Single Photoelectron timing resolution of SiPM

XVII SuperB Workshop - Kick Off meeting

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Plan

- List of the SiPMs studied at LAL

- Basic characterization of SiPM: operational voltage range, gain, dark noise, variation with temperature ... .

- Test bench for timing measurement

- Timing resolution measurement principle

- SPTR in function of the bias voltage

- SPTR in function of the wavelength

- SPTR in function of the temperature
1 mm² SiPMs characterized at LAL

<table>
<thead>
<tr>
<th>Reference</th>
<th>Pixel nb</th>
<th>Pixel size (µm)</th>
<th>$V_{BD}$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AdvanSiD (F.B.K)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASD-SiPM1S-M-50</td>
<td>400</td>
<td>50 x 50</td>
<td>29</td>
</tr>
<tr>
<td><strong>Hamamatsu MPPC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S10362-11-25</td>
<td>1600</td>
<td>25 x 25</td>
<td>69.2</td>
</tr>
<tr>
<td>S10362-11-50</td>
<td>400</td>
<td>50 x 50</td>
<td>68.3</td>
</tr>
<tr>
<td>S10362-11-100</td>
<td>100</td>
<td>100 x 100</td>
<td>68.7</td>
</tr>
<tr>
<td>10-50S-BK 4S</td>
<td>400</td>
<td>50 x 50</td>
<td>69.1</td>
</tr>
<tr>
<td>10-100S-FS</td>
<td>100</td>
<td>100 x 100</td>
<td>69.1</td>
</tr>
<tr>
<td><strong>SensL SPM</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SPM1020X13</td>
<td>848</td>
<td>20 x 20</td>
<td>27</td>
</tr>
<tr>
<td>SPM1035X13</td>
<td>400</td>
<td>35 x 35</td>
<td>27.5</td>
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</tbody>
</table>

Non commercial products
9 mm² SiPMs characterized at LAL

<table>
<thead>
<tr>
<th>Reference</th>
<th>Pixel nb</th>
<th>Pixel size (µm)</th>
<th>$V_{BD}$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AdvanSiD (F.B.K) (3 x 3 mm²)</td>
<td>ASD-SiPM3S-M-50</td>
<td>400</td>
<td>50 x 50</td>
</tr>
<tr>
<td>Hamamatsu MPPC (3 x 3 mm²)</td>
<td>S10362-33-25</td>
<td>14400</td>
<td>25 x 25</td>
</tr>
<tr>
<td></td>
<td>S10362-33-50</td>
<td>3600</td>
<td>50 x 50</td>
</tr>
<tr>
<td></td>
<td>S10362-33-100</td>
<td>900</td>
<td>100 x 100</td>
</tr>
<tr>
<td>SensL SPM (2,85 x 2,85 mm²)</td>
<td>SPM-3035X13</td>
<td>3640</td>
<td>35x 35</td>
</tr>
</tbody>
</table>

Non commercial products
Determination of the operational voltage range of the SiPMs

Dark Monitor Temperature Test bench

- Source-meter
  - Stable voltage bias (0 – 200 V, accuracy: 1 µV)
  - Precise current measurement (1 pA)
- SiPM
- Amplifier
- Pt100
- Climatic chamber (0 – 40°C, accuracy = 0.1°C)
- Digital Tektronix Oscilloscope (500 MHz)
- Counter
- Automatic acquisition
- PC running LabView & C++ programs
- Digital Multimeter
- Measurements of $V_{BD}$, gain, DCR
Evolution of $V_{BD}$ with temperature

Breakdown voltage increases with the temperature

$$\frac{dV_{BD}}{dT} \sim 56 \text{ mV/°C}$$
The Timing Test Bench

Pilas laser diode
(405 nm, 470 nm, 633 nm, 40-50 ps)

Laser diode Driver jitter ≤ 3 ps

Dark box (1 m³)

3D translation tables

Temperature variation = 0.1 °C

SiPM

SSiPM

Oscillo Lecroy WAVEPRO 740ZI
4 GHz, 40 Gs/s, 32 Mpts/channel

STOP detector

START laser driver

WaveCatcher

PC Acquisition

cable (delay) trigger laser

V. Puill, SuperB Kick-off meeting, Elba, May 31 – June 1 2011
Measurement principle of the SiPM timing resolution

Threshold for the laser = 50 %

Threshold = 50 % SSiPM

Measurement of the time between the laser and the SiPM signals → distribution of the $\Delta t$
Choice of the SPTR measurement points

\[ \Delta V (V) = V_{bias} - V_{BD} \]

\[ V_{bd} = 5.9 \times 10^{-2} \times \text{temp} + 67.94 \]

Correction of the bias voltage if the temperature changes inside the test bench to maintain a constant gain.

