PhotoDet 2012 の報告

測定器開発室セミナー
2012.Jun.22

中村 勇 / 素核研
International Workshop on New Photon Detectors

PhotoDet 2012
June 13-15, 2012
LAL Orsay, France

Main topics:
The workshop focuses on new development in photosensors. Various types of new photo-sensors and their applications are covered and Geiger-mode multi pixel photon devices is one of the main targets.


Electronics: front-end and readout electronics

Applications: HEP, nuclear physics, cosmic ray physics, astronomy, cosmology, medical science

Local Organizing Committee:
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M. Teschma (Max-Planck)
J.C. Vanel (IPCM)
K. Yoshimura (KEK)

http://photodet2012.lal.in2p3.fr/
PhotoDet2012 workshop

- PD07(神戸), PD09(信州) に次ぐ第3 回
- 6 月 13-15 日 @ LAL-Orsay 参加費 150 Euro
- 登録参加者 116 人 (22 国)、32 talks, 37 Posters
- 3 Summary talks

https://indico.cern.ch/conferenceDisplay.py?confId=164917
Talk と Session 分布

● 3 Summary talks
  ● SiPM overview
  ● SiPM application
  ● SiPM readout

● Sessions
  ● SiPM (12 Talks)
  ● SiPM Application (7 Talks)
  ● SiPM Vacuum photodetectors (5 Talks)
  ● New Devices (2 Talks)
  ● Electronics (6 talks)

● 目立ったトピック (中村選)
  ● dSiPM
  ● Timing Resolution
  ● UV sensitive SiPM
  ● Analog Memory
SiPM General
The SiPM Physics and Technology - a Review -

G. Collazuol
Department of Physics and Astronomy, University of Padova and INFN

Overview

- Introduction
  - Key physics and technology features
    - I-V characteristics
      - Device response
      - Noises
    - Photo-detection efficiency
      - Timing properties
    - Summary and Future
Close up of a cell – custom process

**Shallow-Junction APD**
Example of implementation
*C.Piemonte NIM A 568 (2006) 224*

- Optical window note: light absorption in Si, SiO₂

- Optical dead region
- Optical isolation
- Trench (filled)
- Optical window
- Active volume
- Critical region:
  - Leakage current
  - Surface charges
  - Guard Ring for
    - preventing early edge-breakdown
    - isolating cells
    - tuning E field shape
    - impact on Fill Factor

- Critical region:
  - Leakage current
  - Surface charges
  - Guard Ring for
    - preventing early edge-breakdown
    - isolating cells
    - tuning E field shape
    - impact on Fill Factor

- Optimization for blue light (420nm)

- Shallow n⁺ layer (0.1 µm)
- (fully) depleted region (4 µm)
- Substrate low resistivity contact (500 µm)
- p⁺
- n⁺ on p abrupt junction structure
- Anti-reflective coating (ARC)
- Very thin (100nm) n⁺ layer: “low” doping → minimize Auger and SHR recombination
- Thin high-field region: “high” doping p layer → limited by tunneling breakdown → fixes \( V_{BD} \) junction well below \( V_{BD} \) at edge
- \( R_Q \) by poly-silicon
- Trenches for optical insulation (cross-talk)
- Fill factor: 20% - 80%

- \( \pi \) epitaxial
**CMOS vs Custom processes**

**“Standard” CMOS processes**
- shallow implant depths
- high doping concentrations
- shallow trench isolation (STI)
- deep well implants (flash extension)
- no extra gettering and high T annealing
- non optimized optical stacks
- design rule restrictions

- high E field
  - low $V_{bd}$
- tunneling
- lattice stress
  - defects/traps
- high DCR
- limited PDE
  - often p-on-n
- limited timing performances
  - (long diffusion tails)

**Recent progresses** in CMOS APDs due to:
1) **high voltage (flash) extension** often available in **standard** processes
   - deep wells (needed for the high voltages used in flash memories)

2) **Additional processes** (custom) available:
   - buried implants
   - deep trench isolation
   - optical stack optimization

**Key elements for CMOS SiPMs**
- **APD cell isolation** from CMOS circuitry
- **guard ring** (again)
Close up of a CMOS cell

**APD integration into CMOS**

Example of implementation  *T.Frach in US patent 2010/0127314*

Note
- extended CMOS processes exploited
- careful design of cell isolation and guard ring

**shallow isolation** (STI/LOCOS)

- optical window
- anode (p⁺)
- contact with buried layer

**epitaxial n** (active region)

- buried n (isolation layer)

epitaxial p

**deep isolation trench** (oxide/polysilicon filling)

**buried isolation layer** (also protection from substrate radiation induced carriers)

**APD cell isolated by multiple wells from CMOS circuitry**

Example of

**NMOS FET** of the RO electronics

substrate (gettering sites)

s g d

---

Note • extended CMOS processes exploited
• careful design of cell isolation and guard ring

T.Frach in US patent 2010/0127314
Basic electrical model

Fast Capacitor (cell) discharge and slow recharge (roughly speaking)

\[ i(t) = \text{exp}(-t/\tau_d) \]

\[ 1 - \text{exp}(-t/\tau_q) \]

99% recovery time \( \sim 5 \tau_q \)

Rise time: \( \tau_d = R_d C_d \)

Fall time (recovery): \( \tau_q = R_q C_d \)

\[ \Delta V \rightarrow \text{independent of } T \]

Gain \( \sim C \Delta V \rightarrow \) independent of \( T \)

at fixed Over-Voltage \( (\Delta V = V_{\text{bias}} - V_{bd}) \)

Recovery time: \( T \) dependence due to \( R_q \)

\( C_d \) is independent of \( T \)

\( T \) dependent (to lesser extent) due to \( R_d \)
SiPM equivalent circuit (detailed model)

Single cell model → \((R_d||C_d)+(R_q||C_q)\)
SiPM + load → \((||Z_{cell})||C_{grid} + Z_{load}\)

Signal = slow pulse \((\tau_d\text{ (rise)}, \tau_{slow}\text{ (fall)}) + + fast pulse \((\tau_d\text{ (rise)}, \tau_{fast}\text{ (fall)})\)

- \(\tau_d\text{ (rise)} \sim R_d\text{ (C}_q\text{ + C}_d\text{)}\)
- \(\tau_{fast}\text{ (fall)} = R_{load}\text{ C}_\text{tot}\) \(\text{ (fast; parasitic spike)}\)
- \(\tau_{slow}\text{ (fall)} = R_q\text{ (C}_q\text{ + C}_d\text{)} \) \(\text{ (slow; cell recovery)}\)

\(F. Corsi, et al. NIM A572 (2007) 416\)
\(S. Seifert et al. IEEE TNS 56 (2009) 3726\)

