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OPTOMECHANICS

Listening to quantum grains of sound

An optomechanical device has allowed quanta, or 'grains', of mechanical vibration to be counted by optical means. The system may open up new possibilities in acoustics and thermal engineering. SEE LETTER P.522

IVAN FAVERO

According to quantum theory, all forms of energy come in tiny 'grains' called quanta. This quantum granularity may or may not be discernible, depending on the instruments available and the nature of the energy. The quanta are photons in the case of electromagnetic waves such as light, and phonons for mechanical vibrations in solids. Phonons are ubiquitous in condensed-matter systems, in which they underlie the transport of sound and heat. They also govern the performance of electronic and optical devices, and play a central part in conventional superconductivity. However, whereas photons can be detected at the single-quantum level using today's optical receivers, there is a lack of versatile instruments and techniques to measure phonons at the same level of precision. The scientific and technological stakes are high, given the many potential applications of such systems. On page 522 of this issue, Cohen *et al.*¹ describe a promising step towards building an optical single-phonon detector.

The researchers used an optomechanical device in which photons from an external light source are scattered by phonons associated with the system's mechanical vibration. The phonons are detected by collecting the scattered photons in single-photon detectors. The experiment builds on developments in the field of optomechanics, in which the force of light, circulating in a type of light trap called an optical cavity, is used to control and monitor the mechanical motion of tiny objects such as mirrors, membranes or flexible wires^{2,3}. Although light generally has a feeble mechanical effect on large bodies, it dictates the dynamics of such minute optomechanical systems. Progress in the field over the past five years has involved confining both photons and phonons

in a submicrometre-sized volume to achieve strong coupling between light and mechanical motion^{4,5}.

Cohen and colleagues' optomechanical device is a nanostructured semiconductor crystal that yields such strong coupling. As a result, laser light that is incident on, and scattered from, the optomechanical crystal is efficiently modulated by the crystal's mechanical vibration. The scattered light acquires blue and red spectral sidebands, respectively above and below the laser's frequency, that are analogous to the 'satellite lines' observed in the Raman scattering of photons from a material. If the material absorbs energy during the scattering process, the scattered photon has a lower

energy than the incident photon (red Stokes line); if the material loses energy, the scattered photon has a higher energy (blue anti-Stokes line). The shift in energy provides information about the vibrational or rotational modes of motion of the material's constituents. In a sense, optomechanical devices are simply highly engineered Raman systems.

By appropriately tuning the laser's frequency to the optical resonance of the optomechanical crystal, the system's natural optical vibration frequency, Cohen *et al.* could finely adjust the amplitude of the sidebands. For example, they suppressed the amplitude of the red sideband and selectively enhanced the generation of scattered blue photons (Fig. 1). By using optical filtering, the researchers then suppressed scattered photons that had the same energy as the incident laser photons. In this way, only the blue photons produced 'clicks' on the detector, revealing the presence of phonons in the device. Owing to the strong optomechanical interaction, the optical measurement attained sufficient sensitivity to resolve individual phonons, and enabled their precise counting in the system's vibrational state.

Although the present experiments still fall short of actually generating and measuring vibrational states containing a single phonon, the authors' phonon-counting technique already

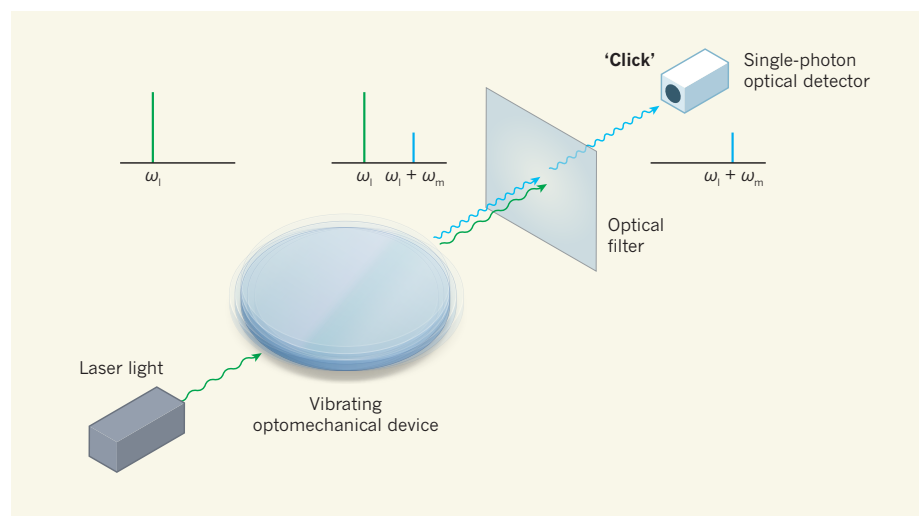


Figure 1 | Optical phonon counting. Cohen *et al.*¹ shone laser light of frequency ω_l on an optomechanical device. The light's photons interacted strongly with phonons (quanta of vibration associated with the device's mechanical motion) of frequency ω_m , such that the output light acquired a blue spectral sideband at $\omega_l + \omega_m$ or a red spectral sideband at $\omega_l - \omega_m$. (For simplicity, only the former case is shown.) The output light was sent through an optical filter that suppressed photons of frequency ω_l but let through blue photons, which were directed to a single-photon optical detector. Photon 'clicks' at the detector indicated the presence of phonons in the system.

allows measurement of the statistical properties of the device's vibrational motion. The authors applied the concept of intensity correlations to their experimental set-up. Such correlations were used by Robert Hanbury Brown and Richard Twiss nearly 60 years ago to detect correlations between photons emitted by distant stars⁶. Cohen *et al.* measured these correlations in the arrival of photons at the detectors, thereby probing phonon correlations in the optomechanical device. Using this technique, they could directly observe a transition in the statistical behaviour of phonons as the system underwent a change from a purely thermal, random state of vibrational motion to a coherent, more-ordered one, which was reached above a certain threshold of power of the incident laser light^{7,8}. In other words, Cohen and colleagues observed the phononic analogue of the 'lasing' transition that

enables lasers to emit coherent light — light that is made up of waves that have the same wavelength and are in step with each other.

