Scientists explain how the giant magnetoelectric effect occurs in bismuth ferrite

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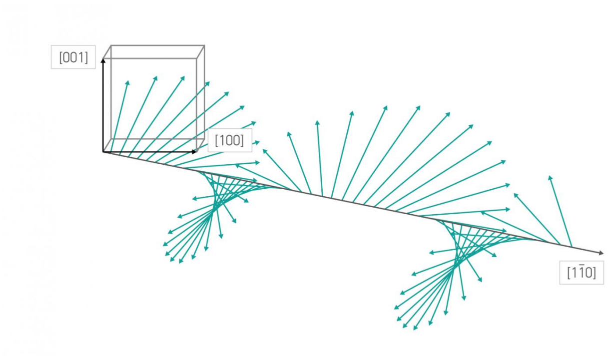

Fig. 1. The spin cycloid structure in BiFeO3. Credit: MIPT

A team of scientists from the Moscow Institute of Physics and Technology (MIPT), the National Research University of Electronic Technology (MIET), and the Prokhorov General Physics Institute have proposed a theoretical model that explains the unexpectedly high values of the linear magnetoelectric effect in $BiFeO_3$ (bismuth ferrite) that have been observed in a number of experiments. The team also suggests a way of enhancing the effect. The results of the study have been published in the journal *Physical Review B*.

One particular feature of bismuth ferrite is that in bulk samples, spins of Fe^{3+} iron ions are arranged in the form of a cycloid (Fig. 1). This spin structure can be destroyed by a strong magnetic field or mechanical stress. Without a spin cycloid, bismuth ferrite exhibits a large linear magnetoelectric effect, and this effect was the focal point of the study.

"The theoretical description presented in the paper may be applicable to other multiferroics similar to $BiFeO_3$. This will help in predicting the value of their magnetoelectric effect, which, in turn, will make it easier to find new and promising materials for industrial applications," says the head of MIPT's Laboratory of physics of magnetic heterostructures and spintronics for energy-saving information technologies, Prof. Anatoly Zvezdin.

Multiferroics and the magneto electric effect

Multiferroics are materials that simultaneously exhibit different ferroic orders, including magnetic, ferroelectric and/or ferroelastic. If there is an interaction between electric and magnetic subsystems in a material, a magnetoelectric (ME) effect may occur.

The magnetoelectric effect is when electric polarization occurs under the influence of an external magnetic field and magnetization occurs under the influence of an electric field. This allows an electric field to control the magnetic properties of a material and a magnetic field to control the electric properties. If the value of the ME effect is high (dozens or hundreds of times higher than normal), it is called a giant ME effect.

The main use of the magnetoelectric effect is in variable and static magnetic field sensors. These sensors are used in navigation systems, electric motors, and also in vehicle ignition systems. Compared to similar devices based on the Hall effect or magnetoresistance, sensors based on the ME effect are more sensitive (according to research, up to one million times more sensitive) and they are also relatively cheap to manufacture.

The ME effect offers exciting possibilities for the use of multiferroics in new types of magnetic memory, including read-only memory. The ME effect could also potentially be used to create high-precision equipment for working with radiation in the microwave range, and to wirelessly transmit power to miniaturized electronic devices.

Bismuth ferrite

The subject of the study was bismuth ferrite (BiFeO3), a highly promising multiferroic with many practical applications including ultra-energy-efficient magnetoelectric memory.

In addition, bismuth ferrite exhibits a magnetoelectric effect at room temperature, while most other magnetoelectrics demonstrate an ME effect of this magnitude only at extremely low temperatures below -160 degrees Celsius. Bismuth ferrite is an antiferromagnetic, which means that the magnetic moments of its magnetic sublattices (structures formed by atoms with the same parallel spins) cancel each other out, and the total magnetization of the material is close to zero. However, the spatial arrangement of the spins forms the same cycloidal spin structure (Fig. 1).

In the 1980s, it was thought that this multiferroic exhibited only a quadratic magnetoelectric effect (i.e. polarization is quadratically proportional to the applied magnetic field). The fact that the linear magnetoelectric effect went unnoticed for a long time had to do with the spin cycloid (Fig. 1). Due to the spin cycloid structure, certain characteristics, such as magnetization and the magnetoelectric effect average out to zero. However, when bismuth ferrite is placed in a strong magnetic field (greater than a certain critical value), the structure is destroyed and a linear ME effect emerges when polarization is linearly proportional to the applied field.

Early experiments indicated a low value of the linear magnetoelectric effect in bismuth ferrite (almost 1000 times lower than the actual value), however later experimental studies revealed a large ME effect and it was also demonstrated that by using it in layered structures, record values of the magnetoelectric effect can be achieved.

The authors of the paper developed a theoretical justification for the occurrence of the linear ME effect based on the Ginzburg-Landau theory and explained the previously large experimental value of the effect. As part of their theory, the researchers also showed that the ME effect could be enhanced in the presence of an electrostatic field.

More information: A. F. Popkov et al, Origin of the giant linear magnetoelectric effect in perovskitelike multiferroic, *Physical Review B* (2016). DOI: 10.1103/PhysRevB.93.094435

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