2·6 THE HALL EFFECT

If a specimen (metal or semiconductor) carrying a current I is placed in a transverse magnetic field B, an electric field $\mathcal{E}$ is induced in the direction perpendicular to both I and B. This phenomenon, known as the *Hall effect,* is used to determine whether a semiconductor is *n*- or p-type and to find the carrier concentration. Also, by simultaneously measuring the conductivity σ, the mobility μ can be calculated.

The physical origin of the Hall effect is not difficult to find. If in Fig. 2-10 I is in the positive X direction and B is in the positive Z direction, a force will be exerted in the negative Y direction on the current carriers. The current I may be due to holes moving from left to right or to free electrons traveling from right to left in the semiconductor specimen. Hence, independently of whether the carriers are holes or electrons, they will be forced downward toward side 1 in Fig. 2-10. If the semiconductor is n-type material, so that the current is carried by electrons, these electrons will accumulate on side 1, and this surface becomes negatively charged with respect to side 2. Hence a potential, called the *Hall voltage,* appears between surfaces 1 and 2.

If the polarity of V_H is positive at terminal 2, then, as explained above, the carriers must be electrons. If, on the other hand, terminal 1 becomes charged positively with respect to terminal 2, the semiconductor must be p-type. These results have been verified experimentally, thus justifying the bipolar (two-carrier) nature of the current in a semiconductor.

If I is the current in a p-type semiconductor, the carriers might be considered to be the *bound* electrons jumping from right to left. Then side 1 would become negatively charged. However, experimentally, side 1 is found to become positive with respect to side 2 for a p-type specimen. This experiment confirms the quantum-mechanical fact noted in Sec. 2-2 that the hole acts like a classical *free* positive-charge carrier.

Experimental Determination of Mobility In the equilibrium state the electric field intensity $\mathcal{E}$ due to the Hall effect must exert a force on the carrier which just balances the magnetic force, or

$$q\mathcal{E} = Bqv \tag{2-21}$$

where q is the magnitude of the charge on the carrier, and v is the drift speed. From Eq. (1-3), $\mathcal{E} = V_H/d$, where d is the distance between surfaces 1 and 2.

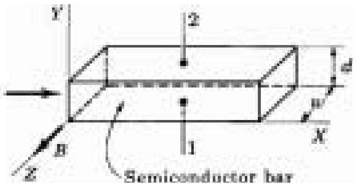

Fig.2.10 Pertaining to the Hall effect. The carriers (whether electrons or holes) are subjected 'to a magnetic force in the negative Y direction.

From Eq. (2-6), $J = \rho v = I/wd$, where J is the current density, ρ is the charge density, and w is the width of the specimen in the direction of the magnetic field. Combining these relationships, we find

$$V_H = \mathcal{E}d = Bvd = \frac{BJd}{\rho} = \frac{BI}{\rho w} \tag{2-22}$$

If V_H, B, I, and w are measured, the charge density ρ can be determined from Eq. (2-22).

It is customary to introduce the Hall coefficient R_H defined by

$$R_H \equiv \frac{1}{\rho} \tag{2-23}$$

Hence $$R_H = \frac{V_H w}{BI} \tag{2-24}$$

If conduction is due primarily to charges of one sign, the conductivity σ is related to the mobility μ by Eq. (2-8), or

$$\sigma = \rho\mu$$

If the conductivity is measured together with the Hall coefficient, the mobility can be determined from

$$\mu = \sigma R_H \tag{2-26}$$

We have assumed in the foregoing discussion that all particles travel with the mean drift speed v. Actually, the current carriers have a random thermal distribution in speed. If this distribution is taken into account, it is found that Eq. (2-24) remains valid provided that R_H is defined by $3\pi/8\rho$. Also, Eq. (2-26) must be modified to $\mu = (8\sigma/3\pi)R_H$.

Applications Since V_H is proportional to B (for a given current I), then the Hall effect has been incorporated into a magnetic field meter. Another instrument, called a *Hall-effect multiplier,* is available to give an output proportional to the product of two signals. If I is made proportional to one of the inputs and if B is linearly related to the second signal, then, from Eq. (2-22), V_H is proportional to the product of the two inputs.

2-7 CONDUCTIVITY MODULATION

Since the conductivity σ of a semiconductor is proportional to the concentration of free carriers [Eq. (2-17)], σ may be increased by increasing n or p. The two most important methods for varying n and p are to change the temperature or to illuminate the semiconductor and thereby generate new hole-electron pairs.