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Semiconductor Radiation Detector (I)

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Abstract

A description is given of the characteristics of a semiconductor radiation detector as an alpha-paticle spectrometer. Generally a solid state counter has small rise time, good stability and small dimensions. A germanium surface barrier diode was prepared and investigated its response to alpha-particles. Then, its characteristics for temperature and humidity are shown. It was found that the germanium surface barrier diode should be used at low temperature and under dry environment.

I. Introduction

It has been well known that bombardment of radio isotopic radiation gives semiconductor its transient phenomena. It[1] has been reported that germanium surface barrier diode was suitable for alpha particles penetrating thin gold film on the surface and producing hole-electron pairs in the semiconductor. These pairs create potential variation in the barrier layer. This current produces a measurable voltage pulse which is a direct indication of alpha particle energy.

Various semiconductor detectors have been observed[2] to detect alpha particles. The object of this study is to know the operating characteristics of a surface barrier diode.

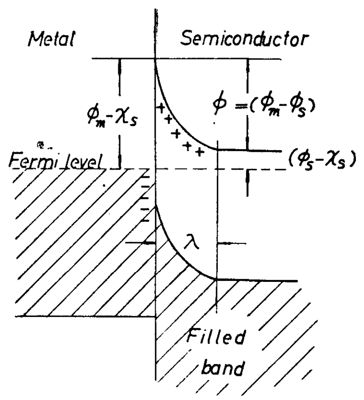

Fig. 1.
Surface barrier of n-type germanium. ϕ_m, ϕ_s are work function of metal and semiconductor, χ_s is electron affinity in semiconductor.

II. Germanium surface barrier diode

(a) Principle

Contact of metal and semiconductor forms a potential barrier. When n-type germanium of comparatively high donor concentration is contacted to gold (Fig. 1), the surface barrier in

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1) W. T. Miyao, Synossis of the lecture delivered at dhe Meeting of Nuclear Instrument Experts Group of the Institute of Applied Physics of Japan, May, 1961.

2) K. G. Mckay; Phys. Rev. **84** 829 (1951)
J. W. Mayer; J. Appl. Phys. **30** 1937 (1959)
F. J. Walter, J. W. T. Dabbs, L. D. Roberts; Rev. Sci. Instr. **31** 756 (1960)

germanium is formed to the width of the space charge region as determined from the solution of Poisson's equation,

$$\frac{d^2V}{d^2x}=\frac{4\pi\rho}{\varepsilon}, \qquad (1)$$

where ε is the static dielectric constant and ρ is the charge density, V and x are the electric potential and the distance respectively. The boundary conditions reduce to the width λ of space charge region as

$$\lambda=\left\{\frac{\varepsilon(V_o+V)}{2\pi eN}\right\}^{1/2}, \qquad (2)$$

where V is equilibrium barrier height; e, N are electron charge and donor concentration respectively. The barrier capacitance can be easily determined as

$$C=\frac{\varepsilon a}{4\pi\lambda}=\left\{\frac{a}{8\pi\rho(V_o+V)}\right\}^{1/2}, \qquad (3)$$

where a is the effective area of the detector. Thus we know that the width of space charge region depends upon the applied bias voltage. Consequently the barrier capacitance is inversely proportional to $V^{1/2}$ in the region of a few volts reverse bias.

(b) Experimental Apparatus

The surface barrier diode used in our work is shown schematically in Fig. 2. Germanium samples were cut into pellets 1 × 1 × 1 mm. The side of ohmic contact was sandblasted and solderplated with silver solder. The pellet with lead wire was encapsulated in epoxy resin, the surface of germanium being exposed. Copper ring 5 mm in diameter with the lead wire was used as capsule. After epoxy resin hardened, its sensitive side was sandblasted with No. 4, No. 6, No. 8 and lapped with Alundum No. 3000. Then, it was etched with CP-4 solution.[3] A gold film was evaporated on the surface. The gold film serves to prevent changes in the surface characteristics, as well as to provide an electrical contact with the barrier layer. Energy loss in the film was negligible for alpha particles with energy greater than 0.5 Mev, because of the thin gold film (less than 1 μ thickness). Fig. 3 shows schematically the electronic equipment used in this experiment. Some bias voltage is given to the detector with electric cell through variable resistance. ^{210}Po

