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High-Sensitivity InSb Thin-Film Hall Elements with Ferrite Sandwich Structure and Their Extensive Commercial Application

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Abstract

The integration of InSb thin film with a territe substrate and territe chip to form high-sensitivity thin-film Hall elements tbr use as a magnetic sensor inside a very small plastic package led to a vast array of commercial applications. Hall elements have a magnetic field sensitivity about 3-6 times that obtained using InSb thin film alone. They have been used to develop many kinds of very small DC brushless, or Hall, motors and have been applied to many key devices such as contactless sensors, switches, current sensors, and many kinds of home-use electrical systems and car sensors. More than 24 billion Hall elements with the ferrite sandwich structure have been fabricated and applied over the last 30 years.

Key Words: Magnetic sensor, Hall element, InSb thin film, Ferrite substrate, Hall motor

I. INTRODUCTION

In the early 1970s, personal computers, home-use VCRs, and many other kinds of electronic and information processing devices were being developed for practical or/and commercial use. Such devices required a very small size and fine angular velocity controlled motors without electrical noise. The development of small and high-sensitivity magnetic sensors that could detect a permanent magnet rotor was required for the development of a DC brushless motor with fine angular velocity control. A DC brushless motor with Hall elements as a rotation sensor could be used for VCRs, PCs, and similar electronic devices. Such a motor is commonly called a "Hall motor.” The potential market for very small Hall elements with high magnetic field sensitivity was large. Moreover, very low cost and mass production was strongly required. However, at the time, there was no InSb Hall element that satisfied such requirements.

In the mid of 1970s, we aimed to fabricate very small Hall elements with high magnetic field sensitivity for use in new small DC brushless motors with a permanent magnet rotor. After several years of research, we developed a multisource vacuum deposition process with programmed substrate temperature control and a specially designed production vacuum deposition system with multiple evaporation sources and a substrate heater. With this vacuum deposition system, we could produce InSb polycrystalline thin films on mica substrates with a thickness of 0.8 μm and a high electron mobility of 20,000-30,000 cm2/Vs.

These InSb thin films were integrated with a ferrite substrate and ferrite chip to form high-sensitivity InSb thin-film Hall elements inside very small plastic packages. Thus, the Hall element has a unique structure: InSb thin film is sandwiched between the ferrite substrate and ferrite chip. This structure enabled the production of Hall elements with magnetic field sensitivity about 3-6 times greater than that obtained using InSb thin film alone. Moreover, using thin InSb film for the Hall element, average value of input resistance of fabricated Hall elements was large and 350 ohms. The Hall voltage of the Hall elements was 122~300mV/50mT at a drive voltage of IV which was the highest sensitivity for mass production products to-date. And thus, by changing from conventional constant current driving to new constant voltage driving, Hall output voltage of the InSb Hall element showed very small temperature coefficient ±0.1-0.2%/℃ at room temperature which was never realized_These were big merits realized by use of thin film for Hall element [1-3],

The use of this new InSb Hall element as a magnetic sensor led to the development of many kinds of very small DC brushless, or Hall, motors. These Hall motors were soon used in VCRs, floppy disk drives, CD-ROM drives, and fan motors in personal computers, which led to the creation of a major, new Hall motor business and a new electrically controlled micro-motor industry. Hall elements were also applied to many other key devices such as contactless sensors, switches, current sensors, and many kinds of home-use electrical systems and car sensors. More than 24 billion Hall elements with a ferrite sandwich structure have been fabricated and put into commercial use over the past 30 years. Most of the Hall elements (-90%) were used as magnetic sensors for Hall motors or micro-motors.

II. KEY TECHNOLOGIES OF HIGH-SENSITIVITY InSb THIN-FILM HALL ELEMENTS

A. Structure of High-Sensitivity InSb Thin-Film Hall Elements

Commercial products of high-sensitivity InSb thin-film Hall elements are shown in Fig. 1. A key technology of these Hall elements is a hybrid structure in which InSb thin film is inserted between a ferrite substrate and a ferrite chip. This results in the highest sensitivity ever attained in a mass-production magnetic sensor [1-3].

