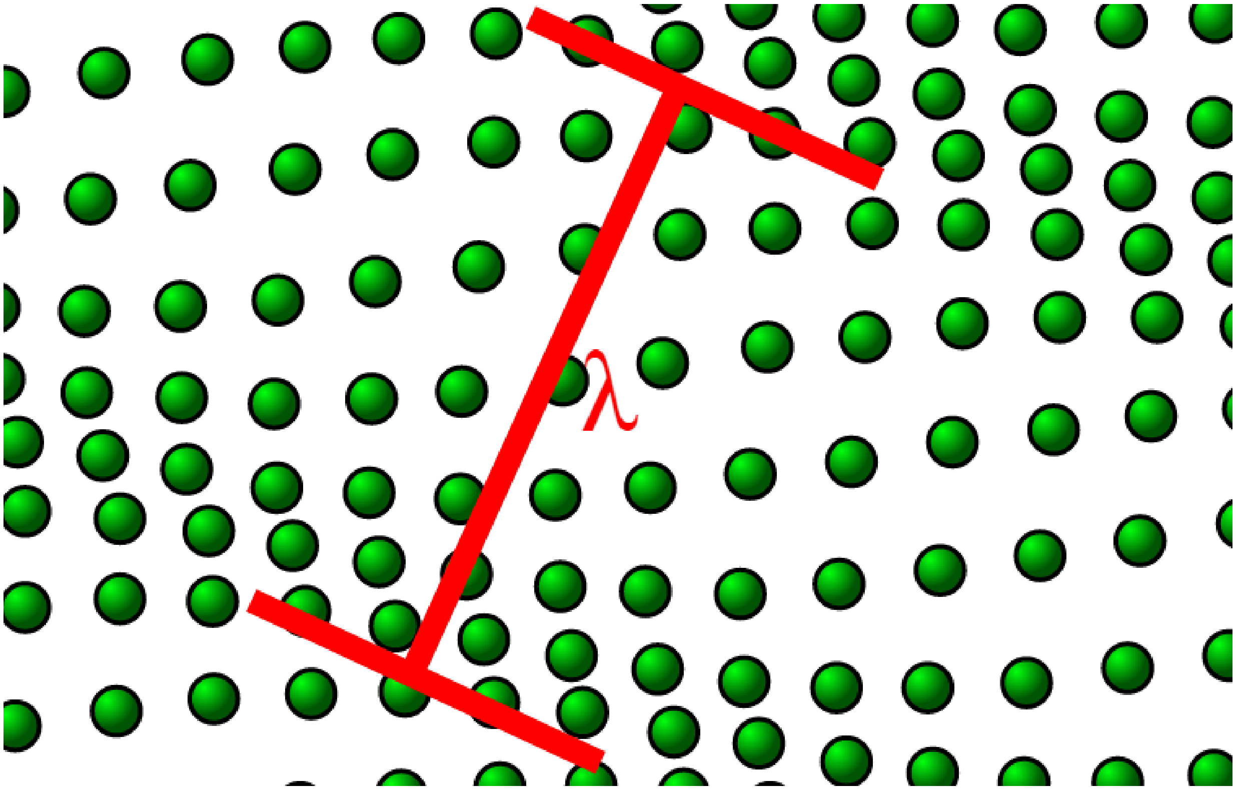
Detecting the birth and death of a phonon

June 5 2018



Phonon propagating through a square lattice (atom displacements greatly exaggerated). Credit: Wikipedia

Phonons are discrete units of vibrational energy predicted by quantum mechanics that correspond to collective oscillations of atoms inside a molecule or a crystal. When such vibrations are produced by light interacting with a material, the vibrational energy can be transferred back and forth between individual phonons and individual packets of light energy, the photons. This process is called the Raman effect.

In a new study, the lab of Christophe Galland at EPFL's Institute of Physics has developed a technique for measuring, in real time and at room-temperature, the creation and destruction of individual phonons, opening up exciting possibilities in various fields such as spectroscopy and quantum technologies.

The technique uses ultra-short laser pulses, which are bursts of light that last less than 10^{-13} seconds (a fraction of a trillionth of a second). First, one such pulse is shot onto a diamond crystal to excite a single phonon inside it. When this happens, a partner photon is created at a new wavelength through the Raman effect and is observed with a specialized detector, heralding the success of the preparation step.

Second, to interrogate the crystal and probe the newly created phonon, the scientists fire another laser pulse into the diamond. Thanks to another detector, they now record photons that have reabsorbed the energy of the vibration. These photons are witnesses that the phonon was still alive, meaning that the crystal was still vibrating with exactly the same energy.

This is in strong contradiction with our intuition: we are used to seeing vibrating objects progressively lose their energy over time, like a guitar string whose sound fades away. But in quantum mechanics this is "all or nothing": the crystal either vibrates with a specific energy or it is in its resting state; there is no state allowed in between. The decay of the phonon over time is therefore observed as a decrease of the probability of finding it in the excited state instead of having jumped down to the rest state.

Through this approach, the scientists could reconstruct the birth and death of a single phonon by analyzing the output of the two photon detectors. "In the language of quantum mechanics, the act of measuring the system after the first pulse creates a well-defined quantum state of the phonon, which is probed by the second pulse," says Christophe Galland. "We can therefore map the phonon decay with very fine time resolution by changing the time delay between the pulses from zero to a few trillionths of a second (10^{-12} seconds or picoseconds)."

The new technique can be applied to many different types of materials, from bulk crystals down to single molecules. It can also be refined to create more exotic vibrational quantum states, such as entangled states where energy is "delocalized" over two vibrational modes. And all this can be performed in ambient conditions, highlighting that exotic quantum phenomena may occur in our daily life—we just need to watch very fast.

More information: Mitchell D. Anderson et al, Two-Color Pump-Probe Measurement of Photonic Quantum Correlations Mediated by a Single Phonon, *Physical Review Letters* (2018). DOI: 10.1103/PhysRevLett.120.233601

Provided by Ecole Polytechnique Federale de Lausanne

Citation: Detecting the birth and death of a phonon (2018, June 5) retrieved 28 April 2024 from https://phys.org/news/2018-06-birth-death-phonon.html