SPINTRONICS ENTERS THE MAINSTREAM

Key breakthroughs by Tohoku University researchers have unlocked the potential of spintronics, resulting in COMMERCIAL DEVICES WITH ULTRALOW POWER CONSUMPTION. The university's dedicated venture start-up, Power Spin Inc, is driving the future of this technology.

Hovering on the cusp of great things since the middle of the last century, spintronic semiconductor technology remained in limbo as it was not able to surpass conventional electronics. That all changed in 2010, however, with the invention by Hideo Ohno's team at Tohoku University in Japan of the magnetic tunnel junction, a high-performance non-volatile spintronic device that is compatible with existing semiconductor fabrication processes. Now, electronics is on the verge of a revolution as the semiconductor industry's big players start picking up the low-power spintronics technology — and just in time, as Tetsuo Endoh, the director of the Center for Innovative Integrated Electronic Systems (CIES) of Tohoku University and representative director and chief technical officer of Power Spin Inc, explains.

"In the past decade, we've witnessed an extraordinary ten-fold annual increase in computing ability demand, which conventional electronics cannot meet. At such computing levels, power consumption becomes a significant global issue," says Endoh. "Spintronics will be the game changer."

Shunsuke Fukami, a professor at the Center for Science and Innovation in Spintronics (CSIS) of Tohoku University, concurs: "Spintronics has potential to realize high performance, ultralow power consumption and more," he says. "It offers a way to advance technologies in various areas, such as quantum computing and energy harvesting, which are key to realizing a low-carbon society."

THE SECRET OF SUCCESS

Endoh was part of the group that, in the late 1980s, developed the NAND flash memory now used in most memory sticks, and invented a three-dimensional stacking of NAND elements called 3D NAND technology now used in high-performance solid-state drives. Spintronics, he remarks, is his third great challenge, and as director of Power Spin Inc, he is well positioned to make this technology another industrial mainstay.

Like NAND and 3D NAND, spintronic semiconductors is tremendously attractive for industrial applications. "Ohno's achievements provided a step change in performance and could be fabricated using conventional semiconductor processes," says Endoh. It's cheap and scalable, and fast enough for most memory applications, while enabling a hundredfold reduction in power consumption and chip area with virtually no drawbacks."

THE BENEFITS OF SPIN

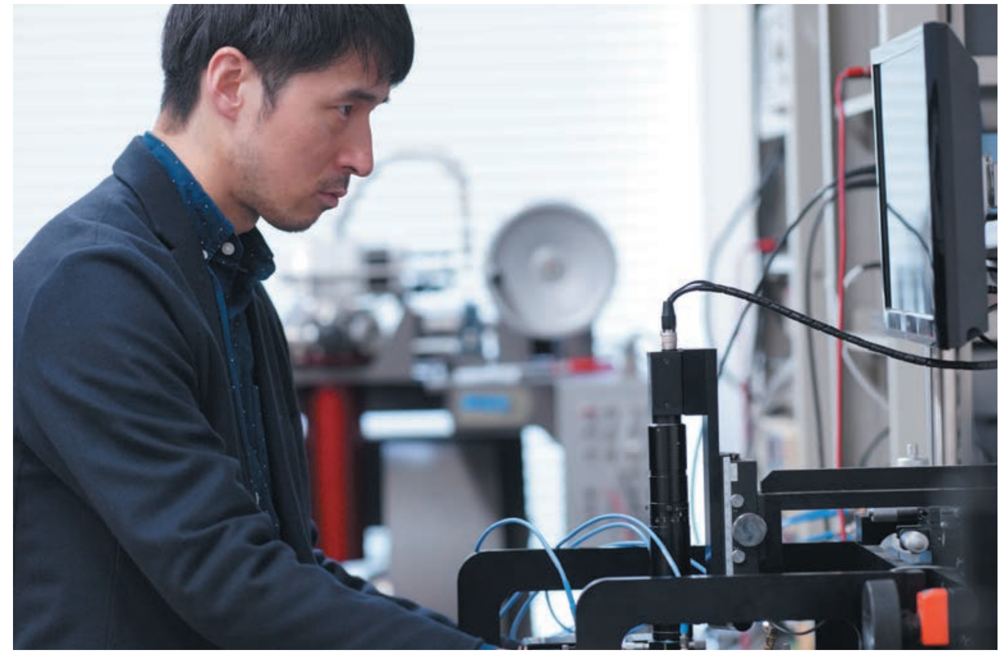
Spintronics relies on the simultaneous usage of the magnetic and electric properties of electrons. "Spintronics essentially builds on electronics and magnetics," explains Fukami. Spin is the property of electrons that gives rise to magnetism, and can be oriented either up or down. Magnetism arises when the spins are aligned in the same direction. Using the electron's two properties allows the state of a 'bit' to be set in the form of a magnetization direction that can be detected and switched electrically in the magnetic tunnel junction.

