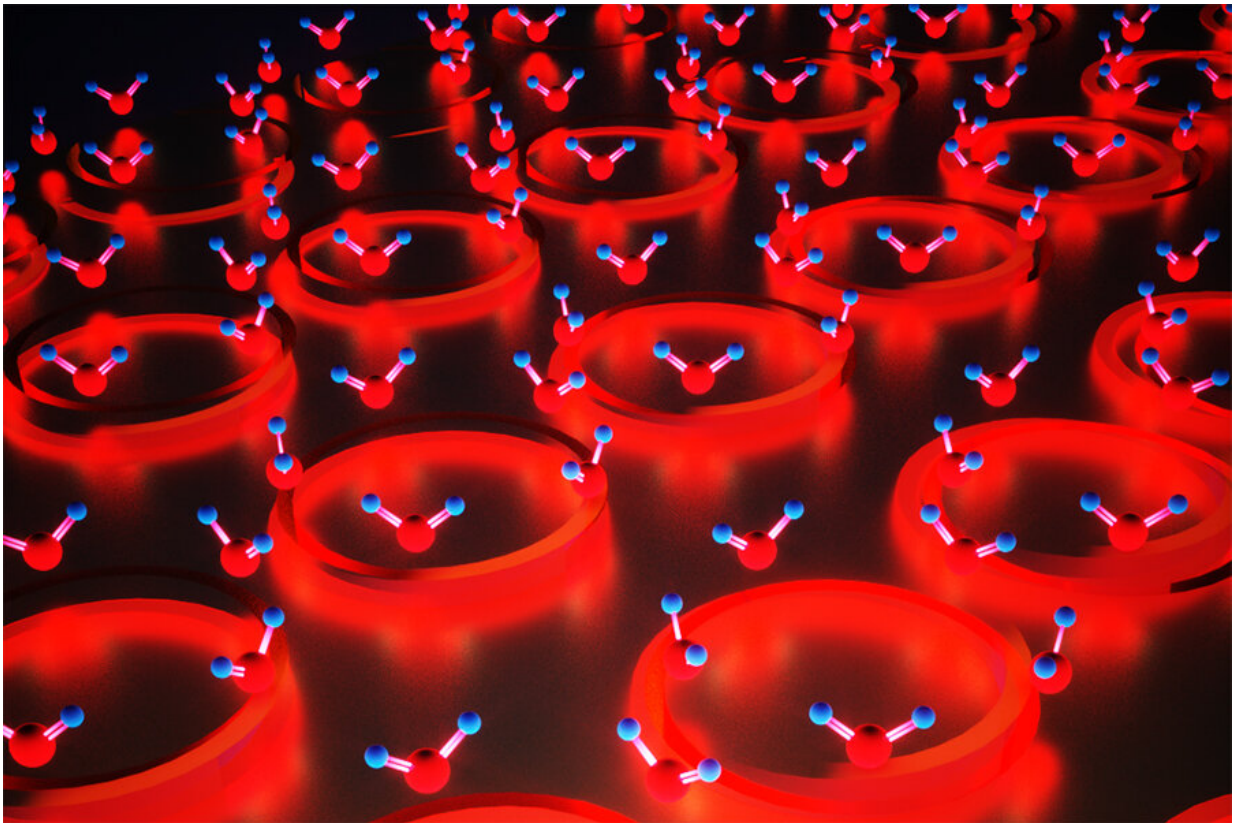


# Researchers develop unique process for producing light-matter mixture

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Annular holes in a thin gold film filled with silicon dioxide enable ultrastrong coupling between light and atomic vibrations. This structure provides opportunities to probe molecules interacting with quantum vacuum fluctuations and develop novel optoelectronic devices. Credit: Oh Group, University of Minnesota

In groundbreaking new research, an international team of researchers led by the University of Minnesota Twin Cities has developed a unique process for producing a quantum state that is part light and part matter.

