

Experimental Examinations of Electrical Properties of Germanium Semiconductor by Use of Hall Effect

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ABSTRACT

Making use of the Hall Effect, we have studied some electrical properties of Germanium semiconductor, which is doped with a little impurity Arsenic, in this experiment. The energy gap E_g and the kind of the carrier in the crystal are determined. The exponential dependence of the conductivity of the crystal on temperature is also measured. In addition, the temperature ranges for the intrinsic region and for the extrinsic region are searched in this paper.

The energy bands for an insulator, metal, and semiconductor are different. A pure semiconductor (such as Germanium) becomes an insulator at about absolute zero. At a finite temperature, the property of conductivity of the semiconductor reveals with the thermal excitation of conduction band. Furthermore, as an impurity (such as Arsenic) is doped into the semiconductor, the energy level figure changes. At low temperature, the doped semiconductor will be an extrinsic semiconductor. However, for high temperature range, (say, $T \geq 300^\circ\text{K}$), the impurity carriers are almost in the conduction band and the semiconductor acts an intrinsic semiconductor.

The Hall Effect is a good measurement tool to determine the energy gap of the semiconduc-

tor and the carrier concentration of the semiconductor. Theoretical studies give the relation between the Hall voltage V_H and the carrier concentration n . We also have the exponential dependence of the resistivity of the semiconductor on temperature T as a current source is applied to the semiconductor crystal in a homogeneous magnetic field. We can find this relation from the experimental data. In addition, the energy gap of the semiconductor is calculated by the relation between the resistance R and temperature T . The kind of the carriers in our sample is determined to be electrons as expected.

THEORY

I. Semiconductor of Germanium doped with

Arsenic

(1) semiconductor

A semiconductor is a crystalline solid in which the conduction band lies close to the valence band, but is not populated at low temperature. In a semiconductor, both electrons and holes are responsible for the properties of conductivity. For a pure crystal semiconductor, raising an electron from the valence band to the conduction band will leave a hole in the valence band. Thus, the concentration p of holes (positive carriers) is equal to the concentration n of free electrons (negative carriers). In this case, p and n are called the intrinsic carriers. However, for most semiconductor materials, there is a certain amount of impurities in them. The impurities can either donate electrons to the conduction band (making an n-type crystal) or accept electrons from the valence band to create holes in it (making a p-type crystal). These impurities are called extrinsic carriers. In this case, $n \neq p$.

(2) Semiconductor energy band structure

Quantum-mechanically, due to the interaction of the conduction electron wave of the atoms in a crystal with the periodic ioncores of the crystal, the distinct energy levels of the electrons split into bands. The energy band for which no wavelike electron orbitals exist are called forbidden bands. The allowed bands in which the electrons have higher energies and contribute to the conductivity are called conduction bands. The other allowed bands in which the electrons have lower energies and are unmovable are called valence bands. The energy difference between the lowest point of the conduction band (conduction band edge) and the highest point of the valence band (valence band edge) is called the forbidden gap energy E_g . An electron

band scheme leading to intrinsic conductivity is indicated in Fig. 1

For semiconductor, the conduction band is vacant at 0°K and is separated by a moderate energy gap E_g (for example, 0.744 eV for Germanium crystal) from the filled valence band. Hence, there is no contribution to conduction from either bands. In this situation, the semiconductor acts like an insulator. As temperature is increased, however, many electrons are thermally excited from the valence band into the conduction band due to the small energy gap E_g . Both the electrons in the conduction band and the vacant orbits or holes left behind in the valence band contribute to electrical conductivity.

(3) Semiconductor of Germanium doped with Arsenic⁽¹⁾

Germanium is one of Group IV in the Periodic Table. When Ge atoms are brought together, they form a covalent bond with each other with four atoms in each unit cell. If we dope Ge with the impurity Arsenic (one of Group V), we see that, in As-atom, four of its five valence electrons are shared by four neighboring Ge-atoms, and its fifth valence electron is almost free. Therefore, simply by Bohr's model, this extra electron should have hydrogen-like energy levels E_n in the forbidden band due to the periodic potential $V = -\frac{e_2}{\epsilon r}$ of the Ge-atoms.

E_n can be shown as

$$E_n \cong -\left(\frac{m_e^* e^4}{2\epsilon^2 \hbar^2}\right) \frac{1}{n^2} \quad (1)$$

where m_e^* is the effective mass of the free electron in a perturbed field. For $n = 1$, $E \cong 0.01$ eV. So, E_n is a very small quantity below zero, where zero means that the free electron is just at the bottom of the conduction band⁽²⁾. This is shown

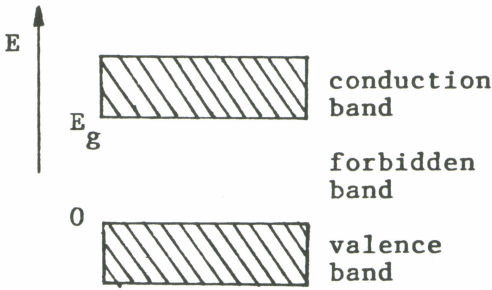


Fig. 1 Band scheme for intrinsic conductivity in a semiconductor.

