High-Efficiency Readout of Scintillating Fibers by Avalanche Photodiodes (APDs)

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T. Yoshida, T. Okusawa, T. Sora, M. Yamasaki
Osaka City University

- Properties of a short-wavelength enhanced type APD
- Readout of a 3-m long scintillating fiber
- A preliminary test of APD arrays
Scintillating-fiber tracking detector

Typical number of photons per fiber = 10 - 20

Photosensors for scintillating fibers

- Image intensifier:
  High gain (MCP + Phosphor screen), Q.E. < 25%

- Multi-anode PMT:
  High gain (~10^6), Q.E. < 25%

- Visible light photon counter (VLPC):
  Q.E. > 70%, Gain > 20000, Operating temp. ~ 7K

- Avalanche photodiode (APD):
  Q.E. > 70%, Gain < 100 at room temperature
### Short-wavelength enhanced type Si APD S5343

#### Specifications of S5343

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
<td>Hamamatsu</td>
</tr>
<tr>
<td>Sensitive Area</td>
<td>Ø 1 mm</td>
</tr>
<tr>
<td>Quantum Efficiency</td>
<td>75 - 80% at 500 - 600 nm (Emission of 3HF-fiber)</td>
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<tr>
<td>Breakdown Voltage</td>
<td>~150 V</td>
</tr>
<tr>
<td>Dark Current</td>
<td>~2 nA @ gain=100 (at room temperature)</td>
</tr>
<tr>
<td>Capacitance</td>
<td>15 pF</td>
</tr>
</tbody>
</table>
Avalanche gain & Dark current (S5343)

(a) 
- +28°C
- −50°C (Bias ≤ 142.8 V)

(b) 
- +28°C
- −50°C (Bias ≤ 142.8 V)
- −50°C (Bias = 143.1 V)
Monte-Carlo simulation

(a) Triggering $\beta$-particle
   Mean 113 keV
   RMS 29 keV

(b) 560 MeV/c $\pi^+$ (M.I.P.)
   Mean 110 keV
   RMS 27 keV

Number of Events

Ionization energy loss in the fiber core (keV)
Signal & Noise Spectra, Distance from APD = 2.37 m

Average # of p.e. ≈ 19

Threshold to exclude 99.5% of noises

- **+28°C**
  - $V_B = 151.4$ V
  - $I_D = 2.1$ nA
  - $M = 115$

- **−20°C**
  - $V_B = 145.5$ V
  - $I_D = 0.6$ nA
  - $M = 200$

- **−50°C**
  - $V_B = 142.0$ V
  - $I_D = 0.6$ nA
  - $M = 520$

Number of Events

Preamp. Output Pulse Height (mV)
Detection efficiency for a triggering β-particle

Distance from APD = 2.37 m
Average # of p.e. = 19
Distance from APD = 2.82 m (≈ the far end)

APD Temp. = -50°C

Detection Efficiency (%)

- • with Mirror, <# of p.e.> ≈ 19
- ○ without Mirror, <# of p.e.> ≈ 11

Bias Voltage (V)
Uniformity of the APD array at −50°C

APD Array No. 1

APD Array No. 2
Summary

• We have tested a short-wavelength enhanced type APD as a photosensor for a 3-m long scintillating fiber (Ø 0.75 mm).

• Detection efficiency for a M.I.P. is nearly 100% when the APD is operated at $\mu_4$ or below. (The average # of p.e. is $\sim 19$ with a mirror.)

• Detection efficiency is still high ($\sim 99\%$) even when the average # of p.e. is $\sim 11$ (with no mirror).

Next step

• Building and testing a prototype scintillating-fiber tracking detector using APD arrays and highly integrated preamplifier circuits such as SVX chips, VA chips etc.