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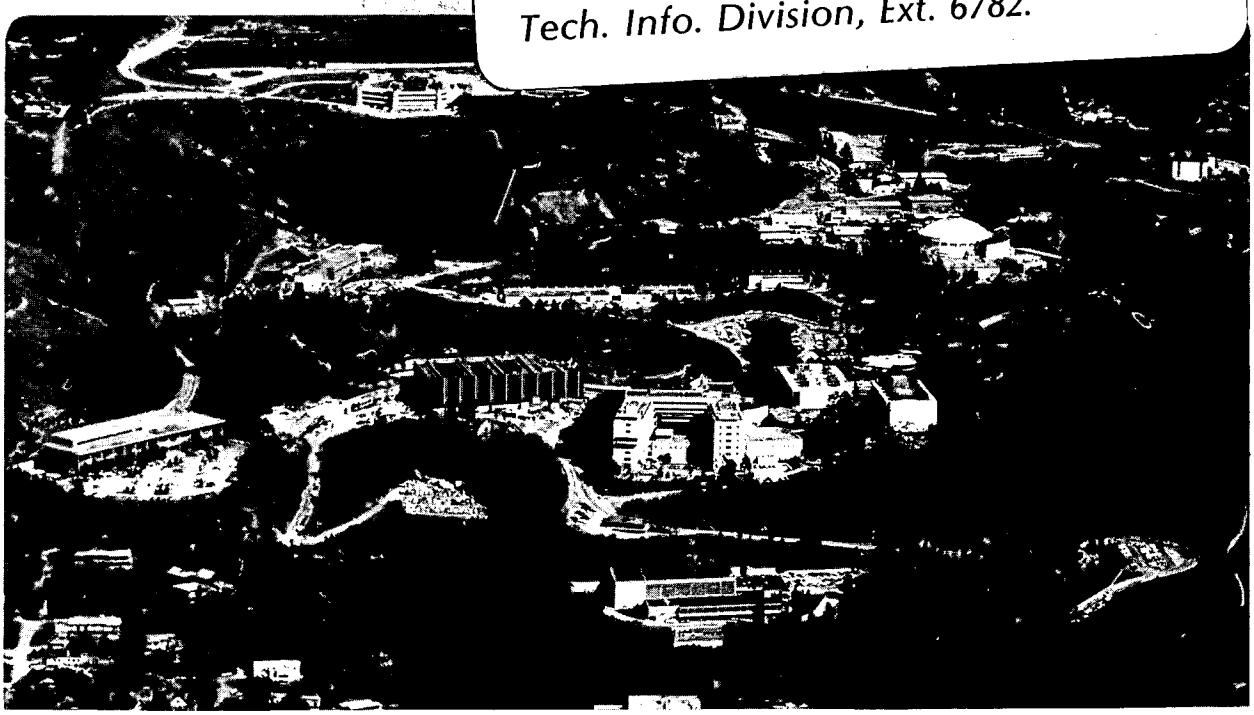

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GOLD-MASK TECHNIQUE FOR FABRICATING SEGMENTED-ELECTRODE GERMANIUM DETECTORS

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Abstract

A simple gold-mask technique has been developed for use in the fabrication of germanium nuclear radiation detectors. A layer of gold deposited over the contacts of the detectors acts as masks for chemical etching and surface treatments. It also serves as a reliable, low-resistance electrical connection to the underlying germanium contact. This technique greatly facilitates the fabrication of a wide variety of segmented-electrode planar and coaxial detectors. Examples of these detectors with applications in medical imaging, gamma-ray astronomy and high-energy physics are presented.

Introduction

Growing interest in the use of different types of segmented-electrode germanium detectors exists in a variety of fields. While the technology of making basic high-purity germanium detectors is well developed, fabrication of these segmented-electrode detectors using standard techniques may be very difficult and often impractical.

We have developed a technique which greatly facilitates the fabrication of segmented-electrode germanium detectors. This method involves coating the detector contacts (electrodes) with gold and then dividing them either mechanically or by chemical etching. The gold film serves two purposes. First, it acts as a mask to protect each contact element during chemical etchings and surface treatments needed in the fabrication process, thus eliminating the need for masking the contact elements manually which can be tedious or even impossible to do for very fine elements. Second, reliable electrical connections can be readily made when each contact element is metallized with gold; this avoids possible electronic noise arising from contact resistance.

