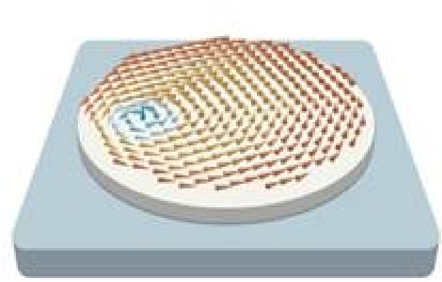
Physicists demonstrate a simpler method of magnetic vortex excitation

December 2 2015, by Neil Atherton



Permalloy/Bi2Se3 disk. Credit: MIPT Press Service

A team of scientists, including physicists from MIPT and the Russian Quantum Centre, have demonstrated a method of exciting magnetic vortices, which could potentially be used in the electronics of the future as information carriers, using less current. The corresponding theoretical calculations have been published in *Physical Review B*.

Magnetic vortices are microscopic areas of magnetized material with uniquely arranged magnetization vectors. In the centre of the vortex, the magnetization vector is oriented perpendicularly to the surface, and at the edges these vectors form a structure resembling a vortex or whirlpool.

The magnetization vector is linked to spin, a quantum characteristic of individual particles. Controlling magnetic vortices, through spin or otherwise, is what scientists are researching as a foundation for the electronics of the future – spintronics. In order to store and process information in spintronics, the movement of electrons from one position to another or the flow of electronic charges is not important – what is most important is spin and the movement of electrons with a certain spin, a spin current. Information can be transmitted by spin rather than electronic charge, and the charged particles do not necessarily need to move anywhere – they can remain in the same position, but their spins will rotate, transmitting information "along the chain".

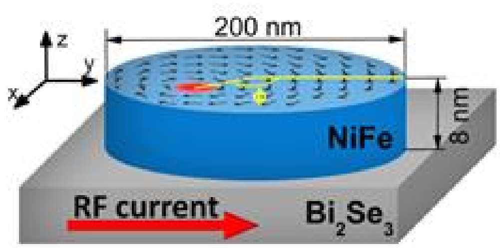
Using spin to transmit a unit of information is very interesting because the processing (e.g. changing 0 to 1 in binary code through one spin revolution) requires much less time and energy than a similar operation in modern electronics. Microchips operating with electron spin will heat up less and a number of calculations also demonstrate that they will be less sensitive to radiation. Spintronics stands a good chance of replacing many common devices, but for this to happen, scientists will first need to address a number of fundamental and practical issues.

Spintronics will require new methods of storing and processing information. Magnetic vortices could potentially be a solution – they can be used both to store information (0 – spin clockwise, 1 – spin anti-clockwise, or 0 – core magnetized up, 1 – magnetized down) and process information – different vortices interact differently with the spin current (a flow of electrons, in which the largest portion is made up of electrons with a certain spin), which will make it possible to build complex devices and even artificial neural networks. These vortices will also be able to be used to create AC nanogenerators, which could potentially be used in telecommunication applications.

Methodology

In their paper, the authors examined the process of an alternating radio frequency current (of approximately 1GHz) passing along the surface between permalloy and bismuth selenide, a ferromagnet and topological insulator respectively, and proposed a theoretical description of the observed phenomena.

This combination of materials was, of course, not chosen at random. Permalloy is highly ferromagnetic and its ability to be magnetized in the absence of an external magnetic field is of key importance. This is why magnetic vortices can be excited within it. These vortices contain small "spinning" "magnets" (or magnetic moments to be precise), which is what this material is made up of. In addition, permalloy has been used in industry for a very long time – it was first discovered in the early 20th century and has since been used extensively, in the manufacture of transformer plates for example.



Experimental heterostructure: permalloy disk (NiFe) on the surface of bismuth selenide (Bi2Se3). Credit: Image courtesy of the authors of the study.

Bismuth selenide is a topological insulator: it will only allow an electric current to flow along its surface. This effect should not be confused with the skin effect, where high-frequency current has a marginal level of distribution within a conductor: a topological insulator prevents the movement of charge in bulk, this includes low-frequency charges and even direct current (DC). In addition, its properties are the result of purely quantum effects. The unique characteristics of topological insulators also prevent electrons from changing their spin during motion, which makes them a perfect conductor for spin current.

It should be emphasized that the authors conducted the numerical simulation using the SpinPM package they developed previously. This program has already been used by the authors and its predictions were confirmed during experiments, which were later described in the scientific journals *Physical Review Letters* and *Nature Physics*.

The study found that in order to excite magnetic vortices with a topological insulator, alternating current (AC) must be used, as direct current (DC) has almost no effect on them. When AC was applied, a sharp resonance excitation of the vortices was observed – on approaching a certain current frequency the vortex radius increases rapidly, forming a sharp peak, the top of which shifts slightly at different current densities. We also note that the current densities required to excite the vortices were several times lower than previously observed.

"We have demonstrated that the torques with certain symmetry that arise at the Py/Bi2Se3 interface while alternating current passes along it can be used to effective excitation of a magnetic vortex. The magnitude of the effect was taken from an experimental paper written by our colleagues, and for this value the required current densities were indeed significantly lower than previously observed. It is worth noting that these torques can be observed not only for Bi2Se3, but also for a wide range of materials including topological insulators and materials with a giant Rashba effect," explains Petr Skirdkov, the main author of the article.

Previous experimental studies have shown that current passing along the surface between different layers of a heterostructure such as this is able to generate a torque. The authors of the paper have demonstrated that it is possible to effectively excite magnetic vortices using this torque.

Research in the field of spintronics is essential for the development of modern technologies. It is now an indisputable fact that semiconductor electronics will no longer develop according to Moore's Law (the first signs of this are already evident). And it is possible that in the future all technologies will switch from using electrical charges to particle spins, which require minimal amounts of energy and will increase speed thousands of times. Some studies in the field of magnetic heterostructures have even been awarded the Nobel Prize, which only emphasizes their importance.

More information: Large amplitude vortex gyration in permalloy/Bi2Se3-like heterostructures. *Phys. Rev. B* 92, 094432 – Published 18 September 2015. dx.doi.org/10.1103/PhysRevB.92.094432

A. V. Khvalkovskiy et al. High Domain Wall Velocities due to Spin Currents Perpendicular to the Plane, *Physical Review Letters* (2009). DOI: 10.1103/PhysRevLett.102.067206

A. Chanthbouala et al. Vertical-current-induced domain-wall motion in MgO-based magnetic tunnel junctions with low current densities, *Nature Physics* (2011). DOI: 10.1038/nphys1968

A. R. Mellnik et al. Spin-transfer torque generated by a topological insulator, *Nature* (2014). DOI: 10.1038/nature13534

Provided by Moscow Institute of Physics and Technology method-magnetic-vortex.html