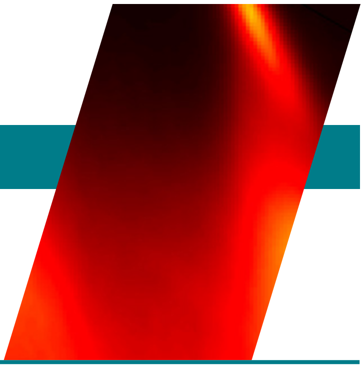
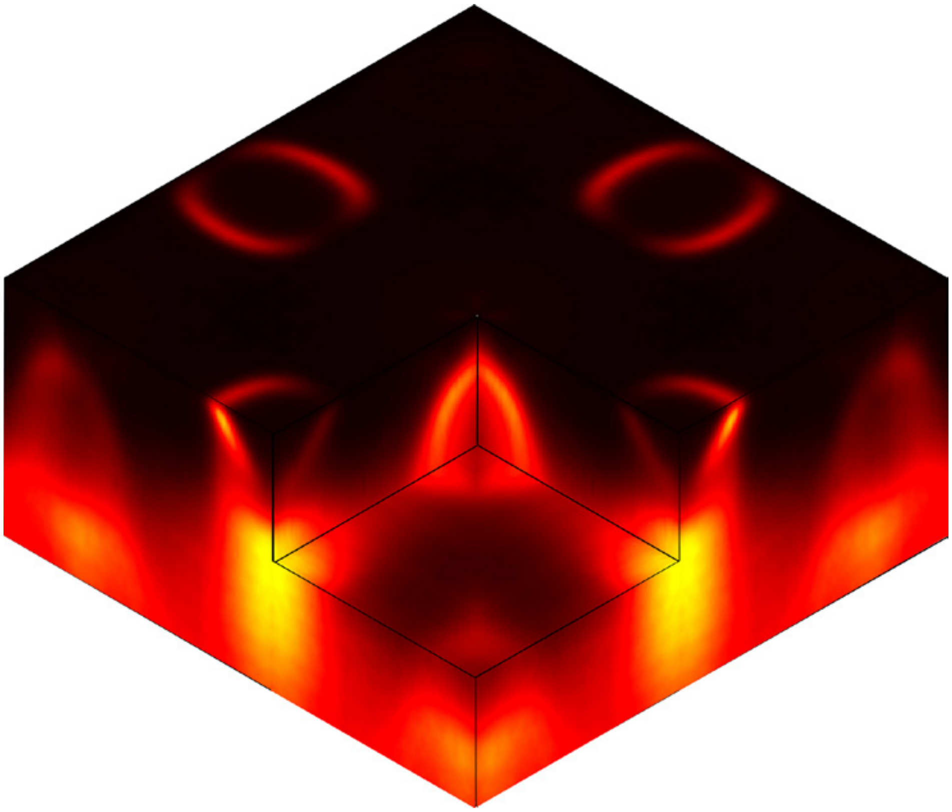
ADVANCED LIGHT SOURCE



MATERIALS SCIENCES

A New Universal Parameter for Superconductivity



This 3D representation shows the electronic structure of $RbFe_2SeS$, one of the high-temperature superconductors studied.

Scientists have been researching high-temperature (high-T_c) superconductors for decades with the goal of finding materials that express superconducting capabilities at room temperature, a requirement for practical and cost-effective applications. The higher the operating temperature, the more realistic energy-saving applications such as lossless electrical transmission or magnetically levitated trains become. Scientists thought they'd found the key component to high-temperature superconductivity in iron-based materials—that they have a certain type of Fermi surface—but new research at the ALS points to electron correlation as the universal factor.

Currently, known high-T_c superconductors are complex materials where the mechanism for superconductivity is still far from clear. The newest materials to gain scientific interest are iron-based superconductors, and the first few years of research have led scientists to believe that these materials all have in common a certain type of Fermi surface, an abstract "map" that defines the allowable energies of electrons in a solid. But recently, researchers from UC Berkeley, Stanford, and Berkeley Lab working at the ALS dispelled that theory. They showed that electron correlation—the strength of

What Makes a Superconductor?

Superconductors are materials that can conduct electricity with absolutely no resistance, and thus could offer energy savings in a wide range of applications from MRI scanners to magnetically levitated trains. However, superconductors are limited by their operating temperatures, which usually hover around –389 °F. Unfortunately, the cost of cooling superconductors to activate their capabilities offsets the energy savings they offer.

For decades, scientists have been on a quest to discover new materials with superconducting qualities at higher temperatures, with the ultimate goal being a superconductor that works at room temperature. Progress has been challenging, and the materials that have been discovered are incredibly complex and difficult to study due to the plethora of quantum phases that coexist in these materials in addition to superconductivity. Understanding of the roles of the various phases to superconductivity requires detailed lab work and a combination of complementary measurement techniques.

