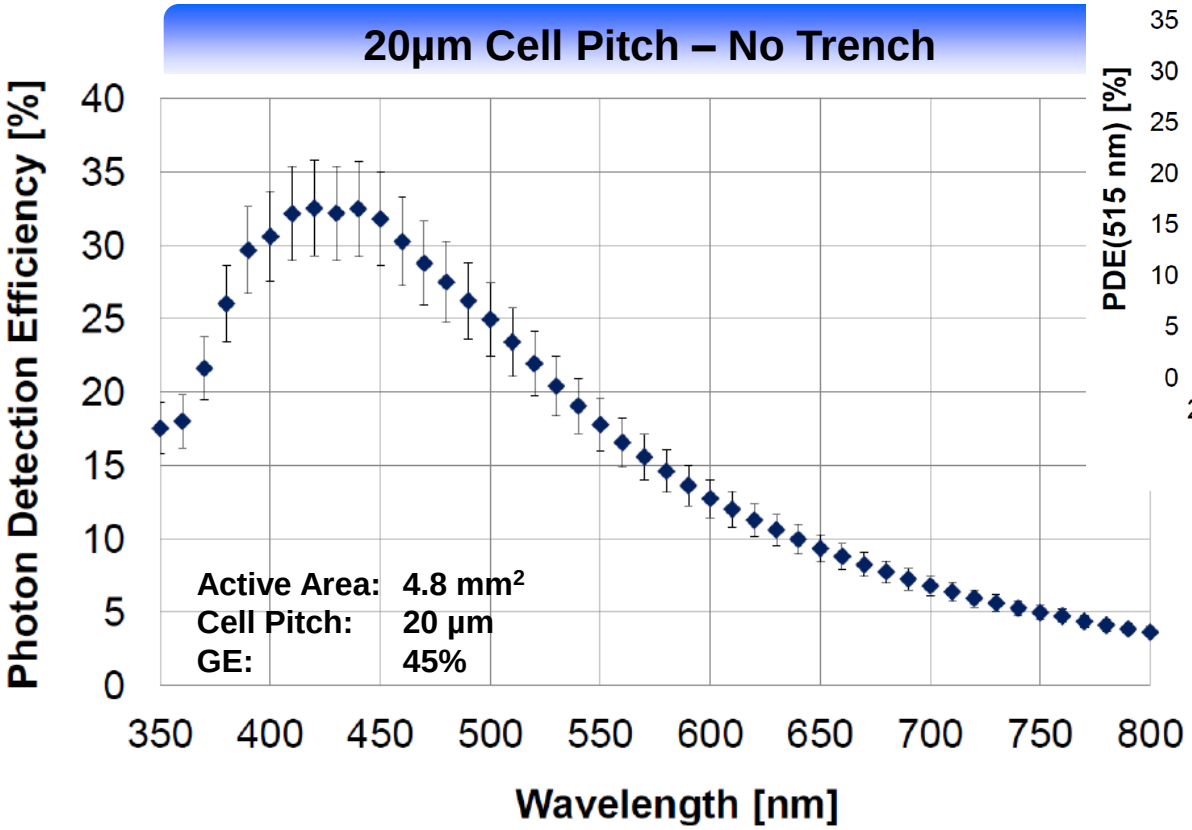


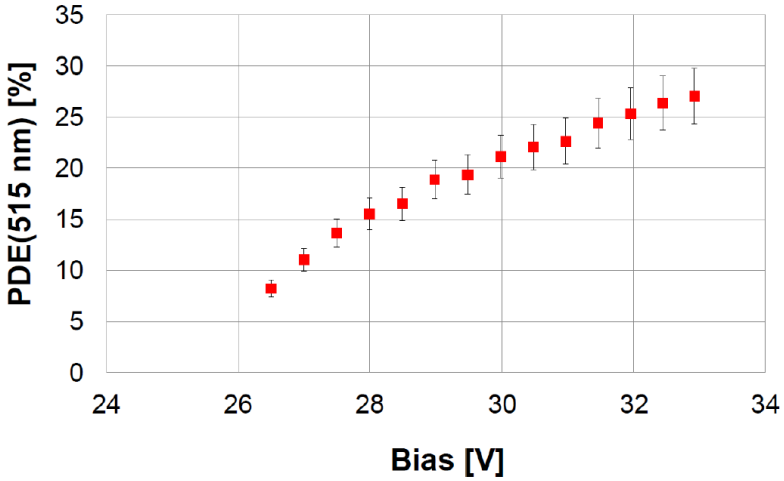


- Measurements performed by CERN / Iouri Musienko
- PDE is not affected by crosstalk and afterpulsing
- **60%** PDE for blue light (50% for green light)