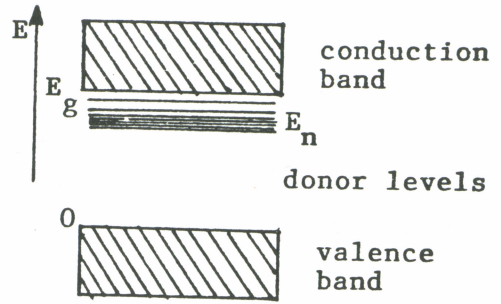


Fig. 2 A donor level in the gap between valence and conduction bands of a semiconductor.

in Fig. 2. Hence, the effect of the embedded As-atom in the crystal of pure Ge is to introduce additional levels at energies between the top of the valence band and the bottom of the conduction band.

II. Electrical conductivity of the semiconductor^(1,3)

(1) Fermi-Dirac distribution

In semiconductors, the thermal excitation of electrons from the valence band into the conduction band can be calculated by using Fermi-Dirac distribution since the electrons in the conduction band or the holes in the valence band, which are all away from the edges of the allowed bands, are quite free. The Fermi-Dirac distribution gives the probability that a free electron gas in thermal equilibrium at temperature T has an orbital at energy E:

$$f(E) = \frac{1}{e^{(E-E_F)/kT} + 1} \quad (2)$$

where E_F is called the Fermi energy which is defined as the electron energy of the topmost filled orbital at $T=0^\circ\text{K}$ (at $T=0^\circ\text{K}$, $f(E < E_F) = 1$). E_F is also equal to the value of the chemical potential of a semiconductor. We see that $f(E = E_F) = 1/2$. This means that the chemical potential of a semiconductor almost always lies in the energy gap. Let the energy level of the top of

the valence band be ϵ_v and the energy level of the bottom of the conduction band be ϵ_c . Then $E_g = \epsilon_c - \epsilon_v$.

Since every conduction band level exceeds ϵ_c and every valence band level is less than ϵ_v , and $(\epsilon_c - E_F) \gg kT$, $(E_F - \epsilon_v) \gg kT$, we have

$$f_c(E) = \frac{1}{e^{(E-E_F)/kT} + 1} \approx e^{-(E-E_F)/kT}, \quad (E > \epsilon_c) \quad (3)$$

$$\text{and } f_v(E) = \frac{1}{e^{(E-E_F)/kT} + 1} \approx e^{-(E-E_F)/kT}, \quad (E > \epsilon_v) \quad (4)$$

(2) Number of carriers in thermal equilibrium

Since conduction is entirely due to electrons in conduction band level or holes in valence band levels, regardless of the concentration of impurities, the number n_c of electrons per unit volume in the conduction band at temperature T will be given by

$$\begin{aligned} n_c(T) &= \int_{\epsilon_c}^{\epsilon_c + T} dE g_c(E) f_c(E) \\ &= \int_{\epsilon_c}^{\infty} dE g_c(E) e^{-(E-E_F)/kT} \\ &= \left\{ \int_{\epsilon_c}^{\infty} dE g_c(E) e^{-(E-\epsilon_c)/kT} \right\} e^{-(\epsilon_c - E_F)/kT} \end{aligned} \quad (5)$$

and similarly, the number p_v of holes per unit volume in the valence band at temperature T will

be given by

$$p_v(T) \approx \left[\int_{-\infty}^{\epsilon_v} dE g_v(E) e^{-(\epsilon_v - E)/kT} \right] e^{-(E_F - \epsilon_v)/kT} \quad (6)$$

, where $g_c(T)$ and $g_v(T)$ are respectively level densities in the conduction band and in the valence band, which can be shown to be

$$g_c(E) = \frac{1}{2\pi^2} \left(\frac{2m_e^*}{\hbar^2} \right)^{3/2} (E - \epsilon_c)^{1/2} \quad (7)$$

$$\text{and } g_v(E) = \frac{1}{2\pi^2} \left(\frac{2m_h^*}{\hbar^2} \right)^{3/2} (\epsilon_v - E)^{1/2} \quad (8)$$

Inserting Eq(7) into Eq(5), and Eq(8) into (6), we have

$$n_c(T) \approx 2 \left(\frac{m_e^* kT}{2\pi\hbar^2} \right)^{3/2} e^{-(\epsilon_c - E_F)/kT} \quad (9)$$

$$\text{, and } p_v(T) \approx 2 \left(\frac{m_h^* kT}{2\pi\hbar^2} \right)^{3/2} e^{-(\epsilon_v - E_F)/kT} \quad (10)$$

Therefore, we get the law of mass action

$$n_c p_v = 4 \left(\frac{kT}{2\pi\hbar^2} \right)^{3/2} (m_e^* m_h^*)^{3/2} e^{-(\epsilon_c - \epsilon_v)/kT} \\ = 4 \left(\frac{kT}{2\pi\hbar^2} \right)^{3/2} (m_e^* m_h^*)^{3/2} e^{-E_g/kT} \quad (11)$$

Eq (11) means that, at a given temperature T , it suffices to know the density of one carrier type to determine that of the other.

