Search for Scintillation in Doped Lead Fluoride Crystals

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Introduction

- This work focuses on a search for scintillation in doped lead fluoride (PbF$_2$) for the homogeneous hadronic calorimeter detector concept, where both Cherenkov and scintillation lights are measured for good hadronic energy resolution.

- Why PbF$_2$?
  - High density: 7.77 g/cc and short $\lambda_I$: 21 cm.
  - Good UV transparency down to 250 nm for Cherenkov.
  - Can be grown for large size of 20 cm.
  - Potentially low cost ($2/\text{cc}$): melting point at 824$^\circ$C and low material cost: 1/3 of BGO.

- Lead fluoride samples with rare earth doping were grown by Bridgman method. Photo- and X- luminescence, decay kinetics and $\gamma$-ray excited anode current and pulse height spectrum were measured.
Cherenkov Needs UV Transparency

Cherenkov figure of merit

Using UG11 optical filter, Cherenkov light can be effectively selected with negligible contamination from scintillation.
PbF$_2$ Samples

- A total of 116 samples with various rare earth doping were grown by vertical Bridgman method at SIC and Scintibow.

- SIC samples are of 1.5 $X_0$ (14 mm) cube, while most of the Scintibow samples are of $\Phi$ 22 x 15 mm.
Photo- and X-luminescence

- Photo luminescence was measured by using Hitachi F-4500 fluorescence spectrophotometer.
- An AMTPEK portable X-ray tube was used for the X-luminescence measurement.
Luminescence: Er & Eu Doped PbF$_2$

Consistent Photo- and X-luminescence observed

PbF$_2$ (Er doping)

Em: 546 nm  
Ex: 377 nm

PbF$_2$ (Eu doping)

Em: 588 nm  
Ex: 318 nm

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Luminescence: Gd & Ho doped PbF$_2$

Consistent Photo- and X-luminescence observed

**PbF$_2$ (Gd doping)**
- *Em: 312 nm*
- *Ex: 273 nm*

**PbF$_2$ (Ho doping)**
- *Em: 538 nm*
- *Ex: 360 nm*
Luminescence: Pr & Sm Doped PbF$_2$

Consistent Photo- and X-luminescence observed

![Graphs showing luminescence spectra for Pr and Sm doped PbF$_2$.]
Luminescence: Tb doped PbF$_2$

Consistent Photo- and X-luminescence observed

![Graph showing luminescence spectra with peaks at 272 nm and 543 nm.]

- **Em: 543 nm**
- **Ex: 272 nm**
Decay Time Measurement

Tunable Pulsed UV laser (6~8 ns)
OPOTEK Opolett 355 II + UV

Sample

Monochromator (Oriel MS257)

PMT (R2059)

H.V.

Digital Scope

Trigger

Signal

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Verified with BGO & CsI(Tl)

Decay time consists with well known values

BGO

\[ I = A \exp(-t/\tau) \]
\[ A = 1.0 \]
\[ \tau = 289.2 \]
\[ \chi^2/DOF = 1.3 \]

290 ns

CsI(Tl)

\[ I = A \exp(-t/\tau) \]
\[ A = 1.0 \]
\[ \tau = 1280.0 \]
\[ \chi^2/DOF = 1.4 \]

1280 ns
Decay Time: Er & Eu Doped PbF$_2$

**PbF:Er**
Laser excited

\[ I = A \exp\left(-\frac{x}{\tau}\right) \]
\[ A = 1.0 \]
\[ \tau = 1.52 \]
\[ \chi^2/DOF = 1.7 \]

1.5 ms

**PbF:Eu**
Laser excited

\[ I = A \exp\left(-\frac{x}{\tau}\right) \]
\[ A = 1.0 \]
\[ \tau = 8.52 \]
\[ \chi^2/DOF = 1.9 \]

8.5 ms
Decay Time: Ho and Sm Doped PbF$_2$

\[ I = A \exp\left(-\frac{x}{\tau}\right) \]

- **PbF:Ho**
  - Laser excited
  - \( A = 1.0 \)
  - \( \tau = 1.33 \)
  - \( \chi^2/DOF = 2.2 \)
  - 1.3ms