**e.g:** MPPC 10-100S-FS
SiPM illumination conditions

High power of the laser diode $\rightarrow$ pulse width $\sim$40 ps-50 ps depending on the laser head

neutral filters

$\sim$ 1 photon/pulse/mm²

at the SiPM output: majority of 0, few 1 photo-electron

+ small quantity of signal $\alpha$ 2 p.e due to cross-talk

![Graph showing the distribution of signal amplitudes with peaks at 1 p.e and 2 p.e indicating cross-talk.](image)
Contribution to the timing resolution of the detection chain

- Pilas pulsed laser diode

- Pilas driver: jitter ≈ 3 ps

- Timing resolution of the LECROY scope ≈ 1 ps

- Timing resolution of the Wavecatcher ≈ 8 ps
1 mm² SiPM SPTR in function of the applied voltage

SiPM SPTR 1 mm² - 20 °C - 467 nm

Vbias-VBD (V) vs. FWHM (ps)

- S10362-11-25
- S10362-11-50
- S10362-11-100
- MPPC-BK-4S (50 µm)
- MPPC 10-100-FS (100 µm)
- ASD-1-S-50
- SPM1020
- SPM1035

VDB : breakdown voltage
9 mm² SiPM SPTR in function of the applied voltage

SiPM SPTR 9 mm² - 20 °C - 467 nm

- S10362-33-25
- S10362-33-50
- S10362-33-100
- ASD-9-S-50

SPM-3035X13 too noisy to measure the SPTR
SiPM SPTR = $f(\lambda)@20^\circ C$ and $V_{bias}$ max

**SPTR MPPC 1 mm² 50 & 100 µm**

![Graph showing FWHM vs. lambda for MPPC 1 mm² with data points for 50 and 100 µm.]

- MPPC 10-50S @ 2,4 V
- MPPC 10-100S @ 1,4 V

**SPTR Sensl 1 mm² 20 & 35 µm**

![Graph showing FWHM vs. lambda for Sensl 1 mm² with data points for 20 and 35 µm.]

- SPM1035X13 @ 2,4 V
- SPM1020X13 @ 2,4 V
SiPM SPTR = f(λ) @ 20 °C and Vbias max

**SPTR ASD SiPM1S-M-50**

- FWHM vs. lambda (nm)
- Data points for ASD 1M-50 @ 1 V
- 105 ± 5
- 110 ± 10
- 139 ± 15
- +32%

**SPTR MPPC 25 & 100 µm 9 mm²**

- FWHM vs. lambda (nm)
- Data points for MPPC 10362-33-25 @ 4 V
- 242 ± 12
- 225 ± 5
- MPPC 10362-33-100 @ 1 V
- 196 ± 10
- -20%
$1 \text{ mm}^2 \text{ SiPM SPTR} = f(\text{temperature}) @ V_{\text{bias max}}$
1 mm² SiPM SPTR = f(temperature) @ Vbias max

**SPTR SPM1020x13 - 1 mm²**

- Temperature vs. FWHM for different wavelengths (405 nm, 467 nm, 635 nm)
- Linear fit for 405 nm

**SPTR SPM1035x13 - 1 mm²**

- Temperature vs. FWHM for different wavelengths (405 nm, 467 nm, 635 nm)
- Linear fit for 405 nm
1 mm² SiPM SPTR = f(temperature) @ Vbias max

9 mm² SiPM SPTR = f(temperature) @ Vbias max

**ASD 9S-M-50**
and
**SPM-3035X13** (Sensl)

too difficult to measure at 1 p.e
9 mm² SiPM SPTR = f(temperature) @ Vbias max

**SPTR MPPC S10362-33-100 - 9 mm²**

![Graph showing the relationship between temperature and FWHM for SPTR MPPC S10362-33-100 at 9 mm². The graph includes data points for different wavelengths: 405 nm, 467 nm, and 635 nm.](image1)

**SPTR MPPC S10362-33-25 - 9 mm²**

![Graph showing the relationship between temperature and FWHM for SPTR MPPC S10362-33-25 at 9 mm². The graph includes data points for different wavelengths: 405 nm, 467 nm, and 635 nm.](image2)
## Conclusion

<table>
<thead>
<tr>
<th>Area (mm²)</th>
<th>Producer</th>
<th>Pixel size (µm)</th>
<th>Best SPTR (FWHM ± 5%) @ 467 nm &amp; Vbias max</th>
<th>SPTR Variation 405 nm → 635 nm</th>
<th>SPTR variation 0 °C → 20 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HAMAMATSU</td>
<td>50</td>
<td>150 ps</td>
<td>≈ 0 %</td>
<td>≤ 5 %</td>
</tr>
<tr>
<td>1</td>
<td>HAMAMATSU</td>
<td>100</td>
<td>160 ps</td>
<td>≈ 10 %</td>
<td>≤ 5 %</td>
</tr>
<tr>
<td>1</td>
<td>Sensl</td>
<td>20</td>
<td>160 ps</td>
<td>≈ 0 %</td>
<td>≤ 10 %</td>
</tr>
<tr>
<td>1</td>
<td>Sensl</td>
<td>35</td>
<td>200 ps</td>
<td>≈ 15 %</td>
<td>≤ 15 %</td>
</tr>
<tr>
<td>1</td>
<td>ASD (FBK)</td>
<td>50</td>
<td>140 ps</td>
<td>≈ 30 %</td>
<td>≈ 0 %</td>
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<tr>
<td>9</td>
<td>HAMAMATSU</td>
<td>25</td>
<td>250 ps</td>
<td>≈ 10 %</td>
<td>≈ 0 %</td>
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<tr>
<td>9</td>
<td>HAMAMATSU</td>
<td>100</td>
<td>170 ps</td>
<td>≈ 20 %</td>
<td>≈ 0 %</td>
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<tr>
<td>9</td>
<td>Sensl</td>
<td>35</td>
<td>measurement impossible at single p.e level</td>
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</tr>
<tr>
<td>9</td>
<td>ASD (FBK)</td>
<td>50</td>
<td>300 ps ± 10 %</td>
<td>measurement impossible</td>
<td></td>
</tr>
</tbody>
</table>
Additional slides
References of the plots


MPPC 50 µm « wide trace »

NEW HAMAMATSU PROTO

MPPC 100 µm « wide trace »