・2018 年　The Yamazaki-Teiichi Prize

Development of high sensitivity InSb・InAs thin film Hall sensors and their applications

MST　山崎貞一賞　|　第 18 回（平成 30 年度）山崎貞一賞　半導体及び半導体装置分野

Award Citation (English Translation)

In the 1970s, semiconductor magnetic sensors were limited in practical applications due to their large size, low sensitivity, and poor high-temperature performance. Mr. Shibasaki focused on thin films of III-V compound semiconductors such as InSb and InAs, which exhibit excellent Hall effect characteristics. He conducted research on electron transport, developed fabrication methods for polycrystalline and single-crystal thin films as well as quantum wells, and established mass production technologies. Pioneering globally, he developed and commercialized ultra-small, ultra-sensitive thin-film Hall devices, including InSb thin-film Hall devices, InAs single-crystal thin-film Hall devices, and InAs quantum well Hall devices.

The first high-sensitivity InSb thin-film Hall device developed had 20–30 times higher magnetic field sensitivity compared to conventional InSb Hall devices. It also exhibited an order-of-magnitude reduction in temperature dependence of sensor signals and was packaged in a compact resin case for high reliability. As a result, it was widely adopted in rotational detection sensors for consumer VTRs, PC CPU cooling fans, HDDs, CD-ROMs, and other Hall motor applications. The subsequent development of InAs single-crystal thin-film and quantum well Hall devices further expanded applications to motor control in air conditioners, non-contact current sensors essential for power measurement and inverter control, and automotive sensors including electric vehicles. Cumulative production has exceeded 30 billion units, and applications continue to grow.

For these achievements, Mr. Shibasaki is awarded the 18th Yamasaki Teiichi Prize in the field of semiconductors and semiconductor devices.

Background of Research and Development

In the late 1970s, Japanese electronics manufacturers were focused on developing consumer VTRs and personal computers. To drive mechanical systems in these devices, there was a need to develop ultra-compact DC brushless motors—also known as Hall motors—that could be electronically controlled with high precision and without generating noise. However, the Hall elements available at the time were handmade probes for magnetic field measurement, with low sensitivity and unsuitable for mass production, making them impractical for use in Hall motors. Moreover, semiconductor research at the time was concentrated on Si LSI and GaAs devices, with little attention given to Hall elements.

Meanwhile, in the mid-1970s, Japanese chemical companies, facing the need to restructure their businesses following the oil shock, began exploring entry into new fields and industries.

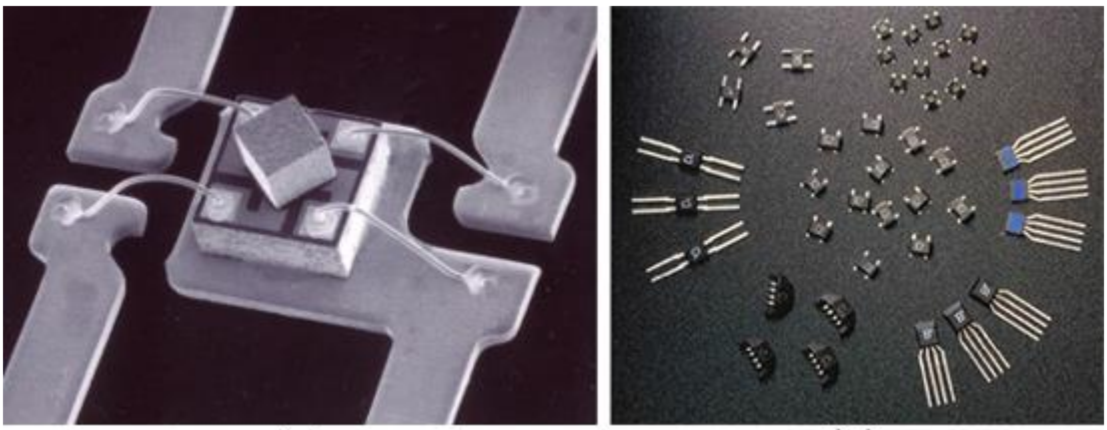
Asahi Kasei Corporation also aimed to diversify and began research into Hall elements.