(i) For an intrinsic semiconductor

In the intrinsic case (in doped material), conduction band electrons can only have come from formally occupied valence band levels, leaving holes behind them. Thus,

$$n_c(T) = p_v(T) = n_i(T)$$

From Eq (11), we have

$$n_i(T) = 2 \left(\frac{kT}{2\pi\hbar^2} \right)^{3/2} (m_e^* m_h^*)^{3/4} e^{-(E_g/2kT)} \quad (12)$$

Thus, it should be expected that, as the temperature is raised, the intrinsic carriers of a semiconductor will increase by $\exp(-E_g/2kT)$. This temperature is usually very high since $E_g = 0.7$ eV for Germanium. Also, if we set Eq(9) to be equal to Eq(10), we obtain

$$E_F = \frac{1}{2} E_g + \frac{3}{4} kT \ln(m_h^*/m_e^*) \quad (13)$$

This asserts that as $T \rightarrow 0^\circ K$, $E_F \rightarrow \frac{1}{2} E_g$, and the Fermi level of an intrinsic semiconductor is in the middle of the forbidden gap.

(ii) For an extrinsic (doped) semiconductor

When a Germanium crystal is doped with a little Arsenic, we see that the dominant carriers are electrons. Thus $n_c \gg p_v$. This means that this kind of semiconductor is n-type.

The properties of an extrinsic Ge semiconductor are obviously determined by the impurity Arsenic, especially at low temperature, since very few electrons of Ge atoms are populating the conduction band. At low temperature, the number of electrons in the conduction band is given by

$$n_c = N_d \left(\frac{2m_e^* kT}{2\pi\hbar^2} \right)^{3/2} e^{-E_d/2kT} \quad (14)$$

where $E_d = |E_1| = \frac{m_e^* e^4}{2\epsilon^2 \hbar^2}$ in Eq(11), which is

the separation of the donor energy level from the conduction band. Since $E_d = 0.01$ eV, and $kT \approx 0.01$ eV for $T = 120^\circ K$, we see that most of the

electrons will be in the conduction band at $T \gtrsim 120^\circ K$. So, in this situation, $n = N_d$, the concentration of Arsenic atoms, i.e. the number of electrons becomes saturated in the conduction band and these electrons behave like the free electrons of a metal at low temperature.

(3) Electrical conductivity σ and resistivity ρ

We know that conduction in solid is due to the motion of the charge carriers under the influence of an applied E -field. The drift velocity of the carrier can be simply found to be proportional to E , the field strength, according to the equation $V_d = \mu E$, where the proportionality μ is

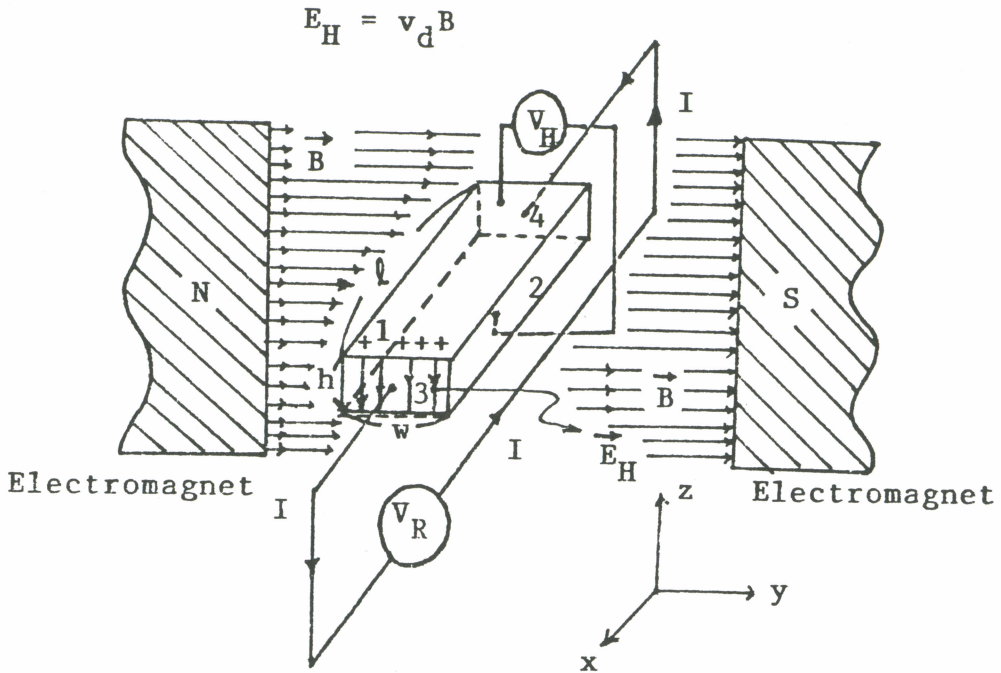


Fig. 3 The experimental geometry for the Hall Effect.

called mobility of the carrier. If the carriers have concentration n and charge e , the current density

$$j = di/dt = dq/(dtdA) = d(edN)/dtdV = nev \quad (15)$$

, where $n = dN/dV$, and $v_d = dl/dt$. By Ohm's law, $j = \sigma E$, where σ is the conductivity, we have

$$j = \sigma E = nev_d \quad (16)$$

Thus, $\sigma = ne\mu$.