Cq → fast current supply path in the beginning of avalanche

Pulse shape

- Rise: Exponential
- Fall: Sum of 2 exponentials

\[ V(t) \approx \frac{Q}{C_q+C_d} \left( C_q \frac{e^{-t/\tau_{\text{FAST}}}}{R_{load}} + C_d \frac{e^{-t/\tau_{\text{SLOW}}}}{R_q} \right) \]

for \(R_{load} \ll R_q\)

where \(Q = \Delta V\text{ (C}_q\text{ + C}_d\text{)}\) is the total charge released by the cell

\[ \rightarrow \text{'prompt' charge on } C_{\text{tot}} \text{ is } Q_{\text{fast}} = Q \text{ C}_q/(\text{C}_q\text{ + C}_d) \]
**Pulse shape**

\[ V(t) \simeq \frac{Q}{C_q + C_d} \left( \frac{C_q}{C_{tot}} e^{-t/\tau_{fast}} + \frac{R_{load}}{R_q} \frac{C_d}{C_q + C_d} e^{-t/\tau_{slow}} \right) = \frac{QR_{load}}{C_q + C_d} \left( \frac{C_q}{\tau_{fast}} e^{-t/\tau_{fast}} + \frac{C_d}{\tau_{slow}} e^{-t/\tau_{slow}} \right) \]

→ gain \[ G = \int dt \frac{V(t)}{q_e R_{load}} = \frac{Q}{q_e} = \frac{\Delta V (C_d + C_q)}{q_e} \text{ independent of } R_q \]

→ charge ratio \[ \frac{Q_{slow}}{Q_{fast}} \sim \frac{C_d}{C_q} \]

\[ V_{\text{max}} \rightarrow \text{peak voltage on } R_{\text{load}} \]

\[ V_{\text{max}} \sim R_{\text{load}} \left( \frac{Q_{fast}}{\tau_{fast}} + \frac{Q_{slow}}{\tau_{slow}} \right) \text{ dependent on } R_q \]

(increasing with \(1/R_q\))

\[ \frac{V_{\text{max}}}{V_{\text{fast}}} \sim \frac{C_q C_{tot} R_{load}}{C_d^2 R_q} \]

→ peak height ratio

- \(C_d = 10\text{fF}\)
- \(C_q = C_d\)
- \(C_q = 10\text{pF}\)
- \(R_q = 400\text{k\Omega}\)
- \(R_q = 50\text{\Omega}\)

Note: valid for low impedance load \(R_{\text{load}} << R_q\)

- \(\tau_{fast} = R_{\text{load}} C_{\text{tot}}\)
- \(\tau_{slow} = R_q (C_q + C_d)\)

increasing with \(C_d\) and \(1/R_q\)
Optimizing signal shape for timing

Single cell model → $(R_d || C_d) + (R_q || C_q)$
SiPM + load → $(|| Z_{cell}) || C_{grid} + Z_{load}$

Signal = slow pulse ($\tau_d$ (rise), $\tau_q$-slow (fall)) +
+ fast pulse ($\tau_d$ (rise), $\tau_q$-fast (fall))

• $\tau_d$ (rise) $\sim$ $R_d(C_q + C_d)$
• $\tau_q$-fast (fall) = $R_{load} C_{tot}$ (fast; parasitic spike)
• $\tau_q$-slow (fall) = $R_q (C_q + C_d)$ (slow; cell recovery)

Pulse shape

$$V(t) \approx \frac{Q}{C_q + C_d} \left( \frac{C_q}{C_{tot}} e^{-\frac{t}{\tau_{FAST}}} + \frac{R_{load}}{R_q} \frac{C_d}{C_q + C_d} e^{-\frac{t}{\tau_{SLOW}}} \right)$$

$V_{max}$

→ charge ratio

$$\frac{Q_{fast}}{Q_{slow}} \sim \frac{C_q}{C_d}$$

→ peak height ratio

$$\frac{V_{max\_fast}}{V_{max\_slow}} \sim \frac{C_q^2 R_q}{C_d C_{tot} R_{load}}$$

Increasing $C_q/C_d$ or/and $R_q/R_{load}$
→ spike enhancement
→ better timing

$C_d = 10fF$
$C_q = C_d$
$C_g = 10pF$
$R_d = 400k\Omega$
$R_q = 50\Omega$
Overview of Multicell Geiger-mode Avalanche Photodiodes (SiPM) Applications

Gabriela Llosá,
Instituto de Física Corpuscular - IFIC (CSIC-UV), Valencia, Spain

IRIS group  http://ific.uv.es/iris

CMS Outer Hadron Calorimeter (HO) upgrade

- Replace HO HPD (susceptible to discharge at intermediate B fields) with SiliconPhotoMultipliers (SiPM)
  - SiPM PDE >2x HPDs and gain a factor of 50 to 500 larger;
  - Compact and Vbias ~100V compared to ~10KV for HPDs;
  - Not affected by magnetic fields
- Scintillator/wavelengthshifting fiber.

Board with 18 MPPCs and Peltier on the back. Temp stabilization system.

- Components (2200 SIPMs, 160 SIPM Mounting Boards, 160 Control Boards) built and tested. Electronics will be complete by the end of 2012.
- The full HO SIPM system will be installed during the LHC LS1 shutdown in 2013.
BELLE II Particle ID detector upgrade

- Proximity focusing Aerogel RICH considered for the forward particle ID detector upgrade.
- Req: limited space, mag field 1.5 T, rad damage (neutrons).
- Light guides to concentrate light on MPPCs. Pyramidal light concentrators (different options considered).
- Module with 64, 1 mm\(^2\) MPPCs and light guide array.

S. Korpar et al. NIMA. In press.
PEBS

- Positron Electron Balloon Spectrometer for measurement of cosmic ray electron and positron flux up to the TeV scale.
  - Cheaper than space detectors
  - Multiple flights
  - Reoptimization between flights
- ECAL aimed at rejecting proton background. Large area, high resol, low power and low weight. (PEBS1 ECAL: Weight ~2000 kg Power Consumption ~900 W).
  - Scintillating bars (7.75 x 3 x 837 mm³), optically isolated with embedded WLS fibres. Tungsten absorber plates.
  - MPPCs (Hamamatsu) adapted, 1.4 x 1.4 mm², 25 x 25μm² microcell size.
  - Readout with SPIROC chip.
  - Monitoring system and temp controller with Peltier.
- Proton rejection better than $10^{-3}$ up to 50 GeV
MU-RAY telescope

- Study density variations in volcanoes through muon radiography. Resol (optimal ~10 m) can be better than with gravimetric techniques - eventual anomalies.
- Detect horizontal muons through volcano. Energy loss in rock. Need to know the morphology.
- Telescope: Tracking capability with millirad resolution, low cost, low consumption, resistant, temp var > 60°C.

Principal investigators INFN and Univ. Naples

Pictures courtesy R. D'Alessandro.
SiPMs in PET: innovative designs

Several layers of 0.8 mm crystals

PS-SiPMs

Crystals of 0.5 mm resolved

Song et al. PMB 2010

Mc Clish et al. 2010 IEEE NSS MIC Conf Rec
SiPMs in PET: full working ring

Small animal PET ring

Two types of LGSO crystals (phoswich)
1.1mm x 1.2mm x 5mm
1.1mm x 1.2mm x 6mm

Images of mice obtained

Yamamoto et al.
PMB 2010

Already tested in PET/MR applications.
(Presented in PSMR 2012)
SiPMs in PET: PET/MR

- Simultaneous combination of PET and MR imaging modalities.
- Provides very high resolution anatomical reference with no additional radiation (as CT).
- SiPMs: 'photodetectors of choice'.

