High sensitivity InSb Hall device and its practical application.

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1. introduction

A Hall device is a semiconductor magnetoelectric conversion device that uses the Hall effect, which is caused by charged particles (electrons or positively charged holes) traveling in a solid body subjected to a force at right angles to the direction of motion due to the presence of a magnetic field. A Hall device is an element that is configured to extract a voltage signal proportional to the flux density of the magnetic field applied to the device by the Hall effect of a semiconductor, that is, the Hall output voltage o R_H all voltage. Now, the Hall devices developed and commercially available to date use the Hall effect of n-type semiconductors (InSb, InAs, GaAs, Si, Ge, etc.).
The photo shows the InSb Hall devices HW-300A, HW-300B, and HW-101A developed by Asahi Kasei. InSb
As you can see in this photo, the Hall element has four leads and is packaged in resin. As mentioned above, Hall elements are small and simple magnetic field detection elements (so-called magnetic sensors). Although the market for such Hall devices has grown significantly in the past few years. In 1987, although it is estimated, the production of Hall elements is well over 300 million units per year.
The reason for the expansion of the Hall element market is that small motors using Hall elements are
This is because the technology of DC pledgeless motors (so-called Hall motors) has advanced rapidly with the advent of high-performance Hall elements, and Hall motors have become indispensable for equipment such as rapidly developing VTRs, CDs, 8mm VTRs, Flobbie disk

drips, and hard disk drips. Therefore, the expansion of demand for Hall elements is linked to the expansion and spread of the above-mentioned equipment.
Asahi Kasei has been developing lnSb Hall elements by vacuum deposition method from an early age, and as a result, it has developed the "high-degree InSb Hall element" that is currently used in the market. In other words, we have industrially perfected a technology to obtain high electron mobility and high jit resistance by vacuum deposition method and developed a high-degree InSb Hall device with a magnetic amplification structure that sandwiches thin films from top to bottom by ferrite.
This Hall element was the catalyst for changing the common sense of InSb Hall elements.
Expensive and hard-to-obtain magnetic sensors, hard-to-use magnetic sensors, etc.It was an opportunity to completely change the image of Hall elements, and to change the usage method from the constant current drive method, which had been established as the driving method for Hall elements, to the constant voltage drive method that is now widely practiced. Since then, it has been used in large quantities as magnetic sensors for DC placid motors, and it is still used today.
In this way, if we think about the reason why Asahi Kasei's Hall elements are used in large quantities today, the background is considered as follows. The first is in a magnetic field with a small input voltage, such as a 1V input, and a magnetic flux density of about 0.5KG, which can be simply made with a normal ferrite magnet. The high degree of disturbance obtained with a large output of 100~270mV, and secondly, the temperature change of the Hall output voltage of the previous InSb Hall element was very large at -2%/deg., which was the biggest cause of its difficulty in use, while the Hall element developed in this case had an input resistance of about 350Ω, which was very large compared to the conventional Hall element. For this reason, a constant voltage of 1~2V was applied to the input terminal of the Hall element
This made it possible to drive in a state, and the so-called constant voltage drive method was possible, and the temperature change of the Hall output voltage near room temperature was almost eliminated. When applied to motors, etc., there is no need for temperature correction of Hall output voltage, and the operating conditions can be greatly improved. The third reason is that it is now possible to supply products with low prices and large quantities of performance. In addition, these performance, cost, and supply problems have been solved, and the reliability of the Hall element has been resolved. The improvement to the level of Si-based semi-pure body devices was also an important factor in mass use. In other words, the emergence of highly reliable Hall devices that can be used in large quantities with confidence. In addition, because of the significant progress in LSI technology after the oil shock, the drive circuits of Hall motors, which would be very expensive to manufacture discretely, have been converted into

ICs, leading to a situation where they can be manufactured in large quantities and at low prices. In addition, Japan's electrical manufacturers have announced that the next color TV
As a large-scale product, it was moving in the direction of VTR development, and there was a great need for the development of a small, low-noise DC brushless motor. As a magnetic sensor that is qualified to meet the requirements in such an objective situation, it can be said that the highly sensitive InSb Hall element developed in this case was well received.

2. Overview of Technology Development

In 1973-1974, Asahi Kasei Kogyo Suzu was engaged in the development of various sensors for the activation of airbags as an automobile safety system, and this development began when the future potential of InSb thin-film Hall elements as magnetic sensors was focused on when one of them was taken up.
At that time, only Hall devices were available in which a single crystal was first sliced, thinly polished, and an electrode was attached to a thickness of about 5~20 μm, and was used for special purposes such as measurement. In addition, the price of a single Hall element was high, ranging from hundreds of yen ~ thousands of yen, or more, making it difficult to obtain Hall elements as low-cost, versatile, and highly sensitive magnetic sensors as they are now.
Around this time, research on DD (direct drive) motors for players began to improve the performance of audio players, especially to reduce noise and improve wah flutter, and there was a very strong demand for low-cost, high-sensitivity Hall elements.
Furthermore, Hall devices are expected to have a large market in the future as sensors for DC motors and plans to develop highly sensitive Hall elements targeting this field have begun.
The sensitivity of the Hall element increases in inverse proportion to the thickness of the semiconductor used, and since the material with high electron mobility is good, the material is InSb, and the vacuum deposition method was considered as a thin-film technology. As a deposition substrate, we tried to form a polycrystalline InSb thin film on top of the natural mica by taking advantage of the extremely flat and heat-resistant surface of natural mica, and succeeded in finding conditions with a thickness of 0.8~1.0 μm, large sheet resistance, and electron mobility of 20,000~30,000 cm/V·sec. By adopting a magnetic amplification structure that sandwiches this thin film from top and bottom with ferrite, we succeeded in designing and prototyping an InSb Hall device with unprecedented sensitivity. The high-sensitivity InSb Hall element produced by this technology was immediately found to be ideal for DD motors for audio players, and development began in earnest.
After that, he continued his research, examined the deposition method, established industrial wafer process technology, reliability technology, etc., conducted user evaluations, and started

a mass production plant for high-sensitivity Hall elements in Nobeoka in August 1980. From the beginning of development, there was a very strong demand for high-sensitivity Hall elements, and Hall motors using Hall elements were adopted in audio players, and they first occupied the mainstream of audio players. Next, the development of electronically controlled high-performance Hall motors that do not generate noise in principle, have good control accuracy, and can be miniaturized for VTRs has met the demand, and first, the cylinder motors of VTRs have been converted to Hall motors, and the demand for Hall elements has grown rapidly. In addition, this technology has spread to microcassette and CD drivers and is rapidly being adopted into motors in the field of office automation.

For this reason, the production technology of high-sensitivity Hall elements was also required to be produced efficiently in large quantities and at low cost, and the current Hall elements were completed by developing technologies such as device design for mass production and the incorporation of wire bonding.

Table 1 briefly summarizes the development history of high-sensitivity InSb Hall devices.

In addition, Table 2 summarizes the characteristics of the developed high-sensitivity InSb Hall element. These features make it a suitable magnetic sensor for high-performance DC brushless motors due to its small size.

3. Hall element operating principle, driving method, unbalanced voltage

Next, we will describe the operating principle of this Hall element and the unbalanced voltage. In Fig. 1, the schematic diagram of the Hall effect of the Hall element of an N-type semiconductor with a width w, length l, and thickness d is shown schematically. In FIG. 1, 1 and 3 are the input control current terminals (input electrodes), and 2 and 4 are the Hall output voltage terminals (output electrodes).

When an input control constant current I is passed through the input electrodes 1 and 3 and a magnetic field of magnetic flux density B is applied perpendicular to the semiconductor piece, the Hall output voltage V_H generated between the output electrodes 2 and 4 is given by the below formula. [1,2)]

$V_H = R_H \cdot I \cdot B/d$ (1)

Here R_H is the Hall coefficient. In the model where only simple electrons exist as carriers, they are given as $R_H = 1/e{\cdot}n$ (e = charge of electrons, n = concentration of electrons).

