

RADIATION DAMAGE EFFECTS ON SOLID STATE DETECTORS

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The solid state detectors I will discuss are totally depleted silicon diodes used as nuclear particle detectors in investigations of galactic and solar cosmic radiation and also trapped radiation. The convenient size of these detectors, their relatively low bias voltage requirements, their extremely good energy resolution, and their small dead time effects have often led to their selection over competitive detector systems (witness the Pioneer F and G and Helios A and B experiment selections).

To the list of their advantages, one can now add an extremely long lifetime as a typical characteristic. In the mid 1960's, this statement could not have been made because there was a history of these detectors failing, becoming noisy, or developing other problems. In fact, we now understand that most of these detectors behaved normally, expiring just about on schedule because of radiation damage effects. Those effects were not well understood then because much of the information existing at that time came from studies of irradiations in nuclear reactors or in accelerators where one had to contend with multiple nuclear radiations: charged particles and neutrons, gamma rays, and X-rays with complicated spectra. Usually, results were presented as a critical parameter versus absorbed dose in rads. We now know that this is not a good way to analyze the problem, which is a fairly complicated one. The important effects are dependent on the type and energy of the particle, and the results are best understood in terms of the parameter of interest versus the integrated flux, or fluence, as it is called.

For several years, we have been involved in a systematic study of these radiation effects, and, more recently, chemical effects also. Normally, one is interested in the detector's noise, leakage current, capacitance, and energy resolution in the measurement of the particles emitted from a convenient radiation source, such as Am^{241} . Work on electron and proton irradiation of surface barrier detectors with thicknesses up to 1 mm has been completed, and indepth work on lithium-drifted silicon devices with thicknesses of several millimeters is beginning.

Figure 1 is an example of our early results and shows a quite unexpected result. In the figure, the detector noise is plotted versus the integrated flux of protons incident on a surface barrier detector. Four curves are shown: two for irradiation by 200-keV and 800-keV protons through the front, gold surface and two for the same particles through the rear, aluminum surface. All other conditions were identical in each case. The noise produced by the damage effects of low energy protons incident on the rear, aluminum contact of the detectors is lower by a factor of 10^3 to 10^4 than the effect of protons incident on the front, gold contact. For the typical steep spectrum we are dealing with in space, this effect can markedly extend the lifetime of a detector if the rear contact is preferentially exposed.

Figure 2 is taken from recent work which will be published in the February issue of *IEEE Transactions on Nuclear Science*. The device's capacitance is plotted versus the fluence of electrons. The upper set of curves is for a 50-V bias on the device; the lower curves are for a full bias of 150 V. The effect of electron energy is clearly visible. Similar effects are present for noise and leakage current.

Figure 3 shows a somewhat more subtle effect. What one is really interested in measuring with these detectors is the energy deposited in a given detector or series of detectors (and really measuring this deposited energy with good resolution). One can get a good feeling for this by looking at pulse height spectra. The number of events recorded is plotted on the ordinate and the energy deposited in the detector is plotted on the abscissa. These spectra are taken from a detector irradiated by 400-keV electrons.

Spectrum (a) is a normal spectrum showing the expected alpha particle distribution from Am^{241} and the distribution from a good pulser. The width of the pulser peak is a measure of the resolution or noise of the detector. Spectrum (b) shows the accumulated effect of an irradiation of 3×10^{14} electron/cm². There is very little broadening of the pulser peak, but there are prominent changes in the response to the alpha particles. Some of the charge liberated in the detector is not being collected.

Spectra (c) and (d) continue the rapidly deteriorating picture. Although the noise, resolution, capacitance, and leakage current have changed little, this detector is useless for spectral analysis after irradiation exceeding 10^{14} electron/cm². The loss of charge collection efficiency is due primarily to the

trapping of charge carriers on defects, which leads to smaller pulse heights and longer rise times.

Although a complicated set of processes is going on here, two things are clear: (1) there is a great advantage in using the aluminum contact as the detection front surface and (2) detector biases should be as large as possible (i.e., in the range of 100 to 200 V/mm) to minimize the loss of charge collection efficiency and to maintain the depletion depth.

