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RADIATION DAMAGE OF GERMANIUM DETECTORS

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RADIATION DAMAGE OF GERMANIUM DETECTORS*

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Energetic particles can produce interstitial-vacancy pairs (a Frenkel defect) in a crystal by knocking the atoms from their normal positions. Detectors are unique among semiconductor devices in depending on very low concentrations of electrically active impurities, and also on efficient transport of holes and electrons over relatively large distances. Because the dense regions of damage produced by energetic particles may result in donors and/or acceptors, and also provide trapping sites for holes and electrons, detectors are very sensitive to radiation damage. (Compared to fast neutrons and charged particles, the damage caused by electrons and gamma rays is negligible and will not be discussed here.) In addition to these effects occurring within the detector, radiation may also change the characteristics of the exposed surfaces causing unpredictable effects on the detector leakage current. Fortunately, radiation-induced surface degradation has rarely, if ever, been observed for germanium detectors.

It has been known for a number of years that fast neutrons generate predominantly hole trapping centers in germanium detectors. This fact leads to a consideration of the possibility of minimizing hole trapping in charge collection by the use of a high-purity germanium coaxial detector configured with the p^+ contact on the coaxial periphery. As depicted in Fig. 1, the holes then make only a short traversal from the outer portions of the detector (where most interactions occur) to the contact of collection. To establish high electric fields at the periphery one would want to use n-type germanium.

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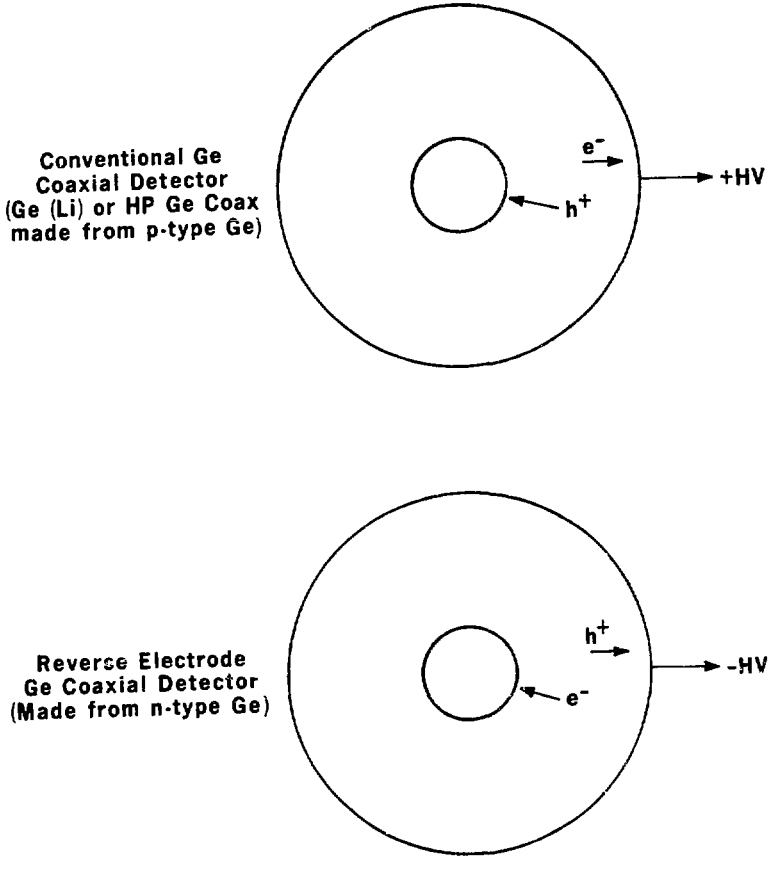

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Fig. 1 Charge collection direction in germanium coaxial detectors.

Although this hypothesis had not been tested--at least not directly--it was generally accepted that typical coaxial detectors (conventional electrode configuration) were considerably more vulnerable to neutron damage than were planar detectors.[1] However, no controlled experiments were done. (By controlled one means directly comparing a planar and coaxial detector made from the same germanium crystal to the same neutron irradiation. In light of the range of radiation damage sensitivities among detectors made from different crystals,[2] it is important that comparisons be made from detectors made from the same crystal.) Nevertheless, it is safe to say that a typical moderate size coaxial detector is at least 20 times more sensitive to neutron damage than is a 1 cm thick planar detector.

In the course of a continuing study of the proton damage of germanium detectors, (Reference 3, which reports the first experiment in this study, provides a far more extensive discussion of proton damage and subsequent annealing of germanium detectors than will be attempted in the present paper. Reference 4 also provides some pertinent general background on the subject.) a reverse electrode configuration coaxial detector that had been fabricated at Lawrence Berkeley Laboratory (LBL) five years ago and a 1 cm thick planar detector made from the same crystal were irradiated with 5.1 GeV protons in a recent experiment by L. S. Varnell, R. H. Parker, B. D. Wilkins, L. Finnin, M. Fong and myself. These detectors were irradiated simultaneously--there were actually a total of five detectors in line.

