InSb and InAs Hall Elements from Asahi Chemical

The company that claims >70% of the world market for Hall sensors shows us their next generation of products

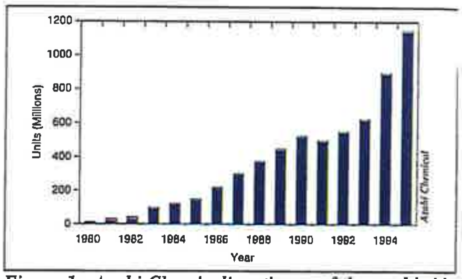

Figure 1: Asahi Chemical's estimate of the worldwide market for Hall elements as magnetic sensors.

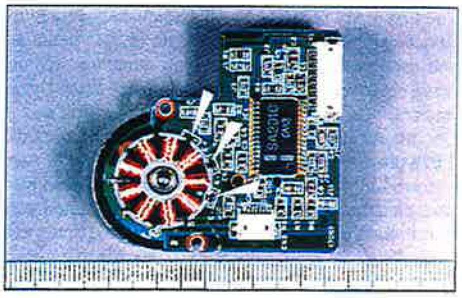

Figure 2: Photograph of a typical CD-ROM drive Hall motor showing three Hall elements (white arrows).

The current status of the market for Hall elements, as portrayed by Asahi Chemical Industry Co. [Fuji-city, Shizuoka, Japan] could be classified as a "good news - bad news - good news" story. The first piece of good news is that the market for Hall elements, in terms of units required, is huge, approaching 1200 million units in 1995 (see Figure One). Furthermore, demand is likely to continue to grow, due to ever-increasing sales of audio, video and computer electronics. These types of equipment need high performance, finely controlled DC motors to perform functions like driving and taking up the tape in a VCR, spinning a CD in an audio player, and accessing the drives in a personal computer. Figure Two shows the location of 3 such motors in a CD-ROM drive. It is now commonplace for these motors to be controlled by magnetic sensors instead of brushes, and the Hall element is the perfect sensor for the job.

The bad news, at least as far as most readers of this magazine are concerned, is that the very large majority of this market is served by a relatively "low tech" utilization of the classic Hall element material, InSb. Asahi Chemical, which entered the market in 1980, currently supplies around 70% of the world's requirements for Hall sensors by depositing a 0.8 μm thick layer of polycrystaline InSb on mica, then peeling off the InSb layer and transferring it to a ferrite substrate. See Figure Three. Electron mobilities in such a device are 20,000 - 30,000 cm^2 /Vsec, and the device produces output voltages of 150 - 270 mV. See Table 1. While the development of this these Hall elements is obviously a significant business achievement for Asahi - last year they sold 800 million such devices - persons with an interest in science and technology would likely prefer to see more reliance on state-of-the art compound semiconductor engineering.

The good news is that the next generations of Hall elements from Asahi are moving in exactly that direction, using different materials (InAs active layers, grown on GaAs substrates), different deposition methods (multi-wafer MBE growth) and different device structures (quantum wells) to produce Hall elements which offer improved characteristics over current production models.

The Next Generation

Ichiro Shibasaki and his colleagues at the Asahi Chemical Corporate R&D Facility are responsible for finding ways to make the next generation of Hall elements. Like the very successful InSb models, the new products will need to offer small packages, low costs, and

Properties of InSb, InAs thin film, and InAs QW structures.

Material	Doping	Electron Mobility (cm^2/Vsec)	Electron Density (x 10^{16} cm^{-3})	Thickness (μm)
InSb	none	20,000 ~ 30,000	2	0.8
InAs	Si	11,000	8	0.5
InAs QW	none	20,000 ~ 28,000	50	0.015

Properties of InSb, InAs thin film, and InAs QW Hall elements

Material	Driving Voltage	Hall output voltage (mV) (B= 0.05T)	Offset Voltage (mV) (B=0T)	Resistance (Ω)
InSb	1	150 ~ 270	< + 7	240 ~ 550
InAs	6	100	< + 16	400
InAs QW	6	250 ~ 300	< + 16	700

