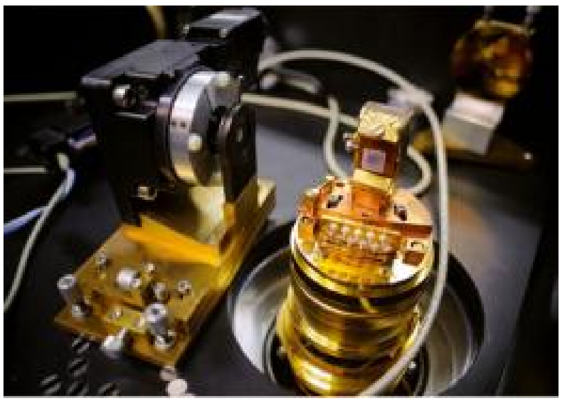
A new dimension in materials research

May 26 2011



Light measures the conductivity: The physicists working with Bernhard Keimer use infrared light from the ANKA synchrotron source at the Karlsruhe Institute of Technology to determine the electronic properties of films comprising two and four layers of material. The sample can be seen as a white/grey square that is mounted on a gold-coloured cylinder. The laser beam comes in from the right, falls onto the sample and is reflected towards the left onto the detector. © MPI Institute for Solid State Research

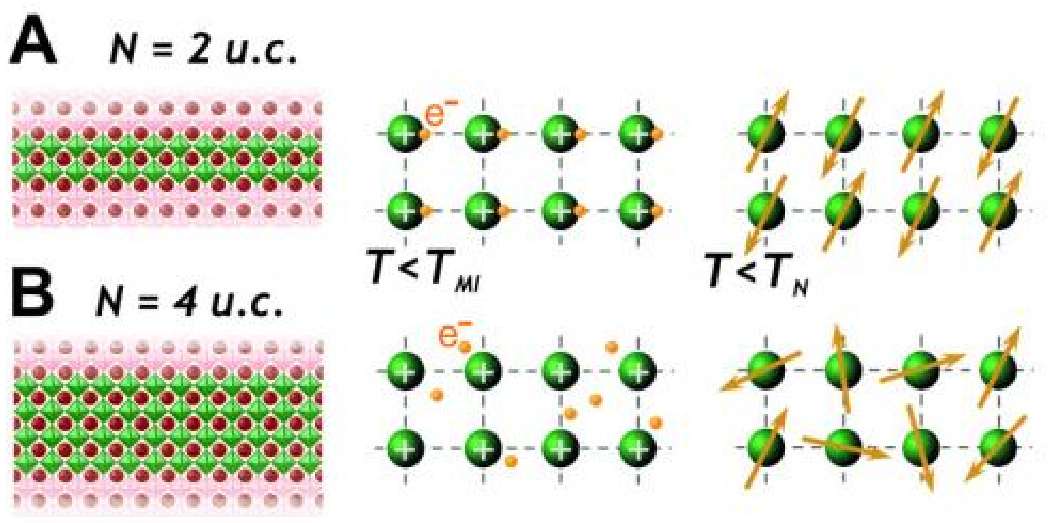
(PhysOrg.com) -- In the future, physicists will be able to follow a new lead in their search for new materials for electronic components, for example. An international team of researchers headed by scientists at the Max Planck Institute for Solid State Research in Stuttgart is the first to accurately observe how the physical properties of a substance – or to be more precise of the metal oxide lanthanum nickel oxide – change when it is used in two-dimensional, instead of three-dimensional form. In fact, a film consisting of two layers of material exhibits completely different electronic and magnetic effects when cooled to very low temperatures than does a film comprising four layers. The ability to control the physical characteristics via the dimension as well opens up new possibilities to identify materials from which the chips of the future could be made.

The semiconductor industry is gradually reaching its limits. As it continues to decrease the size of electronic components, conductor tracks and transistors are probably soon going to shrink to the size of atoms. It is almost impossible to control the manufacture of structures as tiny as this with the methods in use today. Moreover, when they are in operation, they generate so much heat due to their electrical resistance that they would probably quickly lose their shape. The era of semiconductor electronics could therefore come to an end in the foreseeable future. Metal oxides might then be a viable alternative. This class of materials includes not only those which lend themselves because of their magnetic properties – some metal oxides are also superconductors that conduct electricity with zero resistance.

