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MAGNETORESISTANCE DEVICES

by

T. W. Kim

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W. W. Grannemann

Progress Report PR-94(70)NASA-028

March 1970

Prepared for the National Aeronautics and Space Administration under Contract No. NGR32-004-002

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Introduction

Since last July, we have investigated the geometry shapes on magnetoresistance including the modified Corbino disk. A special nonlinear and asymmetric magnetoresistance device, using a diode to drive the Hall terminals, has been made. It shows some interesting results which will be discussed later. We designed and installed the flash evaporation equipment for Indium Antimonide thin or thick film research. We also measured the mobility of Indium Antimonide thin film by the flash evaporation method.

The self-biased electric field enhanced magnetoresistance devices which are proposed in the last report (1) will be investigated after we obtain thick Indium Antimonide film.

Properties of Indium Antimonide

Indium Antimonide is one of the most important materials for the magnetoresistance devices. It is necessary to describe and discuss its properties.

Because of its high mobility properties, Indium Antimonide is one of the III-V compound semiconductors which have been almost fully explored by scientists. The electron mobility in Indium Antimonide is very large. This is due to its small effective mass. The physical properties of Indium Antimonide are listed in Table 1.

TABLE I. PHYSICAL PROPERTIES OF InSb

Physical Properties	Descriptions
Crystal Structure	Zincblende
Lattice Constant at 300°K	6.4788Å
Melting Point	525°C
Effective Mass of Electrons	$(0.016\pm0.007)m_e$ (2), $0.036m_e$ (3)
Energy Gap at 300°K	0.167 eV
Energy Band Structure	Direct energy band. The minimum in the conduction band occurs at k=0 and the constant energy surfaces are spherical near the minimum. The maximum in the valence band is also at k=0, but this band is degenerate so that two types of hole should occur as for silicon and germanium (2)
Mobility of Electrons	$\mu_e = e\tau/m_e$
Minority Carrier Lifetime	10^{-7} second near room temperature for purest crystal; 5×10^{-9} second for the doping density of 10^{17} cm^{-3}. Near room temperature, both n type and p type material, the lifetime increases rapidly as the temperature decreases. (2).

It is known that Cd and Zn act as acceptor impurities and are frequently used to provide p type material, while Te acts as a donor impurity and is used to provide n type material (2). Usually the impurity energy level above or below the valence band and conduction band is about 0.01 eV. At room temperature, the mobility of 77,000 cm^2/V-sec can be obtained.

Geometry Shapes of Magnetoresistance Devices

The geometry shapes of magnetoresistance devices have been investigated by several authors (4) (5) (6) (7). They show that the Corbino disk shape has the highest magnetoresistance. The reason is due to the short circuiting of the circumferential Hall field induced in the disk by the orthogonal electric and magnetic fields.

We have nine samples with different geometry shapes of magnetoresistance devices. The length/width ratio is about 0.625 on sample #1, l/w = 1.07 on sample #2, and l/w = 5.5 on sample #3. Our results show that sample #2 has a higher magnetoresistance than sample #3. This coincides with the results from the mentioned authors. However, the lower magnetoresistance on sample #1 is due to the high contact resistance compared with the bulk resistance. Samples #4, #5, and #6 are specially designed geometry shapes. All electrodes are on one side of the sample with small spacing. Under very weak magnetic field, the sample shows asymmetric properties of magnetoresistance. However, it tends to saturate as the magnetic field increases. Sample #7 is like a capacitor with two electrodes mounted on the surfaces of the Indium Antimonide wafers. The low magnetoresistance of this sample is also due to the contact resistance. Sample #8 is a triangle-like shape. We use the copper-plating method to make the contact electrodes on the above samples. Then we use the solder to connect the leads to the electrodes. Sample #9 is called the modified Corbino disk. The outer electrode is rectangular instead of circular. Our result shows that this modified Corbino disk is comparable with the regular Corbino disk in magnetoresistance.

Experimental data on our nine samples are listed on Table II. Figure 1 shows the magnetoresistance versus magnetic field with different bias currents at room temperature on a modified Corbino disk (sample #9). The higher bias current may cause the temperature rise and reduce the magnetoresistance as expected. However, when the bias current is small enough, the contact resistance or contact potential on the contact area of the electrodes causes the drop of the magnetoresistance. Figure 2 shows the electrode voltage versus magnetic field with different bias currents. From this figure, I_b = 100 ma has the steepest slope; therefore, it shows the highest magnetoresistance. The magnetoresistance versus bias current is shown in Figure 3. Finally the I-V curve of sample #9 with or without magnetic field is shown in Figure 4. On the modified Corbino disk, the magnetoresistance value ($\Delta R/R_o$) is about 35.7 at 15 kilogauss. This

TABLE II

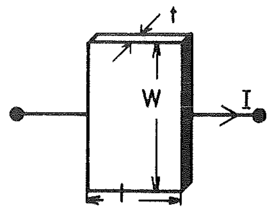
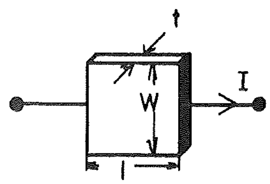
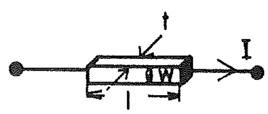
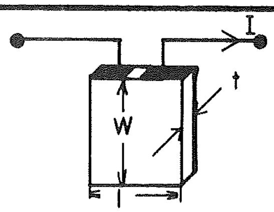
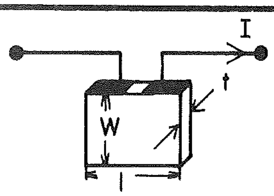
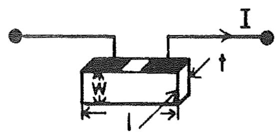
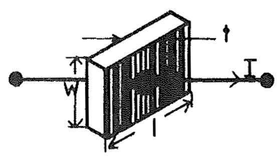
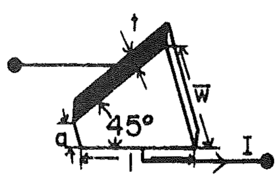
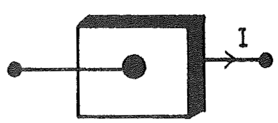
SAMPLE	DIMENSIONS (mm)				
	THICKNESS	LENGTH	WIDTH	B Kilogauss	$\frac{\Delta R}{R_o}$
1 	0.647	8.38	13.15	24 21 15 I=100ma	7.8 6.38 3.62
2 	0.647	8.38	7.85	24 21 15 I=100ma	8.85 6.6 3.65
3 	0.749	8.4	1.525	8.1 6.2 4.3 2.25 I=1 amp	0.31 0.22 0.103 0.031
4 	0.80	8.42	9.27	8.1 6.2 4.3 2.25 I=1amp	1.1 0.885 0.488 0.222
5 	0.812	8.42	5.92	24 21 15 I=100ma	10.5 8.7 5.2

TABLE II (Cont.)