Hyperimage + Sublima

- SiPMs from FBK-irst
- PETA3 ASIC

C. Piemonte et al.  
PSMR 2012
PETに関しては
http://agenda.infn.it/conferenceOtherViews.py?confId=3899
Delayed avalanche in SiPMs and especially MPPCs

Fabrice Retiere and Kyle Boone
(Undergraduate student)
With help from Y. Iwai (Hamamatsu)
Cross-talk and after-pulse

• Cross-talk
  – Prompt = by definition
  – Origin: photons produced in the avalanche absorbed in neighboring high field region

• After-pulse
  – Delayed = by definition
  – “Usual” origin: carrier produced in the avalanche trapped on impurities
  – Alternative origin: photons absorbed in bulk
    • Delay due to diffusion
    • Lets test this hypothesis
Use external light source

Spectrum of photons emitted in MPPC avalanches

- Setup
  - Light sources: 404, 437, 637, 820nm
    - Pulse width and jitter <80ps
    - 820nm lent to us by Hamamatsu thanks to Y. Iwai
  - MPPC (or other SiPM)
  - High speed amplifier
  - Oscilloscope to record waveforms
  - Temperature controlled chamber

Analysis method

- Look for pulses within a 1us window
- Accept only events with 1 pulse to avoid after-pulse
  - Set the light level to maximize efficiency
- Subtract out the noise contribution
  - Measure prior to light pulse
- Normalize distribution to one
- Fit prompt peak by the convolution of a Gaussian and exponential
Look beyond the prompt pulse
Evidence for delayed avalanches

T2K MPPC, -60C, ΔV~1.5V

T2K MPPC, 20C, ΔV~1.5V

Time of the prompt peak set to 0.3 ns to show well on the logX plot

13/06/2012
Dark noise is an issue at 20C

- Large correction in the tail. Limit the statistical accuracy
- Prompt peak a bit wider at 20C
- Tail does not seem to change
  - Expected because the coefficient of diffusion vary weakly with temperature
Over-voltage dependence

T2K MPPC, 820 nm, -60°C
Summary

• Delayed avalanches clearly visible at 637 and 820 nm
  – Late avalanche probability increase with $\Delta V$
  – Timing distribution mostly unaffected by $\Delta V$
  – Weak dependence with temperature
  – More late avalanches for Hamamatsu than Excelitas

• Phenomena consistent with holes created in the bulk diffusing back to junction
  – Simulations can reproduce the data
  – Several free parameters because junction structure is unknown

• Phenomena can explain after-pulsing
  – Required x2 photon flux however
Study of MPPC with Multiwavelength Laser Microscope system

Koji YOSHIMURA and Isamu NAKAMURA for KEK Detector R&D Group
Motivation

Why is multi-wavelength light useful for study PPDs?

Variety of applications which cover different range of wavelength

Understanding of sensor structure and mechanism

Orme’s Study (PD’09)
Geiger Efficiency

Simulation Results

- **Electron Seed**
  - Saturated at high bias voltages

- **Hole Seed**
  - Linear relationship between bias voltage and avalanche probability

**Impact ionization prob.**

- 1 order of magnitude difference between electron and hole

**Graph:**
- X-axis: Bias Voltage [V]
- Y-axis: Avalanche Probability

**Figure:**
- Comparison of electron and hole avalanche probabilities as a function of bias voltage.

**Note:**
- H. Otono, et al., PANIC08
New stage for sample switching

Reference PMT

Laser

MPPC

150 mm span
PDE vs Wavelength

PDE vs Wavelength

Very Preliminary

Over voltage
0.25 - 1.1 V

Reference

Wave length (nm)
Very Preliminary
Normalized PDE

PDE vs HV

Very Preliminary
dSiPM
Initial Experience with Digital SiPMs in Detectors for Time-of-Flight PET

D. R. Schaart, G. Borghi, H. T. van Dam, G. J. van der Lei, S. Seifert, V. Tabacchini

PhotoDet 2012, Orsay, 14-Jun-2012
SiPM arrays – some examples

Individual readout of array elements => position-sensitive light sensor
Digital SiPMs

**Analog Silicon Photomultiplier**

- SiPM
- Vbias
- Readout ASIC
  - Discriminator
  - TDC
  - Shaper
  - Integral
  - ADC
- Time
- Energy

**Digital Silicon Photomultiplier**

- Vbias
- Cell Electronics
- Recharge
- Detector + Readout
  - Trigger Network
  - TDC
  - Photon Counter
- Time
- Energy

---

dSiPM provides a digital timestamp and the photon count for each light pulse, without the need of any analog front-end electronics.
dSiPM array

- dSiPM pixels: 64 (8x8)
- Microcells per pixel:
  - 6396 (DPC-6400-44-22)
  - 3200 (DPC-3200-44-22)
- Silicon dies: 16 (4x4)
- Sub-pixels per pixel: 4 (2x2)
- Array size: 32 mm x 32 mm

Magnifying glass shows 1 Si die
Test setup: initial timing measurements

- Stepper motors X and Y
- dSiPM array
- Flatcable
- Daughterboard
- Motherboard
- Temperature chamber
- Tungsten collimator
- Exit hole Ø 0.5 mm
- Na-22
- 3 mm x 3 mm x 5 mm LSO:Ce,Ca
- USB
- PC

Dennis R. Schaart
Delft University of Technology
Timing resolution

Two coincident detectors:
- DPC-3200-44-22 dSiPM arrays
- 3 x 3 x 5 mm³ LSO:Ce,Ca crystals

Timing spectra at different positions of one of the two detectors. The step size is 20 mm. The average coincidence resolving time (CRT) is 123 ps FWHM.
Monolithic scintillator detectors

Light distribution depends on the entry point on the front surface...

...and on the depth of interaction (DOI).
Monolithic scintillator detectors

Compared to segmented crystals:

• Intrinsic depth of interaction (DOI), even with single-sided readout
• High sensitivity (100% packing fraction)
• Easier crystal surface processing and detector assembly
• Fewer reflections of scintillation photons before reaching sensor
  • Fewer losses
  • Smaller transient time spread

=> intrinsically better characteristics?
The monolithic scintillator 2.0

Monolithic TOF/DOI detector with improved performance due to Ca co-doped LSO scintillator, digital photon counting (dSiPM), and optimized readout algorithms

24 mm x 24 mm x 10 mm LSO:Ce, Ca scintillator on PDPC digital SiPM array

Spatial resolution

20 mm thick crystal

• 16 x 16 x 20 mm$^3$ LSO:Ce,Ca
• DPC-3200-44-22 array
• Smoothed k-NN method
  \[ n_{\text{ref}} = 100 \]
• Measured at -25 °C
• Crystal average:
  • $x$: 1.89 mm FWHM
  • $y$: 1.79 mm FWHM
• Uncorrected for beam diameter

Coincidence resolving time

10 mm thick crystal

CRT for 2 detectors: 167 ps FWHM

Timing measurement against 85 ps FWHM reference detector

- 24 x 24 x 10 mm$^3$ LSO:Ce,Ca
- DPC-3200-44-22 array
- Measured at -25 °C
- Corrected for electronic skews of individual Si dies (50 ps laser measurement)
- Corrected for mean optical transit time, given the (x,y) interaction position

Preliminary results
Sub-mm resolution, TOF & DOI!

