Charge collection physics in very large diameter germanium crystals

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A collaboration with C.J. (Kim) Lister at U. Mass Lowell

• PHDS Co. Introduction
• Very large diameter crystal properties (140 mm)
• New products from very large-diameter HPGe crystals
PHDS Co.

- Est. Fall 2004 – Nuclear and Solid State Physics Origin
  - History: Custom Nuclear-Physics Detectors
  - Recently: Modular HPGe Systems
- Complete Germanium Detector Manufacturing and R&D
  - Concept
  - Design
  - Crystal Growth
  - Detector Fabrication
  - System Integration
  - Software application
  - Sales & Service

NPX (150 lbs.)

GeGI-5 (15 lbs.)

A nuclear physics lab in one hand, Scientist OR Soldier
Vertical manufacturing of GeGI Imaging Spectrometers

- Ge Zone Refine
- HPGe Crystal Growth
- Analysis
- Fabrication
- GeGI 5
- Integration
- Electronics
- Cryogenics
A product with global impact
9 countries, 4 continents
Fulcrum: The newest PHDS Co. commercial detector

- Ge Zone Refine
- HPGe Crystal Growth
- Fabrication
- Analysis
- Integration
- Cryogenics
- Electronics
- Detector

HPGe Crystal Growth

Fulcrum: The newest PHDS Co. commercial detector
The most compact HPGe detector in the world (7-8 lbs.)
Gamma Ray Imaging Detectors

Germanium System Evolution at PHDS Co.

- **2008 NPX LN$_2$** 150 lbs.  Non-portable
- **2009 NPX-M** 75 lbs.  Non-portable
- **2010 GeGI-1** 55 lbs.  Movable
- **2013 GeGI-3** 33 lbs.  Transportable
- **2014 GeGI-4** 28 lbs.  Personnel Portable
- **2017 GeGI-5** 15 lbs.  Hand Portable
- **2017 Fulcrum 7-8** lbs.  Hand Portable
- **2017 !!**
This program: Make larger diameter detectors commercially viable

Excessive Leakage Current (and Trapping)

Most of the time they do not work....
Increase the hot zone from 240 to 310 mm
Keep away from the outside of the puller
The first crystal from CZ300 10.1 kg
Need:
1. High purity
2. Mass ~ 20 kg

\[ C(m) = C_0 k (1 - m/m_0)^{(k-1)} \]

- Boron \( k = 20 \)
- Phosphorus \( k = 0.08 \)
- Aluminum \( k = 1 \)
- Indium \( k = 0.001 \)

\[ B \sim 0 / \text{cm}^3 \]
\[ P \sim 5.9 \times 10^{12} / \text{cm}^3 \]
\[ Al \sim 1 \times 10^{11} / \text{cm}^3 \]

CZ300 10.1 kg

Not HPGe
10140 g

$P = 5.9 \times 10^{12} \text{ /cm}^3$
9470 g

\[ P = 3.0 \times 10^{12} \text{ /cm}^3 \]
12229 g
$P = 2.0 \times 10^{12} \text{ /cm}^3$
14516 g
$P = 1.7 \times 10^{12} \text{ /cm}^3$
19696 g
$P = 0.9 \times 10^{12} / \text{cm}^3$
51 crystals grown and analyzed

Mass ~ 19 kg

HPGe level
Gamma Ray Imaging Detectors

\[ 1.6 \times 10^{12} / \text{cm}^3 \text{ n-type} \]

\[ 2.1 \times 10^{11} / \text{cm}^3 \text{ n-type} \]

\[ 2.2 \times 10^{10} / \text{cm}^3 \text{ n-type} \]

\[ 3.8 \times 10^{10} / \text{cm}^3 \text{ p-type} \]

\[ 1.0 \times 10^{12} / \text{cm}^3 \text{ n-type} \]

\[ 1.1 \times 10^{11} / \text{cm}^3 \text{ p-type} \]

\[ 3.0 \times 10^8 / \text{cm}^3 \text{ p-type} \]

**Test detectors**

- HPGe 5-6 kg!!
- 20-mm diameter
- 5-mm thick

\[ E (\text{keV}) \]

\[ \text{Al}_0 = 1.1 \times 10^{11} / \text{cm}^3 \text{ p-type} \]

\[ \text{Al}_1 = 1.0 \times 10^{11} / \text{cm}^3 \text{ p-type} \]

**<20171220>**

18.9 kg
30 analyzed crystals

20-mm diameter
5-mm thick
Test detectors

Test detector results

\[
FWHM_{\text{det}} \approx \left( FWHM_{122}^2 - FWHM_{662}^2 \right)^{\frac{1}{2}}
\]

122 keV
FWHM = 1.05 keV
FWTM = 2.03 keV

662 keV
FWHM = 1.44 keV
FWTM = 2.69 keV

PHDS
Gamma Ray Imaging Detectors
Spectroscopy

Slice 1 FWHM_{det}

Slice 3 FWHM_{det}
For large mass (19 kg) crystals strain regions lower E fields where it matters the most (center detector data)
Direction of asymmetric swing
“Fast Facet”
Multiple samples – axis properties

\[ FWHM_{\text{det}} \approx \left( FWHM_{662}^2 - FWHM_{122}^2 \right)^{\frac{1}{2}} \]
Impurity Segregation is as radially uniform in [] crystals
1. New Commercial Detector – Fulcrum
Commercial Impact

1. New Commercial Detector – Fulcrum

- Fulcrum
- 25 cm³
- 70 cm³
Commercial Impact

1. New Commercial Detector – Fulcrum

1332-keV
FWHM = 2.16 keV
(ext JFET)

It works!
2. New very-large rare-particle DOE Nuclear Physics research detector

Very large (6.7 kg) HPGe Slab Being made into a novel (customer specified) detector design Enabled by this program
Commercial Impact
2. Practice grinding and polish etch

Thank you