Table 1. Selected properties of three different structures and Hall elements fabricated from them.

compatibility with high volume production. The primary improvements that are sought are in the area of operating temperature range, because the one significant weakness of the established InSb product line is the large temperature dependence of the input resistance (see Figure 4), caused by the narrow bandgap of InSb. This has the practical effect of restricting their use to near-room temperature conditions. A possible alternative is to use GaAs, which has a larger bandgap (1.43 eV, compared to 0.17 eV for InSb). However, the R&D team at Asahi concluded that the GaAs Hall elements did not offer sufficient sensitivity to magnetic fields, due to GaAs's lower electron mobility compared to InSb, and that they could not be used where high signal-to-noise ratios are required.

In the late 1980's, work began on another alternative: Si-doped InAs layers. The structures, with a typical thickness of 0.5 μm, are grown on 2" semi-insulating GaAs wafers, using one of the industry's first multiwafer (12 x 2") MBE systems. The variation in thickness uniformity among the wafers on the platen is + 3%, which is more than sufficient for this work. At 300 K and a doping level of 8 x 10^{16} cm^{-3}, electron mobilities of 11,000 cm^2/Vs are obtained. A device fabricated from these layers in described in Figure 5. The electrode structure allows highly reliable Au wire bonding using high volume equipment. Standard epoxy resin processes are used for packaging. Electron mobilities are ~11,000 cm^2 /Vsec, and typical output voltage is 100 mV. See Table 1. Although the sensitivity of these devices is reduced in comparison to the InSb models, they do offer much greater temperature independence - see Figure 6. This has helped them find a market niche, and, to date, Asahi has sold more than 5 million of these devices for use in brushless motors and as current sensors.

The State-of-the-Art

The challenge which is currently being addressed at Asahi is the development of low cost product that offers both the wide temperature range of the InAs Hall elements and the high output voltage of the InSb devices.

Higher sensitivity, and even lower temperature dependence, could be expected if it were possible to fabricate high quality ultra-thin films of InAs (<0.1 μm). However, it is virtually impossible to do this, because of the lattice mismatch (7.0%) between InAs and GaAs. As an alternative, researchers at Asahi have turned to quantum well (QW) structures, using InAs sandwiched between insulating barrier layers which are lattice-matched to InAs. The InAs/AlGaAsSb material system was chosen because of the large conduction band offset of ~1.3 eV - see Figure 7. The structure of a device using such a QW is shown in Figure 8. Experimental results show that the quality of the InAs layer is very high, yielding electron mobilties of ~20,000 cm^2/Vs. Higher mobilities have been reported for InAs QW structures which use AlSb barriers and buffer layers, but this approach was considered to unsuitable for high volume manufacturing due to the potential for oxidation of the Al-containing layers.

The typical characteristics of the InAs QW Hall elements have been found to be exceptional. As shown in Table 1, electron mobilities comparable to InSb have been obtained, but even higher Hall output voltages are achieved. According to Shibasaki, the Hall output voltage for constant drive voltage is as large as 600 mV @ V_{in} = 6 V and B=1kG, which is 2 to 2.5 times larger than that of the Si-doped InAs deviçes, and 4 or 5 times larger than that of conventional GaAs Hall elements. Under normalized conditions (the same Hall