Summary of first results with LSO:Ce,Ca monolithic scintillators on digital SiPM arrays:

- Coincidence resolving time $\leq$ 200 ps FWHM
- $< 1$ mm FWHM resolution (height = 10 mm)
- $< 2$ mm FWHM resolution (height = 20 mm)
- 11% - 12% FWHM energy resolution
- Intrinsic depth-of-interaction (DOI) information

$\Rightarrow$ A highly promising detector concept for clinical PET/CT and PET/MRI
Technical Evaluation Kit

- Our evaluation kit is made of:
  - 2 DLS 3200 sensor with 3200 cells per pixel
  - 2 DLS 6400 sensor with 6400 cells per pixel
  - 4 kapton cables
  - One base to connect the tiles
  - One power supply
  - One computer for detector configuration and data acquisition

<table>
<thead>
<tr>
<th>Few characteristics</th>
<th>DLS 6400</th>
<th>DLS 3200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell size [μm²]</td>
<td>30 x 50</td>
<td>59.4 x 64</td>
</tr>
<tr>
<td>Fill factor [%]</td>
<td>54</td>
<td>78 (→ 84)</td>
</tr>
<tr>
<td>PDE [%] @ 420 nm</td>
<td>30</td>
<td>43 (→ 47)</td>
</tr>
<tr>
<td>DCR [MHz/pixel] @20°C</td>
<td>&lt;5</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Op. voltage [V]</td>
<td>&lt; 35</td>
<td></td>
</tr>
<tr>
<td>Temp. dep of PDE [% / K]</td>
<td>- 0.33</td>
<td></td>
</tr>
</tbody>
</table>

MPPC:
3600 cells
3x3 mm²

32 mm
Timing Resolution
The SiPM Physics and Technology
- a Review -

G. Collazuol
Department of Physics and Astronomy, University of Padova and INFN

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  - Summary and Future
GM-APD avalanche development

(1) Avalanche "seed": free-carrier concentration rises exponentially by "longitudinal" multiplication.

(1') Electric field locally lowered (by space charge R effect) towards breakdown level.

Multiplication is self-sustaining. Avalanche current steady until new multiplication triggered in near regions.

(2) Avalanche spreads "transversally" across the junction.

(diffusion speed ~up to 50µm/ns enhanced by multiplication)

(2') Passive quenching mechanism effective after transverse avalanche size ~10µm.

(if no quench, avalanche spreads over the whole active depletion volume → avalanche current reaches a final saturation steady state value.)
GM-APD avalanche transverse propagation

Avalanche transverse propagation by a kind of shock wave: the wavefront carries a high density of carriers and high E field gradients (inside: carriers' density lower and E field decreasing toward breakdown level)

\[
\frac{dS}{dt} = \frac{d}{dt} 2\pi r(t) \Delta r = 2\pi \nu_{diff} \Delta r = 4\pi \Delta r \sqrt{\frac{D}{\tau}}
\]

Rate of current production:

\[
\frac{dI}{dt} = \frac{dI}{dS} \frac{dS}{dt} \sim \frac{\sqrt{D}}{R_{sp} \sqrt{\tau}}
\]

Rate of current production:

\[
\frac{dI}{dS} = J = \frac{V_{bias}}{R_{sp}(S)}
\]

Internal current rising front: the faster it grows, the lower the jitter

dI/dt → understand/engineer timing features of SiPM cells

→ timing resolution improves at high \(V_{bias}\)
→ E field profile affects \(\tau\) and \(R_{sp}\) (wider E field profile → smaller R)
(should be engineered when aiming at ultra-fast timing)
→ T dependence of timing through \(\tau\) and D
→ slower growth at GAPD cell edges → higher jitter at edges
reduced length of the propagation front

\[
S = \text{surface of wavefront (ring of area } 2\pi r \Delta r)\\
R_{sp}(S) = \text{space charge resistance } \sim w^2/2\varepsilon v \sim O(50 \, k\Omega \, \mu m^2)\\
\nu_{diff} \sim O(\text{some } 10\mu m/\text{ns})\\
D = \text{transverse diffusion coefficient } \sim O(\mu m^2/\text{ns})\\
\tau = \text{longitudinal (exponential) buildup time } \sim O(\text{few ps})\\
\tau \sim \frac{1}{1 - (E_{max}/E_{breakdown})^n}
\]
GM-APD timing jitter: fast and slow components

1) Fast component: gaussian with time scale $O(100\text{ps})$

Statistical fluctuations in the avalanche:

- **Longitudinal** build-up (minor contribution)
- **Transversal** propagation (main contribution):
  - via multiplication assisted diffusion (dominating in few $\mu$m thin devices)
    
    \[ A. Lacaita et al. APL and El. Lett. 1990 \]
  - via photon assisted propagation (dominating in thick devices – $O(100\mu m)$)
    
    \[ PP. Webb, R.J. McIntyre RCA Eng. 1982 \]
    
    \[ A. Lacaita et al. APL 1992 \]

Fluctuations due to

a) impact ionization statistics

b) variance of longitudinal position of photo-generation: finite drift time even at saturated velocity

note: saturated $v_e \sim 3 \, v_h$

(n-on-p are faster in general)

$\rightarrow$ Jitter at minimum $\rightarrow O(10\text{ps})$

(very low threshold $\rightarrow$ not easy)

c) variance of the transverse diffusion speed $v_{\text{diff}}$

d) variance of transverse position of photo-generation: slope of current rising front depends on transverse position

$\rightarrow$ Jitter $\rightarrow O(100\text{ps})$

(usually threshold set high)
GM-APD timing jitter: fast and slow components

2) Slow component: non-gaussian tails with time scale $O(ns)$

Carriers photo-generated in the neutral regions above/beneath the junction and reaching the electric field region by diffusion

$G.\text{Ripamonti, S. Cova Sol. State Electronics (1985)}$

- Neutral regions underneath the junction: timing tails for long wavelengths
- Neutral regions in APD entrance: timing tails for short wavelengths

tail lifetime: $\tau \sim L^2 / \pi^2 D \sim$ up to some ns

$L = \text{effective neutral layer thickness}$

$D = \text{diffusion coefficient}$

$S.\text{Cova et al. NIST Workshop on SPD (2003)}$
PDE vs timing optimization


\[ k = \text{ratio of hole (} \beta \text{) to electron (} \alpha \text{) ionization coefficient (increasing with E field)} \]

**narrow avalanche region, high E:**
- small \( w \)
- high \( k = b/a \)

**better for TIMING**

**wide avalanche region, low E:**
- wide \( w \)
- small \( k = b/a \)

**better for PDE**

Plots are courtesy of C.H. Tan
SiPM readout electronics overview
Charge preamp

Capacitive feedback $C_f$

$V_{out}/I_{in} = -1/j\omega C_f$

Perfect integrator: $v_{out} = Q/C_f\int$

Difficult to accommodate large SiPM signals (200 pC)