▲ Tetsuo Endoh in his office (left) and holding a 300-millimetre wafer (right). As director of Power Spin Inc, Enhoh is excited about the potential of harnessing spintronics for commercial applications.

A key advantage of spintronics is that it can be used to create fast integrated memory that is non-volatile — preserving stored data even when unplugged from electrical power. In the conventional 'volatile' memory used for fast random access memory (RAM) on central processing units (CPUs), data is only maintained when the memory chip is powered. NAND Flash memory achieves non-volatile storage, but is orders of magnitude slower than that needed for processor-adjacent memory. Since spin-transfer torque magnetoresistive RAM (STT-MRAM) only needs to power each bit of memory just during operation, it has a drastically reduced power consumption. Endoh's team has demonstrated a power consumption reduction of 97% for STT-MRAM compared to a CMOS-based equivalent.

This reduction in power consumption eliminates much of the circuitry devoted to power distribution, enabling memory chips to be a fraction of their current size. "More than 80% of the area of modern CPUs is taken up by cache memory," says Endoh. "STT-MRAM can reduce this area by 85% or more."

Other remarkable advances at Tohoku University are speed and compactness. Fukami's team is working on both aspects. "We have realized the world's smallest magnetic tunnel junction, which is as small as 3 nanometres across," Fukami says. "We have also made a very fast magnetic tunnel junction operating in sub-nanosecond timescale."



▲ Shunsuke Fukami in his laboratory. He and his team are developing magnetic tunnel junctions that are faster and smaller.

CURRENT AND NEW APPLICATIONS

Endoh notes that industries have already applied STT-MRAM, for example, in their latest smartwatches, which has increased the battery life from 4 days to 2 weeks. These applications show that the STT-MRAM technology is ready to grow, and CIES are working closely with major worldwide players in industries while creating innovative technologies required in future.

"I expect low-power spintronics to become mainstream in the near future, and many semiconductor electronics eventually being superseded by spintronics," says Endoh. "This can be achieved without changing most of existing fabrication processes — STT-MRAM can be fabricated using the standard silicon-based CMOS process used throughout industry."

What particularly excites Endoh, however, is the potential for new applications, such as artificial intelligence (AI). Execution of AI models requires intensive memory operations involving accessing and updating of memory over many cycles. Different types of memory have different 'endurance' levels, or how many times a bit in memory can be switched before it deteriorates. STT-MRAM has an endurance of 10^{12}–10^{15} operations, or a trillion to a quadrillion switches, putting it on par with the best volatile CMOS memory.

"AI processors are a particularly good application for STT-MRAM because it is fast enough and has high enough endurance for cache memory, while being ultralow power, has a small footprint, and operates at the same voltage as the CMOS processor allowing for excellent integration," says Endoh. "This is an example of specific applications that we're working on at CIES."

CIES is also working on another type of the MRAM, called spin-orbit-torque MRAM (SOT-MRAM), which offers even faster speeds.

"CIES develops spintronics technologies and potential applications and Power Spin will accelerate the implementation of these technologies suitable for business domains" says Endoh. "We have over 400 patents, and we're always exploring new opportunities. We see immediate applications in ultralow-power devices, devices for tough environments and high temperatures, and also in space because spintronics is not susceptible to radiation."

"The CMOS technology that has enabled our modern information-driven society was born 60 years ago, but at the time few could imagine what the technology would become today," says Endoh. "I think we will look back in the future and recognize this time now as the start of the era of low-power spintronics." ■