Thermal isolation is achieved by attaching the water-jacketed reservoir to the flange by means of thin-wall stainless steel tubing. The tubing for the working fluid runs inside the support tubing and is attached only at the water jacket (to reduce heat conduction). To reduce heat losses even further, the drive shaft is removable after the vial is broken. The cross-section view in Fig. 1 does not show a third tube (on the outer bolt circle) which allows introduction of a thermocouple or resistance thermometer into the jacket to measure the temperature of the working fluid. The total rate of heat loss for a 100°C temperature gradient between the jacket and flange is 0.23 cal/sec. For example, a water flow rate of 1.48 liters/min will maintain the reservoir temperature within 0.01°C of the temperature of the constant-temperature bath.

The configuration of thumb wheel, drive rod, and expansion joint gives a total linear motion of 0.032 in. An expansion joint was chosen after several attempts to use a bellows failed because of the development of leaks. The expansion joint provides more material than a bellows at the point where the welds are made, a condition which reduces the difficulty of producing strong, leak-free welds. A \( \frac{3}{16} \)-in. cross section at the welded joints (with 0.005- to 0.010-in. wall elsewhere) is quite satisfactory for the construction of the expansion joint.

Except for the three welded joints, brazing with a suitable alloy was used. To allow ease of assembly, three press-fitted support rods, equally spaced between the three support tubes on the outer bolt circle, were used to hold the assembly together during the brazing operation. These rods were cut out after assembly was completed.

*This work was sponsored by Rome Air Development Center, U. S. Air Force.

**Stable, High Field Silicon p-n Junction Radiation Detectors**

G. C. Huth, H. E. Bergeson, and J. B. Trice

*Space Sciences Laboratory, Missile and Space Division, General Electric Company, Box 8555, Philadelphia 1, Pennsylvania*

(Received 28 June 1963; and in final form, 29 July 1963)

This note reports a development which we think will be useful in solving some of the problems which are especially severe when semiconductor p-n junctions are used as radiation detectors. Such detectors require characteristic optimizations unusual to semiconductor technology and can include various combinations of the following: thick depletion regions, high internal fields, ability of the junction to operate without housing and without a controlled atmosphere, absence of a dead layer, and low junction current and noise. Many of these characteristics demand much better control of surface fields and currents than has been possible up to the present time.

The approach that we have found useful in this regard involves the geometrical control of a reverse bias created depletion region at the surface of a p-n junction by the physical removal (by grinding or etching) of bulk charge. Such removal results in a "bevel" or other shaped surface termed a "surface contour." By this means the space charge region is controllably distorted or spread out at the surface, the result of which can be, as shown in Fig. 1, a lower surface field. By this technique it is possible to build up peak internal (or bulk) fields to the avalanche point in silicon (200–300 kV/cm) at voltages in the kilovolt range while maintaining the surface field at a low, manageable value—as low as 5–10 kV/cm in the detectors described. This situation is in contrast to that generally occurring in semiconductor detectors (and other p-n junctions) where the high surface field causes instability and precludes the attainment of high internal field values. The results that
we have observed the application of this effect are (1) exceptional stability even when the detector junctions are unhoused and biased to the 2000–3000 V region and (2) very low junction noise values even at high internal fields.

The results presented in this note concern two silicon p-n junction geometries that have been developed that are thought will be useful for radiation detection. In one, 1200 Ω-cm n-type base material with a moderately steep contour angle (14°) is used to create a thick depletion region. In the second, 30 Ω-cm n-type silicon is used in a geometry with a very shallow angle (2–3°) that directly exposes the reverse bias created depletion region over an extended area. In both cases, gallium is used in a closed tube process as the acceptor diffusant and junctions are normally diffused at 1250°C in an argon atmosphere to a depth of 0.008 cm. Surfaces are shaped by lens grinding techniques using brass tools and No. 50 grit alumina optical finishing powder (The Carborundum Company) in a lapping oil vehicle. Subsequent to grinding, detectors are etched in cp etches containing iodine to remove grinding damage, and optimize leakage current and noise characteristics.

