Rare iron oxide could be combined with 2-D materials for electronic, spintronic devices

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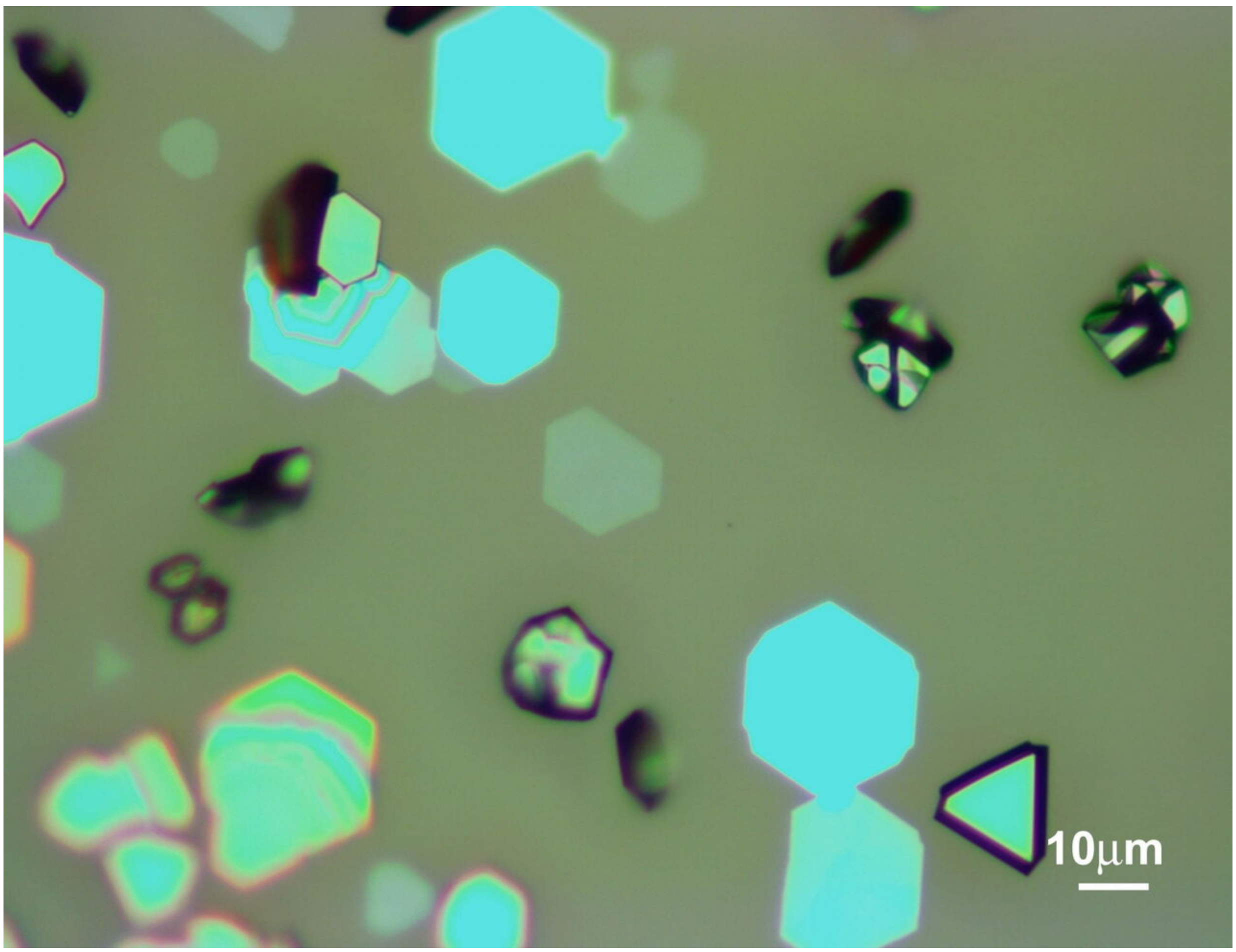


