Sound amplification by the stimulated emission of radiation (SASER)

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LASERS are cool!

They provide a source of light waves that is

- \blacktriangleright High intensity
- \blacktriangleright Monochromatic
- \blacktriangleright Highly columnated
- ▶ Spatially Coherent

Can we do the same thing for sound waves?

What makes a LASER a LASER?

- \blacktriangleright Stimulated emission
- \blacktriangleright Population Inversion

1.Gain medium 2.Laser pumping energy 3.High reflector 4.Output coupler 5.Laser beam

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Stimulated emission

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Population Inversion

Ratio of two populations of $N/2 /N/1 = exp(-E/2 - E/1) / kT$ Boltzman distributions at thermodynamic equilibrium:

D. W. Ball, *Field Guide to Spectroscopy* (SPIE Press, Bellingham WA, 2006).

Phonons

- \blacktriangleright Phonons are the quantized form of acoustic radiation, derived from the quantization of the vibrational modes of a crystal lattice.
- \blacktriangleright Like photons, phonons are bosons and obey $E=\hbar\omega$
- \blacktriangleright Because of the inhomogeneous nature of crystals the dispersion relations linking frequency and momentum are complex, typically with multiple branches.

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Maybe SASERS really aren't that cool?

"Saser beams that operate at much lower frequencies, in which the phonons oscillate a billion times per second (gigahertz) rather than a trillion times per second (terahertz), have been made before. However, they have had little impact because there are other methods of generating sound at such frequencies, says Kent"

C. Baras, *Most Powerful "sound Laser" to Shake up Acoustics*, https://www.newscientist.com/article/dn17310 most-powerful-sound-laser-to-shake-up-acoustics/.

In 2010 two laboratories published implementations of SASERS using two very different systems and attracted a lot of press.

old. Phonon lasing is further confirmed by the narrow-

 $\mathcal{O}_\mathcal{A}$ bosons are in the phonon lasing, so it is in can also be interpreted as a three-wave parametric process in which two waves (the "pump" and the "pump" and the "pump" and the "idler" in th $\frac{d\mathcal{L}}{d\mathcal{L}}$ are optical, and the third one (the third one (the third one) $\frac{1}{2}$ is account $\frac{1}{2}$ lated Brillouin scattering—an inelastic collision in which a photon is converted to a downshifted photon is converted to a downphonon with energy equal to the difference is energy equal to the difference is expected. $\mathbb{B}^{\mathcal{B}}$ ut is important that the threshold is achieved when $\frac{1}{2}$ \mathbb{R}^n are \mathbb{R}^n . Which the threshold is which the threshold is \mathbb{R}^n \mathcal{A} achieved when the photon gain supersedes photon loss gain supersedes pho and the coherent phonons are no more than a byproduct phonons are no more than a byproduct phonons are no more than a byproduct phonons are no more than $\mathcal{L}_\mathcal{P}$ $\mathcal{L} = \frac{1}{2} \sum_{i=1}^{n} \frac{1}{i} \sum_{j=1}^{n} \frac{1}{j} \sum$

 $W = \frac{1}{2} \$ between two photon states as a source of coherent phonons, the group at Nottingham [3] used a different strategy to achieve the evidence of coherent phonon and \mathcal{C} pliftication in the THZ range. This is a "sound" with a "sound" with a "sound" with a "sound" with a "sound" w
This is a "sound" with a "sound" wi pitch 15 octaves higher than that of the acoustic wave in $\frac{1}{2}$ $\frac{1}{2}$ cascades down a state of energy states in a state of energy states in a biased semiconductor superlattice, releasing the accumulated energy in the form of coherent photons in the infrared $\frac{1}{2}$ rangement (Fig.1, both the electrons tunnel from one semiconductor quantum well to the next, with each step releasing a half-THz action $\mathcal{L}_\mathcal{F}$ $t_{\rm c}$ energy conservation. The mechanism conservation. The mechanism conservation conservation. The mechanism coupling \mathcal{L}_c

the phonon gain surpasses the phonon loss, in contrast

fiber (blue). The two cavities are placed very cavity cavity to two cavity of the two cavity close to the place
The two cavity close to two cavity close to the two cavity cavity cavity control to the two cavity control of

GaAs/AlAs superlattice (University of Nottingham) Coupled microcavities (Californian Institute of Technology)

But it is important that the threshold is achieved when the experiment of Grudinin *et al.*[2], two coupled microcavi-J. B. Khurgin, *Phonon Lasers Gain a Sound Foundation*, Physics **3**, (2010). $\mathbf{t} = \mathbf{t} - \mathbf{t}$ and $\mathbf{t} = \mathbf{t} - \mathbf{t}$ and $\mathbf{t} = \mathbf{t} - \mathbf{t}$

R. P. Beardsley, A. V. Akimov, M. Henini, and A. J. Kent, *Coherent Terahertz Sound Amplification and Spectral Line Narrowing in a Stark Ladder Superlattice*, Phys. Rev. Lett. **104**, 085501 (2010).

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G. Wang, M. Zhao, Y. Qin, Z. Yin, X. Jiang, and M. Xiao, *Demonstration of an Ultra-Low-Threshold Phonon Laser with Coupled Microtoroid Resonators in Vacuum*, Photon. Res. **5**, 73 (2017).

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Pros and cons of the two systems

- \blacktriangleright The Nottingham group's superlattice device produced phonons that were near half a THz, which is where the interesting applications seem to be.
- \triangleright Coherence was only demonstrated for a few hundred picoseconds, responding to femtosecond LASER pulses.
- \blacktriangleright It's easer to envision the superlattice being integrated into larger semi-conductor components.
- \blacktriangleright The CalTech group's microresonator device could be operated continuously, but only produced 41 MHz phonons, far below the frequencies of interest.
- \blacktriangleright It's not clear how to get phonons out of the microresonator and into a larger experimental system.

The Outlook for SASERS

"Ultimately, it's still rather unclear what sasers will be useful for. "They will find applications, but honestly I don't know where or for what,"

Jérôme Faist, a researcher at the Swiss Federal Institute of Technology in Zurich

G. Brumfiel, *"Sasers" Set to Stun*, Nature (2010). https://www.nature.com/articles/news.2010.92 "It is a great work. A high-energy coherent phonon source like a saser is the best tool we can have to noninvasively probe the unknown nanoworld."

Chi-Kuang Sun a laser specialist at the National Taiwan University in Taipei City

C. Baras, *Most Powerful "sound Laser" to Shake up Acoustics*, https://www.newscientist.com/article/dn17310-most-powerfulsound-laser-to-shake-up-acoustics/.

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