Copper-based materials called cuprates had offered the most promise, but recently, iron-based materials have gained interest as a second class of high-temperature superconductors. Having two types of high-temperature superconductor materials gives researchers an advantage in their quest to discover the parameters that define high-temperature superconductivity. Discovering the differences between the materials is helping scientists narrow down what may be the similarities among all high-temperature superconductors.

interactions of electrons within the material as expressed in the electronic bandwidth—is the essential factor.

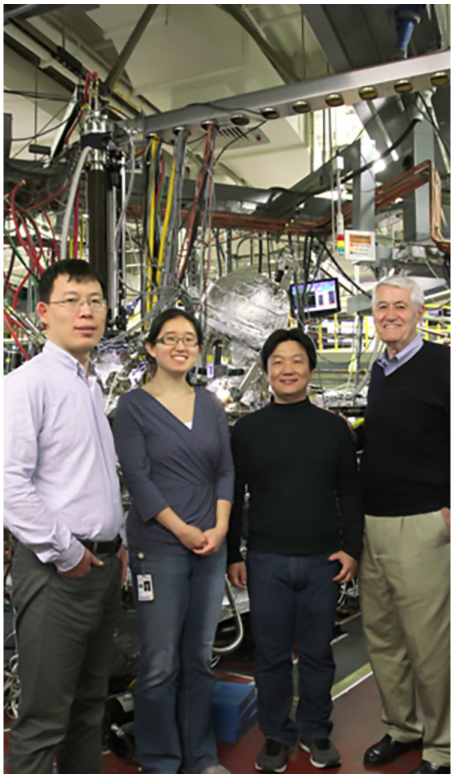
Most iron-based superconductors combine a conducting layer of iron with a pnictogen (Group 15 of the periodic table), typically arsenic or phosphorous. These types of iron-based superconductors, discovered just eight years ago, provided a second class of high-temperature superconductors (the first being copper-based cuprates), which has been helpful for determining the minimal ingredients necessary for superconductivity.

In this vein, researchers set out to look at an even newer subclass of iron-based materials called iron chalcogenides, which combine iron and a chalcogen (sulfur, selenium, or tellurium). Studies had noted that iron-based superconductors had a set of hole Fermi surfaces and a set of electron Fermi surfaces that were separated such that electrons could scatter from one to another. The widely accepted theory was that it was magnetic fluctuations between these two sets of Fermi surfaces that mediated superconductivity.

However, recent research at ALS Beamline 10.0.1 using angle-resolved photoemission spectroscopy (ARPES) has shown that the specific Fermi surfaces previously observed do not have to be present in order for iron-based materials to perform as high-T_c superconductors. The iron chalcogenide materials that ALS researchers studied only had electron Fermi surfaces and were still observed to superconduct at a relatively high temperature.

More importantly, the researchers found that it was not the shape of the Fermi surfaces that dictated the superconducting properties of the materials. The three samples they studied ranged from a non-superconductor to a superconductor with a T_c of 32 K, all having the same Fermi surfaces. Instead, the characteristic that distinguished superconducting characteristics in the iron chalcogenide samples was their electronic bandwidth, a measure of the strength of electron interactions in these compounds. The high flux available at Beamline 10.0.1 allowed researchers to chart the slope of the electronic bands in the iron chalcogenide samples. The band slopes, which indicate the velocity at which electrons travel in the materials, were much lower in the samples that had the highest levels of superconductivity. The lower band slope reveals that the electrons travel more slowly due to the strong interaction with other electrons in the materials. From the non-superconducting sample to the 32 K superconductor, the band slope changed by a factor of two, revealing that the strength of electron interaction is an important and necessary factor for the occurrence of superconductivity in iron-based superconductors.

It has been known that the copper-based high-T_c materials are very strongly correlated. However, the role of electron correlation has not been given as much attention for the iron-based superconductors due to the previous attention on the common Fermi surface topology. This work shows that looking at electron correlations could be one of the most significant methods of understanding and discovering new and existing high-T_c materials.



The researchers at ALS Beamline 10.0.1, from left: Meng Wang and Ming Yi (UC Berkeley Postdoctoral Scholars), Sung-Kwan Mo (ALS Beamline Scientist), and Robert J. Birgeneau (UC Berkeley professor of physics, materials science and engineering, and public policy, Chancellor Emeritus).

Publication about this research: M. Yi, M. Wang, A.F. Kemper, S.-K. Mo, Z. Hussain, E. Bourret-Courchesne, A. Lanzara, M. Hashimoto, D.H. Lu, Z.-X. Shen, and R.J. Birgeneau, "Bandwidth and Electron Correlation-Tuned Superconductivity in $Rb_{0.8}Fe_2(Se_{1-z}S_z)_2$," *Phys. Rev. Lett.* **115**, 256403 (2015).

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Research funding: U.S. Department of Energy (DOE), Office of Basic Energy Sciences (BES). Operation of the ALS is supported by DOE BES.

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