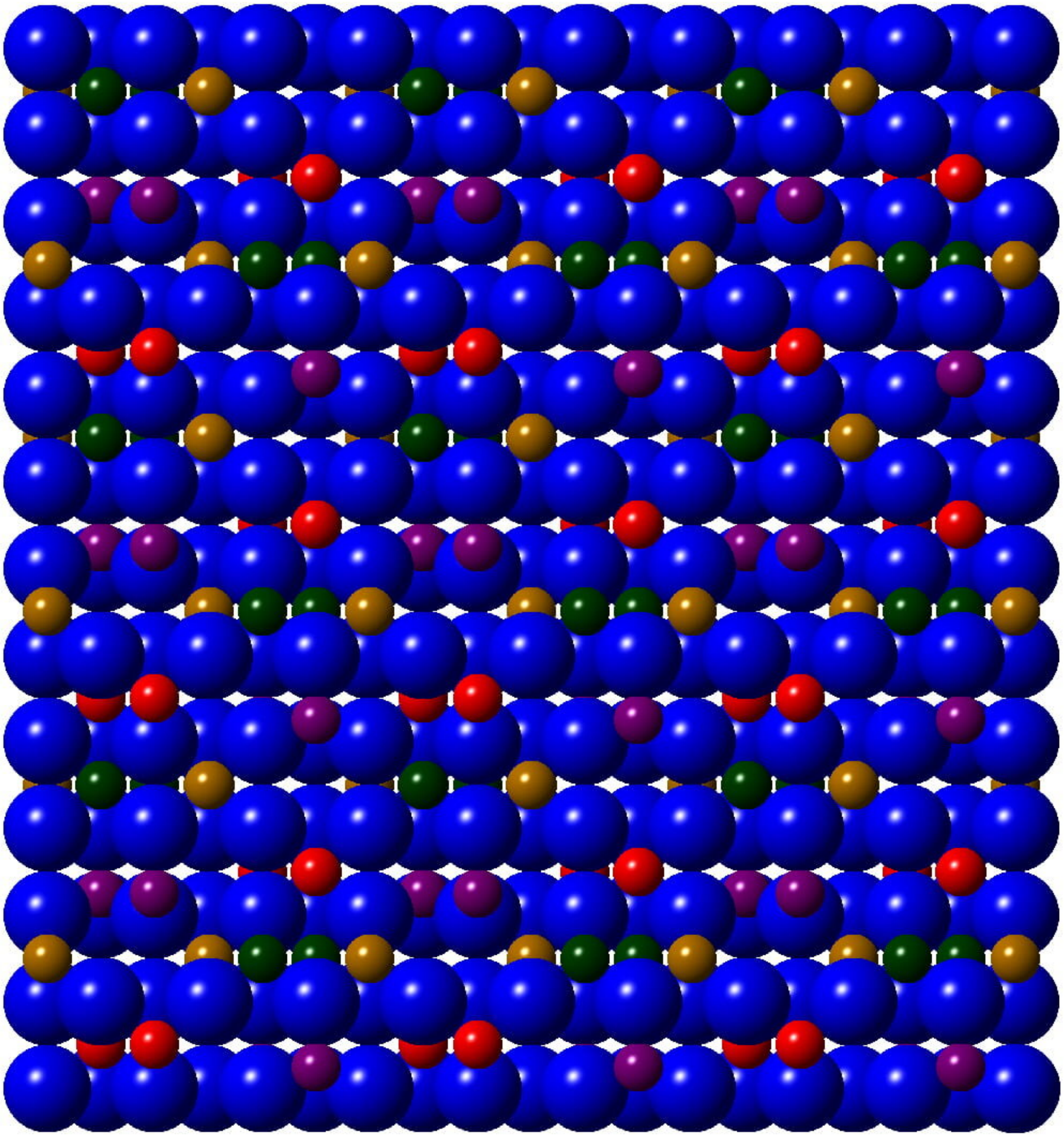
A microscope image shows flakes of epsilon-iron(III) oxide grown on mica by Rice engineers. The nearly 2D crystals are promising building blocks for electronics and spintronics that take advantage of their stable magnetic properties. Credit: the Lou Group

Rice University researchers have simplified the synthesis of a unique, nearly two-dimensional form of iron oxide with strong magnetic properties that is easy to stack atop other 2-D materials.

