

spatially correlated motions for understanding the structural changes that underpin protein function, we need to get this right. Biologically relevant protein motions are like music, albeit playing at frequencies we can't hear. We need to observe the motions that correspond to certain frequencies, and discern how those motions are damped to produce net displacements. Imagine listening to music in which violin strings are struck too strongly, causing the accidental playing of different chords together. You would not hear the music as written, but something else entirely. To understand how nature works, we need to listen to the molecular music as nature wrote it. Barends *et al.* have done just that.

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Photonics

Nanotraps boost light intensity for future optics

Kirill Koshelev

A method for configuring light-trapping devices promises better optical nanodevices by amplifying light and enhancing the emission efficiency of luminescent nanomaterials – without the need for complex technology upgrades. **See p.765**

Intense light beams are crucial for myriad applications, ranging from medicine to electronics, but they are challenging to produce with everyday light sources. They can, however, be generated by lasers. Lasers work by trapping light in a cavity, called an optical resonator, in which reflected light waves interfere constructively to amplify the light's intensity through a phenomenon known as optical resonance. But light can be emitted, scattered or absorbed by the resonator material, limiting the extent to which its intensity can be enhanced – especially in devices that operate on a nanometre scale, such as ultraprecise sensors. On page 765, Schiattarella *et al.*¹ report a smart way of balancing the possibilities for light to escape a nanoresonator, and therefore increase light intensity by a factor of up to 36,000.

In the past two decades, advances in nanoscale materials have enabled researchers to engineer visible and infrared light resonators that are no thicker than a human hair². However, decreasing the size of a resonator inevitably leads to an increase in light emission. One way around this involves a special optical resonance called a bound state in the continuum, also known as a dark mode. This mode amplifies light intensity with very small losses³. Dark modes are produced by carefully tuning the properties of a resonator to induce

destructive interference between two or more 'bright' waves, which are formed through constructive interference.

Confining light with dark modes might limit unwanted emission, but it doesn't overcome the challenges posed by absorption and by fabrication defects that lead to light being scattered. Optimal light intensity is usually achieved by satisfying the critical coupling condition⁴, in which the escape rates of light through emission, scattering and absorption

“This approach could benefit biosensing by enhancing sensitivity to small sample volumes.”

are perfectly matched. But Schiattarella and colleagues showed that they could enhance light confinement beyond the range of conventional critical coupling by tailoring the exchange of energy between a dark mode and a bright mode. In doing so, they achieved 'supercritical' coupling.

The authors investigated a resonator consisting of a 130-nm-thick slab of silicon nitride that was patterned with a square lattice of circular holes and placed on a silicon dioxide substrate of 0.1–1 millimetres in length (Fig. 1). They first

calculated how the optical resonances of the slab could be optimized by adjusting various structural parameters of the slab, including its crystal-lattice spacing and thickness, as well as the diameter of the holes. They then used this information to create a dark mode and a bright mode with similar frequencies and waveforms.

By illuminating the centre of the slab with light that has the same frequency as the dark mode, the authors showed that they could induce conventional critical coupling. This offered moderate intensity enhancement that was limited by imperfections in the surface of the silicon nitride slab. They then showed that illuminating the edge of the slab had the effect of inducing a specific energy-exchange rate between the dark and bright waves, which modified the critical coupling. The authors' calculations suggested that incorporating this exchange into the usual loss-balancing equation could lead to the fulfilment of a supercritical coupling condition that would substantially improve the enhancement of the light intensity.

Schiattarella *et al.* used a process known as upconversion to demonstrate that their resonator could achieve the predicted supercritical coupling. Upconversion involves two or more photons combining and being absorbed to generate one higher-energy photon. It occurs, for example, when nanoparticles fabricated from the lanthanide series of elements absorb infrared light and convert it into visible light. These nanoparticles upconvert with increased efficiency when they are integrated with nanoresonators⁵.

The authors covered their silicon nitride slabs uniformly with two layers of upconverting nanoparticles: one layer contained a compound that emits green light when excited by infrared light, whereas the particles in the other layer emitted red light. Using a laser producing extremely short pulses of light, they measured the change in luminescence as a result of upconversion, and found that it was substantially more enhanced at the edge of the resonator than it was at the centre. This is consistent with the authors' model predictions, which suggest that emission from the edge of the nanoparticle–resonator system should be up to 36,000 times higher than that from a thick bulk layer of these nanoparticles.

As well as being brighter, the luminescence from the edge was also more precisely focused than that from the centre – emerging from the side of the device as a beam that remained collimated (that is, its rays were parallel) for several millimetres. Compared with emission from the bulk, the directionality of this beam further enhanced the emission – by a factor of more than 100 million, in the authors' estimation. Schiattarella *et al.* also showed that the direction of emission could be gradually swapped by changing the direction in which the incoming laser light was polarized (the

From the archive

Tutankhamun's magnificent coffin is revealed, and Charles Darwin gets a letter that he has to share.

100 years ago

In the *Times* of February 13, an account is given of the raising of the lid of the sarcophagus of Tutankhamen, which took place on the previous day in the tomb at Luxor ... [T]here appeared an anthropoid coffin ... of colossal size ... with gilt lion heads superbly modelled at the head ... The face was of gold ... with eyes of crystal ... The face was evidently a portrait.

