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Segmented Rectifying and Blocking Contacts on Germanium Planar Detectors

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DE-SC0002477
Phase II: 8/15/2010-8/14/2012

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

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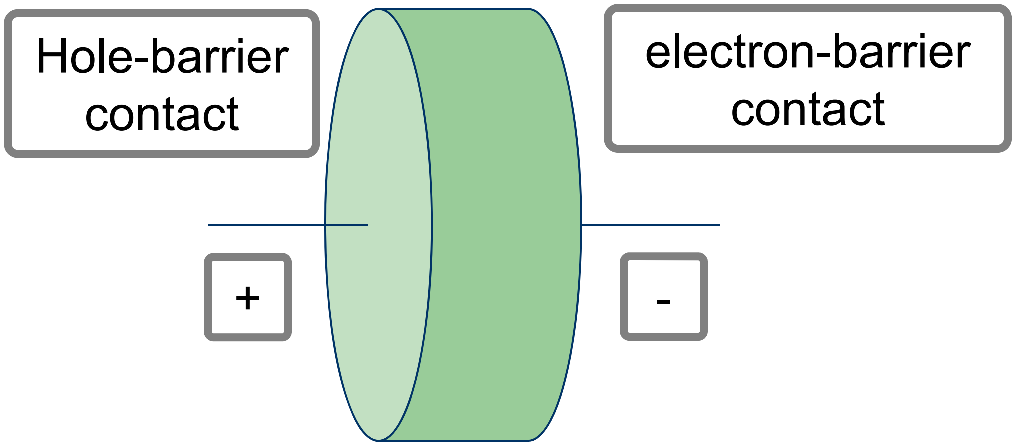

E Field – depletion and charge collection ~ 500 – 5000 V/cm

Low leakage current (~ 10 pA) – low noise

Good electrical connection to Ge – low noise

HPGe

$|N_A - N_D| \sim 10^{10}$ /cm^3
$\mu \sim 4\text{x}10^4$ cm^2/Vs (77 K)

$\rho \sim 15$ kΩ cm
1 cm^3, 1 V ~ 67 μA !!!!

