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Berkeley, California

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ABSTRACT

A method is described for producing thin-window lithium-drifted germanium x- or γ-ray detectors. The success of the process is indicated by a high yield of good detectors. Measurements show that the window thickness is in the range of 1 micron or less and x-ray energy resolution figures of 1.4 keV (full width at half minimum) have been obtained. Some initial tests using the detectors for long-range proton energy measurements show that the negligible window thicknesses combined with thick depletion layers (easily obtained with germanium) promise to extend the usefulness of semiconductor detectors in particle as well as x-ray experiments.

INTRODUCTION

The past two years have seen the development of lithium-drifted germanium γ-ray detectors in a wide variety of shapes and forms,[1-3] and their application to studies of nuclear energy level schemes has revolutionized this area of research.[4, 5] One possible major area of application of detectors--that of x-ray spectroscopy--has so far escaped the impact of germanium detectors owing to the lack of thin-window detectors. For very low energy x rays, thin-window lithium-drifted silicon detectors[6] provide adequate efficiency, and these detectors combined with FET preamplifiers[7] promise to be important tools in x-ray fluorescence analysis and other work. However, in the energy range above 30 keV the low efficiency of silicon detectors reduces their usefulness and thin-window germanium detectors are required.

A further possible area of application for thin-window germanium detectors is to particle reaction studies. The thickness of silicon lithium-drifted detectors is restricted to about 3 mm (i. e., for high-resolution work) at present, and such detectors are adequate only for stopping protons of energy up to 25 MeV. If thin-window germanium detectors (1 cm thick) were available, total energy measurements on protons up to 50 MeV would be possible.

Thin-window germanium detectors have recently been described by Armantrout and Camp[8] and Janarek et al.[9] Tavendale[1] also mentioned the possibility of producing a thin window by using an aluminum alloyed back for the drifted region. However, all these methods appear to suffer from disadvantages. The aluminum alloyed back described by Tavendale has proved unreliable--presumably owing to nonuniformity of the alloy contact. The technique described by Janarek, which involves drifting close to an electrolytically gold-plated surface layer, results in a finite window. According to these authors, drifting could not be continued beyond the point where a 10-μ dead layer exists. The technique of Armantrout is based on the side-window philosophy. In this case particles (or radiation) impinge on the side of a crystal normal to the electric field lines. The crystal is cut from a lithium-drifted piece of germanium and one hopes that a windowless detector results. Our experience with both silicon and germanium is that the cutting and etching process usually results in a finite dead layer and, moreover, the electric field near the surface can be seriously affected by the precise nature of the surface states. These factors result in poor and nonuniform charge collection from the surface layers.

A TECHNIQUE FOR PRODUCING VERY-THIN-WINDOW DETECTORS

In view of the problems with other methods we have recently been employing a technique with germanium similar to that used for silicon p-i-n lithium-drifted detectors.[10] In its simplest form this technique consists of drifting from a lithium-diffused face (referred to here as the front face) of a germanium block, continuing the drift until the drifted region reaches the lapped back face. When punch-through occurs the detector leakage current increases rapidly. In our case, the drift controller adjusts the temperature to maintain the leakage current constant, and a sudden fall in temperature results when punch-through occurs. The back face is now etched in a standard 3:1 HNO_3-HF etchant and, after washing and drying, gold is evaporated onto the back face to form a P+contact. Earlier tests made with various etchants on silicon showed that the gold probably contacts a very thin layer of material depleted of lithium by the etching process. However, the details of the P+contact do not need to concern us here.

It is tempting to apply this process directly to a standard germanium detector structure in which the lithium diffusion covers the whole of one face of a rectangular germanium block and in which the entire volume is lithium compensated. Experiments have been made with this simple structure, but all samples exhibit very high leakage currents and noise. This may be attributed to the presence of an n-type surface channel providing a conducting path between the lithium-diffused face and the gold back. Llacer's work[11] illustrates the importance of such surface layers in producing low breakdown voltages and noise in lithium-drifted silicon diodes. It is likely that germanium surfaces exhibit similar behavior.

As an n-type surface might form a conducting layer from the n-type lithium-diffused face to the gold back we must modify the simple detector structure to provide a periphery of the original p-type germanium surrounding the gold back. Several possible structures meet these requirements, and we have found that shown in Fig. 1 to be the most convenient to manufacture. Several sizes of detector have been made, but most of our work has been concerned with rather small detectors in which the area ABCD is 1×1 cm and the total thickness of the germanium is 0.6 cm. In these detectors AE is about 4 mm with a 45-deg flare-out near the back. The area of the back is 1.4×1.4 cm.

The manufacturing process for this type of detector is as follows:

(i) A block of germanium $1.4 \times 1.4 \times 0.7$ cm is cut from single-crystal p-type germanium in the resistivity range 10 to 30 ohms cm.

(ii) Lithium is diffused into one of the 1.4×1.4-cm faces. This diffusion is carried out in a vacuum evaporator as described in Ref. 12, p. 64.

