Measurements of electron emission reduction from grid electrodes in the R&D test platform for the LZ experiment

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CPAD 2019

On Behalf of the LZ Experiment
LZ detector

- Search for WIMP dark matter candidate
- 4850-ft underground at Sanford Lab

TPC with 7 tonne LXe active volume

Cathode HV feedthrough

Instrumented Xe skin

Water tank

Gadolinium loaded liquid scintillator

DD (NR) calibration conduit
LZ TPC

TPC = Time Projection Chamber

Electron extraction region

Drift region

Particle

S1

S2

Time

E field

Drift time indicates depth

Ionization electrons

UV scintillation photons (~175 nm)

LZ projected sensitivity

Image by CH Faham (Brown)
LZ grids

Electric fields established by 4 woven SS mesh grids

<table>
<thead>
<tr>
<th></th>
<th>Wire pitch (mm)</th>
<th>Wire diameter (μm)</th>
<th>Transparency (%)</th>
<th>Voltage (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anode</td>
<td>2.5</td>
<td>100</td>
<td>92</td>
<td>5.75</td>
</tr>
<tr>
<td>Gate</td>
<td>5</td>
<td>75</td>
<td>97</td>
<td>-5.75</td>
</tr>
<tr>
<td>Cathode</td>
<td>5</td>
<td>100</td>
<td>96</td>
<td>-50 / -100</td>
</tr>
<tr>
<td>Bottom</td>
<td>5</td>
<td>75</td>
<td>97</td>
<td>-1.5</td>
</tr>
</tbody>
</table>

Hamamatsu R11410 3” Ø PMTs, radioactivity: ~mBq, high QE.
Grid production: weave

- Commercially available wire mesh does not come in the LZ grid diameter
- Challenges: Maintain wire spacing & tension
- Video of weaving process
Grid production: glue
Electron emission

Electron emission from wires is problematic:

- Impacts low energy dark matter search → Accidental coincidence can mimic low energy events & limit S2-only search
- Affects detector operability → high DAQ rate from electron trains can increase dead time

Events with an “S2” from electron emission can mimic NR event (red).

LZ simulated data set for a background-only 1000~live day run and a 5.6 tonne fiducial mass. ER and NR bands are indicated in blue and red, respectively (solid: mean; dashed: 10% and 90%). The 1σ and 2σ contours for the low-energy ⁸B and hep NR backgrounds, and a 40 GeV/c² WIMP are shown as shaded regions.
Electron emission mitigation

1. **Dust removal**: Construct grids in a cleanroom & remove dust

2. **Passivation**: Changes chemical composition of the oxide layer & increases the Cr:Fe ratio.

Collaborators at ICL measured reduction of electron emission from passivation

System test platform at SLAC

<table>
<thead>
<tr>
<th>Large</th>
<th>Small</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1.5-m ø grids)</td>
<td>(14-cm ø grids)</td>
</tr>
</tbody>
</table>

**TPC**

**Gas only**
Small 2-PMT gas-only detector

- Scaled-down extraction region
- Quick turnaround
- Xenon gas, 3.3 bar
Gas test nitric passivation

35% Nitric acid at room temperature for 30 min

Figure 4.7: Electron emission rate before and after nitric passivation at APC: (a) rate vs. $\Delta V_{T-B}$; (b) Fowler-Nordheim plot.

LZ requirement: $\Delta V_{A-G} = 6.8$ kV

LZ requirement
0.019 kV/cm

W. Ji PhD, Stanford, 2019.
Gas test citric passivation

3-5% Citric acid at 175°F for 2 hr

LZ requirement: \( \Delta V_{A-G} = 6.8 \text{ kV} \)

LZ requirement: \( 0.019 \text{ kV/cm} \)

Figure 4.8: Electron emission rate before and after citric passivation at APC: (a) rate vs. \( \Delta V_{T-B} \); (b) Fowler-Nordheim plot. The blue (or green) dashed line fit to the F-N equation gives the before (or after) entry for APC treatment in Table 4.1.

W. Ji PhD, Stanford, 2019.
Small 32-PMT detector
R. Mannino  
University of Wisconsin — Madison  
CPAD 2019  

32-PMT gas detector: citric passivation results

Before citric passivation, 2 hot spots
After 130°F and 140°F citric passivation, same hot spots remain
After passivation and 48 hr oxidation, hot spots gone

Systematic errors not shown

LZ equivalent $\Delta V_{A-G}$

Plots at $\Delta V_{A-G} = 16$ kV
System test: Large gas-only detector
Emission from dust

Results from passivation of a prototype grid are being analyzed.
LZ passivation & grid cleaning

- Gate grid passivated in 3-5% citric acid.
  - Cathodic and in the electron extraction region
- Each grid was spray washed with DI water and UV-inspected for dust before assembly.
HV in future experiments

- HV issues affect many noble liquid detectors.
  - Fermilab’s 2013 HV in Noble Liquids workshop
- Future larger-scale detectors affected by HV issues.
  - Scaling up can increase likelihood of dust or surface defects on electrodes.
- Techniques to mitigate electron emission may become increasingly important.
Conclusions

- SLAC R&D System Test studied passivation as a treatment for electron emission reduction.

- Promising results observed in many prototype grids

- Paper in preparation now.
Thank you
Extra slides
32-PMT TPC nitric & citric passivation

Plots at dV = 12.5 kV

- Nitric, dirty, before spark
- Nitric, dirty, after spark
- Citric, clean

LZ equivalent field at 11.5 kV
Drift and reverse field region

<table>
<thead>
<tr>
<th>Grid</th>
<th>Voltage (kV)</th>
<th>Surface field (kV/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cathode</td>
<td>-50</td>
<td>-30.1</td>
</tr>
<tr>
<td></td>
<td>-100</td>
<td>-61.4</td>
</tr>
<tr>
<td>Bottom</td>
<td>-1.5</td>
<td>-33.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-68.6</td>
</tr>
</tbody>
</table>
Electron extraction region

- Liquid-Anode gap = 8 mm
- Gate-Liquid gap = 5 mm

<table>
<thead>
<tr>
<th>Grid</th>
<th>Voltage (kV)</th>
<th>Surface field (kV/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anode</td>
<td>5.75</td>
<td>46.2</td>
</tr>
<tr>
<td>Gate</td>
<td>-5.75</td>
<td>-48.4 -51.8</td>
</tr>
</tbody>
</table>

Cathode @ -50 kV
Cathode @ -100 kV