The material, epsilon iron(III) oxide, shows promise as a building block for exotic nanoscale structures that could be useful for spintronic devices, electronic or storage applications that take advantage of not only the charge of electrons but also their spin states.

Researchers at Rice's Brown School of Engineering and Wiess School of Natural Sciences reported in the American Chemical Society journal *Nano Letters* that they had produced oxide flakes through simple chemical vapor deposition. The flakes are easily transferable from their growth substrates and retain their magnetic properties over the long term at room temperature.

"Iron oxide is nothing new," said Rice materials scientist and co-principal investigator Jun Lou. "But this epsilon phase is very rare. In epitaxial growth (in which the crystal aligns with the atomic structure of the surface), the bonding is strong and crystals are hard to transfer. But one of the features of this crystal structure is that it has relatively weak interaction with the substrate. You can pick it up and put it on different things."



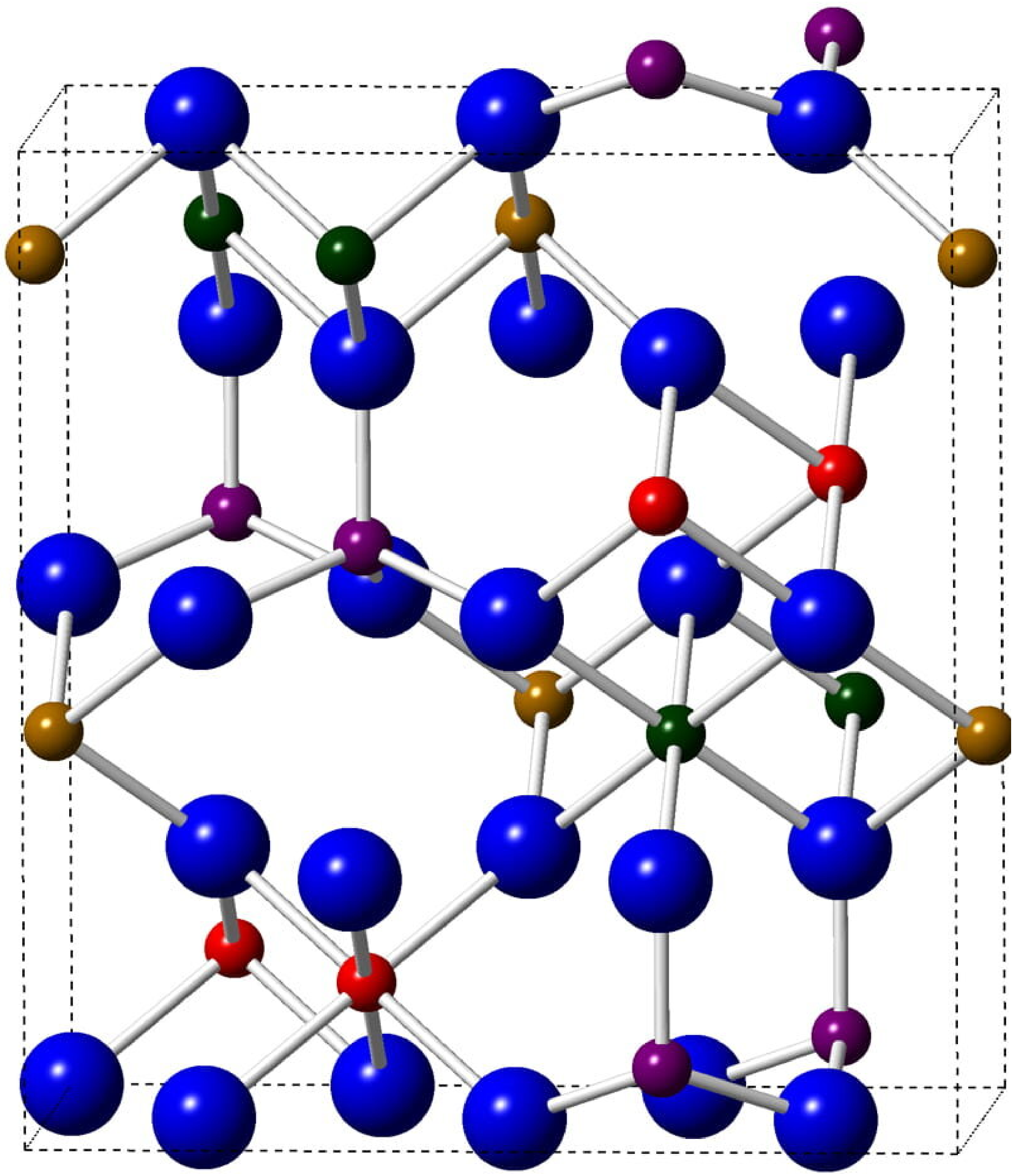
An illustration shows the structure of epsilon-iron(III) oxide, an atomically thin material that is stable, stackable and unlike other iron oxides retains its unique magnetic properties at room temperature. Credit: Jiangtan Yuan