In addition, in actual Hall devices, there is a shape effect that depends on the shape of the semiconductor L/W, but it was ignored because it was small. $KH \equiv R_H / d$ is a quantity called constant current product sensitivity, which indicates the sensitivity characteristic of Hall elements to the magnetic field. In general, the higher this value, the greater the Hall voltage and the better the magnetic detection characteristics.

In order to increase this value, it is necessary to increase the Hall coefficient or reduce the thickness of the semiconductor, that is, to reduce d. When using InSb to make Hall devices, the value of the Hall coefficient is often determined in the process of manufacturing semiconductors, and it is difficult to control because it is in the true region at room temperature. In general, it is determined by the purity and crystallinity of the InSb used. However, the thickness of the semiconductor D can be changed quite freely during the manufacturing process. Therefore, a method is currently being taken to increase the volume sensitivity of Hall devices by reducing the thickness of semiconductors. When creating Hall elements by vacuum deposition, the thickness of InSb is ideally about 1 μm.

Next, the Hall voltage V_H when a constant input voltage Vin is added to the input electrode of the Hall element is given by the following equation if the magnetic field is small and the resistance change of the Hall element due to the magnetoresistance effect is small3)。

$$V_H = \mu H \cdot w/l \cdot Vin \cdot B \quad (2)$$

Here, μH is the electron mobility (Hall mobility) of the semiconductor. KH' is called constant voltage product sensitivity, which indicates the sensitivity characteristic of the Hall element to the magnetic field at constant voltage input. The magnetic field detection performance of the Hall element is better if the KH' is larger.

In order to increase KH', the electron mobility of semiconductors needs to be large. Now, strictly speaking, when the electron mobility μH is large, the proportional characteristic of the Hall voltage to the magnetic flux density decreases due to the magnetoresistance effect. Therefore, it is difficult to obtain the proportionality of the Hall output voltage to the magnetic flux density up to high magnetic fields. However, the magnetoresistance effect can be ignored in a low magnetic field, that is, a good field proportionality of the Hall output voltage can be obtained according to Equation (2). Furthermore, in the constant voltage drive of the Hall element represented in Equation (2), the temperature change of the Hall output voltage V_H is extremely small, and when using the InSb Hall element in the temperature range near room temperature, the drive by the constant voltage input is extremely important from a practical point of view. This constant voltage drive was put into practical use for the first time by a high-resistance deposition Hall element using an InSb thin film with a thickness of less than 1.0 μm fabricated by vacuum deposition.

Now, in Hall devices that are actually manufactured, there is always a deviation in the symmetry of the input electrode, and in semiconductors made of thin films, there is an uneven distribution of the electric field in the semiconductor, and an offset voltage is generated at the output electrode of the Hall element even when the magnetic field is not applied.

This is usually called unbalanced voltage Vu, and is expressed as the potential difference between the output electrodes 2 and 4 when a constant current or voltage is input between the input electrodes 1 and 3 in the absence of a magnetic field. Therefore, the Hall output voltage V_H of the Hall element is obtained by subtracting the unbalanced voltage Vu from the actual potential difference between the output electrodes.

Unbalanced voltage is undesirable for use and is proportional to the voltage applied to the input electrode of the Hall element, and can be either positive or negative.

Although it is undesirable in terms of use, unbalanced voltages are inevitably generated due to the manufacture of Hall elements. Therefore, how small the unequilibrium voltage is compared to the Hall voltage when the Hall element is actually used is an important point in determining the quality of a practical Hall element along with high sensitivity. It is generally displayed as a value under a constant input condition of Vu or as a value in Vu/ V_H. In particular, when using Hall elements as sensors for detecting small magnetic fields, the unbalanced voltage must be kept as small as possible.

In order to reduce the value of the unequilibrium voltage of the Hall element, it is necessary to improve the pattern formation accuracy of the Hall element, to reduce the variation of the in-film characteristics of the thin-film InSb, to reduce the variation of the sheet resistance value distribution, and to make the film thickness distribution uniform. From this point of view, InSb Hall devices made by vacuum deposition have a small unequilibrium voltage and are easy to obtain with high sensitivity by uniformly distributing the film thickness and sheet resistance.

Figure 2 shows an example of a pattern of Hall elements in practical use. As can be seen from Figure 2, in the actual Hall element, the input electrode and the output electrode are formed symmetrically.

Fig. 3 shows the relationship between Hall output voltage V_H, unbalanced voltage Vu, and voltage Vout between output terminals. Vu can be positive or negative, and this figure shows the case of Vu>0. The dashed line shows the case of an ideal Hall element with Vu=0. In this case, the Hall output voltage and the voltage between the output terminals of the Hall element match. In general, V_H >Vu is required when using Hall elements, and for this to do this, either the magnetic field applied to the Hall element is larger, or the Vu is smaller, and furthermore, the sensitivity of the Hall element is larger. however

The size of the applied magnetic field is usually determined by the purpose of use, and since the Vu is determined by the manufacturing process, it is required to reduce the Vu in the process and increase the sensitivity of the Hall element in the practical Hall element. When the magnetic field used is large, the conditions for unequilibrium voltage are relatively mild, but when used with a weak magnetic field, the conditions are severe and high sensitivity of the device is required.

4. Structure and high sensitivity of InSb Hall element

Hall elements have two different structures3). The first type is basically a structure in which the thin-film Hall element part of InSb formed on a non-magnetic substrate such as ceramics is packaged as it is, and no ferromagnetic material is used in the Hall element. In the Hall element of this structure, according to equations (1) or (2), the Hall voltage V_H has a V_H -B property proportional to the magnetic flux density B, as shown in (A) in Fig. 4. On the other hand, the second type of structure is a soft ferrite ferromagnet, which is highly sensitive by sandwiching the Hall element part consisting of a thin film of InSb from the top and bottom. In this case, due to the saturation of the magnetization of the magnetic material, there is a bend point in the V_H -B properties of the Hall element, and the V_H -B property has a proportional limit. This structure is adopted for the purpose of increasing the sensitivity of Hall elements in low magnetic fields and has the advantage of increasing Hall voltage V_H without increasing the unequilibrium voltage. This is called magnetic amplification or magnetic flux effect of Hall elements, and it is extremely useful in practical use, and it has been incorporated into practical use by increasing the sensitivity of the InSb Hall element developed in this study.

Now, as shown in Fig. 5, consider a case where the magnetistic part of the Hall element is sandwiched with a ferromagnet from top to bottom, and the whole is placed in a uniform external magnetic field. In this way, the magnetic flux density B' actually received by the Hall element becomes B' when the magnetic flux density of the external uniform magnetic field is set to B'> B due to the magnetization of the upper and lower ferromagnets, and the Hall output voltage is greater than that without the ferromagnet (amplification effect only by the applied magnetic field).

For example, for the sake of simplification, the upper and lower ferromagnets are cylindrical in shape, with a diameter of 2A and a thickness of h/2, and the gap inserted by the Hall element is negligible enough to be negligible compared to the thickness of the ferromagnet h/2. Furthermore, since the permeability of ferromagnets is large enough than normal, the magnetic flux density applied to the Hall element is the antimagnetic field coefficient of a cylindrical magnetic material with a height h and a diameter of 2a as L.

$B' = (1/L) \cdot B$ (3)

The magnetic flux density B' is expressed by the above equation. Therefore, the output voltage V_H of the Hall element is doubled by 1/L when $B/L \leqq Bs$

$V_H = R_H \cdot (I/d)$ and (B/L) (4)

The Hall voltage V_H is expressed by the above equation. However, Bs is the saturated flux density of ferromagnets.

In general, the antimagnetic field coefficient is determined only by the shape of the ferromagnet, and in this example,

$L=1-h/\sqrt{(h2+4a2)}<1$ (5)

The antimagnetic field coefficient L is expressed by the above equation.