An international team working with Alexander Boris and Bernhard Keimer at the Max Planck Institute for Solid State Research in Stuttgart is now pointing the way to a new method of custom-designing the properties of metal oxides. The researchers, including scientists at the Max Planck Institute for Metals Research, the Paul Scherrer Institute in Villingen/Switzerland and the University of Fribourg, also in Switzerland, are the first to have accurately worked out how the spatial dimension of a material influences its physical behaviour. “We are thus selectively tweaking the control variable that physicists have so far been able to control only imprecisely,” says Bernhard Keimer, Director at the Max Planck Institute for Solid State Research. Neither have they been able to find out what effect the dimension has among all the other factors which are involved in determining the electronic and magnetic behaviour. And the effect is huge, as the researchers have now discovered.

The scientists investigated the metal oxide lanthanum nickel oxide $LaNiO_3$, which contains nickel in addition to the electronically inactive lanthanum and oxygen atoms. This composition was chosen not least because nickel is endowed with a special type of electron whose magnetic moments always make them good for physical surprises. This is scarcely noticeable in a massive block of nickel, however, and the same applies to all samples which are thicker than four layers of material, i.e. also those which measure only a few nanometres. In this form, lanthanum nickel oxide belongs to the metallic conductors, and the magnetic moments of the electrons move about like twirling bar magnets. This remained the case when the physicists cooled a sample comprising four layers of the material to a temperature of almost absolute zero at minus 273 degrees Celsius.

“In a sample made of two layers of material, this changes completely,” says Bernhard Keimer. When cooled to around minus 100 degrees, the material lost its electrical conductivity. The thin layer puts the electrons in a predicament: they repel each other, but can no longer distance themselves from each other to any great extent. They therefore remain more or less stuck at an atom, and the current stops.



A question of dimension: As they cool, the electrons in a film made of two layers of lanthanum nickel oxide are first localized to positively charged cores of the nickel atoms. If the temperature decreases further, the spins, which give the electrons a magnetic momentum, align so as to be anti-parallel. In a film of four layers of metal oxide, however, the electrons remain freely mobile even at low temperatures, and their spins remain unordered. © Max Planck Institute for Solid State Research

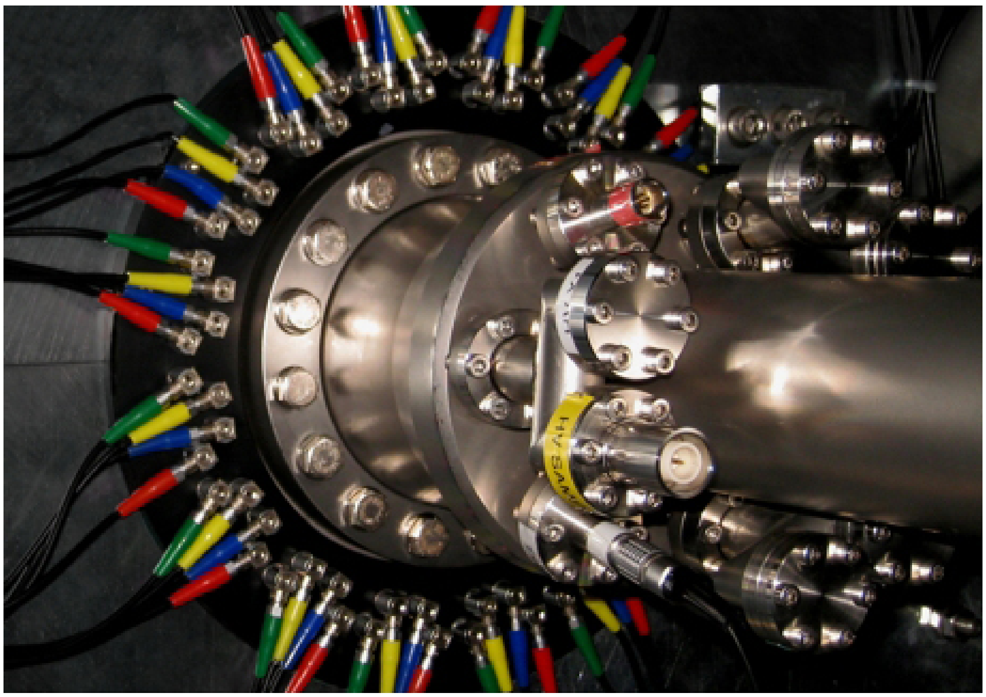
This was not the only effect which the slimming treatment had on the metal oxide, however. When the physicists cooled the thin sample even further, to around minus 220 degrees Celsius, the material assumed a magnetic order, or to be more precise, an anti-ferromagnetic one: the magnetic moments of the electrons align themselves so as to be antiparallel, just like bar magnets which are lying alternately with their north and south poles next to each other.

