Fast, Low Noise Photodetectors for Nuclear Physics

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Outline

• Motivation for SSPM development
• SSPM introduction
• Overview of SSPM performance properties
  ❖ Discrete
  ❖ Position sensitive
• RMD corporate background

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Motivation to Replace PMTs

PMTs possess high gain ($10^6$) and low noise (ENF ~ 1) but...
- PMTs are bulky and fragile
- PMTs are sensitive to magnetic fields
- PMTs require high bias (~1000 V)
- PMTs have low quantum efficiency
- Spectral response of PMTs is narrow
Solid-State Photomultipliers

General SSPM main features

• Very high gain (>10^5), very simple electronic readout
• Low bias operation (~30 V)
• Fast response (sub-ns rise time)
• Very low excess and electronic noise (<1 electron level)
  ❖ Dark noise a problem at very low light levels
•Insensitive to magnetic fields
• Position sensitive structures possible
• RMD fabricates these devices by CMOS process, hence cost should be very low upon mass production.
• On-chip integration of readout electronics possible

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Silicon Photomultiplier Introduction

- Independent Geiger Mode Micro-APDs (~ 30 μm)
- Passively quenched
- Binary output, constant amplitude
- Common substrate, signals are summed
- Single macro analog output

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1 cm² Large Area CMOS SSPMs

1 cm² monolithic SSPM

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CMOS SSPM Arrays

- 1.5 x 1.5 mm² each element
- Each element composed of 34 x 34 micro-pixels
- Fill factor is 49%

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Position Sensitive CMOS SSPMs

Sensitivity on micro-pixel level

5 x 5 mm² PS-SSPM

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1 cm$^2$ SSPM Linearity

![Graph showing the linearity of ADC channels vs. energy for a 5.5 x 5.5 x 5.5 mm$^3$ LYSO with $^{22}$Na source, large-area SSPM, and room temperature.]
1 cm² SSPM Energy Resolution

**Energy Resolution**

- **511 keV**
  - PMT: 12% 7%
  - SSPM: 13% 7%

**Device**

- 5.5 x 5.5 x 5.5 mm³ LYSO
- ²²Na

**Large-area SSPM**

- Room Temperature
- 1274 keV
SSPM Timing Resolution

Timing Resolution FWHM = 425 ps at 511 keV
LaBr₃:Ce scintillator
SSPM Neutron Detection

1 cm² SSPM coupled to CLYC

Neutron peak measured with CLYC on SSPM

Counts

Energy (keV)

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Position Sensitive SSPM Concept

\[
X = \frac{(C1 + C2) - (C3 + C4)}{\Sigma} \\
Y = \frac{(C1 + C4) - (C2 + C3)}{\Sigma}
\]

Micro-pixels

Network Resistors
PS-SSPM & Readout PCB

- PS-SSPM chip was packaged on a ceramic 145 pin grid array
- Zero insertion force (ZIF) socket for easy removal

<table>
<thead>
<tr>
<th>PS-SSPM Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of micro-pixels</td>
</tr>
<tr>
<td>Micro-pixel area</td>
</tr>
<tr>
<td>Micro-pixel pitch</td>
</tr>
<tr>
<td>Geometrical Fill Factor</td>
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<tr>
<td>Quench Resistors</td>
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<tr>
<td>Network Resistors</td>
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<tr>
<td>Detection efficiency @ 400 nm</td>
</tr>
<tr>
<td>Dark Current (µA/mm²)</td>
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<tr>
<td>Dark Count Rate (kHz/pixel)</td>
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<tr>
<td>Operating Bias</td>
</tr>
<tr>
<td>Operating gain</td>
</tr>
<tr>
<td>Excess Noise Factor</td>
</tr>
<tr>
<td>Capacitance (fF/pixel)</td>
</tr>
</tbody>
</table>

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PS-SSPM Energy Resolution

5 x 5 x 3 mm$^3$ LYSO scintillator

511 keV Photopeak
Energy Resolution (FWHM) = 14%
PS-SSPM Spatial Resolution

![Graph showing the relationship between resolution and intensity.](image-url)
PS-SSPM Scintillator Images

6 x 6 LYSO array having 500 μm pixels

Uniform flood with $^{22}\text{Na}$ (511 keV)

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NS Potential Applications

• Nuclear and particle physics research
   Calorimeter
   Fiber tracker
   General charged particle or gamma-ray detector (with scintillator)

Other Potential Applications

• Nuclear medical imaging
• Astrophysics experiments
• Nuclear detection for non-proliferation
• Dosimetry
RMD Background

RMD Research Groups

- **Biosensor Technology**
  - Microfluidic Channels
  - Quantum Dots

- **Instrumentation**
  - Magnetic Imaging
  - Portable defect detection and imaging

- **Instrumentation Research and Development**
  - SSPM Technology
  - Standoff radiation imager

- **Optics and Photonics**
  - LIDAR
  - Biomedical imaging

- **Imaging Technology**
  - Imaging screens and detectors
  - Fast imaging photodetectors

- **Material Science**
  - Scintillation Materials
  - Solid-state detectors (Si-APDs, TIBr)

RMD was founded in 1974
Located in Watertown MA, 5 miles from Boston
80 Research Staff

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RMD Products

CZT Arrays

13mm x 13mm Si APD

64-element APD Array

CdTe Detectors

LPA-1 Lead-in-Paint Analyzer

CsI Imaging Screens

Navigator™ Surgical Probe

RadCam 2000™ Portable Gamma/Video Imager

RadCam 2000™ Image

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