The discovery provides fundamental new insights for more efficiently developing the next generation of quantum-based optical and electronic devices. The research could also have an impact on increasing efficiency of nanoscale chemical reactions.

The research is published in *Nature Photonics*.

Quantum science studies natural phenomena of [light](#) and matter at the smallest scales. In this study, the researchers developed a unique process in which they achieved "ultrastrong coupling" between infrared light (photons) and matter (atomic vibrations) by trapping light in tiny, annular holes in a thin layer of gold. These holes were as small as two nanometers, or approximately 25,000 times smaller than the width of a human hair.

These nanocavities, similar to a highly scaled-down version of the coaxial cables that are used to send electrical signals (like the cable that comes into your TV), were filled with silicon dioxide, which is essentially the same as window glass. Unique fabrication methods, based on techniques developed in the computer-chip industry, make it possible to produce millions of these cavities simultaneously, with all of them simultaneously exhibiting this ultrastrong photon-[vibration](#) coupling.

"Others have studied strong coupling of light and matter, but with this new process to engineer nanometer-sized version of coaxial cables, we are pushing the frontiers of ultrastrong coupling, which means we are discovering new quantum states where matter and light can have very different properties and unusual things start to happen," said Sang-Hyun Oh, a University of Minnesota professor of electrical and computer

engineering and the senior author of the study. "This ultrastrong coupling of light and atomic vibrations opens up all kinds of possibilities for developing new quantum-based devices or modifying chemical reactions."

The interaction between light and matter is central to life on earth—it allows plants to convert sunlight into energy and it allows us to see objects around us. Infrared light, with wavelengths much longer than what we can see with our eyes, interacts with the vibrations of atoms in materials. For example, when an object is heated, the atoms that make up the object start vibrating faster, giving off more infrared radiation, enabling thermal-imaging or night-vision cameras.

Conversely, the wavelengths of infrared radiation that are absorbed by materials depend on what kinds of atoms make up the materials and how they are arranged, so that chemists can use infrared absorption as a 'fingerprint' to identify different chemicals.

These and other applications can be improved by increasing how strongly [infrared light](#) interacts with atomic vibrations in materials. This, in turn, can be accomplished by trapping the light into a small volume that contains the materials. Trapping light can be as simple as making it reflect back and forth between a pair of mirrors, but much stronger interactions can be realized if nanometer-scale metallic structures, or 'nanocavities,' are used to confine the light on ultra-small length scales.

When this happens, the interactions can be strong enough that the quantum-mechanical nature of the light and the vibrations comes into play. Under such conditions, the absorbed energy is transferred back and forth between the light (photons) in the nanocavities and the [atomic vibrations](#) (phonons) in the material at a rate fast enough such that the light photon and matter phonon can no longer be distinguished. Under such conditions, these strongly coupled modes result in new quantum-

mechanical objects that are part light and part vibration at the same time, known as polaritons.

The stronger the interaction becomes, the stranger the quantum-mechanical effects that can occur. If the interaction becomes strong enough, it may be possible to create photons out of the vacuum, or to make chemical reactions proceed in ways that are otherwise impossible.

"It is fascinating that, in this coupling regime, vacuum is not empty. Instead, it contains photons with wavelengths determined by the molecular vibrations. Moreover, these photons are extremely confined and are shared by a minute number of molecules," said Professor Luis Martin-Moreno at the Instituto de Nanociencia y Materiales de Aragón (INMA) in Spain, another author of the paper.

"Normally, we think of vacuum as basically nothing, but it turns out this vacuum fluctuation always exists," Oh said. "This is an important step to actually harness this so-called zero energy fluctuation to do something useful."

**More information:** Yoo, D., de León-Pérez, F., Pelton, M. et al. Ultrastrong plasmon–phonon coupling via epsilon-near-zero nanocavities. *Nat. Photonics* (2020).  
[doi.org/10.1038/s41566-020-00731-5](https://doi.org/10.1038/s41566-020-00731-5) ,  
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Provided by University of Minnesota

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