(iii) The shape shown in Fig. 1 is cut out with a diamond saw. We have experienced occasional problems due, apparently, to damage at the intersection of the 45-deg and vertical faces. These problems have been overcome by using an air-abrasive unit to remove surface damage around this intersection.

(iv) The rear face is now lapped lightly and, after through cleaning, is protected with an etch-resistant masking tape. The rest of the surfaces are now etched for 1/2 min in a 3:1 HNO_3-HF etch.

(v) Both front and back faces are now masked and the sides are etched for 2 min. Surface states are then set as described in Ref. 12, p. 64. The masking tape is removed and drifting started as described in this reference.

(vi) When the drifted region reaches the back surface a sudden large drop in the temperature of the drifting plate occurs. The detector is then removed from the drift unit.

(vii) The back face is now lapped lightly and a standard ohmeter is used to determine the extent of the intrinsic region on the back face. The two lead prongs contact the surface about 1 mm apart. Moving their position on the surface while observing the resistance gives a clear definition of the intrinsic region. The lapping process is continued until the intrinsic area is equal to the area of the lithium-diffused face. This leaves a rim of p-type material around the intrinsic area.

(viii) The lithium face is now protected with etch-resistant tape and the rest of the surface (including the back) is given a 1-min etch in 3:1 HNO_3-HF etching fluid. The etch is quenched in CH_3OH, the masking tape is removed, and the detector is washed in trichlorethylene and methanol and dried with a blast of nitrogen.

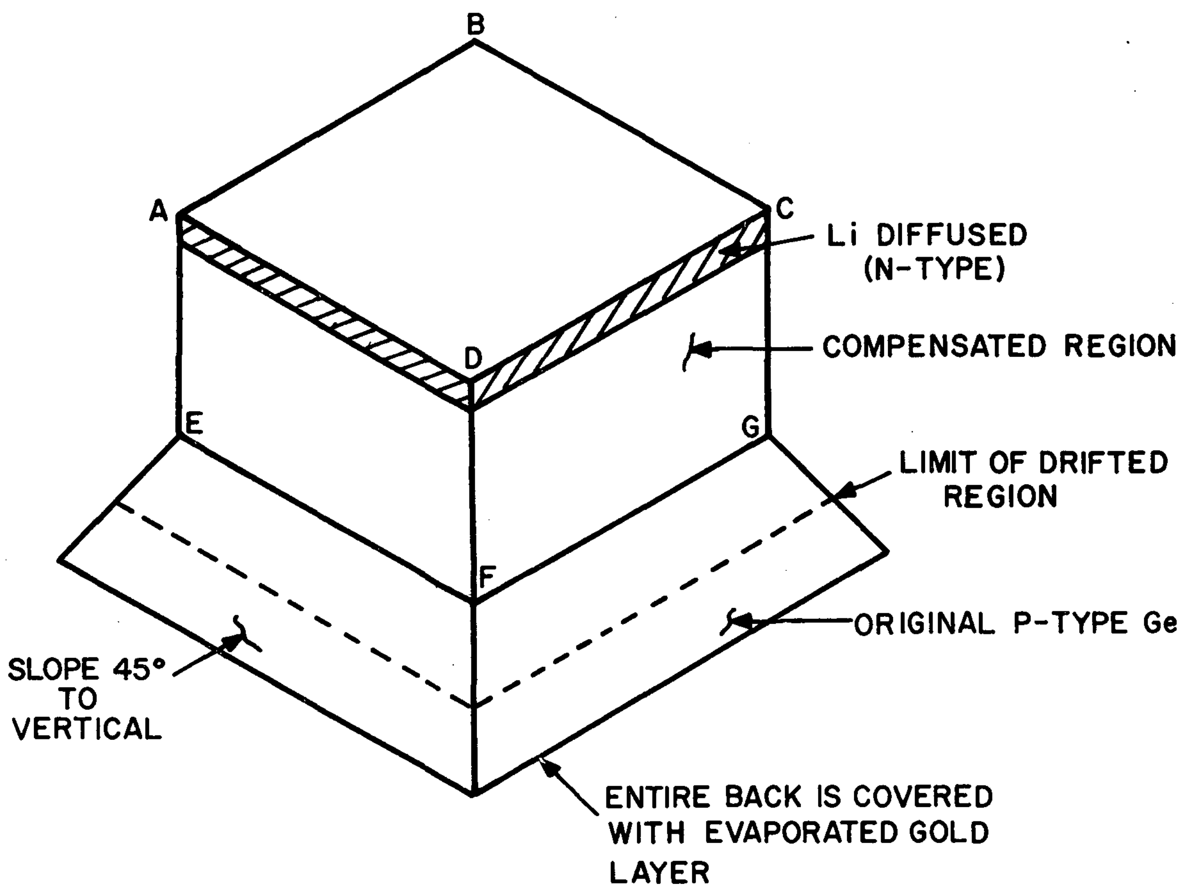

Fig. 1. The detector structure.

