Theoretical methods for femtomagnetism and ultrafast spintronics

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Maarten Beens. Credit: Eindhoven University of Technology

Today's society relies on the processing and storage of large amounts of data. The urgent need for increased data storage capacity and the booming energy consumption of data centers requires the optimization and innovation of magnetic data storage devices, in which data is stored in the orientation of tiny magnetic domains. Specifically, the aim is to reduce energy consumption and enable higher data reading and writing speeds.

For his Ph.D. research, Maarten Beens discovered that the use of very short laser pulses is a promising candidate for the development of faster magnetic memory devices.

Femtomagnetism

The research field that focuses on the control of magnetic order with ultrashort (femtosecond) laser pulses is referred to as femtomagnetism. The field emerged in the late 1990s when it was discovered that upon laser-pulse excitation the magnetization of a magnetic thin film changes surprisingly fast and is quenched within a trillionth of a second.

Later, it was demonstrated that laser pulses can be used to switch the magnetization direction in specific types of magnetic alloys, a phenomenon dubbed as all-optical switching (AOS). Since it provides a way to direct the magnetic order from a "0" to a "1" state, the discovery of AOS proved that femtomagnetism might lead to the development of innovative data-writing technologies.

More recent studies show that the control of magnetism with laser pulses goes beyond the influence at a local level and can be used to generate so-called "spin currents" that enable the manipulation of magnetization over a finite distance. Here, "spin" refers to the elemental magnetic property of an electron. The listed processes create various opportunities to create a robust and reliable data-writing scheme.

Building on the past

In order to reach the full potential of implementing femtomagnetism in future memory devices, it is required to understand the abovementioned phenomena at a microscopic level. In his Ph.D. research, Maarten Beens along with his collaborators build on the theoretical fundamentals that have been developed over the past decades and present new insights regarding the mechanisms underlying ultrafast magnetism.

For instance, the mathematical models developed by Beens and his colleagues result in a better understanding of the connection between the local quenching of magnetization and the generation of spin currents. In agreement with recent experimental studies, it turned out that the two processes seem to have the same physical origin. Here, the essential ingredients are the heating induced by the laser pulse and the subsequent wave-like magnetic excitations that are generated within the magnet.

Furthermore, Beens developed a theoretical model that makes it possible to compare the various magnetic material systems that allow all-optical switching. A bilayer consisting of a layer of cobalt and a layer of gadolinium turned out to be an ideal candidate with respect to the robustness and reliability of the switching process. The layered structure enables a relatively straightforward way of tuning the magnetic characteristics of the complete system, such that the properties of the material that are critical for the AOS process can be optimized.

In addition, the smart engineering of magnetic stacks enables the generated spin currents to play a role in assisting the switching process. Results Been's simulations emphasize that the use of femtosecond laser pulses remains a promising data-writing tool for future magnetic memory devices. Nevertheless, the underlying physics is still not completely understood and needs to be explored further in the coming years to determine its full potential.

More information: Theoretical methods for femtomagnetism and ultrafast spintronics. research.tue.nl/nl/publication … ltrafast-spintronics

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