SAMPLE	DIMENSIONS (mm) THICKNESS	LENGTH	WIDTH	$B_{Kilogauss}$	$\frac{\Delta R}{R_0}$
6 	0.787	8.33	2.96	24 21 15 8.1 6.2 I=100ma	8.92 7.32 4.24 0.92 0.745
7 	1.24	8.38	5.52	8.1 6.2 4.3 2.25 I= 1amp	0.185 0.10 0.053 0.0184
8 	0.889 a=1.93mm	8.43	8.61	24 21 15 I=100ma	10 8.4 5.0
9  Modified Corbino Disk	1	10	8	15 12 9 6 3 I= 100ma	35.6 25.4 16.4 8.4 2.7

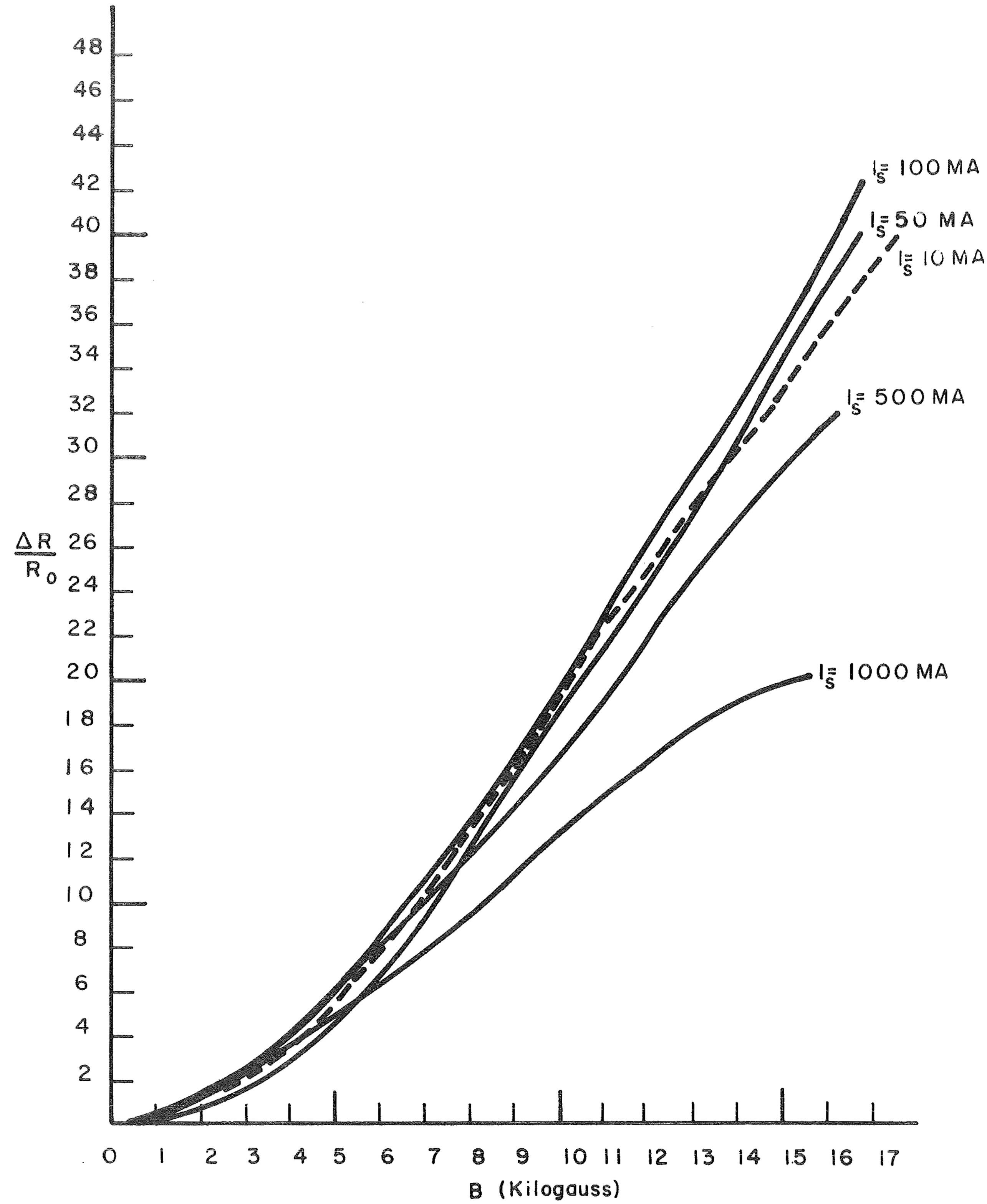


Figure 1. Magnetoresistance of sample #9 with different bias currents in the magnetic field.

