Study of PC-HPGe detector for dark matter search

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CDEX collaboration

Application of Germanium Detector in Fundamental Research
March 23-30, 2011, Beijing, China
Outline

- What’s a PC-HPGe detector?
- What we have done?
- Conclusion
Point-contact HPGe detector

- First developed in the late 1980s as large volume, low noise HPGe detectors
  - \( \sim 1 \) pF capacitance
  - \( \sim 300 \) eV noise threshold
- Recently “rediscovered” for neutrino detection, dark matter search, etc.
  - MAJORANA, GERDA, CoGeNT, CDEX,…

[Diagram of coaxial and PPC HPGe detectors]
Charge Collection & Signal Induction

- Charge collection and signal induction characteristics can be used to separate single- and multi-site events

- **Electric Field Distribution**

- **Drift Time**

- Strong field exists in front of the point contact
- Significant signal induced only in close proximity to point contact
  - significant contribution typically only made by holes
  - relatively insensitive to electron trapping
Very useful for background suppression:
- WIMP interaction is eminently single-site type.
- A large fraction of background is not.
What We Have Done

- Laboratory set-up
- Crystal processing
- Pre-amplifier design
  - JFET based
  - CMOS based
- Cryostats design
- Simulation study
Laboratory Set-up

- Clean room
- Wet Lab
- Machine-shop

Vacuum Coating Machine
Magnetron Sputtering Device
Crystal Processing

- Typical Processing Technology is used (so far)

- Mechanical Preparation
- Lithium Diffusion
- Wet Lab
- Boron Implant
- Boron Implant Accelerator
Detector Performance(1)

- Planar Configuration

- Recycled crystal ~10 g

- $\Delta E = 2.13$ KeV

- $\Delta E = 2.24$ KeV

- @132 K
Detector Performance(2)

- Point-contact Configuration

Recycled crystal
~10 g

Test Result with 2-outer grooves

ΔE = 1.33 KeV

Low Chan=10

ΔE = 880 eV

Low Chan=15

Peak=3633.93
0.202%@662KeV

Peak=50
~10KeV

Peak=323.99
1.48%@59.5KeV

Peak=3633.93
0.202%@662KeV
Pre-amplifier Study: J-FET based

- Feedback methods
  - Resistor feedback
  - Pulse-reset feedback

![Test Cryostat for Pre-amplifier](image1)

Teflon substrate for J-FET die

![Cryostat for Pre-amplifier](image2)

![Teflon substrate for J-FET die](image3)
Performance: J-FET based

• Resistor Feedback

  - ENC=55 e @ -100°C

• Pulse-reset feedback

  - ENC=14 e @ -112°C

• For detail, please see Zhu Weibin’s talk this afternoon
Performance: CMOS ASIC based

- For detail, please see Deng Zhi’s talk this afternoon
Cryostat Design

- Traditional design:
  - not optimized for point-contact configuration
- New design:
  - Point-contact probe
  - Scalable for different sizes of crystal
  - Low background material:
    - Quartz substrate for J-FET bonding
Simulation Study

- **Simulation items**
  - Electric field
    - Real field
    - Weighting field
  - Capacitance
  - Depletion characteristics
    - Depletion profile
    - Full depletion voltage
  - Energy Deposit & Energy spectrum
  - Charge collection & Signal induction

- **Software tools used**
  - Maxwell 3D
  - GEANT4
  - + MaGe

Many thanks to Dr. Liu Xiang and Dr. Liu Jing for their help concerning the use of MaGe
Simulation: Electric Field

- \( \phi \): 50 mm
- \( H \): 50 mm
- \( P^+ \): \( \phi = 1 \text{mm}, D = 1 \text{mm} \)
- \( \rho(\text{bottom}) = 0.8 \times 10^{10} / \text{cm}^3 \)
- \( \rho(\text{top}) = 1.5 \times 10^{10} / \text{cm}^3 \)
- \( V(N^+) = 3000 \text{ V} \)
- \( V(P^+) = 0 \text{ V} \)
# Simulation: Capacitance

<table>
<thead>
<tr>
<th>Detector Configuration</th>
<th>Capacitance  pF</th>
<th>By Theory Calculation</th>
<th>By Maxwell simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Planar</strong> ((\phi=5\text{mm}, H=8.5\text{mm}))</td>
<td>1.31</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td><strong>Open-ended Co-axial</strong> ((R_1=25\text{mm}, R_0=50\text{mm}, H=50\text{mm}))</td>
<td>64.18</td>
<td>64.5</td>
<td></td>
</tr>
<tr>
<td><strong>Point-Contact Detector</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crystal Size</td>
<td>Point Contact Size (Depth = 1mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\phi=50\ \text{mm}, H=50\text{mm})</td>
<td>(\phi=1\ \text{mm})</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>(\phi=2\ \text{mm})</td>
<td>1.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\phi=40\ \text{mm}, H=40\text{mm})</td>
<td>(\phi=1\ \text{mm})</td>
<td>0.72</td>
<td></td>
</tr>
<tr>
<td>(\phi=2\ \text{mm})</td>
<td>1.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\phi=50\ \text{mm}, H=50\text{mm})</td>
<td>(\phi=1\ \text{mm})</td>
<td>0.73</td>
<td></td>
</tr>
<tr>
<td>(\phi=2\ \text{mm})</td>
<td>1.13</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Simulation: Depletion characteristics

**Depletion Profile**

**Full Depletion Voltage**

**XY Plot 1**
Simulation: Charge Collection

- Drift Trajectory

- Drift Time

Carriers drift line
Energy deposit position
Electron
Hole

X unit: mm
Z unit: mm

CJPL

Application of Germanium Detector in Fundamental Research, Mar.23-30, Beijing, China
Simulation: Signal Induction

- Charge Pulse

- Current Pulse
Conclusion

• We are at the very beginning;
• Some preliminary results are achieved;
• Next step:
  – Further understanding
  – Larger size
  – Better performance
    • New processing technology
      – Passivation: Amorphous germanium sputtering
    • Amorphous-Ge $R_f$
    • Digital signal processing
    • ……
  – Low radiation background material selection.
Ends

Many Thanks for Your Attention!!

Thanks the authors from whom I “stole” slices/pictures for this talk.
CDEX & PC-HPGe

- CDEX @ CJPL proposed to use to Point Contact HPGe detector to detect WIMP directly, because of its:
  - Low capacitance > low threshold
  - Pulse shape analysis > discrimination between SSE and MSE
  - High purity material > low background
  - Module availability > good for manufacture, test, installation, maintenance, ready for extension to larger volume
  - High density, small volume > good for shielding