As can be seen from this example, it is generally L<1, and by designing the value of L appropriately, the magnetic flux density applied to the Hall element can be several times the magnetic flux density B of the external magnetic field according to Equation (3). Moreover, in this case, of course, there is no increase in the unbalanced voltage.

The proportional limit of the Hall output to the external flux density of the magnetically amplified Hall element is

$B=LBs$ (6)

The magnetic flux density is expressed by the above equation. This point is shown in (B) in Figure 4.

The increase in Hall output voltage beyond this proportional limit naturally corresponds only to the increase in external magnetic flux density, and in B>LBs,

$V_H = R_H \cdot (I/d) \cdot [(1-L) \cdot Bs+B]$ (7)

The Hall voltage V_H is expressed by the above equation.

In this equation, if L=1, corresponds to the absence of ferromagnets.

Now, the ferromagnets generally used as substrates for Hall devices are square, and the ferromagnets used as counterparts are often cylindrical or prismatic, and their size is generally smaller than that used as substrates for Hall devices, that is, on the lower side. The antimagnetic field in this case is slightly more complex than Equation (5). Since the saturated flux density varies depending on the material such as ferrite and permalloy, the V_H -B characteristics of Hall devices sandwiched with ferromagnetic materials can be varied. However, in the case of Hall elements using ferrite, which are generally available for practical use, about 1 KG is the proportional limit. Some of the especially sensitive ones have a proportional limit of 500G or less.

Now, for InSb deposition Hall devices, the thickness of the thin film of the magnetically sensitive semiconductor is less than 1.0 μm, and the gap between the magnetic materials can be small enough, so the above magnetic amplification can be easily realized. Fig. 6 and Fig. 7 show the structure of these InSb deposition Hall elements in a cross-sectional view. Fig. 6 is

the first type, that is, the type without magnetic amplification, and there is no proportional limit in the V_H -B characteristics, and Fig. 7 is a Hall element with a magnetically amplified structure sandwiched with ferrite. In the example shown in Figure 6, ceramics are generally used as Hall substrates. In the example in Fig. 7, soft ferrite is used as a pole element substrate, and as the other ferromagnetic material, a cube of soft ferrite similar to the substrate material (called a magnetic amplification chip) is used.) is used.
In addition, FIG. 8 shows how such a Hall element is packaged with resin in a cross-sectional view.

5. Manufacturing process of high-sensitivity InSb Hall elements

Here, I would like to describe the basic process of InSb deposition Hall elements and vacuum deposition. When manufacturing Hall elements by vacuum deposition method, as mentioned above, the production of InSb deposition thin films with high electron mobility becomes a problem, and then this thin film is photolithography to form a tiny Hall element pattern, and then the Hall element is fabricated through processes such as electrode attachment, ferrite tip insertion for magnetic amplification, lead wire bonding, and resin molding. Figure 9 shows the flow chart of the process of making such a Hall element.
In the vacuum deposition process, the thin film properties of InSb, which determine the basic characteristics of the Hall element, are determined, and in the etching process, the input/output resistance value and rated characteristics of the Hall element are determined according to the design values. Except for the vacuum deposition process, it is a manufacturing process similar to that of general semiconductor devices, and as a process unique to high-sensitivity InSb Hall devices, there is a process of placing ferrite chips (0.3~0.5 mm square cubes) for magnetic amplification5,6).
Now, the biggest problem when fabricating InSb Hall elements by vacuum deposition is how to obtain a thin film with high electron mobility. Several slightly different methods have been proposed as vacuum deposition methods for industrial obtaining InSb deposition films with a film thickness of less than 1 μm and electron mobility values of 10,000 $cm^2/V{\cdot}sec$ or more. By appropriately selecting several conditions for each method, it is possible to produce electron mobility μH of 10,000 $cm^2/V{\cdot}sec$ or more. Also, from a laboratory point of view, this is not the case.
Now, the reason why InSb deposition is particularly difficult is the big difference in vapor pressure between In and Sb. For this reason, when InSb is deposited in a vacuum, the atomic

ratio of In and Sb is 1:1 in the thin film of InSb deposited on the substrate. There is a problem that the so-called stoichiometric composition does not constitute, and the semiconductor properties of the formed thin films are extremely reduced. Another problem is that the thin films produced by deposition are polycrystalline, and the size of these crystal particles greatly affects the characteristics of semiconductors, but the state of these crystal particles varies greatly depending on the deposition conditions. Therefore, if these factors that affect the characteristics of semiconductors are not properly controlled, it is impossible to obtain a deposited film of InSb with good properties.

In general, the conditions for the deposition of InSb are heated and evaporated at 10-6 Torr levels, and at the same time, a thin film of InSb is deposited on a heated deposited substrate that is set at the top opposite and heated. However, when deposition is performed in this way, many Sb atoms with high vapor pressure evaporate in the early stage of deposition than the evaporation source, and the residual In mainly evaporates in the later stage. On the other hand, on the substrate, the reevaporation of Sb atoms with overwhelmingly high vapor pressure is large (the attachment probability of Sb atoms is smaller than that of In atoms).

As a result, the formed deposition film has more in atoms than Sb atoms, and the stoichiometric ratio is off. In addition, the ratio of Into Sb atoms also changes in the direction of film thickness. The composition near the substrate is close to 1:1, and the composition is more in on the surface. For this reason, it is difficult to obtain thin films with high electron mobility.

In this way, there are many difficult problems in the formation of InSb thin films by vacuum deposition, and it was necessary to develop new industrial technologies to produce thin films for high-sensitivity InSb Hall devices in large quantities and at low cost. Therefore, as a result of examining numerous conditions such as the study of large-scale vacuum equipment, the study of thin film formation conditions in vacuum, and the selection of substrates, we established a unique industrial vacuum deposition method for high-performance InSb Hall devices, and made it possible to produce InSb thin films with electron mobility of 20,000~30,000 cm^2/V·sec with a thickness of less than 1.0 μm, which was not possible until then.

In other words, as a method for obtaining high electron mobility thin films of InSb, Asahi Kasei developed a method to obtain InSb thin films with high electron mobility close to the stoichiometric composition by using thin mica as a substrate, using several ports as evaporation sources, and optimally controlling the substrate temperature according to the thickness of the InSb film to which it is attached. This method has the characteristics of being able to produce polycrystalline thin films with an electron mobility of 20,000 cm^2/V·sec or more relatively easily and stably despite being as thin as 1.0 μm or less thick. In addition, important factors in InSb deposition are the purity of the InSb used in the evaporation source and the surface condition of the substrate. The InSb used as an evaporation source should be as high purity as possible, and it is desirable to have a high-purity non-Dope product. As a substrate for deposition, it is necessary to be stable at high temperatures, without the risk of impurities being released or decomposed due to heating, and with a smooth surface and insulating properties. In addition, a smooth mirror surface is also favorable for improving thin film properties. From this point of view, mica is chosen.

Next, we will look at the characteristics of InSb thin films made by this method. In Fig. 10, the temperature dependence of the resistivity of an InSb deposition film with a thickness of 1.0 μm is shown. The horizontal axis is the reciprocal of the absolute temperature. Figure 11 shows the temperature dependence of the electron mobility of the same deposited film. As you can see from this figure, electron mobility does not change much around room temperature. At low temperatures, electron mobility tends to decrease slightly.

Due to the temperature characteristics of this electron mobility near room temperature, it is expected that the deposition Hall element will show good temperature characteristics of Hall voltage compared to Equation 2 when driven by constant voltage input. On the other hand, in the case of constant current driving, as can be seen from Equation 1, the Hall output is proportional to the Hall coefficient, so it does not show little temperature dependence as described above.

Figure 12 shows the temperature dependence of the Hall coefficient. Between the Hall coefficient R_H and the electrical conductivity σ, the electron mobility μ_H via

$\mu H = R_H \cdot \sigma$

The large temperature dependence of R_H is due to the large temperature dependence of electrical conductivity ($1/\rho$ = resistivity). This temperature dependence is due to the increase in electron concentration in the conduction band with increasing temperature. The difference in temperature characteristics of μH and R_H described here appears as the difference in temperature dependence of the Hall output voltage in Equations (1) and (2) when the Hall element is fabricated.