(i) For intrinsic semiconductor⁽⁴⁾

We see that σ should be written as

$$\sigma(T) = e(n_e \mu_e + n_h \mu_h) = ene(\mu_e + \mu_h)$$

Since $n_e = n_i$, from Eq(12), we have

$$\sigma(T) = 2e \left(\frac{kT}{2\pi\hbar^2} \right)^{3/2} (m_e^* m_h^*)^{3/4} e^{-E_g/2kT} (\mu_e + \mu_h)$$

Therefore,

$$\log \sigma(T) = -\frac{E_g}{2kT} + \frac{3}{2\log T} + \log 2e(\mu_e + \mu_h) \left(\frac{k}{2\pi\hbar^2} \right)^{3/2} (m_e^* m_h^*)^{3/4}$$

The resistivity ρ is defined as $\rho = 1/\sigma$. Thus,

we obtain $\log \rho(T) = -\log \sigma(T)$

$$= \frac{E_g}{2kT} - \frac{3\log T}{2} - \log 2e(\mu_e + \mu_h) \left(\frac{k}{2\pi\hbar^2} \right)^{2/3} (m_e^* m_h^*)^{3/4} \quad (18)$$

Since $\log T$ varies very slowly, we see, from Eq(18), that $\log(T)$ will be approximately to $1/T$. This property can be found by plotting $\log \rho(T)$ vs. $(1/T)$. The straight line will have a slope of $E_g/2k$ and then E_g can be determined.

(ii) For Extrinsic semiconductor⁽³⁾

A simple calculation for an electron gas in an applied E-field can find that $\sigma(T) = ne\mu = c' \frac{ne^2}{m_e^*} T^{-3/2}$ (19)

, where c' is a constant. At low temperature (the extrinsic region), because the number n of the electrons is almost constant, we see that the resistivity ρ of an extrinsic semiconductor will be proportional to $T^{3/2}$. Thus, we have

$$\log \rho = \frac{3}{2} \log T + c \quad (20)$$

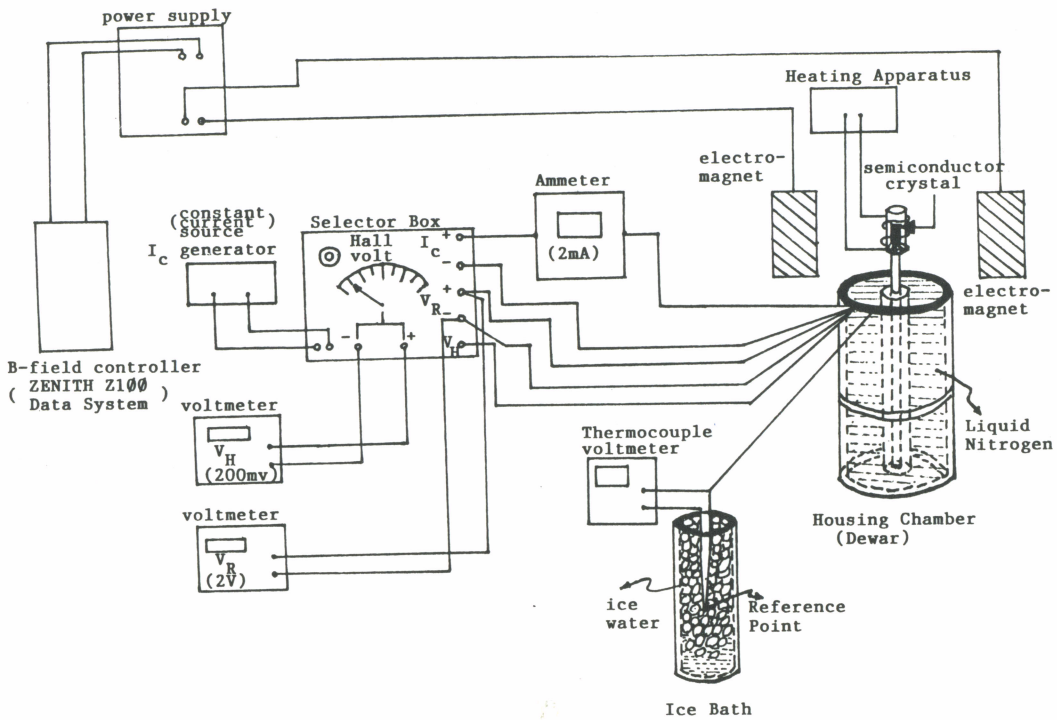


Fig. 4 Experimental Apparatus

Where c is a constant. Therefore, plotting $\log \rho$ vs. $\log T$ will get a straight line of slope $3/2$.

III. Experimental Determination of E_g , n , and exponent of power law⁽⁵⁾

(1) Determination of n

From Eq(17), we see that the concentration n of electrons is related with the current density flowing through the semiconductor sample. We also see, from Eq(19), that E_g can be determined by measuring the resistivity ρ of the sample. However, n and E_g can be experimentally obtained from Hall Effect measurement. Consider a Germanium semiconductor sample, which is doped with a little Arsenic, of length l , width w , and thickness h . This sample is mounted in a uniform magnetic field \vec{B} in the y direction as shown in Fig. 3. If a current with constant current density

