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THE DEFERMINATION OF MINORITY CARRIER DIFFUSION COEFFICIENT FROM THE C-V CHARACTERISTICS OF THE Au/Ge/Sn STRUCTURE

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ABSTRACT

We here aimed to determined the minority carrier diffusion coefficient of germanium from the capacitance -voltage characteristics of the Au/Ge/Sn Schottky diode. For the device fabrication and 10 Ohm-cm resistivity was used. The evaporation of gold and tin metals were performed under a vacuum of 10^{-5} Torr. Capacitance-voltage-frequency characteristics were measured at room temperature and liquid nitrogen temperature. We experimentally determined minority carrier diffusion coefficient as 47–57 cm^2/s by means of the diffusion capacitance concept of p/n junction which had been adapted into a Schottky barrier.

INTRODUCTION

The capacitance-voltage characteristic of some metal/semiconductor/metal structure strongly depends on frequency because of the small energy band gap (Serin, 1983). Since the diffusion potential of the minority carriers is small they easily diffuse into the semiconductor bulk. The diffusion of minority carriers causes to rearranging of the charge distribution within the depletion layer. The capacitance of the structure, especially for forward biases, increases strongly with increasing voltage and decreases with increasing frequency. This excess capacitance is explained by means of the diffusion concept of the minority carriers. It is the so-called diffusion capacitance. In this case, the measured capacitance of a metal/semiconductor/metal structure consists of diffusion capacitance, depletion capacitance and geometrical capacitance (Scharfetter, 1965).

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The comparison which bases on D.L. Scharfetter's paper (Scharfetter, 1965) showes that the minority carrier injection ratio of germanium is approximately 10^3 times and $2x10^4$ times greater than the minority carrier injection ratio of silicon for low and high injection conditions respectively. (Yu, 1969), (Green, 1973). The reason for this is largely due to the small energy band gap of germanium. The strong temperature and frequency dependence normally disqualifies germanium for device applications.

Here we aimed to determine the minority carrier diffusion coefficient of germanium by means of capacitance-voltage-frequency characteristics of the Au/Ge/Sn Schottky diode in the same manner as followed for Au/Ge/Sb structure (Serin, 1985). In order to clarify the influence of the minority carriers on the characteristics we carried out the measurements for various frequencies. We found that our experiments followed closely the diffusion capacitance theory (Serin, 1977).

EXPERIMENT

A piece of n-type germanium single crystal (thickness 85 μm) having 10 Ohm-cm resistivity and <111> direction was chemically cleaned. The sample was placed on the fiber holder by means of araldite. A gold rectifing contact and a tin ohmic contact were applied to the crystal.

Capacitance-voltage measurements were carried out at room temperature. In order to exclude the influence of the diffusion capacitance, for the reverse biases, a measurement was also performed at liquid nitrogen temperature (Serin, 1982), (Serin, 1983). For the experiments the following equipment was used; Wayne Kerr Radio Frequency Bridge, SR268 Wayne Kerr Source and Dedector, Keitheley's Digital Electrometer. For the measurement at liquid nitrogen temperature, the device was inserted in to a closed and evaculated glass tube and plunged into liquid nitrogen. Measurements were taken two hours later in order to establish thermal equilibrium. We observed that the capacitance of Au/Ge/Sn structure generally increased at low temperature and decreased with increasing frequency. At forward bias, (gold positive and tin negative), capacitance first increased then decreased and approached to zero. At reverse biases, it monotomically decreased and then approached to the geometrical capacitance figure 1–2.

