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MAGNETORESISTANCE DEVICES

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Introduction

This work is a continuation of the project on galvanomagnetic effects. Its aim is to find higher magnetoresistance devices for a low-voltage high-current switch.

Previous studies have been made of the effect of the geometry of indium antimonide (InSb) and bismuth (Bi) magnetoresistance devices [References 1 and 2]. According to previous results, lowering of the Hall voltage can create higher magnetoresistance. Use of the Corbino disk has obtained the best results. Its magnetoresistance coefficient may reach 51 at room temperature [Reference 1]. We shall extend the previous analysis and try to find even better results.

One of our proposed studies is the use of self-biased electrical-field-enhanced magnetoresistance devices. We shall adopt the best geometrical shape and use the electric field effect to increase the magnetoresistance of the devices. Next, we plan the use of an InSb p-n junction to get higher magnetoresistance. Finally, we propose the use of p-n-p or p-i-n magnetic field-sensitive devices; these are described in the last section.

Magnetoresistance

The magnetoresistance phenomenon has close relationship with the Hall effect. The current changes its direction when a magnetic field is applied perpendicular to the current direction. That is, the current flows over a longer path than before. The material has more effective resistivity with a crossed magnetic field. There is a difference in the magnetoresistance phenomenon and the Hall effect that is caused by geometrical shape. A high Hall voltage device may accompany a low magnetoresistance coefficient. Both the Hall voltage and magnetoresistance coefficient are dependent upon the geometry of the device.

Lippmann and Kuhrt [Reference 3] derived the low-field magnetoresistance of a rectangular isotropic specimen by conformal mapping in terms of Hall angle θ, the resistivity in a magnetic field ρ_B, the corresponding resistivity in zero field ρ_o, and a function of geometry $g(\ell/w)$, evaluated numerically and graphically:

$$\frac{R_B}{R_o} = \frac{\rho_B}{\rho_o} \left[1 + g\left(\frac{\ell}{w}\right)\tan^2\theta\right] \qquad (1)$$

Since $(\rho_B/\rho_o) = (\mu_o/\mu_B)$, and since $\tan^2\theta = (\mu_B B)^2$, Equation 1 may be expressed as

$$\frac{\Delta R}{R_o} = \frac{\Delta\mu}{\mu_B} + \left[g\left(\frac{\ell}{w}\right) \cdot \Delta\mu \cdot \mu_B\right]B^2 \qquad (2)$$

where $\Delta\mu/\mu_B$ is a "physical magnetoresistance" in small magnetic fields, which may be considered negligible in comparison with the geometrical magnetoresistance which is quadratic in B. Lippmann and Kuhrt have shown that the magnetoresistance coefficient in high magnetic fields and for large (ℓ/w), may be expressed as

$$\frac{\Delta R}{R_o} = \frac{\Delta\rho}{\rho_o} + (\frac{w}{\ell})[\mu_o B - \frac{\mu_o}{\mu_B} \cdot \frac{4}{\pi} \ln 2] \qquad (3)$$

The magnetoresistance coefficient ($\Delta R/R_o$) of monophase, dendritic InSb films is a quadratic function of the magnetic field B, for $\mu B<<1$, and a linear function of B in high magnetic fields [Reference 4].

Simmons [Reference 6] confirmed that the enhancement of the magnetoresistance effect in rectangular elements is due to the Hall effect rather than to is absence. He also showed that the bulk property has a B^2 relationship while the geometrical effect is linear in B and inversely proportional to the length-to-width ratio.

Experimental Procedures Being Investigated

1. Geometrical Shape of Magnetoresistance Devices

The geometrical shape of magnetoresistance materials has been investigated by several authors [References 1, 2, 4, and 5]. They confirm that the geometrical shape is very important to the magnetoresistance coefficient of the materials. Corbino disks and modified devices with shorting electrodes of the Hall voltage are among the best shapes to produce the optimum of the magnetoresistance coefficient. This is due to the shorting of the Hall voltage.

