Chap. 12 – Germanium Based Detectors

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The semiconductors provide the lowest value of "w" and thus the highest resolution for the energy, Silicon has become widely available in thin disks but the low atomic number (14) limits its use for photon detection – a higher Z is needed.

13	14	15
5 B 10.811	6 C 12.011	7 N 14.007
13 Al 26.982	14 Si 28.086	15 P 30.974
31 Ga 69.72	32 Ge 72.59	33 As 74.922
49 In 114.82	50 Sn 118.69	51 Sb 121.75
81 Tl 204.37	82 Pb 207.19	83 Bi 208.98

- Sn & Pb are "metallic"
- Ge is only elemental option
- GaAs, InSb are used somewhat

Germanium is more metallic than silicon – band gap is lower, higher signals, higher thermal noise, easier to purify, donor/acceptor level must be lower

Large volumes are available (~1 L) from zone refining
n-type usually has Oxygen in the matrix
p-type usually has Aluminum in the matrix
"hyperpure" material has become available .. Intrinsic.

Diode Detectors – lithium compensation

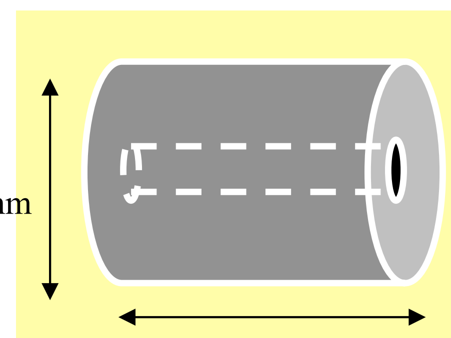
A technique we discussed that can control the resistivity/conductivity of semiconductor diodes was adding dopants. Another important use of dopants is to cancel or compensate for trapping sites in the material due to impurities, crystal defects, etc. Lithium metal (Group 1, a good donor) can be applied to the surface with some interesting results:

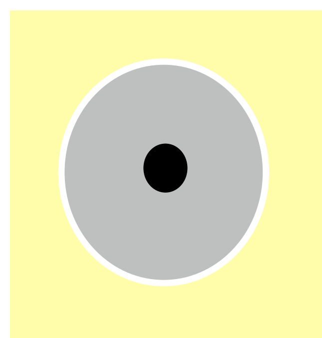
Electron → existing hole site

Li^+ (under bias & heat) → existing donor site

- The ions will remain in place with a bias (Si) or with cooling (Ge).
- These devices are labeled as Si(Li) or Ge(Li) …
- The Si(Li) are generally planar, Ge(Li) cylindrical called “coaxial” and “coax”
- The Ge(Li) devices have mostly been retired from active service because they must ALWAYS be kept at liquid nitrogen temperatures. The Si(Li) devices remain important due to the inability to produce large volume ultrapure silicon at at present.

