Karlsruhe Institute of Technology

HELMHOLTZ ASSOCIATION

Alliance for Astroparticle Physics

Photosensors: new developments and applications

Institute for Nuclear Physics, Karlsruhe Institute of Technology

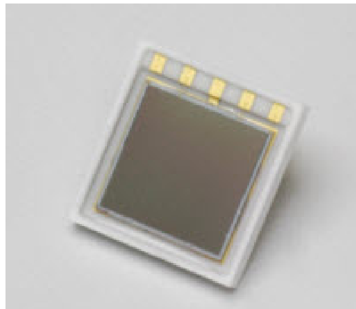
Parallel session at **„HAP Topic 4 Advanced technology“** workshop
Karlsruhe, 24-25 January, 2013

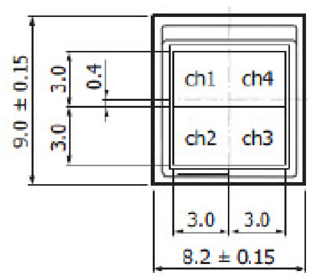
Parallel session: ~10 attendees, main focus on SiPM (Tim Niggemann)

Photon Detection Efficiency of SiPMs

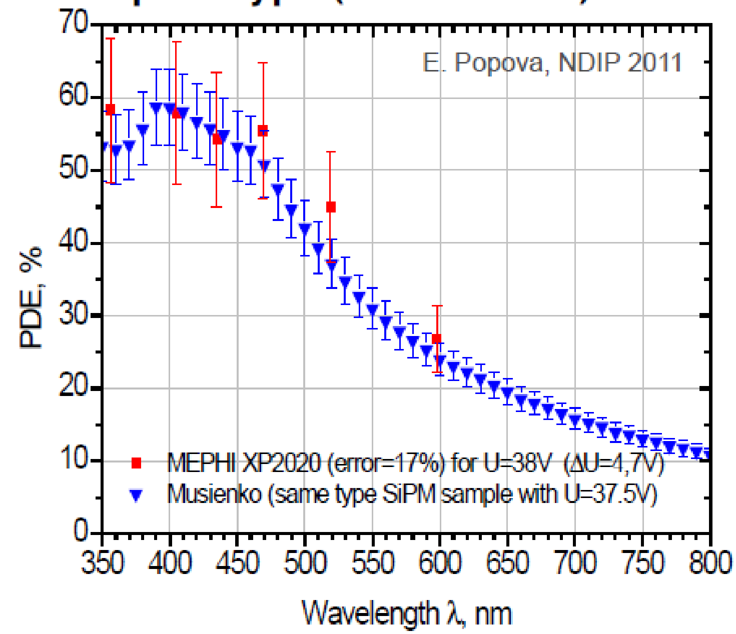
Hamamatsu S10985-100C

- 3600 cells
- PDE in UV regime $\approx 25\,\% - 36\,\%$
- Extensively studied in our laboratories
- Used for FAMOUS





SiPM prototype (MEPhI 100B)



Very high PDE in UV regime up to $60\,\%$
Not yet commercially available!

SiPM's:

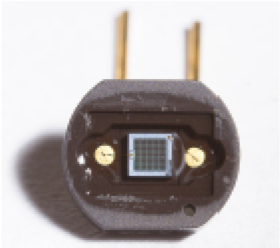
- Low bias voltage (<100V)
- Low power consumption
- Gain $10^5 - 10^7$
- PDE: 30-40%, up to 60% (UV)

PMT's:

- High bias voltage (1000V)
- Gain $10^6 - 10^7$
- PDE: up to 35% (UV)

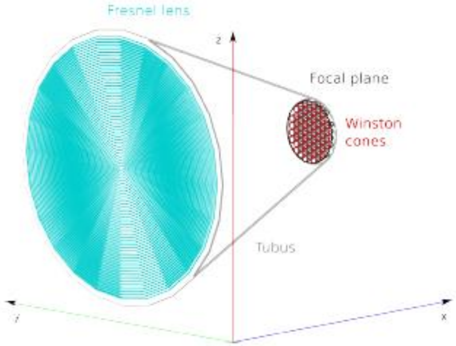
Weak points: Cross-talk, afterpulses, dark counts

- **Cross-talk**: At breakdown a micro-plasma is formed and e^- are lifted to high bands → relax with photon emission.



- **Afterpulses**: during the breakdown deep traps in the silicon are filled with carriers which are subsequently released.