From Nature 23 February 1924

150 years ago

The accompanying letter, just received from Fritz Müller, in Southern Brazil, is so interesting that it appears to me well worth publishing in *NATURE*. His discovery of the two sexually mature forms of Termites, and of their habits ... now published in Germany ... justly compares, as far as function is concerned, the winged males and females of the one form, and the wingless males and females of the second form, with those plants which produce flowers of two forms, serving different ends ... The facts ... given by Fritz Müller with respect to the stingless bees of Brazil will surprise and interest entomologists. **Charles Darwin**

"For some years I have been engaged in studying ... our Termites ... The most interesting fact in the natural history of these curious insects is the existence of two forms of sexual individuals, in some (if not in all) of the species ... I have lately turned my attention to ... stingless honey-bees (*Melipona* and *Trigona*) ... Wasps and hive-bees have no doubt independently acquired their social habits, as well as the habit of constructing combs of hexagonal cells, and so, I think, has *Melipona*. The genera *Apis* and *Melipona* may even have separated from a common progenitor, before wax was used in the construction of the cells ... [I]n hive-bees ... wax is secreted on the ventral side: in *Melipona* ... on the dorsal side of the abdomen; now it is not probable, that the secretion of wax, when established, should have migrated from the ventral to the dorsal side, or *vice versa*."

From Nature 19 February 1874

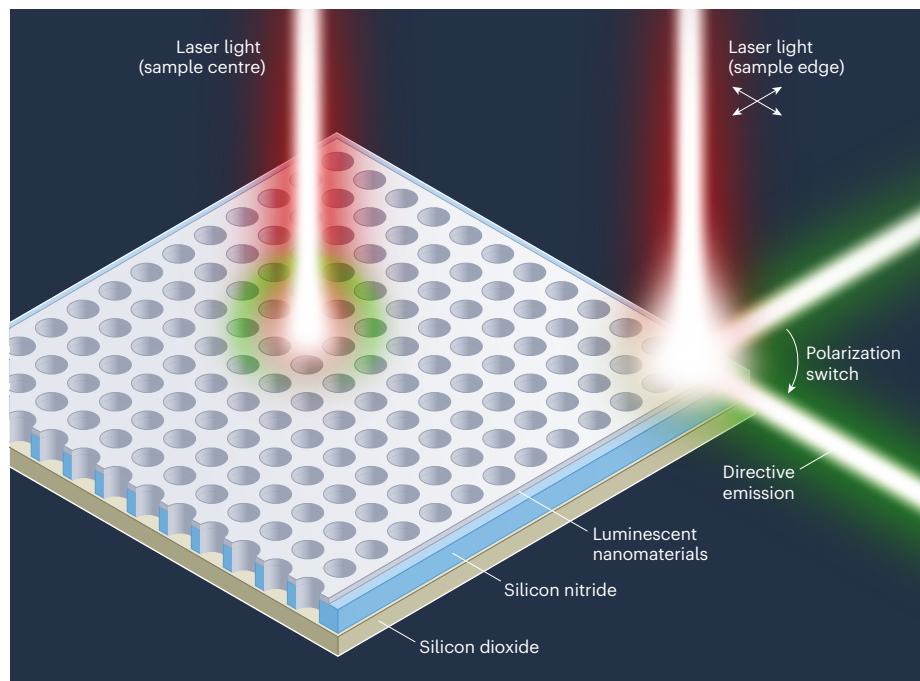


Figure 1 | An optical nanoresonator for enhancing light's intensity. Schiattarella *et al.*¹ designed a device called an optical nanoresonator, which boosts the intensity of light by trapping light waves. The nanoresonator comprises a 130-nm-thick slab of silicon nitride, patterned with circular holes, on a silicon dioxide substrate. By optimizing the device, the authors induced an exchange of energy between trapped light waves that led to a huge increase in the intensity of the light it emitted. It also increased the efficiency of a process called upconversion, in which luminescent nanoparticles on the nanoresonator's surface emit photons with higher energies than those of a laser that excites them. Emission from the nanoparticles at the edge was more intense and more focused than that from those in the centre of the device, and the direction of the emission at the edge could be switched by changing the laser's polarization (the plane in which the electric and magnetic fields of its light waves oscillate). (Adapted from Fig. 1 of ref. 1.)

plane in which the light waves' electric and magnetic fields oscillate).

Schiattarella and colleagues' main innovation is a smart photonic engineering method that significantly enhances light intensity in nanostructured optical devices through optical optimization alone, without requiring advances in fabrication technology or material quality. This approach will certainly enable more efficient upconversion processes, but it could also benefit biosensing by enhancing sensitivity to small sample volumes and improve quantum communications by helping quantum bits (qubits) to retain information.

A key limitation of the study is that strong emission occurs only at the sample's edge. Many nanodevices need light to be emitted perpendicular to the surface of a device, as is the case for conventional optical components, such as lenses. Another issue is that Schiattarella *et al.* achieved supercritical coupling by precisely adjusting several of the slab's structural parameters. Simplifying this approach would make the photonic design process much easier.

Advances in the physics of optical resonance have already improved the efficiency of nanoscale optical devices, and their performance is now nearing that of conventional optical devices, such as lasers. Schiattarella

and colleagues' work in improving the resonant properties of optical nanostructures is expected to give rise to even smaller and more efficient nanodevices. This progress could eventually lead to the lenses in spectacles and cameras being replaced with ultrathin optical components that boast superior performance.

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