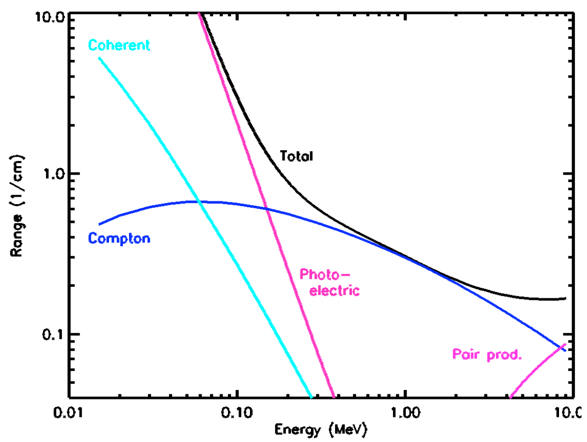
Typical:
40 mm x 150 mm

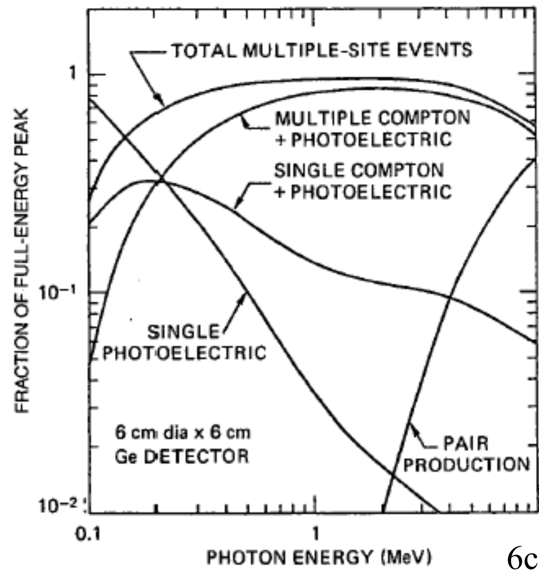




Li (donor) on outside is n-type
creates the rectifying contact
Crystal then is p-type
Inner contact can be ohmic
Electric field is radial in a “true coax”

Germanium Based Detectors – contacts





6cm x 6cm Fig. 12.16 Knoll, 3rd Ed.

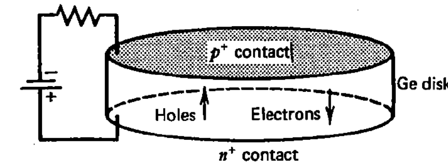
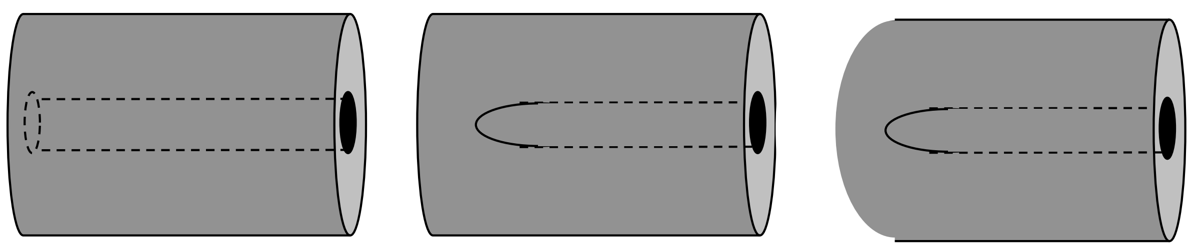
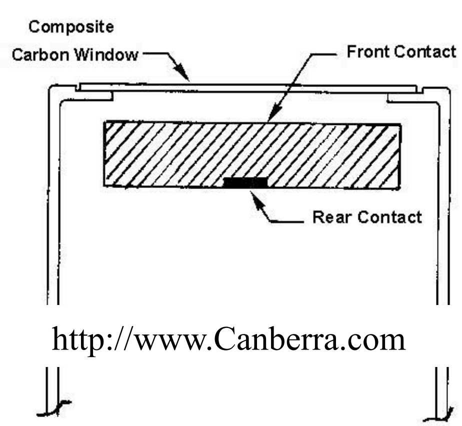


Fig. 12.2 Knoll, 3rd Ed.

Multiple Compton Scattering is most likely process in “nuclear regime”
Planar devices: low energy photons.

Intrinsic or high purity germanium can be formed into coaxial shapes with radial electric fields but end-caps are often left on and they are often “bulletized”





http://www.Canberra.com

Extremely low capacitance device with unusual electrode design but funky electric field

Shape, material and contacts are separate variables.

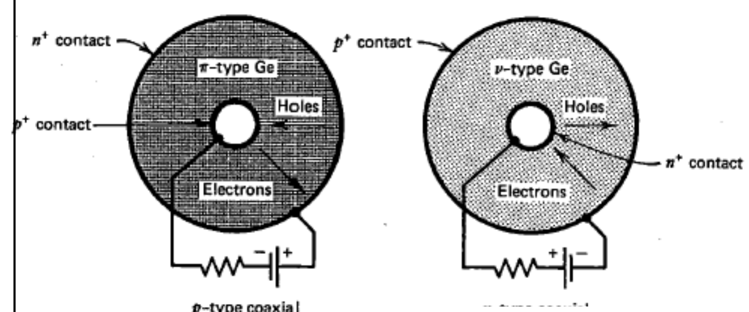


Fig. 12.3 Knoll, 3rd Ed.