Resistivity is far too low

Contacts must form charge-injection barriers

Rectifying and Blocking germanium detector contacts

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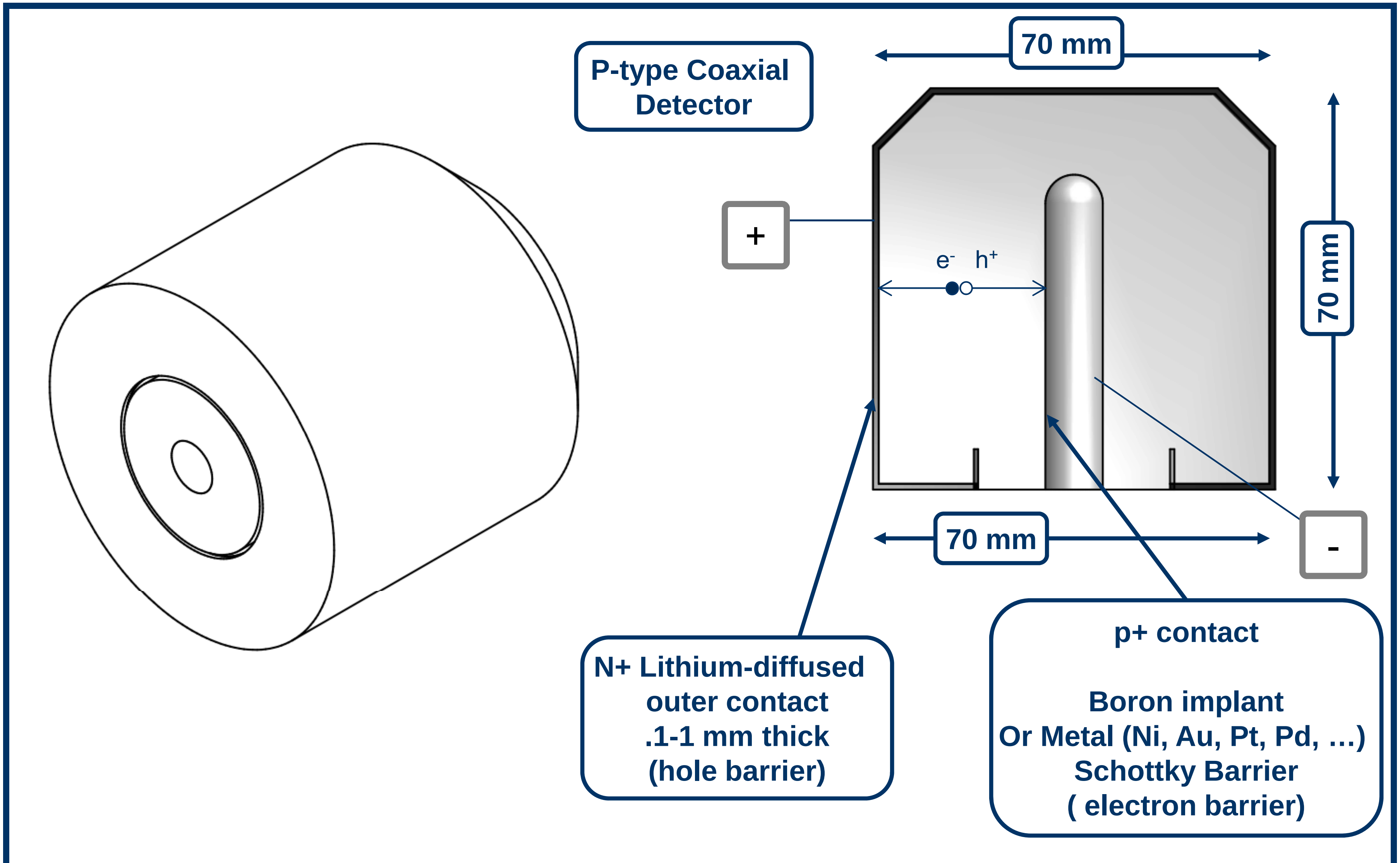
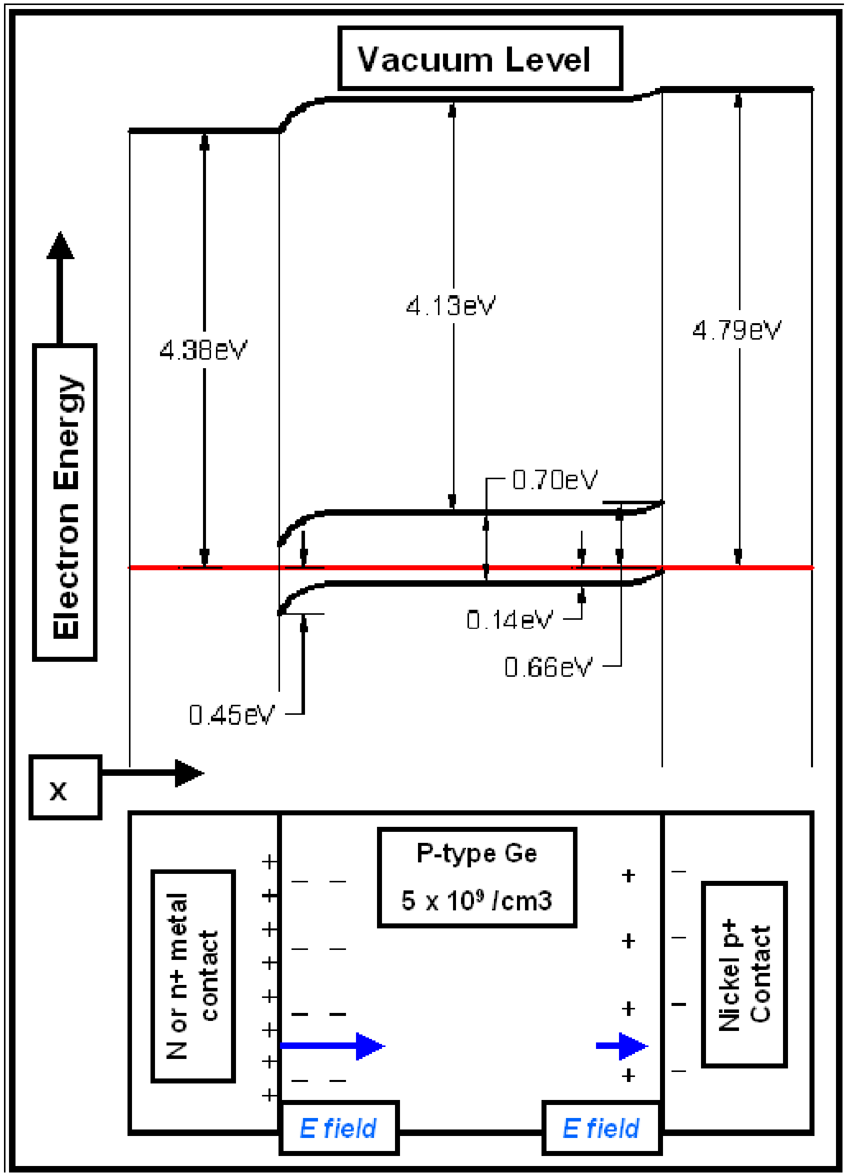
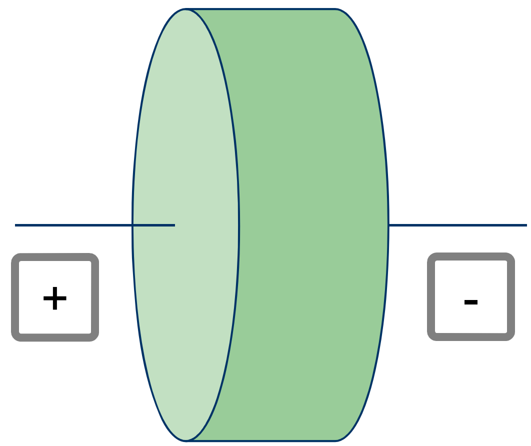


Rectifying and Blocking germanium detector contacts



Hole-barrier contact

electron-barrier contact



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

Many options: B, Ni, Cr, Pt, Pd, Au, ..

