A New Germanium Photo-Resistance Cell

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THE various photoelectric properties of the semi-conductor germanium have been studied by a number of investigators. Bray and Lark-Horovitz[1] observed both photo-conductive and photo-e.m.f. effects in germanium crystal rectifiers. Benzer has observed a "photo-diode" effect[2] due to the illumination of an N-P barrier in series with a rectifying contact, and has studied both the photo-behavior of rectifying germanium-to-metal contacts in the presence of applied bias voltages[3] and the rectification behavior of such contacts in the presence of light.[4] The spectral response and quantum efficiency of the photo-e.m.f. effect at N-P boundaries in germanium were determined by Goucher.[5]

The purpose of the present letter is to report a device utilizing a photo-conductive property of germanium which combines high spatial resolving power with an over-all quantum efficiency greater than unity. These features are obtained in one construction with an electrode geometry which is similar to that of the double-surface transistor.[6] In the double-surface transistor the characteristics of the collector are modified by the injection of charge into the neighboring semiconductor from a nearby emitter electrode. In the present photo-cell the characteristics of the collector are modified by the photo-liberation of charge in the neighboring semiconductor. Figure 1 shows an illustrative drawing of

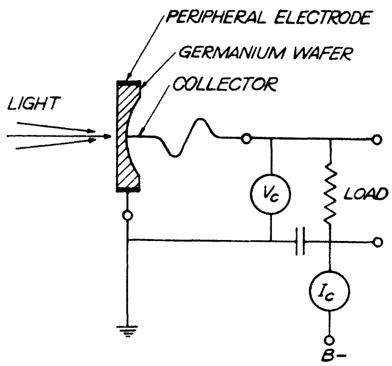

FIG. 1. Diagram of photo-cell showing electrical connections for testing and typical use.

such a photo-cell, in which the germanium has the dimpled pill-shape used in the Kock-Wallace transistor mounting.[7] The preparation of the (N-type) germanium wafer and the electrical forming treatment of the collector contact are described elsewhere.[8]

The area of the germanium wafer over which incident light affects the cell resistance is confined to a region a few hundredths sq. mm in extent on the illuminated side immediately opposite the collector contact. The responsive areas of a number of cells have been explored with a small spot of light from the vertical illuminator attachment of a metallurgical microscope. When the resulting current response of a typical cell is plotted *vs.* distance along a line passing through the center of the responsive area, an error-function-shaped curve is obtained whose breadth at half-maximum, corrected for the diameter of the exploring light spit, is about 0.2 mm. Allowing light to fall uniformly all over the wafer surface not only wastes light, but avoids the realization of the spatial resolving power of which the cell is capable. In the measurement of the characteristics reported below a condensing lens was used to focus an image of the light source substantially within the responsive area of the cell under test.

In operation the collector is biased negatively with respect to the peripheral contact through a load resistance of from 5000 to 30,000 ohms. This polarity corresponds to the blocking direction of diode rectification of metal against N-type germanium at the collector contact. A family of static collector current *vs.* collector voltage curves for several different values of steady light flux is shown in Fig. 2. By selecting suitable battery voltage and load

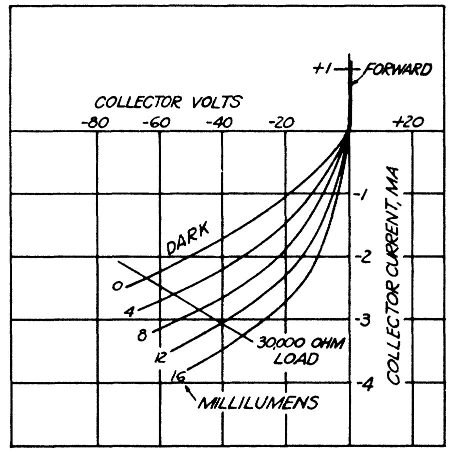

FIG. 2. Static characteristics of photo-cell.

resistance values, drawing the corresponding load line across this family of characteristics, and analyzing, in the usual way, for the performance of the circuit, load power responses of the order of several tenths milliwatt per millilumen can be deduced. The response of the cell to different frequencies of modulation of the incident light is substantially flat to the highest frequency studied, about 200 kc per second.

Preliminary measurements of the spectral distribution of the sensitivity of the photo-cell have been made in collaboration with H. B. Briggs. The response rises slowly from visible yellow to a peak at about 1.5μ and decreases rapidly beyond 1.6μ. The shape of this response *vs.* wave-length relationship is practically identical with that determined by Goucher and Briggs for the photo-e.m.f. effect at N-P junctions in germanium. The breadth of the forbidden band in germanium, obtained from the intrinsic region of the resistivity-temperature relationship, corresponds to about 1.75μ. Detectable responses have been found for some germanium cells as far as 1.9μ.

Measurements of the over-all quantum efficiency of this cell show that with 1.5μ radiation, current increments corresponding to 3 or 4 electrons per incident quantum are realized. The seat of this effect is believed to be a current-multiplication occurring at the collector barrier in the process of collecting the primary charge already produced photoelectrically. The above current amplification is about the same as that ordinarily observed between emitter and collector in transistors.

[1] R. Bray and K. Lark-Horovitz, Phys. Rev. **71**, 141 (1947).
[2] S. Benzer, Phys. Rev. **72**, 1267 (1947).
[3] S. Benzer, Phys. Rev. **73**, 1256 (1948).
[4] S. Benzer, Phys. Rev. **69**, 683 (1946).
[5] F. S. Goucher, Phys. Rev. **75**, 1625 (1949).
[6] J. N. Shive, Phys. Rev. **75**, 689 (1949).
[7] W. E. Kock and K. L. Wallace, Jr., Elec. Eng. **68**, 222 (1949).
[8] J. Bardeen and W. H. Brattain, Phys. Rev. **74**, 230 (1948); also H. C. Torrey and C. A. Whitmer, *Crystal Rectifiers* (McGraw-Hill Book Company, Inc., New York, 1948), Ch. X.

Neutron Induced Radioactivities in V^{52}, Mo^{99}, and W^{185}

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ON exposing specimens of vanadium, molybdenum, and tungsten to neutron capture in the Argonne and Oak Ridge piles, certain new radioactivities are found to be produced. While