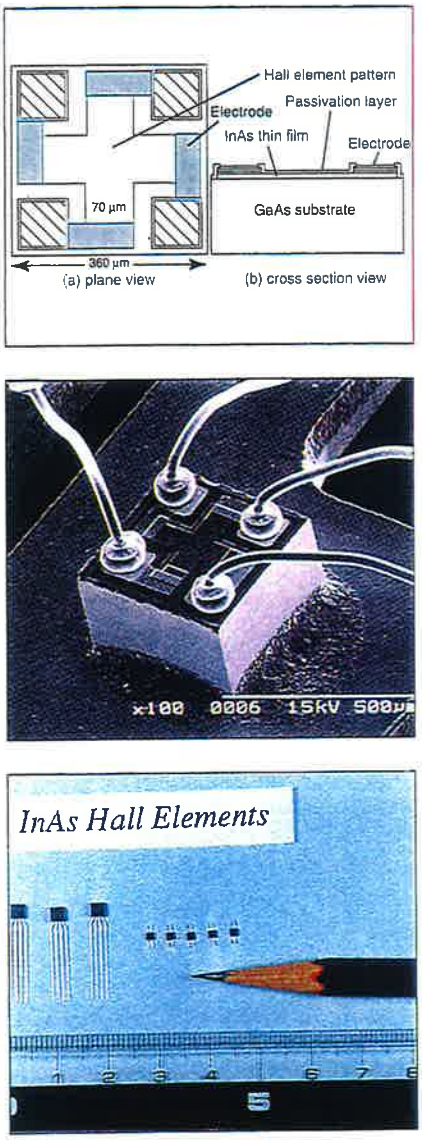

Figure 5: Top: structure of the InAs thi film Hall element chip; Middle: photograp of an unpackaged chip (actual size = 0.36 0.36 mm²); Bottom: photograph of the fi ished product.

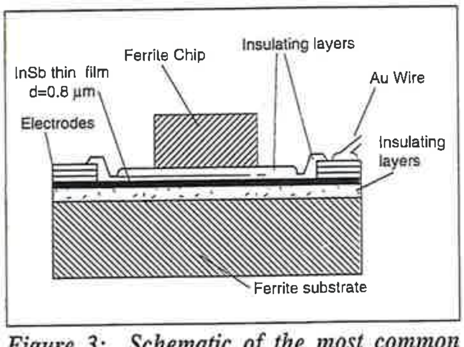

Figure 3: Schematic of the most common type of Hall element, formed by depositing polycrystaline InSb on mica, and then lifting off the InSb layer and transferring it to a ferrite substrate.

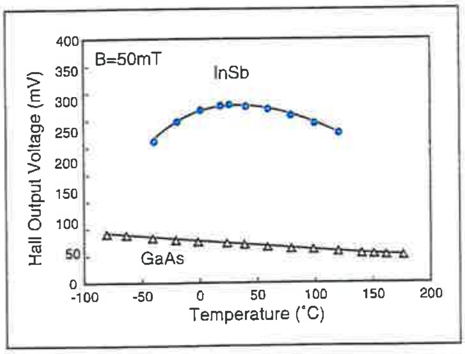

Figure 4: Temperature dependence of Hall output voltage for InSb and GaAs Hall elements. The driving voltage for the InSb models is 1 V, and for the GaAs models it is 6 V.

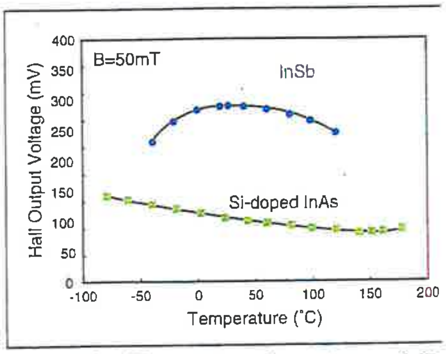

Figure 6: Temperature dependence of Hc output voltage for InSb and InAs thin-film Hc elements. The driving voltage for the InS models is 1 V, and for the InAs models it is 6

output voltage and the same magnetic field), the power dissipation of the InAs QW elements is 1/5 to 1/10 that of commercial GaAs Hall elements - an attractive feature for use in battery operated devices.

As shown in Figure 9, Hall output voltage at constant driving voltage decreases monotonically as temperature increases, corresponding to the monotonic decrease in electron mobility. The temperature coefficient of Hall output voltage for voltage driven InAs QW Hall elements is 0.1%/deg., which is the lowest figure for all reported Hall elements. Regarding sensitivity, the InSb devices characterized in Figure 9 may appear superior; however, Hall output voltage is proportional to the driving voltage and the maximum driving voltage for InSb Hall elements is limited up to 2 V due to burnout, and the breakdown voltage at room temperature is 4 or 5 V due to the negative temperature coefficient of resistance. On the other hand, a driving voltage of more than 12 V is possible for InAs QW Hall elements because of its positive temperature coefficient of input resistance. Therefore, InAs QW Hall elements are more than equivalent to InSb hall elements in their effective sensitivity.

