Just One Thing at a Time

ORNL and UT's physicists find it's possible to change a single parameter in complex materials, opening the door to new and useful properties

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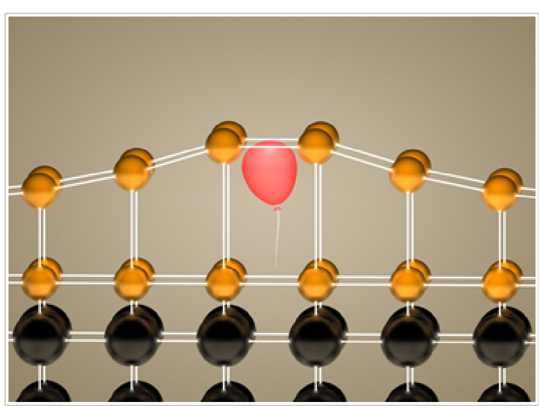
Much of the world's history can be told through the materials people have found, forged, composed and adapted to meet their needs. The Stone Age, the Bronze Age, and the Iron Age gave rise to the steel, glass, aluminum, plastics, and semiconductors that mark modern life. Yet as the need for materials grows more sophisticated, understanding what they can do is increasingly a matter of figuring out how their most fundamental components work. Like an atomic-scale game of pickup sticks, ORNL and UT physicists and their colleagues have found it's possible to reversibly control a single parameter in a material's structure without disturbing any of the others. The results were published this summer in *Physical Review Letters* (PRL) and lay the groundwork for new possibilities in controlling a material's properties.

Helium Tuning and Happy Mismatches

Almost all natural and man-made solids have a crystalline structure: a repeating pattern of atoms or molecules called a lattice. Within this framework, the edges of each individual unit cell are called the lattice parameters. Controlling a single parameter, along a single axis, has until now been an elusive experimental goal. In their paper "Strain Doping: Reversible Single-Axis Control of a Complex Oxide Lattice via Helium Implantation," scientists from UT, Oak Ridge National Laboratory, Louisiana State University, and Southeast University in China explain how to do just that.

Inserting helium atoms (one is symbolized here by a red balloon) into a crystalline film (gold) allows for fine control over the elongation of the out-of-plane direction while the in-plane directions remain fixed by the underlying substrate (black). (Image Courtesy of Zac Ward, ORNL.)

The approach involves two well-known players in modern physics: complex oxides and thin films. Crystalline materials comprising oxygen and other elements have magnetic and electronic properties that have made them attractive for commercial uses like inductors and capacitors. Tuning those properties could translate into even more advanced applications. An ideal miniature laboratory for testing and tweaking complex oxides is to grow them as films only a few nanometers thick on a base layer, or substrate, of another material. This kind of epitaxial growth—crystal film on crystal substrate—is crucial to the semiconductor industry. If the lattice structures of the film and base are mismatched, the film may strain to better accommodate the substrate, changing the electronic structure.



In this study, researchers grew a 20-nanometer thick-layer of lanthanum, strontium, manganese and oxygen on a substrate of strontium titanium oxide. They deposited a gold buffer layer on the film surface and then injected helium ions, in varying doses, into the sample. What they found is that while the helium ions induced strain, the film's lattice was still locked to the base layer. The strain could be independently and continuously controlled along a single axis without disturbing any additional parameters, which could lead to finely-controlled electronic and magnetic behaviors. The helium-implanted film, for example, showed higher magneto-resistance as the c-axis expands. The most important aspect of the results is that the process is reversible, so the strain states can be controlled after the helium ions are added. In a broader sense, the authors point out the ability to tune a material's properties using wafer-scale processing is critical in fitting complex oxide materials for commercial applications.

The paper represents the strong collaborative nature of the physics department's relationship with ORNL. Contact author Thomas (Zac) Ward earned a Ph.D. in physics at UT in 2008 and is a UT-ORNL Joint Faculty Assistant Professor. Hangwen Guo earned a Ph.D. in 2013 and is now a postdoc at LSU. Shuai Dong, now with Southeast University in China, is a former visiting student and visiting Assistant Professor. Paul Snijders is a UT-ORNL Joint Faculty Assistant Professor, and Elbio Dagotto is a UT-ORNL Distinguished Professor and Scientist. Their co-authors are John D. Budai, Christianne Beekman, Zheng Gai, Wolter Siemons, and Andreas Herklotz of ORNL; along with C. M. Gonzalez, R. Timilsina, Anthony T. Wong, and Philip D. Rack of UT Materials Science and Engineering.

More Information:

- **Strain Doping: Reversible Single-Axis Control of a Complex Oxide Lattice via Helium Implantation (*Physical Review Letters*)** **(http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.114.256801)**