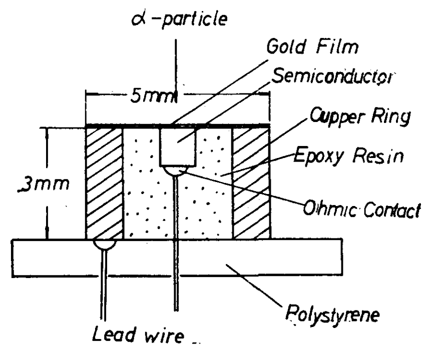

Fig. 2. Experimental sample (Ge is 5Ω-cm, 1 × 1 × 1 mm)

3) CP-4 solution; 5 parts (vol.) HNO_3, 3 parts HF, 3 parts glacial acetic acid and several drops of Br_2.

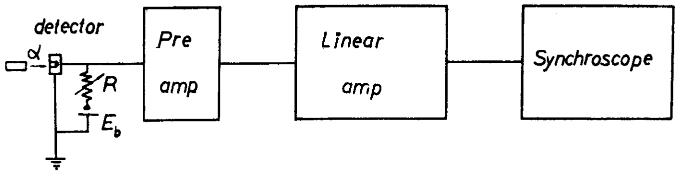

Fig. 3. Circuits diagram used in measurements.

was used as the source to provide alpha particles (5.3 Mev). The distance between the alpha source and detector was made less than 2 mm so that the alpha beam might not diverge and its energy loss in the air might be as little as possible. The amplifier with small rise time (0.2 μ sec) was chosen so as to resolve pulses from the detector. A synchroscope was used to observe the pulses.

III. Results

The pulse from amplifier was observed with a synchroscope (Fig. 4). The rise time of pulse was about 0.5 μ s. The response to alpha particles depends upon the applied bias voltage (Fig. 5), and the pulse height is proportional to $V^{1/2}$ within experimental limits. The fluctuation of pulse height was 25% at maximum value. If average energy from alpha source is constant, the barrier capacitance is inversely proportional to $V^{1/2}$. The ratio S/N was about 10. Noise increased extraordinarily with more than 1 volt bias. Thus, the equation of pulse height was determined experimentally, as

$$E_P = 6.65\, V_b^{1/2} + 9.1 \qquad (4)$$

In Fig. 5 the chain line indicates the value of it. Experiment was done at room temperature. The characteristics of germanium dependency of the surface barrier diode is shown in Fig. 6 and Fig. 7. Fig. 8 shows the characteristics at 1 volt bias. We found that the temperature for measurement should be kept below ice temperature.

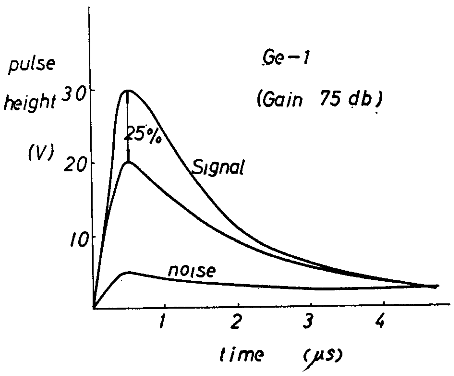

Fig. 4. Pulse forms observed with synchroscope.

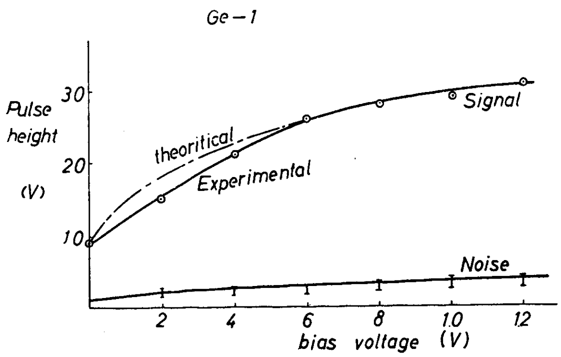

Fig. 5. Pulse heights dependency on applied bias voltages.