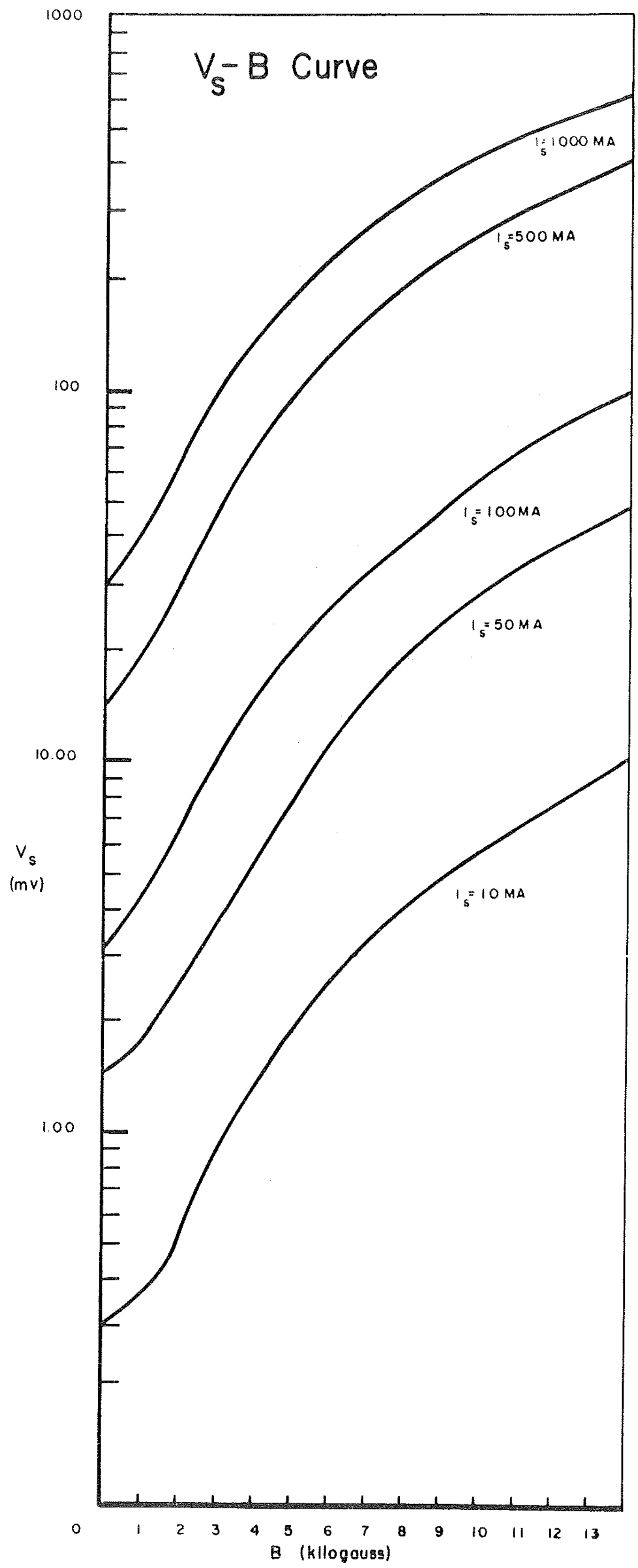


Figure 2. Voltage of sample #9 in the magnetic field with constant bias currents.

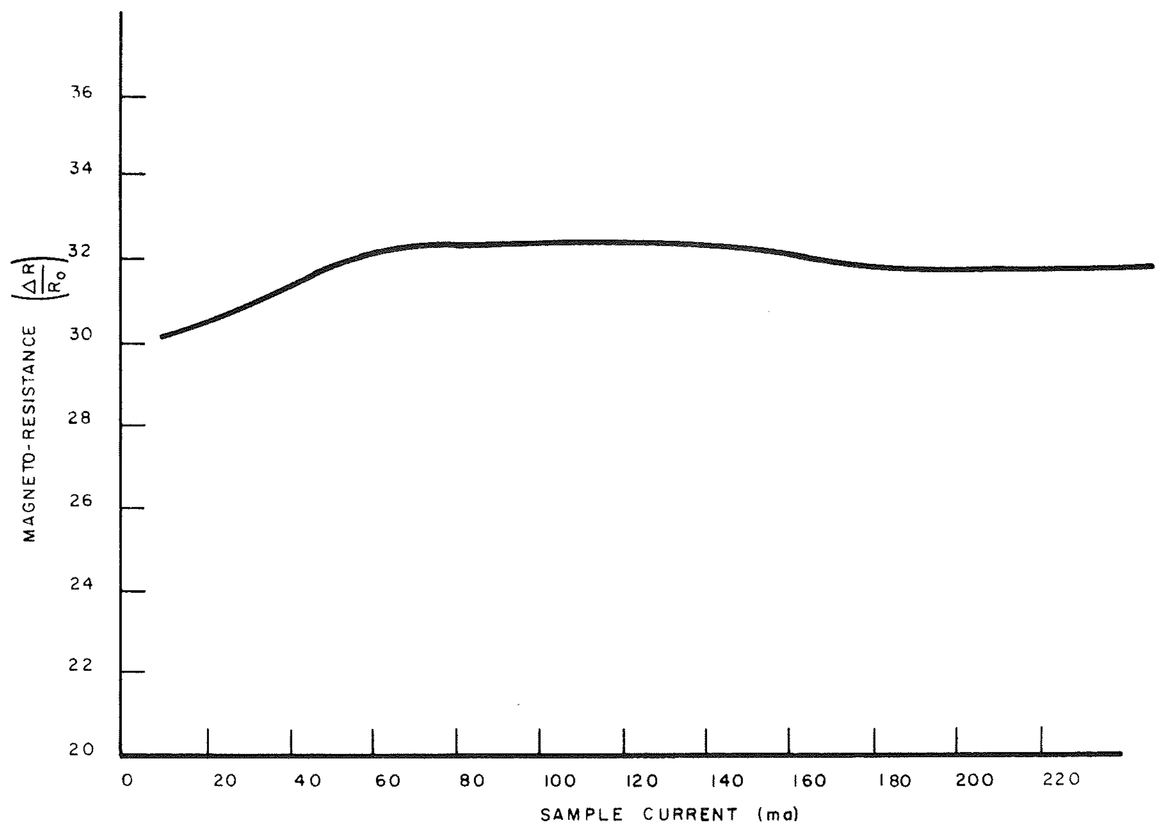


Figure 3. Magnetoresistance of the sample versus sample current.