Using the InSb thin film prepared by the above method, the input resistance value of the Hall element can be designed to several hundred ohms, and a Hall element that can be driven at a constant voltage can be easily made. In addition, if the element resistance value is so large, the drive current is low, and the power consumption of the Hall element is also low, making it possible to manufacture Hall elements. This is a property that cannot be done with other materials or single crystals and is one of the major features of high-sensitivity InSb Hall devices.

6. Basic characteristics of deposition Hall elements

There are two types of InSb Hall devices described in Section 4. The most basic ones have structures made on a ceramic non-magnetic substrate. Asahi Kasei has put it into practical use as the HW-300C Hall element. Furthermore, the most important Hall element in practical use is the one that has been made highly sensitive by magnetic amplification by magnetic materials and has been put into practical use as HW-300A. Tables 4 and 5 show the basic specifications of these representative vapor deposition Hall elements9). In addition, the outline diagram is shown in Fig. 13.

Here, HW-300C is a Hall element with the basic structure of FIG. 6, and HW-300A is a magnetically amplified Hall element with the structure of FIG. 7. Now, the sensitivity of the Hall element is shown in the value of Hall voltage V_H when the input voltage is 1V and the magnetic flux density is 500G. In addition, the value of the unbalanced voltage Vu is expressed as the voltage between the output terminals when the input is 1 V and the magnetic flux density B=0. The unbalanced voltage Vu is very small compared to the Hall voltage V_H, and the value of Vu/ V_H (B=500G) is within ±5% in Table 5. HW-300A, that is, the practical vapor deposition Hall element with the structure shown in Fig. 7, has a Hall voltage V_H value that is about 3~5 times larger than that without a magnetic amplifier due to magnetic amplification by ferrite. On the other hand, the proportional range of Hall voltage relative to the magnetic flux density is limited.

Next, let's look at the characteristics of these devices. Figure 14 shows the relationship between the Hall output voltage V_H and the magnetic flux density of the basic HW-300C type deposition Hall element, i.e., V_H -The B characteristics are shown in the case of constant current input drive. Fig. 15 shows the characteristics of V_H -B in the case of constant voltage drive. In either case, the proportionality to the magnetic flux density is good. The difference in the magnetic flux density proportionality on the high magnetic field side compared to the constant current drive in the case of constant voltage drive in Fig. 15 is due to the magnetic field causing a magnetoresistance effect on the InSb thin film. That is, due to the magnetoresistance effect, in which the input resistance value increases very slightly in proportion to the square of the magnetic flux density. This effect is greater for materials with greater electron mobility. As long as InSb thin films with high electron mobility are used, the effect of the magnetoresistance effect appears, but it is negligible in use.

Next, the V_H -B characteristics of HW-300A, that is, a magnetic amplification type of practical vapor deposition Hall element by ferrite sandwich, are shown in Fig. 16. Figure 16 shows the case of constant current drive. The magnetic flux density proportionality of the Hall output voltage is characterized by bending around 1 KG as described in Section 4 due to the saturation of the ferrite's magnetic force. The magnitude of this proportional range generally varies in terms of magnetic amplification rate. Normally, the upper limit of this proportional range is determined in the range of 500 to 800G with a little margin.

Next, the characteristics of V_H -B in the case of constant voltage input drive, which is a commonly used driving condition, are shown in Fig. 17. In this case, too, a slight decrease in Hall voltage due to the magnetoresistance effect of the input resistor of the Hall element is observed on the high magnetic field side compared to the case of constant current. The magnetic flux density of the magnetic field when using Hall elements in DC motors, etc., is almost always within the proportional range of this Hall element.

In small motors, it is often difficult to place the Hall element in a place with a sufficiently large magnetic flux density, and a high output voltage is required at a low magnetic field. For such use problems, the proportional range of V_H -B characteristics is good at low magnetic fields, and instead, high sensitivity by magnetic amplification is required. The HW-300A Hall element is designed with its basic performance to adequately meet these application requirements, and Figures 16 and 17 are examples of typical V_H -B characteristics, usually in several types depending on the proportional range or sensitivity rank.

Next, we will describe the temperature characteristics of Hall elements, which are very important in practical use. There is a temperature dependence on the Hall output voltage of the Hall element and the temperature dependence on the input and output resistance values, both of which are important for use. Therefore, the temperature characteristics of the InSb deposition Hall element are determined by the temperature characteristics of the InSb deposition film, namely electron mobility, Hall coefficient, and resistivity.

When considering the temperature characteristics of Hall output voltages, those with magnetic amplification structures may have to take into account the temperature characteristics of the magnetic materials used. This is especially true when ferrite materials with large temperature dependence are used, and when considering the temperature characteristics of Hall output voltage near the Curie point, ferrite, which is a practical magnetic amplification material for Hall elements, is used with a material with little temperature change in the service temperature range of the Hall element, and the Curie point is much higher than the operating temperature range. Therefore, when considering the temperature dependence of the Hall output of a Hall element, there is no need to consider the effect of magnetic amplification.

Therefore, the InSb deposition Hall element exhibits the same temperature dependence of Hall voltage as shown in Fig. 6 and Fig. 7, and the temperature characteristics of the resistance value are also common to both.

Now, Fig. 18 and Fig. 19 show the temperature dependence of the Hall output voltage of a

magnetically amplified Hall element by ferrite sandwich.
Fig. 18 shows the temperature characteristics of the Hall output voltage at constant current input drive, and Fig. 19 shows the temperature characteristics of the Hall output voltage in constant voltage input drive, which is important for application.
As is evident here, for a constant current input, there is a large temperature dependence of the Hall voltage, which corresponds to the temperature dependence of the Hall coefficient, Normally, it is $(1/V_H) \cdot (dV_H/dT)_{(IC=const)} \simeq -1.9\%/deg$.
On the other hand, the temperature dependence in the case of constant voltage input drive shown in Figure 19 is flat around room temperature and does not change much even if the temperature changes. This corresponds to the temperature dependence of electron mobility shown in Figure 11 of Section 5. In fact, the temperature coefficient is $(1/V_H)$ and $(dV_H/dT)_{(Vin=const)}=+0.18\%/deg$ (low temperature) and $-0.17\%/deg$ (high temperature), which are very good temperature characteristics. As mentioned above, this temperature dependence of the Hall output voltage is a completely common characteristic of both the basic Hall element in Paragraph 4 and Fig. 6 and the type of Hall element in Fig. 7.
In the deposition of Hall elements, important technical considerations are made to utilize the temperature dependence of such a good Hall output voltage as a practical element characteristic, which is a major feature that enhances the practicality of Hall elements. In other words, in the vapor deposition InSb Hall element, the input resistance value of the Hall element is designed with a high resistance value (hundreds of Ω or more) to facilitate constant voltage driving.
Under this condition, the deposition film thickness of InSb is less than 1 μm, and a high resistance value is obtained, and the magnetically sensitive part pattern of the Hall element is obtained. It was only when L/W optimal design was made that it could be realized as a practical device. When trying to achieve high sensitivity of Hall devices, electron mobility needs to be large. As a result, the input resistance of the Hall element inevitably decreases due to the decrease in sheet resistance of the thin film. To cover this, it is essential to thin the InSb deposition film. Therefore, in order to realize the high-sensitivity InSb Hall device driven by constant voltage, an InSb deposition film with a thickness of less than 1.0 μm and an electron mobility of 20,000~30,000 cm2/V·sec was required as an improvement of deposition technology and film properties.
Next, the temperature dependence of the input resistance of the Hall element is shown in Fig. 20. This is
$(1/Rin) \cdot (dRin/dT)=-2.0\%/deg$
Be.
The output resistance of the Hall element also shows exactly the same temperature

dependence.
Figure 21 shows the V_H -I characteristics that show how the Hall output voltage of the Hall element depends on the current driving the Hall element. In the heat generated by the input control current, a slight deviation is observed in the current proportionality of the Hall voltage, that is, as in equation (1). In addition, Figure 22 shows the V_H -Vin characteristics. In this case, there is almost no deviation from Equation (2), and it only changes linearly.
As mentioned above, in the characteristics of V_H -I_C or V_H -Vin, the phenomenon caused by the increase in the temperature of the element mentioned above appears in the practical Hall element, although it is very small. However, when using Hall elements, the input voltage or input control current is used constantly, so there is no problem at all.
Finally, another feature of the highly sensitive InSb deposition Hall element is that it provides a high Hall output voltage with low power consumption. This is also characterized by low driving current, and it goes without saying that it is extremely advantageous in terms of use. In particular, it is advantageous for driving Hall elements in situations where the electrode is small, and the high sensitivity and high output characteristics of the deposition Hall element using thin films are utilized.