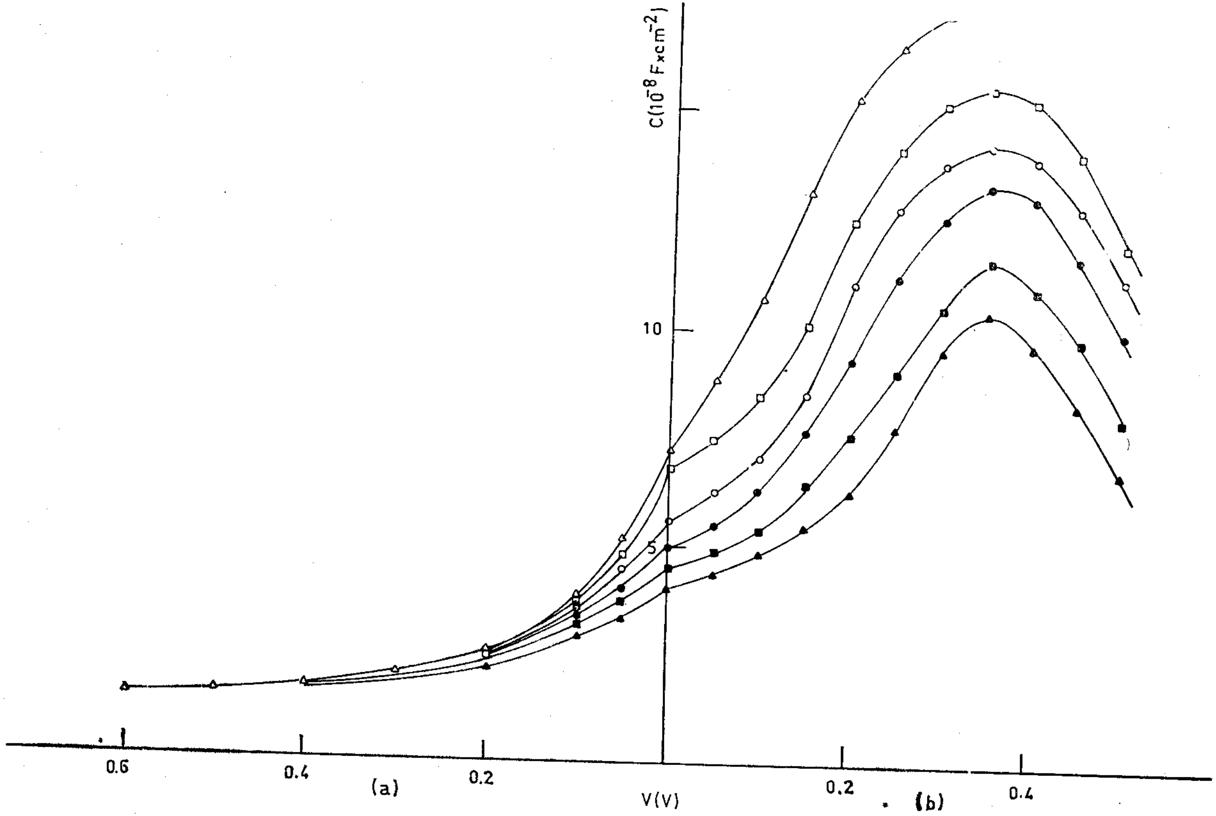
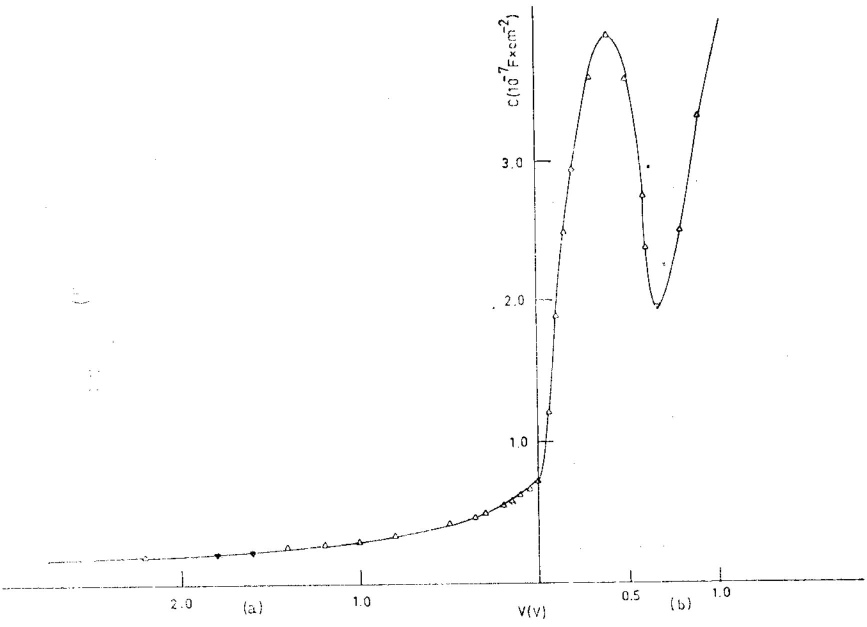


Figure 1. Capacitance-Voltage characteristics for several values of frequency. f(KHz): △500, □650, ⊙1100,1 ● 600, ■2000, ▲2500. Bias: (a) (—) Au/Ge/Sn (+); (b) (+) Au/Ge/Sn(—).



Figur 2. Capacitance-Voltage characteristics for liquid nitrogen temperature. f(kHz): △500. Bias: (a) (—) Au/Ge/Sn(+); (b) (+) Au/Ge/Sn(—).