Lowest noise configuration

Need $R_f$ to empty $C_f$

Current preamp

Resistive feedback $R_f$

$V_{out}/I_{in} = -R_f$

Keeps signal shape

Need $C_f$ for stability

V = $-1/C_f \int i(t)dt$

V = $-R_f \ i(t)$

15 jun 2012 CdLT  Photodet conference
High speed configurations

- Open loop configurations: current conveyors, RF amplifiers
- Usually designed at transistor level MOS or SiGe (ex PETIROC)

- **Current conveyors**
  - Small Zin: current sensitive input
  - Large Zout: current driven output
  - Unity gain current conveyor
  - E.g.: (super) common-base configuration
  - Low input impedance: \( R_{in} = 1/gm \)
  - Transimpedance: \( R_c \)
  - Bandwidth: \( \frac{1}{2\pi R_c C} > 1 \text{ GHz} \)

- **RF amplifiers**
  - Large Zin: voltage sensitive input
  - Large Zout: current driven output
  - Current conversion with resistor \( R_S \)
  - E.g. common-emitter configuration
  - Transimpedance: \(-gmR_c R_s\)
  - Bandwidth: \( \frac{1}{2\pi R_s C t} \)

15 jun 2012 CdLT Photodet conference
**Noise and jitter**

- **Electronics noise dominated by series noise en**
  - Large detector capacitance
  - For voltage preamp and load resistor RL,
  - Output rms noise $V_n^2 = (en^2 + 4kTR_s) G^2 n/2*BW_{-3dB}$
  - Typical values: $R_s=50 \, \Omega$, $en=1 \, \text{nV/}\sqrt{\text{Hz}}$ $V_n=1 \, \text{mV}$ for $G=10$, $BW=1\,\text{GHz}$
  - For current sensitive preamps, possible noise peaking due to $C_d$

- **Jitter**
  - Part due to electronics noise:
  - $\sigma_t = \sigma_v / (dV/dt)$
  - Minimized by increasing $BW$

\[ \sigma_j = \frac{\sigma_e}{\left(\frac{dV}{dt}\right)_{\text{threshold}}} \]
A few (personal) comments

- **Strong push for high speed front-end > GHz**
  - Essential for timing measurements
  - Several configurations to get GBW > 10 GHz
  - Optimum use of SiGe bipolar transistors

- **Voltage sensitive front-end**
  - Easiest: 50Ω termination, many commercial amplifiers (mini circuit...)
  - Beware of power dissipation
  - Easy multi-gain (time and charge)

- **Current sensitive front-end**
  - Potentially lower noise, lower input impedance
  - Largest GBW product

- **In all cases, importance of reducing stray inductance**
Timing resolution of MPPCs

13th June, 2012
Akito Kobayashi
Shinshu University
Setup

- We can control drive pulse height for the LED by keeping the width of 15ns.
- We have tested four different pixel sizes of the MPPC.
- Signal shape into the discriminator is degraded by amplifier response at high intensity light.
Setup view

For the plastic package

For the ceramic package

• LED located from MPPC about 5cm.
• MPPC sensor positions is the same for two kinds of packages.
Timing resolutions are around 40 ps.
Resolution becomes slightly better with increasing amount of light.
Data points of 400pixel, 1600pixel, 2500pixel aligned except 100pixel.
Threshold dependence result

- Timing resolution was bitter at lower threshold.
SiPM Photodetectors for Highest Time Resolution in PET

Cern/PH Lab27 TOF-PET Group

Using NINO for TOF-PET

Scintillator
LSO:Ce, 0.4% Ca
(2x2x5mm³)

Photodetector
SiPM

Readout Electronics
NINO

Pulse Width
~ τ ln(A/a)

Threshold
A exp(-t/τ)

Pulse Width
~ τ ln(A/a)

Photodetector output, NINO input

Timewalk

Pulse width is nonlinear function of the charge.

NINO output

511 keV gamma rays

50–100 keV X-rays

111 keV gamma rays

F. Powolny et al., IEEE Transactions, pp. 2465-2474, October 2008

Photodet 2012, June 13-15, 2012 – LAL Orsay, France

Stefan GUNDACKER
Data Analysis

Crystal: LSO:Ce,0.4% Ca, 2x2x5mm³
SiPM: Hamamatsu 50μ

Acquire pulse width and delay time trends of both channels with oscilloscope. After selecting the photopeak on both sides we deduce the time resolution.

FWHM=142±4ps
Parameters to optimize

Threshold voltage of NINO chip

Bias voltage of SiPM

These two parameters can be scanned in order to optimize for the three different types of MPPCs (25μm, 50μm and 100μm SPAD size)
## Optimization Results

<table>
<thead>
<tr>
<th>SPAD Size [µm]</th>
<th>Fill Factor [%]</th>
<th>(&lt;V_{op}&gt;) [V]</th>
<th>(V_{BD}) [V]</th>
<th>Bias [V]</th>
<th>NINO Threshold [mV]</th>
<th>CTR FWHM [ps]</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>30.8</td>
<td>71.47</td>
<td>69.2</td>
<td>73.0</td>
<td>40</td>
<td>202±4</td>
</tr>
<tr>
<td>50</td>
<td>61.5</td>
<td>72.10</td>
<td>70.5</td>
<td>72.2</td>
<td>40</td>
<td>142±4</td>
</tr>
<tr>
<td>100</td>
<td>78.5</td>
<td>70.84</td>
<td>69.3</td>
<td>70.3</td>
<td>40</td>
<td>192±8</td>
</tr>
</tbody>
</table>

- **Optimum timing performance** for the 50µm type, due to low DCR and good fill factor.
- The 100µm type cannot be operated at optimum bias voltages, because of rapid increase in DCR.
- Lower fill factor for the 25µm directly degrades timing because of photon statistics.

![Dark Count rate vs. Bias overvoltage](image)
Introduction – Fast Pulses with SPM

• SensL’s new technology creates fast pulses without sacrificing PDE
• This new technology is described in SensL’s international patent application no. WO2011117309
• MicroFM family sampling now with general availability Q3 2012
FM Signal with L(Y)SO Output

- Superior ability to trigger from the first photoelectron
- Less dependence on PDE
FM Coincidence Resolving Time

- SensL new FM series SPM demonstrates <250ps coincidence resolved timing
  - Over wide range of timing thresholds
  - Over wide range of operating voltages and temperatures

- LYSO 3x3x15mm³
- 3mm devices

![Graph showing observed CRT between two detectors (i.e. ‘folded’)](image)

- FWHM=226ps
UV Sensitive SiPM
Characterization of Hamamatsu MPPC for use in liquid xenon scintillation detectors

F. Neves, F. Balau, V. Solovov, V. Chepel, R. Martins, A. Pereira, M.I. Lopes

LIP–Coimbra & Department of Physics of the University of Coimbra, Portugal
A SiPM is an array of **avalanche photodiodes** (pixels) working independently in **Geiger mode**. The device output signal is the linear sum of all pixels.