General Technique

A high-purity germanium detector usually has a relatively thick (~ 300 μm) n^+ contact formed by lithium diffusion, and a very thin (~ 500 Å) p^+ contact formed by boron ion implantation. Metal Schottky-barrier contacts are often used in place of boron-implanted contacts, but we have not tried this technique on such contacts. Segmentation of the lithium and boron contacts are made in different ways.

Lithium-Diffused Contact

The processing steps used to segment the lithium contact are shown schematically in Fig. 1. Gold is deposited over the full lithium contact prior to segmentation. To ensure good adhesion of the gold film, the lithium contact is first etched briefly in 7:2:1 (HNO_3:HF:red fuming HNO_3) followed by a methanol quench and then blown dry with a nitrogen jet; alternately, quenching with DDW after the etch followed by a 10-min soak in 1% HF has also been found to result in good adhesion. Gold evaporation is then performed in a vacuum of < 10^{-6} Torr. Evaporation is usually done using a tungsten filament, although electron-beam evaporation or sputtering in argon will also work. The thickness of the gold film used ranges from ~ 1000 Å to > 1 μm. Next, the contact is segmented by cutting through the gold film and the lithium-diffused layer using a diamond saw or other mechanical means. Mechanical damage in the grooves is removed by chemical etching; each contact element is protected from the etchant by the gold film.

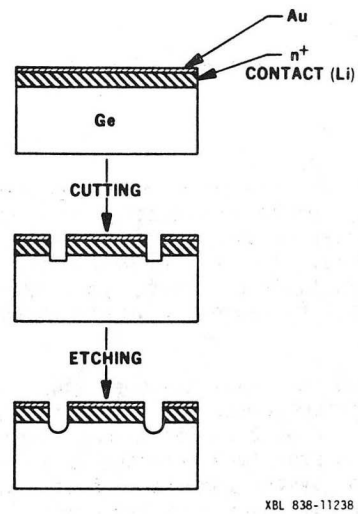

Fig. 1. Process for segmenting the lithium-diffused contact.

Boron-Implanted Contact

Since the boron-implanted contact is very thin, segmentation can be made simply by chemical etching, using the gold film as the etching mask. Before ion implantation, the germanium surface is polished by etching in 7:2:1 followed by a DDW quench and a 10-min soak in 1% HF. After implantation with boron ($10^{14}cm^{-2}$, 25 keV) and just before gold evaporation, the surface is given another few minutes' soak in 1% HF. Gold deposition method is the same as that for the lithium contact. The desired contact pattern can be obtained by doing the gold evaporation through a shadow mask, or by subsequent etching of the gold film using an aqueous solution of KI + I_2 with the contact areas masked out (Fig. 2). One masking material that can be used for the gold etch is photoresist which allows one to use photolithography technique to produce very fine contact structures. Once the desired gold pattern is obtained, a brief germanium etch will serve to separate the contact. This can be done during the final surface treatment.

When using this technique to segment the boron-implanted contact, we often found it necessary to anneal the detector (~ 200°C, 1 hr) in order to obtain low leakage current. The reason for this is not clear at the present time.

Specific Examples

The gold-mask technique has been applied to the fabrication of the following different types of segmented-electrode germanium detectors:

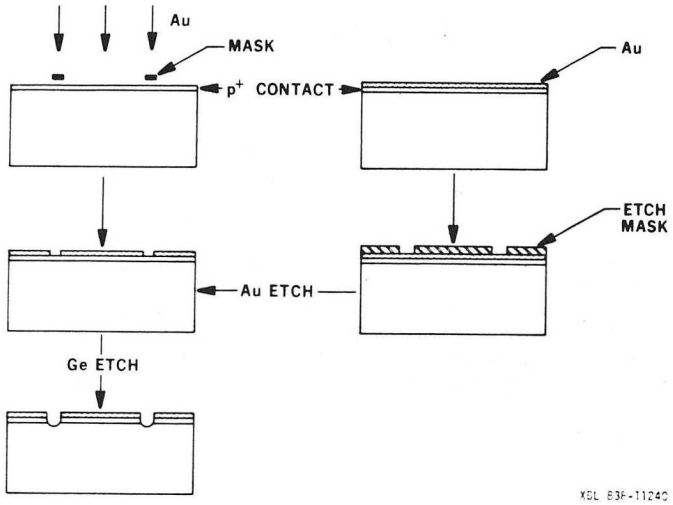

Fig. 2. Process for segmenting the boron-implanted contact.

