Segmented Rectifying and Blocking Contacts on Germanium Planar Detectors
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New detector contact technologies have been developed for the fabrication of segmented planar germanium detectors. Yttrium metal contacts have the correct combination of physical properties to provide segmented low-noise detector contacts. Photolithographic yttrium segmentation techniques are being developed to provide relatively fine and well-defined contact features.

1. Rectifying and Blocking germanium detector contacts
2. Phase II Program Goals
3. Progress During Phase II
Rectifying and Blocking germanium detector contacts

Hole-barrier contact

Electron-barrier contact

\[ |N_A - N_D| \sim 10^{10} /\text{cm}^3 \]
\[ \mu \sim 4 \times 10^4 \text{ cm}^2/\text{Vs} \ (77 \text{ K}) \]
\[ \rho \sim 15 \text{ k\Omega cm} \]
\[ 1 \text{ cm}^3, \ 1 \text{ V} \sim 67 \mu\text{A} \ !!!! \]

E Field – depletion and charge collection
\sim 500 – 5000 \text{ V/cm}

Low leakage current (~ 10 pA) – low noise

Good electrical connection to Ge – low noise

Contacts must form charge-injection barriers

PHDs Co.
Rectifying and Blocking germanium detector contacts

**P-type Coaxial Detector**

- **N+ Lithium-diffused outer contact**
  - 1-1 mm thick (hole barrier)

- **p+ contact**
  - Boron implant
  - Or Metal (Ni, Au, Pt, Pd, …)
  - Schottky Barrier (electron barrier)

Dimensions:
- 70 mm
Rectifying and Blocking germanium detector contacts

Hole-barrier contact

Electron-barrier contact

Li diffusion, amorphous Ge or Si(?)
P implant (?)

Many options: B, Ni, Cr, Pt, Pd, Au, ..
Rectifying and Blocking germanium detector contacts

The surface (interface states) of crystalline HPGe is p type. Most materials form an electron barrier – historic dilemma.

Lithium thermal diffusion (100+ μm) forms the only good, high, hole barrier. 99% of detectors are made with lithium hole barrier.
Lithium-diffused contacts are rugged and have great process yield (~ 100%). However, the thickness limits the use.

**X ray detectors** require n-type (reverse-electrode) germanium detector.

**Charged particle spectroscopy** is adversely affected by dE/dx in the lithium dead layer.

**Position-sensitive applications:**

Nuclear physics, nuclear medicine, ...

Lithium contacts are extremely difficult to coarsely segment.
Rectifying and Blocking germanium detector contacts

**Phosphorus implanted** n+ contacts (thin) have been used for charged particle detectors – long and dangerous annealing cycles, edge problems, low electric field….

**Amorphous germanium contact** (thin) can be used, low barrier height (0.3-.4 eV) (temperature limited ~ 90 K), yield is questionable over large areas – overall this is the best alternative.

Barrier height is critical

- Lithium hole barrier (n+-p jtn) barrier height ~ 0.7 eV (130 K)
- Amorphous germanium 0.35 eV (avg) (90-95 K)
- $j \sim \exp \left(-\phi/k_B T\right)$

A thin (segmented) hole-barrier contact with a high barrier height would be of great benefit to germanium-detector technology.
NPX and NPX-M Germanium Strip Detectors

LN$_2$ Cooled NPX Systems

Mechanically Cooled NPX-M Systems
NPX and NPX-M Germanium Strip Detectors

16 x 16 Strip NPX Detector

NPX Detector in a cryostat

A better hole barrier contact could make the gaps narrower
Phase I: Are there any low work-function metals that form a useful hole barrier?

Yes, Yttrium (A = 39) metal forms a hole barrier that can function as a detector contact.

Phase II Program Goals:
1. Study and optimize the yttrium contact using test detectors
2. Work out photolithography and processing for full-sized detector fabrication – demonstrate.