**Advantages:**
- ✔ High gain;
- ✔ Good single photoelectron resolution;
- ✔ Low noise at low temperatures;
- ✔ High radio-purity and low mass;
- ✔ Insensitive to external electric fields;

**Disadvantages:**
- ✗ Low linearity range (dependent on the number of pixels);
- ✗ Crosstalk and afterpulsing (but devices are evolving...);
- ✗ Small area (growing and arrays are already available...);

**Unknowns:**
- ● QE/PDE @ 175 nm?
- ● Robustness (cooling/warming, pressure variations)
- ● Xe purity impact
### Windowless SiPM

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Hamamatsu</td>
</tr>
<tr>
<td>Type</td>
<td>S10362-33-100X</td>
</tr>
<tr>
<td>Number of pixels</td>
<td>30x30</td>
</tr>
<tr>
<td>Effective active area</td>
<td>3x3 mm</td>
</tr>
<tr>
<td>Fill factor</td>
<td>78.5 %</td>
</tr>
<tr>
<td>Peak sensitivity</td>
<td>440 nm</td>
</tr>
<tr>
<td>Spectral response range</td>
<td>320-900 nm</td>
</tr>
<tr>
<td>Room dark counts</td>
<td>~2 MHz</td>
</tr>
<tr>
<td>-35 °C</td>
<td>12.7 KHz</td>
</tr>
<tr>
<td>Time resolution (1 pe)</td>
<td>0.6 ns (FWHM)</td>
</tr>
<tr>
<td>Gain</td>
<td>$2 \times 10^6$</td>
</tr>
</tbody>
</table>
QE measurement: SiPM

Cooling with a Peltier cell:
- Single stage: 17W;
- $\Delta T = -62 \, ^\circ C$ (2.5W);
- Prec: 0.02 $^\circ C$ rms.

Signal formatting:
- Shaping: 2 $\mu s$;
- Gate: 6 $\mu s$.

PhotoDet 2012 - June 13-15 - LAL Orsay, France
SiPM PDE & QE estimate

λ=175 nm, T=-35°C

<table>
<thead>
<tr>
<th></th>
<th>$N_{\text{phe}}$</th>
<th>QE</th>
<th>PDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMT</td>
<td>20.4</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>SiPM</td>
<td>2.1</td>
<td>2.6%</td>
<td>2.0%</td>
</tr>
</tbody>
</table>

What about liquid xenon?

Aprile et al.,
PDE = 5.5% → QE = 22%

VS

Akimov et al.,
Nuc. Exp. Tech., v.52 (2009) 345-351
PDE < 1% for the same SiPM!
WLS coating

TPB (Tetraphenyl butadiene)

- Efficiently absorbs VUV and re-emits in blue region
- Successfully used in LAr (P K Lightfoot et al., 2009, JINST 4 P04002)

Emission spectrum of TBP
(W. M. Burton and B. A. Powell
Appl. Opt. v.12, pp. 87-89)

Hamamatsu SiPM
S10362-33-100X
3 mm x 3 mm

LXe

Diaphragm ø1 mm

\(^{241}\text{Am}\) source on a gold-plated support

10.7 mm
WLS coating

@ SiPM gain of $\sim 2 \times 10^6$
46 ph.e / $\alpha$ – uncoated
220 phe / $\alpha$ – TPB uncoated

About x5 improvement

\[ \chi^2 / \text{ndf} = 153.8 / 147 \]
\[ \text{Constant} = 79.77 \pm 1.24 \]
\[ \text{Mean} = 677.6 \pm 1.0 \]
\[ \text{Sigma} = 69.02 \pm 0.82 \]
In this work we present the performance results for windowless SiPM (Hamamatsu) operating at temperatures down to -100ºC:

- A intrinsic noise of <1 Hz for a threshold of ≥1 pe has been measured at -100ºC;
- The SiPMs maintain a good single electron response at high gain (>10^6) and low temperature;
- The standard SiPM with window is not sensitive to xenon light;
- A QE of ~2.6% (PDE ~ 2%) at 175 nm has been measured using xenon proportional scintillation light source;
- Works immersed in liquid xenon with the same estimated PDE (2%)
- A glass plate coated with TPB in front of SiPM improves PDE by at least a factor of 5, but probably causes optical feedback
Evaluation of high UV sensitive SiPMs from MEPPhI/MPI for use in liquid argon.

L. Bezrukov, B. Lubsandorzhiev, N. Lubsandorzhiev, INR RAS
B. Dolgoshein, E. Popova, P. Buzhan, A. Ilyin, A. Stifutkin, A. Pleshko, MEPHI
R. Mirzoyan, MPI
A. Zhukov, MIET
Phase I of GERDA experiment has been successfully completed. One of the tasks for Phase II is:

Liquid Argon instrumentation:

LAr – from passive to active shielding

Detection of LAr scintillation

WLS + Cryogenic PMT:
- several designs under consideration
- MC in progress

WLS + Cryogenic SiPMs:
- under preparation for testing in LAr,
- MC shows ~100 noise from $^{228}$Th suppression

Cryogenic SiPMs for direct LAr light redout:
- VUV sensitive (128 nm)
- Large area ($\geq 1 \text{cm}^2$)
- MC study just started

UV SiPMs from MEPhI/MPI can be the possible candidates
UV SiPMs from MEPhI/MPI/Excelitas collaboration
(produced at Zelenograd, Russia)
100 micron pixel size (100B type), geometrical efficiency 80%

**Spectral sensitivity**

Measurements at MEPHI and MPI

- Dark rate at room temperature is 400-800 kHz/mm²
- Gain temperature stability is 0.5%/C
GERDA requirements. Task 1: VUV sensitivity

- AR coating
- High internal quantum efficiency (abs. length for 128nm ≈ 5 nm)

Actual MEPi/MPi/Excelitas SiPMs

**ARC transparency**

- ARC should be shifted to 128nm

**Internal QE**

- Internal QE already is quite high

Task 1 seems to be possible to solve
Summary:

- MEPhl/MPI/Excelitas UV SiPMs look like promising candidates for LAr instrumentation usage in GERDA experiment

It requires developments of:

- VUV SiPM
- large area > 10mm$^2$ SiPMs
- precise experimental methods for extraction of SiPM SPICE-parameters
Development of PPD Sensitive to Deep UV Scintillation Photons of Liquid Xenon

ICEPP, University of Tokyo

S. Mihara and H. Nishiguchi
KEK, High Energy Accelerator Research Organization

A. Stoykov
Paul Scherrer Institut
How It Would Look Like

216 PMTs on γ entrance face

~4000 PPDs on γ entrance face
PDE for VUV

- PDE for VUV is nearly zero for commercial device.
- Low transmission for VUV to sensitive layer due to
  - Protection coating (epoxy resin/silicon rubber)
  - Insensitive layer (p+ contact layer with ~zero field)
    - Absorption length in Si for VUV photon: ~5nm
  - High reflectivity for VUV on Si surface

- Possible solution
  - Remove protection coating
  - Thinner p+ contact layer
  - Optimize reflection/refractive index on sensor surface
Development of UV-Enhanced MPPC

- UV-enhanced MPPC is under development in collaboration with Hamamatsu.
- Remove protection coating
- Optimize MPPC parameters
  - Thinner p+ contact layer
  - Anti-reflection coating
  - Refractive index of surface material
  - Quench resistor
  - Pixel size
  - ...
- Currently sensor size: $3 \times 3 \text{mm}^2$
Prototypes of UV-enhanced MPPC

