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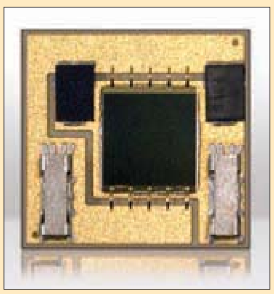
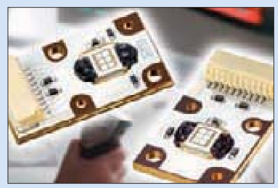
INDUSTRY



EMCORE

Cooling off
Receiver modules help cool down III-V cells from the powerful solar irradiation that they receive in CPV, and also boost Emcore's potential revenues. **p10**

TECHNOLOGY



In the green
Osram employs its ThinGaN technology in small, medium and large green LEDs for video walls, LCD screens and color projection systems. **p18**

Main cover image: *Blue LEDs based on InGaN are far more efficient than green ones based on the same material. Why is this and how are companies like Osram trying to solve the problem? See p16. Credit: BridgeLux.*

Compound Semiconductor*'s circulation figures are audited by BPA International*

Hall sensors have the power to deliver unforgettable memory

Hall sensors are incredibly versatile devices. They can analyze the constituents of mining samples, form accurate magnetometers and team up with tiny magnets to create a novel magnetic memory that retains its information when the power is switched off, says Micromem's **Steven Van Fleet**.

Laptops have come on in leaps and bounds. Prices have plummeted, batteries last much longer and backache is now a thing of the past, thanks to their slim designs. However, they still have one major weakness – lengthy start-up times.

The long wait stems from the design of the laptop's memory. DRAM or SRAM technologies are used for this, which are non-volatile memories that cannot retain data unless power is applied continuously. Since it's not possible to keep the laptop on all of the time, the user has to wait while a copy of all of the software is transferred from the hard disk to the memory every time the computer is turned on.

It is possible to eliminate the laptop's long start-up time by switching to a form of non-volatile memory – magnetic random access memory (MRAM). This allows the computer to jump instantly back to life with its most recent settings. The laptop can also operate for longer between recharges because the computer's memory doesn't drain any power.

MRAM is not just a technology for improving the laptop performance, however – it is also a strong contender in the race for a form of universal memory. It could, for example, replace portable forms of flash memory, such as memory sticks and cards. Although flash memory is convenient, it has limited endurance and there are also question marks over its long-term data retention. These weaknesses are of concern today and put up potential roadblocks to the scaling of this technology in the future.

IBM, Infineon and Freescale have been developing MRAM technologies for several years, employing electric current pulses to change the magnetic polarization of a storage cell. These cells feature a magnetic tunnel junction with a fixed magnetic layer, a thin insulator and a second writable ferromagnetic layer with adjustable polarity (figure 1, p26).

An array of these elements can form a memory, with data written to individual cells through a pair of wire grids suspended above and beneath the devices, which are referred to as the "bit line" and the "word line". When current passes through a cell it induces a magnetic field at the junction, which dictates the polarity of the writable magnetic layer.

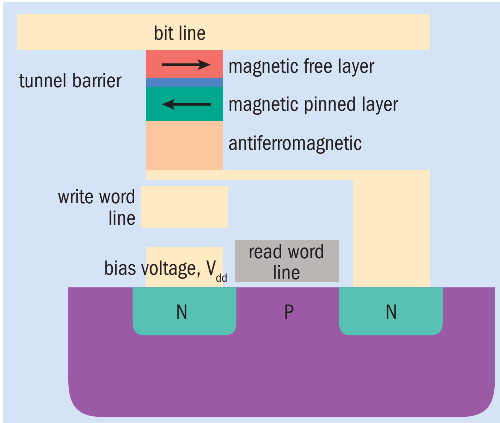
SIEMENS

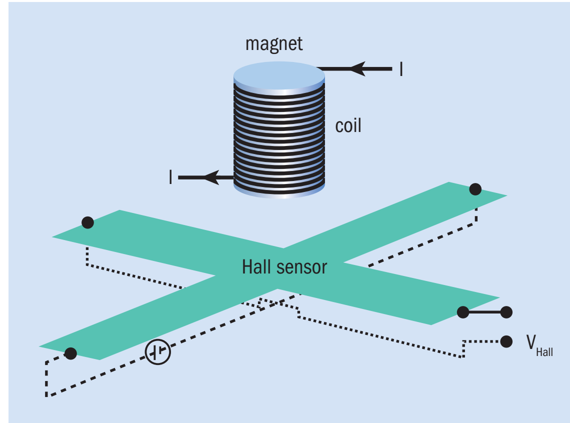
Laptops allow you to lie back and still get some work done, but it takes a while for them to start up. Switching the memory to magnetic RAM could eliminate these irritatingly lengthy waits, although prices will have to fall substantially if this type of memory is to make any real impact.