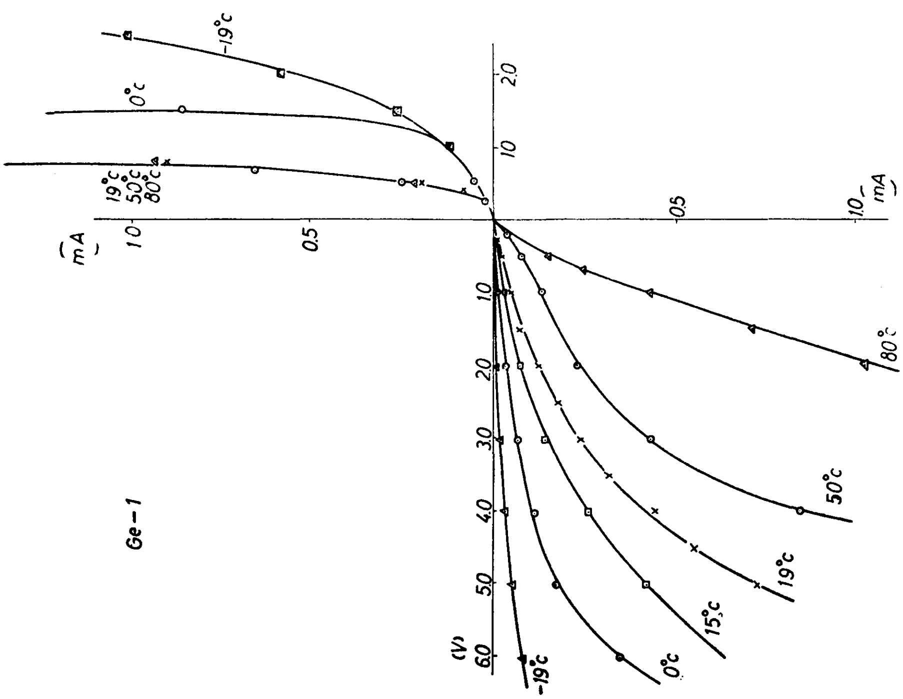

Fig. 6. Temperature dependency of Ge detector (upper ice temp.)

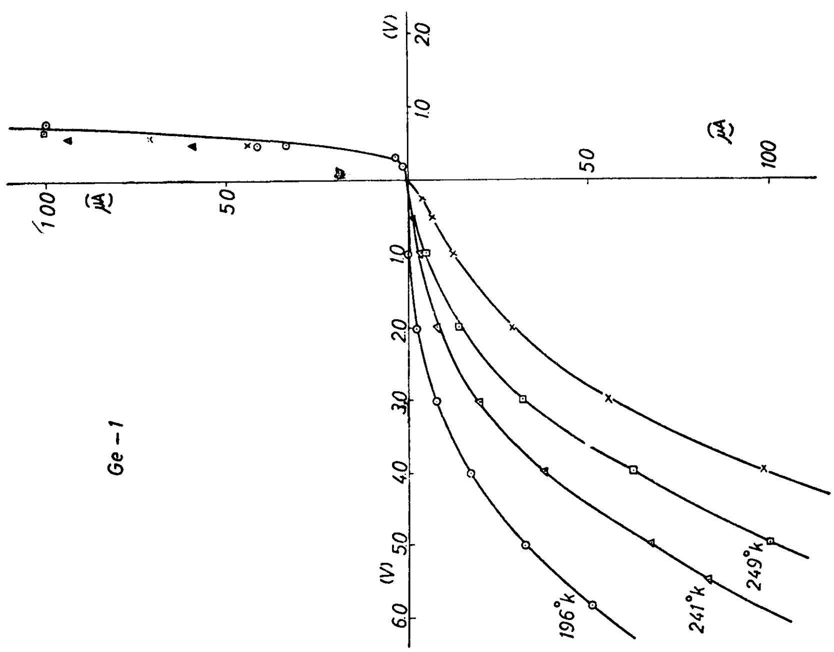

Fig. 7. Temperature dependency of Ge detector (below ice temp.)