Photon Detection Efficiency

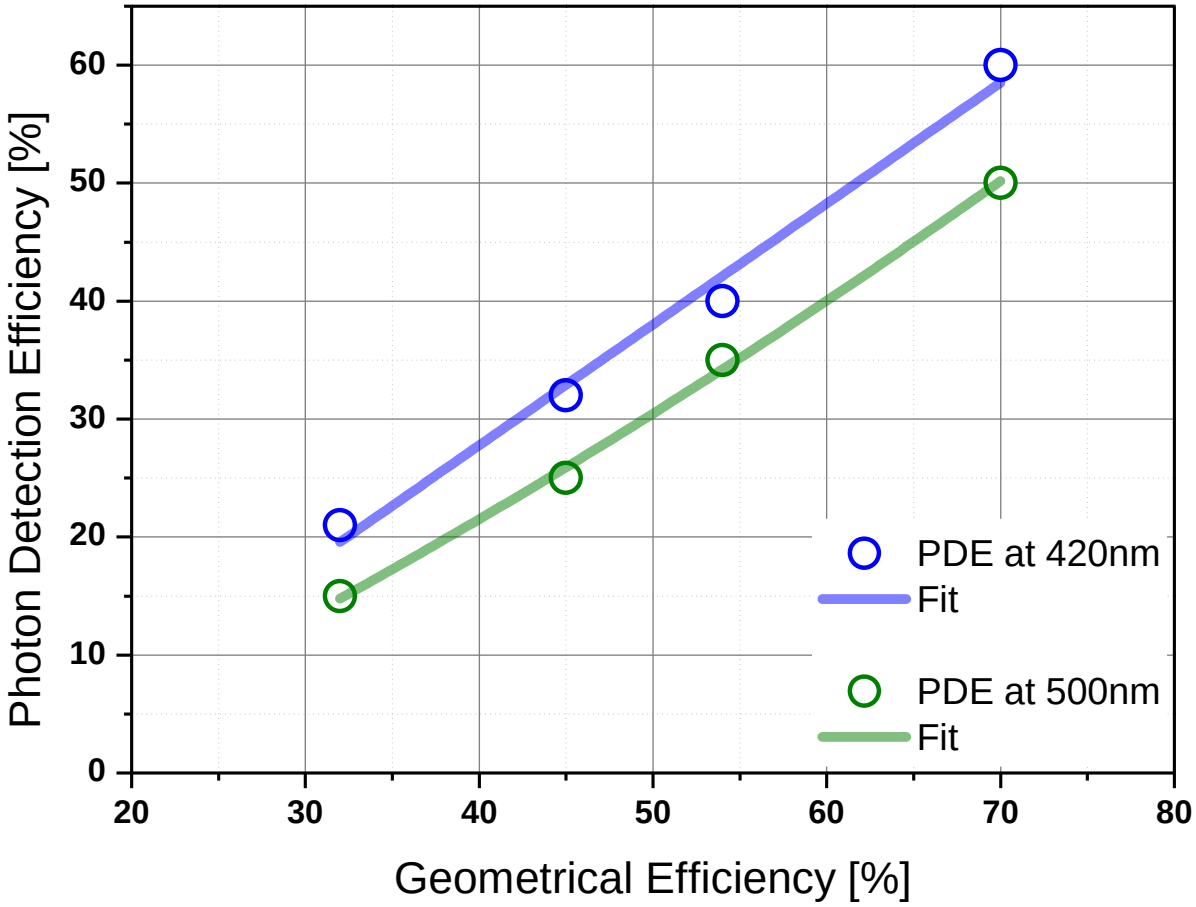
20µm Cell Pitch Type





- Measurements performed by CERN / Iouri Musienko
- PDE is not affected by crosstalk and afterpulsing
- **32%** PDE for blue light (25% for green light)

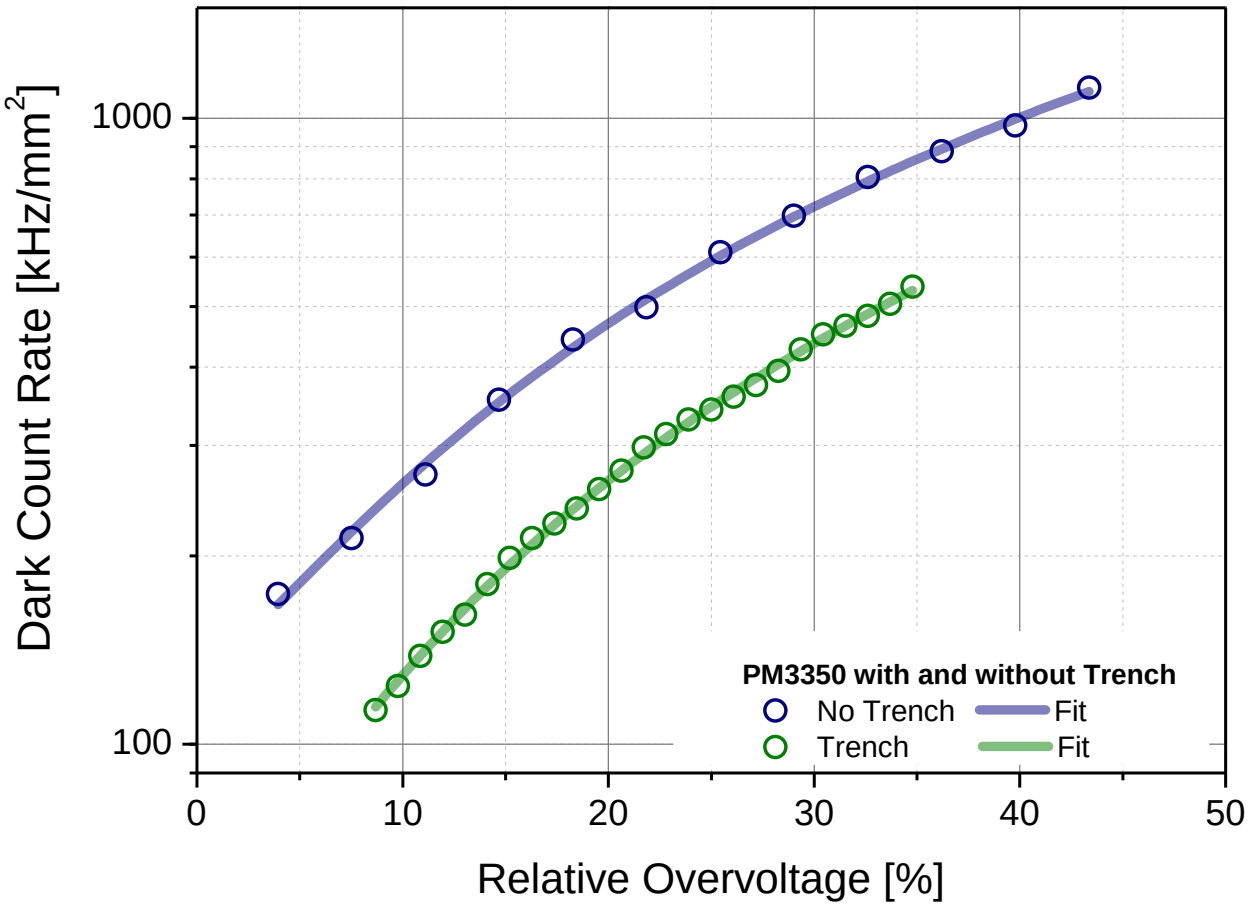
Photo Detection Efficiency vs Geometrical Efficiency



- PDE in the blue range is not scaling exact linear with the geometrical efficiency
- A slightly lower efficiency of the active microcell edge compared to the center is indicated