Achievements

In 1974, Mr. Shibasaki joined Asahi Kasei Corporation (formerly Asahi Kasei Kogyo Co., Ltd.) and took charge of Hall element research. With a background in physics, he focused on the high electron mobility of narrow bandgap III-V compound semiconductors such as InSb and InAs, recognizing their potential for Hall elements. Despite initial skepticism about vacuum deposition and molecular beam epitaxy (MBE) as industrial technologies, he pursued their development with ingenuity and overcame challenges to establish mass production techniques for polycrystalline and single-crystal thin films, as well as quantum wells of InSb and InAs—pioneering these technologies globally.

He studied electron transport properties under magnetic fields in thin films from a unique perspective and applied these findings to the fabrication of Hall elements. This led to the development and commercialization of ultra-compact, high-sensitivity magnetic sensors using InSb thin-film Hall elements, InAs single-crystal thin-film Hall elements, and InAs quantum well Hall elements, all packaged in resin.

In developing the first high-sensitivity InSb thin-film Hall element, he established a proprietary vacuum deposition method that controlled the five-digit vapor pressure difference between In and Sb to produce InSb thin films with strong Hall effects. He also implemented a magnetic field amplification structure by sandwiching a 0.8 μm thick InSb thin film between ferrite layers to enhance sensitivity. The resulting Hall element had 20–30 times higher magnetic field detection sensitivity than conventional InSb Hall elements and was the world's first InSb thin-film Hall element with a high input resistance of 350 Ω. It could operate with a constant voltage of 1V and exhibited a tenfold reduction in temperature dependence of the Hall voltage, making it a highly practical ultra-compact magnetic sensor.



(a) (b)

Figure 1 shows the high-sensitivity InSb thin-film Hall element:

(a) Bare chip before packaging, (b) Commercial product.

Immediately after development, this Hall element was used in the creation of ultra-compact Hall motors capable of precise electronic control of angular velocity. These motors were mass-produced and widely used in consumer VTRs and PCs, significantly contributing to their development, proliferation, and advancement. Furthermore, this marked the beginning of a new field in motor technology—electronic control.

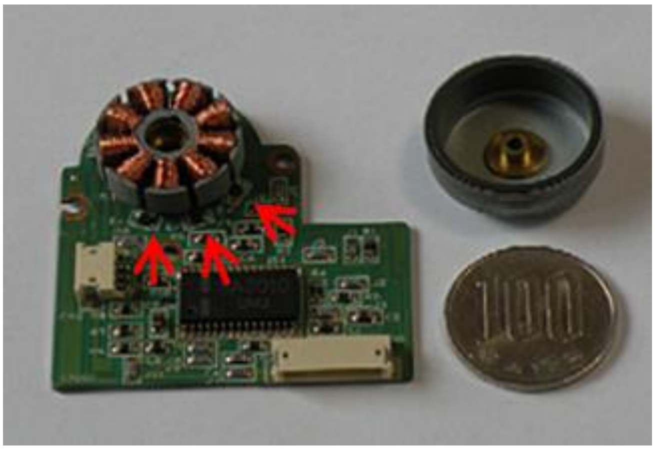
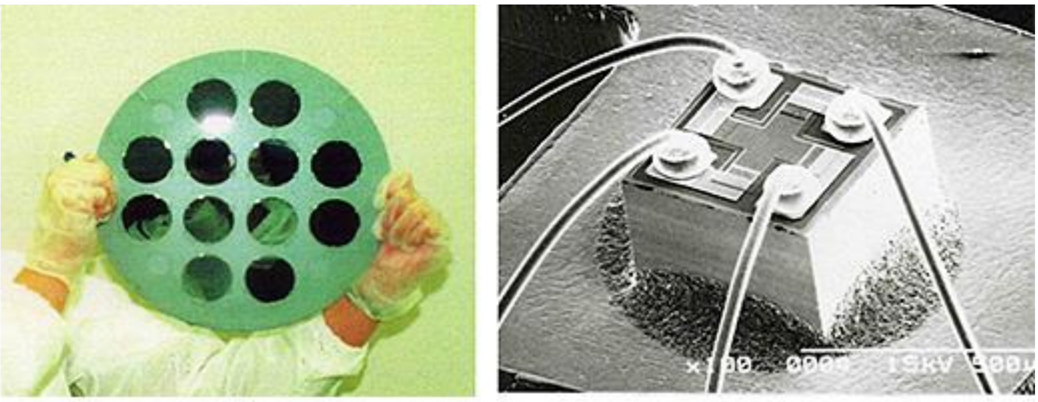


