Science Highlight
Speed Limit Set for Ultrafast Electrical Switch

SLAC researchers have clocked the fastest-possible electrical switching in magnetite, a naturally magnetic mineral. Their results could drive innovations in the tiny transistors that control the flow of electricity across silicon chips, enabling faster, more powerful computing devices.

**Trillionth-of-a-Second Changes**
Using SLAC’s Linac Coherent Light Source (LCLS) X-ray laser, the scientists found it takes only 1 trillionth of a second to flip the on-off electrical switch in samples of magnetite, which is thousands of times faster than in transistors now in use. The results were published in *Nature Materials*.

“This breakthrough research reveals for the first time the ‘speed limit’ for electrical switching in this material,” said Roopali Kukreja, a materials science researcher at SLAC and Stanford University and a lead author of the study.

The experiment also showed how the electronic structure of the sample rearranged into non-conducting “islands” surrounded by electrically conducting regions, which began to form just hundreds of quadrillionths of a second after a laser pulse struck the sample. The study shows how such conducting and non-conducting states can coexist and create electrical pathways in next-generation transistors.

**A One-Two Laser Punch**
Scientists first hit each sample with a visible-light laser, which fragmented the material’s electronic structure at an atomic scale, rearranging it to form the islands. Then they hit it with an ultrabright, ultrashort X-ray laser pulse to look at the timing and details of the resulting changes and measure how long it took the material to shift from a non-conducting to an electrically conducting state.
The magnetite had to be cooled to minus 190 degrees Celsius to lock its electrical charges in place, so the next step is to study more complex materials and room-temperature applications, Kukreja said. Future experiments will test new techniques for inducing the switching and tap into other properties that are superior to modern-day silicon transistors.

The researchers have already conducted follow-up studies on a hybrid material that exhibits similar ultrafast switching properties at near room temperature, which makes it a better candidate for commercial use than magnetite.

**A Major Global Effort**

Hermann Dürr, the principal investigator of the LCLS experiment and senior staff scientist for the Stanford Institute for Materials and Energy Sciences (SIMES), said there is a major global effort underway to go beyond modern semiconductor transistors using new materials to satisfy demands for smaller and faster computers, and LCLS has the unique ability to home in on processes that occur at the scale of atoms in trillionths and quadrillionths of a second.

Other collaborating scientists on this research were from Helmholtz-Zentrum Berlin for Materials and Energy; Hamburg University/Center for Free Electron Laser Science (CFEL); University of Amsterdam; the T-REX laboratory at the ELETTRA-Sincrotrone Trieste and University of Trieste; Cologne, Potsdam Regensburg and Purdue universities; the Advanced Light Source at Lawrence Berkeley National Laboratory; and SwissFEL.

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