- **PbF:Sm**
  - Laser excited
  - \( A = 1.0 \)
  - \( \tau = 7.02 \)
  - \( \chi^2/DOF = 1.3 \)
  - 7.0ms
Decay Time: Tb Doped PbF$_2$

$I = A \exp\left(-\frac{x}{\tau}\right)$
$A = 1.0$
$\tau = 4.95$
$\chi^2/DOF = 1.7$

5.0 ms
Anode Current Measurement

Distance between source and sample: 2 cm

Cs-137 Source

Crystal

PMT

Multimeter

HV supply

PC
Anode Current: PWO & Un-doped PbF$_2$

PWO: L.O. = 20 p.e./MeV, anode current = 240 nA

- **Sample:** 1.5x PWO
- **Source:** $^{137}$Cs
- **PMT:** Hamamatsu R2059, HV = 2000V

- **Sample:** PbF (undoped)
- **Source:** $^{137}$Cs
- **PMT:** Hamamatsu R2059, HV = 2000V

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Anode Current: All Samples

PbF$_2$ with R.E. Doping
Gamma ray excited (Cs-137)

Anode Current (nA)

Sample ID

0 100

undoped PbF$_2$
## Summary of Anode Current

<table>
<thead>
<tr>
<th>ID</th>
<th>Anode current (nA)</th>
<th>Size (mm)</th>
<th>Doping</th>
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</thead>
<tbody>
<tr>
<td>Scintibow-1</td>
<td>51</td>
<td>18 x12 x10</td>
<td>Eu</td>
</tr>
<tr>
<td>Scintibow-18</td>
<td>52</td>
<td>Φ22X15</td>
<td>Eu/Gd</td>
</tr>
<tr>
<td>Scintibow-27</td>
<td>53</td>
<td>Φ20X15</td>
<td>Eu/Tb</td>
</tr>
<tr>
<td>Scintibow-B19</td>
<td>56</td>
<td>Φ20X15</td>
<td>Eu/Tb/Na</td>
</tr>
<tr>
<td>Scintibow-B21</td>
<td>83</td>
<td>Φ22X15</td>
<td>Eu/Bi/Na</td>
</tr>
<tr>
<td>Scintibow-B23</td>
<td>73</td>
<td>Φ20X15</td>
<td>Eu/Bi/Na</td>
</tr>
<tr>
<td>Undoped</td>
<td>42</td>
<td>14 x 14 x14</td>
<td>--</td>
</tr>
</tbody>
</table>
γ-ray Excited Pulse Height Spectrum

Diagram showing the setup with:
- Cs–137 Source
- Crystal
- PMT
- CAMAC Crate
- qvt MCA
  - LeCroy 3001
- Gate generator
  - LeCroy 2323A
- Discriminator
- H.V. Supply
- PC
γ-ray Excited PHS: PWO

PWO (3x3x4 cm)

PMT: R2059, HV = -2100 V, Cs-137
Gate: 1000ns, Ped: 155 ch, Cali. = 3.0 ch/p.e.
L.Y. = 13.8 p.e./MeV

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<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Constant</td>
<td>1104.</td>
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<tr>
<td>Mean</td>
<td>196.8</td>
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<tr>
<td>Sigma</td>
<td>27.22</td>
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</tbody>
</table>
γ-ray Excited PHS: Doped PbF$_2$

PMT: R2059, HV = -2100 V
Gate: 1000 ns, Cs-137
Summary

- Lead fluoride crystal samples doped with various rare earth dopant were grown by Bridgman method.
- Consistent photo and x-ray luminescence found in samples with Er, Eu, Gd, Ho, Pr, Sm and Tb doping.
- The decay time of doped samples was found to be very long at ms scale as expected from the f-f transition of the rare earth elements.
- While some doped samples show anode current larger than the un-doped samples, their γ-ray excited pulse height spectra were found identical to un-doped sample, indicating no scintillation light.
- Investigation will continue to search for scintillation in doped lead fluoride and other host materials.