- Prototypes of UV-enhanced MPPC of various types are being tested.
- Sensor size: 3×3mm², pixel pitch: 50µm

<table>
<thead>
<tr>
<th>Type</th>
<th>p+ contact layer</th>
<th>Reflection/refractive index</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>thinner</td>
<td>Anti-reflection</td>
</tr>
<tr>
<td>B</td>
<td>thinner</td>
<td>Anti-reflection</td>
</tr>
<tr>
<td>C</td>
<td>thinner</td>
<td>Anti-reflection</td>
</tr>
<tr>
<td>D</td>
<td>thinner</td>
<td>Anti-reflection</td>
</tr>
<tr>
<td>E</td>
<td>thinner</td>
<td>Anti-reflection</td>
</tr>
<tr>
<td>F</td>
<td>thinner</td>
<td>Anti-reflection</td>
</tr>
<tr>
<td>G</td>
<td>normal</td>
<td>Refractive index</td>
</tr>
<tr>
<td>H</td>
<td>normal</td>
<td>Refractive index</td>
</tr>
</tbody>
</table>

Sorry, but we can’t show details of the parameters. (we don’t know either!)
PDE

* Estimation of absolute PDE
  * PDE = (Observed # of p.e.) / (expected # of photons) for alpha event
  * PDE includes effects of optical crosstalk and afterpulsing.

![Graph showing PDE vs. Over voltage with various markers and labels for different samples at T=165K.](image-url)
PDE

- Effective PDE after subtracting effect of optical crosstalk (5-20% prob.) and afterpulsing (10-30% prob.)
- **Effective PDE ~10%** achieved for best samples (type G)
- Small contribution from NIR component of LXe scintillation (~1% level) included.
Summary and Outlook

* MPPC sensitive to LXe scintillation photons is under development in collaboration with Hamamatsu for possible upgrade of MEG LXe γ-detector.
* Prototypes of UV-enhanced MPPC show promising performance (PDE of ~10% for best sample) although there are still some issues to be addressed.
* Next steps
  * Further improvement of performance
    * Improvement of PDE
    * Optimization of MPPC parameters such as pixel pitch and quench resistor
  * Production of large area prototype (~12×12mm²)
  * We plan to build LXe detector prototype with 100ℓ-LXe and ~600 large area MPPCs by spring next year and to perform a beam test.
  * We aim at the construction of the final detector with ~4000 MPPCs within next year.
Analog Memory
SiPM readout electronics overview
Waveform digitizers [S. Ritt]

FADCs

- 8 bits – 3 GS/s – 1.9 W → 24 Gbits/s
- 10 bits – 3 GS/s – 3.6 W → 30 Gbits/s
- 12 bits – 3.6 GS/s – 3.9 W → 43.2 Gbits/s
- 14 bits – 0.4 GS/s – 2.5 W → 5.6 Gbits/s

1.8 GHz!

24x1.8 Gbits/s

1/10 k€/ch

PX1500-4:
2 Channel
3 GS/s
8 bits

See talk by D. Breton

4 channels
5 GSPS
1 GHz BW
8 bit (6-7)
15k€

4 channels
5 GSPS
1 GHz BW
11.5 bits
900€
USB Power

4 channels
5 GSPS
1 GHz BW
8 bit (6-7)
15k€
Switched Capacitor Array (Analog Memory)

**Inverter “Domino” ring chain**

- Clock
- Shift Register
- IN
- Out
- Waveform stored

- 0.2-2 ns
- 10-100 mW
- FADC 33 MHz
- “Time stretcher” GHz → MHz

\[ \delta t_s \]
How is timing resolution affected?

$$\Delta t = \frac{\Delta u}{U} \cdot \frac{1}{\sqrt{3f_s \cdot f_{3dB}}}$$

$$\frac{\Delta u}{\Delta t} = \frac{U}{t_r}$$

today:
- $U = 100$ mV
- $\Delta u = 1$ mV
- $f_s = 2$ GSPS
- $f_{3db} = 300$ MHz
- $\Delta t \approx 10$ ps

optimized SNR:
- $U = 1$ V
- $\Delta u = 1$ mV
- $f_s = 2$ GSPS
- $f_{3db} = 300$ MHz
- $\Delta t = 1$ ps

next generation:
- $U = 1$ V
- $\Delta u = 1$ mV
- $f_s = 10$ GSPS
- $f_{3db} = 3$ GHz
- $\Delta t = 0.1$ ps

Assumes zero aperture jitter
Switched Capacitor Arrays for Particle Physics

STRAW3  LABRADOR3  TARGET
• 0.25 µm TSMC
• Many chips for different projects (Belle, Anita, IceCube ...)

www.phys.hawaii.edu/~idlab/

AFTER  SAM  NECTAR0
• 0.35 µm AMS
• T2K TPC, Antares, Hess2, CTA

matacq.free.fr

PSEC1 - PSEC4
• 0.13 µm IBM
• Large Area Picosecond Photo-Detectors Project (LAPPD)
psec.uchicago.edu

DRS1  DRS2  DRS3  DRS4
• 0.25 µm UMC
• Universal chip for many applications
• MEG experiment, MAGIC, Veritas, TOF-PET

Stefan Ritt
R. Dinapoli
PSI, Switzerland
drs.web.psi.ch

G. Varner, Univ. of Hawaii
E. Delagnes
D. Breton
CEA Saclay
H. Frisch et al., Univ. Chicago

Poster 232
Poster 15, 106
Things you can buy

- **DRS4 chip (PSI)**
  - 32+2 channels
  - 12 bit 5 GSPS
  - > 500 MHz analog BW
  - 1024 sample points/chn.
  - 110 µs dead time

- **MATACQ chip (CEA/IN2P3)**
  - 4 channels
  - 14 bit 2 GSPS
  - 300 MHz analog BW
  - 2520 sample points/chn.
  - 650 µs dead time

- **SAM Chip (CEA/IN2PD)**
  - 2 channels
  - 12 bit 3.2 GSPS
  - 300 MHz analog BW
  - 256 sample points/chn.
  - On-board spectroscopy

- **DRS4 Evaluation Board**
  - 4 channels
  - 12 bit 5 GSPS
  - 750 MHz analog BW
  - 1024 sample points/chn.
  - 500 events/sec over USB 2.0
Plans

**DRS5 (PSI)**
- Self-trigger writing of 128 short 32-bin segments (4096 bins total)
- Storage of 128 events
  - Accommodate long trigger latencies
  - Quasi dead time-free up to a few MHz
  - Possibility to skip segments → second level trigger
- Attractive replacement for CFG+TDC
- First version planned for 2013

**CEA/Saclay**
- Dual gain channels
- Dynamic power management (Read/Write parts)
- Region-of-interest readout
Comments

• **Trends**
  - Reduce dead time
  - Increase analog bandwidth
  - Increase depth, give more latency
  - Include high speed low noise preamps (NECTAR...)