"An ultrathin magnetic material like this, which maintains its magnetic properties up to room temperature and can be integrated with other materials by stacking, is very exciting," said Rice physicist Doug Natelson, a co-principal investigator with Lou and Scott Crooker of Los Alamos National Laboratory. "It will be a great testing ground for seeing how magnetic properties act across interfaces, an important aspect relevant to future information technologies."

Lou said the material is technically not 2-D, because of the prismlike orthorhombic atomic structure that gives the lattice its unusual properties. "But basically, it has all the features of a 2-D magnet," he said.

He said other 2-D magnetic materials discovered to this point have two negative characteristics: Their Curie temperature is far below room temperature, meaning the materials need to be cooled to preserve their magnetic effects, or the materials are not structurally stable and decompose quickly in ambient conditions.

"Our material has neither of those problems," Lou said. "It's air-stable and the Curie temperature is slightly above room temperature. If we test the material we grew a year ago now, it still shows the same behavior."



Epsilon-iron(III) oxide incorporates oxygen atoms (blue) and iron atoms (everything else) into a crystal lattice with magnetic properties that, unlike other iron oxides, remain stable at room temperature. This makes the nearly 2D material a good candidate for combining with other atom-thick materials for novel electronic and spintronic applications. Credit: Jiangtan Yuan

If the material were as thick as a refrigerator magnet, it too would stick. "The magnetic effect is very strong, around 300 milliTeslas," Lou said. "But this material cannot exist in bulk. It will phase out of epsilon into some other kind of oxide."

The researchers grew the smooth flakes, as thin as 5.1 nanometers, on silicon dioxide and mica substrates. They successfully tested its ability to bond via the weak van der Waals force with graphene. The flakes' magnetic properties, measured at Los Alamos, were found to be stable at room temperature with a magnetic field between 200 and 400 milliTeslas.

The research is the result of an interdisciplinary Rice IDEA proposal by Lou, Natelson and Rice chemist Gustavo Scuseria to investigate the magnetic properties of 2-D materials. They plan to combine the oxide with more 2-D materials to see how its magnetic field affects the properties of heterostructures. "This interfacial coupling process is going to be very interesting for us," Lou said.

Rice alumnus Jiangtan Yuan, now a postdoctoral researcher at Northwestern University, and Andrew Balk of the National High Magnetic Field Laboratory at Los Alamos, New Mexico, are co-lead authors of the study. Co-authors are assistant research professor Hua Guo, graduate students Qiyi Fang and Xuanhan Zhao, undergraduate Sahil Patel and research specialist Tanguy Terlier of the Shared Equipment Authority at Rice. Crooker is a technical staff member of the National High Magnetic Field Laboratory. Natelson is a professor of physics and astronomy, of electrical and computer engineering and of materials science and nanoengineering. Lou is a professor of materials science and nanoengineering and of chemistry.

More information: Jiangtan Yuan et al. Room-Temperature Magnetic Order in Air-Stable Ultrathin Iron Oxide, *Nano Letters* (2019). DOI: 10.1021/acs.nanolett.9b00905

Provided by Rice University