- **Dark counts**: initiated by thermal generation or field-assisted generation (tunneling) of free carriers



Example: Ketek PM3350

DEVICE CHARACTERISTICS

GEOMETRICAL DATA	STANDARD	TRENCH
Active Sensor Area	$3.0 \times 3.0\ mm^2$	
Micropixel Size	$50 \times 50\ \mu m^2$	
Number of Pixel	3600	
Geometrical Efficiency	70 %	60 %

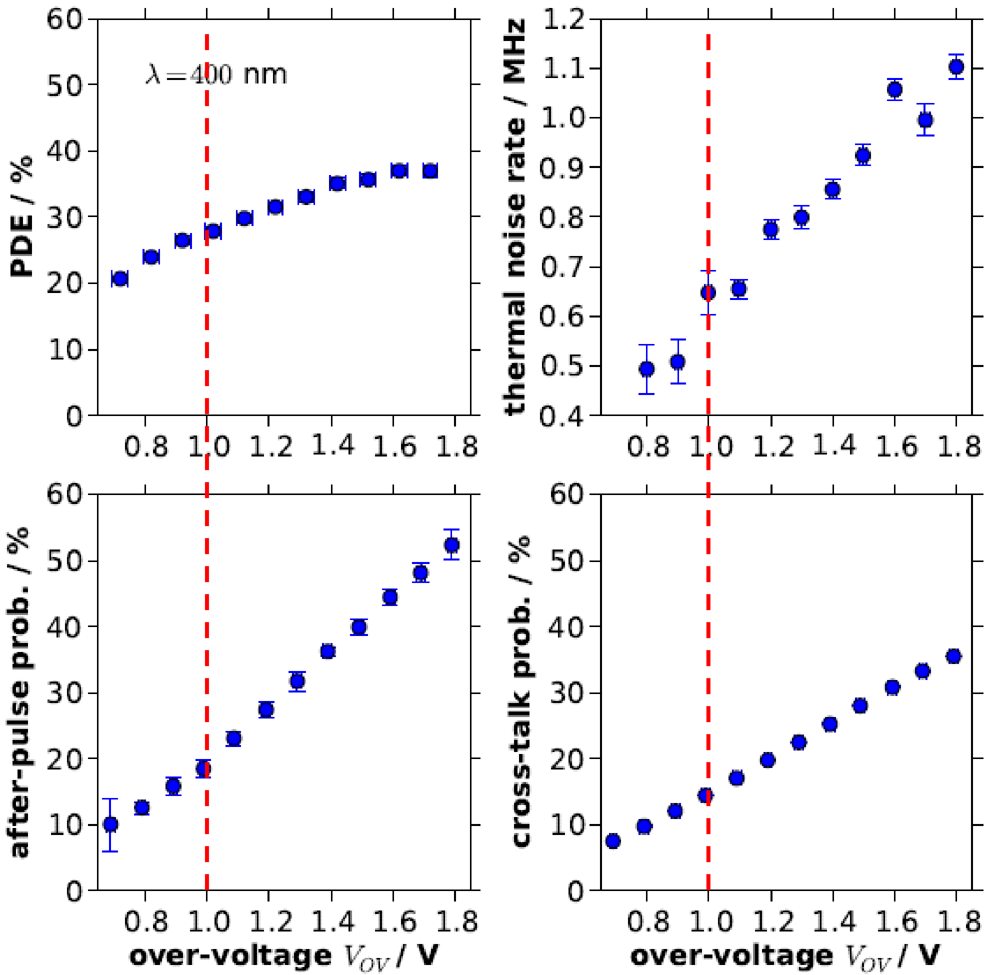
SPECTRAL PROPERTIES		
Spectral Range	300 to 800 nm	
Peak Wavelength	420 nm	
PDE[2] at 420 nm	≥ 50 %	≥ 40 %
Gain[1] M	$\sim 2 \times 10^6$	
Temp. Coeffiezient[1]	$\left\|\frac{1}{M}\cdot\frac{\partial M}{\partial T}\right\| \leq 1\ {}^\circ C^{-1}$	
Dark Rate[1]	$\leq 500\ kHz/mm^2$	$\leq 300\ kHz/mm^2$
Crosstalk[1]	~ 35 %	~ 20 %

ELETRICAL PROPERTIES		
Breakdown Voltage	27 (typ.) V	23 (typ.) V
Operation Voltage	20 % rel. Overvoltage	

(1) at 20% Overvoltage

(2) PDE measurement based on zero peak Poisson statistics; value not affected by cross talk

Cross-talk, afterpulses, temperature dep.