The InAs QW structures are also suitable for mass production. They can be grown in the same MBE system which is used to produce the Si-doped InAs structures, and the growth time required is only one hour. Shibasaki and his colleagues believe that the InAs QW structures are the ultimate solution for industrial sensors, automotive sensors, and other new applications for the future. And, given the characteristics of the device, including its very high output voltage, low power dissipation, and small temperature dependence, the evidence suggest that they may be right.

***Editor's Note:** Ichiro Shibasaki was awarded the 1996 Commendation as "the person of scientific and technological merits" for the development of high sensitivity thin film Hall elements by the Japanese Ministry of State for Science and Technology.*

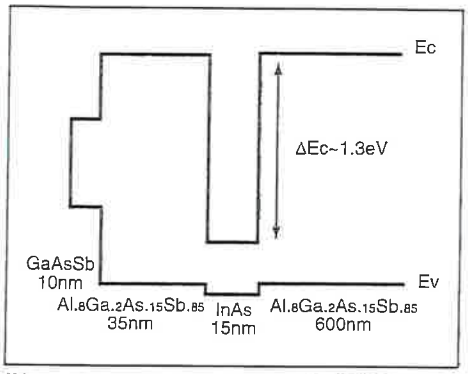

***Figure 7:** Schematic energy band diagram of an InAs quantum well with AlGaAsSb barriers.*

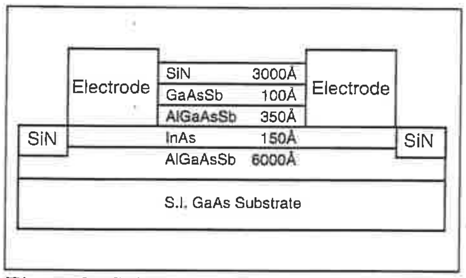

***Figure 8:** Schematic cross-section of an InAs QW Hall element.*

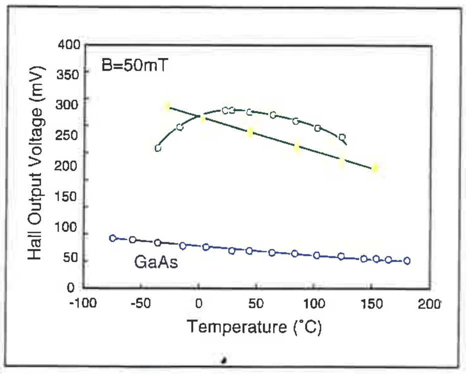

***Figure 9:** Temperature dependence of Hall output voltage for InSb and InAs QW Hall elements, with a commercially available GaAs Hall element shown for comparision. The driving voltage for the InSb models is 1 V, and for the InAs QW and GaAs models it is 6 V.*

Invitation to Contribute

The mission statement for our magazine is "to provide a focal point for the global compound semiconductor industry". To help achieve that goal we encourage our readers to share their unique viewpoints or specialized knowledge about compound semiconductor science and technology by analyzing or explaining recent developments.

We are soliciting contributions from qualified individuals who wish to make a contribution to the general understanding of compound semiconductors and the industry which is based upon them. Almost any compound semiconductor-related topic is acceptable, provided that it is not too narrowly focused. Our primary selection criteria are the article's level of interest and/or usefulness to our readers.

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Additional Reading

"High sensitivity Hall elements made from Si-doped InAs on GaAs substrates by molecular beam epitaxy", T. Iwabuchi et al., J. Crystal Growth 150, 1302 [1995].

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"AlGaAsSb buffer/barrier on GaAs substrate for InAs channel devices with high electron mobilitiy and practical reliability", S. Miya et al., J. Electron. Matls. 25(3), 415 [1996].

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