$\vec{j} = j \hat{x}$ is flowing through the sample in the x direction by application of a voltage V_R between contacts 3 and 4, the Lorentz force $\vec{F} = -e \vec{v}_d \times \vec{B}$ will deflect the conducting electron in the $-z$ direction (downward). But, the electrons can not move very far in the $-z$ direction before running down against the side of the sample. As they accumulate there, an electric field, called Hall field \vec{E}_H , builds up in the $-z$ direction. At equilibrium, this field will balance the Lorentz force, and the current will flow only in the x direction. Since we originally set the direction of the drift velocity of the electrons to be perpendicular to the applied \vec{B} -field, we see that, at equilibrium,

$$-e v_d B = -e E_H,$$

$$\text{or } E_H = V_d B \tag{21}$$

From Eq(17), we have $v_d = \frac{j}{ne}$. So, $E_H =$

$\frac{jb}{ne} = \left(\frac{IB}{hwn}\right)$. The Hall voltage V_H is given by

$V_H = hE_H$. Thus, we get

$$V_H = \frac{IB}{wne} \quad (22)$$

Hence, for fixed magnetic field B and fixed input current I, the Hall voltage is proportional to $1/n$, or V_H will be proportional to $T^{-3/2} \exp(E_g/2kT)$ from Eq(12). By Eq(22), we see that the sign of V_H will give the information about the kind of carriers, electrons or holes. Furthermore, if I, B, and w are known, the carrier concentration can be determined by the measurement of V_H .

(2) Determination of E_g

We know that the resistance R across the contacts 3 and 4 in Fig. 3 can be expressed as $R = \rho \ell / A = \rho \ell / hw$, where ρ is the resistivity.

According to Ohm's law, we have $V_R = IR = \frac{I \ell}{hw}$

$$(23)$$

Thus, V_R is proportional to ρ . Since $\rho = \rho(T)$, a function of temperature T, we see that $V_R = V_R(T)$, a function of temperature T, also. Using Eq(19), we have

$$\log V_R(T) = \log \rho(T) + \log (I \ell / hw)$$

$$= \frac{E_g}{2kT}$$

$$- \frac{3}{2} \log T - \log [2e(\mu_e + \mu_h) \left(\frac{k}{2\pi\hbar^2}\right)^{2/3} (m_e^* m_h^*)^{3/4}] + \log \left(\frac{I \ell}{hw}\right). (24)$$

Hence, if the current I is kept constant in the experiment, we have $\log V_R(T) \propto 1/T$. By plotting $\log V_R(T)$ vs. $(1/T)$, the slope of the straight line will give the value of E_g . Or, from Eq(24), $\log R(T)$

$$= \frac{E_g}{2kT} - \frac{3}{2} \log T - \log [2e(\mu_e + \mu_h) \left(\frac{k}{2\pi\hbar^2}\right)^{2/3} (m_e^* m_h^*)^{3/4}] + \log \left(\frac{I \ell}{hw}\right)$$

$$. (25)$$

By plotting $\log R(T)$ vs. $(1/T)$, the value of E_g can be also determined by the slope of the straight line.

(3) Determination of the exponent of power law $\rho \propto T^{3/2}$

Since $R \propto \rho$ for fixed semiconductor crystal dimension, we will see that $\log R = \log \rho + c_1$, where c_1 is a constant. Therefore, $\log R(T)$ can be expressed as

$$\log R(T) = \frac{3}{2} \log T + c_2$$

, where c_2 is a constant. Plotting $\log R$ vs. $\log T$ can obtain the exponent 3/2 of the power law $\rho \propto T^{3/2}$.

EXPERIMENTAL PROCEDURE

The following steps were taken to perform in this experiment.

1. Connect the equipment as shown in Fig. 4.
2. Fill an insulated bottle with a mixture of ice and water. Insert the reference end of the thermocouple, which will be used to measure the temperature of the semiconductor crystal sample used in this experiment, into the ice bath. Keep the reference point at 0°C.
3. Turn on the connected meters shown in Fig. 4.
4. Adjust the constant current source flowing through the sample at 1mA. Then turn on the magnetic field, which was controlled by a "ZENITH Z100, DATA SYSTEM".
5. Rotate slowly the crystal until the Hall voltage showing on the voltmeter obtains the largest value. (This step is to make sure that the Lorentz force acting on the electron has the maximum magnitude of $ev_d B$.)
6. Heat the crystal to a temperature of about 100°C (373°K). It is usually necessary to use a

heating coil to reach this point. As this point is reached, turn off the heating apparatus and allow the crystal to cool down to about 140°K by filling the dewar, which mounts the crystal in its cavity, with liquid nitrogen.

7. When the temperature of the sample was decreased, at every 5°C (5°K) interval starting at 373°K, record (a) the crystal temperature from the thermocouple voltage using the conversion chart; (b) the voltage V_R across the internal resistance R of the crystal; (c) the Hall voltage V_{H1} when \vec{B} -field is absent; and (d) the Hall voltage V_{H2} when \vec{B} -field is applied on the crystal.

8. From the data recorded in step 7, plot (a) Resistance R vs. Temperature T ; (b) Hall Voltage V_H vs. Temperature T , where $V_H = V_{H2} - V_{H1}$; (c) $\log R$ vs. $\log T$; and (d) $\log R$ vs. $1/T$.