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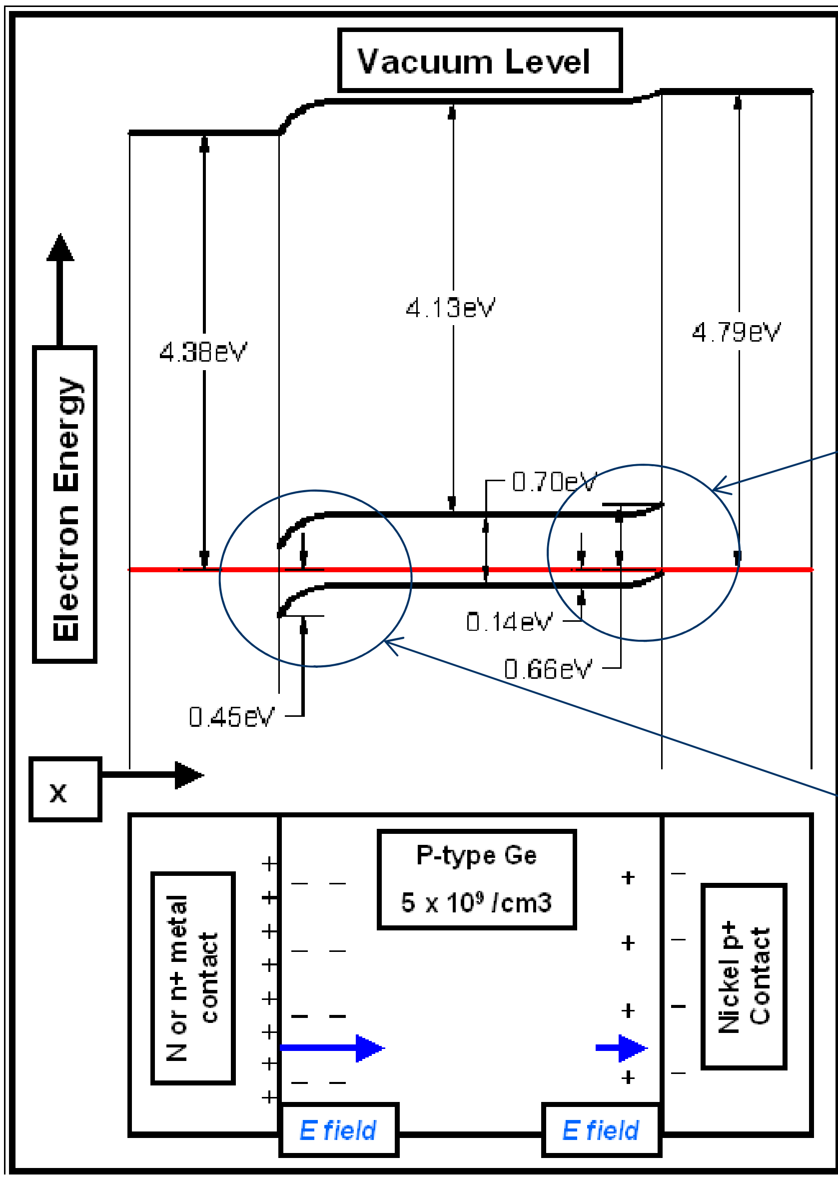
Rectifying and Blocking germanium detector contacts



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.

Rectifying and Blocking germanium detector contacts

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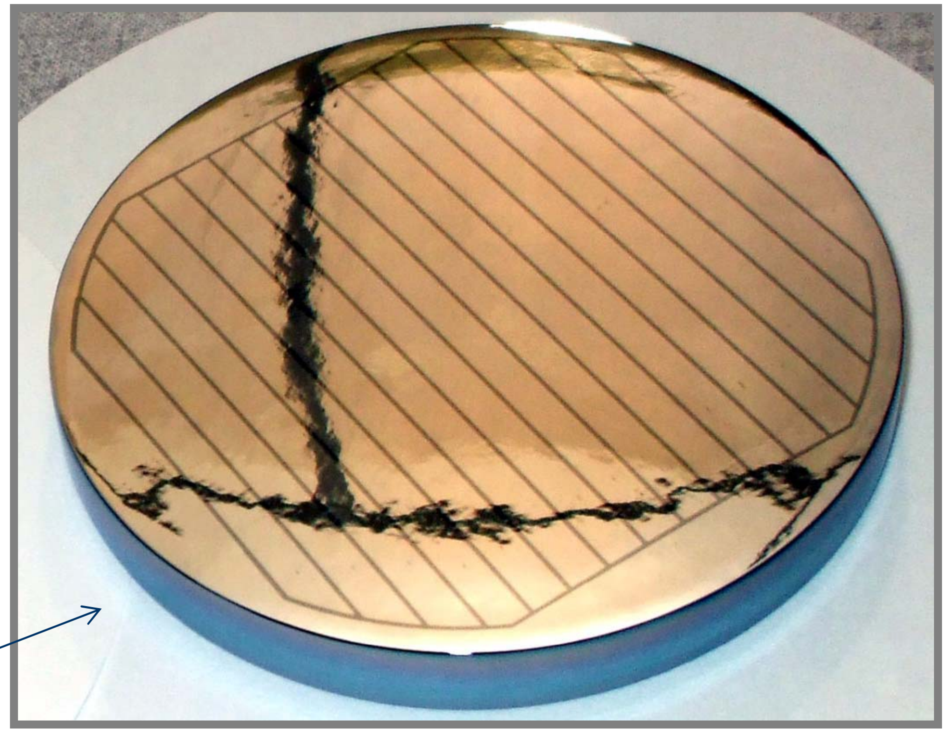
Lithium-diffused contacts are rugged and have great process yield (~ 100%). *However, the thickness limits the use*.

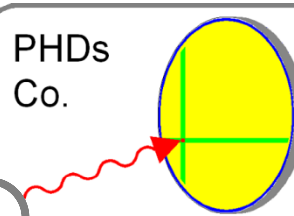
x ray detectors require n-type (reverse-electrode) germanium detector.

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)
- $j \sim \exp(-\varphi/k_B T)$

A thin (segmented) hole-barrier contact with a high barrier height would be of great benefit to germanium-detector technology.

