$LuMnO_3$ thin films reveal ferromagnetic and antiferromagnetic properties simultaneously

Electronic components made of several layers with different magnetic orders are frequently used in various devices such as in read heads for hard drives, which read the data stored, or in highly sensitive magnetic field sensors, which are read electrically. An international team of researchers from the Paul Scherrer Institute (PSI), Switzerland; École Polytechnique Fédérale de Lausanne, Switzerland; the Institut Laue-Langevin, France; the University of Fribourg, Switzerland; and ETH Zürich have now found a material that combines different magnetic properties. The material used is lutetium manganese oxide ($LuMnO_3$), which has a perovskite structure much like high-temperature superconductors. The thin, single crystalline layers were grown using pulsed laser deposition on a nonmagnetic, single crystalline carrier crystal ($YAlO_3$).

Normally, single crystalline $LuMnO_3$ with an orthorhombic structure exhibits an antiferromagnetic order where two spins always point in one direction, and the next two in the opposite direction (E-type antiferromagnet). In this study, however, a ferromagnetic order (where all spins point in the same direction) was observed in the direct vicinity of the surface of the carrier crystal. "Normally, you can't convert an antiferromagnet into a ferromagnet—for reasons of symmetry apart from anything else. Something special must have happened here," said Christof Schneider, one of the researchers involved at PSI.

As reported in the July 19 issue of *Physical Review Letters* (DOI: 10.1103/PhysRevLett.111.037201), the most likely explanation for the effect is that the crystal structure of the material becomes distorted because it adapts to the structure of the carrier crystal and is therefore highly strained. The ferromagnetic order is preferred in the distorted structure. The crystalline structure relaxes as the distance to the $YAlO_3$–$LuMnO_3$ interface increases, but complete relaxation is not achieved even in films ~200 nm thick. The expectation is that the bulk E-type antiferromagnetic order should appear from a certain distance. Instead, an antiferromagnetic spin spiral is observed where the spins are arranged in the form of a spiral staircase.

Experiments with neutrons to study the magnetic structure on $LuMnO_3$ demonstrate these spin spirals. The measurement results suggest that there is also the expected antiferromagnetic order. "To unravel the mystery of the magnetism in the thin films, we realized that we had to apply multiple neutron scattering techniques. Particularly crucial were novel neutron reflectivity measurements which allowed us to identify the exact location of ferromagnetism," said Christof Niedermayer, who conducted part of the neutron experiments at PSI.

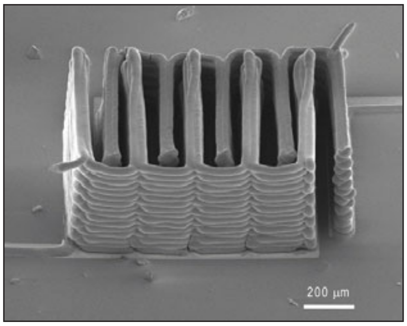
Energy Focus

Li-ion microbattery fabricated by 3D printing

Three-dimensional (3D) printing can now be used to print lithium-ion microbatteries. The printed microbatteries could supply electricity to tiny devices in fields from medicine to communications, including many that have lingered on laboratory benches for lack of a battery small enough to fit the device, yet powerful enough to drive the device.

As reported in the June 17 online edition of *Advanced Materials* (DOI: 10.1002/adma.201301036), a research team based at Harvard University and the University of Illinois at Urbana-Champaign created an ink for the anode with nanoparticles of $Li_4Ti_5O_{12}$ (LTO), and an ink for the cathode from nanoparticles of $LiFePO_4$ (LFP). Through nozzles of 30 μm in diameter, the printer deposited the inks onto the teeth of two gold combs, creating a tightly interlaced stack of anodes and cathodes. The researchers found that LTO and LFP inks produced with respective solids loadings of 57 wt% and 60 wt% yielded the desired rheological and printing behavior. The research team then packaged the electrodes into a tiny container and filled it with an electrolyte solution of de-ionized water, ethylene glycol, glycerol, and a cellulose-based viscosifier to complete the battery.

"Not only did we demonstrate for the first time that we can 3D-print a battery, we demonstrated it in the most rigorous way," said Jennifer Lewis, senior author of the study, who is also the Hansjörg Wyss Professor of Biologically Inspired Engineering at the Harvard School of Engineering and Applied Sciences (SEAS), and a Core Faculty Member of the Wyss Institute for Biologically Inspired Engineering at Harvard University. Lewis led the project in her prior position at the University of Illinois at Urbana-Champaign, in collaboration with co-author Shen Dillon, an Assistant Professor of Materials Science and Engineering there.



This image shows the interlaced stack of electrodes that were printed layer by layer to create the working anode and cathode of a microbattery. Photo by Jennifer Lewis.

After fabricating the microbatteries, the research team measured how much energy could be packed into the batteries, how much power they could deliver, and how long they held a charge. "The electrochemical performance is comparable to commercial batteries in terms of charge and discharge rate, cycle life, and energy densities. We're just able to achieve this on a much smaller scale," Dillon said. □

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