As shown in Fig. 2, the coaxial detector was considerably less sensitive to the high-energy proton damage than was the planar detector. These data indicate a factor of ~3. This would imply a factor of ~60 when comparing coaxial detectors having the opposite electrode configuration. Although additional experiments must be done, the evidence is now quite strong that coaxial germanium detectors having the n^+ contact on the coaxial periphery should not be used in any situation subject to significant radiation damage such as on an extended mission in space. To illustrate the problem, the anticipated resolution as a function of proton flux is plotted in Fig. 3 which one can then translate to days in orbit by making some estimates. Carefully studied proton irradiations of germanium detectors have been made only at 5.1 GeV, consequently the dependence of radiation damage on proton energy has not been established.

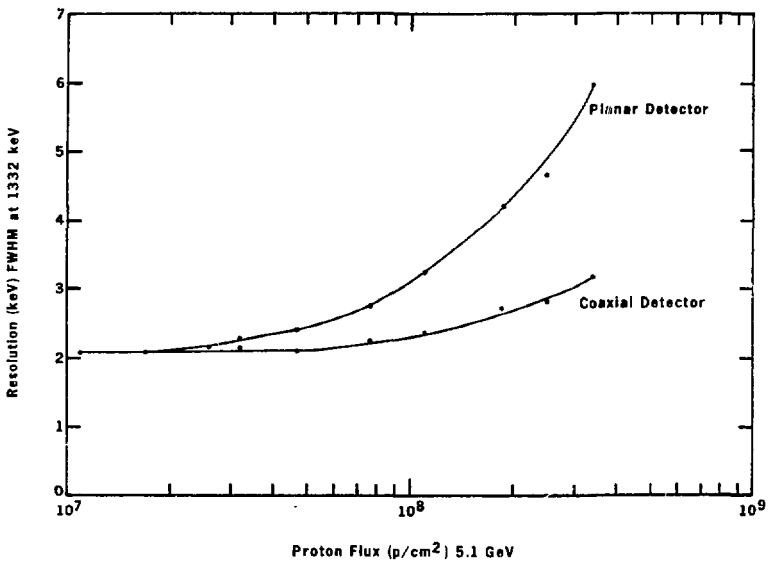

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Fig. 2 Effect of proton flux on energy resolution. Electronic noise has not been substracted but is equal in both systems.

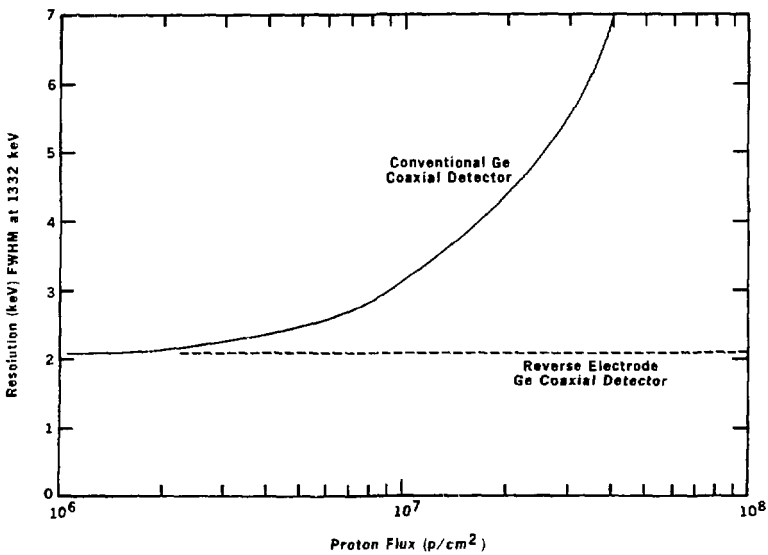

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Fig. 3 Predicted effect of proton flux on energy resolution of germanium coaxial detectors.

Thus the predictions presented in Fig. 3 include an allowance (best guess) for this factor. Although heavy ions are known to produce more damage per particle than protons, this cosmic-ray component has been ignored in the predictions presented in Fig. 3.

Our conclusion is that large germanium coaxial detectors are much more viable for extended space missions than many people thought several years ago--at least as far as radiation damage is concerned. Unfortunately, some of the early experiments scheduled to fly germanium coaxial detectors for an extended time in space are presently planning to use detectors having the improper electrode configuration. Their anticipated difficulties should not diminish interest in the use of germanium coaxial detectors in the future.

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