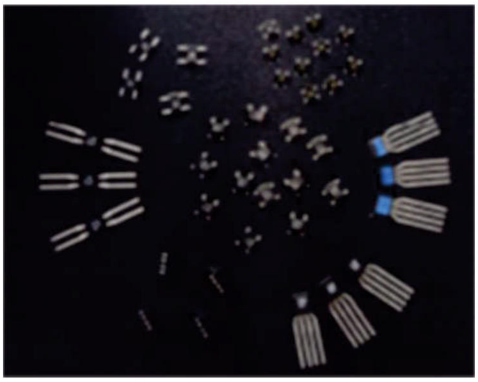
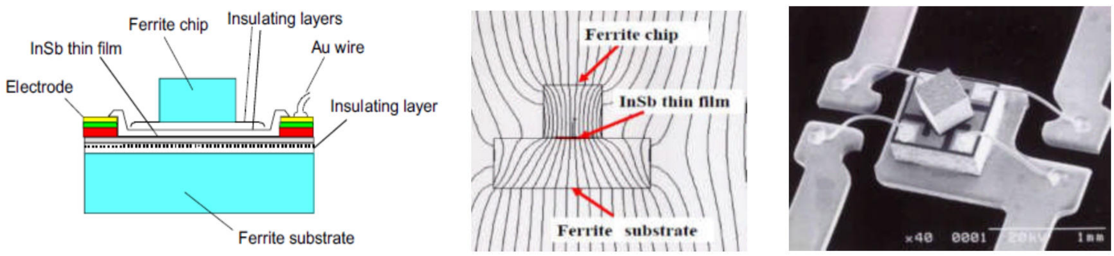


Fig. 1 Commercial products made of high-sensitivity InSb thin-film Hall elements with plastic package.

The structure of a typical Hall element is shown in Fig. 2: (a) shows the cross-sectional structure of the ferrite substrate, InSb thin film, and ferrite chip, (b) shows the collimation of the magnetic flux in the gap between the ferrite chip and substrate, and (c) shows a photograph of the wired Hall element sandwich with a ferrite substrate and ferrite chip bonded to the center of the Hall element pattern.

The sensing part of the high-sensitivity InSb thin-film Hall element is the InSb thin film, which has high electron mobility and is made using the specially designed vacuum deposition system. The substrate (-1.0 mm square and ~0.3 mm high) is made of Ni-Zn soft ferrite, and the small cubic ferrite chip (-0.3 mm cubic chip) is made from Mn-Zn soft ferrite.

These ferrites have a Curie temperature higher than 100℃ and very small residual magnetization with no magnetic field. Since these ferrites must have no micro cracks or pinholes, they are fabricated using the hot isostatic pressing (HIP) process. With this ferrite sandwich structure, the magnetic field sensitivity of the InSb thin-film Hall element is about 3-6 times greater than the sensitivity using InSb thin film alone. Such a large gain in sensitivity by using the ferrite sandwich structure is unobtainable by simply improving the thin-film properties and was a major achievement. The weight of the ferrites in a Hall element is less than 2 mg. Thus, the ferrite used fbr Hall elements are about 2~3t every recent year which may be very small amount in ferrite business. However, the effect fbr practical application may be big or the largest.



(a) (b) (c)

Fig. 2 Ferrite sandwich structure of high-sensitivity InSb thin-film Hall element:
(a) cross-sectional structure of ferrite substrate/InSb thin film/ferrite chip
(b) collimation of magnetic flux at gap between ferrite chip and substrate
(c) photograph of wired Hall element sandwich with ferrite substrate and ferrite chip bonded to center of Hall element pattern

B. Mass Production of High-Electron Mobility InSb Thin Films by Multisource Vacuum Deposition

The mass production of stoichiometric InSb thin films with high electron mobility under high substrate temperature conditions is very difficult because the difference in vapor pressure between In and Sb is five orders of magnitude. To enable us to produce InSb thin films under such condition, we developed the " 2-temterature multisource vacuum deposition method with programmed substrate temperature control. The stoichiometry of the InSb thin films is controlled by sequential evaporation of InSb fiom several source boats. With InSb as the source material and thin mica as the substrate, specially programmed source temperature control and programmed time-dependent substrate heating were combined to grow stoichiometric InSb thin films on heated thin mica substrates. This enabled mass production of InSb poly-crystal thin films with thickness of 0.8 μm on thin 2-inch square mica substrates. The measured electron mobility was

20,000—30,000 cm2/Vs, and the sheet resistance was greater than 100 Ω. The electron mobility of the InSb thin 21ms produced by vacuum deposition was almost constant fbr temperature changes around room temperature. Since InSb thin films have high sheet resistance (> 100 Ω), Hall elements with input resistance of approximately 350 Ω could be fabricated and driven at 1 V without over-current damage. The Hall output voltage is directly proportional to electron mobility at constant voltage driving. Thus, at the constant voltage driving, Hall voltage of this Hall element must be almost constant for temperature changes around room temperature [1].