7. Conclusion

Hall devices are the most recently expanded applications of semiconductor devices, especially as sensors for driving motors for audio and VTR motors. The high-sensitivity vapor deposition InSb Hall element developed by Asahi Kasei has several advantageous features such as low power consumption and high sensitivity, and the temperature characteristics of InSb, which were initially regarded as a problem, have been resolved by designing a constant voltage drive element. As a result, its application is expanding, mainly in precision motors, and it is expected that further progress will be made through new applications and new device designs by taking advantage of the above characteristics. To this end, it is necessary to continue to accumulate new ideas and ideas from both the production side and the user side.
Furthermore, as the application of the Hall element itself expands in the future, improvements and performance improvements are required, and the future is expected.
Finally, I would like to note that the Hall element developed by Asahi Kasei was realized with the cooperation of many people.
In writing this article, Deputy Director General Manager Sakai of the General Department of Information Equipment Technology Development cooperated with me from beginning to end. I would like to thank you from the bottom of my heart.

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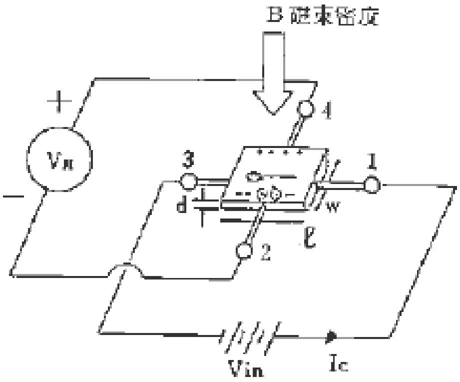
Japan Chemical Association Monthly Report May 1988 No. 15



Element form factor

d: Semiconductor thickness

W: Hall element width

l: Hall element length

Input Ports: 1,3

Output terminals: 2,4

Fig.1 Hall element drive diagram

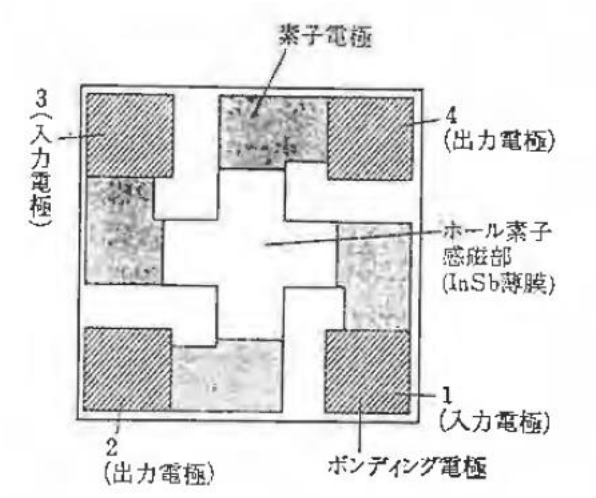


Fig.2 Example of Hall element sensing part pattern (floor plan)

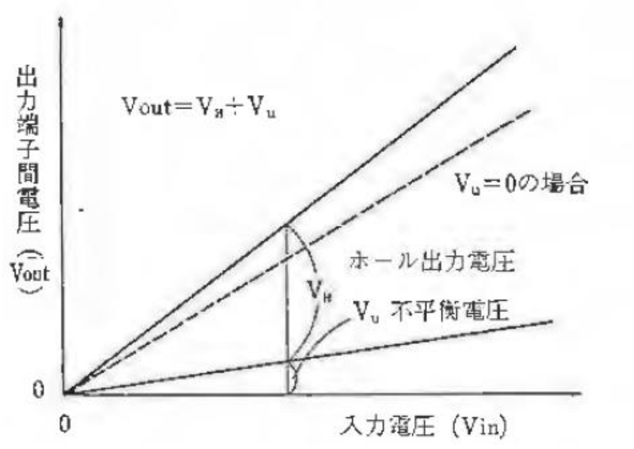


Fig.3 Input voltage and unbalanced potential of Hall element
Relationship between Hall output voltage (flux density = constant)

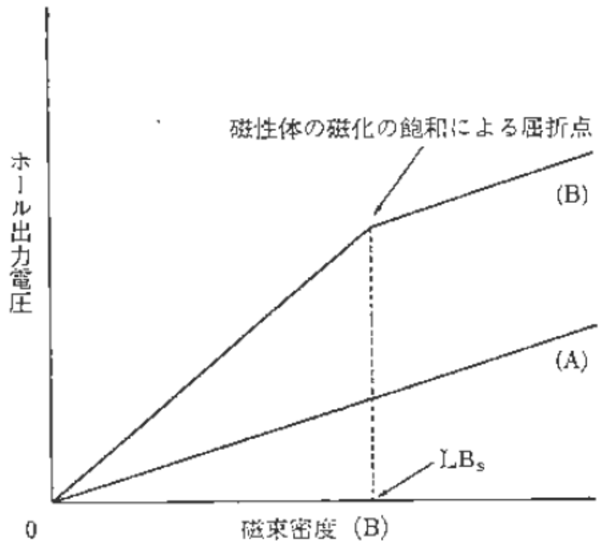


Fig. 4 Differences in the basic structure of Hall elements and V_H -B characteristics

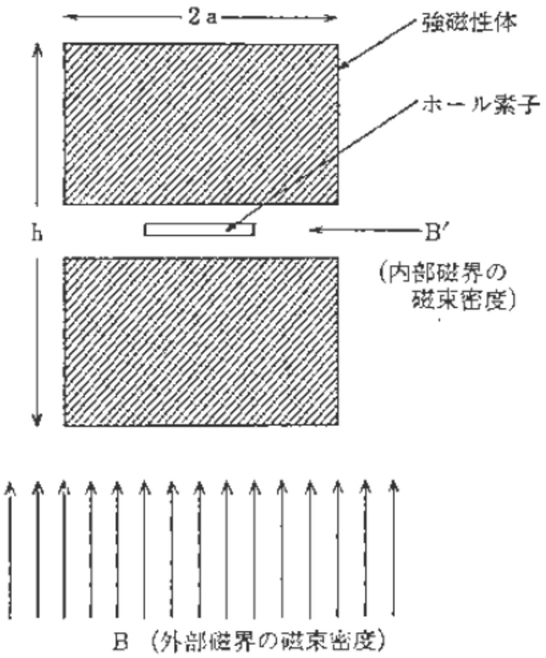


Fig.5 Principle of high sensitivity of Hall elements by ferromagnetic sandwich (B'=BJL>B)