THEORY

Under the some circumstances minority carriers of a semiconductor can create an additional capacitance in the rectifier contact. It is the so-called the diffusion capacitance. It is due to the rearrangement of minority carriers within the depletion layer. The small band gap of a semiconductor is largely responsible for the diffusion capacitance. It is of particular significance for a semiconductor such as germanium (Neuberger, 1966). For the high frequency limit (Sze, 1969) diffusion capacitance is given by

$$C_d = \frac{e^2 \sqrt{D_p} p_{no} \exp(eV/kT)}{\sqrt{2\pi f}\, kT} \tag{1}$$

where e, D_p, p_{no}, V, k, T, f are electronic charge, the hole diffusion coefficient, hole density in n-type semiconductor, voltage, Boltzmann's constant, absolute temperature and frequency respectively.

When a metal makes a rectifier contact with a semiconductor a depletion layer capacitance also occurs in contact region. It depends on the voltage and its polarity. It is given by

$$C_s = \left[\frac{e\varepsilon\varepsilon_0 N_d}{2(V_d - V)}\right]^{1/2} \tag{2}$$

where V_d, N_d, ε, ε_0, are the diffusion potential, donor density, semiconductor permittivity, free space permittivity respectively (Goodman, 1962).

RESULT AND DICCUSSION

The characteristics indicated that the equivalent capacitance of the Au/Ge/Sn structure was equal to

$$C_t = C_d + C_s + C_g \tag{3}$$

the parallel combination of the diffusion capacitance C_d, Schottky capacitance C_s and geometrical capacitance C_g. Figure 3–4.

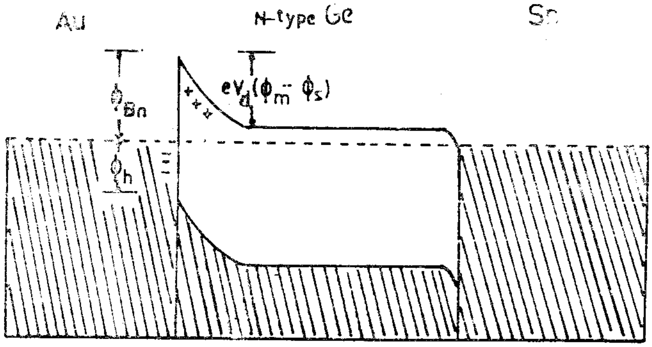


Figure 3. The energy-band diagram of Au/Ge/Sn structure.

When equation (1), equation (2) and the value of geometrical capacitance $C_g = \varepsilon\varepsilon_0/L$ are substitued in equation (3) a general expression for the total capacitance

$$C_t = \frac{e^2\sqrt{D_p} p_{no} \exp(eV/kT)}{\sqrt{2\pi f}\, kT} + \left[\frac{e\varepsilon\varepsilon_0 N_d}{2(V_d - V)}\right]^{1/2} + \frac{\varepsilon\varepsilon_0}{L} \tag{4}$$

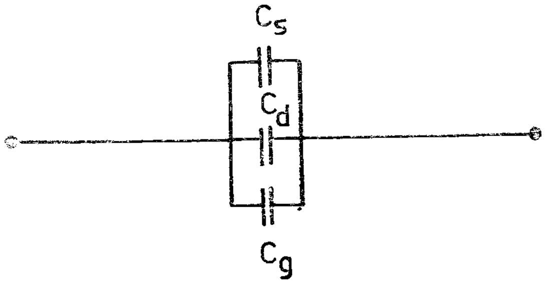


Figure 4. The equivalent capacitance of Au/Ge/Sn Structure.

is obtained. Where L is the thickness of semiconductor. Equation (4) generally relates voltage-temperature-frequency characteristics of the Au/Ge/Sn structure. For reverse biases the first term decreases exponentially with increasing voltage and leaves the second and third terms. As the voltage is increased, second term becomes smaller than the third and later approaches to the geometrical capacitance. For sufficiently small forward biases the first term of equation (4) is highly dominant. For moderate biases, the second term also begins to contribute to the first term. Capacitance of the structure nearly increases exponentially. We also observed that capacitance exponentially increased with increasing voltage, especially for smal frequencies and biases. For larger frequencies exponential region was narrow. Capacitance showed a maxima then approached to zero due to the series resistance effect of the semiconductor (Wiley, 1975).