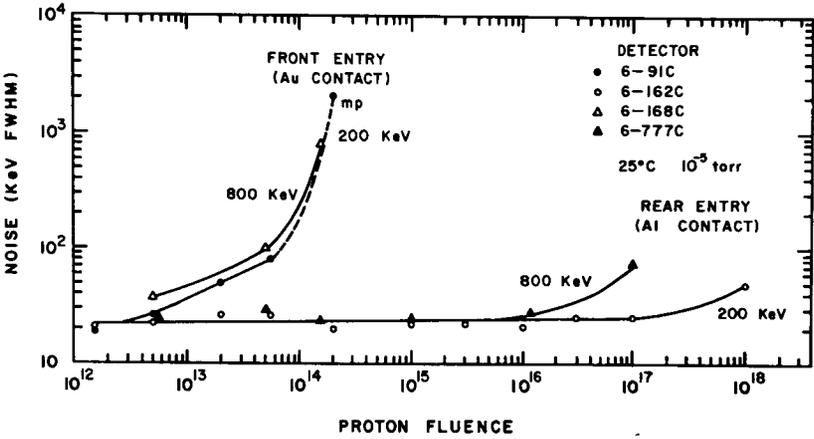


Figure 1

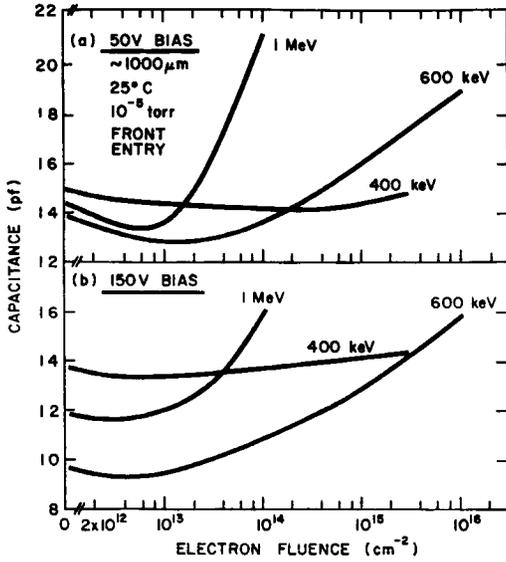


Figure 2

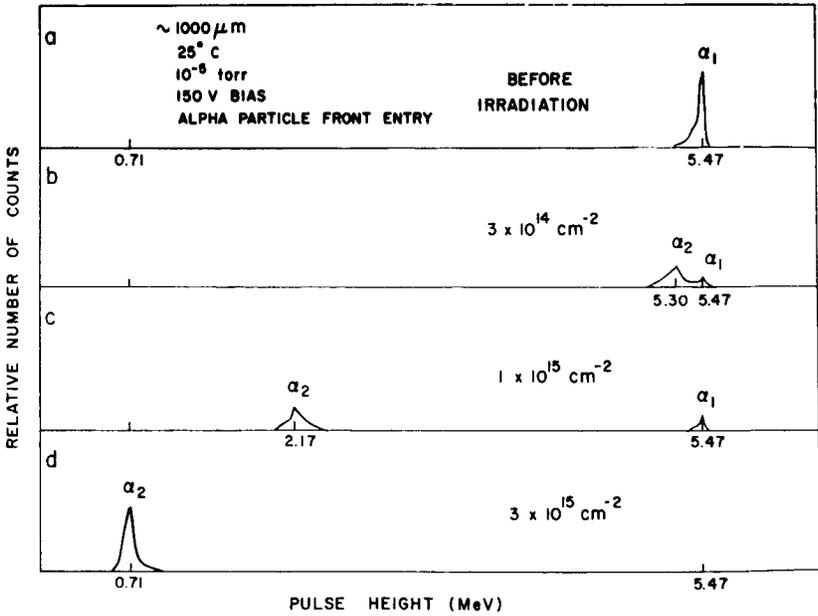


Figure 3