Researchers at UC Irvine are first to image directional atomic vibrations

New microscopy method unveils pathways for developing advanced materials.
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Brian Bell
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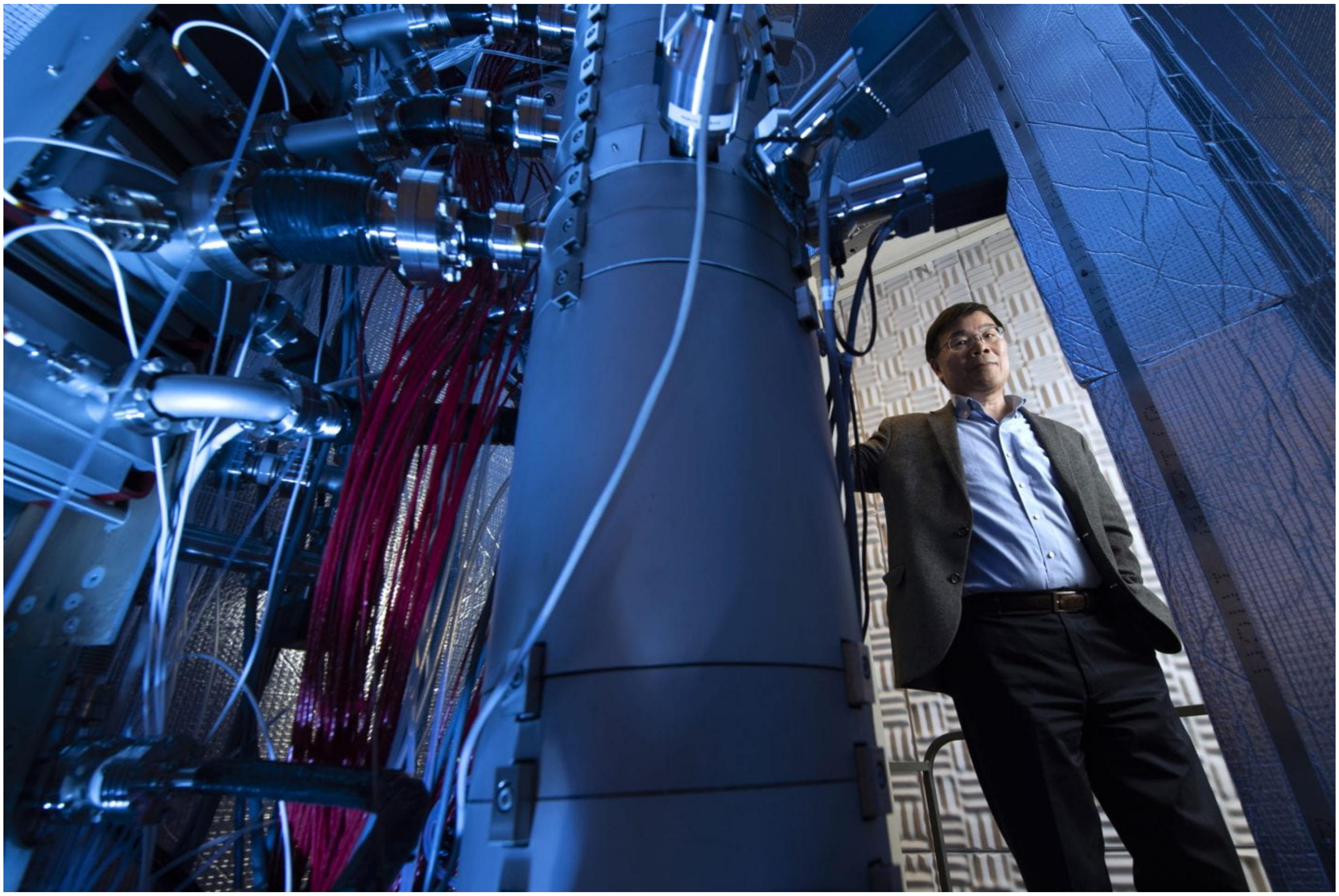


“Our results also clearly demonstrated that the collective atomic vibrations in crystals undergo atomic-level fluctuations depending on the elements and atomic sites, challenging the traditional model that assumes a uniform distribution of phonon wave functions,” says co-author and UC Irvine Distinguished Professor Xiaoqing Pan, here beside an electron energy-loss spectroscopy instrument in his laboratory. Steve Zylius / UC Irvine

Picture Credit:
Steve Zylius / UC Irvine

- UC Irvine-led team develops new electron microscopy technique that can detect directional dependence of vibrations in solids.
- Anisotropic phonon propagation governs material properties such as heat management, ferroelectricity and superconductivity, key factors in a wide range of technologies.
- Research was funded by U.S. Department of Energy and National Science Foundation.

Irvine, Calif., Sept. 17, 2025 —Researchers at the University of California, Irvine, together with international collaborators, have developed a new electron microscopy method that has enabled the first-ever imaging of vibrations, or phonons, in specific directions at the atomic scale.