Overvoltage dependency of the Hamamatsu S10362-11-100C
$V_{OV} = V_{applied} - V_{breakdown}$

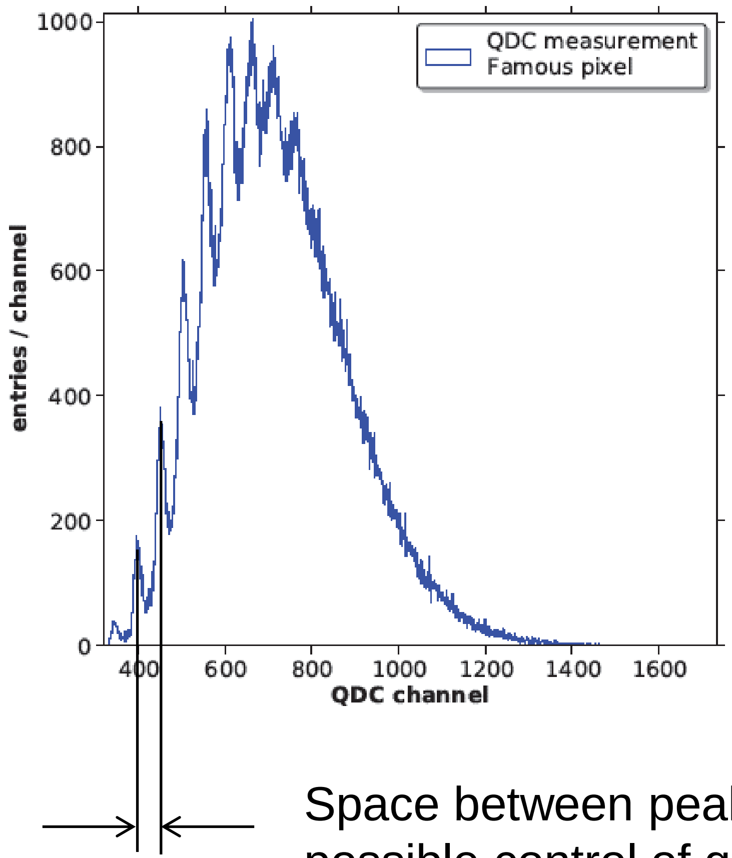
To remember: the breakdown Voltage changes with temperature, i.e. with constant $V_{applied} \rightarrow V_{OV}$ changes