In addition to the geometrical shapes, the most important factors in obtaining the best magnetoresistance are the choice of material and the reducing of the contact resistance of the electrodes. InSb is considered to be the best material for magnetoresistance devices at room temperature while bismuth is the best material at low temperature, because of their high carrier mobility. Contact resistance of the electrodes can cause an increase in the zero field resistance and this can reduce the magnetoresistance coefficient. For InSb, indium alloyed into the contact surface of the InSb bulk material can reduce the contact resistance [Reference 1].

Several geometrical shapes of the bulk magnetoresistance devices, which will be considered later, are shown in Figure 1.

2. Self-Biased Electric-Field-Enhanced MOS Magnetoresistance Device

A self-biased electric-field-enhanced MOS magnetoresistance device is a two-terminal passive device. We will use the Corbino disk geometry shape with self-biased gate voltage on a MOS device. The structure of this device is shown in Figure 2. This device is the combination of a magnetoresistance bulk device and the MOS device. Without applying the magnetic field, the voltage drop on the terminals of this device is small. The lower gate voltage does not have too much effect on the resistance of the device. When a magnetic field is applied to the device, due to the structure of the Corbino disk, the resistance of the device increases, and as

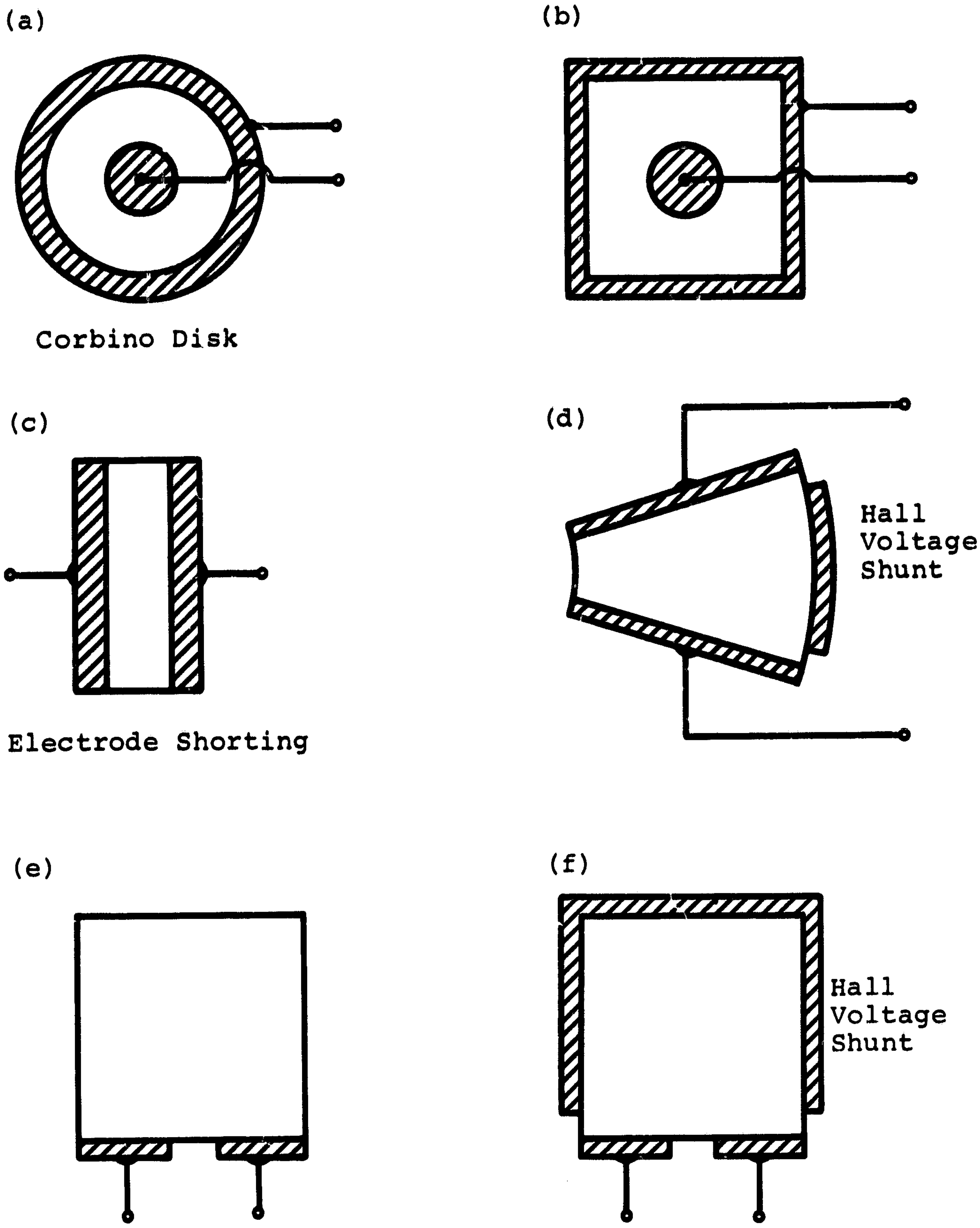

Figure 1. Six Different Geometrical Shapes of the Bulk Magnetoresistance Devices

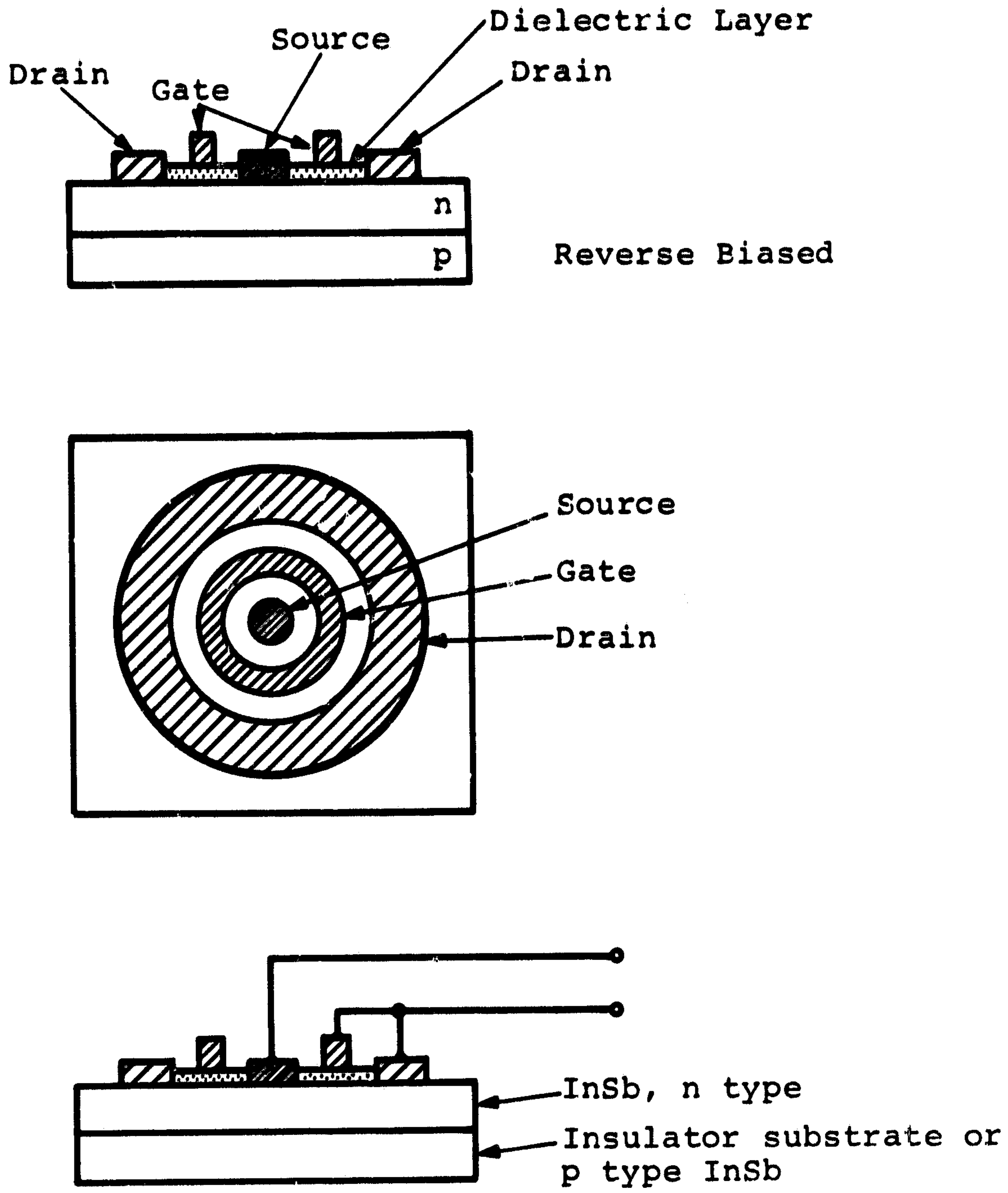

Figure 2. Self-Biased Electric-Field-Enhanced MOS Magnetoresistance Device

a result the voltage on the terminals also increases. Therefore, the higher voltage on the gate cuts more current. Such a type of self-biased magnetoresistance device has a higher magnetoresistance coefficient. This is the main idea of the device. We will work on the structure of this device in order to attain the best performance on the magnetoresistance coefficient ($\Delta R/R_o$). A p-n InSb wafer or an InSb film on the insulator substrate will be used for the MOS structure.

3. <u>p-n Junction Magnetoresistance Devices</u>

Different arrangements of a high carrier mobility p-n junction have different resistances under different directions of the magnetic field applied. Several different models of the p-n junction magnetoresistance devices are briefly described below.

a Reverse-biased p-n junction

A reverse-biased p-n junction device is shown in Figure 3. It is polished and etched except for one side of the p-n junction, which is lapped. When the magnetic field is applied in a proper direction, the carriers flow to the side of the smooth surface. However, the carriers flow to the other side of the lapped surface for a different direction of the magnetic field. Different recombination velocities at different surface states have different properties. It is expected that there is a low value of the resistance of