SiPM Dark Rate vs Bias

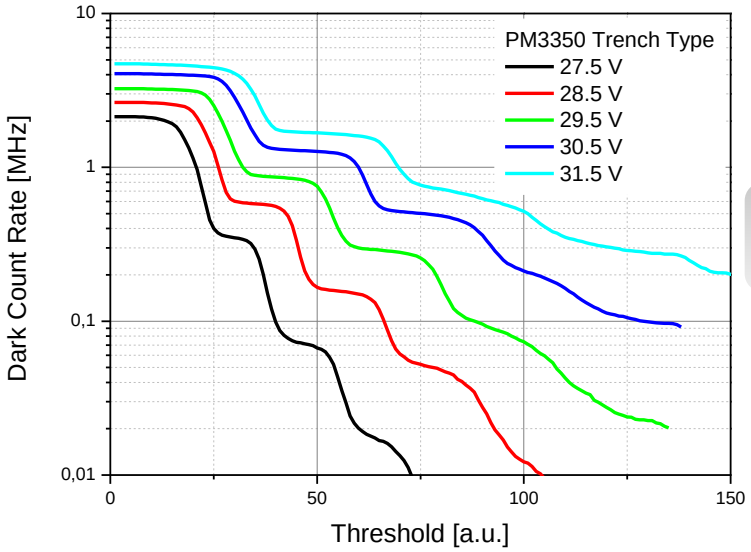
(50µm Standard Type)



Dark count rate at 20% overvoltage

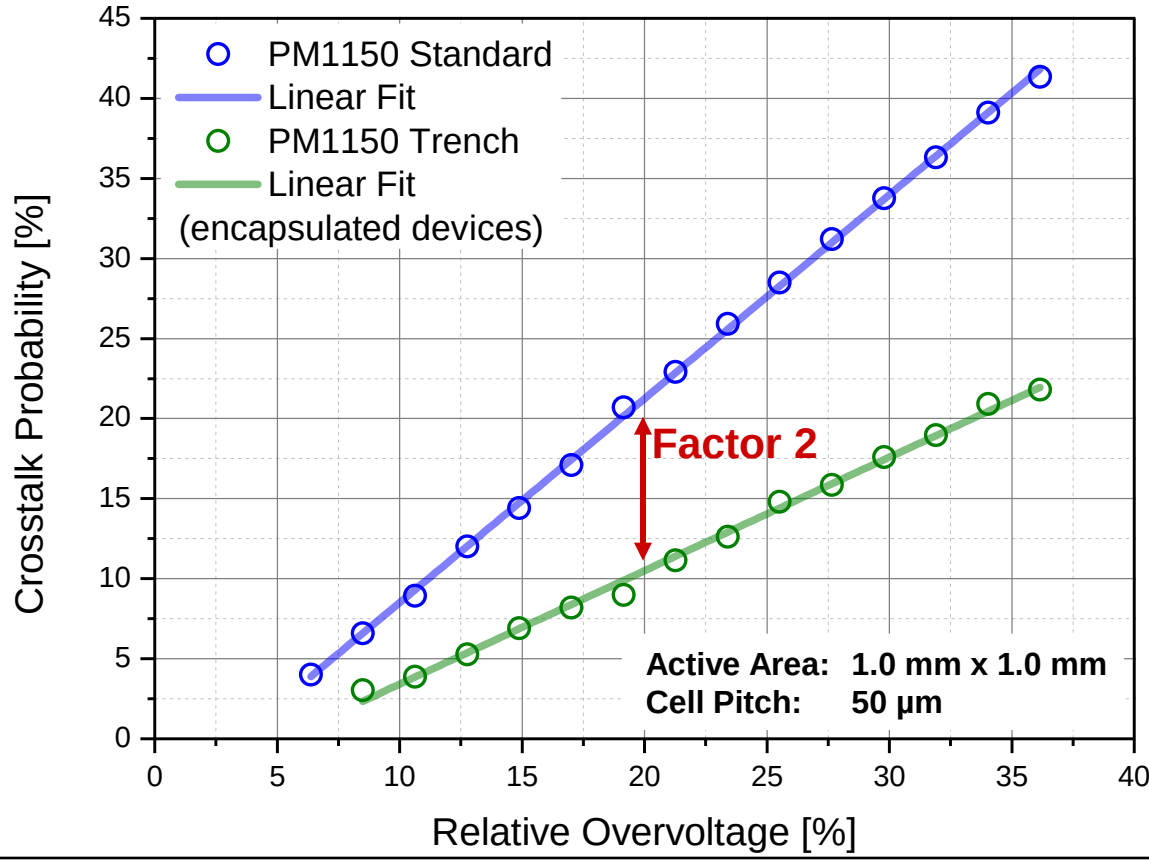
- standard technology ≤ **500 kHz/mm²**
- trench technology ≤ **300 kHz/mm²**

Optical Cross Talk

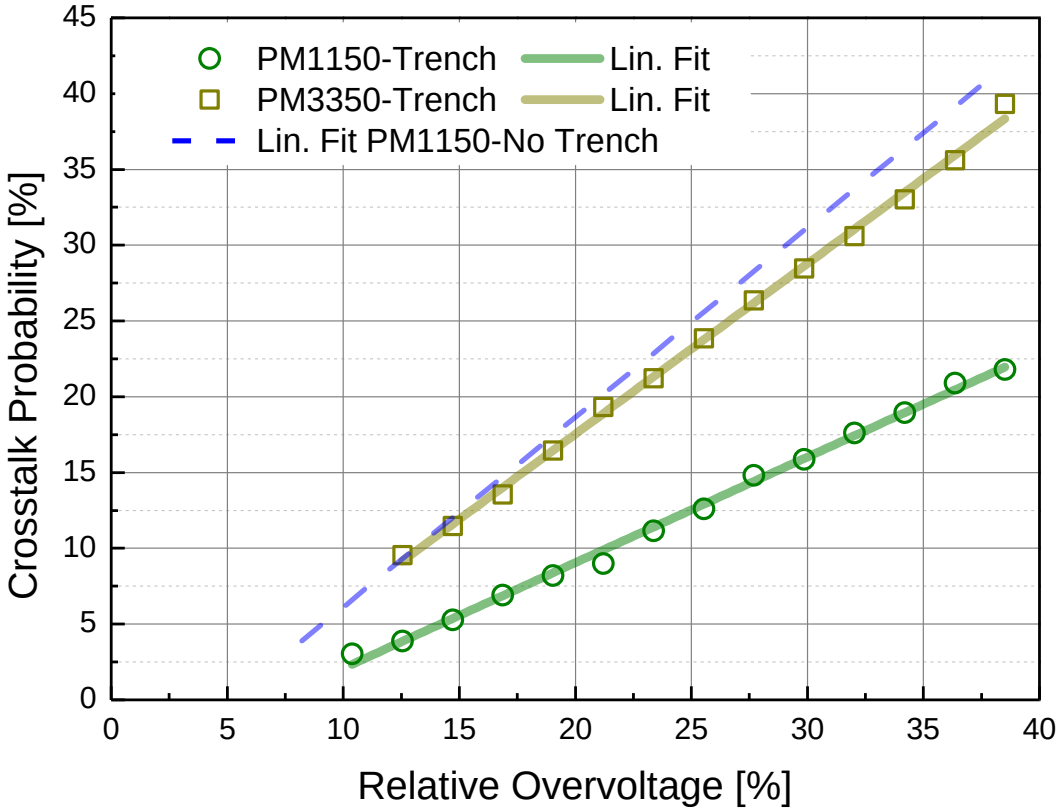


- Crosstalk evaluation based on dark rate versus threshold measurement
- PM1150 **no trench** and **trench** type encapsulated
- **10% crosstalk probability** at 20% overvoltage