In many crystalized materials, atoms vibrate differently along varying directions, a property known as vibrational anisotropy, which strongly influences their dielectric, thermal and even superconducting behavior. Gaining a deeper understanding of this anisotropy allows engineers to tailor materials for use in electronics, semiconductors, optics and quantum computing.

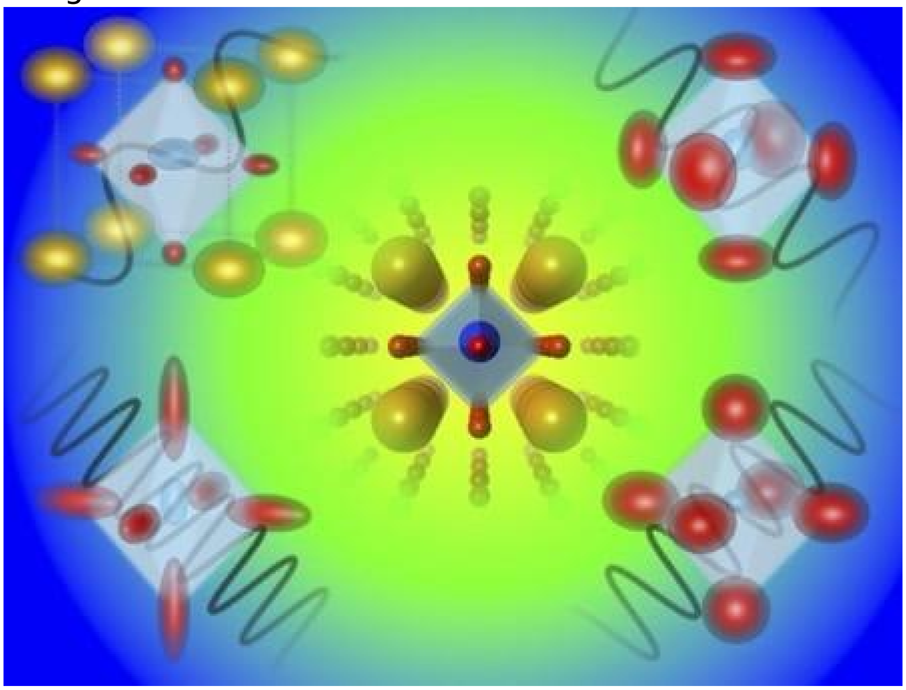
In a paper published today in *Nature*, the UC Irvine-led team details the workings of its momentum-selective electron energy-loss spectroscopy technique and its power to unveil the fundamental lattice dynamics of functional materials.

The researchers used their EELS microscope system to study strontium titanate and barium titanate, two perovskite oxides that differ in their thermoelectric, optical, piezoelectric and ferroelectric functionalities. By collecting atom-by-atom vibrational signals along selected directions, they observed contrasts in the anisotropic behavior of acoustic and optical phonons for the two materials.

“The altered anisotropic vibrations offer measurements totally different from those obtained from the whole crystals and integrated across full energy ranges,” said co-author Xiaoqing Pan, Henry Samueli Endowed Chair in Engineering and Distinguished Professor of materials science and engineering as well as physics and astronomy at UC Irvine and director of the campus’s Materials Research Institute. “Our results also clearly demonstrated that the collective atomic vibrations in crystals undergo atomic-level fluctuations depending on the elements and atomic sites, challenging the traditional model that assumes a uniform distribution of phonon wave functions.”

Pan added that the new microscopy method enables materials scientists to map vibrational anisotropy with unprecedented spatial and energy resolution across a wide range of materials.

Image



Atomic vibrations, known as phonons, in crystalline materials propagate in a nonuniform, or anisotropic, manner, and this phenomenon governs the substances' abilities to serve as building blocks for a wide variety of computing and energy technologies. UC Irvine researchers and international collaborators have invented a microscopy technique that helps them detect and image anisotropic atomic vibrations, a breakthrough that can lead to new advancements in high technology.
Xiaoqing Pan / UC Irvine

"The team's findings align closely with theoretical predictions," said senior co-author Ruqian Wu, UC Irvine professor of physics and astronomy. "This work opens the door for further studies of critical phonon-related phenomena, including ferroelectric phase transitions, the origins of ferroelectricity and the role of oxygen sites in shaping electron-phonon interactions in high-temperature superconductors."

Joining the UC Irvine team on this project were scientists from Sweden's Uppsala University and China's Nanjing University and Ningbo Institute of Materials Technology and Engineering. Funding was provided by the U.S. Department of Energy's Office of Basic Energy Sciences and the National Science Foundation.

About the University of California, Irvine: Founded in 1965, UC Irvine is a member of the prestigious Association of American Universities and is ranked among the nation's top 10 public universities by *U.S. News & World Report*. The campus has produced five Nobel laureates and is known for its academic achievement, premier research, innovation and anteater mascot. Led by Chancellor Howard Gillman, UC Irvine has more than 36,000 students and offers 224 degree programs. It's located in one of the world's safest and most economically vibrant communities and is Orange County's second-largest employer, contributing $7 billion annually to the local economy and $8 billion statewide. For more on UC Irvine, visit www.uci.edu.

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