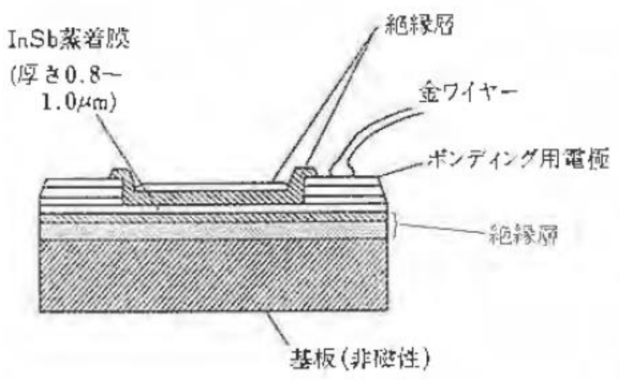


Fig.6 Cross-sectional view of Hall element

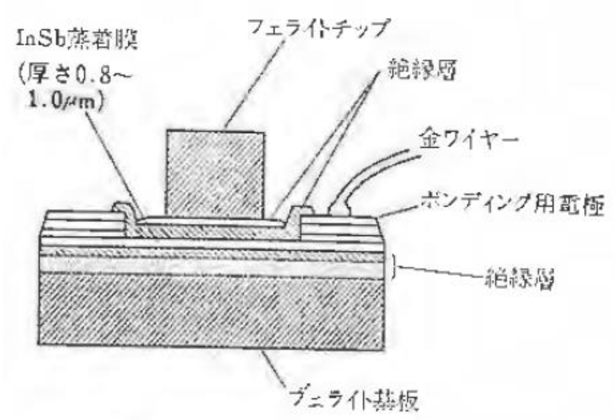


Fig.7 Cross-sectional view of Hall element (magnetic amplification type)

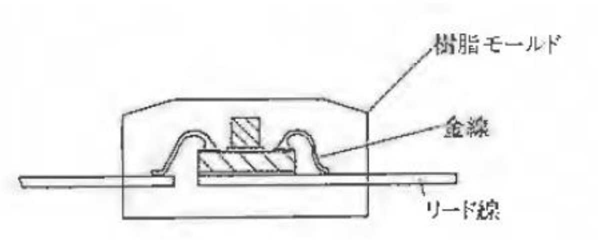


Fig.8 Cross-sectional view of a resin-packaged Hall element (HW-300A)