"We can alter the electronic and magnetic properties of the material in a specific way by adding two layers of the material," says Bernhard Keimer. The first challenge for the physicists in their investigation was to discover how to control the thickness of the sample in such an exact way. "With the usual chemical methods one does not really have an accurate idea of what the final result will be," says Alexander Boris, who made an essential contribution to the work. The researchers therefore made use of a method found in physics: pulsed laser deposition (PLD). Working in a vacuum chamber, they used laser pulses to vaporize the lanthanum nickel oxide in carefully dosed quantities. The metal oxide deposits on an almost perfectly plane and clean surface of the carrier material and at the right temperature forms a completely ordered, plane layer with the required thickness.

However, this did not mean that the researchers had now mastered the experimental challenges, because in samples which are only a few atomic layers thick the electronic and magnetic characteristics can only be determined with a few tricks. The physicists can hardly attach cables to two sides of the sample and measure the current in order to determine the conductivity of the sample, for instance. "No matter how accurately the thin layers have grown, the carrier material will always have an atomic step somewhere. This atomic step can then also be found in the deposited layer," explains Alexander Boris. A conventional measurement of conductivity would fail at such a step because it interrupts the current flow. The researchers therefore directed an intense, infrared laser beam produced by the ANKA synchrotron in Karlsruhe onto the sample. The light waves from this source oscillate in one direction only. How this direction of oscillation changes when the beam is reflected at the sample provides the researches with information on the mobility of the electrons in the material and thus on its conductivity.

Slow muons shed light on the magnetic order

It is at least as tricky to determine an anti-ferromagnetic order in a film made up of just two layers. Since the magnetic moments cancel each other out exactly in this case, the order does not produce any external magnetisation. The scientists therefore put their faith in muons, instable elementary particles which are produced in particle accelerators. They resemble electrons, but have a much weaker magnetic moment. “Muons are therefore suitable as sensitive probes for the magnetic order,” says Thomas Prokscha, researcher at the Paul Scherrer Institute in the Swiss town of Villingen, home to a particle accelerator which supplies muons.



A probe for the magnetic order: The Swiss muon source at the Paul Scherrer Institute enables the researchers to observe the anti-ferromagnetic order in very thin films. The sample is introduced via the main access to the measuring chamber. The colourful contacts are used to connect the positron detectors. © LMU/Paul scherrer Institute

Only the Paul Scherrer Institute has the facility which enables the researchers to also regulate the speed with which the muons impact on the sample. This is necessary in order for them to be able to take a precise look into the film of two or four layers of material. If the speed is not regulated, the particles race through the lanthanum nickel oxide and only get stuck when they are somewhere inside the carrier material. The scientists at the Paul Scherrer Institute teamed up with their colleagues from the University of Fribourg to probe the magnetic order in the lanthanum nickel oxide layers. Although the muons, which they targeted at the samples, decay in the metal oxide layer, the trajectories of their fragments tell the physicists what the orientation of the magnetic moments in the material is.

"We now want to adopt a similar approach to investigate how the dimension of the sample influences the electronic properties of metal oxides, which become superconducting below a certain temperature", says Bernhard Keimer. It is possible that they can give metal oxides properties which can also be used to solve the increasing problem of space on microchips.

More information: Alexander V. Boris, Yulia Matiks, Eva Benckiser, Alex Frañó, Paul Popovich, Vladimir Hinkov, Peter Wochner, Miguel Castro-Colin, Eric Detemple, Vivek K. Malik, Christian Bernhard, Thomas Prokscha, Andreas Suter, Zaher Salman, Elvezio Morenzoni, Georg Cristiani, Hanns-Ulrich Habermeier und Bernhard Keimer, Dimensionality Control of Electronic Phase Transitions in Nickel-Oxide Superlattices, *Science*, 2011; doi: 10.1126/science.1202647

Provided by Max-Planck-Gesellschaft

Citation: A new dimension in materials research (2011, May 26) retrieved 10 April 2024 from https://phys.org/news/2011-05-dimension-materials.html