e.g. gain changes too

e.g. 1V → 15% cross-talk

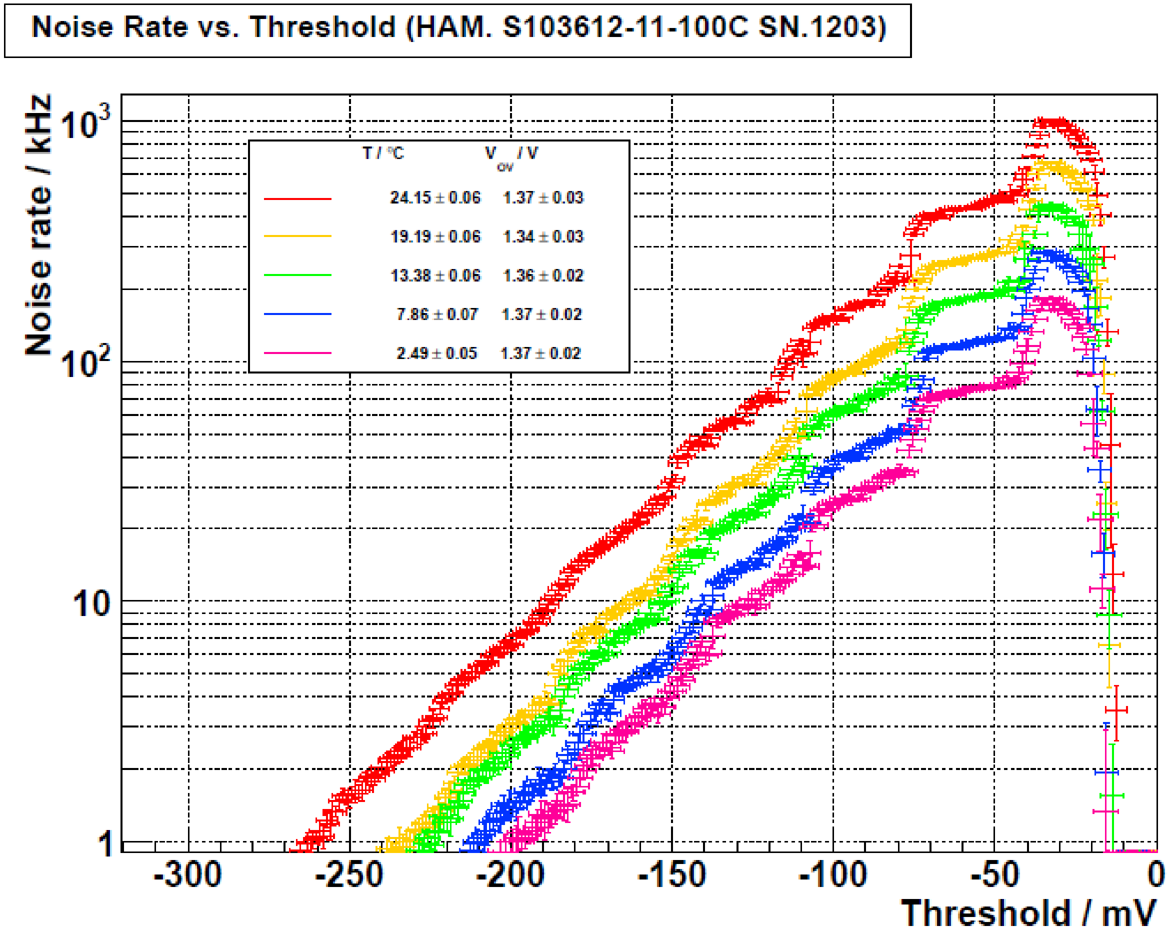
Gain control possibility

Charge Spectrum of a measurement
with a pusled UV LED



Space between peaks depends on gain, i.e.
possible control of gain fluctuations

Temperature dependence: Noise rate



Thermal noise rate vs. threshold for various temperatures T and constant overvoltage V_{OV} . Bachelor Thesis Johannes Schumacher

⇒ The rate reduces in first order by a factor of 2 every 8°C

⇒ It is of advantage to cool SiPM‘s down BUT one needs double glazing to avoid moistures, i.e. the transparency is also reduced

Simulation codes for SiPM

- **G4SiPM** – developed by the Auger and CMS groups in Aachen

  - based on Geant4

  - publicaly available soon (+ publication)

- Another one developed in Uni-Heidelberg:

  GosSiP - Generic framework for the simulation of Silicon Photomultipliers

  http://www.kip.uni-heidelberg.de/hep-detektoren/gossip

  - downloadable for free for Linux

  - ROOT based (root.cern.ch)

‚Big‘ players, i.e. SiPM producers

1. Hamamatsu Photonics, http://www.hamamatsu.com/

2. KETEK , http://www.ketek.net/

   Headquarter: Munich, Germany

3. Excelitas Technology, http://www.excelitas.com

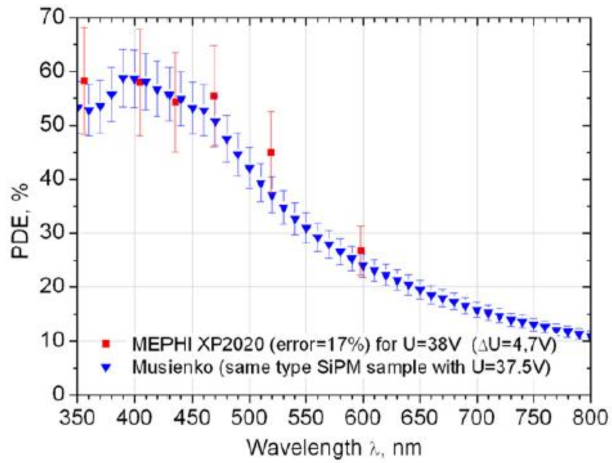


Fig. 4. The measured PDE of SiPM of type 100B. Square boxes: measurement performed in MEPhI, triangles: measured by Y. Musienko.