CONCLUSION AND DISCUSSION

We see, from the figure of $\log R$ vs. $1/T$ (see Fig. 9) that the extrinsic region for our Germanium semiconductor is the range for $T < 293^\circ K$, where conduction will be mainly due to the extra electrons of the Arsenic atoms. The region for $T > 293^\circ K$ is the intrinsic region where conduction is due to the electrons of the Germanium atoms which are transferred thermally from the valence band to the conduction band. In the intrinsic region, we see that $\log R$ is indeed proportional to $1/T$ with a positive slope as Eq(25) expected. Calculation of this slope leads to the gap energy E_g of the Germanium semiconductor crystal.

$$\frac{E_g}{2k} = \frac{\Delta(\log R)}{\Delta(1/T)} = \frac{4.4588 - 4.1441}{0.002833 - 0.002755} = 4034.615(^{\circ}K)$$

Taking the Boltzmann constant $k = 1.381 \times 10^{-23}$

j/K , we obtain $E_g = 0.696$ ev, which is close to the previous measured value 0.66 ev.⁽⁶⁾ From the figure of $\log R$ vs. $\log T$ (see Fig. 8), we see that, in the extrinsic region, $\log R$ is proportional to $\log T$ with a positive slope as Eq(20) expected. For $T < 293^\circ K$, the slope of the straight line is given by

$$\frac{\Delta(\log R)}{\Delta(\log T)} = \frac{5.500 - 4.673}{5.450 - 5.000} = 1.84$$

which is very close to $\frac{3}{2} = 1.5$. The difference is mainly due to the simple derivation for Eq(19). Thus, we have the power law: $\rho(T) \propto T^{1.84}$, or $\sigma(T) \propto T^{-1.84}$.

By the figure of Hall voltage $V_H(T)$ vs. Temperature T (see Fig. 7), we find that the magnitude of $V_H(T)$ decreases as T increases. This phenomenon can be explained by the property that $V_H(T)$ is proportional to $T^{-3/2} \exp(E_g/2kT)$ for fixed magnetic field B and fixed input current. Since $V_H = 0$ as $B = 0$ (the magnetic field is turned off), the measuring of V_H on the voltmeter should always be properly zeroed when the magnetic field is off. But, the actual measurements showed that $V_H \neq 0$ as $\vec{B} = 0$. The mainly probable reason might be due to the fact that the contacts of our Germanium semiconductor crystal sample are not quite opposite to each other. This results in a potential gradient between the contacts due to the input current.⁽⁵⁾ Hence, we should take the values of V_H as $V_H = V_H(\vec{B} \text{ on}) - V_H(\vec{B} \text{ off})$. The peaks appearing in Fig. 7 at temperatures $T = 228^\circ K$, $178^\circ K$, and $143^\circ K$ are due to the instability of the Hall voltage V_H and the temperature of the Germanium semiconductor crystal sample. They happened as we poured the liquid nitrogen to cool it down below $0^\circ C$ ($273^\circ K$). But, we did not do further investiga-

Table I Hall voltage and resistance across the Germanium semiconductor doped with impurity Arsenic used in this experiment.

