Practical High Sensitivity Hall Elements for Magnetic Sensor by Thin Film Technology
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This is an English translation of selected parts from Chapter 3.

3. InAs thin film Hall devices by MBE method

Non-contact sensors such as automobiles, which are expected to be used in the future for Hall devices, need to operate stably in the range of -40~+150° C. In such a new application, the operating temperature range is practically twice as large as before. InAs has the second highest electron mobility after InSb, and the bandgap is larger than InSb, with a range of 0.36eV (300K), Hall elements can be expected to operate stably from low to high temperatures with high sensitivity. (9,10,11)

InAs have a lattice constant of 6.06 Å, an electron mobility of 33,000 $cm^2/V\cdot s$ at room temperature, and a $d(\triangle Eg)/dT$ of 0.35×10^{-4} eV/K. The temperature dependence of the energy gap is less around room temperature. The MBE method is a method that can easily produce InAs single crystal thin films with excellent properties. In addition, it is an excellent thin-film fabrication method that is easy to fabricate ultra-thin films and quantum well structures and has excellent temperature characteristics and can produce highly sensitive Hall devices. In addition, it is possible to produce large-area InAs single crystal thin films.

3.1 Si-doped InAs Hall element

When InAs thin films are doped with impurities during MBE crystal growth and the electron concentration is increased, the temperature coefficient of electron concentration and the temperature coefficient of electron mobility can be reduced at the same time. For the purpose of fabricating Hall devices, when using an InAs thin film with a film thickness of 0.5 μm doped with Si on a surface 2° off the (100) surface of a semi-insulating GaAs substrate (there is a fairly large lattice mismatch of 7% compared to GaAs substrates, but I dare to ignore it), the electron mobility at room temperature exceeds 10,000 $cm^2/V\cdot s$. Furthermore, the temperature dependence between the resistance value (sheet resistance) and electron mobility is smaller than that of the doping effect, making it suitable for the fabrication of Hall devices. Using a large-area MBE device for thin film growth developed for the purpose of mass production of InAs Hall devices (this device can simultaneously set 12 2-inch GaAs substrates in a single substrate holder, and 12 Si-doped InAs thin films can be grown simultaneously), the thickness grown on GaAs substrates is 0.5 μm, Si-doped InAs thin films were grown. The standard properties of this thin film are electron concentration of

8×10^{-16}/cm^3 and electron mobility of 1,000~10,000 cm^2/V·s. Using this thin film, the magnetic sensing part is designed in a symmetrical pattern of a cross, with an input and output resistance of 350 Ω and a chip size of 0.36 mm^2 squares, and the device was converted into an element by a process unique to this device, and then packaged on a mass production line to manufacture an InAs Hall element. (11,12.13.14,15) In addition, the characteristics in the magnetic field are shown in Table 2.

Table 2 Basic characteristics of InAs Hall devices (Asahi Kasei Electronics)

item	Characteristic values	condition
Hall Output Voltage VH	100 mV	Input Voltage 6V, Flux Density 0.05T
Input Resistance Rin	350 Ω	
Output Resistance Rout	350 Ω	
Unbalanced Voltage Vu	less than ± 8 mV	Input Voltage 6V

This element has the following characteristics.

1) Excellent linearity of output in magnetic fields.

2) The sensitivity in the magnetic field is also about 50% higher than that of commercially available GaAs Hall devices, and the sensitivity (Hall output voltage) of Hall elements is 100mV/6V・0.5T obtained by mass-produced devices.

3) The temperature dependence of Hall output voltage is -0.18%/° C, extremely small. By selecting the appropriate driving conditions, it can be driven in a wide temperature range of -40~150° C.

4) It also has the characteristics of low noise and offset voltage drift. (Especially important in applications such as current sensing)

In particular, the resistance value of the element, which is important when driving at high temperatures, is maintained at the room temperature level even at 100° C or higher, and the possibility of failure of the element due to overcurrent at high temperature is extremely low and the reliability is good.

The main application other than the small motor of such a Si-doped InAs Hall device is current sensing, and it is actually used as a magnetic sensor for current sensors that can accurately detect transient currents, including direct current, and is well received. In addition, taking advantage of its characteristics, it is also considered for application as a magnetic sensor for automobile applications. If there is any complaint, it is that the sensitivity in the magnetic field is not as good as that of the InSb Hall element.

3.2 InAs deep quantum well (DQW) Hall elements.

In order to obtain low temperature dependence of InAs Hall elements and large sensitivity or output in the magnetic field, high electron mobility, high electron concentration, and high sheet resistance are required for the InAs thin film in the sensor part. To meet this contradictory requirement, it is necessary to make the InAs thin film in the sensor extremely thin. To achieve such conditions, an insulation layer with good lattice alignment with InAs is required. AlxGa1-xAsySb1-y (A Hall element with a quantum well structure consisting of a four-way system consisting of $0 \leqq x \leqq 1$, $0 \leqq Y \leqq 1$) as a potential barrier layer has been fabricated. In this system, the bandgap difference between InAs and the conduction band is more than 1 eV. Figure 7 shows a barrier layer with the potential of Lattice matching the $Ga_{0.35}Al_{0.65}As_{0.02}Sb_{0.98}$ layer to InAs, i.e., the buffer layer, and the deep quantum well (DQW) with the InAs as the operating layer fabricated by the MBE method on a GaAs (100) substrate as the cap layer. (15,18,19,20,21,22)