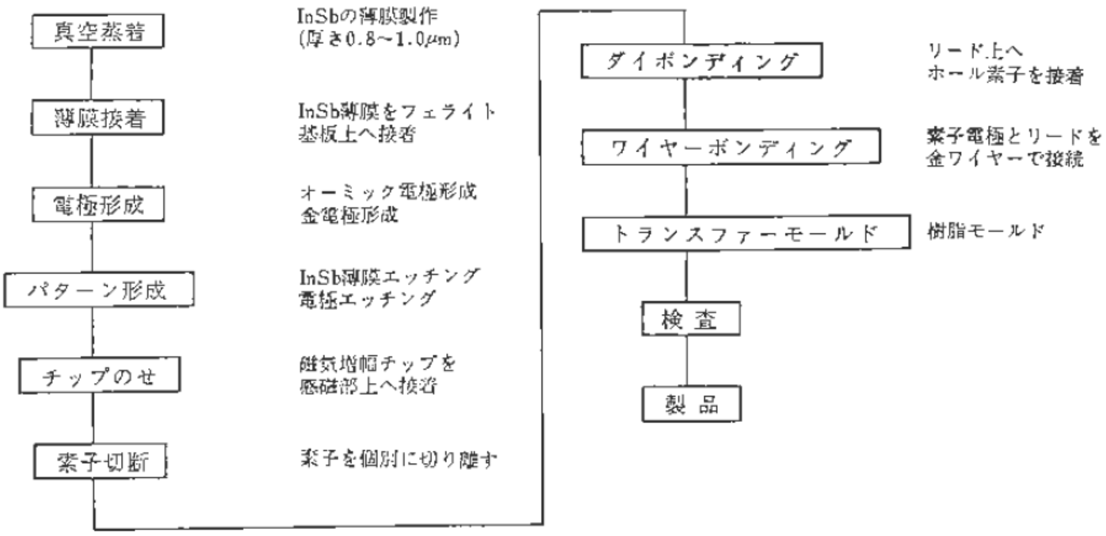


Fig.9 Manufacturing process of high-sensitivity InSb Hall element

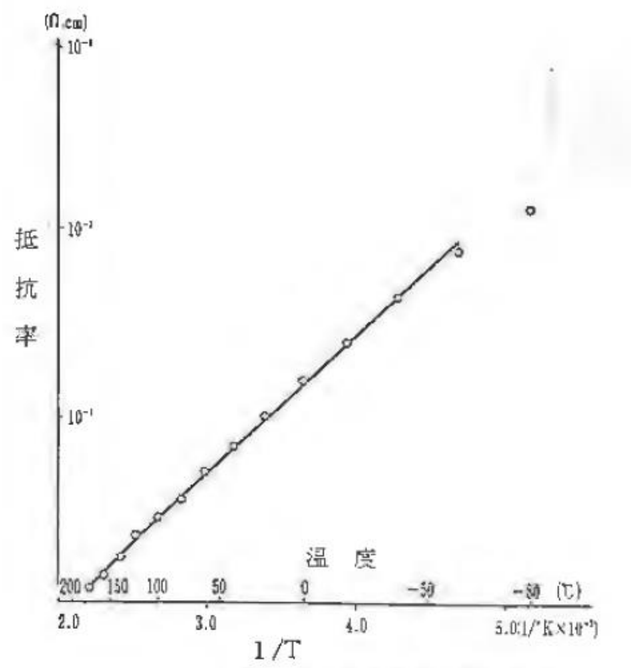


Fig.10 Temperature dependence of resistivity of InSb deposition film

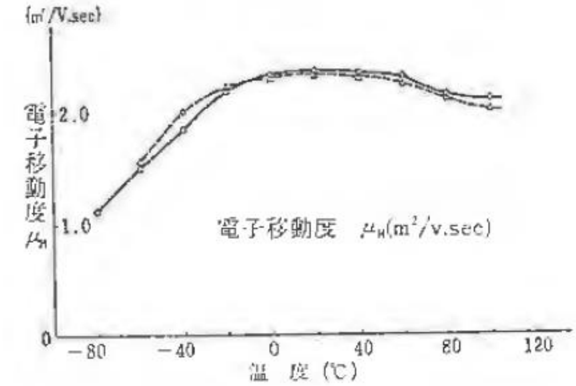


Fig.11 Temperature dependence of electron mobility of InSb deposition films

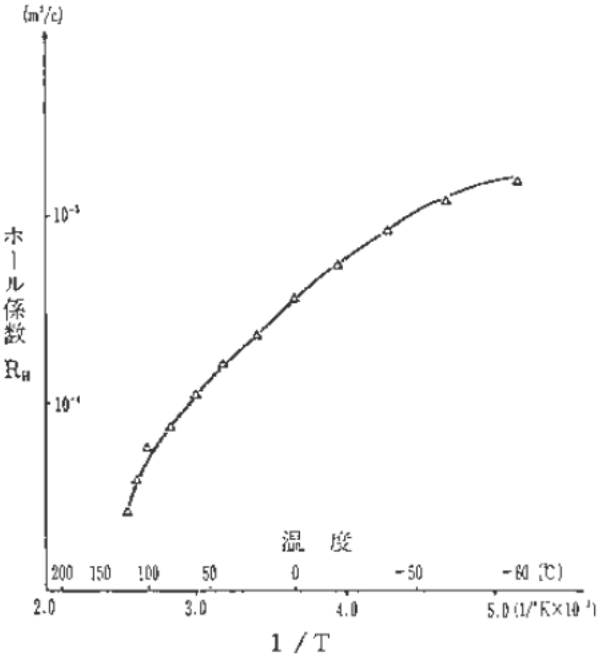


Fig.12 Temperature dependence of Hall coefficient of InSb deposition film

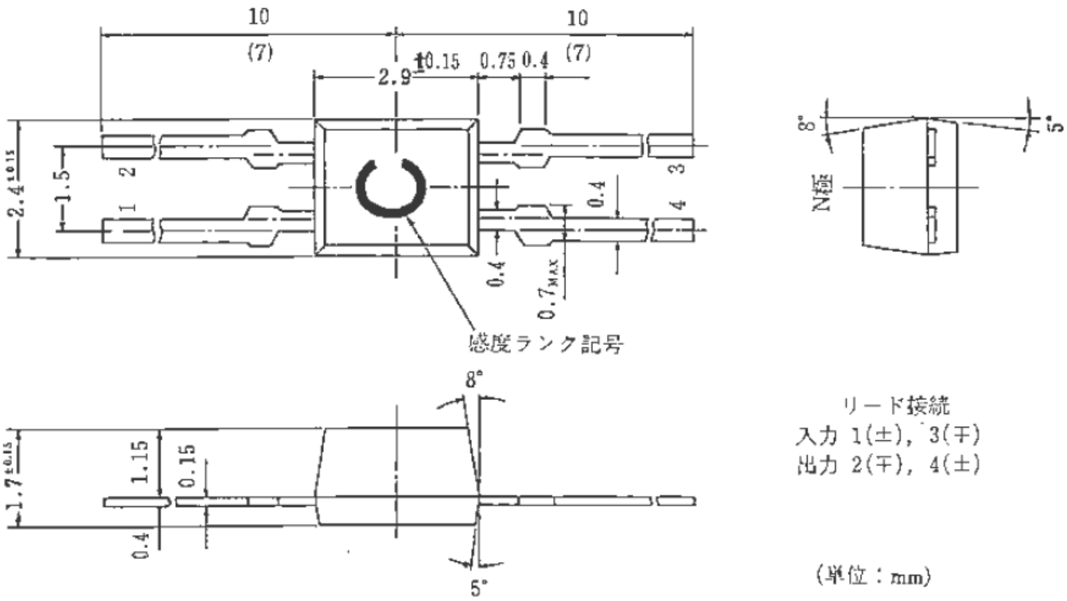


Fig.13 Outline of a high-sensitivity InSb Hall element (HW-300A)

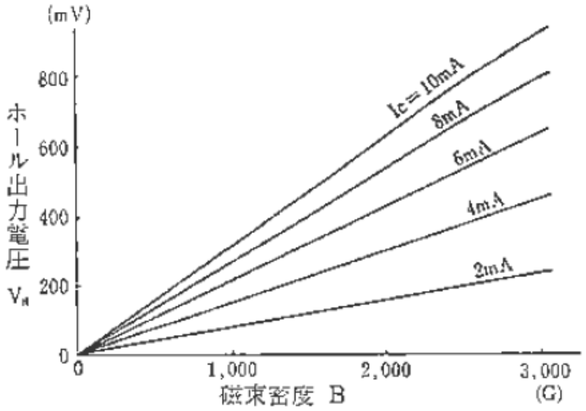


Fig.14 V_H -B characteristics of the HW-300C Hall element (constant current drive)

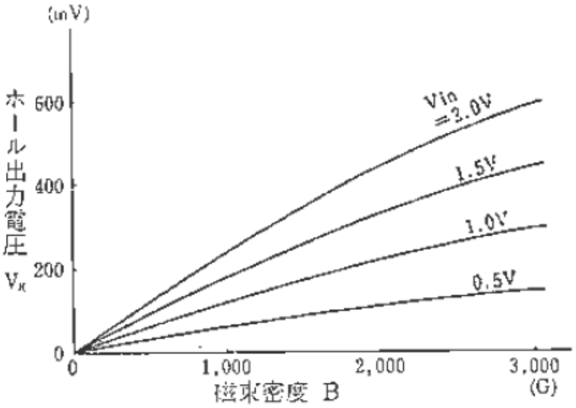


Fig.15 V_H -B characteristics of HW-300C Hall element (constant voltage drive)

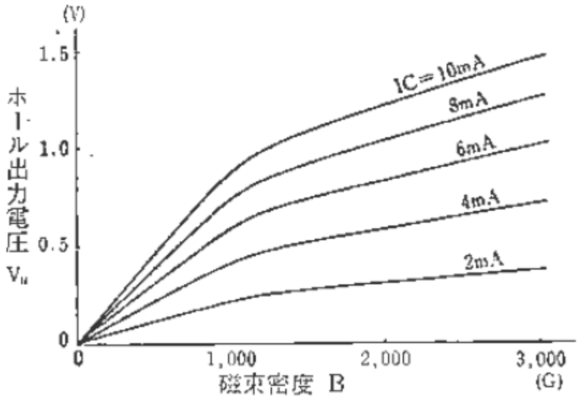


Fig.16 V_H-B characteristics of the HW-300A Hall element (constant current drive)

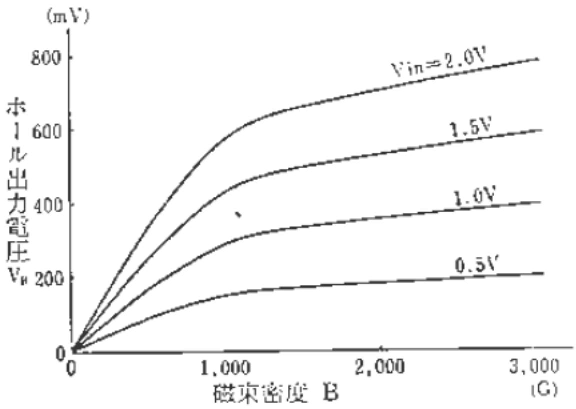


Fig.17 V_H -B characteristics of the HW-300A Hall element (constant voltage drive)

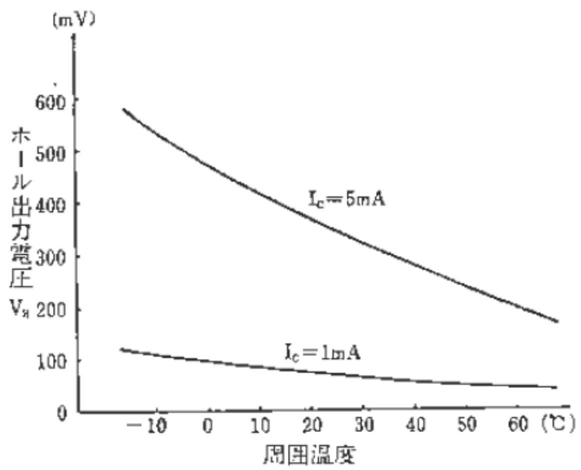


Fig.18 Temperature dependence of Hall output voltage (constant current drive, HW-300A)
Constant flux density

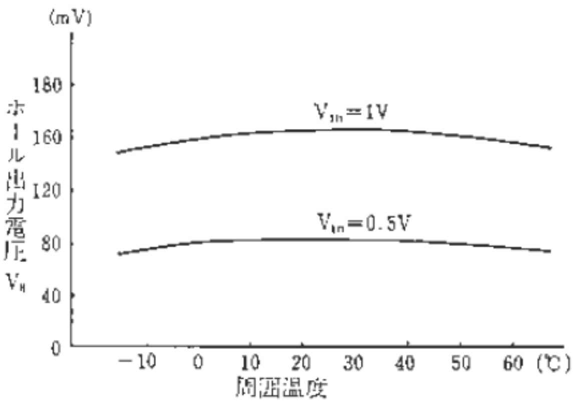


Fig.19 Temperature dependence of Hall output voltage (constant voltage drive, HW-300A)
Constant magnetic flux density