Better, less expensive (higher yield), more reliable NPX-M detectors with narrower gaps will be available for nuclear physics.
Metal Selection

<table>
<thead>
<tr>
<th>Metal</th>
<th>Work function (eV)</th>
<th>Barrier Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel</td>
<td>5.2</td>
<td>p+</td>
</tr>
<tr>
<td>Chromium</td>
<td>4.5</td>
<td>p+</td>
</tr>
<tr>
<td>Gold</td>
<td>5.1</td>
<td>p+</td>
</tr>
<tr>
<td>Palladium</td>
<td>5.1</td>
<td>p+</td>
</tr>
<tr>
<td>Platinum</td>
<td>5.7</td>
<td>p+</td>
</tr>
<tr>
<td>Germanium</td>
<td>~ 5</td>
<td>n-p</td>
</tr>
<tr>
<td>Silver</td>
<td>4.3</td>
<td>not n</td>
</tr>
<tr>
<td>Samarium</td>
<td>2.7</td>
<td>not n</td>
</tr>
<tr>
<td>Antimony</td>
<td>4.5</td>
<td>slightly n</td>
</tr>
<tr>
<td>Yttrium</td>
<td>3.1</td>
<td>n+</td>
</tr>
<tr>
<td>Niobium</td>
<td>4.3</td>
<td>?</td>
</tr>
</tbody>
</table>

1. Low work function
2. Can be handled (not horribly toxic)
3. Produces n-type interface states on Ge

The most electropositive metals are Li, Na, K, Rb, Cs, (can’t be handled easily)
Yttrium test detector (20 mm diameter)
$T_p = 5 \mu$s

122-keV Peak
FWHM = 1.05 keV
FWTM = 1.90 keV

662-keV Peak
FWHM = 1.67 keV
FWTM = 3.14 keV
Yttrium hole-barrier contacts for germanium semiconductor detectors

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ABSTRACT

Sputtered yttrium metal forms a thin hole-barrier contact on both p- and n-type germanium semiconductor detectors. Yttrium contacts can provide a sufficiently high hole-barrier to prevent measurable contact leakage current below ~130 μA. Detectors having yttrium contacts produce good gamma-ray spectroscopy data.

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1. Introduction

Germanium semiconductor single-particle radiation detectors require both electron-barrier and hole-barrier contacts to provide full depletion and sufficient electric field for good charge-carrier collection while blocking the flow of significant leakage current. In addition, the contacts must provide a sufficiently conductive electrical connection to the germanium to avoid series noise problems. Negatively biased electron-barrier contacts can be fabricated using various well-developed technologies. Electron-barrier contacts can be fabricated by deposition of thin (~1000 Å) metal layers directly onto the crystalline germanium surface. Gold, nickel, chromium, platinum, and palladium have been demonstrated to form good Schottky barrier layers on germanium detectors [1]. Most detector-manufacturing now relies on thin boron-implanted p+ contacts to provide the electron-barrier contact. All these electron-barrier contacts are sufficiently thin to allow segmentation into arbitrary contact geometries and provide this dead-layer entrance window on the live detector volume for minimal charged-particle energy loss and photon thick-window contact. Although lithium contacts can be made less thick, they cannot approach the 1000 Å thickness level required for truly thin entrance windows. When a thin outer contact is needed for low-energy photon spectroscopy, the reliance on thick lithium-diffused contacts often forces the use of coaxial and pseudo-coaxial detectors fabricated from n-type germanium. Although extremely rugged and reliable, thick lithium-diffused contacts have greatly limited the use of germanium detectors as transmission detectors in charged-particle telescopes for nuclear physics experiments. Lithium-diffused contacts can be coarsely segmented by gluing through the lithium-diffused layer and/or by the use of relatively wide gap features between segments [2]. A thin hole-barrier contact that can be finely segmented in a convenient manner would be a tremendous improvement in germanium-detector technology.

The search for a thin hole-barrier contact on germanium detectors has continued since 1979 [3,4]. Phosphorus-implanted p+ contacts were successfully implemented in long-standing nuclear-physics array and telescope programs. However, fabrication of the phosphorus-implanted p+ contact is an extremely involved