The 30 Ω-cm base detector is shown diagrammatically in Fig. 2. Also shown are the profiles of the surface field as determined by potential probing and the internal field calculated for the center of the detector; both are for a reverse bias of 550 V. The peak surface field value is 6 kV/cm while the internal peak field is of the order of 150 kV/cm. Reverse leakage current and resolution (FWHM) measured with a mercury pulser and the ORTEC 101–210 amplifier are shown in Fig. 3 for a typical detector of this type. The increasing resolution with increasing bias reflects the decreased amplifier noise due to decreasing capacitance. At 750 V, the detector begins to go into an injection type of breakdown and the detector noise increases sharply. It should be noted that if sufficient base region is provided the junctions go into avalanche breakdown in the 1000–1100 V range which is correct for the base resistivity and junction depth used. Resolution values as low as 6–8 keV have been observed and this level seems to depend mainly on surface perfection (residual damage from deeper scratches incurred during grinding). Our experience indicates that ambient sensitivity does not play a major role in determining these values. Values do not, for example, change in cycling from atmospheric pressure to high vacuum. Nor does the use of silicone grease on the active, beveled edge (for coupling to a plastic light pipe) seem to have measurable effect on either of these parameters.

In the 30 Ω-cm detector geometry a large fraction of the contour area represents directly exposed space charge region. This potentiality of windowlessness combined with low noise and low leakage currents may make this device useful as a low energy ion detector and as a sensitive light detector. The peak surface field in the junction described here is comparable to the bulk fields in currently used surface barrier detectors. Should this field be too low for efficient charge collection on the surface, it is possible to produce a higher field by increasing the contour angle, lowering the base resistivity, or a combination of both. The point of importance is that surface fields are controllable with the maximum field being dependent upon the care taken with surface cleanliness, and control of device ambient.

Thick depletion regions can be achieved by use of surface contouring limited only by (1) the highest base resistivity that can be diffused without changing value and (2) the price in increased area (and thus detector capacitance) that must be paid for the surface controlling contour.
Floating zone, high lifetime silicon to a resistivity of 1200 Ω-cm (n-type) has thus far been diffused at 1250°C without changing resistivity value (as measured by junction capacitance and probe resistivity measurements). Depletion regions of 275 and 625 μ at 700 and 2300 V biases, respectively, have been achieved. Noise resolution averages 12 keV (FWHM) for these detectors. The chief source of noise in high resistivity detectors seems to be injection at the base contact (presumably by formation of a surface junction). Care must be taken to prevent this and either vapor-plated aluminum or silver-epoxy solder seem to suffice for this purpose.

In addition to the usual uses, detectors of this type may also be useful at elevated temperatures. Without any attempt at optimization, a resolution of 600 keV (FWHM) was measured at 100°C. It may well be possible to reduce the noise at higher temperatures.

**Plasma Waveguide Cell for Afterglow Measurements**

E. H. Holt and K. C. Stotz

Rensselaer Polytechnic Institute, Troy, New York

(Received 14 March 1963; and in final form, 16 July 1963)

If a dielectric completely fills a given section of waveguide, the interaction of a microwave signal with the dielectric medium may be conveniently calculated. Any complication in the dielectric-waveguide arrangement introduces not only a complication in the calculation but also an uncertainty in the distribution of the microwave fields.

The plasma afterglow has been previously investigated by a bounded electromagnetic wave technique by Anderson and Goldstein and others.1,2 The plasma was created in a cylindrical glass vessel enclosed by a square-sectioned waveguide. Waveguide transitions connected the standard rectangular guide to the square guide. The ends of the thin-wall Pyrex vessel were drawn out in a taper to reduce reflections of electromagnetic waves. Electrodes were mounted external to the waveguide with two glass tubes passing through holes in the waveguide walls. Certain problems complicated the evaluation of the results obtained with this cell design. The plasma filled only the cylindrical glass cell rather than the waveguide. The effect of the glass, with its high dielectric constant, on the distribution of the fields in the waveguide was ignored. Reflections from the glass ends of the cell, even though they are tapered, were present. The tapers introduced a complication in determining the length of the plasma-filled section.

The plasma cell developed for present experiments (see Fig. 1) consists of a length of OFHC X-band waveguide with bakeable windows on each end. The entire cell is constructed of ultrahigh vacuum materials suitable for bakeout to 400°C. Small holes are drilled in the top of the waveguide and anode wires extend down to these holes flush with the top of the waveguide. The waveguide acts as a hollow cathode and the negative glow of the discharge spreads down into the cell and out to several inches from the anode. The cell in the figure has two anodes approximately 7 in. apart in order to provide a longer interaction path for the microwave signal.

The approximations and assumptions necessary with the enclosed glass cylinder mentioned previously are removed. The rectangular cross section of the waveguide cell provides well-defined boundaries for both plasma and electromagnetic wave and also provides a simple shape for the calculation of the microwave-plasma interaction.

With 3/8-in. holes in X-band waveguide, the VSWR is less than 1.05. Discharges have been obtained in helium in the pressure range 0.5-35 Torr and in nitrogen in the pressure range 0.3-7.5 Torr.