Germanium Based Detectors – damage

The devices can be n-type or p-type …
p-type is easier to produce but n-type is more resistant to neutron damage ..
(cf. H.W. Kramer, IEEE NS-27 (1980) 218)

^{A}Ge (n,n') ^{A}Ge E_n ~ 2-5 MeV the E_{recoil} ~ 40 keV   Range ~ 40 nm
σ ~ 3-4 b   (r_{Ge} ~ 0.122 nm)

^{74}Ge (n,γ) ^{75}Ge $\rightarrow \beta^{-}+\nu$-bar+ ^{75}As $T_{1/2}$ = 83 m
σ ~ 1 b for thermal neutrons

Mean free path: $\lambda = 1 / \sigma N_0$

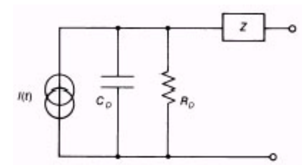
$$\lambda_{Fast} = \frac{1}{4x10^{-24}\,cm^2\left(5.35g/cm^3 N_A/72.6g\right)} = 6\ cm$$

$$\lambda_{Thermal} \sim 24\ cm$$

Lattice defects are more likely to trap holes than electrons – minimize hole travel:
Implant boron to make outside contact on n-type germanium

Position-dependence of the signal shapes from planar Ge detectors follows that for gas filled parallel plate ion chambers but with a slow rise. (no Frisch grid !)

$$t \sim \frac{3.8cm}{4x10^{6}\,cm/s} \sim 10^{-6}\,s$$



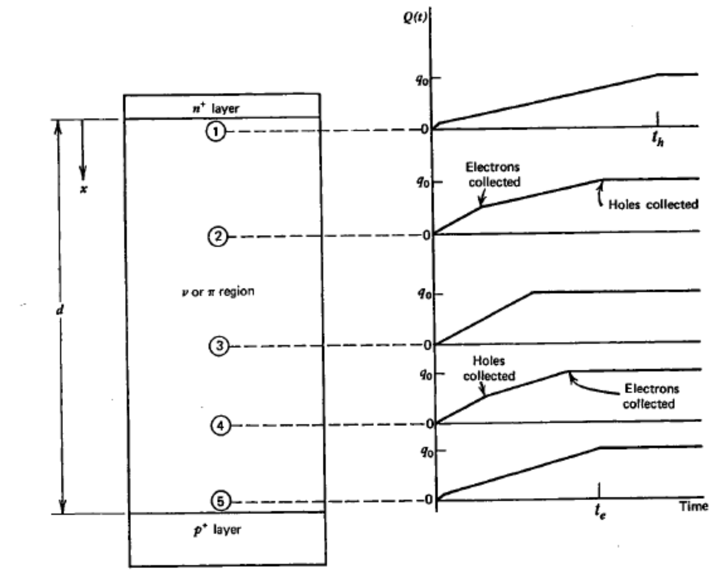


Fig. 12.11 Knoll, 3rd Ed.

Pulse shapes from coaxial and end-cap devices are more complicated due to shapes of electric fields.

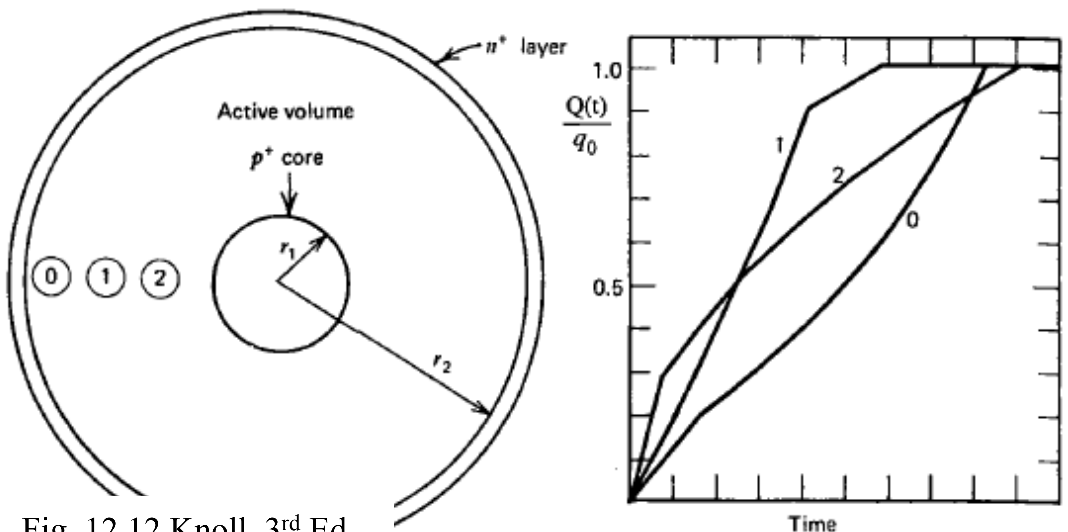
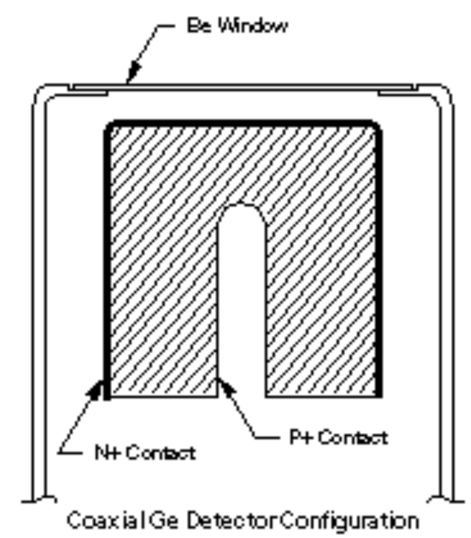


