Characterization of Multipixel Avalanche Photodiodes

Hege Austrheim Erdal

Department for Physics and Technology

June 24th, 2009
Outline

Electromagnetic Calorimeters in use today

Different photodetectors

Applications for MAPDs

Experimental Setups and Results
Electromagnetic Calorimeters in use today

Crystals

- The crystal converts one photon into many photons in the visible light region
- Normally:  # photons \( \propto \) E deposited in the crystal
- Example: LYSO PbWO\(_4\) used in PHOS

Photodetectors

Optical Photons

Example: MAPD
Different Photodetectors

- Photomultipliers Tubes (PMT)
  - High Gain ($G \approx 10^6$)
  - High operating voltage (few kV)
Different Photodetectors

- Photomultipliers Tubes (PMT)
  - High Gain ($G \approx 10^6$)
  - High operating voltage (few kV)

- pin-diode
  - Gain = 1
Different Photodetectors

- Photomultipliers Tubes (PMT)
  - High Gain ($G \approx 10^6$)
  - High operating voltage (few kV)

- pin-diode
  - Gain $= 1$

- Avalanche PhotoDiode (APD)
  - Low Gain
  - Small and insensitive to magnetic field
  - Sensitive to temperature and bias voltage
Different Photodetectors

- Photomultipliers Tubes (PMT)
  - High Gain \( (G \approx 10^6) \)
  - High operating voltage (few kV)

- pin-diode
  - Gain = 1

- Avalanche PhotoDiode (APD)
  - Low Gain
  - Small and insensitive to magnetic field
  - Sensitive to temperature and bias voltage

- MAPD/SiPM/MPPC
  - High Gain \( (G \sim 10^5 - 10^6) \)
  - Low operating Voltage \( (< 140V) \)
  - Small and insensitive to magnetic field
Multipixel Avalanche Photodiode

- Pixelated device
- Operated in Geiger Mode, $V_{op} > V_{breakdown}$
- $S_{out} = \# \text{ pixels fired}$
- Linear Response when $N_{\text{pixel}} \gg N_{\text{photons}}$
- $E_\gamma \propto S_{out}$
- Gain is sensitive to voltage and temperature change

Pictures taken with a microscope

MPPC S10362-11-25C from Hamamatsu, 1x1 mm$^2$

MAPD from Zecotek, 3x3 mm$^2$
Multipixel Avalanche Photodiode

MPPCs/SiPMs

- Depletion region (0.7-0.8 µm) with high electric field between p⁺ and n⁺ layer
- The pixels are joined together by common aluminum-strips
- The MPPCs/SiPMs have a finite # pixels / mm²
- Reaches a higher gain than the MAPDs
Depletion region (0.7-0.8 µm) with high electric field between p⁺ and n⁺ layer
- The pixels are joined together by common aluminum-strips
- The MPPCs/SiPMs have a finite # pixels / mm²
- Reaches a higher gain than the MAPDs

Homogeneous entrance window
- Microwells for charge trapping and collection located a few µm below surface
- High Dynamical range
- Relative low gain
Multipixel Avalanche Photodiode

From left: MAPD/MAPD3-A from Dubna and Zecotek, MPPC S10362-33-050C and MPPC S10362-11-025C from Hamamatsu

<table>
<thead>
<tr>
<th>Type</th>
<th>Size</th>
<th>Pixel Density</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAPD</td>
<td>3x3mm²</td>
<td>10000/mm²</td>
<td>&lt; 10⁵</td>
</tr>
<tr>
<td>MAPD3-A</td>
<td>3x3mm²</td>
<td>15000/mm²</td>
<td>40000</td>
</tr>
<tr>
<td>MPPC S10362-11-025C</td>
<td>3x3mm²</td>
<td>3600</td>
<td>2.75x10⁵</td>
</tr>
<tr>
<td>MPPC S10362-33-050C</td>
<td>1x1mm²</td>
<td>1600</td>
<td>7.5x10⁵</td>
</tr>
</tbody>
</table>
Applications for MAPDs

Calorimeters

Example: Projectile Spectator Detector (PSD) at Na61/SHINE (CERN) and CBM at FAIR (GSI)

- Hadronic Calorimeter consisting of 108 modules
- Each module: 60 lead-scintillator tile sandwiches
- Wave Length Shifting fibers → Photodetector
- Testing: MAPDs (Dubna), Readout of full calorimeter: MAPD3-As (Zecotek).
Applications for MAPDs

Positron Emission Tomography

- Is a nuclear medical imaging technique
- Produces a 3D image of biochemical processes in the body
- Detect photon pairs emitted indirectly from a positron emitting nuclei
Applications for MAPDs

Positron Emission Tomography

- Is a nuclear medical imaging technique
- Produces a 3D image of biochemical processes in the body
- Detects photon pairs emitted indirectly from a positron emitting nuclei

MAPDs are fast devices → Time-of-Flight PET

- Uses time-difference in arrival time
- Can among other things reduce statistical noise in the image

\[ \text{SNR}_{TOF} \approx \sqrt{\frac{D}{\Delta x}} \cdot \text{SNR}_{conv}, \quad \Delta x = \frac{c \cdot \Delta t}{2} \]

D-size of patient, \( \Delta x \) - uncertainty in position, \( \Delta t \) - uncertainty in time
Motivation

