Growth of large diameter high-purity germanium crystals for Nuclear Physics research
Presented by Ethan Hull
DE-SC0004256 Richard Pehl PI

8/15/2011-8/14/2014 (including NCE)

Extremely large diameter high-purity germanium crystals are being developed for large diameter segmented Nuclear Physics planar detectors. A high-purity germanium crystal puller has been demonstrated to grow crystals having sufficient purity and charge-collection properties to produce detector-quality germanium. The crystal diameter and purity levels have been iteratively improved to produce several successful commercial detectors delivered to customers during the past year. Significantly larger diameter germanium crystals have been grown with the correct properties for successful detector yield. These larger prototype detectors are being fabricated.

Collaboration with Kim Lister at UMass Lowell

- Introduction to PHDs Co.
- Motivation
- Large diameter germanium process and crystal growth
  - Established commercial viability of 90-mm PHDs Co. HPGe!!
- Increasing the diameter further → 140 mm
- Material understanding – Al –Si example
10,000 ft² Manufacturing and R&D Facility in Knoxville, TN

Office area (~ 2000 ft²)

Technical area (~ 8000 ft²)
Goal: Grow significantly larger diameter HPGe crystals for larger diameter detector systems

Motivation:
- Greater detection efficiency/system
- Less edge – more detector
- Higher detector proportion
- Lower cost per active volume and area
System Progression

2007
NPX LN$_2$
150 lbs

2008
NPX-M 70 lbs

2010
GeGI-1 55 lbs

2012
GeGI-3 33 lbs

2014
GeGI-4 28 lbs
2.5 times the detector and half the supporting hardware
Summary of Accomplishments

- Solved some large-diameter challenges ~ N(r) – Acceptors
- Lowered Impurity concentration to tolerable levels
- Established a viable doping method
  - Sources of contamination
  - Improved understanding of electron trapping – continues evolving
- Transitioned 90-mm HPGe to commercial level – repeatable.
  - NPX Prototypes, then GeGI and GGC systems
  - GeGI product becomes viable – now marketing
- Larger crystals → Goal 140-mm diameter
  - Grown diameters as large as 170 mm
  - Grown mass as large as 15 kg
    - Desirable intrinsic crystal properties exist at large size
GeGI shipped first product spring 2013 – Enabled by this crystal program

GeGI: The Germanium Gamma Ray Imager

- Complete Spectroscopy and Imaging System
- Compton-Vision Tactical Output
- 50-mm diameter 10-mm thick Ge crystal grown by PHDs Co.
- 66 cm² active detector area inside guard ring
- 122-keV energy resolution FWHM ~ 1.3 keV
- 662-keV energy resolution FWHM ~ 2.2 keV
- Locates and identifies 100 µCi of 137Cs in 5-10 sec at 1 meter
- Locates and identifies Special Nuclear Material (SNM)
- Data acquisition runs under Windows
- A/R/SI 42.42 output format
- User friendly operation
- Portable 33 lbs
- Includes an internal battery (30-45 minutes)

PHDs Co. 3011 Amherst Road, Knoxville, TN 37921 (865) 292 6253
www.phdsco.com, sales@phdsco.com

133 Ba 356 keV

137 Cs 662 keV

90-mm
Detector-Grade Germanium Process

Electronic Grade ZR Ge – Ar, N₂, Graphite

High Purity Zone refinement, SiO₂, H₂

Detectors!

Slicing and Evaluation

High Purity CZ Puller, SiO₂, H₂
Increasing crystal diameter and mass

10 kg Crystal
(from last year’s presentation)
161.4 mm max sho
6 cm of length > 140 mm dia.
13,659 g

→ 140-mm diameter selected for the next standard sized detector (cryostat etc)
Slicing

200+ mm ID saw
final component
Inspired by the successful crystals
Crystal Evaluation

122-keV FWHM = 1.09 keV

1.1x10^{10} n type

662-keV FWHM = 1.39 keV

F = 0.08
- Mass of each slice
- Net impurity concentration
- Typeness

$C(m) = C_0 k (1 - m/m_0)^{(k-1)}$

Boron $k = 20$
Phosphorus $k = 0.08$
Aluminum $k = 1$

<table>
<thead>
<tr>
<th>Mass Range</th>
<th>p-type Impurity</th>
<th>n-type Impurity</th>
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<tbody>
<tr>
<td>0 – 421 g</td>
<td>$7.0 \times 10^{10}$/cm$^3$</td>
<td>$5.6 \times 10^{11}$/cm$^3$</td>
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<tr>
<td>1 – 158 g</td>
<td>$2.9 \times 10^9$/cm$^3$</td>
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<td>2 – 4702 g</td>
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<td>3 – 404 g</td>
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<td>4 – 3005 g</td>
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<td>5 – 245 g</td>
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<td>6 – 2150 g</td>
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<tr>
<td>7 – 178 g</td>
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<tr>
<td>8 – 807 g</td>
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</tbody>
</table>
\[ C(m) = C_0 k(1 - \frac{m}{m_0})^{(k-1)} \]

Boron \( k = 20 \)
Phosphorus \( k = 0.08 \)
Aluminum \( k = 1 \)

B: \( C_0 = 1 \times 10^{10} \) /cm\(^3\)
P: \( C_0 = 8 \times 10^{11} \) /cm\(^3\)
Al: \( C_1 = 5 \times 10^{10} \) /cm\(^3\)