Fig. 12.12 Knoll, 3rd Ed.



Germanium Based Detectors – Peak-to-Total

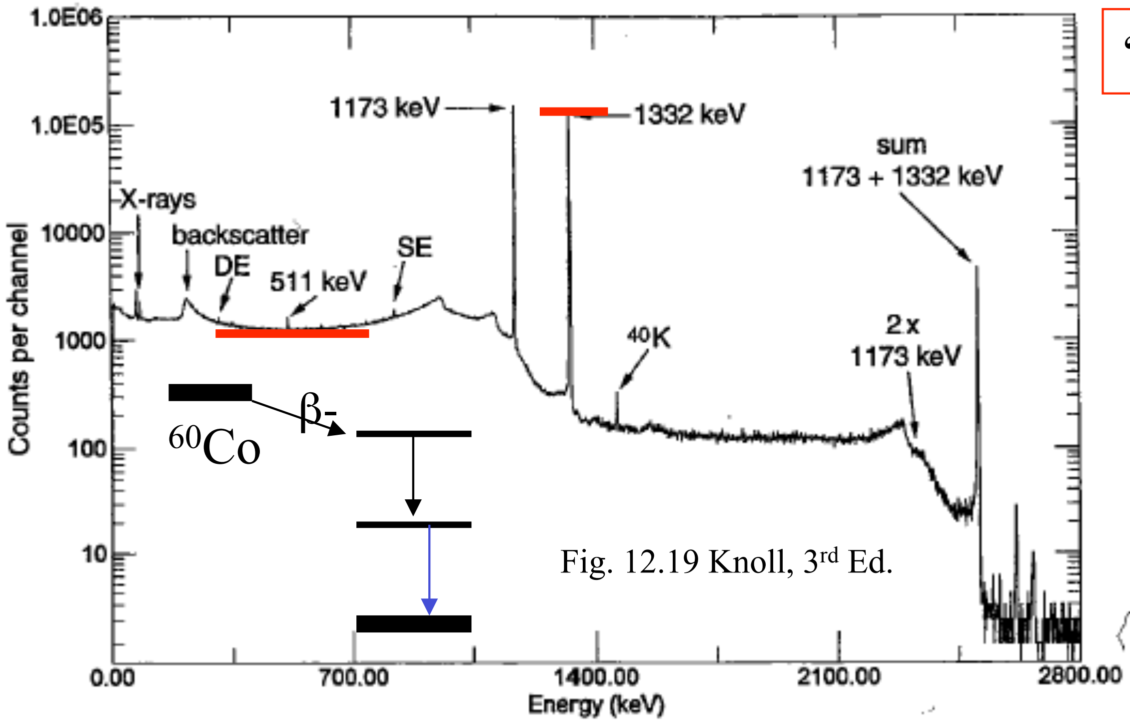
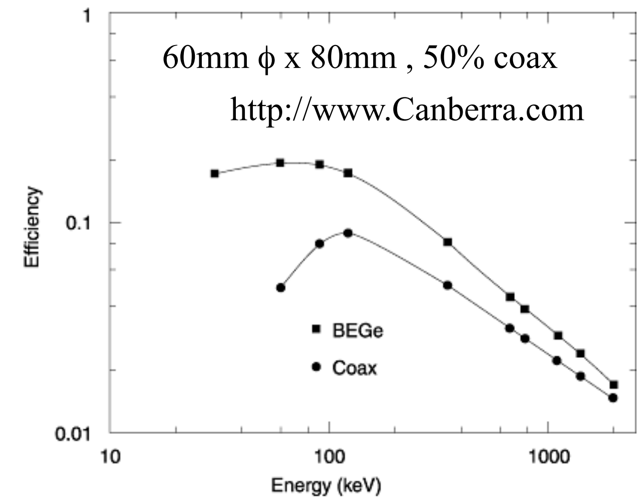
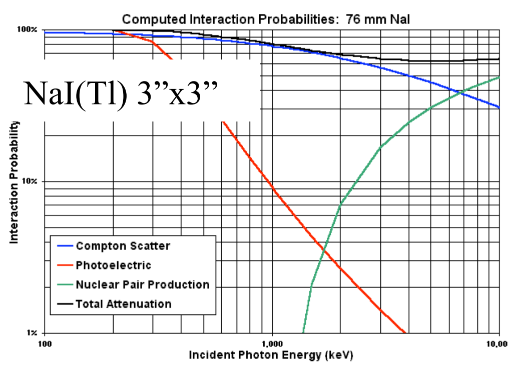