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NPX and NPX-M Germanium Strip Detectors

LN_2 Cooled
NPX Systems

Mechanically Cooled
NPX-M Systems

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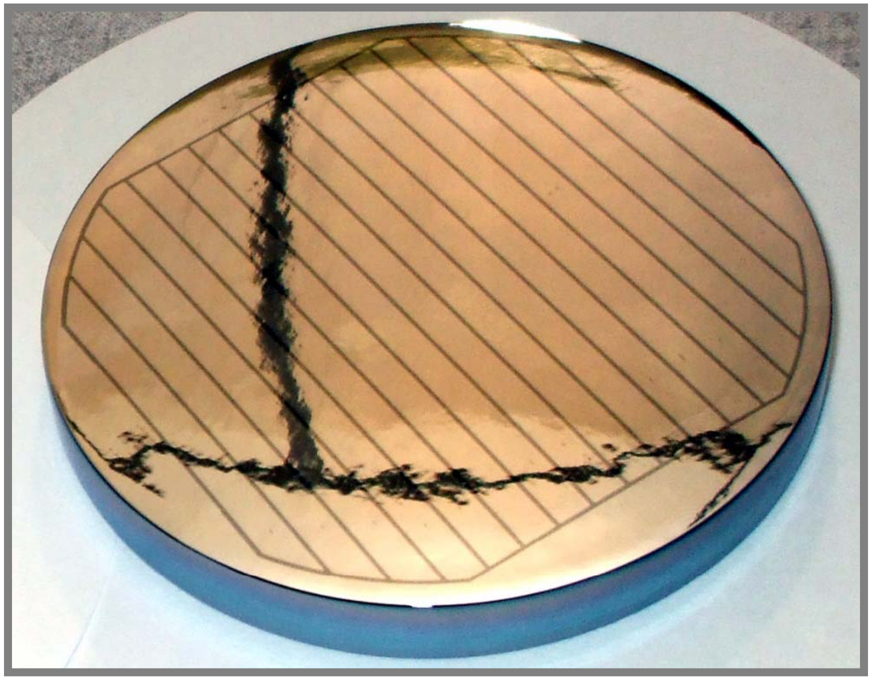
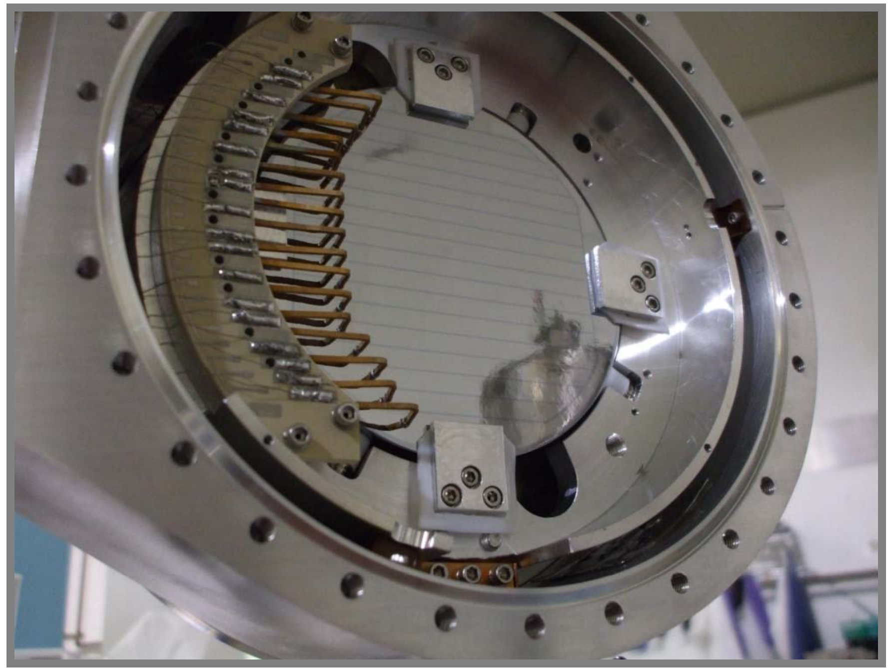
NPX and NPX-M Germanium Strip Detectors

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?