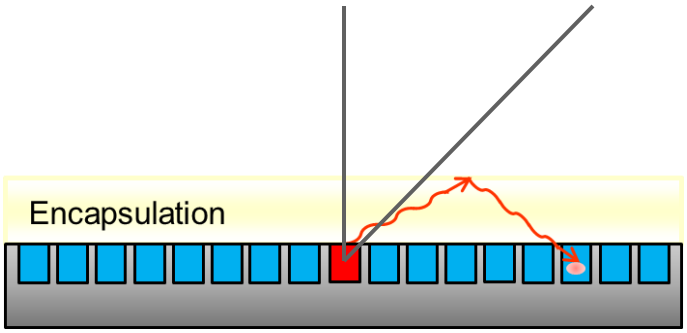
PM1150: No-Trench and Trench Type



Optical Cross Talk



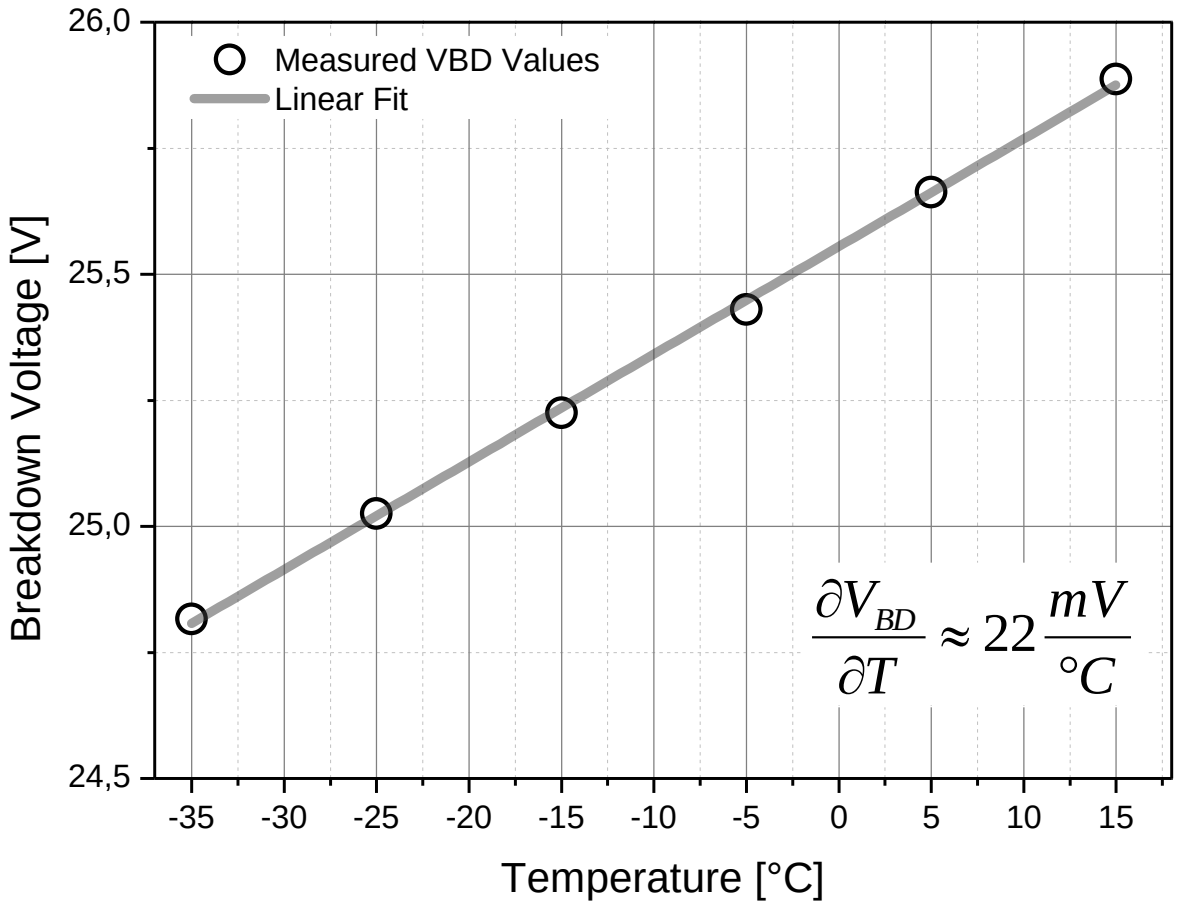
$\alpha_{max} \propto Device\ Size$



Section of Encapsulated Device

- The optical crosstalk probability increases with increasing active area
- Crosstalk probability of a **PM3350 with trench** is comparably to a **PM1150 without trench**
- Main contribution is caused by photons being reflected at the package interface

Temperature Coefficient of the Breakdown Voltage (V_{BD})