Fig. 12.19 Knoll, 3rd Ed.

“Peak-to-Total” ratio



Detector efficiency is often quoted in percent of that for a 3”x3” NaI(Tl) detector (for historical reasons) and generally for the 1332.5 keV line from ^{60}Co.

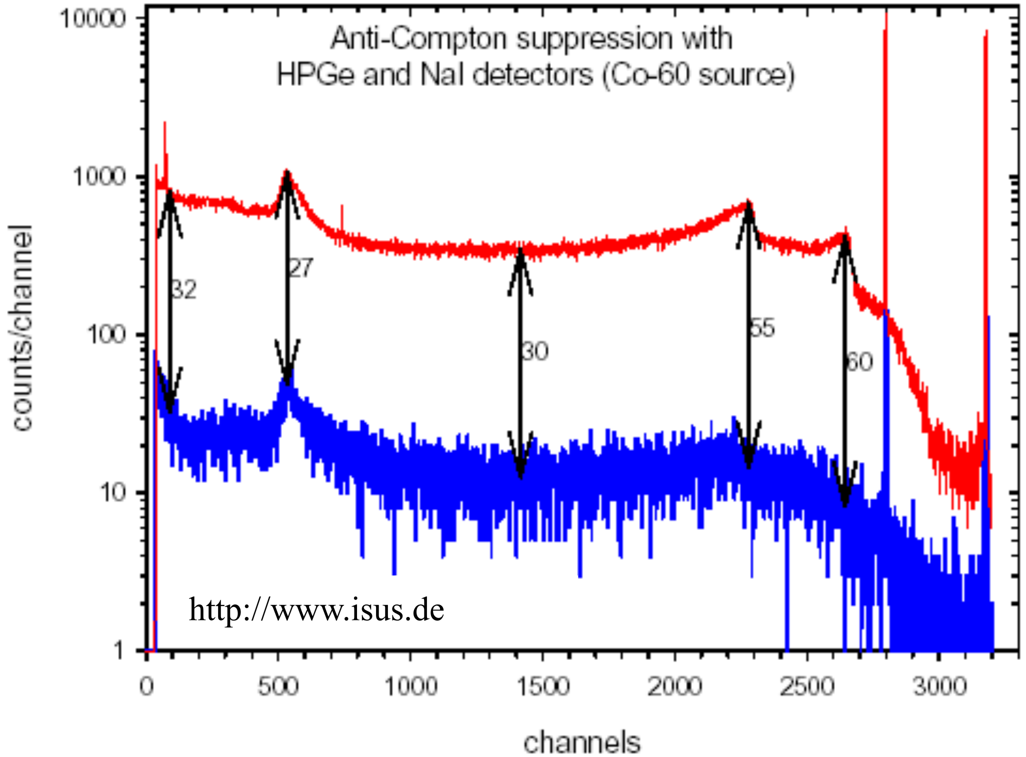


$$\varepsilon_{geo} = \frac{1}{2}\left(1 - \frac{d}{\sqrt{d^2 + a^2}}\right) \qquad d = 25cm, a = 1.5''$$