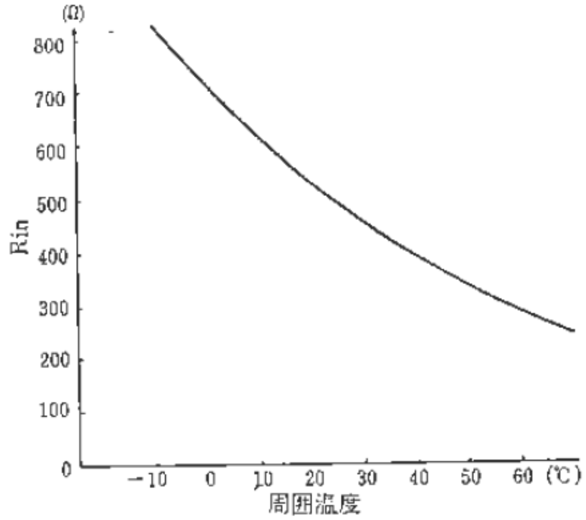


Fig.20 Temperature dependence of input resistance of HW-300A Hall element

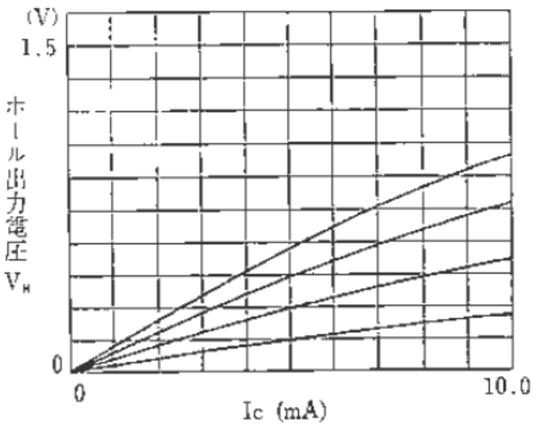


Fig.21 V_H - I_C characteristics of the HW-300A Hall element

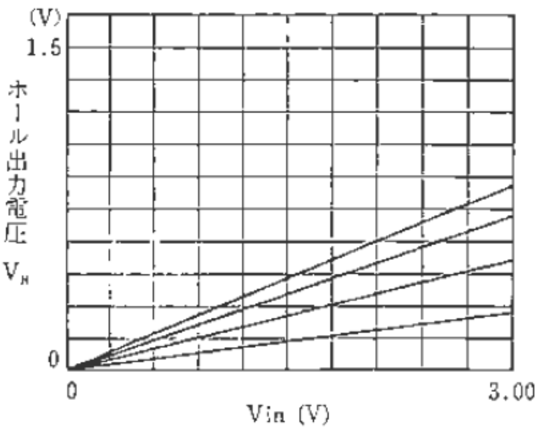


Fig.22 V_H -Vin characteristics of HW-300A Hall element

Table 1 Development history of high-sensitivity InSb Hall element

1973 Planning and study of InSb Hall element development

1974 Examination of basic structure of InSb type Hall element, study of deposition conditions.

1975-1976 Market evaluation for audio players, adoption for players decided

1977-1978 Planning of a full-scale mass production plant and development of production technology

August 1980 Started mass production of high-sensitivity InSb Hall elements.

April 1981 Achieved production target of 1 million units/month and started mass production for video

1982 Temporary decrease in Hall element production due to the integration of VTR.

1983 With the rapid growth of VTR, achieve 5 million pieces/month production

1985 1Achieved 00 million pieces/year output

1986 1Achieved production of 700 million units per year, expanded Hall elements for floppy disk drives

Table 2 Characteristics of high-sensitivity InSb Hall devices

① Highly sensitive elements: can operate in low magnetic fields

② Constant voltage drive element: Good temperature service characteristics not found in conventional InSb Hall elements.

③ Low power consumption: ideal for battery, battery powered

④ High-reliability element: can be used in large quantities with confidence

⑤ Small devices: advantageous for miniaturization of equipment

Table 3 Operating Modes of Hall Elements

1) Constant voltage drive (Vin = constant)

$V_H = \mu_H \cdot (w/l) \cdot Vin \cdot B$

V_H: Hall Output Voltage

μH: Electron Mobility

B: Flux density of the applied magnetic field

Vin: Input voltage (drive voltage)

2) Constant current drive (I_C = constant)

$V_H = R_H I_C B / d$

R_H: Hall coefficient

IC: Input Control Current

Table 4 Specifications of high-sensitivity InSb Hall elements (HW-300C)

(a) 最大定格

項目	記号	測定条件	定格	単位
最大入力電流	I_c	40℃ 定電流駆動	20	mA
最大入力電圧	V_{in}	40℃ 定電圧駆動	2.0	V
動作温度			−20~100	℃
保存温度			−40~110	℃

(b) 電気的特性（測定温度25℃）

項目	記号	測定条件	最小値	標準	最大値	単位
ホール出力電圧	V_H*	定電圧駆動 $B=500G$, $V_{in}=1V$	31		74	mV
入力抵抗	R_{in}	$B=0G$, $I_c=0.1mA$	240		550	Ω
出力抵抗	Rout	$B=0G$, $I_c=0.1mA$	240		550	Ω
不平衡電圧	V_u	$B=0G$, $V_{in}=1V$	−7		7	mV
出力電圧の温度係数	α_{HI}	20℃基準 0~40℃間の平均 $B=500G$, $I_c=5.0mA$			−2	%/℃
入力抵抗の温度係数	α_R	25℃基準 0~40℃間の平均 $B=0G$, $I_c=0.1mA$			−2	%/℃
直線性	β_L	$I_c=10mA$ 不平衡分を除き $B=0, 500, 8KG$ の3点測定			5	%
絶縁抵抗		100V D.C.	1.0			MΩ

* V_Hは，実測の出力端子間電圧から不平衡電圧 V_u を差し引いた値。

(a) Maximum Rating

Item Symbol Measurement Condition Rating

Maximum input current I_C 40° C constant current drive

Maximum input voltage Vin 40° C constant voltage drive

Operating temperature

Storage temperature

(b) Electrical characteristics (measurement temperature 25° C)

Item Symbol Measurement Condition

Hall output voltage V_H * constant voltage drive

Input Resistor Rin

output resistor Rout

Unbalanced Voltage Vu

Temperature coefficient of output voltage αHI 20° C standard, average between 0~40° C

Temperature coefficient of input resistance: αR 25° C standard, average between 0~40° C

Linearity β_L

Insulation resistance

* V_H is the value of the actual output terminal open voltage minus the unbalanced voltage Vu.

Table 5 Specifications of high-sensitivity InSb Hall elements (HW-300A, magnetic amplification type)

(a) 最大定格

項目	記号	測定条件	定格	単位
最大入力電流	I_c	40℃ 定電流駆動	20	mA
最大入力電圧	V_{in}	40℃ 定電圧駆動	2.0	V
動作温度			−20〜100	℃
保存温度			−40〜110	℃

(b) 電気的特性（測定温度25℃）

項目	記号	測定条件	最小値	標準	最大値	単位
ホール出力電圧	V_H*	定電圧駆動 B=500G, V_{in}=1V	122		274	mV
入力抵抗	R_{in}	B=0G, I_c=0.1 mV	240		550	Ω
出力抵抗	Rout	B=0G, I_c=0.1 mA	240		550	Ω
不平衡電圧	V_u	B=0G, V_{in}=1 V	−7		7	mV
出力電圧の温度係数	α_{HI}	20℃基準 0〜40℃間の平均 B=500 G, I_c=5.0 mA			−2	%/℃
入力抵抗の温度係数	α_R	20℃基準 0〜40℃間の平均 B=0G, I_c=0.1 mA			−2	%/℃
絶縁抵抗		100 V D.C.	1.0			MΩ

* V_Hは，実測の出力端子間電圧から不平衡電圧 V_u を差し引いた値。

(a) Maximum Rating

item

Maximum Input Current ICs

Maximum Input Voltage Vin

Operating temperature

Storage temperature

Measurement conditions

Constant current drive

constant voltage drive

(b) Electrical characteristics (measurement temperature 25° C)

Item Symbol Measurement Condition Minimum Standard Value Maximum Unit

Hall Output Voltage V_H

Input Resistor Rin

output resistor Rout

Unbalanced Voltage Vu

Temperature coefficient of output voltage αHI 20° C standard, average between 0 and 40° C

Temperature coefficient of input resistance αR 20° C standard, average between 0 and

40° C

Insulation resistance

* V_H is the value of the actual output terminal-to-terminal voltage minus the unbalanced voltage Vu.