Thin-window p-type point-contact germanium detectors for rare particle detection

DE-SC0006348 Ethan Hull PI

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New thin-contact technologies have been developed for germanium-semiconductor detectors. Sputter-deposited contacts have been demonstrated to form reliable, rugged, thin, and easily segmented hole- and electron-barrier contacts with good fabrication yield on small planar germanium detectors. Detectors fabricated with these contacts exhibit low noise and excellent gamma-ray spectroscopy. The contact fabrication is being modified to accommodate the fabrication of p-type point contact detectors for low-background counting experiments. The thickness of the contact is being evaluated using alpha particles.

Collaboration with David Radford at ORNL

- Physics of the hole-barrier contacts on germanium detectors – p-type surfaces
- Advantages of a thin contact that can be segmented for low background counting
  - Poor low-energy spectroscopy (Ge(Li) 1960s)
  - Slow pulses from the lithium transition region (David Radford)
  - Dead material loss of volume
- Detector fabrication development with thin contacts
  - Photolithography modifications
  - Detector results
  - Modified cryostat including alpha source holder
Basic Contact Physics – the need for barriers on HPGe detectors

HPGe

\[ |N_A - N_D| \sim 10^{10} /\text{cm}^3 \]
\[ \mu \sim 4 \times 10^4 \text{ cm}^2/\text{Vs (77 K)} \]
\[ \rho \sim 15 \text{ k}\Omega \text{ cm} \]

1 cm\(^3\), 1 V \sim 67 \mu\text{A} !!!

Resistivity is far too low

Contacts must form charge-injection barriers

Electric Field
Low leakage current (\sim 10 \text{ pA})
Low noise connection

Hole-barrier contact

\begin{align*}
\text{e}^- & \hspace{1cm} \text{h}^+ \\
+ & \hspace{1cm} - \\
E \text{ field} & \\
\end{align*}

electron-barrier contact

Coaxial Detector Li-diffused contact n+

Orthogonal Strip Detector \(\alpha\)-Ge (2\text{nd talk})

P-type Point Contact Detector (PPC)
Li-diffused contact n+
Vacuum

Hole-barrier contact

Electron Energy

4.38eV

4.13eV

4.79eV

0.70eV

0.14eV

0.66eV

Vacuum

h^+

e^-

5x10^9 /cm^3 p

However...
Damage is p-type (an acceptor state) in crystalline Ge

- Highly Stressed Crystals
  - Poly ZR Bars
  - Crystals grown and maintained at a high temperature too long
- Radiation damage from massive energetic particles (p, n, heavy ions)
- Grinding, slicing, and etching!!!
  - Surfaces become p-type – this makes it very difficult to fabricate the hole-barrier (n+) positively biased contact
  - Passivation is an attempt to neutralize this α-Ge

5x10⁹ /cm³ p
Many options: B, Ni, Cr, Pt, Pd, Au, ...

Li diffusion, α-Ge
α-Si (Oₓ)
P implant (anneal), Y(Oₓ)

Vacuum Level

Hole-barrier contact

electron-barrier contact

Electron Energy

P-type Ge
5 x 10⁹/cm³

Nickel p+ Contact

Nor n+ metal contact

E field

E field

V

E field

Many options:  B, Ni, Cr, Pt, Pd, Au, ..
P-type Coaxial Detector

P-type Point Contact Detector (PPC)

Lithium-diffused outer contact 1-mm thick

p+ contact

70 mm

70 mm

70 mm

70 mm

35 mm

p+ contact

7-8% of the detector is Li dead layer
The **Majorana Demonstrator**

**Goal:** 1000kg

$^{76}\text{Ge}$

$^{76}\text{Ge}$ $100-200\text{/g}$

7% loss is $7M-14M$ due to Li-diffused contact

1. Thick lithium-diffused contacts result in a loss of valuable material.
2. Thick lithium-diffused dead layer causes spectral artifacts

- "thin" contact
- 59.5-keV $^{241}$Am
- Li 0.4 mm

Be windows
2a. Thick lithium-diffused show slow pulses from a “Transition Layer”

David Radford

Normal 59.5-keV Photopeak events

60 ns

241Am 59.5-keV

Li-diffused contact 0.4 mm thick

Depleted Ge

Transition

Dead

Good

No signal

Slow signal

\[ e^- + h^+ \]

\[ h^+ \]
Np x ray peaks 59.5-keV peak Li

59.5-keV $^{241}$Am

Li

Np x ray peaks 59.5-keV peak Li
Thick Li-diffused contact has the single redeeming quality that it stops alphas (5 MeV) in 20 μm.

