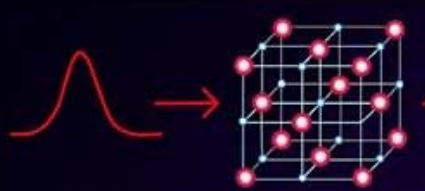


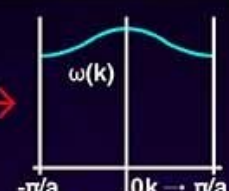
Controlling electrons and vibrations in a crystal with polarized light

October 8 2021

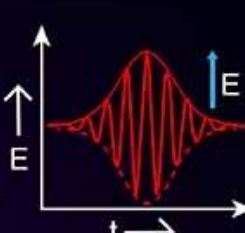
Modeling Coherent Control of Crystal Vibrations with Light



In solids, ultrashort light pulses can coherently excite and manipulate optical phonons




These phonons have an interesting dependence on light polarization



Longitudinal optical (LO) phonons in gallium arsenide (GaAs) with polarized double pulses

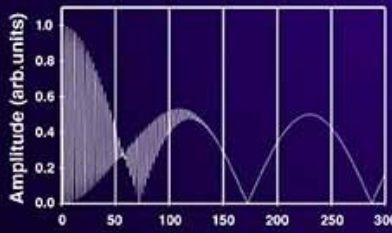
Theoretical modeling



Phonon control

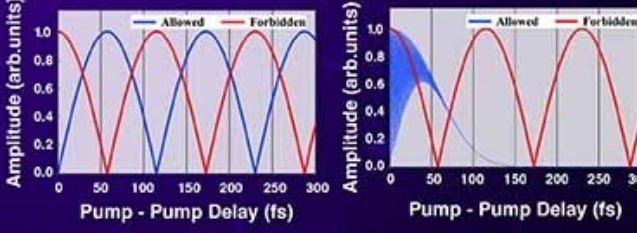
Interference patterns due to quantum-path interference can be predicted for different polarizations

Parallel polarization



- Electronic + phonon interference independent of crystal orientation and Raman scattering

Orthogonal polarization




- Only phonon interference at an angle $\pi/4$ from [100] direction
- Electron + phonon interference for one pulse traveling along [100] axis

LO phonons in GaAs crystals can be coherently controlled by polarized light for applications in electronics and thermoelectrics

Theory for coherent control of longitudinal optical phonons in GaAs using polarized optical pulses with relative phase locking

Takagi et al. (2021) | *Physical Review B* | DOI: 10.1103/PhysRevB.00.004300



東京工業大学
Tokyo Institute of Technology

Credit: Tokyo Institute of Technology

The quantum behavior of atomic vibrations excited in a crystal using light pulses has much to do with the polarization of the pulses, say materials scientists from Tokyo Tech. The findings from their latest study offer a new control parameter for the manipulation of coherently excited vibrations in solid materials at the quantum level.

To the [naked eye](#), solids may appear perfectly still, but in reality, their constituent atoms and molecules are anything but. They rotate and vibrate, respectively defining the so-called "rotational" and "vibrational" energy states of the system. As these atoms and molecules obey the rules of quantum physics, their rotation and vibration are, in fact, discretized, with a discrete "quantum" imagined as the smallest unit of such motion. For instance, the quantum of atomic vibration is a particle called "phonon."

Atomic vibrations, and therefore phonons, can be generated in a solid by shining light on it. A common way to do this is by using "ultrashort" light pulses (pulses that are tens to hundreds of femtoseconds long) to excite and manipulate phonons, a technique known as "coherent control." While the phonons are usually controlled by changing the relative phase between consecutive optical pulses, studies have revealed that light polarization can also influence the behavior of these "optical phonons."

Dr. Kazutaka Nakamura's team at Tokyo Institute of Technology (Tokyo Tech) explored the coherent control of longitudinal optical (LO) phonons (i.e., phonons corresponding to longitudinal vibrations excited by light) on the surface of a GaAs (gallium arsenide) [single crystal](#) and observed a "quantum interference" for both electrons and phonons for parallel polarization while only phonon interference for mutually

perpendicular polarization.

"We developed a quantum [mechanical model](#) with classical light fields for the coherent control of the LO phonon amplitude and applied this to GaAs and diamond crystals. However, we did not study the effects of polarization correlation between the [light](#) pulses in sufficient detail," says Dr. Nakamura, Associate Professor at Tokyo Tech.

Accordingly, his team focused on this aspect in a new study published in *Physical Review B*. They modeled the generation of LO phonons in GaAs with two relative phase-locked pulses using a simplified band model and "Raman scattering," the phenomenon underlying the phonon generation, and calculated the phonon amplitudes for different polarization conditions.

Their model predicted both electron and phonon interference for parallel-polarized pulses as expected, with no dependence on crystal orientation or the intensity ratio for allowed and forbidden Raman scattering. For perpendicularly polarized pulses, the model only predicted phonon interference at an angle of 45° from the [100] crystal direction. However, when one of the pulses was directed along [100], electron interference was excited by allowed Raman scattering.

With such insights, the team looks forward to a better [coherent control](#) of optical phonons in crystals. "Our study demonstrates that [polarization](#) plays quite an important role in the excitation and detection of coherent phonons and would be especially relevant for materials with asymmetric interaction modes, such as bismuth, which has more than two optical [phonon](#) modes and electronic states. Our findings are thus extendable to other materials," says Nakamura.

More information: Itsuki Takagi et al, Theory for coherent control of longitudinal optical phonons in GaAs using polarized optical pulses with

relative phase locking, *Physical Review B* (2021). [DOI: 10.1103/PhysRevB.104.134301](https://doi.org/10.1103/PhysRevB.104.134301)

Provided by Tokyo Institute of Technology

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