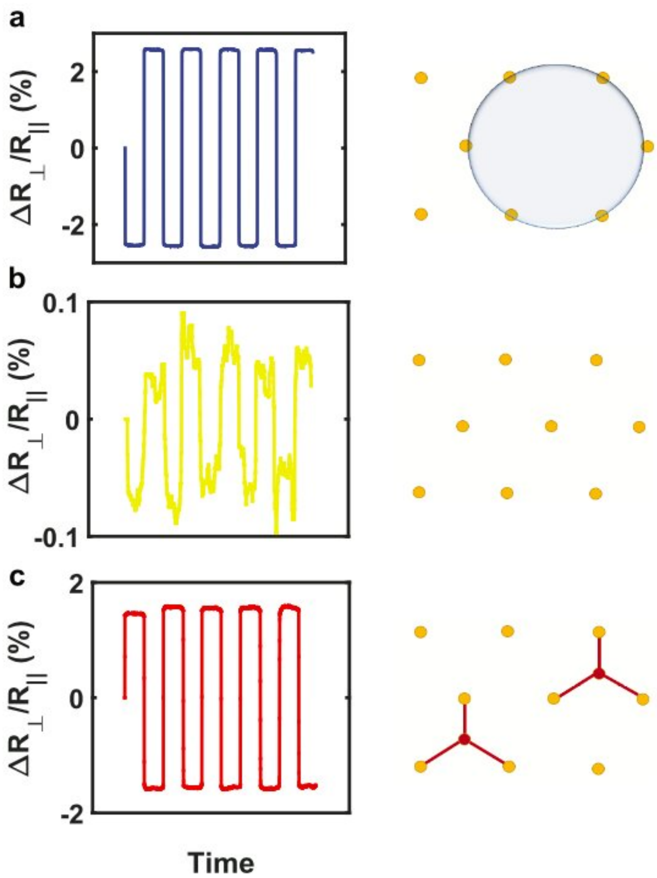
Researchers demonstrate the potential of a new quantum material for creating two spintronic technologies

3 February 2021, by Ingrid Fadelli



Low temperature switching for x = 0.31 (a), 0.34 (b), and 0.35 (c) illustrates the stability and enhanced response while departing x = 1/3 value. An illustration of the iron lattice is presented for the relevant regimes: vacancies (a), stoichiometric (b), and interstitials (c). Credit: Maniv et al.

Over the past decade or so, physicists and engineers have been trying to identify new materials that could enable the development of electronic devices that are faster, smaller and more robust. This has become increasingly crucial, as existing technologies are made of materials that are gradually approaching their physical limits.

Antiferromagnetic (AFM) spintronics are devices or components for electronics that couple a flowing current of charge to the ordered spin 'texture' of specific materials. In physics, the term spin refers to the intrinsic angular momentum observed in electrons and other particles.

The successful development of AFM spintronics could have very important implications, as it could lead to the creation of devices or components that surpass Moore's law, a principle first introduced by microchip manufacturer Gordon Earle Moore. Moore's law essentially states that the memory, speed and performance of computers may be expected to double every two years due to the increase in the number of transistors that a microchip can contain.

While current technologies are reaching their physical limits, AFM spintronics could significantly outperform existing devices in both speed and performance, reaching far beyond Moore's law. Despite their advantageous qualities, finding materials with the exact characteristics necessary to fabricate AFM spintronics has so far proved to be highly challenging.

Researchers at the Lawrence Berkeley National Laboratory, UC Berkeley and the National High Magnetic Field Laboratory in Tallahassee have recently identified a new quantum material ($Fe_{1/3+?}NbS_2$) that could be used to fabricate AFM spintronic devices. In their most recent papers, published in *Science Advances* and *Nature Physics*, they demonstrated the feasibility of using this material for two AFM spintronics applications.

"The work published in *Science Advances* was motivated by our previous publication, which demonstrated antiferromagnetic switching in the intercalated transition-metal dichalcogenide (TMD)-based compounds for the first time," James G. Analytis, one of the researchers who carried out the study, told Phys.org. "In our other recent study, featured in *Nature Physics*, we showed that these same materials have a huge 'exchange bias'—a property that can be used for spin valves to ensure that the transport of spin in spintronic devices travels in one direction but not another."

Analytis and his colleagues found that ultra-low current densities enabled highly stable electrical switching in TMDs, which have shown great promise for the development of new technologies. When compared with other known switchable antiferromagnetic systems, in fact, these materials exhibited additional characteristics such as a single-pulse saturation and a significantly lower activation energy (two orders of magnitude lower).