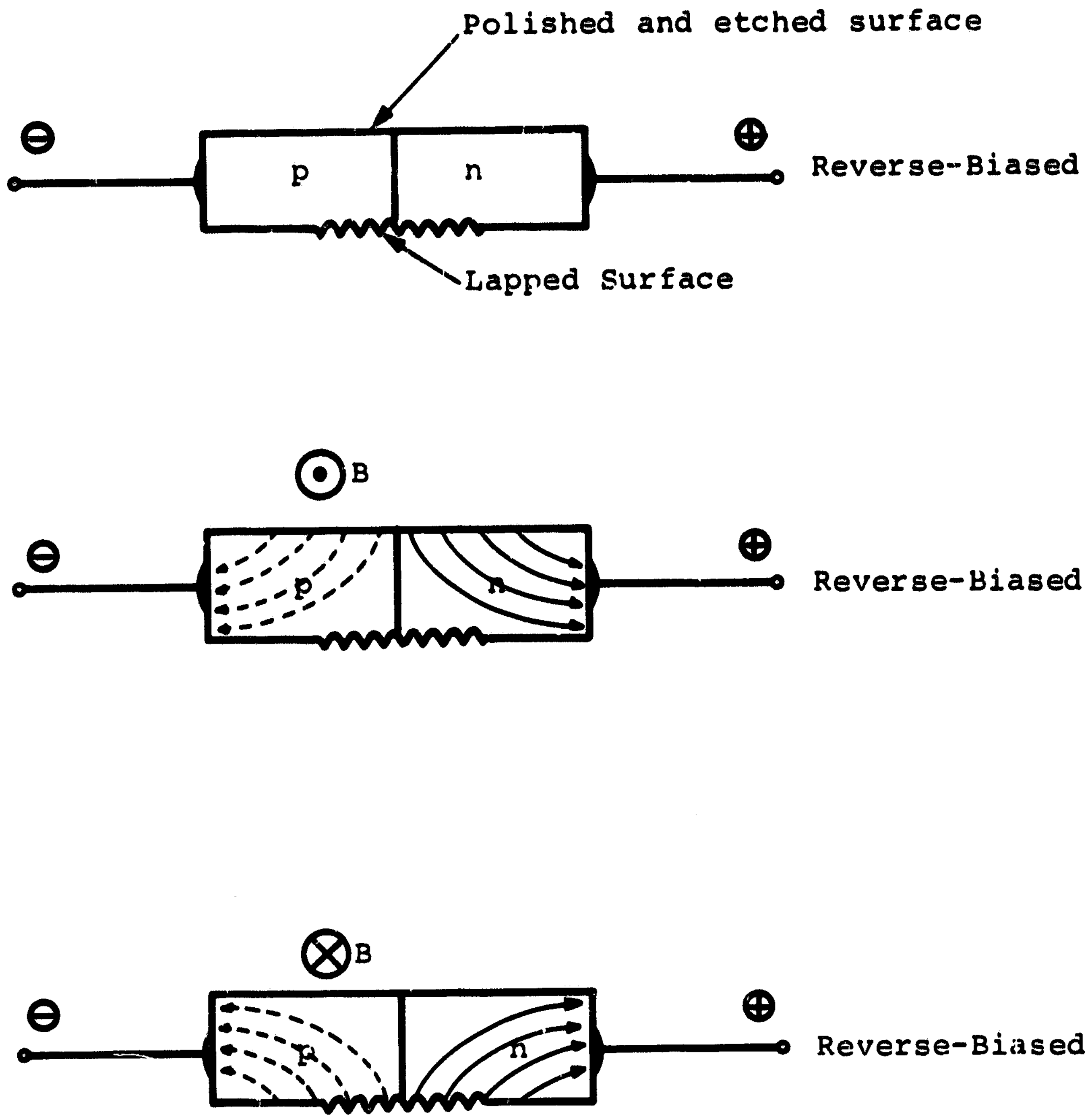

Figure 3. Reverse-Biased InSb p-n Junction

the device when the carriers flow to the lapped surface at the junction.

b. Forward-biased p-n junction magnetoresistance device

In a forward-biased p-n junction magnetoresistance device, the electrodes are connected on one side of the p-n junction as shown in Figure 4, and the device is forward-biased. When the magnetic field is applied to keep the carriers bending toward the junction, the device has lower resistivity. If the magnetic field is in the opposite direction, the carriers must find the longer way to complete the passage. This device, therefore, has higher resistance. It is hoped that its magnetoresistance coefficient will be higher than the basic magnetoresistance devices.

c. Reverse-biased p-n junction magnetoresistance device

A reverse-biased InSb p-n junction with electrodes on one side of the junction is shown in Figure 5. With the proper direction of the magnetic field, the carriers flow toward the p-n junction. In the opposite direction, the carriers flow outward from the electrodes to follow the complete path through the outside-shorted bar. This device is non-linear under the magnetic field.

4. p-n-p or p-i-n Magnetoresistance Devices

It is well known that the change of the width of the center region of p-n-p or p-i-n structures can change the collector current for constant terminal voltage. That is,

