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SPINTRONICS

Protons make the switch

Spin-based devices are promising technologies to go beyond the capabilities of complementary metal-oxide semiconductor (CMOS) technologies. To realize their potential, these spintronic devices must be able to gate their magnetic properties in a similar way to how a transistor gates electrical properties.

Now, writing in *Nature Materials*, Geoffrey Beach and colleagues report the reversible switching of magnetic anisotropy in solid-state heterostructures — a phenomenon that could be exploited in ultralow-power memory as well as logic and sensing devices. Upon application of a gate voltage, a 90° magnetization switching is achieved by the insertion of protons into the solid-state heterostructures.

Credit: Getty Images/Kyoshino

"The injected protons can toggle the magnetic properties of the heterostructure in a reversible way for more than 2,000 cycles," says Beach.

The devices comprise a proton-conducting oxide (GdO_x) sandwiched between a Au anode and a magnetic thin layer (Co), with a Pt cathode at the base. A positive bias voltage at the anode initiates the water molecules in the air to react with the Au anode and split into hydrogen and oxygen. While the latter evolves as a gas, the hydrogen — in the form of protons — is injected into the material and passes through the conducting oxide to the Co layer. When the Co is initially oxidized, the protons chemically reduce CoO to metallic Co, switching it from a non-magnetic to a magnetic state. Upon a negative bias voltage, the metallic Co is oxidized to form CoO and the magnetization consequently vanishes.

Using this method, not only can the Co magnetization be switched on and off, but its orientation can be controlled without changing its chemical state. The researchers discovered that pumping hydrogen towards and away from the Co/GdO_x interface causes the magnetization direction to be reversibly switched between the out-of-plane and in-plane directions.

Previous methods to achieve magneto-ionic control of magnetism have relied on the displacement of O^{2-} to change the magnetic properties. However, although O^{2-} ions can have considerable influence on magnetic properties, the greater accessibility of the smaller H^+ ion speeds up its insertion and lessens the destruction to the chemical structure. As a result, the protons enable reversible switching to occur at room temperature compared with the elevated temperature required for O^{2-} systems. Moreover, the research showed that H^+ can be inserted into heavy metal layers adjacent to the Co layer, which could allow for toggling of other spin-orbital phenomena in spintronics devices.

Beach and colleagues envisage that this magneto-ionic gating set-up could be used in ultralow-power memory devices. For magnetic memory bits to be thermally stable, the energy barrier for switching 1 to 0 must be large, but this energy barrier also limits the switching efficiency. "The higher the thermal stability, the more power is required for writing," explains Beach. "However, with this new magneto-ionic gating scheme, a bit could be toggled into a low-anisotropy 'writing' state or a high-anisotropy (energy barrier) 'retention' state."

"The optimization of materials to increase the speed and further reduce the operating voltage (currently about 1V) are under exploration," concludes Beach. "We also aim to build prototype devices for neuromorphic computing applications to harness the full capabilities of this new switching mechanism."

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