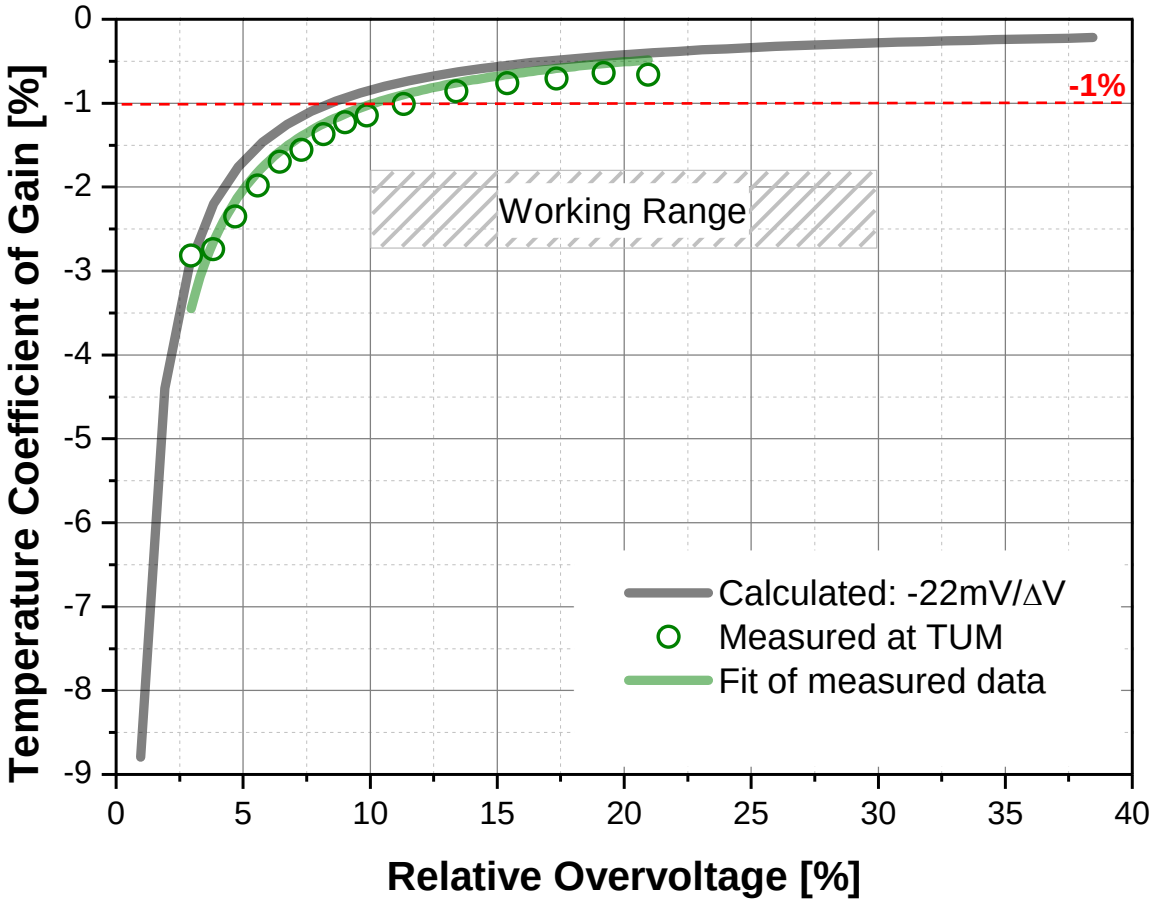
- Avalanche diodes have a positive temperature coefficient of the break down voltage
- For KETEK SiPMs this value is about **22 mV/°C**
- This temperature coefficient is affecting directly the temperature coefficient of the gain:

$$\frac{1}{G} \cdot \left(\frac{\partial G}{\partial T} \right) = -\frac{1}{\Delta V} \cdot \left(\frac{\partial V_{BD}}{\partial T} \right)$$

$$\approx \frac{-22mV}{\Delta V} \cdot K^{-1}$$

G	*Gain*
ΔV	*Overvoltage*
VBD	*Breakdown Voltage*
T	*Temperature*

Temperature Coefficient of the Gain



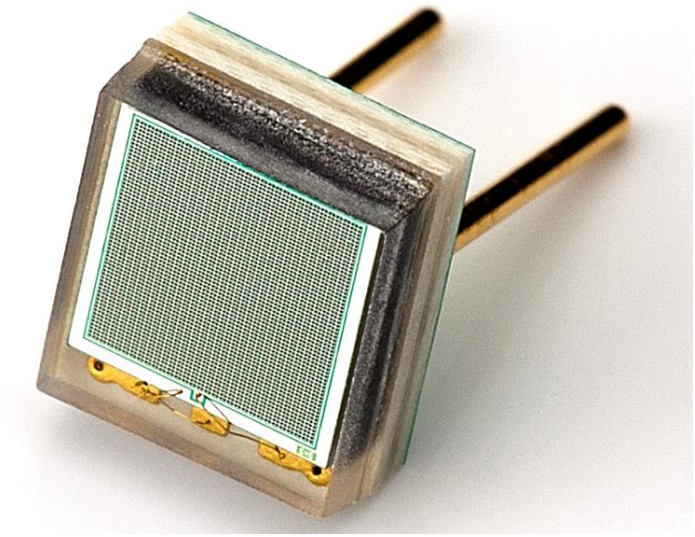
- With increasing overvoltage the temperature coefficient of the gain is decreasing drastically
- In the recommended working range of 10% to 30% OV the temperature coefficient of the gain is below 1%.

Huge Overvoltage + Very Small $\frac{\partial V_{BD}}{\partial T}$ = Minimal $\left|\frac{1}{G}\cdot\left(\frac{\partial G}{\partial T}\right)\right|$

Summary

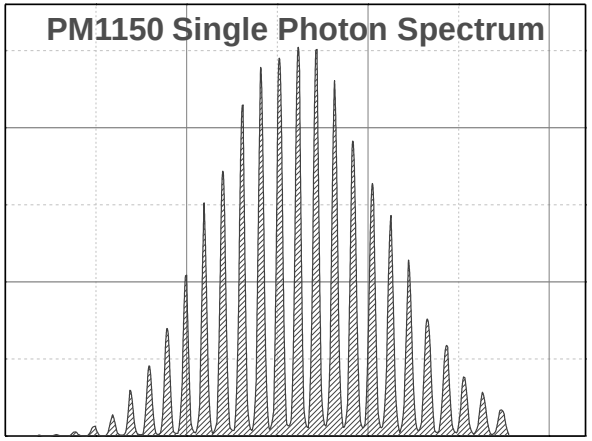
PM3350

3 x 3mm² active area; 50 µm microcell type;
peak wavelength 420 nm; plastic package



KETEK Silicon Photomultipliers
- Fast Single Photon Counting -

- High PDE up to **60 %** for 50µm cell type
- Optimized for **blue light sensitivity**
- Low dark count rate and low cross talk
- Huge bias voltage range of stable operation
- Extremely **low temperature coefficient**