C *Fabrication Process of the InSb Thin Film Hall Elements*

The fabrication process includes special steps fbr forming of ferrite sandwich structure as shown in Fig. 2 which are peel off of InSb thin film from mica substrate and bonding of it on ferrite substrate surface, and bonding of a small ferrite chip on the center of every Hall element. Therefore, as shown in Fig. 3, the fabrication of high-sensitivity InSb thin-film Hall elements comprises five main steps: vacuum deposition of InSb thin film on a mica substrate, peel-off of the film and bonding of the thin film on the surface of ferrite substrate, wafer processing including bonding of ferrite chip in the center of Hall element pattern, dicing, and wire bonding, packaging, and testing.

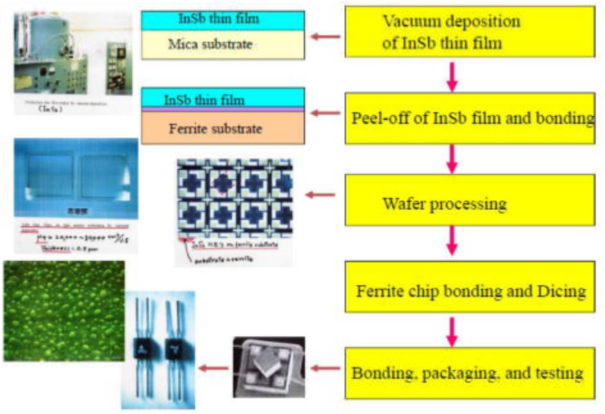
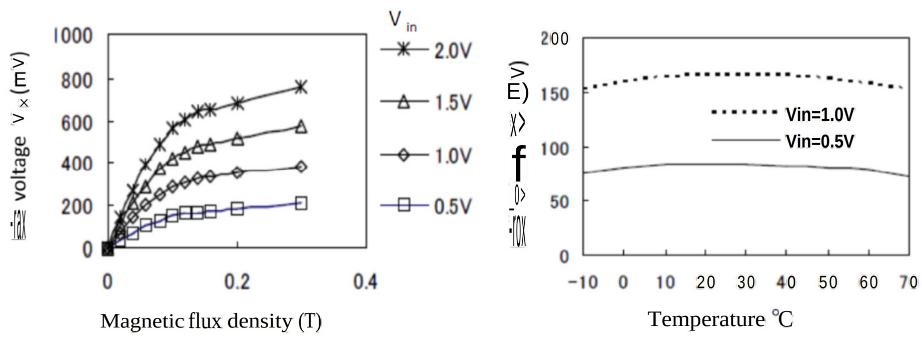


Fig3 Fabrication of high-sensitivity InSb Hall elements.

D. *Typical Characteristics of InSb Thin-Film Hall Elements with Ferrite Sandwich Structure*

The magnetic field characteristics of InSb thin-film Hall elements, as obtained by testing, showed that the sensor output (Hall voltage VH) was 122-320 mV /V・50 mT and that the average value of input resistance RU1 was 350 Ω. As shown in Fig. 4, where V_{in} is the driving voltage, Vh was high at a small magnetic flux density. The temperature dependence of VH was very small at a constant driving voltage[1-3]. This voltage stability was welcomed by many application engineers.