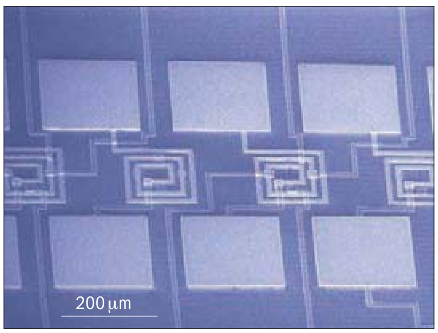
This information can be extracted by measuring the electrical resistance of individual cells, which is dominated by the polarity of the writable layer.

MRAM has advantages over virtually every other type of memory, thanks to its fast write and read speeds, low power requirements, high endurance and CMOS compatibility (see box "Alternative non-volatile memories", p27, for other types of emerging memory technologies). However, it was only commercialized as recently as 2006 and its high price is preventing it from widespread application. At $25 per 0.5 MB, MRAM cannot compete with existing RAM that sells for $25 per 256 MB, never mind flash, which now has a price tag of $25 for 1 GB.

It is possible that MRAM could enjoy success in specialized markets, but even these sectors will require a lower cost-per-byte. This is not out of the question, but it will require a transition from the 0.18 µm lithographic processes used today to smaller feature sizes. Other weaknesses must also be







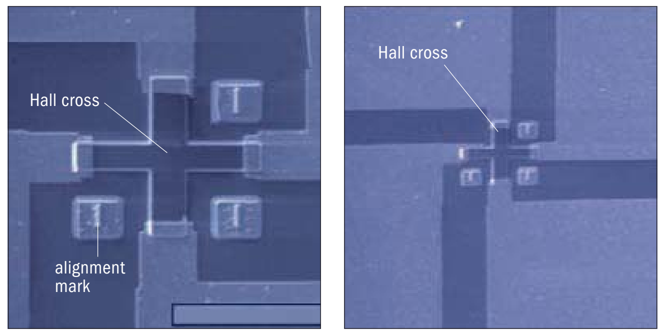


Fig. 1. (top left) Conventional MRAM features two magnetic films – one has a fixed direction, the other can be adjusted by passing a current through the cell. The orientation of this magnetic layer dictates the cell's electrical resistance and provides its memory function. **Fig. 2.** (top right) Micromem's MRAM technology is based on a small magnet and a Hall cross sensor. Passing a current through the magnet defines its state, which can be read by recording the voltage from the Hall sensor. **Fig. 3.** (bottom left) Micromem has spent several years developing its MRAM memory and is now producing devices at the GCS foundry. **Fig. 4.** (bottom center and right) BAE Systems will be producing GaAs-based sensors with Micromem's patented Hall effect sensors for use in accurate magnetometers.

addressed, such as fatigue, complex fabrication techniques and a small range of operating temperatures.

However, there is one area where MRAM technology stands a reasonable chance of success – lower density, higher application-content memory applications that do not face the pressures associated with commodity pricing. At Micromem Technologies Inc, Toronto, Canada, we are pursuing that goal with our novel form of MRAM technology that is based on a tiny magnet and a Hall sensor. This is robust and simple to fabricate. In addition it offers unlimited endurance and incorporates proven and well understood Hall cross sensors.

Writing data to our form of memory is very similar to the process for conventional MRAM, although current is passed through a single coil to define the magnet's polarity (figure 2). However, reading is substantially different, with the Hall cross sensors being used to record the magnet's state. A current is passed between two of the arms on opposite sides of the cross, and voltage across the other two arms is measured. The voltage results from the deflection of electrons by the magnetic field, and its polarity depends on the magnetization state.

We have been developing our technology for seven years. Three years ago we started to work with the University of Toronto, which has performed basic research and development. Our initial focus was GaAs-based memory because a particular client wanted a radiation-hardened memory. However, we have discovered that other materials, including silicon, can provide some degree of radiation hardening thanks to the use of magnets for memory-bit storage. This has encouraged us to work with various materials, and ultimately equipped us with the know-how to launch a range of memory devices based on GaAs, SiGe and silicon later this year. These devices, which will be protected by our recently secured patent portfolio, will target calibration memory on phased array radar and distributed memory applications in automotive, medical and military applications.

Teaming up with GCS

We are a fabless company, and we are producing memory devices on 4 inch material at Global Communication Semiconductors in California. This foundry is equipped with the necessary thin-film and submicron lithography expertise, and has also helped us to refine manufacturing processes and product design, and it was able to draw on its own experience in making non-silicon devices.

Our devices are made with conventional semiconductor thin-film processes and just one epitaxial step – the growth of a proprietary thin-film stack. Semi-insulating and doped layers increase carrier mobilities and carrier densities. A p-n junction is not included, but this is under study for next-generation products that could deliver higher performance.

Photolithography defines the magnets and the Hall sensors, which have feature sizes that are well within the capabilities of today's tools. Scaling to far smaller sizes would only be required if quantum Hall sensors were to replace conventional devices, or magnetic tunneling devices were employed.