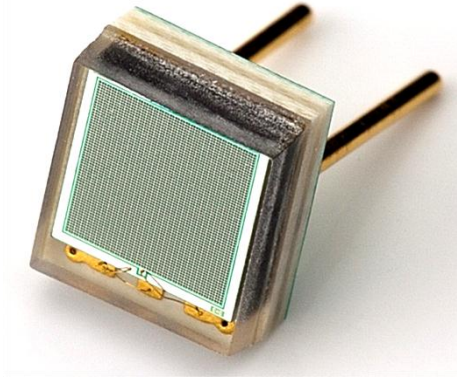
Additional Slides

Scheduled Portfolio - Completely Available until End 2012

	Active Area [mm]	Cell Pitch [µm]	Standard	Trench
PM11 SMD	1.2 x 1.2	50 µm	X	X
	1.2 x 1.2	75 µm	---	X
	1.2 x 1.2	100 µm	---	X
PM22 SMD	2.0 x 2.0	50 µm	X	X
	2.0 x 2.0	100 µm	---	X
PM33 Pin SMD	3.0 x 3.0	50 µm	X	X
	3.0 x 3.0	60 µm	X	X
	3.0 x 3.0	75 µm	X	X
PM66 - Pin	6.0 x 6.0	60 µm	---	X

PM3350 - Pin

3 x 3mm² active area; 50 µm cell type;
peak wavelength 420 nm; plastic package



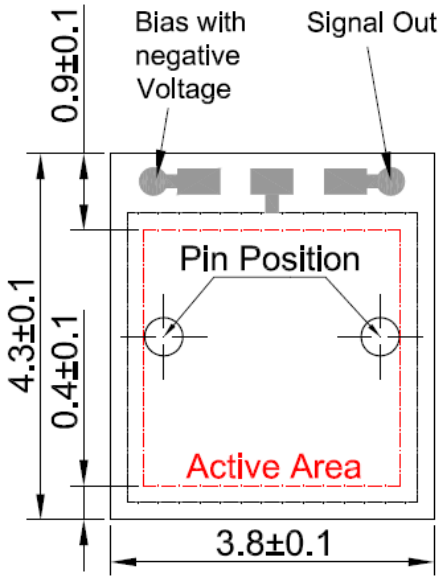
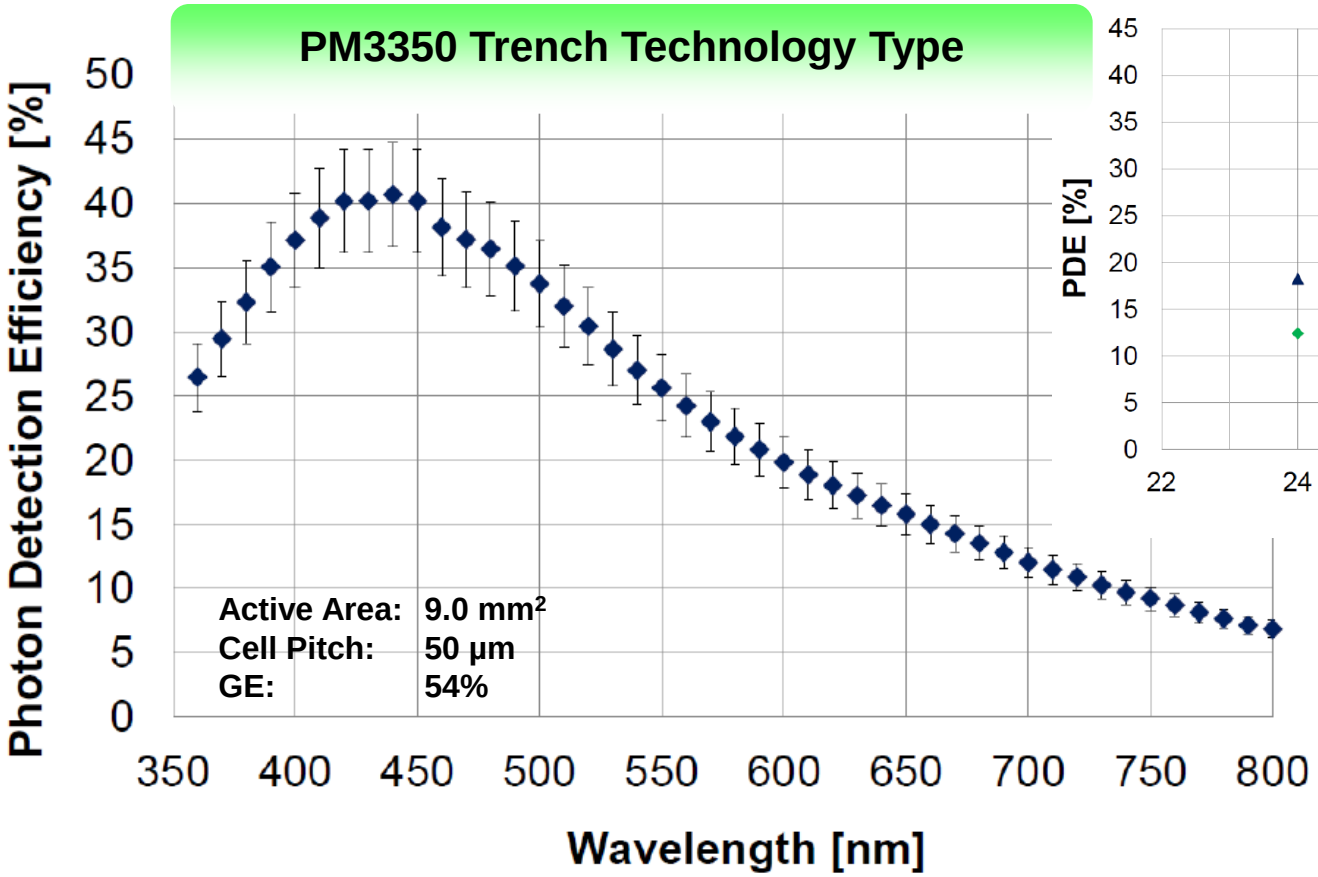
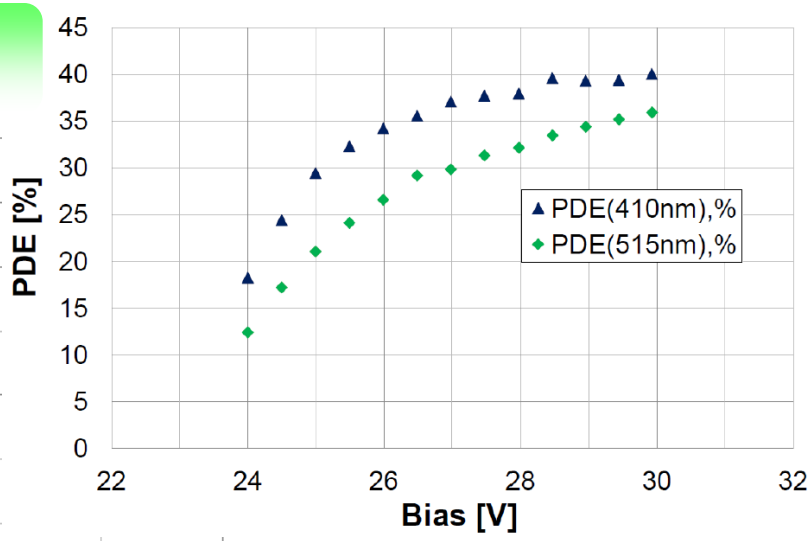