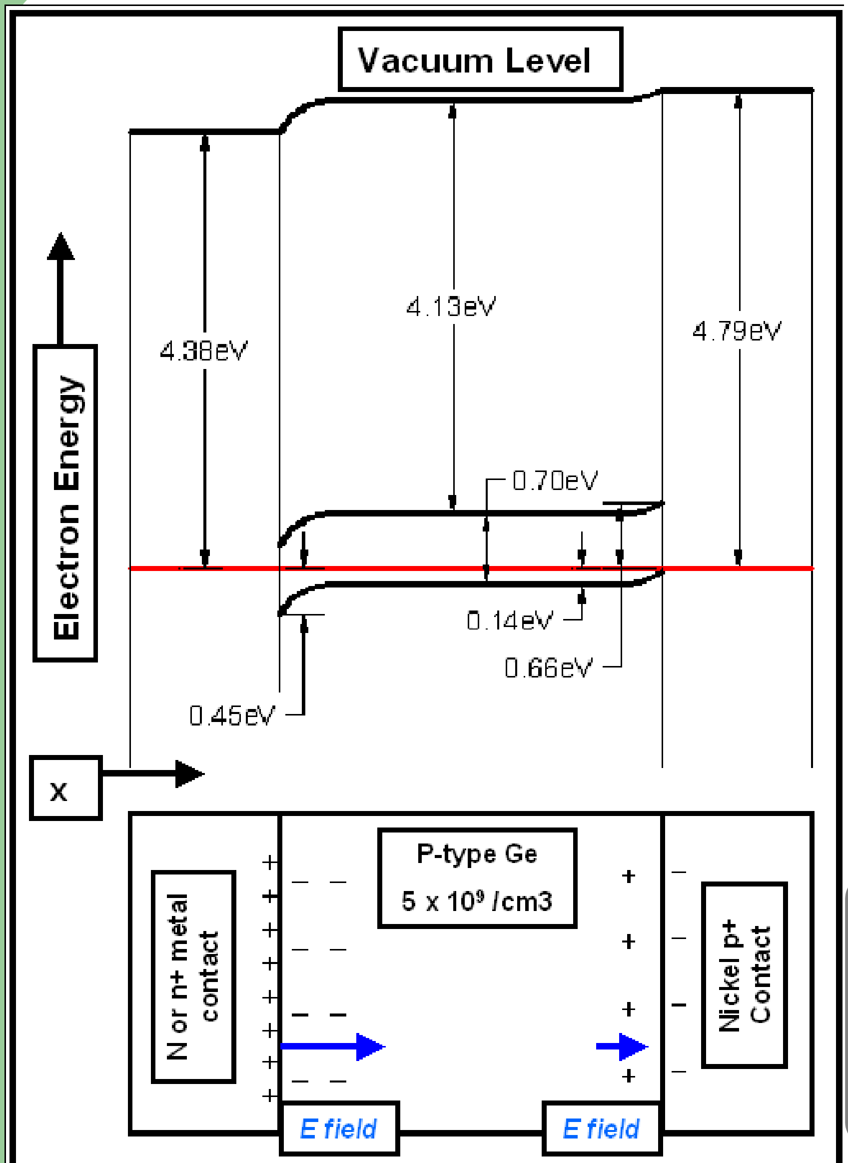
Yes, **Yttrium (A = 39)** metal forms a hole barrier that can function as a detector contact.

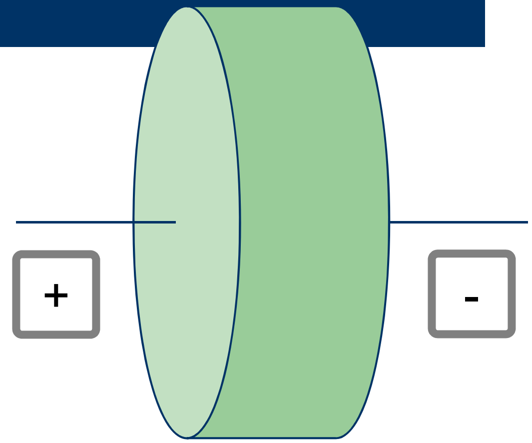
Phase II Program Goals:

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





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Metal	Work function (eV)	Barrier Type
Nickel	5.2	p+
Chromium	4.5	p+
Gold	5.1	p+
Palladium	5.1	p+
Platinum	5.7	p+
Germanium	~ 5	n-p
Silver	4.3	not n
Samarium	2.7	not n
Antimony	4.5	slightly n
Yttrium	3.1	n+
Niobium	4.3	?

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)