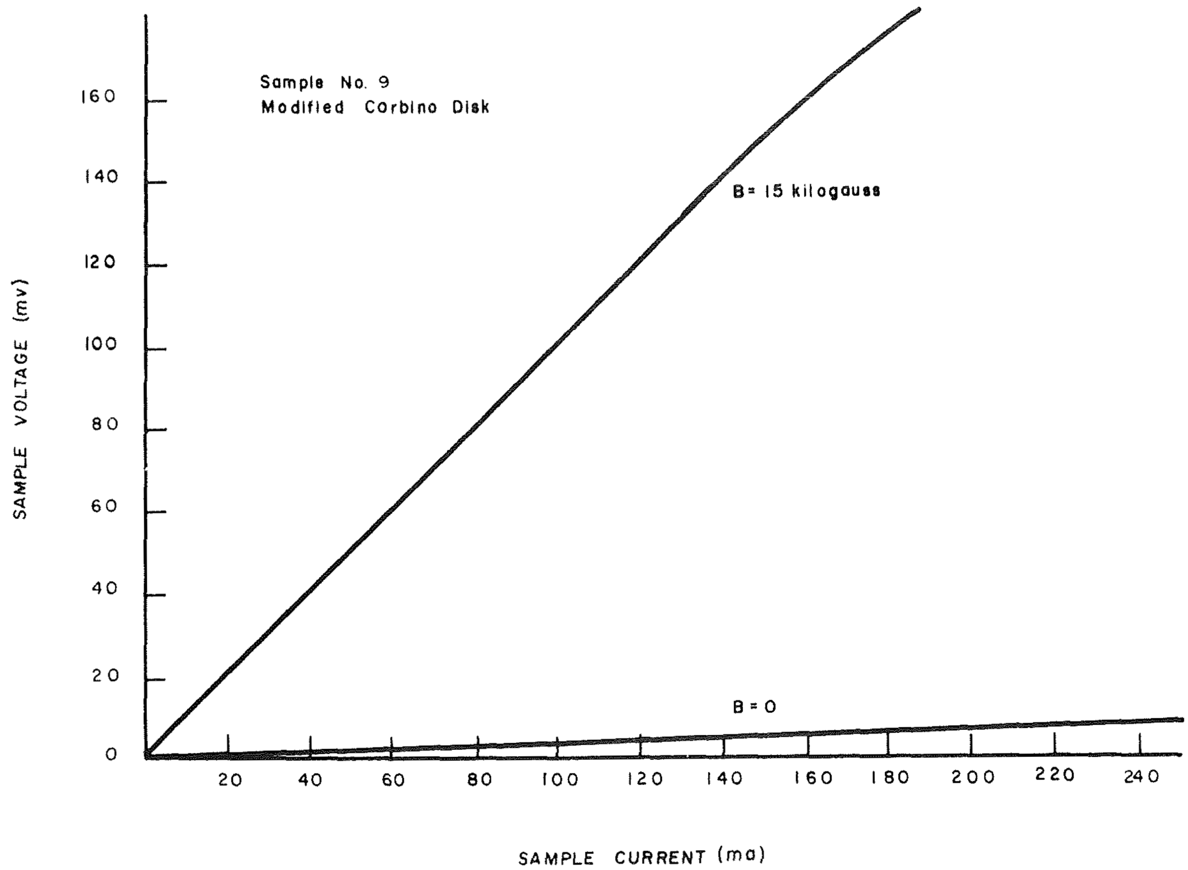


Figure 4. V-I characteristics of the sample with or without the magnetic field.

is comparable with the report by R. Bechtel and W. W. Grannemann (5). We use the Indium as the solder for this modified Corbino disk in order to obtain better contact.

A Special Magnetoresistance Device

A special magnetoresistance device was investigated last Winter. We know that the opening or shorting of the Hall voltage terminals may change the magnetoresistance of the device. If the Hall voltage is in the range of a few volts, then a diode can switch the Hall terminals from "open" to "short" or vice versa under different directions of the bias current or magnetic field. In other words, higher Hall voltage can drive the diode under both conditions. In this case, we have the asymmetric property. The change of the magnetoresistance depends upon the shape of the devices. Several different shapes of the device have been made, e.g., rectangular (length/width = 4) and square (length/width = 1). As an example, a square sample 8.5 mm by 8.5 mm by 1 mm was constructed, using polycrystal Indium Antimonide with the mobility 50,000 cm^2/V-sec at 80°K. The value of the magnetoresistance ratio is 1.62 (open) : 1 (short) at 100 ma bias current with 3 kilogauss magnetic field under liquid nitrogen temperature. The value of the magnetoresistance ratio can be increased by optimizing dimensions and the electrode shape. A room temperature device can be made from a very thin InSb slice or InSb film by using the flash evaporation method with proper annealing. At a specific range of the magnetic field

(3 kilogauss in our square sample), we obtained the peak value of the magnetoresistance ratio. This value decreases as the magnetic field increases or decreases from this optimum point. As we connected a silicon diode at the Hall terminals of this sample, we found that under reverse bias of the diode the curve of the magnetoresistance versus the magnetic field is the same as the curve when the Hall terminals are open. However, the condition on forward bias of the silicon diode is different. The curve stays close to the open curve until the applied field increases to a certain value, it then shifts from the open curve region to the closed curve region. This happened at 4.6 kilogauss with 100 ma bias current and 3.6 volt bias voltage on our square sample. The shift region depends upon the size of the sample and the characteristics of the diode.

Figure 5 shows the structure of this sample (#10) with measuring circuit. The magnetoresistance of the sample with open or short Hall terminals versus magnetic field is shown in Figure 6. Figure 7 shows the characteristics of the magnetoresistance in the sample with a silicon diode connected versus the magnetic field on different bias currents. Figure 8 shows the magnetoresistance ratio of the sample with Hall terminals open and short and for different directions of the sample current under the magnetic field.

Theoretically, the magnetoresistance ratio on this special magnetoresistance device may be increased up to 10 by the arrangement as shown in Figure 9.

