From a window to a mirror: New material paves the way to faster computing

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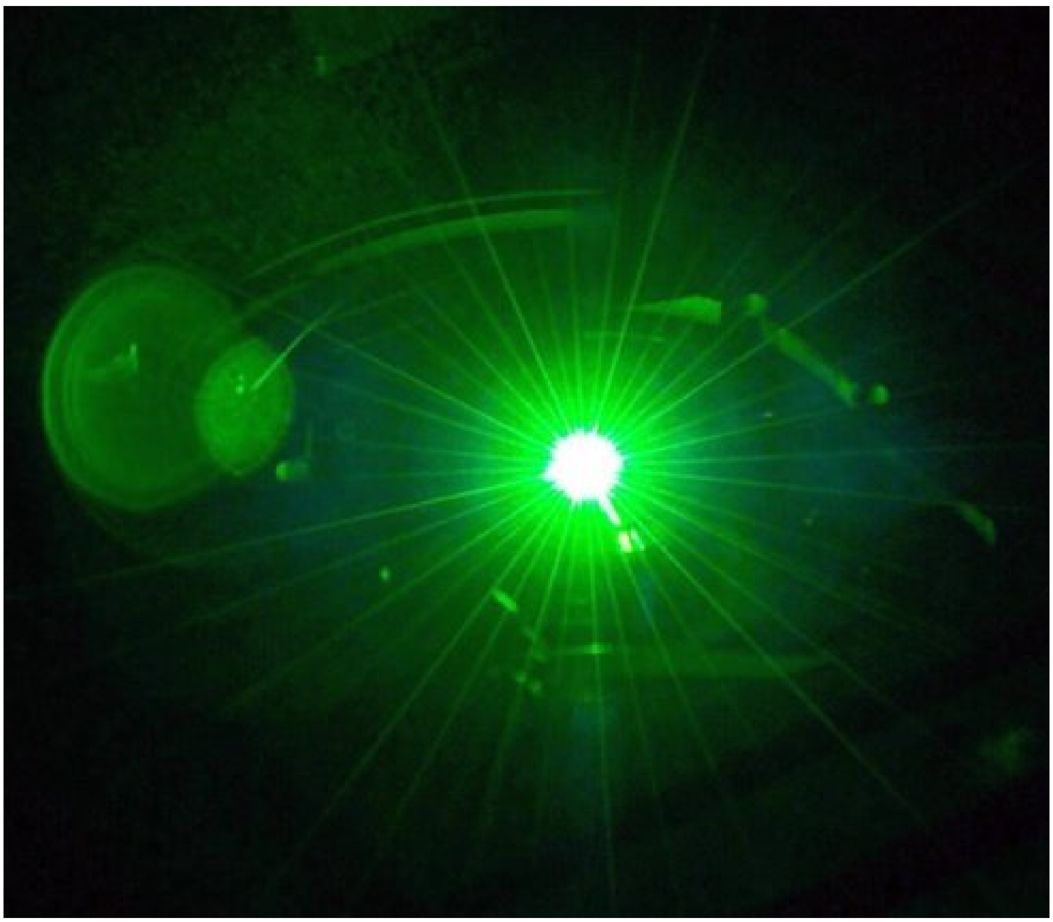

Credit: ORNL

Research led by the Cavendish Laboratory at the University of Cambridge has identified a material that could help tackle speed and energy, the two biggest challenges for computers of the future.

Research in the field of light-based computing—using light instead of electricity for computation to go beyond the limits of today's computers—is moving fast, but barriers remain in developing optical switching, the process by which light would be easily turned 'on' and 'off', reflecting or transmitting light on-demand.

The study, published in *Nature Communications*, shows that a material known as Ta_2NiSe_5 could switch between a window and a mirror in a quadrillionth of a second when struck by a short laser pulse, paving the way for the development of ultra-fast switching in computers of the future.

The material looks like a chunk of pencil lead and acts an insulator at room temperature, which means that when infrared light strikes the material in this insulating state, it passes straight through like a window. However, when heated, the material becomes a metal which acts like a mirror and reflects light.

"We knew that Ta_2NiSe_5 could switch between a window and a mirror when it was heated up, but heating an object is a very slow process," said Dr. Akshay Rao, Harding University Lecturer at the Cavendish Laboratory, who led the research. "What our experiments have shown is that a short laser pulse can also trigger this 'flip' in only 10^{-15} seconds. This is a million times faster than switches in our current computers."

The researchers were looking into the material's behavior to show the existence of a new phase of matter called an 'excitonic insulator', which has been experimentally challenging to find since it was first theorized in the 1960s.

"This excitonic insulating phase looks in many ways like a very normal insulator, but one way to distinguish between an unusual and ordinary insulator is to see exactly how long it takes for it to become a metal," said Rao. "For normal matter, going from an insulator to a metal is like melting an ice cube. The atoms themselves move positions and rearrange, making it a slow process. But in an excitonic insulator, this could happen very fast because the atoms themselves do not need to move to switch phases. If we could find a way to measure how fast this transition occurs, we could potentially unmask the excitonic insulator."

To do these experiments, the researchers used a sequence of very short laser pulses to first perturb the material and then measure how its reflection changed. At room temperature, they found that when Ta_2NiSe_5 was struck by a strong laser pulse, it exhibited signatures of the metallic state immediately, becoming a mirror on a timescale faster than they could resolve. This provided strong evidence for the excitonic insulating nature of Ta_2NiSe_5.

"Not only does this work remove the material's camouflage, opening up further studies into its unusual quantum mechanical behavior, it also highlights this material's unique capability of acting as an ultrafast switch," said first author Hope Bretscher, also from the Cavendish Laboratory. "In fact, for the optical switch to be effective, not only must it transition quickly from the insulating to the metallic phase, but the reverse process must also be fast.

"We found that Ta_2NiSe_5 returned to an insulating state rapidly, much faster than other candidate switch materials. This ability to go from mirror, to window, to mirror again, make it extremely enticing for computing applications."

"Science is a complicated and evolving process—and we think we've been able to take this discussion a step forward. Not only we can now better understand the properties of this material, but we also uncovered an interesting potential application for it," said co-author Professor Ajay Sood, from the Indian Institute of Science in Bangalore.

"While practically producing quantum switches with Ta_2NiSe_5 may still be a long way off, having identified a new approach to the growing challenge of computer's speed and energy use is an exciting development," said Rao.

More information: Hope M. Bretscher et al, Ultrafast melting and recovery of collective order in the excitonic insulator Ta_2NiSe_5, *Nature Communications* (2021). DOI: 10.1038/s41467-021-21929-3

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