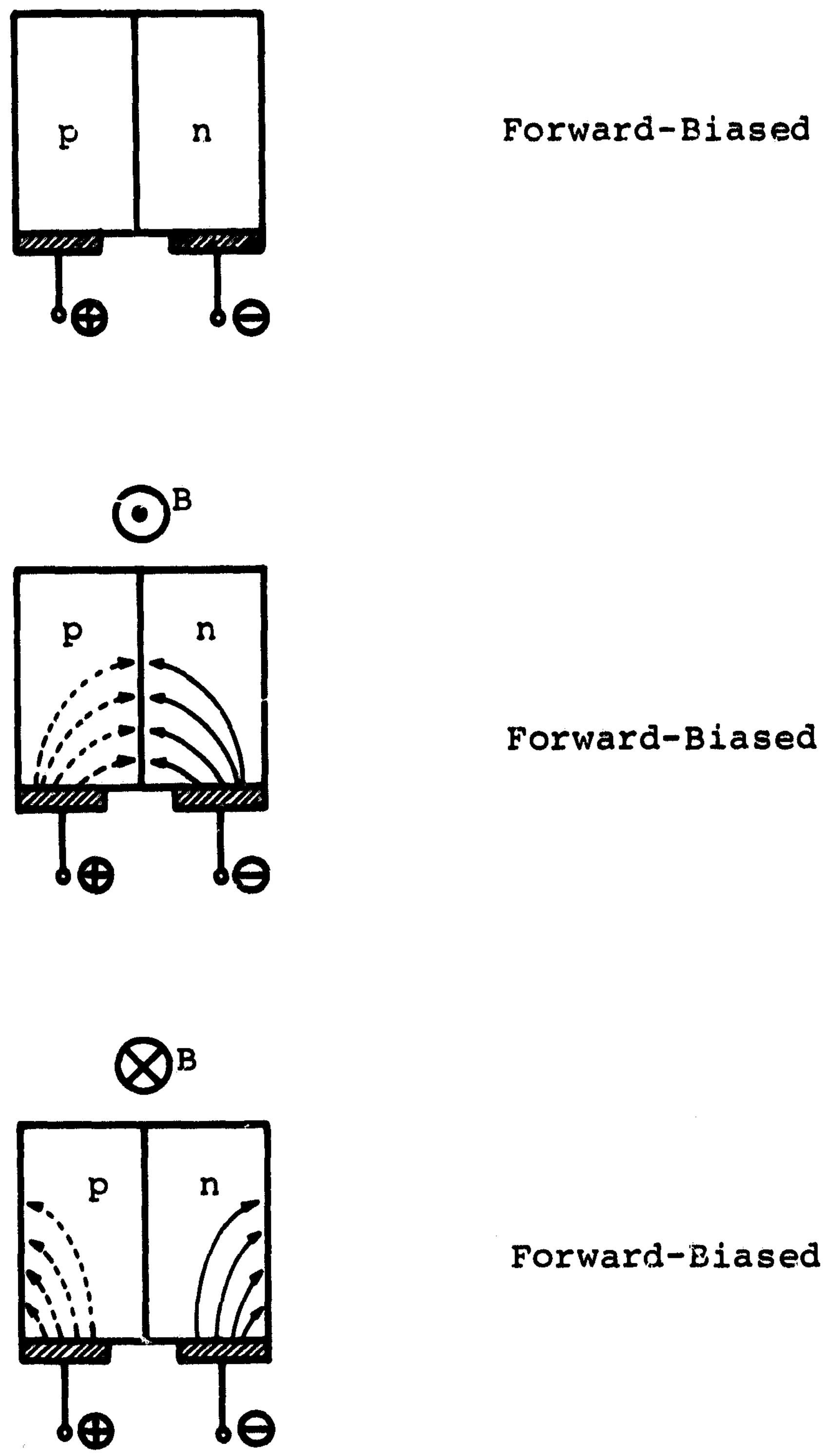

Figure 4. Forward-Biased p-n Junction Magnetoresistance Device

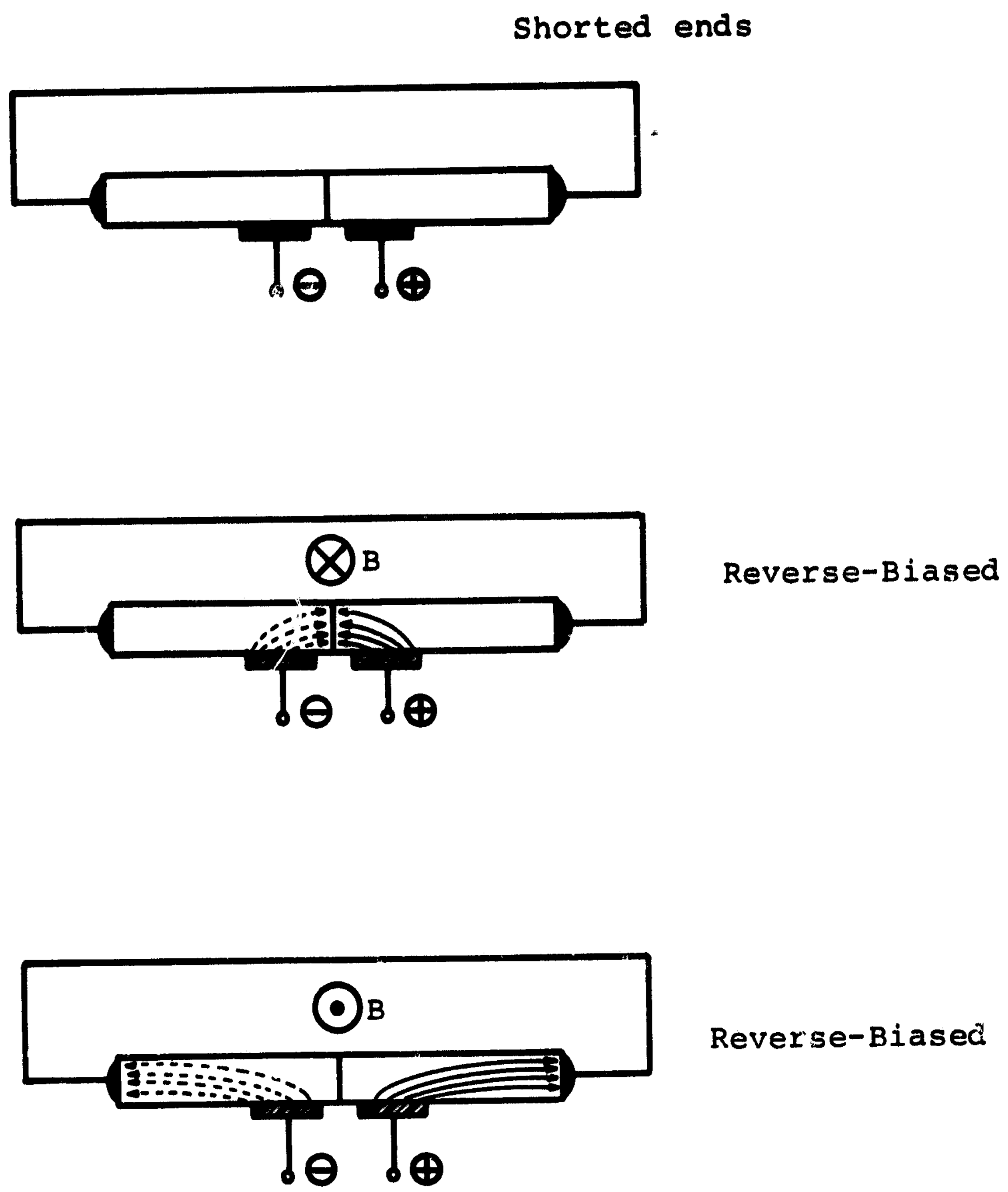

Figure 5. Reverse-Biased p-n Junction Magnetoresistance Devices with Long Bar Structure

the wider center region has less collector current. If we construct the p-n-p or p-i-n devices to have a wider center region (width/diffusion length ≅ 5), we have the following interesting results:

Without applying the magnetic field, the current flowing through the device is small compared with that of the regular structure. But when the magnetic field is applied to this device, due to the Corbino structure, the device has a longer path for the carriers at the center region. In other words, the effective width is increased. If the effective width increases to twice its previous width the W/L ratio can reach 10. By the p-n-p transport factor formula [Reference 6], the collector current can be reduced from its original value by a factor of 150! Such an arrangement has high sensitivity in the magnetic field and a high magnetoresistance coefficient. The main disadvantage of this device, however, is an increase in resistivity.

REFERENCES

1. Bechtel, R., Grannemann, W. W., and Harpter, B. J., "D.C. to A.C. Conversion using Magneto-Resistance," Solid State Electronics, Vol. 7, 1964, p. 357.

2. Bechtel, R., and Grannemann, W. W., Report EE-131, University of New Mexico, December 1965.

3. Lippmann and Kuhrt, "Der Geometrieeinfluss auf den transversalen magnetischen Widerstandseffekt bei rechteckformigen Halbleiterplatten," Zeitschrift fur Naturforschung, Vol. 13a, 1958, p. 462.

4. Wieder, H. H., "Galvanomagnetic Properties of Recrystallized Dendritic InSb Films," Solid State Electronics, Vol. 9, 1966, p. 373.

5. Simmons, C. A., "Influence of the Hall Effect upon the Transverse Magnetoresistance in Indium Antimonide," J. Applied Phys., Vol. 32, 1961, p. 1970.

6. Sze, S. M., Physics of Semiconductor Devices, Wiley-Interscience, 1969.