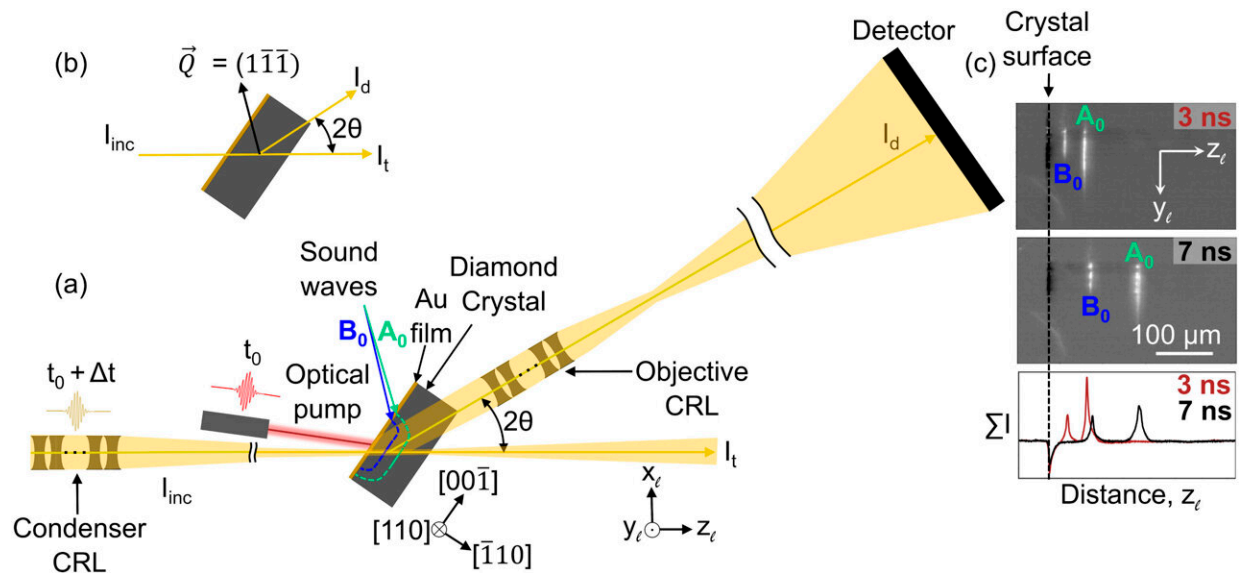


Revolutionary X-ray microscope unveils sound waves deep within crystals

September 28 2023, by Ali Sundermier



(A) Schematic layout of the DFXM experiment. The incident X-ray beam is condensed in one direction using a compound refractive lens (CRL) to illuminate a layer in the sample, which defines the observation plane (horizontal in this figure). The diamond single crystal is oriented such that diffraction takes place on reflection, Q^{\rightarrow} . DFXM images of the observation plane are obtained by using an X-ray objective to magnify the Bragg diffracted X-rays onto a 2D detector. An optical laser pump heats a Au film deposited on the surface of the sample at time t_0 , leading to thermal expansion and the launching of acoustic waves inside the diamond crystal. The associated local strain variations in the crystalline lattice are imaged at different time delays Δt between the laser pump and X-ray probe to create a movie of their propagation. Facets of the crystal and a laboratory coordinate system are shown. (B) Scattering geometry. (C) Experimental DFXM images at $\Delta t = 3$ ns and 7 ns. Below are graphs of intensity

with the vertical y_z -direction integrated out. Two acoustic waves, marked A_0 (aquamarine) and B_0 (blue), are seen to propagate toward the right for increasing Δt . Credit: *Proceedings of the National Academy of Sciences* (2023). DOI: 10.1073/pnas.2307049120

Researchers at the Department of Energy's SLAC National Accelerator Laboratory, Stanford University, and Denmark Technical University have designed a cutting-edge X-ray microscope capable of directly observing sound waves at the tiniest of scales—the lattice level within a crystal. These findings, published last week in [Proceedings of the National Academy of Sciences](#), could change the way scientists study ultrafast changes in materials and the resulting properties.

"The atomic structure of crystalline materials gives rise to their properties and associated 'use-case' for an application," said one of the researchers, Leora Dresselhaus-Marais, an assistant professor at Stanford and SLAC.

"The crystalline defects and atomic scale displacements describe why some materials strengthen while others shatter in response to the same force. Blacksmiths and semiconductor manufacturing have perfected our ability to control some types of defects, however, few techniques today can image these dynamics in [real-time](#) at the appropriate scales to resolve how those the distortions connect to the bulk properties."

In this new work, the team generated soundwaves in a [diamond crystal](#), then used the new X-ray microscope they developed to directly image the subtle distortions inside the crystalline lattice. They did so at the timescales at which these atomic-scale vibrations naturally occur by leveraging the ultrafast and ultrabright pulses available at SLAC's Linac Coherent Light Source (LCLS).

The researchers placed a special X-ray lens along the beam diffracted by the crystalline lattice to filter out the "perfectly packed" portion of the crystal and zero in on distortions in the crystal's structure caused by the sound wave and defects.

"We used this to image how an ultrafast laser transfers its [light energy](#) into heat via successive reflections of the out-of-equilibrium [sound wave](#) off the front and back surface of the crystal," Dresselhaus-Marais said.

"By showing this in diamond—a crystal with the fastest sound speed—we illustrate the new opportunities now available with our microscope to study new phenomena deep inside crystals."

The results identify a way to see super-fast changes in materials without damaging them. Before this discovery, the tools researchers used were much too slow to see these changes. This matters because many things, like how heat moves or how [sound waves](#) spread, depend on these fast changes.

The implications of this breakthrough stretch across various disciplines, from [materials science](#) to physics, and even extend to fields like geology and manufacturing. By understanding the atomic-level changes that lead to larger observable events in materials, scientists can get a clearer picture of transformations, melting processes, and [chemical reactions](#) in materials—accessing a new 13 orders of magnitude of timescales.

"This new tool offers us a unique opportunity to study how rare events caused by defects, atomic-distortions, or other localized stimuli inside a lattice give rise to macroscopic changes in materials," Dresselhaus-Marais said.

"While our understanding of the macroscopic changes in materials is rather advanced, we are often missing the details of which 'instigating events' ultimately cause the phase transformations, melting, or chemistry

we observe at larger scales. With ultrashort timescales now at our fingertips, we have the ability to hunt for these rare events at their native timescales."

More information: Theodor S. Holstad et al, Real-time imaging of acoustic waves in bulk materials with X-ray microscopy, *Proceedings of the National Academy of Sciences* (2023). [DOI: 10.1073/pnas.2307049120](https://doi.org/10.1073/pnas.2307049120)

Provided by SLAC National Accelerator Laboratory

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