Figure 2 shows a Hall motor for PC CD-ROM drives using three of these Hall elements (indicated by red arrows).

Next, leveraging his experience with vacuum deposition, Mr. Shibasaki built a large-scale MBE system for mass production and developed MBE technology capable of fabricating InAs single crystals and quantum wells on twelve 2-inch GaAs substrates.



(a) (b)

Figure 3 shows:

(a) 0.5 μm thick single-crystal thin films grown on twelve GaAs substrates,

(b) InAs single-crystal thin-film Hall element fabricated on a GaAs substrate.

Using this technology, the first practical Si-doped InAs single-crystal thin-film Hall element was developed. Since InAs lacked an insulating substrate, an AlGaAsSb insulating layer lattice-matched to InAs was used as a potential barrier. A quantum well was fabricated on a GaAs substrate with the following layered structure:

GaAs (10 nm) / AlGaAsSb (50 nm) / InAs (50 nm: Hall element layer) / AlGaAsSb (500 nm) / GaAs substrate (0.2 mm).

This led to the world's first practical InAs quantum well Hall element with a 50 nm thick Hall layer.

Due to the extremely thin active layer, this device achieved sensitivity comparable to the magnetic field amplification structure of the InSb thin-film Hall element. Additionally, with a well depth exceeding 1 eV, it was possible to fabricate Hall elements with high input resistance even at high electron densities. The device also featured minimal temperature dependence of Hall voltage and resistance, and low power consumption. These InAs-based Hall elements produced via MBE are highly reliable and can operate stably across a wide temperature range from approximately -40° C to over 100° C. As such, they are widely used in various non-contact sensors, especially in applications where InSb thin-film Hall elements are less suitable, such as magnetic sensors for non-contact current sensors.

Figure 4 shows a current sensor using a linear hybrid Hall IC that integrates an InAs quantum well Hall element and a Si linear amplification circuit in a single package. These are used in inverters for power motors.

The most significant application of thin-film Hall elements is in Hall motors that enable variable angular velocity control for energy-saving operation. These motors are also used in power motors, contributing to energy efficiency in air conditioners and various home appliances. Furthermore, non-contact current sensors using Hall elements are essential for inverter-driven systems and power/current measurement in the energy sector. Thin-film Hall elements are also widely used in non-contact switches and automotive sensors, including electric vehicles. With an estimated market share of 70%, cumulative production has exceeded 30 billion units since development, and applications continue to expand.

Significance of the Achievements

Mr. Shibasaki's work defied conventional wisdom and trends by establishing thin-film and quantum well structures of InSb and InAs as industrial technologies. He developed and commercialized high-sensitivity InSb and InAs thin-film Hall elements that met the needs of the industry at the time.

Beginning in the final two decades of the 20th century and continuing into the 21st, his contributions ushered in an era where ideal electronically controlled motors—Hall motors capable of freely and precisely controlling angular velocity—became widely accessible. This also enabled the widespread use of magnetic-based non-contact sensors, greatly contributing to the advancement of the electronics and information industries. Additionally, the academic achievements from his research and development were published in scientific papers, significantly contributing to the progress of the relevant academic fields.