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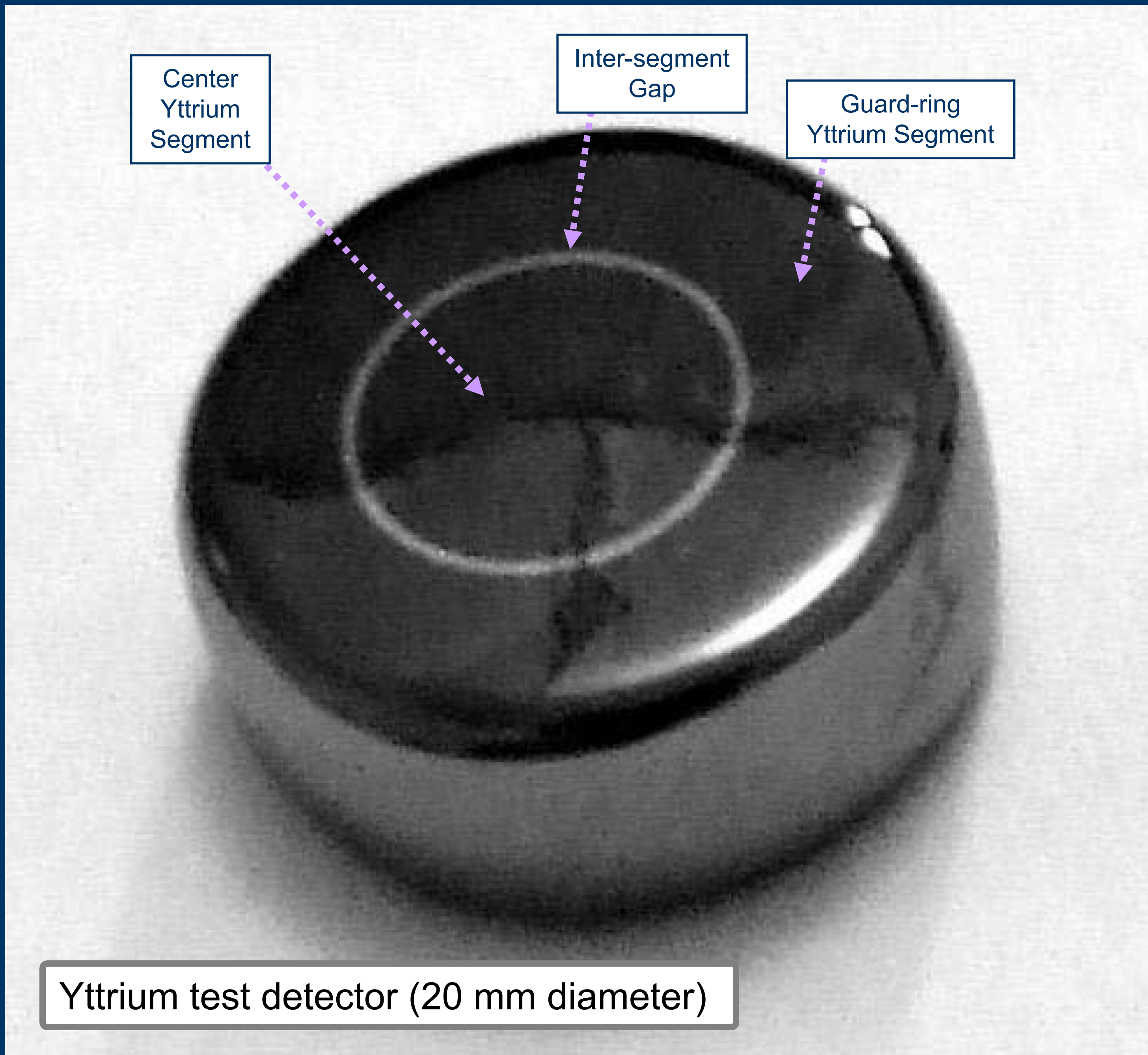