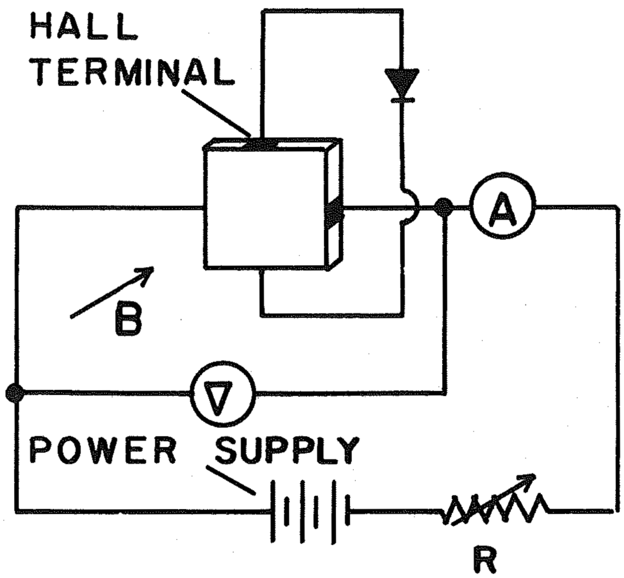


Figure 5. A special biased diode magnetoresistance device.

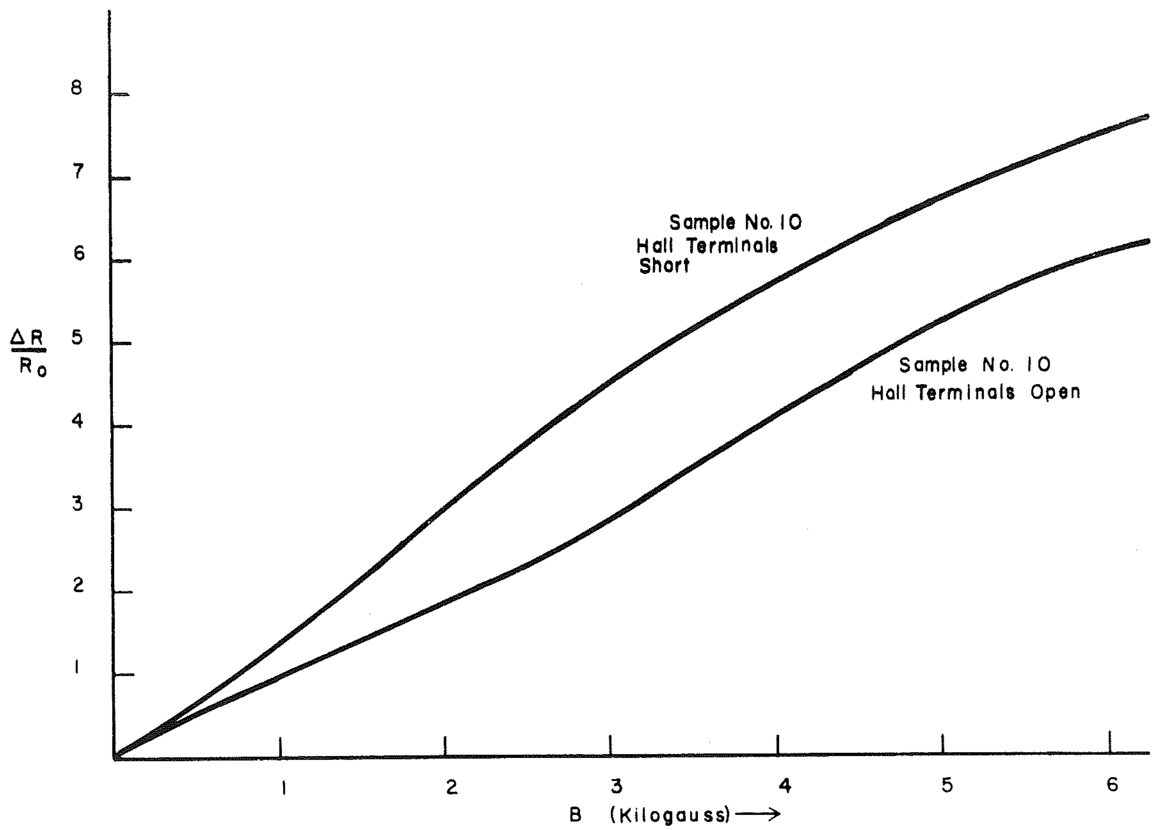


Figure 6. Magnetoresistance versus magnetic field of the special magnetoresistance device (sample #10) with open and short Hall terminal conditions.