• **Comments**
  - Unbeatable for pulse shape analysis or discrimination
  - Ultra low timing measurements (ps)
  - More power hungry than dedicated front-end (many CdV/dt...), needs careful study for large systems (>> kch)
Miscellanea
Lifetime measurements of recent microchannel-plate PMTs

Alexander Britting, Wolfgang Ey rich, Albert Lehmann, Fred Uhlig

supported by BMBF and GSI
Microchannel Plate PMTs

- Typical pore sizes: 6 – 25µm
- Fast signals:
  - Rise time: 0.5 – 1.5ns
  - TTS < 50ps
- Gain > 10^6 with 2 MCP stages
- Low dark count rate

Hamamatsu
R10754X-06-L4

PHOTONIS
XP 85112/A1-HGL

13.06.2012
Alexander Britting
Methods to increase lifetime

- **Hamamatsu:**
  - Protection layer
    - In front of first MCP layer → **reduction of collect. efficiency**
    - Between MCP layers (latest models)

- **Photonis:**
  - Improved vacuum
  - Treatment of MCP surfaces:
    - Electron scrubbing (XP85112/A1, XP85112/A1-HGL)
    - Atomic layer deposition (XP85112/A1-HGL)

- **BINP:**
  - Protection layer in front of first MCP (old models)
  - Electron scrubbing and improved vacuum (#1359, #3548)
  - New photo cathode → **higher darkcount rate**
Latest models of MCP-PMTs (solid dots) have drastically increased lifetime compared with older ones (open dots)!
### Spectral QE

- **Ham. R10754X-01-M16** degrades faster for higher wavelengths
- **Phot. XP85112/A1-HGL** is still unaffected
- Recently developed new cath. \( \text{(Na}_2\text{K} \text{Sb}(\text{Cs}) + \text{Cs}_3\text{Sb}) \) degrades almost constantly for any wavelength!
A new design of large area MCP-PMT for the next generation neutrino experiments

Yuekun Heng
IHEP, Beijing
Representing the collaboration
• Big demanding for PMT
  – Large area
  – Big quantity: low prices
  – Low Radiation Background
  – High QE
The new design of a large area PMT

1) Using two sets of Microchannel plates (MCPs) to replace the dynode chain
2) Using transmission photocathode (front hemisphere) and reflective photocathode (back hemisphere)

High photon detection efficiency + Single photoelectron Detection + Low cost

~ 4π viewing angle!!

- Quantum Efficiency:
  - Transmission photocathode: 20%
  - Reflection photocathode: 40%
- MCP Collection Efficiency: 60%

Photon detection efficiency:
- 20% * 60% = 12%
- 70% * 40% * 60% = 17%

Total Photon Detection Efficiency: ~30%

Photon Detection Efficiency: 14% → 30% ; ×~2 at least!
The Low radioactive background glass

- Large (8", 20")
- Superb water-resistance characteristics;
- Low radioactive background glass;

![Glass Shell]

![Sample 1]

Radioactive background test of different PMT glass (unit: ppb)

<table>
<thead>
<tr>
<th>Glass</th>
<th>DM-308 (g)</th>
<th>DM-305 (g)</th>
<th>Hamamatsu (g)</th>
<th>CN-2# Glass (g)</th>
<th>CN-2# Material (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Mass</td>
<td>211.0</td>
<td>131.1</td>
<td>53.8</td>
<td>335.2</td>
<td>280.9</td>
</tr>
<tr>
<td>Test Time</td>
<td>311023</td>
<td>424110</td>
<td>598930</td>
<td>315394</td>
<td>359618</td>
</tr>
<tr>
<td>$^{238}$U</td>
<td>21.50±0.10</td>
<td>42.40±0.14</td>
<td>8.04±0.27</td>
<td>14.96±0.08</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>$^{232}$Th</td>
<td>18.50±0.32</td>
<td>6.43±0.23</td>
<td>12.50±0.60</td>
<td>4.78±0.16</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>$^{40}$K</td>
<td>2.50±0.01</td>
<td>41.01±0.03</td>
<td>0.3±0.02</td>
<td>3.11±0.01</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

8" ellipse  8" spherical

Low background gamma spectrometer in IHEP
Cathode

- Cs$_3$Sb on MnO (S11, $\lambda_{\text{peak}}$ @400nm, QE ~ 20%)
- (Cs)Na$_2$KSB (S20, $\lambda_{\text{peak}}$ @400nm, QE ~ 30%)
- K$_2$CsSb ($\lambda_{\text{peak}}$ @400nm, QE ~ 30%)
- K$_2$CsSb(O) ($\lambda_{\text{peak}}$ @400nm, QE ~ 35%)

Use of highly purified materials for the photo cathode;
Optimal tuning of the material composition;
Optimal tuning of the photo cathode thickness;
Optimal tuning of the anti-reflective layer;
Optimal tuning of the Cs layer thickness.

- Alkali Metal Dispensers (AMD)
Method of HV setting

Coating MgF₂ and MnO

Assembly of two MCPs

Test equipment for MCP
- HV
- Coating
- length-diameter ratio

New Equipment for MCP test
Prototypes

The progress:

2” MCP-PMT

8” MCP-PMT

8” Dynode-PMT

5” MCP-PMT

transmission photocathode

MCP
8” ellipse MCP-PMT

--- Electron Multiplier:

- small size MCP (φ=18mm)

--- Photocathode Area:

- Transmission + Reflection
- Photocathode

The overview of the prototype

The photoelectron collected by the electron multiplier MCP

- d: 25mm
- d': 25mm
The development of the multi PPD readout electronics with EASIROC and SiTCP

R. Honda, K. Miwa
Tohoku University

I. Nakamura, M. Tanaka, K. Yoshimura
T. Uchida (Open-It), M. Ikeno (Open-It)
KEK
EASIROC (Extended Analogue SiPM Integrated Read Out Chip)
- 32 channels inputs
- HV adjustment (4.5 V, 8 bit)
- Amp, shaper, discriminator
- Analog (serial)
- discriminator (parallel) outputs.

Double gain (1:10)
- High gain (10 → 150)
- Low gain (1 → 15)

HV adjustment (8 bit DAC)

Common threshold (10 bit DAC)

Developed by Omega/IN2P3

PD12 Orsay France
The evaluation board with EASIROC

I/O components

Analog I/O
- MPPC input (32 ch)
- HV input
- Analog output / probe output

Digital I/O
- NIM level input x5 (400 Mbps)
- NIM level output x4 (~ 1Gbps)
- LVDS output (640Mbps)
- SiTCP

On board ADC and TDC
- AD9220
  - Digital MHTDC in FPGA

Power supply
- ±6 V

SOY (general purpose SiTCP board) is needed to use SiTCP.
Bandwidth : 100 Mbps.
今後のPD workshop

● 2015年にRussiaで行う（決定）
  • Y. Kudenkoさんの強い希望
  • 2014年にNDIPがあるのでそれを避ける

● 2013秋に日本でやる？
  • 3年間隔は長過ぎ
  • 二度と日本に帰ってこないかも？
  • 候補はKEK
    ◇ 参加者が集まるか？
    ◇ 吉村中村にできるのか？
    ◇ KEKからのサポートは？
  • 中村は消極的
終わり