For reverse bias of 0.05 Volt and for the liquid nitrogen temperature the first term of equation (4) is approximately equal to $1.1.\mathrm{x}10^{-10}$ F/cm^2. The Schottky capacitance and the geometrical capacitance are $6.8\mathrm{x}10^{-9}$ F/cm^2 and $2.8\mathrm{x}10^{-10}$ F/cm^2 respectively. So sufficiently large reverse biases the first and third terms of equation (4) are negligible. Equation (4) is reduced into equation (2). When it was solved for C^{-2}

$$\frac{1}{C^2} = \frac{2V}{e\varepsilon\varepsilon_0 N_d} + \frac{2V_d}{e\varepsilon\varepsilon_0 N_d} \tag{5}$$

is obtained.

The plotting of C^{-2} versus V we obtained a straight line which followed equation (5). Figure 5. The V axis interception and its slope

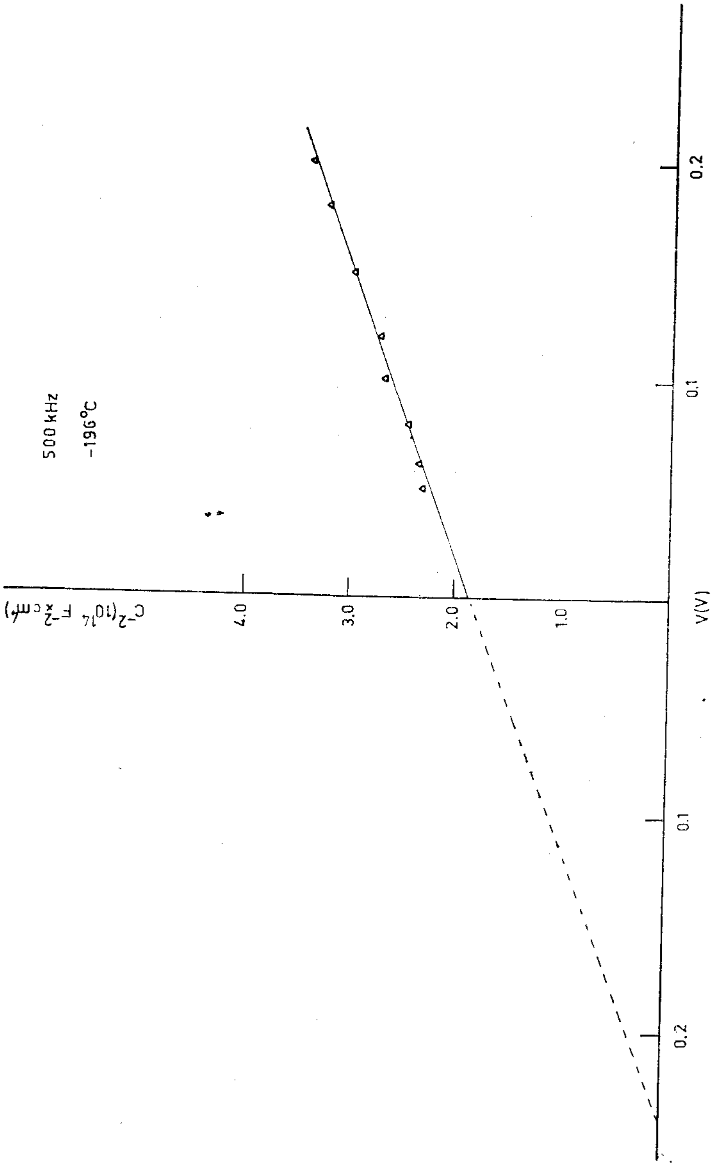


Figure 5. Capacitance-voltage characteristics: C^{-2} versus V. Bias: (—) Au/Ge/Sn(+). Frequency: △500 KHz.

gave the diffusion potential $V_d = 0.240$ eV and donor density $N_d = 1.2 \times 10^{14}$ cm^{-3}. We saw that the value of the donor density was very close to the value of 1.6×10^{14} cm^{-3} calculated from the resistivity equation $\rho = 1/(en\mu)$.

In order to obtain the diffusion capacitance only, for forward biases, we theoretically calculated the depletion capacitance C_s by means of donor density and diffusion potential which were determined from the liquid nitrogen capacitance-voltage characteristic. In order to obtain the diffusion capacitance C_d only we subtracted the depletion capacitance C_s and the geometrical capacitance C_g from the measured capacitance due to equation (3).

