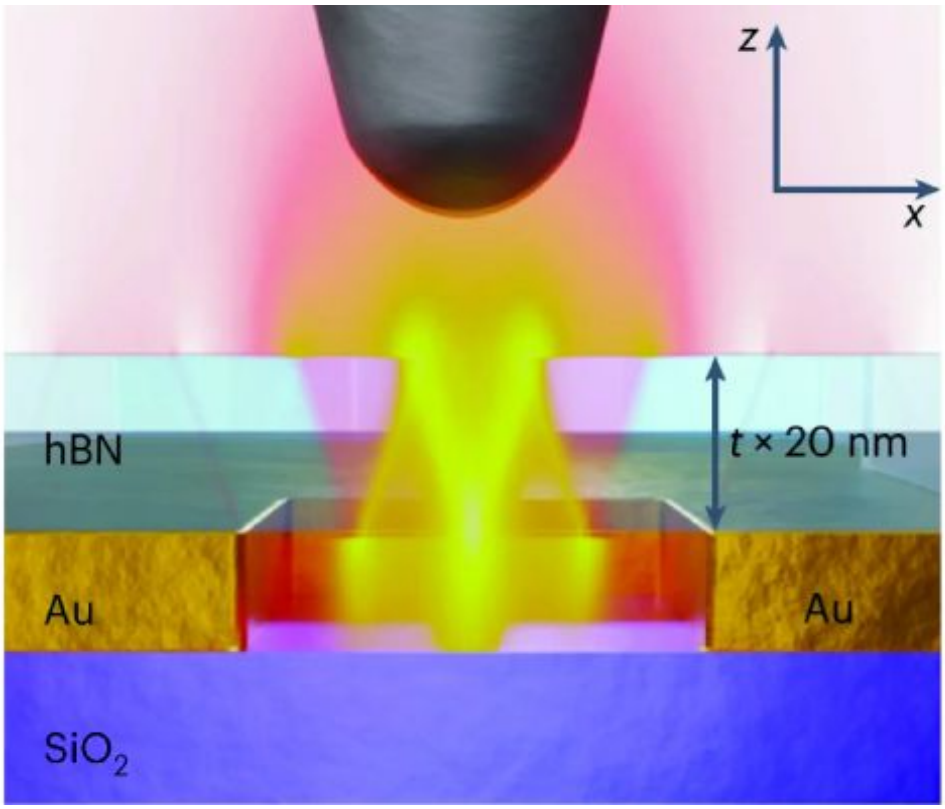


Breaking boundaries in quantum photonics: New nanocavities unlock new frontiers in light confinement

In a significant leap forward for quantum nanophotonics, a team of European and Israeli physicists has introduced a new type of polaritonic cavities and redefined the limits of light confinement. This pioneering work, detailed in a study published in Nature Materials, demonstrates an unconventional method to confine photons, overcoming the traditional limitations in nanophotonics and simultanously achieving small volume and long lifetime photon confinement.

February 12, 2024

Physicists have long been seeking ways to force photons into increasingly small volumes. The natural length scale of the?photon?is the wavelength and when a photon is forced into a cavity much smaller than its wavelength, it effectively becomes more i¿½concentratedi?½. This concentration enhances interactions with electrons, amplifying quantum proce

ses within the cavi
y. However, despite the immense experimental success over the last decades, the effe
t of dissipation (optical absorption) remains a major obstacle in confining light to extremely
mall volumes. Photons in nanocavities are absorbed very quickly, often even before the p
oton reaches from one side of the cavity to the other. This dissipation limits the applicabili
y of nanocavities to some of the most exciting applications in quantum electrodynam
cs. The research group **ICREA Prof. at ICFO Frank Koppens** has published a study in Nature
Materials where they overcome this challenge by creating multimodal-enhanced cavities
(MEC) with an unparalleled combination of subwavelength volume and extended lifetime.
These nanocavities, measuring smaller than 100x100nm² in area and only 3nm thin, confin
light for significantly longer durations. The key lies in the use o
hyperbolic-phonon-polaritons, unique electromagnetic excitations native to the 2D material
used to form the cavity. These hyperbolic polaritons are similar to ordinary light in mos
respects, but can be confined to extremely small volumes (much smaller than the wavelengt
cubed) in ways which defy the common intuition in optics.

