Properties of InSb Thin Films Grown by Molecular Beam Epitaxy and Their Applications to Magnetic Field Sensors

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Recent developments in InSb thin film magnetic sensor technology were reviewed. Tin (Sn) doped InSb thin films grown on GaAs substrates by molecular beam epitaxy, showed high electron mobility and sheet resistance with very small temperature dependence. High sensitivity Hall elements and magnetoresistance elements were fabricated using Sn doped InSb thin films and their electrical and magnetic properties were investigated. The potential use of magnetic sensors for non-contact detection of linear motion, rotation and future energy saving in electric power systems was discussed.

Keywords : Thin film magnetic sensor, InSb thin film, InSb single crystal thin film, Sn doped InSb single crystal thin film, InSb thin film Hall element, InSb thin film magnetresistance element, non-contact rotation detection

Excerpt from Chapter 1: Introduction only

1. Introduction

Compound semiconductors are important because they have the characteristics of being able to realize devices that cannot be realized with Si. In particular, light-emitting elements, ultra-high frequency transistors, magnetic sensors, etc. are representative examples of practical applications and uses. By the way, the most used power source today is the motor. Hall elements, which are magnetic sensors that use the Hall effect of thin films such as InSb and InAs, which are narrow bandgap semiconductors, are DC brushless motors that supply high-quality power to electronic devices such as VTRs and personal computers. It is also widely used as a magnetic sensor for Hall motors [(1)].

Hall elements are sensors that can directly detect position and rotation without contact using a magnetic field. As a magnetic sensor for a brushless motor driven by direct current, we have realized the development of a small and ultra-compact brushless motor with high-precision rotational control and low noise such as electromagnetic noise and grinding noise. Hall motors have brought innovative advances to motor technology, such as electronic control and intelligence, to improve the quality of power, and have played an important role in achieving high performance and miniaturization of video, information, and other electronic devices such as audios, VTRs, and personal computers. In particular, small and high-quality power such as Hall motors are currently

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It is essential in IT technology. For this reason, magnetic sensors, such as thin-film InSb Hall devices, have now become a leading application field for narrow bandgap III-V compound semiconductors, and nearly 2 billion are used worldwide annually as important sensors that support the recent electronics industry.

Figure 1 shows the recent market trend of Hall devices, which are magnetic sensors that use thin films of compound semiconductors. Over the past 20 years, Hall devices have shown a nearly 100-fold increase in production. In particular, it is estimated that InSb's thin-film Hall devices account for more than 90% of the total Hall device production.

Hall elements can detect the position and speed of objects that are in direct motion without contact and can directly control the power using this function. DC brushless motors that use Hall elements are

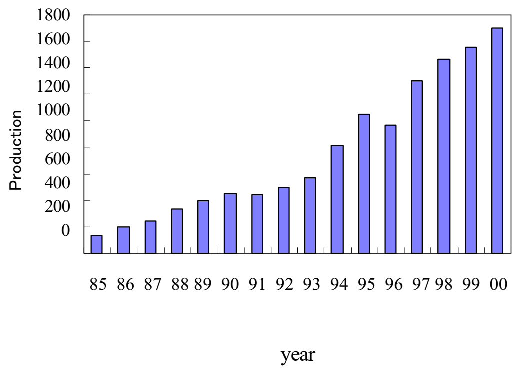


Fig. 1 Trends in production of compound semiconductor Hall devices (world) Fig. 1. Worldwide production of thin film Hall sensors (million/year).

So, as a small and ultra-compact power source, it was mainly used for the purpose of miniaturizing, ultra-miniaturizing, and improving the performance of electronic devices. By the way, the miniaturization of power by Hall elements is not only the result of improving the performance and miniaturization of electronic devices. Let's briefly summarize the utility of such a Hall element. The first is the material-saving effect that reduces the amount of material used in electronic devices due to the miniaturization of power. To give an example of the material-saving effect, the recent production of VTRs and PCs is about 70 million VTRs and 110 million PCs, for a total of 180 million units. If the power used in these VTRs and PCs is reduced by Hall elements, and the weight reduction of 1 g per unit is realized, it is equivalent to saving 180 tons of materials per year.