temp	fieldon	field of	V \ dr	Hall vol	Resistan	Log R	Log T	1/T
373.0	-1.910	-1.510	-0.04680	-0.4000	46.85	3.847	5.922	0.002681
368.0	-2.210	-1.730	-0.05430	-0.4800	54.35	3.996	5.908	0.002717
363.0	-2.530	-1.930	-0.06300	-0.6000	63.06	4.144	5.894	0.002755
358.0	-2.870	-2.180	-0.07360	-0.6900	73.67	4.300	5.881	0.002793
353.0	-3.240	-2.450	-0.08630	-0.7900	86.39	4.459	5.866	0.002833
348.0	-3.980	-2.830	-0.1017	-1.150	101.8	4.623	5.852	0.002874
343.0	-4.450	-3.200	-0.1176	-1.250	117.7	4.768	5.838	0.002915
338.0	-4.930	-3.110	-0.1374	-1.820	137.5	4.924	5.823	0.002959
333.0	-5.970	-3.810	-0.1592	-2.160	159.4	5.071	5.808	0.003003
328.0	-6.960	-4.280	-0.1830	-2.680	183.2	5.210	5.793	0.003049
323.0	-8.090	-4.760	-0.2090	-3.330	209.2	5.343	5.778	0.003096
318.0	-9.570	-5.300	-0.2344	-4.270	234.6	5.458	5.762	0.003145
313.0	-10.87	-5.900	-0.2584	-4.970	258.7	5.556	5.746	0.003195
308.0	-12.22	-6.380	-0.2797	-5.840	280.0	5.635	5.730	0.003247
303.0	-13.45	-6.620	-0.2934	-6.830	293.7	5.683	5.714	0.003300
298.0	-14.55	-7.240	-0.3025	-7.310	302.8	5.713	5.697	0.003356
293.0	-15.47	-7.350	-0.3074	-8.120	307.7	5.729	5.680	0.003413
288.0	-15.75	-7.390	-0.3080	-8.360	308.3	5.731	5.663	0.003472
283.0	-16.11	-7.410	-0.3064	-8.700	306.7	5.726	5.645	0.003534
278.0	-16.06	-7.020	-0.3030	-9.040	303.3	5.715	5.628	0.003597
273.0	-15.39	-6.290	-0.2986	-9.100	298.9	5.700	5.609	0.003663
268.0	-14.80	-5.160	-0.2935	-9.640	293.8	5.683	5.591	0.003731
263.0	-14.02	-4.000	-0.2882	-10.02	288.5	5.665	5.572	0.003802
258.0	-12.98	-2.770	-0.2824	-10.21	282.7	5.664	5.553	0.003876
253.0	-11.99	-1.370	-0.2764	-10.62	276.7	5.623	5.533	0.003953
248.0	-10.69	0.1500	-0.2702	-10.84	270.5	5.600	5.513	0.004032
243.0	-10.30	0.8500	-0.2637	-11.15	264.0	5.576	5.493	0.004115
238.0	-9.9550	1.660	-0.2567	-11.21	257.0	5.549	5.472	0.004303
233.0	-9.340	2.290	-0.2493	-11.63	249.5	5.520	5.451	0.004292
228.0	-3.450	0.8300	-0.2420	-4.280	242.2	5.490	5.429	0.004386
223.0	-6.610	0.8900	-0.2344	-7.500	234.6	5.458	5.407	0.004484
218.0	-9.900	1.600	-0.2264	-11.50	226.6	5.423	5.384	0.004587
213.0	-10.55	1.550	-0.2183	-12.10	218.5	5.387	5.361	0.004695
208.0	-11.79	1.230	-0.2102	-13.02	210.4	5.349	5.338	0.004808
203.0	-12.59	0.7500	-0.2023	-13.34	202.5	5.311	5.313	0.004926
198.0	-13.26	0.3800	-0.1940	-13.64	194.2	5.269	5.288	0.005051
193.0	-13.69	0.1300	-0.1857	-13.82	185.9	5.225	5.263	0.005181
188.0	-13.96	0.05000	-0.1776	-14.01	177.8	5.181	5.236	0.005319
183.0	-14.05	0.1600	-0.1689	-14.21	169.1	5.130	5.209	0.005464
178.0	-13.37	0.1700	-0.1584	-13.54	158.6	5.066	5.182	0.005618
173.0	-13.69	1.230	-0.1516	-14.92	151.8	5.022	5.153	0.005780
168.0	-12.95	2.040	-0.1420	-14.99	142.1	4.957	5.124	0.005952
163.0	-12.34	3.300	-0.1337	-15.764	133.8	4.897	5.094	0.006135
158.0	-11.16	4.808	-0.1247	-15.24	124.8	4.827	5.063	0.006329
153.0	-9.700	5.440	-0.1158	-15.14	115.9	4.753	5.030	0.006536
148.0	-8.250	6.770	-0.1071	-15.02	107.2	4.675	4.997	0.006757
143.0	-6.230	8.060	-0.09910	-14.29	99.20	4.597	4.963	0.006993
138.0	-5.770	9.470	-0.09070	-14.24	90.79	4.509	4.927	0.007246

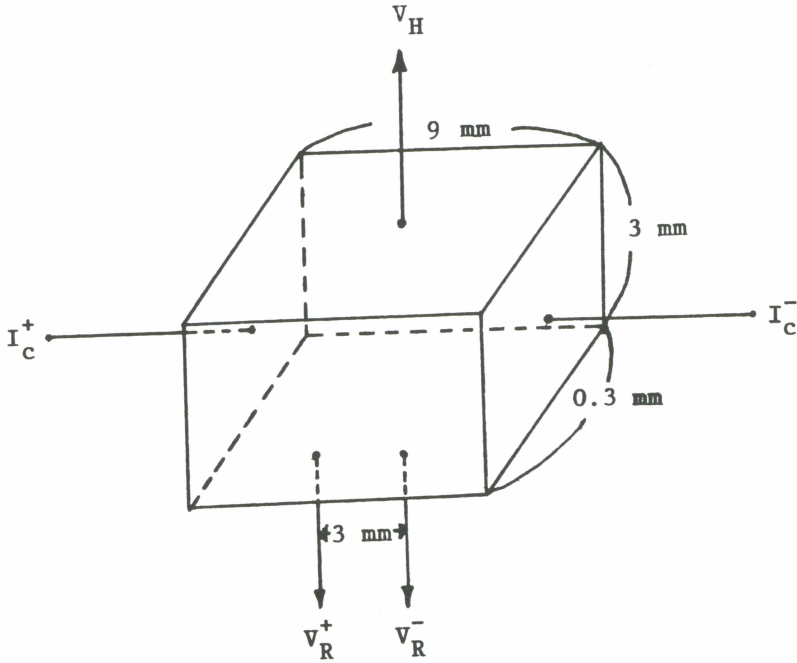


Fig. 5 The dimensions of the semiconductor crystal used in this experiment (The diagram is not to scale)

