Sub-nanosecond Charged Particle Detector with Fast Scintillator and Hybrid Photodetector

TREDI 2020: 15th “Trento” Workshop on Advanced Silicon Radiation Detectors

19-Feb-2020

Jonathan Garel
El-Mul Technologies, Ltd.
About El-Mul Technologies

- Located in Rehovot, Israel
- Established in 1992, private ownership
- 37 employees (15 in R&D), clean room production
- Supplier of customized charged particles detectors for various markets and technologies:
  - Electron and Ion microscopy
    - Analytical instrument industries (SEM, FIB, Litho)
    - Semiconductor tools (inspection, metrology)
  - Mass spectrometry
    - High resolution Time of Flight (TOF) detectors
Motivation for sub-ns Detectors

- Applications for sub-ns particle detectors in numerous fields:
  - Medical Devices (e.g. PET)
  - Particle Physics
  - Electron Microscopy
  - Time-of Flight Mass Spectrometry (TOF-MS)

- Need for fast detector in SEM to increase throughput (semi-conductor) and reduce charging (semi and analytical tools)

- Need for sub-ns detector in TOF-MS to improve isotopic resolution and mass resolution for large molecules
Desirable TOF detector characteristics:

- **fast**: faster detector = better resolution ($\Delta m/m \propto \Delta t/t$)
- **quantitative**
  - pulse front detection not enough
- **wide dynamic range** required (e.g. for isotopic separation)
- **high gain** (ideally no need for additional amplifier)
- **long lifetime**
# Detector Main Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ideal</th>
<th>Min. requirements</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time resolution (Pulse FWHM)</td>
<td>&lt;0.5 ns</td>
<td>&lt;1.0 ns</td>
<td></td>
</tr>
<tr>
<td>Gain</td>
<td>&gt;500,000</td>
<td>&gt;50,000</td>
<td>ideally detector can read single ion signal without MCP nor additional electronics</td>
</tr>
<tr>
<td>Dynamic range (pulse mode)</td>
<td>1-1000</td>
<td>1-100</td>
<td>Number of ions / pulse</td>
</tr>
<tr>
<td>Average output current</td>
<td>&gt;50 μA</td>
<td>&gt;10 μA</td>
<td></td>
</tr>
<tr>
<td>Lifetime</td>
<td>100 C</td>
<td>50 C</td>
<td>Accumulated output charge</td>
</tr>
</tbody>
</table>
## Existing Detectors and Limitations

<table>
<thead>
<tr>
<th>Detector</th>
<th>Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microchannel Plate (MCP)</td>
<td>• Low fill factor&lt;br&gt;• Non-planar $\rightarrow$ ion jitter&lt;br&gt;• Short lifetime&lt;br&gt;• HV electronics</td>
</tr>
<tr>
<td>Electron Multiplier (discrete dynodes)</td>
<td>• HV electronics&lt;br&gt;• Contamination&lt;br&gt;• Short lifetime</td>
</tr>
<tr>
<td>Plastic scintillator &amp; light sensor</td>
<td>• Short lifetime</td>
</tr>
</tbody>
</table>

**El-Mul Solution:**

fast inorganic scintillator **SCINTIFAST**$^\text{TM}$ + light sensor
MTOF™ Concept

- Electrons directed to scintillator by ExB field
- Near 100% detection efficiency (depends on convertor efficiency)
- Switchable polarity
- Cost-effective, high lifetime (no MCP)
- E and B chosen such that the ion and secondary electron jitter remains <0.3 ns
HPD Characteristics

- R10467U Hybrid photodetector (HPK)
- HPD is fast and relatively compact
- Nominal FWHM: 600 ps
- Maximum HPD gain 160,000
  - Recommended 130,000
- Sealed tube → no contamination
- Custom-made electronics
Single Electron Response

- Subassembly: ScintiFast + Light-guide + HPD, irradiated with 10 kV electron gun
- E-gun current < 0.1 pA → Single electron response measured
- HPD gain ~120,000

**Average of 1000 pulses**

**Pulse Height Distribution**

- FWHM = 0.65 ns, no ringing
- Pulse height = 7.5 ± 2.4 mV
- 5.8 ph-e / e → real / false event discrimination
Linearity and Dynamic Range

Average output linearity, measured in vacuum with electron gun

- Average output is linear up to about 50 µA
Linearity and Dynamic Range

- Measurement performed on HPD using pulsed ps laser

- Linearity is output-limited
- Pulse output linear up to ~250 mV output, then monotonic sublinear without pulse distortion up to at least 4 V (80 μA on 50 Ω scope)
- Overall dynamic range of several orders of magnitude with non-linearity corrections
Several prototypes already designed and built for mass spectrometry companies

Several detector have already been tested on real mass spectrometry instruments

All tested detector showed outstanding mass resolution, stability and lifetime
Detector timing currently limited by the HPD

- The HPD pulse width is a combination of:
  - physical transit time of charge carriers inside the Si AD
  - $\tau = RC$: discharge time of the AD capacitor C into the 50Ω load resistor R

→ Decreasing AD diameter → lower C → faster HPD?

Apply analog and / or digital signal processing to improve resolution past FWHM

- Not only front detection – quantitative information and pulse separation also required
- Low number of photons → stochastic variability
Summary and Outlook

- We presented the concept and results of a charged particle detector based on a novel inorganic scintillator coupled to a hybrid photodetector (HPD).

- The detector exhibits:
  - Single electron pulse width of $\leq 0.7$ ns
  - Dynamic range of several orders of magnitude
  - Stability and lifetime far better than competing technologies

- Next steps:
  - Further improve detector time resolution
    - Faster light sensor (e.g. HPD with smaller AD – but other options also considered)
    - Analog and/or digital signal processing
  - Application of the detector concept to other fields (e.g. nuclear physics, PET)
    - Possibly with another light sensor e.g. SiPM
Thank You!