# TECHNIQUES TO IMPROVE THE MAGNETORESISTANCE SENSITIVITY OF InSb THIN FILMS

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***Abstract—****Thin films of indium antimonide (InSb) were deposited onto a well cleaned glass substrate by vacuum evaporation technique using InSb compound as a source material. The galvanomagnetic properties such as Hall voltage, Hall mobility and magnetoresistance sensitivity of the prepared films were investigated in terms of annealing temperature. All the measurements were taken at room temperature under the magnetic field from 0.1 T to 1.0 T. It is observed that the magnetoresistance sensitivity increases with the decrease of length to width ratio of the specimen. The magnetoresistance sensitivity of 85% was obtained for the film with the length to width ratio of 0.8, annealed at a temperature of 470$^o$C for 60 min. For further improvement of the sensitivity of the film, indium (In) short-bar electrodes were deposited on InSb film and a maximum sensitivity of 105% was successfully achieved for the length to width ratio of 0.2 and magnetic field of 1.0 T.*

***Keywords—****Galvanomagnetic properties, Hall mobility Indium antimonide (InSb), indium (In) shortbar electrode.*

## 1. Introduction

InSb has been intensively studied for its extremely high electron mobility at room temperature ($7.8 \times 10^4$ cm$^2$/Vs). It is the material best suited for galvanomagnetic applications, such as Hall devices and magnetoresistance (MR) devices. Magnetoresistors are technologically important devices owing to their numerous industrial applications [1, 2]. In industrial applications of the magnetoresistors, their sensitivity to a magnetic field is an important property. It is generally defined as the percentage change in the resistance R per unit applied magnetic field B, i.e.,

$$\frac{\Delta R}{R_0}\ \frac{100}{B}\ \%\ G^{-1} \qquad (1)$$

where $\Delta R = (R_H - R_0)$ is the change in the resistance, $R_H$ and $R_0$ are the resistances with and without magnetic field, respectively. The sensitivity of the device depends on two factors: (1) the free carrier mobility (normally the electron mobility) and (2) the device geometry. Thus, amongst the intermetallic compound semiconductors, InSb is a widely used material for fabricating magnetoresistors. Lippmann and Kuhrt [3] in 1958 showed that the MR effect depends strongly on the geometrical factor L/W, where W is the width of the current path, and L is the distance between two Hall probe electrodes. Weider et al. back in 1995 reported that the specimen with a lower L/W ratio give high sensitivity [4]. Devices with a linear geometry generally have a lower sensitivity because of Hall voltage generated across the device when it is subjected to a magnetic field. To improve the sensitivity of linear devices, therefore, the Hall voltage has to be short-circuited by metal layers that reduces effective length-to-width ratio.

Similarly, in "Fedplatte" magnetoresistors [5] crystalline InSb is used for high mobility and metallic inclusions are used to short-circuit the Hall voltages. In this case high conductivity NiSb needle inclusions are produced in the InSb crystal during crystal growth and the resistors are fabricated such that the NiSb needles are perpendicular to the current path and to the magnetic field.

Many workers have reported InSb magnetoresistor in which the Hall voltage is short-circuited either by dendrites formed during recrystallization of the film [4] (in which excess indium is incorporated) or by depositing short bar electrodes [6] onto the surface of the InSb films. In the dendritic films, the dendrites of In which are formed may not be effective in the process of short circuiting the Hall voltage as they have random orientations. The sensitivity in this case is only about 30% KG$^{-1}$. On the other hand, the sensitivity of InSb films for the latter case is of about 70% KG$^{-1}$. Recently, Okamoto et al. [7] obtained the magnetoresistance sensitivity of about 75% for InSb films deposited on GaAs using In-shortbar electrodes on the surface of InSb. Until now the highest magnetoresistance sensitivity of 155%KG$^{-1}$ was achieved by Masahide Ohshita [8] with a length to width ratio (l/w) of 0.4 for the films deposited on mica substrate.

This paper discusses a low cost technique to achieve quite a high sensitivity comparable with those of the single crystal and thin film magnetoresistors.

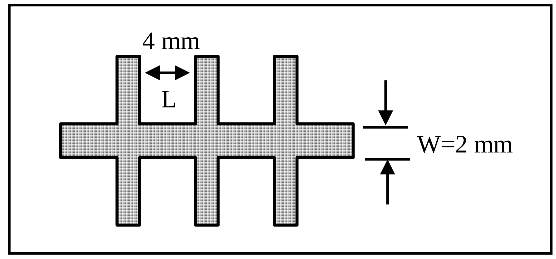
## 2. Experimental Procedure

Thin films of InSb were prepared by evaporating high purity (99.999%) InSb compound onto well-cleaned glass substrates using a conventional vacuum evaporation method at a pressure of less than $10^{-5}$ Torr. Corning 7059 glass was used as a substrate with a mask for galvanomagnetic measurements. The alumina coated tungsten basket was used to evaporate InSb compound. The distance between source material and substrate was about 10 cm. All the films in the present work were deposited at the fixed deposition rate of 10 nm because at this rate the stoichiometric film could be achieved [9]. Since the magnetoresistance sensitivity of InSb films depends on the geometry of the sample, therefore, different types of masks having different geometry (L/W) were used in the present work.