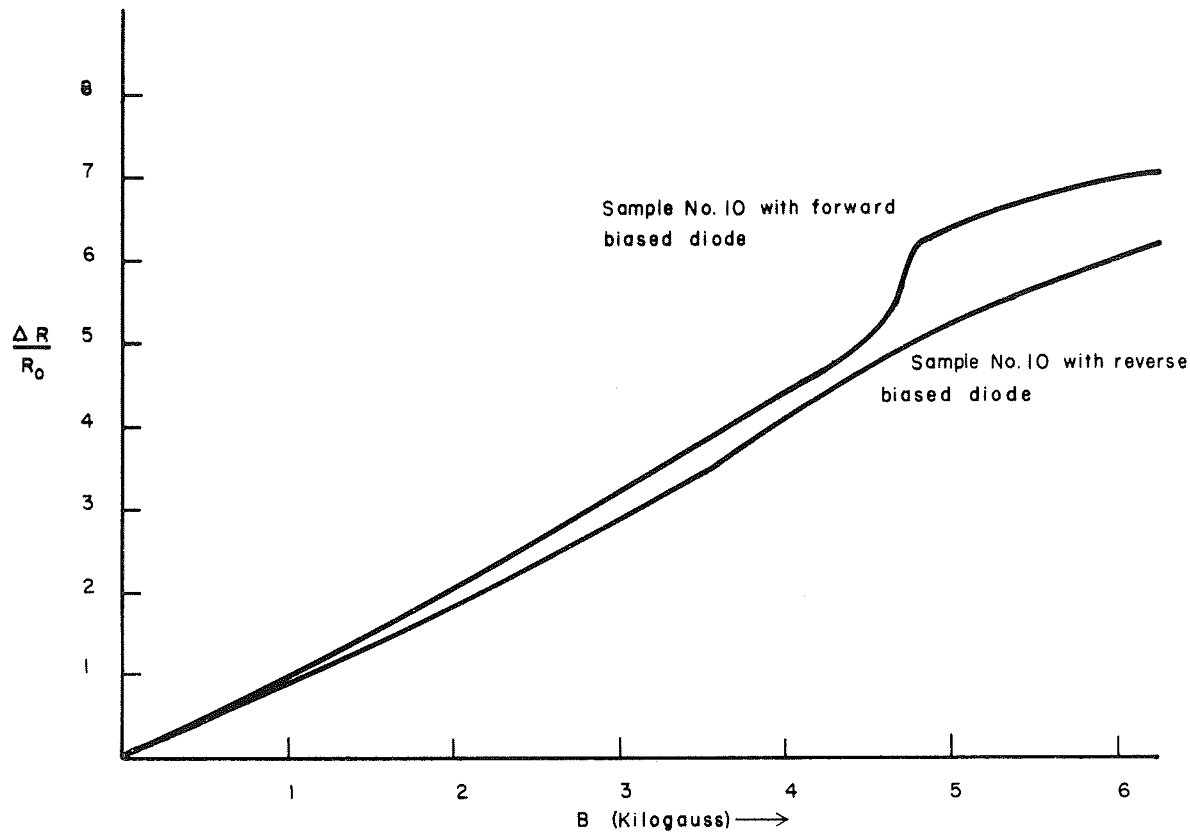


Figure 7. Magnetoresistance versus magnetic field in sample #10 with a silicon diode connected to the Hall terminals.

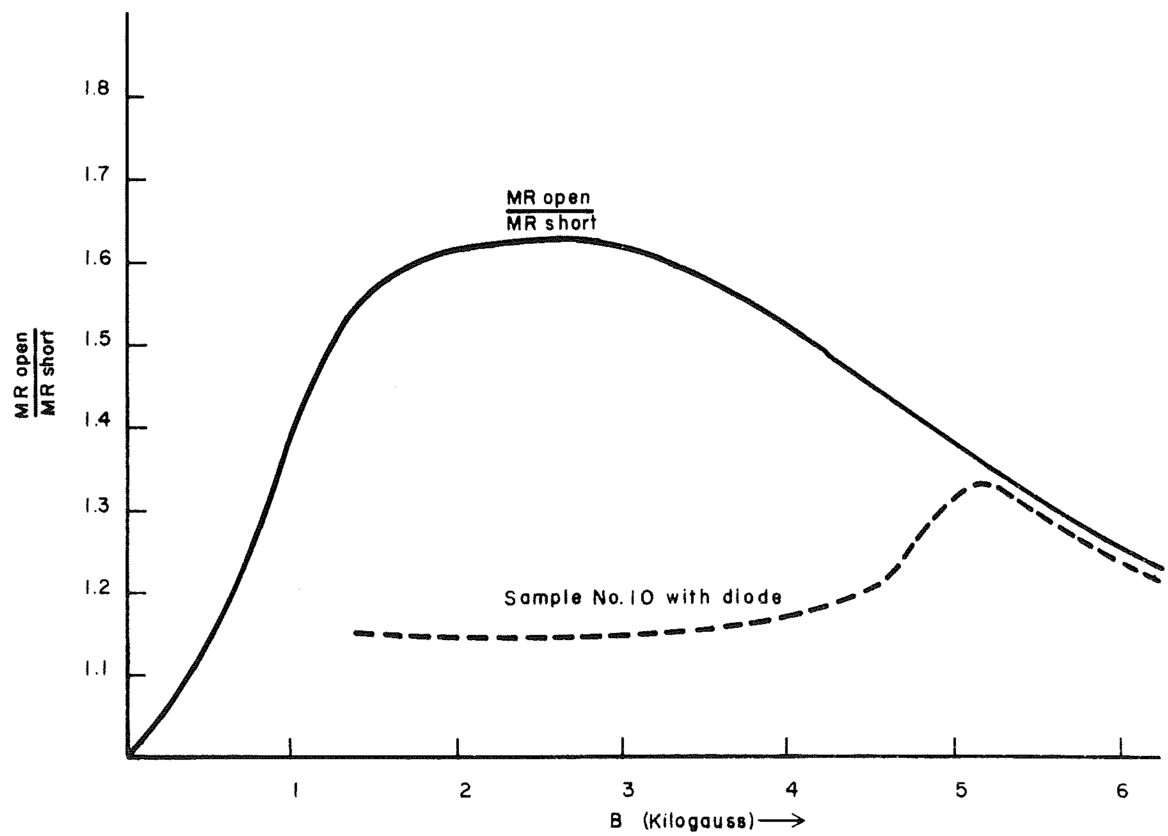


Figure 8. Magnetoresistance ratio $(\frac{\text{MR open}}{\text{MR short}})$ of sample #10.

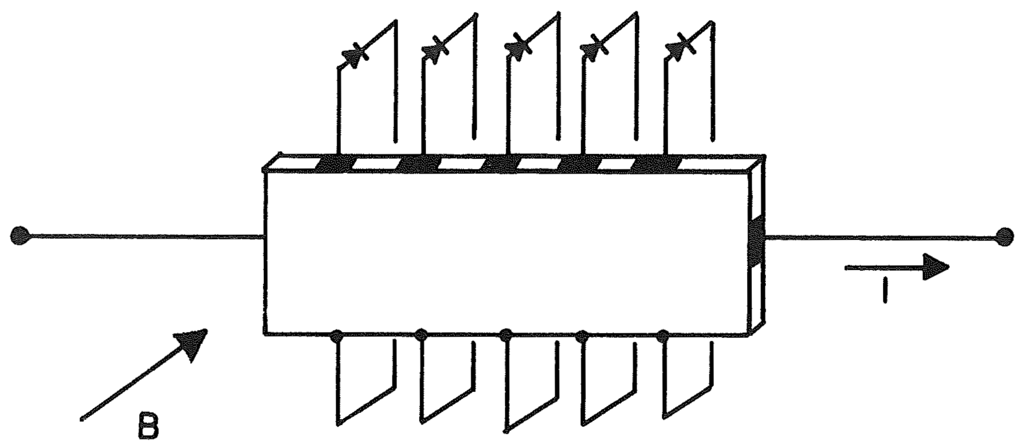


Figure 9. A high-magnetoresistance ratio and asymmetric magnetoresistance device.