This has important background implications for low-level counting.
We have developed a “thin” contact technology. The contact has potential to:
- Save valuable $^{76}\text{Ge} (\$\$)
- Eliminate spectral artifacts
- Eliminate slow pulses

**new contact**
- Forms hole-barrier!
- Good resolution
- Chemical tolerant
- Good definition
- Sputter wraps
  - ppc
- Passivation viable

Contact 100-\(\mu\text{m} \) gap

250-\(\mu\text{m} \) gap

100-\(\mu\text{m} \) gap
Evaluate contact

- Adapt from test detectors to ppcs.
- Look at detectors with an alpha-particle source
  - Measure the true thickness.
  - Evaluate the implications of alpha-particles.
Contact before photoresist
Contact with photoresist
Finished ppcs
4 at a time

- Process refinement
- Evaluation with photons and alphas using tools shown
The graph shows the capacitance (F) against bias (V) for different density concentrations of donors and acceptors.

- For a concentration of $1.5 \times 10^{10}$ cm$^{-2}$, the capacitance is measured at 2400 V.
- For a concentration of $3.5 \times 10^{10}$ cm$^{-2}$, the capacitance is measured at 2700 V.

The capacitance values are given in units of $10^{-12}$ F, $10^{-11}$ F, and $10^{-9}$ F for different points on the graph.
Special cryostat to allow alpha-particle measurements using a variable angle of incidence, 0-60 degrees.
Segmented Rectifying and Blocking Contacts on Germanium Planar Detectors

DE-SC0002477 Ethan Hull PI

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New surface contact technologies are being developed for the fabrication of segmented planar germanium detectors. Three fully functional orthogonal-strip NPX-M planar germanium detector systems with narrower gap widths have now been delivered to UMass Lowell for evaluation. The contacts have been verified to be sufficiently rugged to survive repeated thermal cycles and shipment. Measurements at UMass indicate intrinsic improvements in the detector performance as a result of the narrower gap widths. More importantly, the improved detector fabrication has been used to fabricate several commercial detectors successfully delivered to customers during the past year. More recently, the strip detector fabrication technique has been adapted to make significantly larger diameter orthogonal strip detectors.

Collaboration with Kim Lister at UMass Lowell

- Rectifying AND Segmented contact fabrication
  - Gaps reduced from 500 \(\mu\)m to 250 \(\mu\)m
  - Prototypes fabricated
  - Shipped to UMass Lowell for evaluation
- Contact fabrication transitioned into commercial detector fab
  - GeGI commercial detector systems shipped (250 \(\mu\)m)
- Contacts recently extended to make larger area detectors
  - Gaps reduced from 250 \(\mu\)m to 125 \(\mu\)m
  - Deposition effects particular to larger area detectors
Require hole and electron barriers AND Segmentation (>1 GΩ)

Lithium diffused contacts (~1 mm) are not a good option

Strip detector with 0.5 mm (500 µm) gaps
Implications of narrower gaps for strip detectors

Amorphous-germanium contact 500 µm gaps

60 lbs Bench top system
500 µm gaps
122 keV $^{57}$Co

500 µm gaps

622 keV $^{137}$Cs
Charge loss due to gap collection

Induced Charge

$t$ (ns)

$E$ (keV)

500 µm gaps
500 µm gaps

250 µm gaps
A series of 3 prototype NPX made with 250 µm gaps → UMass Lowell

Then the 250 µm fabrication was made commercial in GeGI and GGC
GeGI - Commercial detectors use the 250 µm fabrication technology

Shipped first commercial product spring 2013

New Product!!

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.
- 55 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
- ANSI 42.42 output format
- User-friendly operation
- Portable 33 lbs
- Includes an internal battery (30-45 minutes)

PHDs Co. 3011 Amberst Road, Knoxville, TN 37921 (865) 202 6253
www.phdsco.com, sales@phdsco.com

133 Ba 356 keV
137 Cs 662 keV
90-mm 250 µm
GGC Commercial detectors use the 250 µm fabrication technology

Shipped first prototype spring 2013

The Germanium Gamma Camera  GGC

- Gamma-ray Imaging and Spectroscopy
- 90-mm diameter 10-mm thick HPGe crystal grown by PHDs Co.
- 55 cm² active detector area inside guard ring
- Detector spatial resolution: FWHM ~ 1.5 mm in x, y, and z
- 122-keV energy resolution FWHM ~ 0.3 keV
- 662-keV energy resolution FWHM ~ 2.2 keV
- Data acquisition runs under Windows
- Shown with 1.0 mm diameter 90-degree pinhole aperture (left)
- Shown with 1.5 mm hex-hole collimator 0.2 mm wall, 20 mm thick (right)
- Adaptable collimator mounting
- Portable 33 lbs + 6 lbs collimator and shielding
- Includes an internal battery (30-45 minutes)
There is still room for improvement in gap width.
500 µm gaps 90-mm

250 µm gaps 90-mm

125 µm gaps 140-mm