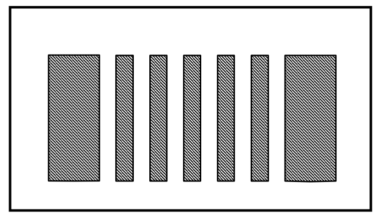
To improve the sensitivity of InSb films, some samples were prepared with shortbar electrode of indium (In) deposited on InSb films. For this procedure, InSb films were first deposited on glass substrate with a mask shown in Figure 1 (a). The substrates were then allowed to cool to room temperature and indium (In) shortbar electrodes were then deposited on InSb films using a new mask as shown in Figure 1 (b) resulting a pattern as in Figure 1 (c). The deposited InSb films with-and without-shortbar electrodes were then annealed at the elevated temperatures between 400 and 490$^{o}$C. The electrical and galvanomagnetic measurements were carried out at room temperature under a magnetic field from 0.1 T to 1.0 T and passing a current of about 5 mA through the films.

## 3. Experimental Results and Discussions

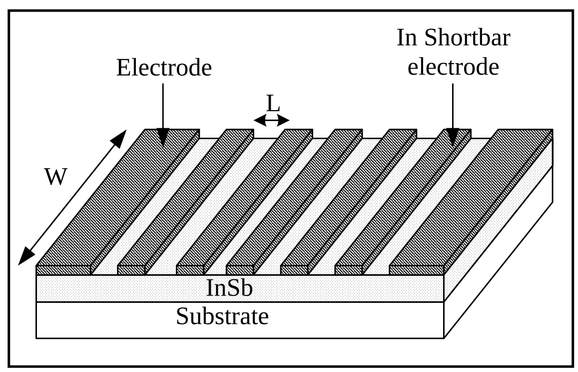
Figure 2 shows that the Hall voltage increases with increasing annealing temperature up to 470$^{o}$C, and then decreases. At higher annealing temperature the re-evaporation of Sb from the films occurs that may result in imperfections and defects in crystal structures. The decrement of Hall voltage at higher annealing temperatures may be due to the impurity scattering associated with the re-evaporation of Sb. On the other hand, Hall voltage slightly increases with increasing L/W ratio. For rectangular shaped specimens with L≤W, there is not much length available for the current lines to become parallel to the x-axis. Therefore, the Hall voltage can not be fully developed across the sample to counteract the Lorentz force. This results slightly lower voltage for the wide specimen.




(a) Mask Pattern, L/W = 2.0



(b) Mask Pattern




(c) Film Pattern

**Figure 1: Shematic patterns of InSb films.**

Figure 3 shows a similar tendency that the Hall mobility increases up to 470$^{o}$C, and slightly increases with increasing L/W ratio. The increment of Hall mobility with the increase of L/W ratio is due to the increment of Hall voltage with increasing L/W. The maximum Hall mobilities of $1.289\times10^4$, $1.329\times10^4$ and $1.351\times10^4$ $cm^2/Vs$ were obtained for the films annealed at 470$^{o}$C for 60 min with the L/W ratio of 0.8, 1.3 and 2.0, respectively. The results indicate that the Hall mobility does not depend markedly on the length to width ratio of the sample. This is consistent with the theoretical result obtained by Kataoka et al. [2].

Figure 4 shows the percentage change of resistance (MR) as a function of the magnetic field for the films annealed at 470$^{o}$C for 60 min. The

