Combining magnetic data storage and logic

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Postdoc Zhaochu Luo with a chip that features both racetrack memory and logic. Credit: Markus Fischer/ PSI

Computers normally store and process data in separate modules. But now researchers at ETH Zurich and the Paul Scherrer Institute have developed a method that allows logical operations to be performed directly within a memory element.

Anyone who has ever accidentally pulled out the plug of a desktop computer will recall the painful moment when they realised that any unsaved information was lost forever. That's because computers make a clear distinction between the tasks of computation and data storage. Whatever data the computer is currently using is stored in the main memory, which—like the computer's CPU—relies on current-controlled transistors. This means the main memory is "volatile": as soon as the power disappears, so does the data. Software, images, videos and any other data that require long-term storage are stored in non-volatile memory such as flash memory or a magnetic disk drive, from where they can be loaded into the main memory as and when needed.

Under the leadership of Pietro Gambardella and Laura Heyderman, a team of scientists from ETH Zurich and the Paul Scherrer Institute (PSI) is now hoping to revolutionise this decades-old principle. Their goal is to build a fast, non-volatile memory system that can also perform logical operations on the data such as NOT, OR and AND. They recently reached an important milestone on that journey, which was described in an article in the scientific journal *Nature*.

Fast racetrack memory

Researchers have been working on the development of magnetic racetrack memory for a number of years. This new type of memory is much faster than traditional hard disk drives in which a read/write head must be moved to a specific region of the disk surface by mechanical means. In contrast, racetrack memory elements work by using current pulses to move tiny magnetic regions, or domains, up and down nanowires that are just a few hundred nanometres thick. In these domains, all the magnetic moments—like tiny compass needles associated with the material's atoms—are oriented in the same direction and can thus be used to represent the binary states 0 and 1. By eliminating the need for the mechanical movement of a read/write head, racetrack memory offers much faster access times than traditional hard disk drives. Nevertheless, even data stored in this way would normally have to be loaded into main memory to be processed.

"What we've managed to do now is to perform logical operations directly within this kind of memory element," says Zhaochu Luo, the postdoc researcher who drove the project forward. Computers use logical operations to process data. For example, the logical operator NOT inverts a bit, switching its value from 0 to 1 or vice versa. Normally this operation is performed in the main memory, with the data being read from and rewritten to the magnetic hard disk but not directly processed there.

A curious interaction

"Our method works differently," says Pietro Gambardella. "We use an electric current to reverse the polarity of the magnetic regions, thereby performing a NOT operation on the stored data. We do this by harnessing a rather peculiar exchange interaction that occurs when we deposit a magnetic cobalt film on a platinum layer." As a result of this interaction, the magnetic moments are neither parallel nor antiparallel to each other, as would normally be the case. Instead, due to the presence of the platinum layer, the interaction causes the magnetic moments in adjacent domains to align perpendicular to each other. "It's almost as if a compass needle were to suddenly point east instead of north," says Gambardella.

This perpendicular alignment of the magnetic moments also leads to a preferred sense of rotation of the magnetisation between one domain and the next, similar to how a corkscrew rotates in a specific direction. So if a current pulse is now passed through the platinum layer, the flowing electrons gradually change the polarity of the atomic "compass needles" in the magnetic cobalt layer. This moves the information encoded in the magnetisation and creates a travelling magnetic domain. Then, at predefined locations where the perpendicular interaction is strong, the direction of the magnetisation in the travelling domain is inverted. This corresponds precisely to a logical NOT operation.

It is possible to combine such operations in different racetrack memory elements, thus providing other logical operations such as AND, OR and NAND. These can be assembled into more complex circuits, for example to add two numbers together (see image). But, unlike conventional circuits based on semiconductors in which each transistor requires its own power supply, the new racetrack memory circuits only need to be supplied with current at the input and output.

Uses in the Internet of Things

"Initially, I see our technology primarily being used in microprocessors with low computing power," explains Gambardella. One example that is particularly relevant in today's world is the Internet of Things, in which a variety of devices and sensors communicate with each other directly. The computers in these kinds of devices need to offer "instant-on" capabilities—meaning immediate operation without the delay of uploading an operating system—and low energy consumption. A technology combining magnetic memory and logical operations would be ideal for this application.

In principle, says Gambardella, there is nothing standing in the way of operating larger computers in the same way. But in practice, he confesses, this is unlikely to happen any time soon: "Optimising the materials and manufacturing processes for this purpose is a very expensive business for chipmakers, so it's too early to say whether our technology can replace conventional semiconductor technology." Even so, he argues, this new approach is certainly interesting enough to warrant further investigation to discover how far it can be taken. The researchers have already applied for a patent, so perhaps we will eventually end up with a computer that allows us to pull the plug without worrying about losing data.

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