Resistance

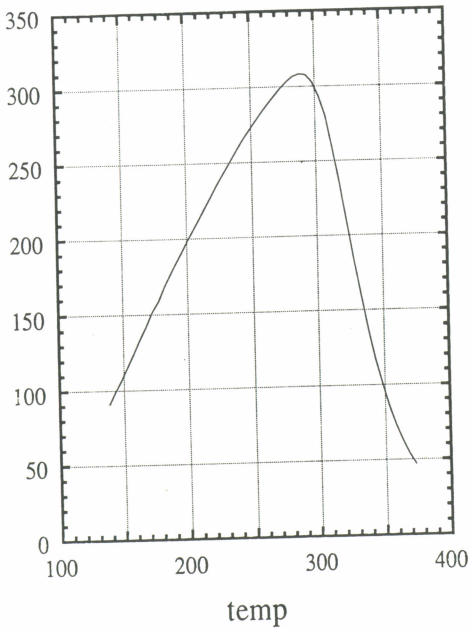


Fig. 6 The resistance of the sample as a function of temperature T

Hall voltage

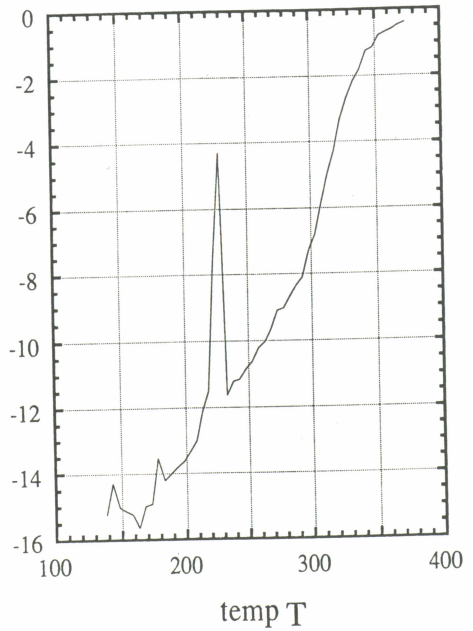


Fig. 7 The Hall voltage across the sample as a function of temperature T

Log R

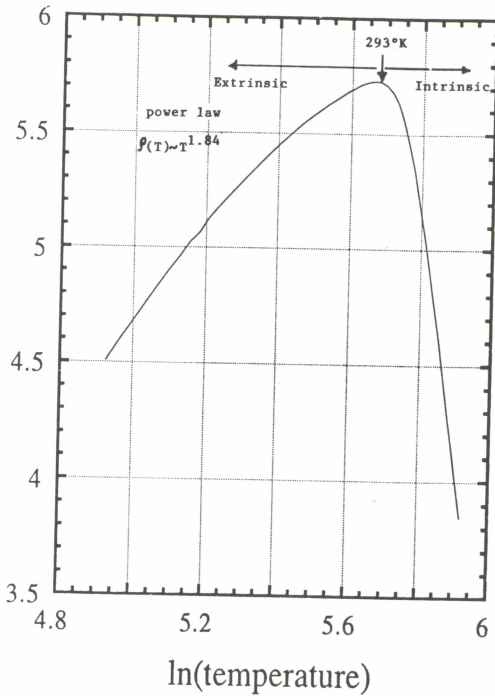


Fig. 8 The logarithm of the resistance of the sample as a function of the logarithm of the temperatures for transition from extrinsic region to intrinsic region. The power law can be also determined from this figure.

tions in this paper. In addition, the concentration n for each corresponding value of V_H was not computed here although we have the information of $w = 0.03$ mm, $I = -0.999$ mA, and $e = 1.6 \times 10^{-19}$ coul. However, from Fig. 7, we see that $V_H(T)$ approaches a constant value as T is below 170°K. This means that, at low temperature, n will have a constant value as the theory expected.

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Log R

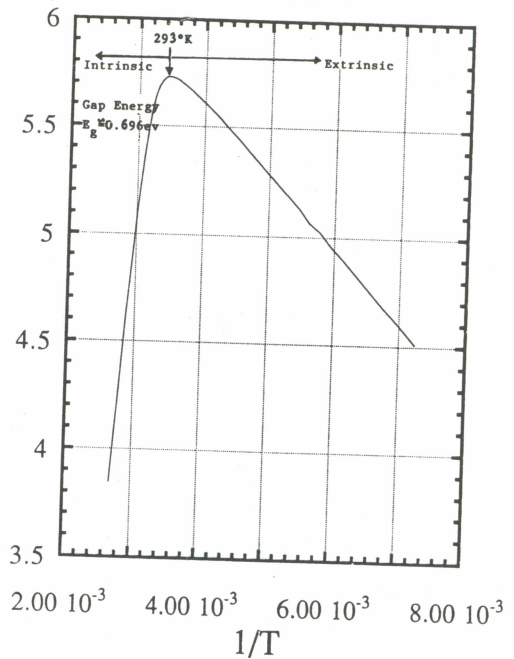


Fig. 9 The logarithm of the resistance of the sample as a function of reciprocal of temperature. The temperature for transition from extrinsic region to intrinsic region is about 293°K. From this figure, the gap energy can be determined.

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利用霍爾效應檢測鍺半導體之電性

蔡文鋒

滲有些許砷(As)元素之鍺(Ge)半導體，可藉霍爾效應(Hall Effect)的方法測定霍爾電位差(Hall Voltage)以及鍺半導體電阻隨溫度的變化關係來檢測此鍺半導體的本質半導體特性(Intrinsic Semiconduction)與外在半導體特性(Extrinsic Semiconduction)的溫度範圍。同時，在本質半導體特性範圍內鍺半導體之間隙能量 E_g (Gap Energy)及在外在半導體特性範圍內，電阻係數 ρ (Electrical Resistivity)隨溫度的指數函數關係也一併檢測。