- PDE ~60% (400 nm)
- Cross-talk 3-5%
- Sensitivity of gain as *f*(T) 0.5%/°C
- Produced by MEPhI with strong help of EXCELITAS
- NIM A 695 (2012) 40-43

Conference / More info…

Karlsruhe Institute of Technology

Passed one but good source of information:

New Developments in Photodetection
(NDIP 2011, Lyon France), http://www.ndip.fr/
Proceedings: ***NIM A 695, p.1-444 (11 December 2012)***

- devoted to the latest developments in photodetection techniques down to single photon, over the entire electromagnetic spectrum
- *Detectors:* Photomultiplier Tubes, Hybrid photodetectors, Silicon Photomultiplier devices, solid-state detectors, gaseous photodetectors, polymer detectors and new sensing media,
- *Systems and instruments:* pixel arrays, front-end electronics, signal and image processing and fast timing techniques.

SPIE: is the international society for optics and photonics

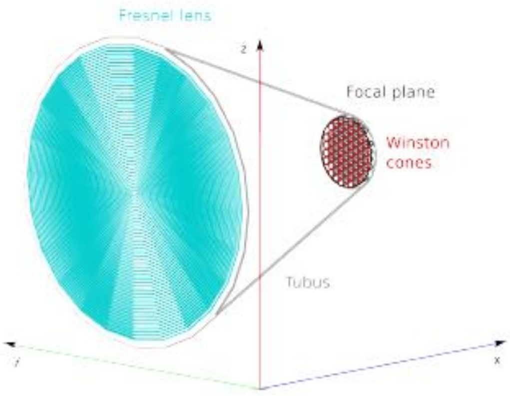
– Organize conferences, exhibitions, educational material
– http://www.spie.org

SPIE

Some other questions …

- What radioactive purity one can achieve with SiPM photosensors?
  => unknown but probably low. Any one else knows?

- Seems to be fine at temperatures of LXe
  (Xenon1T R&D ?), even better for the noise!



- One has to be careful with the Fresnel lens
  -> easy to scratch!

- Can be operated in high magnetic fields, e.g. 4T

- Recovery time ~30ns (Capacitance of the cell x Quenching resistor)

- Costs (example): some 200-300 EUR / SiPM (6x6 mm^2)

- Group in Aachen is the only one from HAP to work with SiPM
  (partners in Granada and Lisbon)

Original notes, questions

‘Start’: What we may discuss

- What is demand from our physics, i.e. Neutrinos, Cosmic rays, Dark matter searches, ...?
- What radioactive purity one can achieve with various photosensors? Any numbers?
- How large areas can be covered? QE, geometry efficiency, dark current?
- Special requirements for Electronics / DAQ?
- Operation of photosensors at low temperatures, e.g. LXe, 10mK?
- Simulation of photosensors, what packages are used, their advantages/disadvantages, someone experience (COMSOL)?
- Operation in strong magnetic field (e.g. 9T)?
- How can we benefit from HAP-internal collaborations?
- …

Discussion #1

Discussion on SiPM, what are disadvantages (Tim Niggemann):

- cross-talk in SiPM depends on overvoltage, optimal parameters 1V -> 15% due to a recombination of e- which happens with a photon emission
- Question of afterpulses
- KETEK PM3350
- New developments of Hamamatsu, replace the resistor with transperent film
- Temperature changes breakdown voltage, but can be corrected
- Costs: 10 for 350EUR each, then 250EUR each (6x6mm^2)
- Cooling chamber to reduce thermal noise, but if one goes <10C one has to avoid a moisture: double glazing
- 1 photon / ns / per pixel
- Trigger efficiency of FAMOUS: 10 showers per night with E~10^17eV
- Filter plate made of UG11
- Simulations: GosSiP another available code (ROOT based, GUIs)
- Studies of afterpulses: can be two-three components but analytical formula exist to fit it
- Recovery time 30ns (Capacitance of the cell x Quenching resistor)
- Tests up to 4T, also at T(LXe) (temperature noise basically zero)
- How many groups: Aachen, Granada, Lisbon

Discussion #1

– MEPhI more concentrated on gain stability, noise level but cross-talk isn‘t known. Patent is sold to a company

Question again and again: what is the temperature dependence?

- Breakdown voltage decreases with temperature
- Noise Rate vs. Threshold (HAM S103612-11-100C):
  Noise rate /kHz goes down by factor of 2 with every 8C.

– Fernel lense very sensitive to scratches, reflective optics is the way to go

SPIE:

Discussion #2

About PMT‘s

- Tests of linearity, was it done at different voltages
- Afterpulses were measured at the same gain of different PMTs