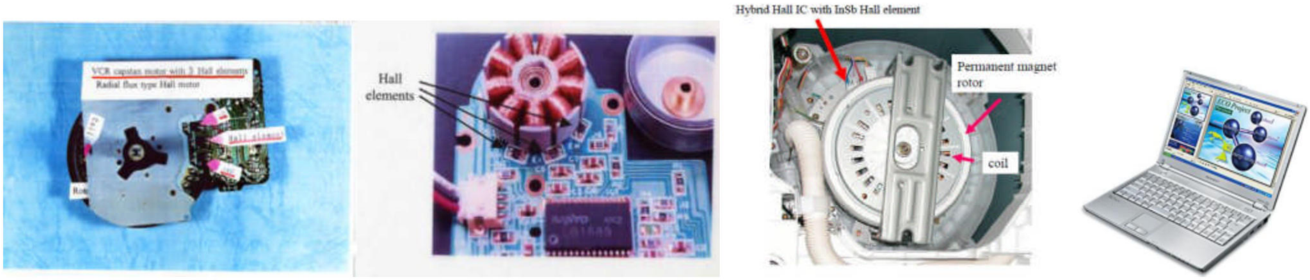


(a) (b)

Fig. 4 Characteristics of InSb thin-film Hall elements: (a) magnetic field characteristics of Hall voltage, and (b) temperature dependence of Hall voltage

III. TYPICAL COMMERCIAL APPLICATIONS AND HISTORICAL IMPACT OF HIGH-SENSITIVITY InSb THIN-FILM HALL ELEMENTS

These InSb thin-film Hall elements with a ferrite sandwich structure have had a great impact. They completely met the requirements for a new magnetic sensor that was small, highly sensitive to magnetic flux density, and highly reliable. They have been used to fabricate small DC brushless, or Hall, motors, contactless sensors, switches, hybrid Hall ICs, and many kinds of contactless sensing devices. Photographs of example devices with the high-sensitivity InSb thin-film Hall elements are shown in Fig. 5. The Hall motor changed the concept of conventional motor technology: it was a new innovative motor with that featured angular velocity control of a small permanent magnet rotor and the absence of electrical noise due to its brushless structure. These characteristics were strongly required for the development of such electronic systems as VTRs and PCs.



(a) (b) (c) (d)

Fig. 5 Photographs of devices with Hall elements: (a) VTR capstan motor, (b) CD-ROM drive motor fbr PC, (c) motor for home-use washing machine, and (d) PC with contactless switch

Since the InSb thin-film Hall elements with final version product were developed on 1982, more than 24 billion Hall elements have been produced, mainly for use as sensors in DC brushless, or Hall, motors, which are used for many kinds of electronic home-use systems. The Hall elements have been covered about 70%/year of recent world production. The growth in the application of Hall elements is plotted in Fig. 5. The figure clearly shows how our daily life has come to depend on high-sensitivity InSb Hall elements with a ferrite sandwich structure. In short, the combination of InSb thin film and ferrites is a highly effective technology.

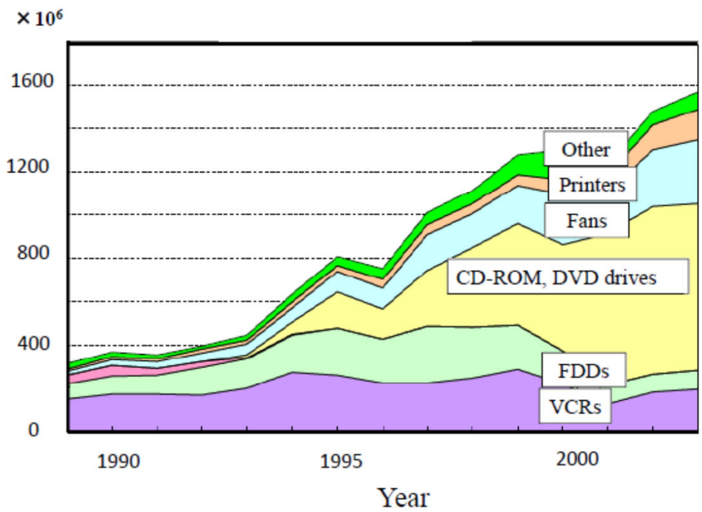


Fig. 4 Growth in application of high-sensitivity InSb thin-film Hall elements with ferrite sandwich structure.

IV CONCLUSION

The high-sensitivity InSb thin-film Hall element was developed by combining different materials and technologies such as thin films, semiconductors, and soft ferrites. The first mass application of the Hall element more than 30 years ago led to the production of very small DC brushless (Hall) motors with fine angular velocity control and no noise. They were applied to VCRs, PCs, and many other electronic and electrical systems and supported the electronics industry. And thus, more than 24 billion Hall elements with the ferrite sandwich structure have been fabricated and applied over the last 30 years. This major impact suggests the importance of combining different technologies and materials.

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