Finally, and looking ahead, it should be noted that, in the realm of quantum physics, measuring is also acting. The very act of measuring a system may alter its state. Therefore, future optomechanical experiments operating in the single-phonon counting regime could be used to generate complex quantum states of phonons. Given the rapid pace at which the field of optomechanics is advancing, this point might be reached in the not-too-distant future. Such quantum optomechanical control of matter could allow researchers both to test the fundamental principles of quantum mechanics and to venture into new applications in acoustics, thermal management and electrical-conductivity engineering. ■

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EARTH SCIENCE

Landscape inversion by stream piracy

A model suggests that active deformation in mountains causes river networks to constantly reorganize, providing an explanation for the paradoxical formation of almost flat surfaces high in craggy mountain ranges. SEE LETTER P.526

JÉRÔME LAVÉ

For more than a century, Earth scientists' curiosity has been piqued by the existence of areas with low topographic relief, some nearly flat, perched high in rugged mountain ranges. One common explanation¹ posits that these surfaces are relicts of large peneplains — low-relief features formed as the ultimate result

of fluvial erosion — that were once close to sea level before being uplifted by mantle convection or plate tectonics and then dissected by rivers or streams. On page 526 of this issue, Yang *et al.*² propose a very different mechanism, whereby low-relief surfaces in mountain landscapes form transiently as a result of the dynamic reorganization of river networks.

One of Earth science's greatest challenges is

to document vertical movements of the crust at geological timescales. Step-like landforms called terraces are commonly used as passive markers of small-scale deformations that occurred during the past million years or less, but it is usually impossible to use such markers for large uplifted regions and events that occurred over longer time periods. Geologists are therefore forced to use other palaeoaltimetric methods³ that generally have large uncertainties and are difficult to implement over large regions.

The lack of reliable tools is particularly problematic for studies of regional uplift caused by deep-seated geodynamic processes, or when investigating the upheaval of wide orogenic plateaus (which form as a result of colliding tectonic plates). In these cases, it is tempting to find other passive markers, such as the dissected and uplifted remnants of peneplains that are assumed to have once been nearly horizontal and close to sea level. By interpreting low-relief surfaces perched across

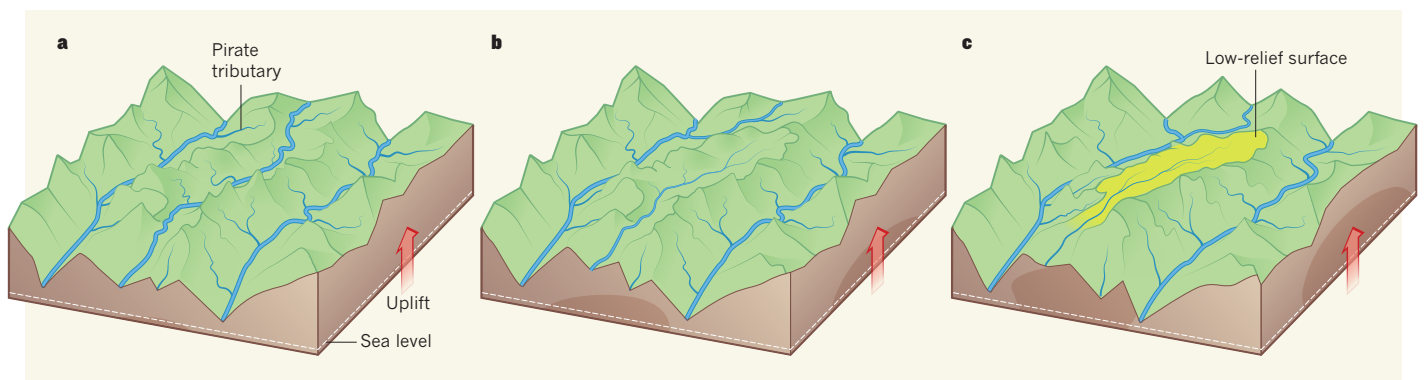


Figure 1 | Proposed origin of low-relief surfaces at high elevation. Yang *et al.*² suggest that when tectonic plates collide, the resulting large-scale deformation of the crust and upper mantle triggers permanent reorganization of river networks. **a**, In this illustration, a mountainous region is subjected to uplift, and a 'pirate' tributary of the left-hand river is indicated. **b**, Over time, the upstream part of the central river is captured by the pirate tributary,

causing a sudden decrease in the central river's stream power and its ability to incise through bedrock. Sustained tectonic uplift is no longer equilibrated by fluvial erosion, leading to uplift of the disconnected valley, with continuous erosion of the hillslope around the valley lowering the relief. **c**, A low-relief surface at high elevation emerges and may survive for some time before being degraded or captured by streams eroding inwards from its outer perimeter.