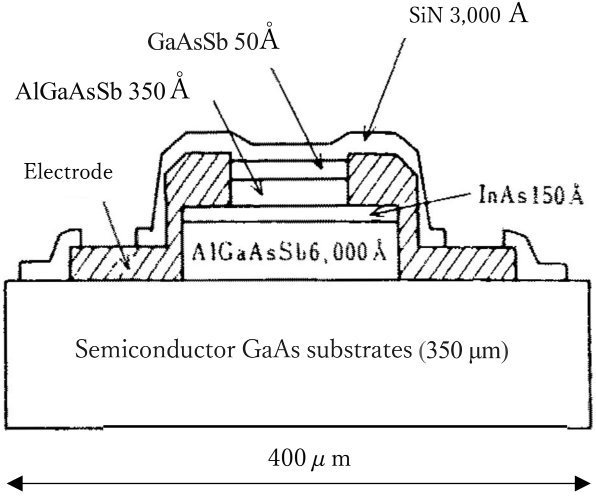

Figure 7: Cross-sectional view of the Hall device with InAs DQW structure

The operating layer of this device is InAs with a thickness of 150 Å, and a value of 20,000~32,000 $cm^2/V \cdot s$ at room temperature was obtained. This value is the highest electron mobility obtained from InAs thin films so far. The Hall device has a Hall output voltage of 2.6 times that of a Si-doped InAs device and a high output of 260 mV/6 V and 0.05 T.

Fig. 8 shows the Hall output voltage and its temperature dependence of the Hall element of the InAs DQW structure compared to other Hall elements.

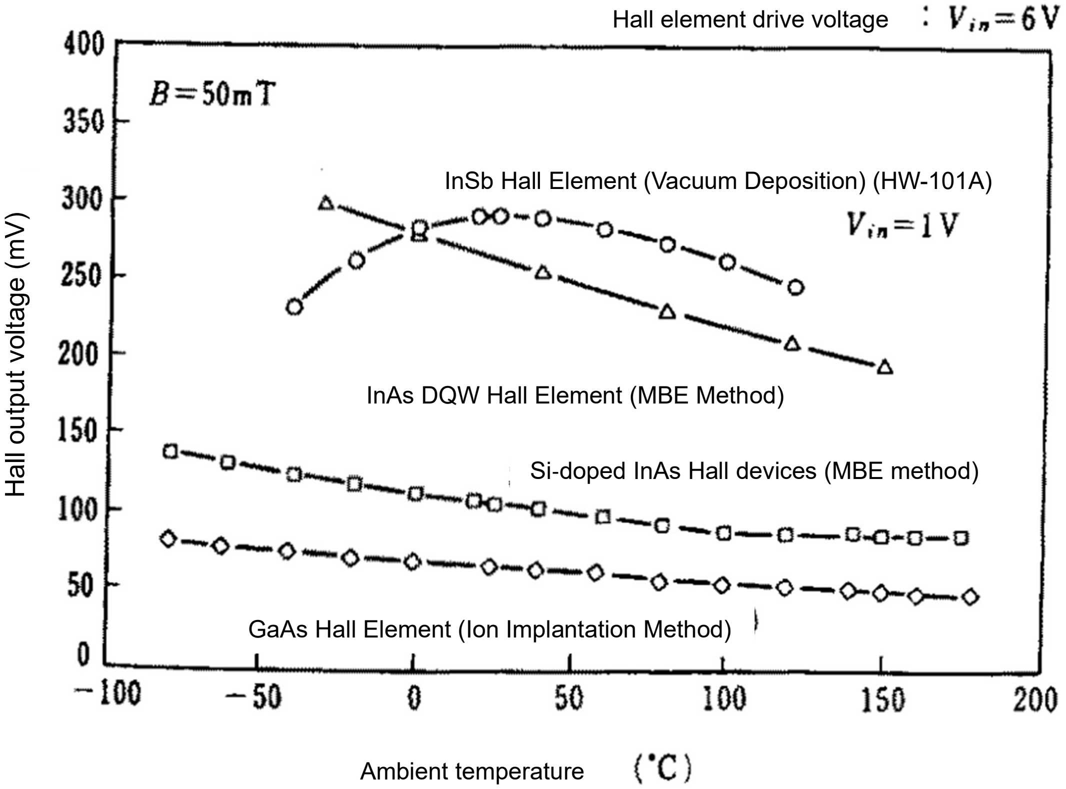

Fig. 8 Comparison of temperature dependence of Hall voltage of various Hall elements

As can be seen from Fig. 8, the Hall element with the InAs DQW structure has the following four characteristics.

1) a high sensitivity comparable to the sensitivity of the InSb Hall element with a magnetically amplified structure.

2) It also has excellent proportionality between the Hall output voltage and the detection magnetic field.

3) The temperature dependence of the Hall output voltage is extremely small.

4) Wide operating temperature range.

Although there are future challenges such as the establishment of mass production technology, this Hall device can be expected to be a next-generation magnetic sensor that can meet the needs of non-contact, contactless sensors in the new and broader future.