The lifetime of minority carriers in germanium and the lowest frequency of the measurement are 10^{-3} s. and 500 KHz respectively. Then the value of $2\pi f \tau_p$ is equal to 3141 which provides the high frequency limit (Sze 1969) and allowes to use equation (1). It is written in the form of

$$\mathrm{Ln}(C_d T) = \frac{e}{kT} V + \mathrm{Ln}\left[\frac{e^2 \sqrt{D_p} p_{no}}{(2\pi f)^{1/2} k}\right] \tag{6}$$

When we plotted $\mathrm{Ln}(C_d T) = \mathrm{Ln}\,[\,[C_t - (C_s + C_g)]\,T\,]$ versus V we obtained the straight lines for 500, 650, 1100, 1600, 2000, 2500 KHz frequencies. Figure 6. The density of minority carrier p_{no} was found from $n.p = n_i^2$ and substituted in $\mathrm{Ln}\,[e^2 \sqrt{D_p}\, p_{no}/(2\pi f)^{1/2} k]$ which was intercept of $C_d T$ axis. The minority carrier diffusion coefficent D_p was determined as follows 47, 49, 50, 55, 58 cm^2/s. They were quite close to the known value of 44 cm^2/s and our previous research (Goucher, 1951), (Serin, 1985).

When we compare the values of the minority carrier diffusion coefficient with each others we saw a shift with increasing frequency. For 500 KHz the first term of equation (4) is highly greater than the others and it decreases with increasing frequency. When the frequency is increased, the first term of equation (4) rapidly decreases and approaches to the depletion capacitance. Thus experimental errors in the value of donor density N_d and diffusion potential V_d becomes more effective.

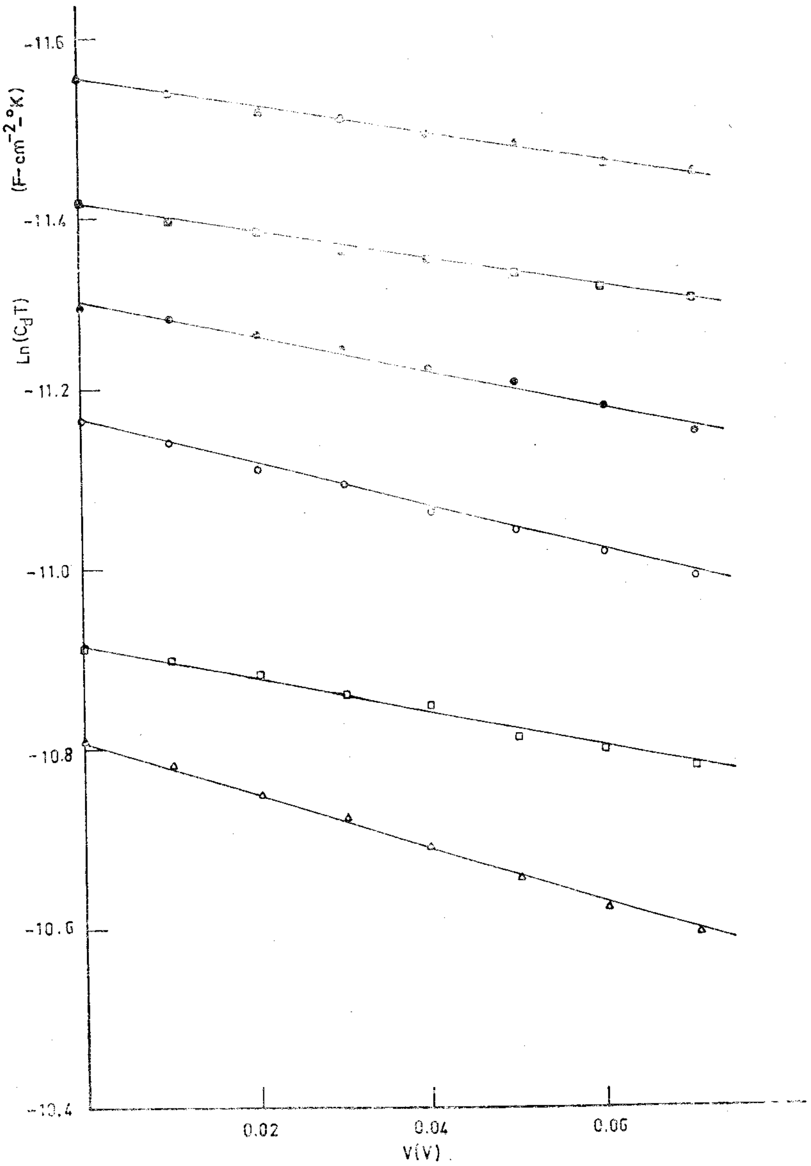


Figure 6. Ln(C_0T) versus V. f(KHz): △500, □650, ⊙1100, ●1600, ■2000, ▲2500. Bias: (+) Au/Ge/Sn (—).

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