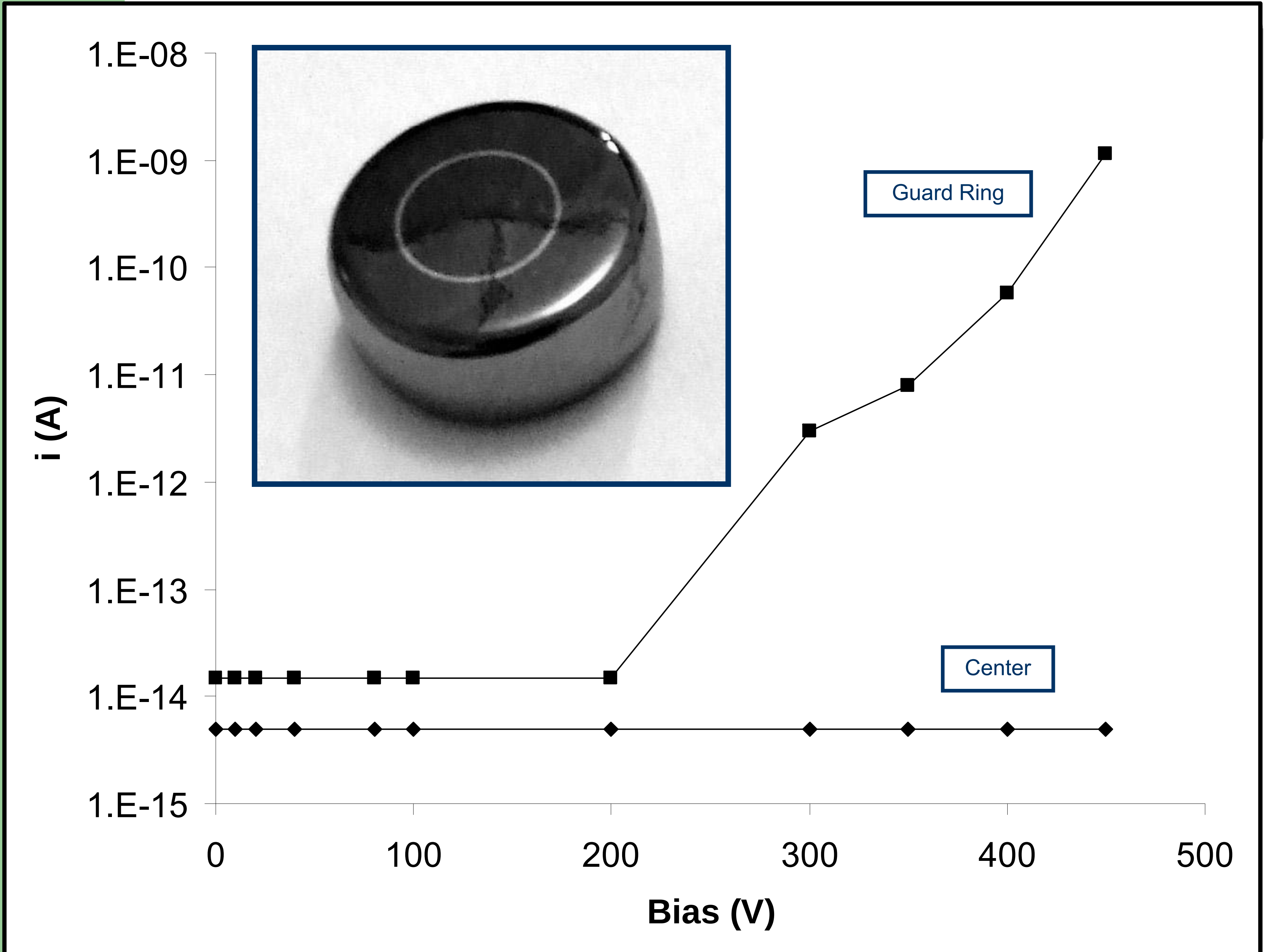
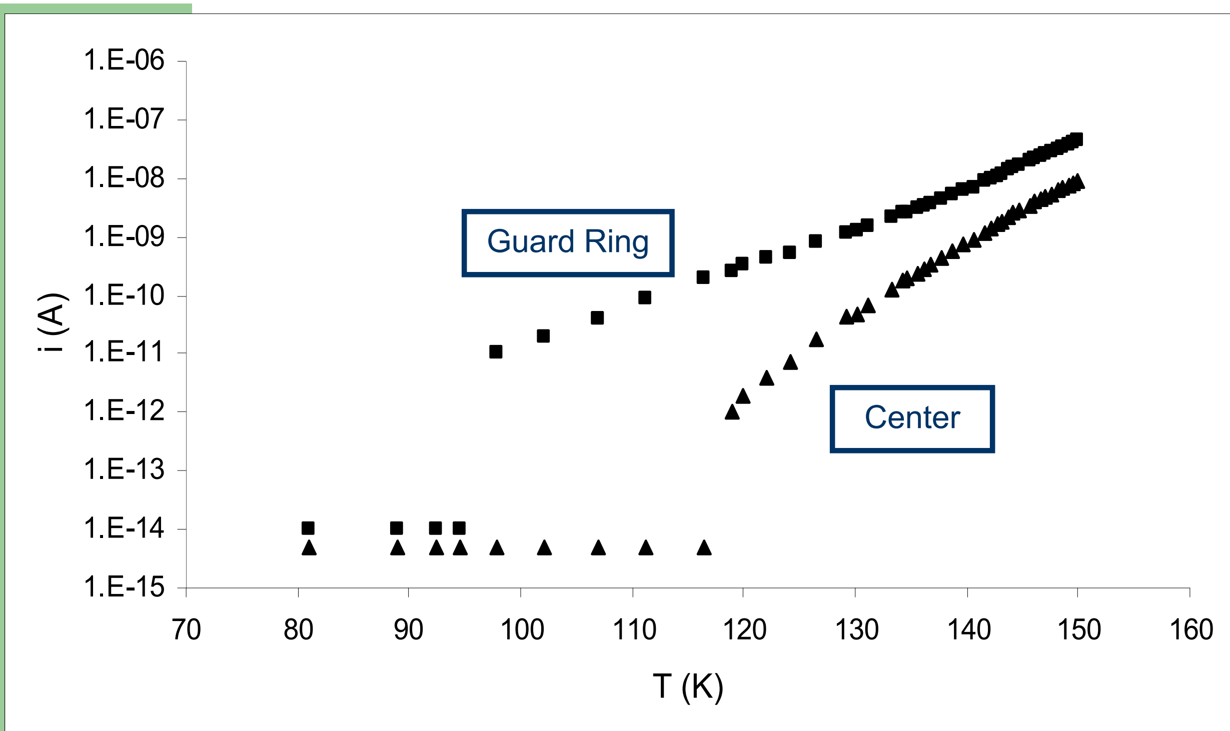
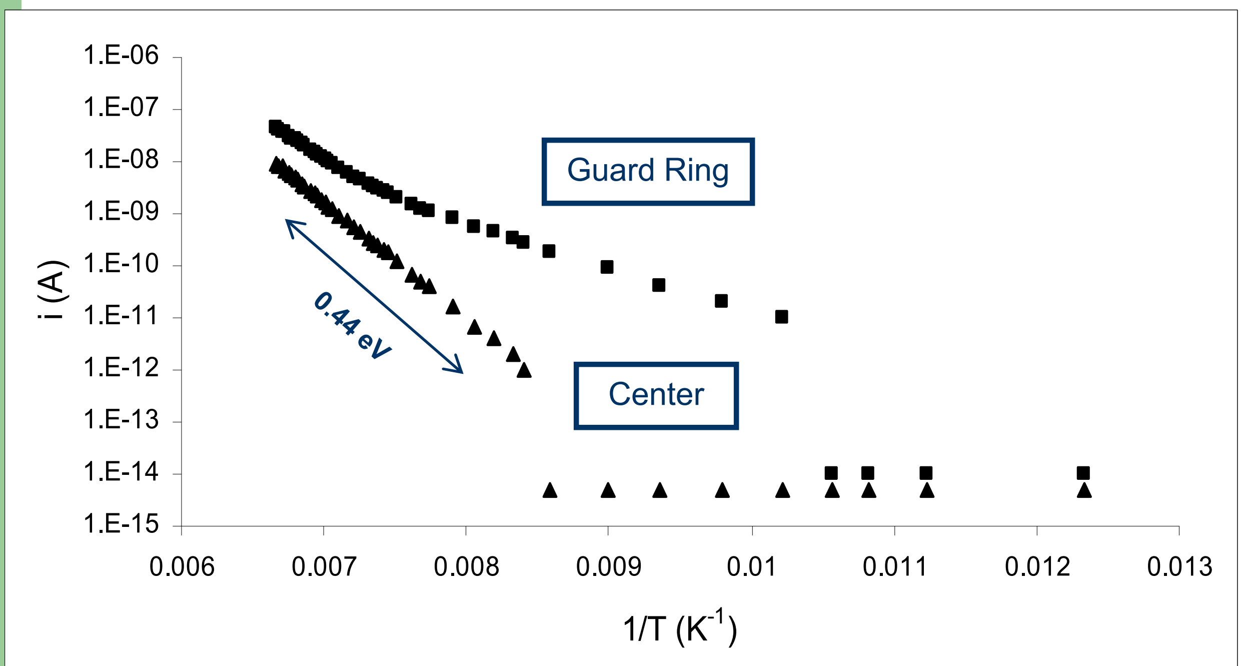