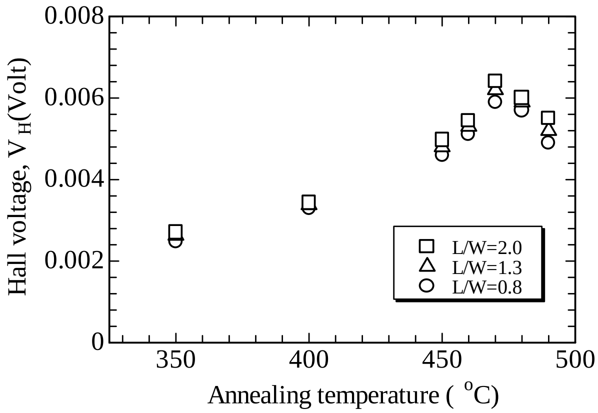



**Figure 2: Dependence of Hall voltage on annealing temperature for films with various L/W ratios.**

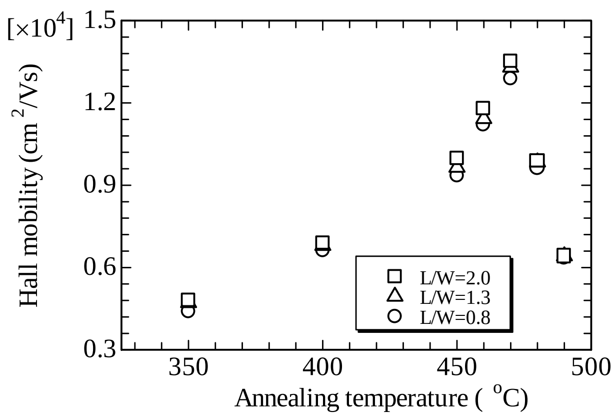



**Figure 3: Dependence of Hall mobility on annealing temperature for films with various L/W ratios.**

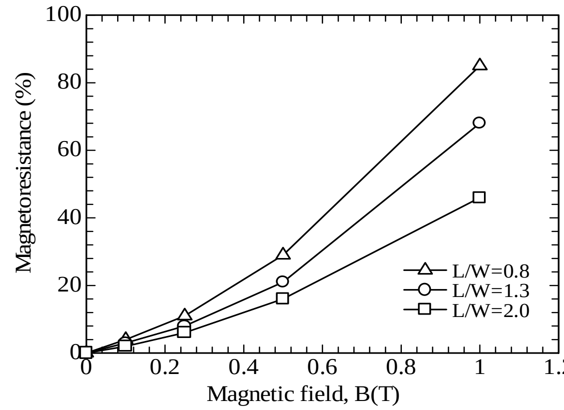



**Figure 4: Percentage change of resistance (MR) as a function of magnetic field for films with different L/W ratio.**

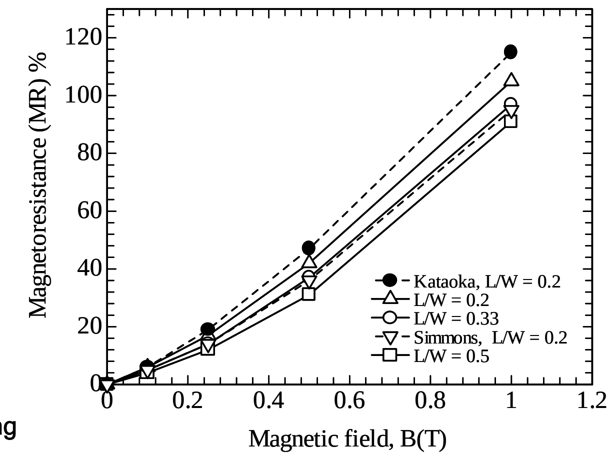



**Figure 5: Magnetoresistance sensitivity of InSb films as a function of magnetic field. All the films are annealed at 470°C for 60 min. The solid curves indicate the present data and dashed curves replotted from the results in ref. [2] and [10].**

magnetoresistance increases with the increase of applied magnetic field. The increase is reasonable because the magnetoresistance is directly proportional to the square of the magnetic field. Furthermore, the magnetoresistance increases with the decrease of L/W ratio, which means that the sensitivity increases with increasing the width of the sample. This can be explained by assuming that when the width of the specimen is comparatively larger than that of length between two electrodes, the Hall voltage becomes shorted out. The current path in such a short, wide sample is longer than that in the same sample at zero magnetic fields. This leads to a large increase in resistance. The maximum magnetoresistance sensitivity of 85% was obtained here for the films with L/W ratio of 0.8. The results are more consistent with the theoretical results [3].

For further improvement of the magnetoresistance sensitivity of InSb films, In-shortbar electrodes were deposited on InSb films in the present study. The magnetoresistace sensitivity of the prepared films was measured at room temperature. Figure 5 shows the magnetoresistance sensitivity of InSb films as a function of magnetic field for the films annealed at 470°C for 60 min. The solid curves represent the results of the present study and the dashed curves replotted from the results of Kataoka et al. [2] and Simmons et al. [10] are also shown here as a comparison. All the curves show the similar tendency that the magnetoresistance increases with the increase of applied magnetic field. But the sensitivity increases with the decrease of L/W ratio. The highest magnetoresistance sensitivity of 105% was obtained in the present study with L/W ratio of 0.2 in a magnetic field of 1T. The results indicate that the sensitivity of InSb films can be increased with the decrease of L/W, a consequence of more effective shunting of the Hall voltage. It is evident that the present results are in good agreement with others and with theoretical results [3] Hall voltage if short-circuited thus improves the sensitivity of InSb films.

## 4. Conclusion

The magnetoresistance sensitivity was found strongly dependent on the length to width ratio of the specimen. The magnetoresistance sensitivity of 85% was obtained for the InSb films (without depositing shortbar electrodes) with the length to width ratio of 0.8 measured at room temperature in a magnetic field of 1T. For the further improvement of the magnetotesistance sensitivity of InSb films, In-shortbar electrodes were deposited on InSb films. The highest magnetoresistance sensitivity of 105% was successfully achieved in the present study with the length to width ratio of 0.2. The improvement of magnetoresistance sensitivity is ascribed to short-circuited the Hall voltage that reduces the effective length to width ratio. The magnetoresistance sensitivity of the present study is comparable to those of others [2] for single crystal InSb. Therefore, it can be said that the improved technique employed in the present work provides the high sensitivity InSb films comparable to those of single crystal InSb and will be usable in various magnetic sensor applications.

## 5. References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