Photo Detection Efficiency measured at CERN (PM3350 Trench Type)

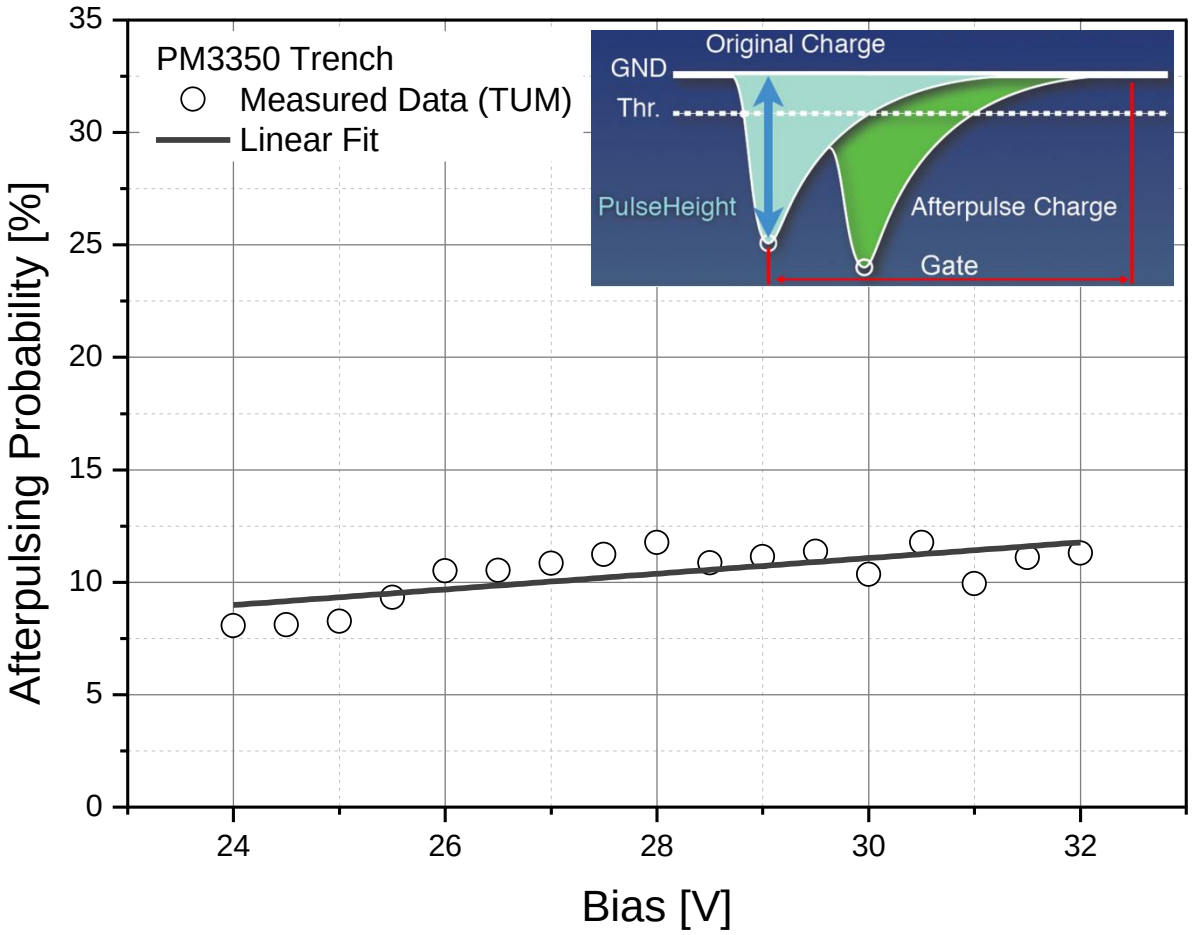




- Measurements performed by CERN / Iouri Musienko
- PDE is not affected by crosstalk and afterpulsing
- **40%** PDE for blue light (35% for green light)