Planar Arrays

In nuclear medicine there has long been a desire to use high-purity germanium detectors for imaging. These applications often require a very large number of small detector elements. A practical way to accomplish this is to produce multiple elements on a single slice of germanium crystal by segmenting one or both of the contacts.

A 4 x 4 detector array has been fabricated by segmenting the lithium contact of a 6 mm thick planar germanium detector (Fig. 3). Each element measures 5 mm x 5 mm. This is a prototype detector of a proposed 1024 element detector system for use as an active collimator in a gamma camera[1]. Such a system would require a number of planar arrays, each consisting of a larger number of elements than the present prototype (perhaps 8 x 8), but the technique used here can be directly extended to the larger arrays. In fact, this technique will prove to be even more valuable as the number of element increases and manual masking becomes impractical.

Segmented-Electrode Coaxial Detectors

Several recent proposals of balloon-borne gamma-ray spectrometers for astronomical observations have called for the use of segmented-electrode reverse-electrode (n-type) germanium coaxial detectors[2]. By observing the energy loss signature of each event in different segments of a detector, it is possible to discriminate against signals arising from induced radioactivities within the detector, thus attaining a significant background reduction[2].

We have fabricated a two-segment reverse electrode coaxial detector by dividing the inner (lithium-diffused) contact[3]. It is shown in Fig. 4 together with a sectioned piece showing the groove structure. Gold deposition over the lithium contact is done using a narrow hair-pin-shaped filament inserted into the core of the detector. A short evaporation (~ 30 sec) produces a gold film of sufficient thickness (~ 1 μm) without undue heating of the detector. Segmentation is made using a small rotating brass disk and a slurry of 600 grit lapping compound. The groove is polished by spraying etchant into the core. The finished detector performed properly; scanning with collimated ^{241}Am 60 keV gamma rays has confirmed the separation of the detector's active volume into two parts. Figure 5 shows a cross-sectional view of the detector indicating the position of the groove and the resulting scan.

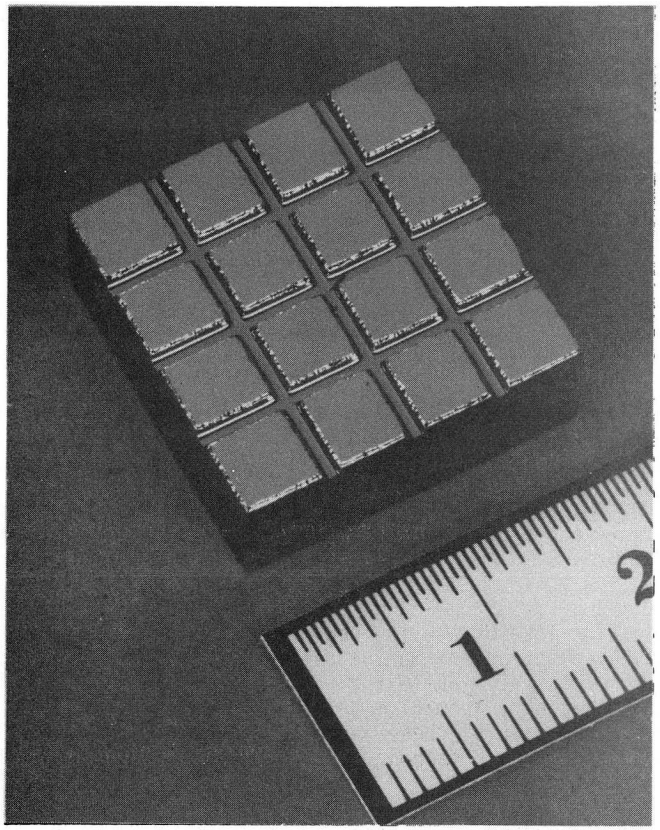

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Fig. 3. A 4 x 4 planar array. Each element measures 5 mm x 5 mm and is 6 mm thick.