If you lose 10 grams, you will save 1,800 tons of materials per year. This will lead to a reduction in CO2 emissions due to the reduction of energy involved in the production of materials used in electronic devices. In other words, it has a large effect on reducing environmental impact [(2)]. The second is energy conservation by converting power motors to Hall motors. Advances in non-contact power control technology using magnetic sensors such as Hall elements have led to a reduction in environmental impact and, recently, energy saving. It is estimated that motors consume more than 50% of the total power generation in Japan, and a 1% reduction in motor power consumption would eliminate the need for a 500,000 kW power plant [(3)]。 For this reason, the conversion of power motors to Hall motors is an application field for Hall elements that can be expected to save a lot of energy, and in the future, it is expected to reduce CO2 emissions from thermal power plants and radioactive waste from nuclear power plants. The conversion of power motors used in home appliances and other appliances to hall motors has already begun. Figure 2 is a photo of a Hall motor of a commercial household washing machine (the large ring is a permanent magnet rotor). A hybrid Hall IC using an InSb thin-film Hall element is used to detect the rotation of a permanent magnet rotor (4) (5).

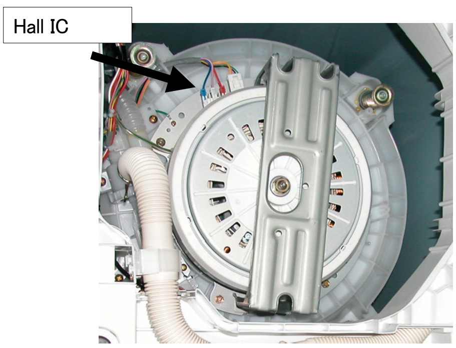
Another important application of Hall elements is non-contact current sensing. Non-contact current detector with Hall element, i.e. current sensor. This energy-saving control technology for power motors that combines Hall element current sensor and inverter technology can be applied to ultra-large motors with large magnetic noise and difficulty in direct rotation detection by magnetic sensors.

Furthermore, the application of thin-film magnetic sensors, such as Hall elements and magnetoresistive devices, is not limited to power control by electric motors. It is an application for position detection of moving objects by non-contact using magnetism, and rotation detection by power other than electric motors is a typical example. These include high-precision detection of rotation by magnetic encoders using thin-film Hall elements and magnetoresistive elements, and detection of engine rotation in automobiles. In this way, magnetic sensor technologies such as high-sensitivity Hall elements and magnetoresistance devices are highly expected for energy conservation, exhaust gas reduction, and safe driving are key issues for controlling automobiles, switching to electric vehicles, and reducing power-related power. This is a new application area for thin-film magnetic sensors, such as Hall and magnetoresistive devices. These new applications, such as saving materials and energy, which lead to reducing environmental impact, are new environmental technologies and environmentally friendly green technologies. The magnetic sensor such as the Hall element used for this is a green sensor. This is also the reason why magnetic sensors are expected now (2).

Table 1 briefly summarizes the applications of magnetic sensors and their expected effects.

In this journal, the author has already reported on the technology of thin-film Hall devices such as InSb and InAs [(1)]. In this article, we report on the recent status and issues of InSb thin-film technology used in magnetic sensors, as well as the technology and application of Hall and magnetoresistive devices by the thin-film technology.

InSb is a compound semiconductor with the greatest electron mobility, and its thin film is the most important material for Hall and magnetoresistive devices. However, InSb has a large temperature dependence on resistivity and Hall voltage due to its narrow bandgap, so Hall elements are used as magnetic sensors at low temperatures and high temperatures exceeding 100°C



Hall motor for household washing machine

Fig. 2. Hall motor in a commercial home washing machine (Arrow shows hybrid hall ICs with InSb thin film hall sensors).

Table 1. Applications of magnetic sensors and corresponding merits.

Examples of application fields	Reduced power consumption, high-precision control, low noise, etc.	Miniaturization, material saving	Energy saving, environmental impact reduction	Safe, comfortable and quiet
Magnetic sensors for small motors.	✓	✓	✓	✓
Magnetic sensors for power motors.	✓	✓	✓	✓
Non-contact current sing sensor	✓		✓	✓
Automotive Non-Contact Rotation Detection Sensor	✓		✓	✓

There was a historical problem that it was difficult to use. In this report, we will focus on the high electron mobility of InSb single crystal thin films and discuss the thin film technology and attempts to reduce the temperature dependence of InSb thin films on resistance and Hall coefficient, which were previously thought to be difficult. Recent developments and applications focusing on sensor applications, such as the fabrication of Hall and magnetoresistive devices using these results, in particular, the doping of n-type impurities to InSb thin films and their effects, and the application of magnetic sensors are discussed.

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