When experiments outperformed the theoretical expectations?

This discovery began with a chance observation made during a completely different project
While using a nearfield optical microscope to characterize a 2D material structure, th
researchers noticed an unusually strong reflection when polaritons excited inside it hit th
edge of a metallic substrate. This unexpected observation, at first sight anecdotal, turned ou
to be the underlying principle of a groundbreaking device.?

The researchers figured out they could potentially use this newly discovered property
to make nanocavities with high quality and small volume simultaneously, an achievement wh
ch until now eluded the nanophotonics community. The expectations were to obtain a sli
ht improvement with respect to previous nanocavities, but when looking into the experimen
al measurements the team was in for a big surprise. The performance of the cavities doub
ed their expectations, exceeding the maximum predicted by the initial theoretical model. E
en better, the nanocavities showed these relatively long lifetimes despite their reduced size
of the order of few nanometers
. "Experimental measurements are usually worse than theory would suggest, but in this c
se, we found the experiments outperformed the optimistic simplified theoretical predictio
s," said first author, Dr. Hanan Herzig Sheinfux, from Bar-Ilan University's Department of Phys
cs. "This unexpected success paves the way to novel applications and advancement
in quantum photonics, pushing the boundaries of what we thought was possibl
." In fact, their MEC cavities were orders of magnitude smaller than any other optical reso
ator of comparable lifetime. However, their enormous achievement became their b
ggest challenge as well, as a theoretical explanation was still lacking. After months of study
they found out that i¿½some really beautiful and surprisingly deep physics related to
ano-ray formation and multimodal interaction was the responsible of it alli¿½, explains Dr

Multimodal-enhanced cavity of hyperbolic polaritons?

The success of their nanocavities relied on a unique confinement mechanism as well as o the construction of the device. The nanocavities were crafted by drilling nanoscale holes in gold substrate with the extreme (2-3 nanometer) precision of an He-focused ion bea microscope. After making the holes, hexagonal boron nitride (hBN), a 2D material that ca support the hyperbolic phonon polaritons, was transferred on top of it. Light was meant to b confined inside the hBN in the region above the holes.?

In the original model used to analyze the experiments, the confinement in the cavity can be likened to the increase in car traffic that occurs when a double lane expressway narr ws down to a single lane. The incompatibility between the single and double lane traffic is forcing cars to congest, which is loosely similar to how light is reflected and confined w en the substrate type changes at the edge of the hole into the gold substrate. he incompatibility between the suspended hBN and the hBN on gold acts as a i¿½bottle ne ki¿½ for polaritons, and light inside the cavity has a harder time leaking out. However, as mentioned earlier, this simple model was unable to fully ex lain the experimental results. To do so, it turns out one needs to consider that hBN polarit ns are a form of light-wave and that, unlike classical particles (like cars on a highway), th y can be combined and interfere in complicated ways. Specifically, hBN polaritons can com ine into multimodal ray-like excitations. The multimodal excitations that form above the nan holes in the metal are even more incompatible with the polaritons outside of the hole, lead ng to an even greater degree of confinement than otherwise po sible. Crucially, this method thus avoids shaping the hBN directly and preserves its pristi e quality, enabling highly-confined AND long-lived photons in t e cavity. Prof. Koppens and Dr. Herzig intend to use these cavities as a novel platform for quantum light-matter interaction experiments in order to see quantum effects that wer previously thought impossible, as well as to further study the intriguing and counterintuitiv physics of hyperbolic phonon polariton

Bibliographic reference:?

Hanan Herzig Sheinfux et al, High-quality nanocavities through multimodal confinement o hyperbolic polaritons in hexagonal boron nitride,Nature Materials (2024). www.nature.com/articles/s41563-023-01785-w