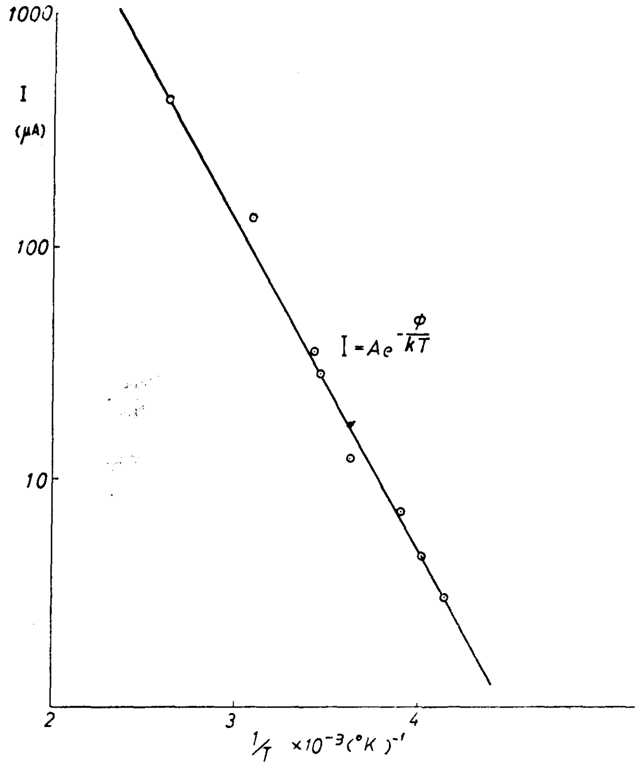

Fig. 8. Temperature dependency of Ge detector ($I = Ae^{-\frac{\phi}{KT}}$).

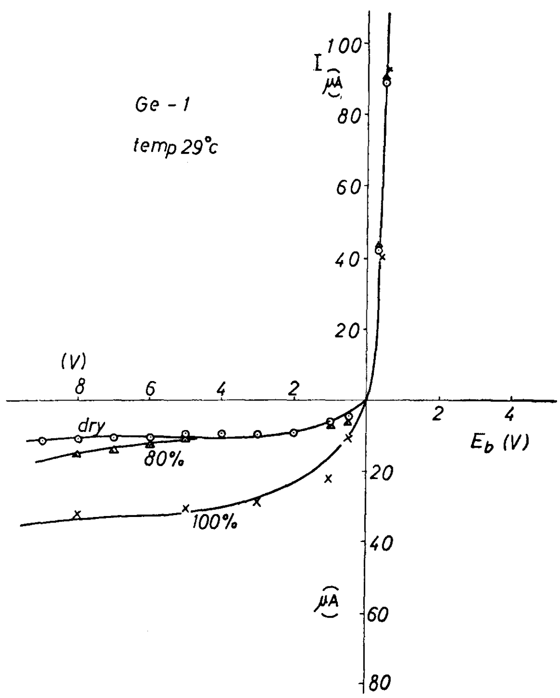

Fig. 9. Voltage-Current characteristics change with humidity.

The voltage-current characteristics changed with humidity (Fig. 3). Gold film is sensitive to humidity.

Here, I shall conider the effect of temperature upon germanium surface barrier diode. As we used *n*-type germanium, the carriers were chiefly electrons. Consequently an equation of reverse current is

$$I = Ae^{-\frac{\phi}{KT}} \quad (5)$$

where A is a constant, ϕ is the barrier height in eV and K is Boltzmann's constant. The barrier height was obtained through the gradient of log I against $1/T$ (Fig. 7). The barrier height against thermal electron at 1 volt bias was determined to be 0.84 eV.

IV. Discussion and Conclusion

The simple construction, good stability, small size and linear response to alpha particles energy of the surface barrier diode are obvious advantages in nuclear research. But it has disadvantages in that the change in experimental conditions such as temperature and humidity brings different operating characteristics. We considered that the detector could be covered with plastics etc., but the range of alpha particle is too short to allow a cover. Thus we came to the conclusion that silicon should be used in place of germanium, because silicon is better in temperature characteristics and probably in the response to alpha particles.

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