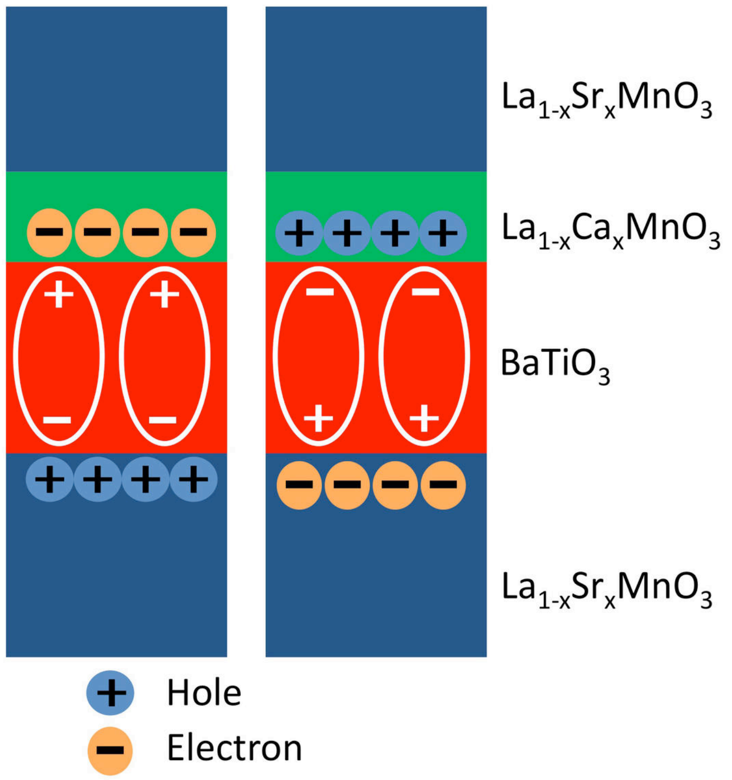
New, multifunctional electronic devices may soon be possible

Penn State



15 February 2013 — For the first time, researchers have designed a special material interface that has been shown to add to and to improve the functioning of non-silicon-based electronic devices, such as those used in certain kinds of random access memory (RAM). According to Qi Li, a professor of physics at Penn State University and the leader of the research team, the new method could be used to design improved, more-efficient, multilevel and multifunctional devices, as well as enhanced nanoelectronic components -- such as non-volatile information storage and processing; and spintronic components -- an emerging technology that uses the natural spin of the electron to power devices. The research has been accepted for publication in the journal Nature Materials.

Li explained that most modern-day electronic chips -- integrated circuits that serve as the building blocks for semiconductor electronic devices such as solar cells, personal computers, and cell phones -- use silicon transistors to process "logical states," or the binary system of ones and zeros used by computers. This binary information is stored for fast access in RAM and also permanently in a magnetic form on hard disks. In this system, the numeral 1 can be understood as "on" -- with a current of electrons flowing freely -- and the numeral 0 as "off" -- with a current blocked. However, in recent years, Li said, researchers in laboratories across the world have been experimenting with different, non-silicon materials that "can toggle between a multilevel state system and can bring the memory into logic operation," and also function with greater speed and less power consumption than are possible with current technology.

Now, in a new research study, Li and her colleagues have designed and tested an alternative way of creating a device that is compatible with non-silicon technology and that combines into one device both an electronic and a magnetic junction. "Magnetic tunnel junctions -- which include two magnetic metallic layers with a very thin insulator barrier in between -- have been used for binary-state devices, such as magnetic random-access memories (MRAM). Tunneling itself is a quantum-mechanical effect," Li said. "Our goal was to create a multifunctional device with improved function by adding what we call a ferroelectric-magnetic interface -- a ferroelectric layer replacing the insulator barrier and a special interface layer, less than one nanometer thick, built into the device that acts to change from metal to insulator as well as from ferromagnetic to antiferromagnetic in response to the negative or positive charge polarization of the barrier." Thanks to this interface and through a phenomenon called the tunneling electroresistance effect, Li said, "we have found that the binary-state resistance difference, or the 1/0 system, is enhanced by up to 10,000 percent. This device is considered a quaternary-state device because we have integrated ferroelectric tunneling -- which can be used as a switch or memory -- into magnetic tunnel junctions, a type of magnetic memory."

Li added that her team's newly designed interface is special because the oxide materials used to build it are "multiferroic" -- one side magnetic and the other ferroelectric, with the magnetic layer changing with the ferroelectric switching. Ferroelectric materials, which are used in the capacitors built into medical ultrasound machines, as well as in other memory devices such as hotel key cards, have a spontaneous electric polarization of negative and positive charges that can be reversed. On the other hand, ferromagnetic materials, such as iron, form permanent magnets with magnetization direction also reversible. "Because our new interface combines both magnetic and ferroelectric properties and because we utilize the coupling effect between the two, we can reproduce a similar binary system with a much larger resistance difference between the two charge-polarization directions. With future modifications, faster switching and storage, or toggling, between 1 and 0 with the information also stored in the same device (or between the states of 1, 2, 3, and 4) may be possible," Li said. "With a 10,000-percent enhancement, the 1 is a stronger 1 and the 0 is a stronger 0, thanks to the physical properties of the materials used to build the interface structures. Stronger 1s and 0s mean sharper switching or fewer memory errors and better and faster information processing and storage power."

Li said that non-silicon materials that use enhanced tunneling-electroresistance-effect technology may be many years away from being available in personal computers and cell phones. However, her research is a next step toward demonstrating the feasibility of this technology. "A few of the exciting outcomes of a multiferroic interface built into tunnel junctions would be doubling the memory states from two to four, a switch and a memory in one chip, and electrical control of the magnetic devices. For example, a new generation of non-volatile multilevel data processing and storage would be possible with the combined memory of MRAM and ferroelectric RAM (fRAM) or logic operation." Li said.

Li explained that memory is considered non-volatile if it is stored even when it is not powered. "Most computers use dynamic random-access memory (dRAM) -- a form of computer data storage in which stored information fades from the capacitor unless it is refreshed periodically," Li said. "But with both MRAM and fRAM, if you shut down your computer while you are watching a video, then the video would pop back up on the screen immediately as soon as you powered the computer back on again. No restart of the window in your personal computer would be necessary."

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