After Pulsing

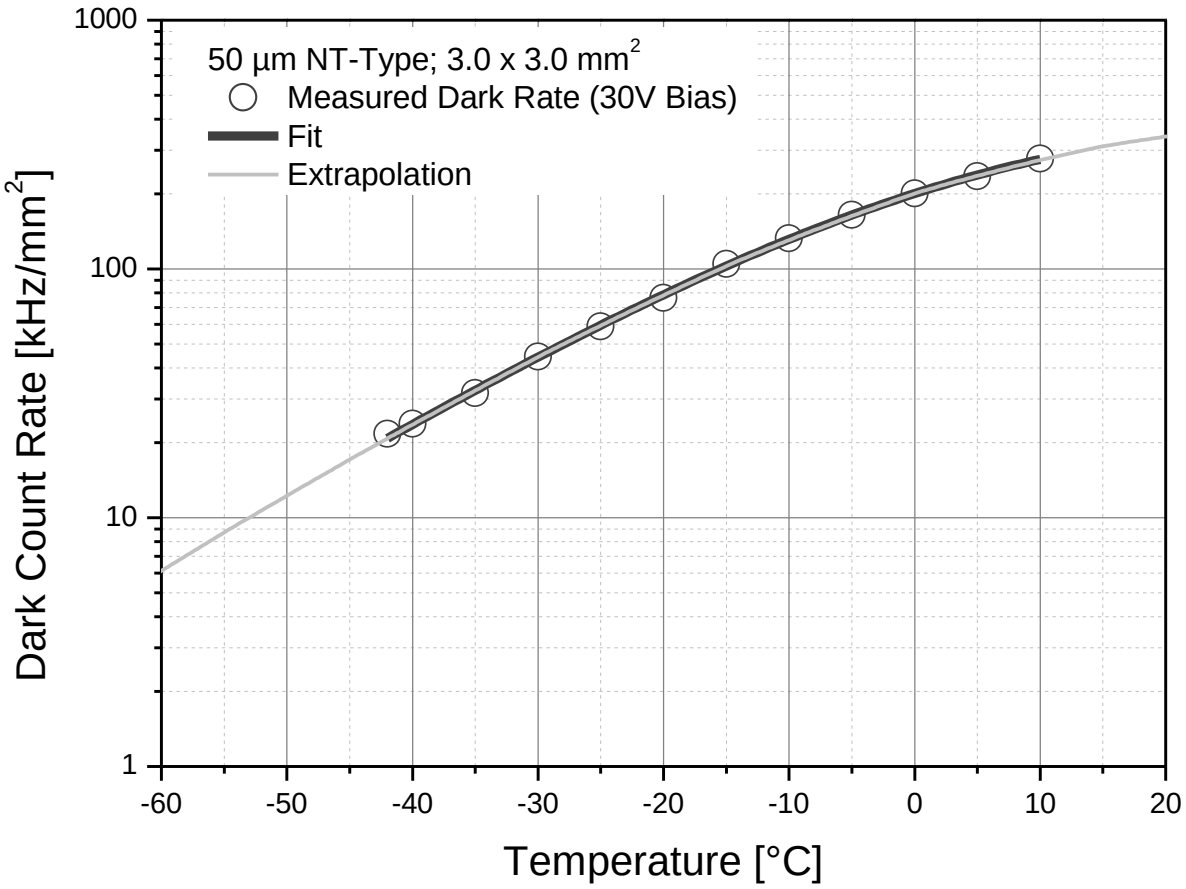
(50µm Standard Type)



- After pulses are generated by trapped and time delayed re-emitted electrons.
- Measurement is based on pulse counting of events within the recovery time of single pulses
- The real afterpulse probability is smaller
- The after pulse probability for KETEK devices is below 10%

SiPM Dark Rate vs Temperature

(50µm Standard Type)

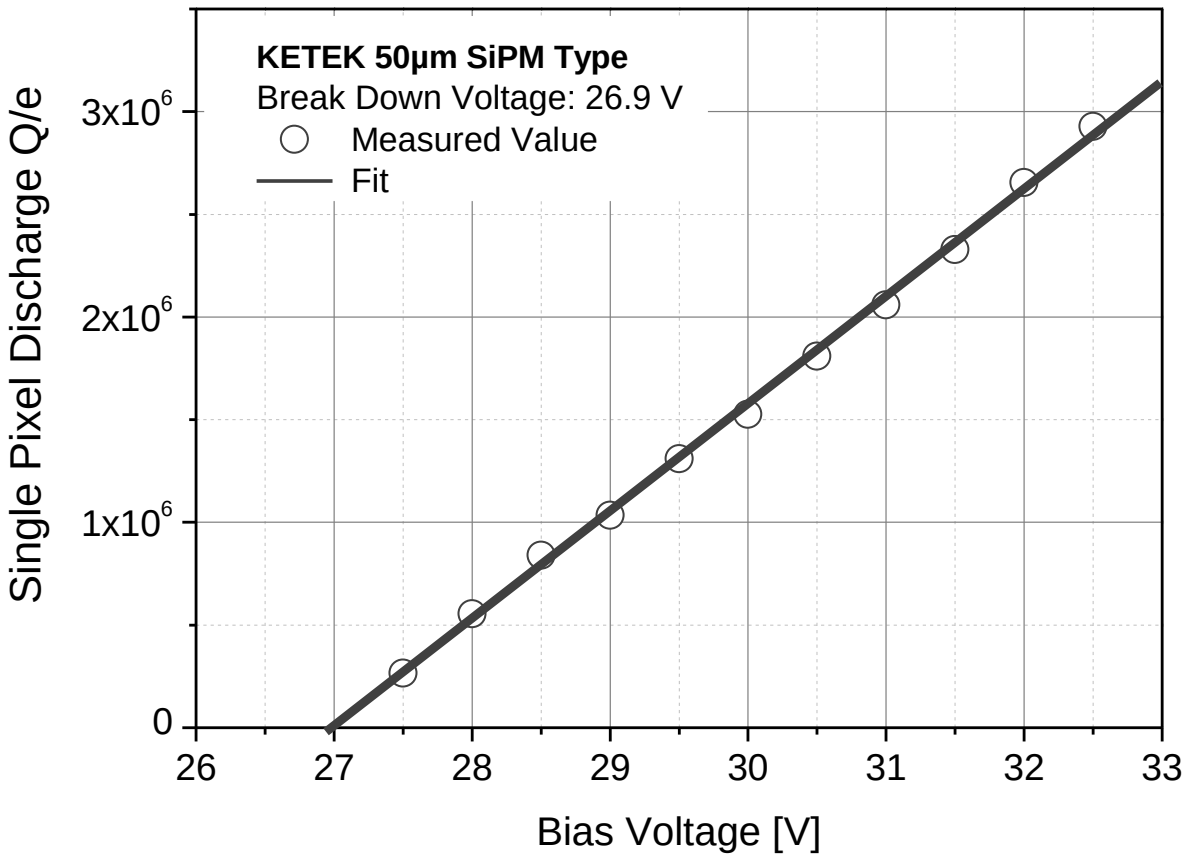


- The dark rate is scaling with the carrier density in silicon

$$n(T) \sim T^{1.5} \cdot e^{-\frac{E_g}{2 \cdot k \cdot T}}$$

- Additional effects like trapping and surface current cause deviations from this formula
- Rule of thumb:
  Every 10°C the dark rate is reduced by factor 2

Single Pixel Discharge and Gain (50µm Standard Type)



- The single pixel discharge defines the gain of a SiPM
- The real gain is slightly lower due to the excess noise (dark count rate, afterpulses, cross talk)
- For a KETEK SiPM the gain is approximately **2 Million** for a 50µm cell pitch device

$$Gain = \frac{C_{Pixel} \cdot \Delta V}{e} \propto GE \cdot \Delta V$$

C_{Pixel}	*Capacitance of Microcell*
ΔV	*Overvoltage*
GE	*Geometrical Efficiency*
e	*Elementary Charge*