The researchers were unsure about why these materials exhibited these extraordinary switching characteristics. An observation that they thought could help them solve this riddle was that the materials presented an additional disordered magnetic phase, known as spin glass, which coexisted with the antiferromagnetic phase.

"Our ongoing research shows that this phase coexistence is highly influenced by the iron intercalation value, and consequently, it determines how this system will respond to the injection of DC electrical pulses," Eran Maniv, the lead author of the project, told Phys.org. "Our new data showed that the switching is pronounced only when the two phases coexist and is significantly suppressed when the spin glass phase is absent."

The key objective of the researchers' recent studies was to understand how the coexistence of the spin glass and antiferromagnetic phases in transition-metal dichalcogenides could impact their electrical switching capabilities. More specifically, Analytis, Maniv and their colleagues hoped to unveil the physics behind the mechanism that enhances antiferromagnetic switching in these materials.

A spin glass is a magnetic system that exhibits randomly distributed and conflicting magnetic interactions. It could be roughly described as a disordered magnet. The spin glass state, which the researchers observed in transition-metal dichalcogenides, is not present in existing switchable antiferromagnetic systems.

"Unlike a ferromagnet or an antiferromagnet where the spins point in specific directions, a spin glass' spin points, on average, in every direction," Analytis said. "However, the spins of a spin glass are still glued to each other, just like the spins of a ferromagnet or an AFM. This makes them move together, enabling so-called collective dynamics. The origin of the new and enhanced switching mechanism we observed lies on the collective dynamics of a spin glass."

Maniv, Analytis and their colleagues found that when an electrical current pulse is injected into a spin glass, its spins collectively rotate. This phenomenon occurs because of the disordered nature of the glassy phase, which allows the frozen spins to rotate in unison without any additional energy cost.

The researchers observed that the collective motion of the spin glass can impart spin torque on the coexisting antiferromagnetic phase, which ultimately rotates the spins of an AFM, so that their domains predominantly point in one direction. The spins' collective rotation is the key mechanism behind the enhanced switching exhibited by TMDs. Interestingly, the researchers found that the interaction between the spin glass and the AFM phases also gives rise to the giant exchange bias reported in their recent paper published in Nature Physics.

"This antiferromagnetic switching, showing single pulse rotated domains with high efficacy, has never been observed, until now," Maniv said. "The ability to control and significantly improve the highly desirable antiferromagnetic switching is a breakthrough in spintronic-related technologies. Moreover, revealing this effect in the rich material playground of the TMDs will enable future room temperature studies and improved characteristics."

Remarkably, the new magnetic and switchable system identified by Analytis and his colleagues has ultra-fast dynamics, is robust to magnetic fields and also activates at lower current densities than any known material. This system's response to electrical pulses enables highly efficient single pulse activation and switching states that are far more stable and powerful than those observed in other known antiferromagnetic materials.

"One of our most striking observations was the possible presence of the theoretically predicted "Halperin-Saslow (HS) Modes' (i.e., spin waves in a spin glass)," Maniv said. "These spin waves are predicted to form in certain spin glass phases and are directly related to the global collective motion enabled by electrical current pulses."

HS Modes are hydrodynamic modes that physicists Halperin and Saslow predicted would exist in spin glasses. While Analytis and his colleagues did not observe these modes directly, they found clues that could pave the way towards their experimental realization. This is a particularly interesting finding, as researchers have been trying to directly observe these modes for decades.

"We now intend to focus on revealing the spin glass—spin wave modes (i.e., HS modes)," Analytis said. "One of my co-authors on the work, Shannon Haley, is now leading new experiments to study non-local switching in focused ion beam fabricated samples. Additionally, we intend to study various intercalated TMDs which can present similar effects but at different temperatures, allowing us to access this new mechanism at room temperature."

More information: Antiferromagnetic switching driven by the collective dynamics of a coexisting spin glass. *Science Advances*(2021). DOI: 10.1126/sciadv.abd8452.

Exchange bias due to coupling between coexisting antiferromagnetic and spin-glass orders. *Nature Physics*(2021). DOI: 10.1038/s41567-020-01123-w
.

Electrical switching in a magnetically intercalated transition metal dichalcogenide. *Nature Materials*(2019). DOI: 10.1038/s41563-019-0518-x.