(ix) A thin layer (about 50% transmission) of gold is now evaporated over the whole back face. The empirical surface-barrier techniques used by makers of silicon surface-barrier detectors do not appear to be necessary in this case. The best results are obtained by carrying out the evaporation immediately after the back has been etched.

(x) Back and front are now protected; the sides are etched for 1 min and appropriate surface treatment is carried out. The detector is then mounted in its final holder, which is immediately pumped and cooled.

EXPERIMENTAL RESULTS

About ten thin-window detectors of this type have been made, and only one has failed to operate successfully in its final application. This failure was attributed to surface problems and did not appear to be related to the use of the gold back. In all cases detectors were operated at voltages in excess of 100 volts/mm (i.e., 600 V for the 6-mm thickness), and no relationship was found between the use of the gold back and the voltage at breakdown. It appears that the surface states at the edge of the detector determine the breakdown voltage. It has been observed that the gold back (if properly protected during etching) remains good even if several successive etches are required in the sides of the device to achieve good voltage-breakdown characteristics.

The early units were used together with EC1000 preamplifiers (see Ref. 12) for x-ray measurements, but later devices were used with 2N3823 field-effect transistor preamplifiers,[7] giving x-ray energy resolutions as small as 1.4 keV (FWHM). A typical x-ray spectrum obtained by H. Bowman[13] on ^{241}Am exhibited relative line intensities which agree well with previously measured values, indicating an efficiency close to 100% in the energy range 10 to 60 keV. This implies that the dead layer must be very small. A more critical test of the window is to use the detector for natural α particles. A test with ^{241}Am α particles showed that the output height was very close to the calculated value. This is difficult to interpret in terms of window thickness, as charge produced in a dead layer may diffuse into the intrinsic region. However, the behavior of signal amplitude as a function of amplifier time constant indicated that the window thickness could be only a very small fraction of the α-particle range (20 μ). We believe that 1 μ would be a good estimate.

In a recent experiment, Pehl, Landis, Goulding[14] have used one of the detectors for total energy measurements of 30- and 40-MeV protons. The energy resolution obtained (≈0.1%) compares favorably with that obtained by using lithium-drifted silicon detectors at lower energies. However, the observation of a small satellite peak suggests that charge collection is not uniform through the whole sensitive volume (at least in the particular detector employed in the experiment). This observation is supported by the presence of low-energy tails on high-energy (1-MeV) peaks in a γ-ray spectrum. It is well known that many germanium detectors exhibit this phenomenon, and it is likely to be a function of the particular material used in the manufacturing process.

The author's attention has been drawn to a detector structure[15] somewhat similar in its essential features to that described in this report. While the same thin-window behavior should be produced by either process, the technique described in this report appears to have distinct advantages as far as construction of the device is concerned.

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REFERENCES

1. A. J. Tavendale and G. T. Ewan, Nucl. Instr. Methods 25, 185 (1963).

2. H. L. Malm and I. L. Fowler, Atomic Energy of Canada Report CRGP-1224, 1964.

3. William L. Hansen and Blair V. Jarrett, Techniques for the Fabrication of Lithium-Drifted Germanium Gamma Detectors, Lawrence Radiation Laboratory Report UCRL-11589, Aug. 1964.

4. David Shirley, Nucleonics 23, 62 (1965).

5. Jack Hollander, The Impact of Semiconductor Detectors on Gamma-Ray and Electron Spectroscopy, Lawrence Radiation Laboratory Report UCRL-16307, Aug. 1965.

6. Fred S. Goulding and William L. Hansen, IEEE Trans. Nucl. Sci. NS-11 [3], 286 (1964).

7. Emanuel Elad, A Preamplifier with 0.7 keV Resolution for Semiconductor Radiation Detectors, Lawrence Radiation Laboratory Report UCRL-16390, Sept. 1965.

8. G. A. Armantrout and D. C. Camp, Phys. Letters 17, 279 (1965).

9. F. J. Janarek, H. W. Helenberg, and H. M. Mann (Argonne National Laboratory), private communications, 1965.

10. Robert L. Lothrop and Harry E. Smith, Lithium-Drifted Silicon Radiation Detector Production Process, Lawrence Radiation Laboratory Report UCRL-16190, June 1965.

11. J. Llacer, Brookhaven National Laboratory Report 9535, 1965.

12. Fred S. Goulding, Semiconductor Detectors for Nuclear Spectrometry, Lawrence Radiation Laboratory Report UCRL-16231, July 1965.

13. Harry Bowman (Lawrence Radiation Laboratory), private communication, 1965.

14. Richard H. Pehl, Donald Landis, and Fred S. Goulding, Phys. Letters 19, 945 (1965).

15. H. D. Lyser, F. P. Zeimba, and W. R. Van Antwerp, IEEE Trans. Nucl. Sci. NS-12, 265 (1965).

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