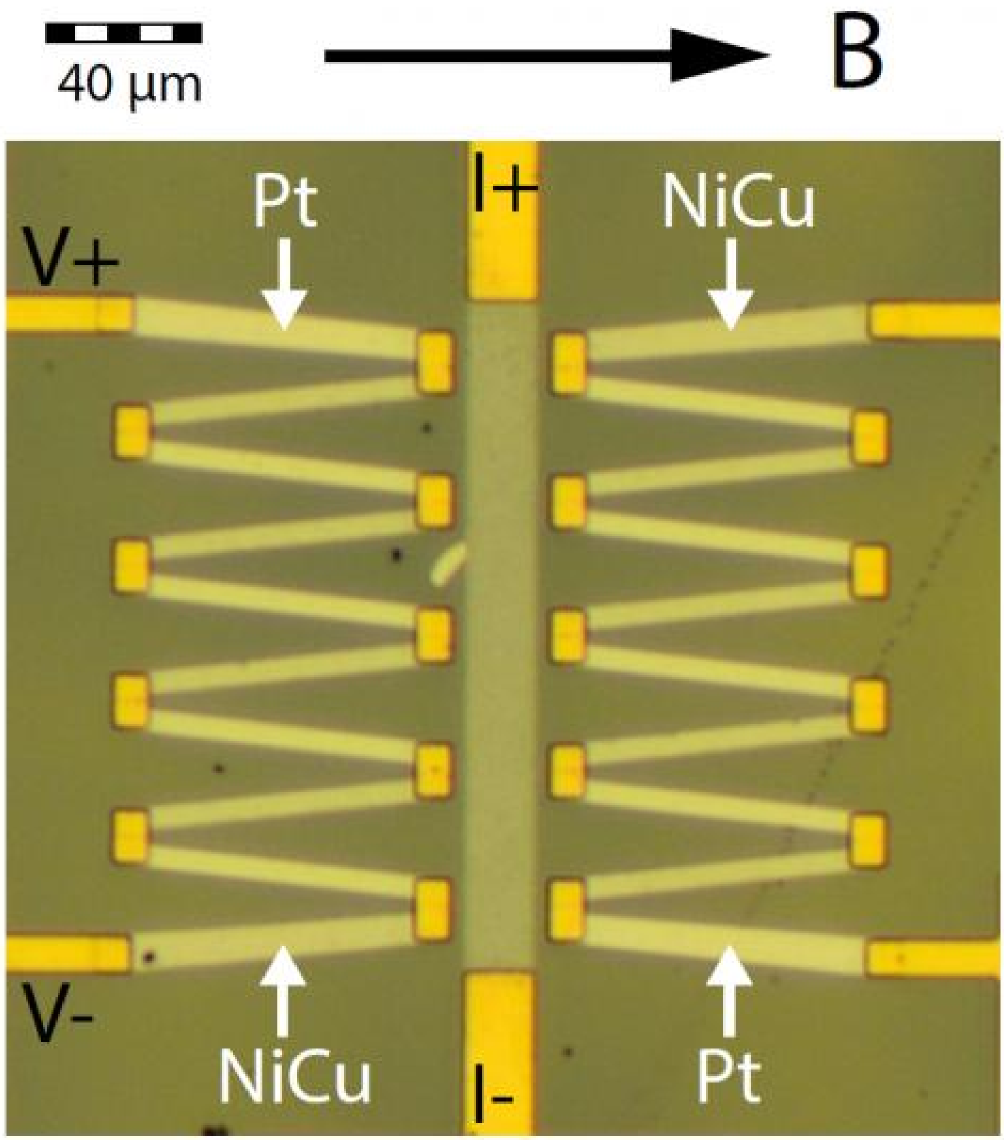
New nanoscale cooling element works in electrical insulators as well

July 8 2014, by Ans Hekkenberg



The sample used for the measurement. In the middle, from top to bottom, is the platinum strip. Electrons move through this strip and produce a spin current in the direction of the underlying insulator. The spins of the electrons that reach the boundary ensure that the spins in the insulator become excited. Two zigzag shaped thermometers made from platinum and constantan measure the temperature difference close to the boundary. Credit: Fundamental Research on Matter (FOM)

(Phys.org) —Researchers from the FOM Foundation, the University of Groningen, Delft University of Technology and Tohoku University in Japan have designed a miniscule cooling element that uses spin waves to transport heat in electrical insulators. The cooling element could be used to dissipate heat in the increasingly smaller electrical components of computer chips. The researchers published their design online on 7 July 2014 in *Physical Review Letters*.

The functioning of the cooling element is based on the spin of the electrons. Spin is a fundamental property of an electron that corresponds with its magnetic moment (the strength and direction of its magnetic field). Although physicists have used spin for cooling purposes before, this is the first time that they have successfully done this in insulating materials.

Heat transport through a nanopillar

In previous research, the scientists let a current of electrons flow through magnetic metals. In a magnetic field, the spins of these electrons will align in the same direction, namely parallel to the magnetisation. The researchers sent the electrons through a pillar that consisted of two magnetic layers (with a non-magnetic layer in between). The pillar used was miniscule – about a thousand times smaller than the thickness of a human hair.

An electron that starts in the bottom layer aligns its spin to the direction of magnetisation in that layer. Subsequently the electron flows to the top layer. If the direction of magnetisation there is the same as in the bottom layer then the spin is still oriented parallel to the magnetisation. Electrons with a parallel spin direction transport more heat than electrons with an opposite spin direction. So in this case, the electrons ensure that a lot of heat is transported through the entire pillar. If the electrons, however, encounter a magnetisation in the opposite direction in the top layer, the heat transport is suppressed. Using this knowledge the researchers successfully caused a measurable temperature difference between the two sides of the pillar.

Spin waves

This method does not work in an electrical insulator – a material that does not easily conduct electrons. Nevertheless, the researchers have now found a cooling method that also works in insulating materials. In the new research they demonstrated that the spins on the boundary between a non-magnetic metal and a magnetic insulator cause so-called spin waves that transport heat to or from the material.

The researchers used a 200-nanometre thick insulator of yttrium-iron garnet (a mineral) with a 20 by 200 micrometre layer of platinum on top. Electrons can easily flow through the conducting platinum but when they reach the insulating garnet they cannot go any further. Nevertheless, the spin of the electrons is transferred: the magnetic moment of the electron influences the magnetic moment (and therefore the spin) of the electrons in the insulator that are at the boundary between the two materials. Through magnetic coupling this spin change is subsequently transferred to electrons that are situated further away from the boundary. In this manner a wave of spin changes appears to proceed through the material. The spin wave also transfers heat to or from the boundary. Dependent on the direction of both the spin and the magnetisation in the mineral, the boundary will therefore cool down or heat up.

Thermometers

The researchers placed small, highly sensitive thermometers just a few micrometres away from the boundary and used these to detect the temperature differences while electrons flowed through the platinum strip. The physicists subsequently compared their measurements with the above-mentioned theory. The temperature differences, just 0.25 millicelsius in size, appear to confirm the theory.

This research was jointly funded by the FOM Foundation, NanoLab NL, JSPS, the Deutsche Forschungsgemeinschaft, EU-FET Grant InSpin 612759 and the Zernike Institute for Advanced Materials.

More information: Observation of the Spin Peltier Effect for Magnetic Insulators, *Phys. Rev. Lett.* 113, 027601. journals.aps.org/prl/abstract/ … ysRevLett.113.027601

The American Physical Society published a viewpoint on this study: physics.aps.org/articles/v7/71

Provided by Fundamental Research on Matter (FOM)

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