Metal and dielectric layers form the interconnects and magnetic write structures. Only one Hall cross

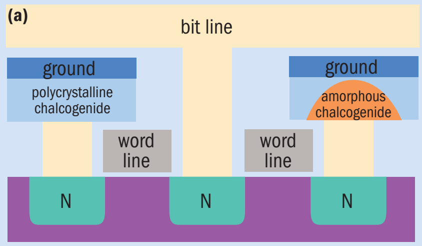
Alternative non-volatile memories

MRAM is competing with three other types of non-volatile memory to provide a universal solution: phase-change RAM; ferroelectric RAM; and carbon-nanotube RAM. Descriptions of all of these technologies and details of their various strengths and weaknesses are provided by iSuppli's report *Handicapping the Emerging Memory Technologies*.

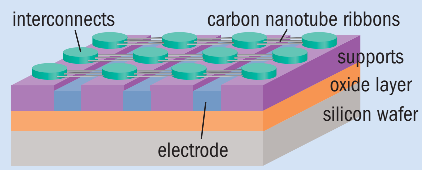
Phase-change RAM **(a)** features a chalcogenide layer within the die. Changing this material's state produces the "zeros and ones" that form the memory. When the material is amorphous it is highly resistive, but when it is crystalline it has a low resistivity. An electrode can provide local heating to "write" the memory, which can take place in just a few nanoseconds. The "word line" is used to activate a row and each column can be accessed individually through "bit lines".

Carbon-nanotube RAM **(b)** employs an array of electrodes that are separated by slightly higher, insulating interconnect layers. Current in the carbon nanotubes – which

(a)

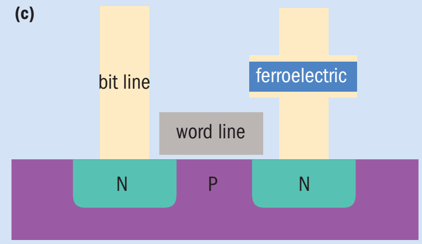


(b)



are suspended from interconnects and hang above the electrodes by several nanometers – are used to define the ones and zeros that provide the memory function. Applying a voltage to an electrode causes sagging of a nanotube so that it touches the electrode

(c)



and passes a current.

Ferroelectric RAM **(c)** features a thin film of lead zirconate titanate (PZT), which forms arrays of capacitors. The electric dipoles within the PZT can be orientated by an external electric field, with the direction of these dipoles providing the ones and zeros. A transistor reads the cell by forcing it into a particular state. If the cell is forced into a new state, then the atoms are reorientated and they produce a brief current pulse. No current pulse occurs if the cell is unchanged by the transistor's action.

sensor is required per bit as non-volatile bit storage only occurs in the ferromagnetic structural element.

Packaging follows, which employs a minimized and controlled ferromagnetic environment and copper lead frames. Bespoke designs can address specific applications. For example, a magnetic shield can be incorporated into ferromagnetic non-volatile RAMs, and packages that are devoid of ferrous materials can be used in stand-alone Hall sensors. These can be hermetically sealed or placed in low-cost packages, depending on the customer's needs.

Our stand-alone Hall sensors (figure 4) combine very low operating powers with a high sensitivity of more than 2.2 V/Tesla. This makes them candidates for defense applications, healthcare, mining, mineral exploration, manufacturing and quality control, and the automotive industry. They have many applications, including *in situ* material analysis of mining sample plugs. The device can take a "magnetic" picture of the core sample and detect mineral constituents through pattern recognition.

We have recently teamed up with BAE Systems, which is planning to manufacture nanosensors with our patented technology at its Nashua, NH, foundry. Over the next few months, devices will be built for use in accurate magnetometers for military equipment.

Extending our GaAs-based MRAM technology to SiGe and silicon has bolstered our chances of making an impact in computer memory. However, we still face competition from three other approaches that promise to advance silicon's memory capabilities. Two of these alternatives are cell-to-cell optical interconnects and forms of wafer-scale technology that feature built-in tolerances to combat low yields. The other threat is niobium rapid single flux quantum superconductive technology – an unpopular technology, but one that could deliver significant power benefits at higher clock speeds.

All of these options promise to increase circuit current density through advanced packaging technologies, such as three-dimensional structures. Managing heat extraction will hold the key to building reliable circuits, and all of the technologies described have the potential to do this.

Where our technology could have the edge is in optical computing, thanks to GaAs MRAM devices' compatibility with GaAs circuits that use optical logic and optical memory. Although optical computing has been touted as tomorrow's technology since the mid-1980s, some recent work on nonlinear optical technology shows genuine promise. Hybrid MRAM is also possible, although magnetic storage is expected to outperform its optical equivalent in terms of density and speed.

All four technologies will have to progress to stand a chance of making an impact on the memory market. In optical devices, the switch offers the biggest challenge. This is needed for logic and store functions, and significant advances in nonlinear optics are required to produce pure optical-to-optical devices. But the real challenge here, which is essential if these devices are to enter the mainstream market, is competitiveness with silicon in terms of performance, power, density and reliability. This is not going to be easy, but success would provide great rewards. We will continue to target this goal by developing our technology, while enjoying success through lucrative Hall sensor sales.

About the author

Steven Van Fleet (svanfleet@micromeminc.com) is a director of Micromem.