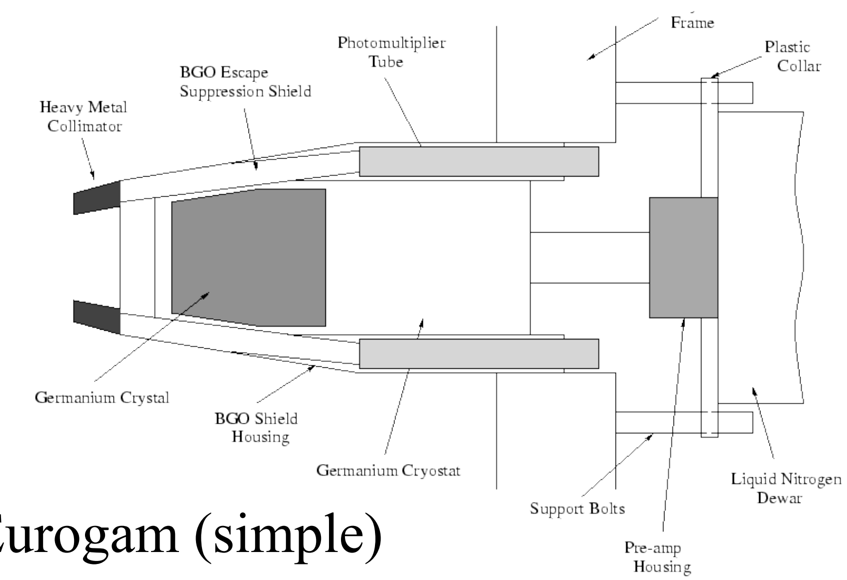
$$\varepsilon_{geo} = 5.707x10^{-3}$$

$$\varepsilon_{total}(NaI) = 1.2x10^{-3} \rightarrow \varepsilon_{\mathrm{intrinsic}}(NaI) = 0.210$$

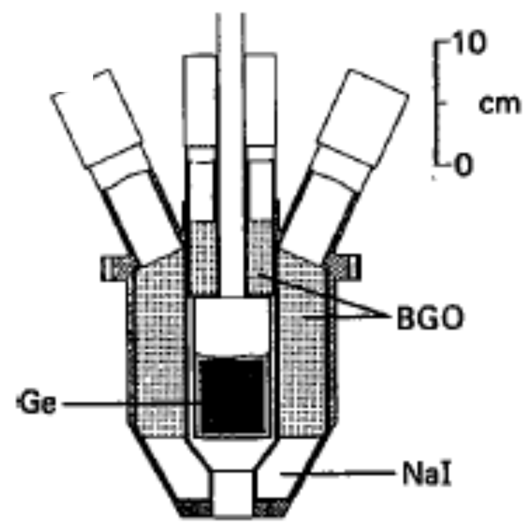
Germanium Based Detectors – Anticompton



Anticompton shields: Improve the quality of the signal by rejecting events when (compton-scattered) photons leave the Ge crystal.

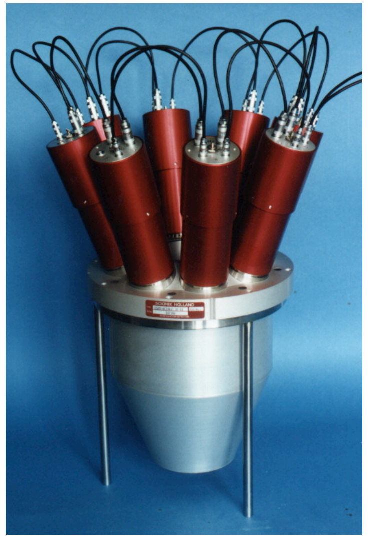


Eurogam (simple)



“Tessa” mixed shield

Fig. 12.25 Knoll, 3rd Ed.



http://www.Scionix.com