As mentioned, these devices are interesting for different applications due to
- high gain comparable to PMT
- fast, small, compact and insensitive to magnetic field
- relatively inexpensive

BUT, these devices are new on the market
- They are not fully understood yet
- Characteristics change for all samples produced
  → Important to characterize each sample
- There is a growing variety of different detectors
  → Important to gain knowledge on each detector type

The aim of this work has thus been to come up with a setup that
makes it easy to characterize each detector with respect to
- dark current
- absolute gain
- dark rate
General Setup

The entire system was connected, here sample 341 is used as an example. The noise was recorded for all detectors used.
General Setup

The noise was recorded for all detectors used.
Current that runs through the detector in absence of light

Tested for all four types of detectors
The dark current increases rapidly with increasing bias voltage → Important to set bias voltage not too high

Internal differences for each detector type → Important to characterize all samples
Absolute Gain

Setup

- Labview Program will integrate signal $\rightarrow$ charge
- Plot single photoelectron spectrum $\rightarrow$ find gain
- Find gain for various bias voltages and temperatures.
Absolute Gain

Typical Signal Shapes

MPPC S10362-11-025C, Sample 741. Timescale: 4ns
Absolute Gain

Results

Gain = \frac{P_{1\text{pe}} - P_{0\text{pe}}}{G_{\text{amp}} \cdot q_e}

\begin{align*}
P_{1\text{pe}} & \text{- Position of 1pe peak in charge} \\
P_{0\text{pe}} & \text{- Position of pedestal peak in charge} \\
G_{\text{amp}} & \text{- Gain of preamplifier} \\
q_e & \text{- electron charge}
\end{align*}
Absolute Gain

Results: Gain versus reverse bias voltage

![Gain vs Bias Voltage Graph]

A linear fit can be applied to the curves, and use this to extract pixel capacitance, breakdown voltage and the gain dependence on voltage:

- Type C measured
  - C given
  - V breakdown
  - G
  - V MPPC S10362-11-025C 23 fF 22 fF 68.3 V, 69.1 V, \( \sim 4.4 \)
  - MPPC S10362-33-050C 96 fF 89 fF 69.8 V, 70.6 V, \( \sim 7 \)
## Absolute Gain

### Results: Gain versus reverse bias voltage

A linear fit can be applied to the curves, and use this to extract pixel capacitance, breakdown voltage and the gain dependence on voltage:

<table>
<thead>
<tr>
<th>Type</th>
<th>$C_{measured}$</th>
<th>$C_{given}$</th>
<th>$V_{breakdown}$</th>
<th>$%G_{0.1V}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPPC S10362-11-025C</td>
<td>23 fF</td>
<td>22 fF</td>
<td>68.3 V, 69.1 V</td>
<td>~ 4.4</td>
</tr>
<tr>
<td>MPPC S10362-33-050C</td>
<td>96 fF</td>
<td>89 fF</td>
<td>69.8 V</td>
<td>~ 7</td>
</tr>
</tbody>
</table>
Absolute Gain

Results: Gain versus Temperature

To do these measurements:

- Used a termistor to measure temperature
- Termistor and detector were placed in close contact with a copper-plate

![Gain vs Temperature Graph](image)

MPPC S10362-11-025C sample 741
Absolute Gain
Results: Gain versus Temperature

Gain dependence on temperature when increasing temperature from 24 °C -25°C:
- MPPC S10362-11-025C: ~ 2.2%
- MPPC S10362-33-050C: ~ 3.8%
Dark Rate

Setup

- Same setup as for gain, just turn off pulse generator.
- Use pulse height of 1 pe from gain measurement, set a threshold to 0.5 of this value.
- Count number of pulses exceeding this threshold, plus store pulse heights.

→ Can now find frequency as a function of threshold values.

![Graph showing dark rate as a function of threshold values.](image)
Some conditions were changed in the Labview program for some of the samples. This lead to:

- all bins over threshold value were counted as a peak
- dark rate for low reverse bias voltage had to be taken away (SNR too low)

For further measurements → average over bins to smooth out signal
Results for one of the MAPD3-As, have fixed the bias voltage at 66.5V
Linearity

What to do next

- The pulse used now has long rise time and are too broad → Fast-pulser, this will generate a narrow pulse (∼1-3ns)
- The measurements will cover the entire dynamical range of the photodetectors
- Will use a photomultiplier as a reference, or use the filters
Risetime

- Same setup as for gain, but with high light intensity and without preamplifier

MAPD, Sample 133. Timescale: 10ns
- Risetime: 2.7 ± 0.2 ns

MPPC S10362-11-025C, Sample 741. Timescale: 4ns
- Risetime: 2.03 ± 0.15 ns

- Done for all samples used in other experiments
- Width gives information about the charge collection time
  - Depends on the geometry
Conclusion and Outlook

▸ Various detectors have been characterized with respect to dark current, absolute gain and dark rate.
▸ A linearity measurement have been done
  - Setup have not been good enough
  - A new setup has been proposed, but not yet tested
▸ The measurements show the importance of characterizing each individual sample
▸ Need to do long term stability measurements
▸ Determine uniformity of the MAPD
▸ Study crosstalk and afterpulsing effects