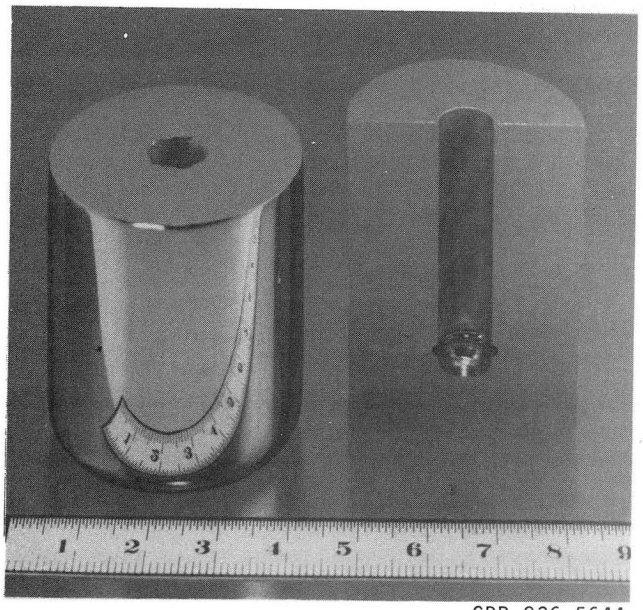

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Fig. 4. A two-segment reverse electrode coaxial detector (left), and a sectioned trial piece showing the inner contact structure. The groove is seen near the bottom of the core.

In principle, reverse electrode coaxial detectors with more than two segments can be readily fabricated using this method. However, making connections to the contact segments inside the core of the detector becomes very difficult both mechanically and electronically as the number of segments increases. Therefore, in such cases, segmentation of the outer (p^+) electrode is preferable. This can be done using the processes

described in Fig. 2. As part of the development process, a two-segment planar detector has been successfully fabricated by dividing the boron-implanted contact using the shadow mask method[4]. Fabrication of a segmented outer electrode reverse-electrode coaxial detector is in progress.

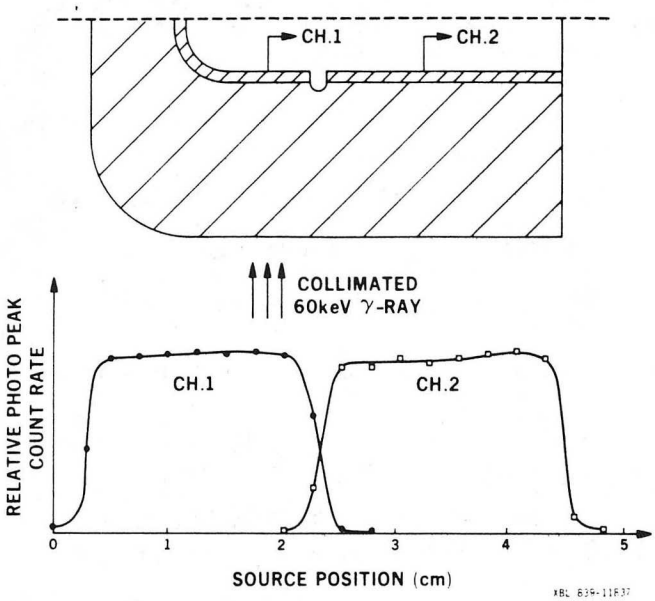

Fig. 5. Collimated 60 keV gamma-ray scan of the segmented-electrode coaxial detector.

Strip Detectors

There is presently intense interest in the use of semiconductor detectors with very fine contact strips, i.e. high spatial resolution, in high-energy physics experiments. Most of the attention and development efforts are directed towards silicon detectors mainly because of their ability to operate at room temperature and the availability of a mature technology generated in part by the microelectronics industry. However, high-purity germanium may be a more suitable material to use in some applications.

Using photolithography and the gold-mask technique, we were able to fabricate germanium detectors with fine contact strips. These detectors were originally developed for use in the measurement of short-lived charmed-particle lifetimes. The fabrication and performance of a detector with 48 contact strips of 50 μm widths and 50 μm spacings (i.e. 100 μm pitch) have been reported[5]. The detector measures 5 x 5 x 20 mm^3 with the strips parallel to the longer side. The strips were made on the boron implanted contact. Metallization of the boron contact was done by RF sputtering of titanium and gold to obtain a thick layer of gold (~ 1 μm) for wire bonding. However, some of the resulting metal strips did not adhere well to the germanium. The finished detector exhibited a high leakage current, although it is quite acceptable for this particular application.