Flash Evaporation

Decomposition of the compound semiconductors during evaporation is a problem in the preparation of the thin films. Recently, flash evaporation seems the best method for obtaining better compound semiconductor films. The idea of flash evaporation is very simple. Suppose the compound semiconductor powder to be continuously sent down to the evaporator during evaporation; even if decomposition occurs, the continuous evaporation of the small compound semiconductor powder results in fairly well-mixed compound semiconductor layers on the substrate. With proper annealing of the sample or proper substrate temperature during evaporation, good thin films may be obtained. Therefore, the flash evaporation is one of the most important tools for compound semiconductor thin film research.

Since last July, we started to design, install, and test our new flash evaporation system, which is described in Figure 10. There are two right-angle drives connected to the mechanical feedthrough. A wire is connected at the end of one of the right-angle drives. This wire serves as a feeder for the compound semiconductor powder. The vibration of the mechanical feedthrough will drive the metal wire to have up and down motion through the powder holder. Then the compound semiconductor powder will be carried out by up and down motion of this metal wire. When the powder is dropped down from the holder, the powder will slide down through the V-shaped sender to the heater (fused quartz boat). Carefully adjusting the

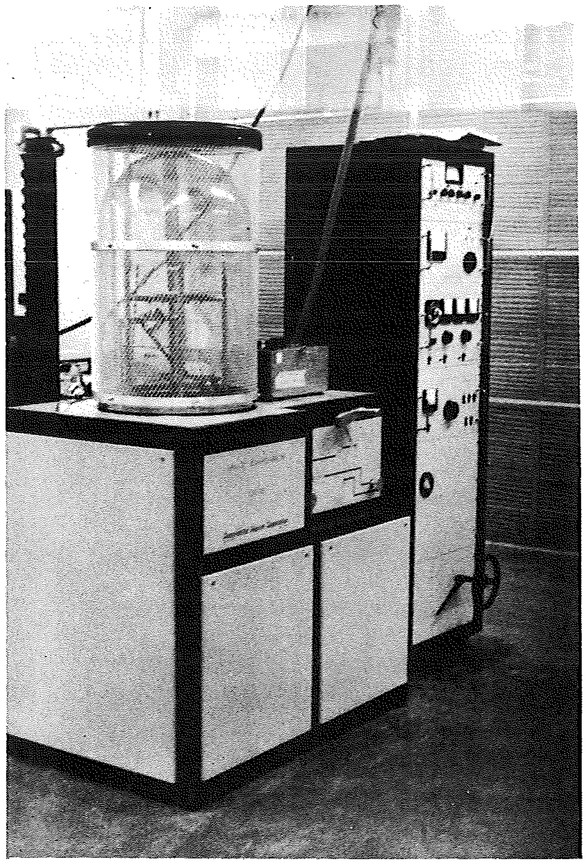


Figure 10.
Flash evaporation
vacuum system

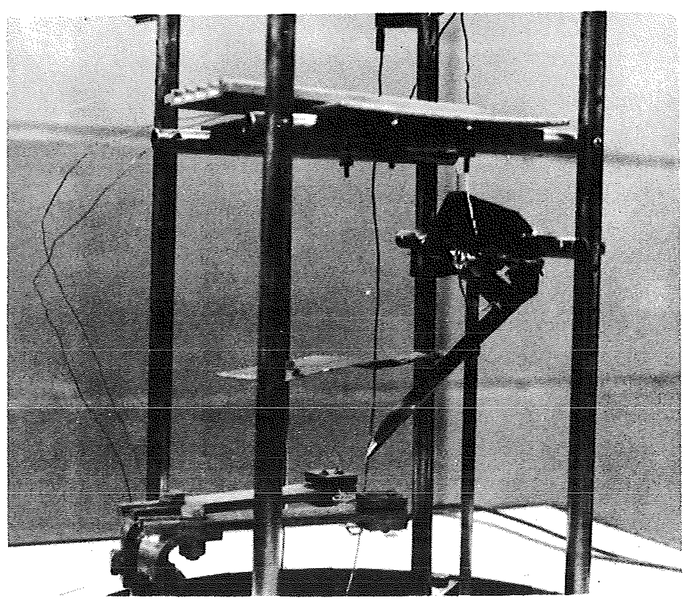


Figure 11.
Substrate heater,
powder-sending
system of the flash
evaporation system

vibration of the mechanical feedthrough will result in a fairly smooth sending rate for the compound semiconductor powder. A shutter is connected to the mechanical feedthrough. The mechanical feedthrough furnishes double action, on the shutter and on the feeding of the powder.

A substrate heater is put on the top of the glass substrate as shown in Figure 11. The temperature of the substrate heater can be measured by the iron-constantan thermocouple which is connected to the heater through the instrument feedthrough.

Testing of this flash evaporation equipment when we had completed the design and installment showed good results in the compound semiconductor thin film we obtained.

Hall Effect on InSb Thin Films

Using the flash evaporation equipment which we designed and made, a fairly good InSb thin film has been obtained. The mobility of our sample with 2000 Å thickness reaches 1000 cm^2/V-sec. However, this thin film can be used as the field effect transistor (8) but is not good for magnetoresistance devices. J. A. Carroll and J. F. Spivak (9) showed that the thicker the InSb film with proper annealing, the higher the mobility obtained. When the thickness of InSb film reaches 4 microns, the mobility tends to saturate. The mobility of our sample at this thickness is good by Carroll's standard.

