Study of MPPC at liquid nitrogen temperature

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On behalf of the KEK Detector Technology Project
Introduction

• We have measured **basic properties** of 1600 pix MPPC produced by HPK at **low temperatures**.
• **Temperatures**
  - Room Temp. (300K)
  - Ethanol / Dry Ice (200K)
  - Liquid Nitrogen (77K)
• **Measured Items**
  - Waveform,
  - Quenching Resistance,
  - Pixel Capacitance,
  - Breakdown Voltage,
  - Noise Rate,
  - Cross-talk,
  - After-pulse

We directly cooled MPPC.
• Fast/Slow components are clearly seen at low temperatures.
Quenching Resistance

- We measured I-V curve by applying forward bias. We evaluated quenching resistance value from the I-V curve.

![IV curve graph]

<table>
<thead>
<tr>
<th>Temperature (K)</th>
<th>Resistance (MΩ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300K</td>
<td>0.21</td>
</tr>
<tr>
<td>200K</td>
<td>0.40</td>
</tr>
<tr>
<td>77K</td>
<td>1.68</td>
</tr>
</tbody>
</table>

Poly-silicon
Gain Curve

- We evaluated pixel capacitance from slope of gain curve.

$$\text{Gain} = \frac{C}{e} (V_{\text{bias}} - V_{\text{breakdown}})$$

### Pixel Capacitance

<table>
<thead>
<tr>
<th>Temperature (°K)</th>
<th>Capacitance (± fF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300K</td>
<td>22.1 ± 0.8 fF</td>
</tr>
<tr>
<td>200K</td>
<td>22.0 ± 0.7 fF</td>
</tr>
<tr>
<td>77K</td>
<td>21.3 ± 0.5 fF</td>
</tr>
</tbody>
</table>
Pulse shape of slow component can be explained by RC time constant.
Breakdown Voltage

- We evaluated breakdown voltage from gain curve.

- Measured slope (50mV/K) is consistent with the slope observed around room temperature.
Dark Noise

- We measured dark noise rate at each temperature.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Noise Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>300K</td>
<td>100kHz~1MHz</td>
</tr>
<tr>
<td>200K</td>
<td>10Hz~100Hz</td>
</tr>
<tr>
<td>77K</td>
<td>1Hz ~ 10Hz</td>
</tr>
</tbody>
</table>

Over Voltage [V]:

bias voltage – breakdown voltage
Cross-talk

- We measured probability that normal pulse generates cross-talk.

\[
\text{Prob.} = \frac{\text{Output Of Disc2}}{\text{Output Of Disc1}}
\]

Cross-talk probability is slightly reduced at low temperature.
We obtained re-emission time constant by measuring time interval between two pulses (=T).

Entries of distribution:

\[ P(t) = A \exp\left(-\frac{t}{\tau_{\text{emission}}}\right) + B \exp\left(-\frac{t}{\tau_{\text{noise}}}\right) \]

\[ \tau_{\text{emission}} \quad [\text{ns}] \]

<table>
<thead>
<tr>
<th>Bias Voltage [V]</th>
<th>( \tau_{\text{emission}} ) [ns]</th>
</tr>
</thead>
<tbody>
<tr>
<td>300K</td>
<td>41.8 ± 2.2</td>
</tr>
<tr>
<td>200K</td>
<td>95.6 ± 7.9</td>
</tr>
<tr>
<td>77K</td>
<td>107.6 ± 4.6</td>
</tr>
</tbody>
</table>

These plots are taken at different applied voltage.
By looking at the pulse shape at 77K, we observed recovery of pulse height after the first pulse. Detailed analysis of this recovery at room temperature will be reported by next speaker.
Summary (1)

• We have studied the MPPC basic properties at low temperature.
  – Waveform
    Fast/Slow components are seen at low temperature.
    Pulse shape of slow component can be explained by RC constant.

– Quenching Resistance and Pixel Capacitance
  300K : 0.21MΩ, 22.1fF
  200K : 0.40MΩ, 22.0fF
  77K : 1.68MΩ, 21.3fF

– Breakdown Voltage
  Measured slope (50mV/K) is consistent with the slope observed around room temperature.
Summary (2)

- Dark Noise
  300K : 100kHz ~ 1MHz
  200K : 10Hz ~ 100Hz
  77K   : 1Hz ~ 10 Hz

- Cross-talk
  Cross-talk probability is slightly reduced at low temperature.

- Re-emission time constant of After-pulse
  300K : 41.8±2.2[ns]
  200K : 95.6±7.9[ns]
  77K  : 107.6±4.6[ns]

•Prospects
  – Measure quantum efficiency at low temperature.
  – Measure individual difference.
backup
Introduction

MPPC and other Geiger-mode APD are expected to be useful at low temperatures for several purposes.

- Use with liquid inorganic scintillators
  - LiAr(90K)
  - LiXe(163K)
- Use in outer space for astrophysics

Our measurement at:
- 300K: Room Temp.
- 201K: Ethanol / Dry ice
- 77K: LiN2 Temp.

Diagram:

- LiN Temp. (77K)
- Ethanol / Dry ice (201K)
- Room Temp. (300K)
- LiAr Temp. (90K)
- LiXe Temp. (163K)
- Outer Space Temp. (200K~)
Probability which after-pulse comes in 50 ns

Entries
- Normal Noise
- Cross-talk
- Accidental Noise
- After-pulse → Prob = After-pulse/Entries

Prob.

Red 300K
Green 201K
Blue 77K

Over Voltage [V]