We have since fabricated similar detectors each with either 48 contact strips of 100 μm pitch or 96 contact strips of 50 μm pitch. Palladium-gold metallization was used instead of titanium-gold. The palladium (300 Å) was deposited by e-beam evaporation followed by gold (1.5 μm) deposition by RF sputtering. The rest of the process was the same as that described previously[3]. The resulting metal strips adhered well to the germanium. Electrical connections to the strips were made by ultrasonic wedge bonding of aluminum wires. A finished 96-element detector is shown in Fig. 6. The leakage current of this detector and a 48-element detector were measured by connecting all contact elements together (Fig. 7). The 48-element detector showed excellent I-V characteristics; the increase in the leakage current up to depletion arose largely from infrared radiation emitted by the room temperature wall of the cryostat. The 96-element detector has higher leakage current but, again, is not a concern in this application. These detectors were made from n-type material, so depletion starts from the strip-contact face and separation between strips is obtained even at below depletion voltages.

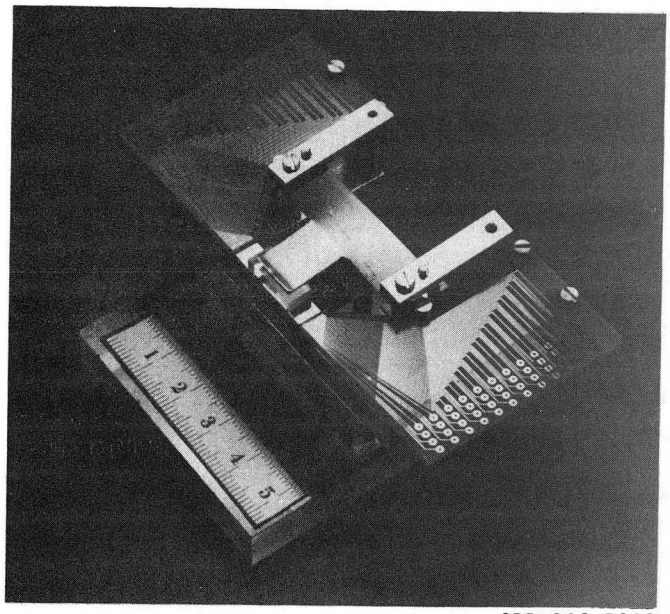

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Fig. 6. A 96-element strip detector.

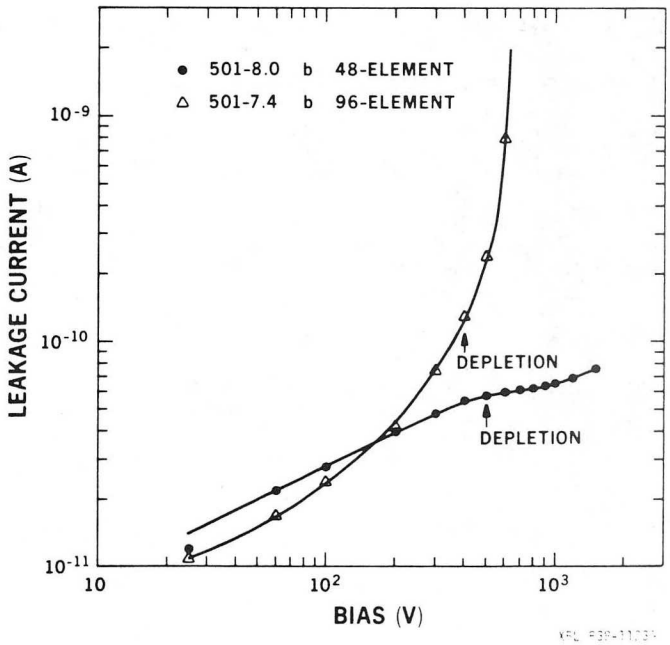

Fig. 7. I-V characteristics of a 48-element and a 96-element strip detector.

Discussion

The examples given here serve to illustrate the variety of detectors that can be made using the gold-

mask technique. Obviously, one can apply this technique to fabricate other types of detectors, such as guard-ring detectors and orthogonal-strip detectors. In addition, we have found this technique to be very helpful in making basic (unsegmented) coaxial detectors where masking of the inner contacts is still difficult to do otherwise.

Acknowledgements

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