We would like to get thicker film (about 5 microns) with proper annealing and substrate temperature (350°C). Hopefully, we may have very high mobility on InSb film which is suitable for the magnetoresistance devices. In the future, we will try the MOS structure electric field enhanced magnetoresistance devices which are described in the last report (1). Figure 12 shows the Hall voltage with respect to the magnetic field with different bias currents. The dimensions of the sample and the measuring circuit are shown in Figure 13.

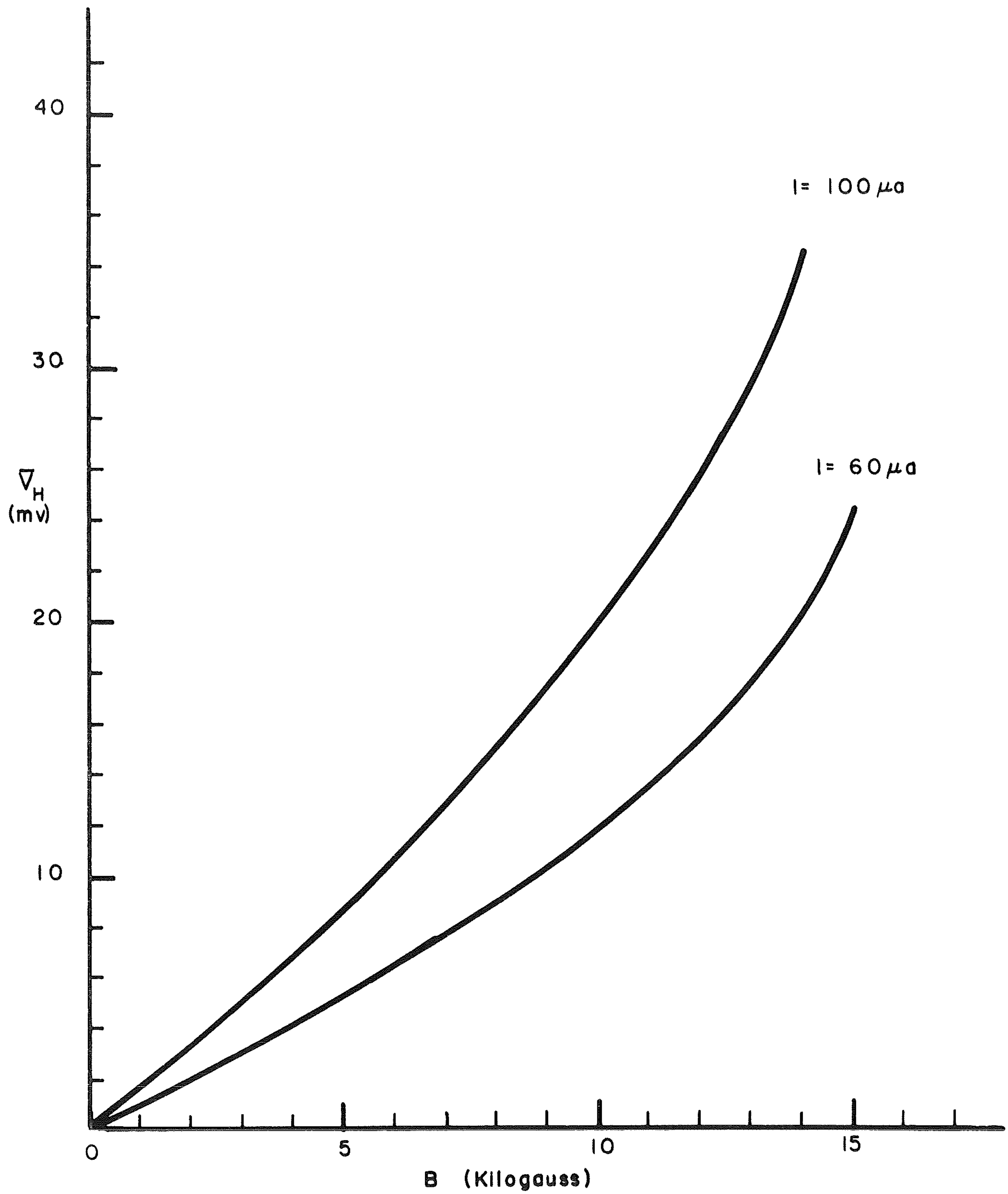


Figure 12. Hall voltage of thin InSb film with different bias currents.

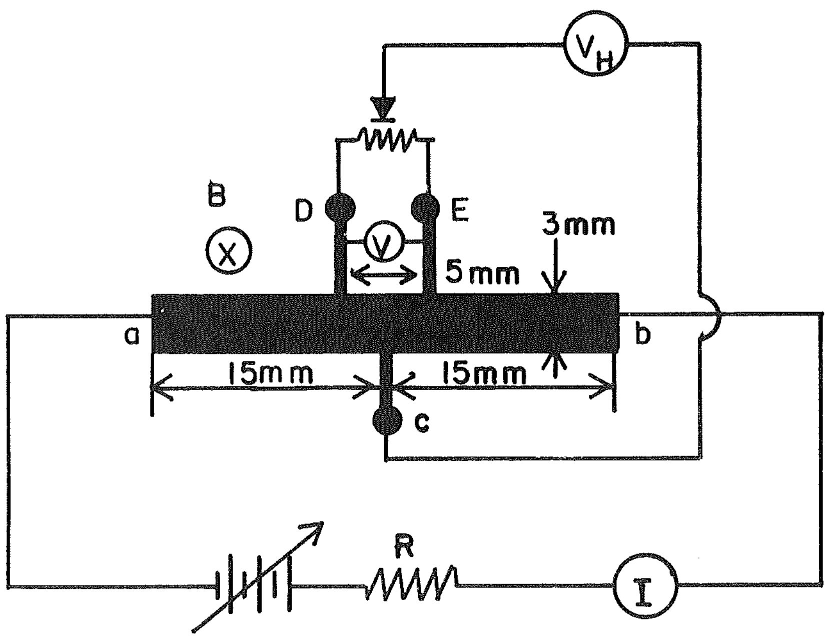


Figure 13. The InSb thin film sample with measuring circuit.

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