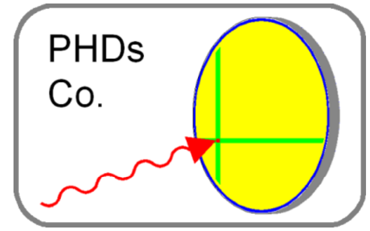
Yttrium test detector (20 mm diameter)



i (A)
1.E-08
1.E-09
1.E-10
1.E-11
1.E-12
1.E-13
1.E-14
1.E-15
Guard Ring
Center
0
100
200
300
400
500
Bias (V)


1.E-06
1.E-07
1.E-08
1.E-09
1.E-10
1.E-11
1.E-12
1.E-13
1.E-14
1.E-15
i (A)
Guard Ring
Center
70
80
90
100
110
120
130
140
150
160
T (K)


1.E-06
1.E-07
1.E-08
1.E-09
1.E-10
1.E-11
1.E-12
1.E-13
1.E-14
1.E-15
i (A)
Guard Ring
0.44 eV
Center
0.006
0.007
0.008
0.009
0.01
0.011
0.012
0.013
1/T (K^-1)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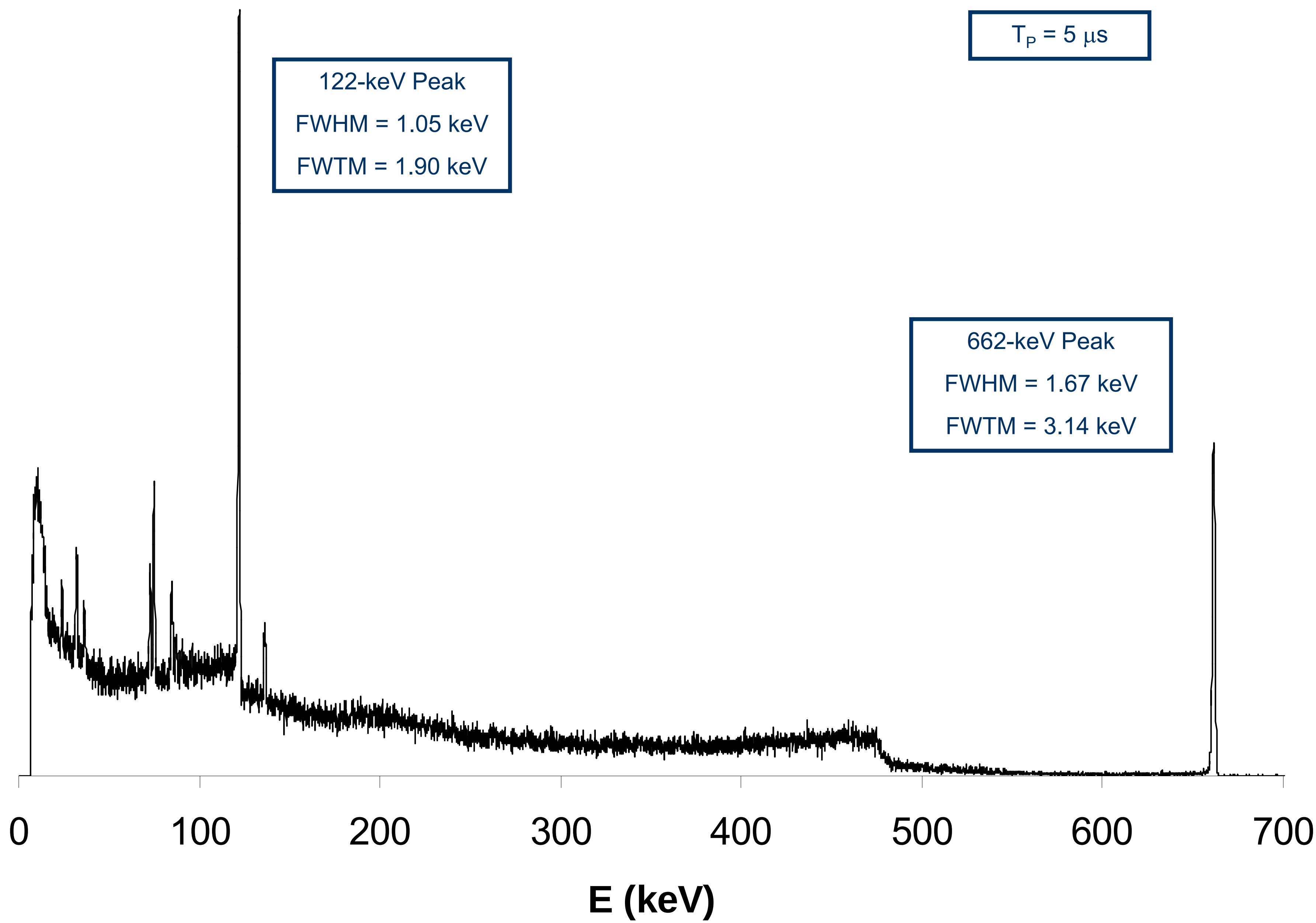

122-keV Peak
FWHM = 1.05 keV
FWTM = 1.90 keV
T_P = 5 μs
662-keV Peak
FWHM = 1.67 keV
FWTM = 3.14 keV
0
100
200
300
400
500
600
700
E (keV)

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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 ~120 K. 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 several 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 electron barriers 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 thin dead-layer entrance windows 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 a truly thin entrance window. 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 grinding 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 1970s [3,4,5]. Phosphorus-implanted n+ contacts were successfully implemented in long-standing nuclear-physics array and telescope programs. However, fabrication of the phosphorus-implanted n+ contact is an extremely involved

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And Patent Pending

Thank you